An Evaluation of the Use of 360° Photographic Technology in a Forensic Context

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Abstract

Crime scenes represent ephemeral and complex environments and the intelligence and evidence that they contain requires them to be documented and collected quickly and efficiently so as to limit any loss of evidence. With the continuous developments of new imaging and recording technologies, there is the opportunity for more innovative and appropriate methods for documenting and managing crime scenes that may improve investigative proffered to the Criminal Justice system and indeed the public. This thesis has explored the potential of new panoramic imaging technologies and crime scene management content software to assist and develop the way in which criminal investigations are investigated, and conducted starting with how crime scenes are recorded and evidence linked with them.

There is currently a vast array of differing panoramic imaging technologies available to Police services such as SceneVision Panorama, Panoscan MK-3, iStar (NCTech), SceneCam (Spheron VR AG), ScanStation C10 (Leica) and Focus^{3D} X 330 (FARO), with each reporting to offer unique merits to an investigation. This can present difficulties for police services when considering the purchase and use of such technologies. With declining budgets, Police services do not have the time and resources to evaluate technology prior to its adoption. Thorough research evaluating the technology would allow Police services to make informed decisions about the adoption of technology which is fit for purpose and cost effective.

This research explored panoramic technologies available to Police services and the considerations which organisations must account for prior to the adoption and integration into current standard operating procedures. An important adoption criteria is the accuracy and precision of capture and measurement of the technology's hardware and software and these factors are essential factors for the successful integration of such equipment within the Criminal Justice System. The accuracy and precision of measurements taken using a 360^{o} panoramic imaging system, 'SceneCam' and its complimentary content management system, 'SceneCenter' (Spheron VR AG) was examined and compared to traditional measurement methods. Measurements taken using the photogrammetry software were identified as being more reproducible than the any manual approach, and this offered flexibility with regards to the time and location of the documentation process in a crime scene.

Additional uses for the panoramic imaging technology were considered focusing upon the ability to successfully locate and visualise human biological fluids within crime scenes. The ability to successfully locate and visualise human biological fluids on different substrates provided the opportunity to allow a more dynamic recording of the spatial placement of biological fluids and allowed fluids located to be placed in context; this is a significant improvement over 'still' digital photography. This technique presented the opportunity to presumptively screen a crime scene for human biological fluids and facilitates simultaneous location and visualisation of biological evidence in addition to capturing a complete 360^{o} view of the entire crime scene for contextual purposes of placing other evidence types (e.g. shoewear, finger marks).

With the exponential increase in the utilisation of digital technologies, Police services must follow suit, adopting technology to become more efficient and to speed up processes that will more effectively engage with the on-going investigation. In order to be used to its full potential such digital technology should be integrated within the entire Criminal Justice System community- therefore it is necessary that courtrooms are appropriately equipped with the end-user requirements to facilitate the presentation of such evidence to all present within the Court. The use of technology within the courtroom has been carefully considered and examined to identify the extent to which panoramic imaging technology can function within the courtroom both now and in the immediate future.

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List of Abbreviations

2D	Two-dimensional
3D	Three-dimensional
ACPO	Association of Chief Police Officers
ALS	Alternate Light Source
ASPRS	American Society for Photogrammetry and Remote Sensing
AV	Audio Visual
CBRN	Chemical, Biological, Radiological, Nuclear
CCD	Charged Couple Device
CCTV	Closed Circuit Television
CG	Computer Generated
CJS	Criminal Justice System
CoP	College of Policing
CPR	Civil Procedure Rules
CPS	Crown Prosecution Service
CSI	Crime Scene Investigation
DNA	Deoxyribonucleic acid
DSLR	Digital Single-Lens Reflex
DVD	Digital Video Disc
EMR	Electromagnetic Radiation
FI	Forensic Investigator
FOV	Field of View
HDR	High Dynamic Range
IR	Infrared
ISO	International Organisation for Standardisation
IT	Information Technology
LCD	Liquid Crystalline Display

LDR	Low Dynamic Range
LED	Light Emitting Diode
MoJ	Ministry of Justice
MP	Megapixels
NIJ	National Institute of Justice
NIR	Near Infrared
NIST	National Institute for Standards and Technology
Nm	Nanometres
NPCC	National Police Chiefs Council
PC	Personal Computer
PDF	Portable Document Format
PPI	Pixels per inch
RSD	Relative Standard Deviation
RTC	Road Traffic Collision
SD Card	Secure Digital Card
SOCO	Scene of Crime Officer
SOP	Standard Operating Procedures
SWGIT	Scientific Working Group on Information Technology
TAM	Technology Acceptance Model
TV	Television
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
USA	United States of America
USB	Universal Serial Bus
UV	Ultraviolet
VR	Virtual Reality
WL	Woods Lamp

Publications List

Sheppard, K., Cassella, J., Fieldhouse, S. (2016) Visualising a Crime Scene Using Novel Crime Scene Documentation Technology. CSEye.

Sheppard, K., Cassella, J., Fieldhouse, S. (2017) A Comparative Study of Photogrammetric Methods using Panoramic Photography in a Forensic Context. *Forensic Science International.* 273. 29-38. (Appendix 1).

Sheppard, K., Cassella, J., Fieldhouse, S., King, R. (2017) The Adaptation of a 360^{o} Camera Utilising an Alternate Light Source (ALS) for the Detection of Biological Fluids at Crime Scenes. *Science and Justice.* 57. (40) 239-249. (Appendix 2).

To provide a comprehensive understanding of the thesis, a supplementary Universal Serial Bus card (USB) has been included which will provide examples of the work in support of the thesis. The USB card icon within the thesis denotes references to the supplementary USB card. Insertion of the USB card will open the main page where examples have been sorted into Chapters and subsections as they are referred to in the thesis.

Chapter 1: Introduction

1.1 Crime Scene Investigation

A crime scene investigation is conducted to assist a Forensic Investigator (FI) or Scene of Crime Officer (SOCO) in determining a series of events, which may have occurred at a scene using deductive reasoning and physical evidence recovered at the scene. The goal of a criminal investigation is ultimately to “ascertain the truth of any alleged matter under investigation” (Fisher and Fisher, 2012). FI’s aim to answer the following questions; who has been at the scene? What happened at the scene? When and how did the incident occur? (Horswell, 2000). The investigation process encompasses many factors that ultimately involve the systematic documentation and recovery of evidence at the scene.

1.2 Crime Scene Documentation

One of the most important aspects of conducting a criminal investigation involves comprehensively recording and documenting the crime scene, given that the process can ultimately determine the success of the subsequent investigation (Gee *et al.*, 2010). Crime scenes often present unstable and short-lived environments, containing ephemeral evidence, which can prove difficult for SOCO’s to document efficiently (Komar *et al.*, 2012). Crime scene documentation is one of the most laborious and time-consuming aspects of an investigation (Elkins *et al.*, 2015; Baber *et al.,* 2006*;* Chan, 2005; Lee *et al.*, 2001), as the resultant documentation must provide a thorough and permanent record of the scene. Crime scene documentation is conducted in order to record and preserve the condition of a crime scene demonstrating the location and relationships of evidence within the scene (Lee *et al.,* 2001). The first hour after an offence has been committed, known as the ‘golden hour’ within an investigation, is crucial for the preservation of evidence based upon the principle that the more time that passes, the more likely it is that evidence can be lost or destroyed (Thames Valley Police Licensing Team, 2012). As a result, the opportunity must not be lost to fully document and acquire all essential information regarding the scene whilst the scene has remained in an untouched state (Chan, 2005).

Documentation methods comprise written contemporaneous notes, graphical sketches, photographs, and video evidence of all contextual information regarding a scene (TWGCSI, 2000; Carrier and Spafford, 2003; Komar *et al.*, 2012). Singly, these methods do not provide a comprehensive insight into the scene and its artefacts, but collectively these methods provide a comprehensive and detailed account of a scene and its analysis. All the documentation described provides a report of contextual information regarding a case, which can assist courts in reconstructing the scene to provide the best evidence available (Horswell, 2000). In addition, comprehensive documentation can allow for subsequent re-evaluation or investigation of the scene later in the investigation process (Bain, 2017; Lee *et al*., 2001).

1.2.1 Contemporaneous Notes

SOCO's continuously record thorough and detailed notes throughout the investigation from their arrival at the scene to provide a written record of the crime scene (Miller and Massey, 2015). Crime scene notes consist of a SOCO's overall observations of the crime scene, a detailed description of the scene and all processes which are undertaken at the scene (Miller and Massey, 2015; Baxter, 2015). The notes serve to inform any personnel not present as to what exactly occurred at the scene from arrival including descriptions such as whether doors were open, lights were on or off, and the weather conditions on the day. Photographs will also be logged with a description of what each photograph contained. In addition, the notes taken at the scene will ultimately be used to create a case report and can serve as an aide memoir to refresh the investigators memory as to what processes occurred at the scene (Miller and Massey, 2015).

1.2.2 Crime Scene Sketches

In addition to the contemporaneous notes which detail what processes and examinations have occurred at a scene a sketch will also be created. A crime scene sketch depicts the entire scene in a pictorial format demonstrating the locations of evidence which have been identified, and measurements associated with the position and location of each item of evidence (Lee *et al.,* 2001). In addition to measurements for evidence items, dimensions of the environment will also be taken (Lee *et al.,* 2001). Figure 1.1 shows an example of a rough crime scene sketch.

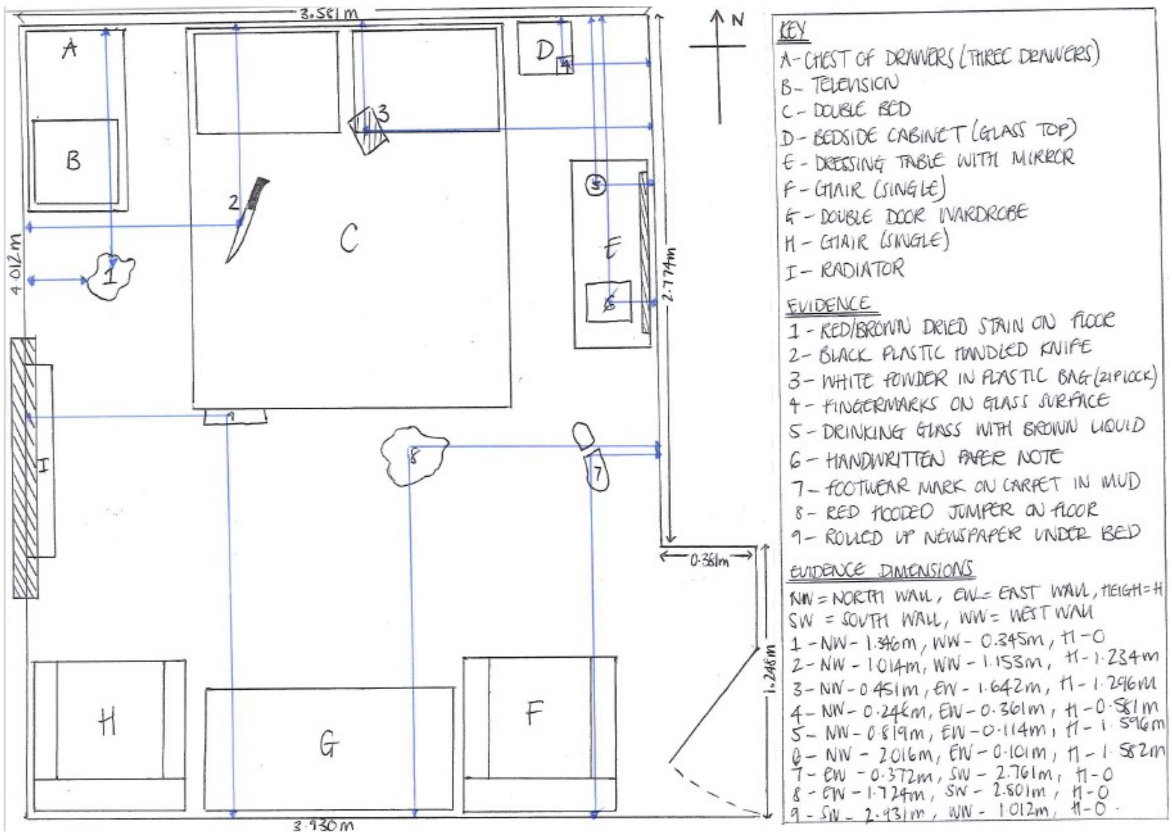


Figure 1.1: Crime Scene Sketch showing locations of evidence and measurements

1.2.3 Crime Scene Photography

Film photography was initially adopted within criminal investigations to methodically photograph the crime scene environment to aid in the spatial understanding and contextualisation of the crime scene using film cameras (Robinson, 2016). The development of technology provided digital cameras which succeeded traditional film cameras which provided the SOCO with the ability to instantly view the photographs taken at the scene on the Liquid Crystalline Display (LCD). The ability to view 'live' photographs whilst at the scene revolutionised crime scene photography, allowing SOCO's to ensure that they had captured the perfect photograph which was in focus and had correct lighting. Traditional film cameras did not possess the ability to view the captured photograph 'live' and photographs could only be viewed after having been developed back at the station. Once developed, the quality of the photograph could be assessed but by this time there may not be the opportunity to revisit the crime scene to re-photograph.

The process of recording a crime scene provides a snapshot of contextual information, allowing those individuals not present at a scene the opportunity to view the scene and its associated evidence (Gardner, 2011). Photographs provide a detailed record of a scene, illustrating items present and their respective distribution and location within a scene (Robinson, 2016). Photographs may show items not described in contemporaneous notes as the item may not have been deemed relevant at the time, and can provide an aide memoire for the examiner, allowing them to refresh their memory on a case (Robinson, 2016). Photographs provide an integral part of criminal investigations and the presentation of evidence in a court of law as they provide a visual representation of the scene, as it was at the time of the incident (Milliet *et al.,* 2014). Photographs must provide a fair and accurate representation of a scene (Robinson, 2016). The photographs taken at a crime scene consist of three types; overviews, mid-range and close ups.

1.2.3.1 Overview Photographs

Overview photographs provide the widest and fullest view of a scene, and show the majority of the evidence within a scene in relation to other objects or furniture within that scene. In an indoor environment, this will often consist of a series of photographs from each corner of a room, looking inwards towards the rest of the environment. For outside areas of interest, photographs will be taken of the building where a crime has occurred, showing the building in relation to its surroundings. Figure 1.2 shows an overview photograph of a scene.

1.2.3.2 Mid-Range Photographs

Mid-range photographs show key pieces of evidence in context to the scene, showing the evidence in its location within the scene and demonstrating its relative distance to other evidence in the scene. Figure 1.3 shows a mid range photograph of an environment.

1.2.3.3 Close Up Photographs

Close up photographs are taken of the individual items of evidence, along with a scale to show the full size of the evidence item. Close up photographs aim to provide a detailed view of the evidence which may not be present in the previous mid-range or overview photographs. A close up photograph should fill the entire frame of the photograph and are often taken from a 'birds eye view' directly above the evidence item. Figure 1.4 shows a close up photograph of a piece of evidence.

All photographs are followed up with a photographic log which details all photographs which have been taken, including the photograph number, what the photograph is showing, when it was taken and detail about the camera set up. The photographic log is completed for each photograph subsequently to the photograph having been taken.

Figure 1.2: An overview photograph of an environment

Figure 1.3: A mid-range photograph of an environment

Figure 1.4: A close up view of evidence within the environment

1.2.4 Limitations of digital photography

Digital photography captures a two-dimensional (2D) representation of a three-dimensional (3D) environment and as a result may distort perception of spatial relationships of objects and evidence within a scene (Lee *et al.,* 2001). Complex crime scene information can easily be conveyed through a photograph as ‘a picture is worth a thousand words’ (Whitney and Greenberg, 2001). However, a still-digital photograph is limited in its ability to present spatial information or relationships of evidence within a scene (Tung *et al*., 2015) as it only captures a scene from a single viewpoint (Chan, 2005). Digital photography will only capture those items within a scene deemed relevant at the time by the SOCO documenting a scene and only present the viewer with a snapshot of the environment (Chan, 2005). The photographs are limited to the single viewpoint of the SOCO who captured the photographs and do not provide the ability to capture the whole environment in one single image as demonstrated in Figure 1.5 (Chan, 2005).

1.3 Technology development

In recent years, technology has become far more abundant within criminal investigations in the aim of improving efficiency and effectiveness and allowing real time transmission of data (Chan, 2001). Technological advancements in digital photography have led to the creation of high-resolution photographic cameras, which are able to capture an entire scene in a very short space of time using panoramas (Strandberg, 2015). Such technology can capture 360^{o} views of crime scene environments allowing the demonstration of spatial relationships more accurately. Panoramas are defined by their large field of view (FOV) and capture more information compared to traditional digital photographs and are omnidirectional, capturing an environment in all directions as demonstrated in Figure 1.6 (Huang *et al.*, 2008; Klette, 2014; Marsh, 2014) panoramic photography provides a 360^{o} representation of an environment (Miller and Marin, 2014). Additional 3D methods for capturing crime scene environments have also been created which utilise laser methods to create accurate 3D point cloud representations of scenes.

This type of technology assists police personnel and jurors in understanding the environment layout (Schofield and Fowle, 2013) and conveying the distribution of evidence (Tung *et al*., 2015). Police are beginning to take advantage of the opportunities that 3D technology can provide to them and are adopting technologies such as 360^{o} photography and laser scanning systems (Cavagnini *et al.,* 2009).

These systems produce 3D representations of scenes, which give spatial perception, something 2D photography cannot provide. In addition they allow a viewer to immerse themselves within a navigable environment (Dang *et al.,* 2011). These immersive environments are becoming more popular for use within criminal investigations as they provide an opportunity to fully document a scene in a highly detailed manner as well as enabling the presentation of the environment.

Figure 1.5: Digital photograph showing a limited field of view of the scene

Figure 1.6: Panoramic photograph capturing a 360^{o} view of a scene. Equirectangular projection preview thumbnail of the panorama. The 360^{o} photograph has been flattened out – due to the fisheye lens used to capture the image – distortion is present.

1.4 Rationale of the Thesis

There are currently 43 independent Police Services operating within England and Wales, each with their own procedures for documenting crime scenes. Due to the nature of crime scenes and the ephemeral evidence that they present, it is a challenging task for SOCO's to document (Komar *et al.,* 2012). Crime scenes are unstable environments, which are often short lived and present difficult types of data to visualise easily and effectively to other individuals who were not present at a scene, particularly a jury (Gardner, 2012; Howard *et al.,* 2000). Many Police Services rely primarily upon laborious manual methods for documenting crime scenes (Strandberg, 2015) including contemporaneous notes, sketches and digital photography (Chan, 2005; Komar *et al.,* 2012; Carrier and Spafford, 2003). Current methods for documenting crime scenes are time consuming, laborious and do not allow for understanding spatial relationships between evidence items.

The National Police Chiefs Council (NPCC) (formerly the Association of Chief Police Officers (ACPO)) identified a need for more innovative and novel solutions for documenting and managing crime scenes that can improve performance and enhance public confidence in the Criminal Justice System (CJS)(Association of Chief Police Officers, 2012). Criminal investigations are a very time consuming and laborious task and police services are continually striving to improve and develop the speed of these processes and new technology presents an opportunity to enhance the speed, effectiveness and the reputation of the CJS (Association of Chief Police Officers, 2012; Baber *et al.,* 2006). The basic techniques of crime scene examination have remained in place for many years; however modern technologies are presenting more effective and efficient solutions (Association of Chief Police Officers, 2012). The NPCC has placed significant emphasis on the need for "live-time forensics' whereby information is collected and disseminated in real time, to improve communication between all personnel involved in an operation and deliver significant improvements to the speed of key processes. Police services are not maximizing the opportunities that innovation is presenting, with the use of new technologies such as real time analysis and recording techniques.

Traditional verbal methods of presenting evidence from crime scenes are no longer sufficient, and significant advances in technology development over recent years have produced systems, which allow an entire scene to be documented quickly and efficiently, using spherical photography or 3D laser scanning. With a drive to improve efficiency and effectiveness with criminal investigations, the adoption of this type of technology is becoming more popular with police (Chan, 2001) for recording and visualising crime scene environments, and for use as visual presentation tools to assist viewers in understanding the environment layout (Schofield and Fowle, 2013) and conveying the distribution of evidence (Tung *et al.,* 2015). The implementation of panoramic imaging technology in police services offers the opportunity to visually present complex crime scene environments in the courtroom. Three-dimensional presentations offer an alternate method for communicating evidence to the courtroom, through mediums which are innovative and familiar to 21st century jurors who have grown up with computers and television (Chan, 2001).

The overall crime scene investigation process would improve from an integrated case management and information system, which could be used remotely at crime scenes, with suitable hardware (Association of Chief Police Officers, 2012). The introduction and integration of a case management system would highly benefit the police services, with the use of fit for purpose hardware and software applications. New technology needs to give the ability to transfer data on a real time basis, to improve interoperability between forces using different systems. Research needs to be conducted into more effective methods of examining scenes using modern technological solutions.

1.5 The technology under investigation

This thesis explores a particular piece of crime scene documentation technology; a 360^{o} camera, SceneCam (Spheron VR AG) that can be used to acquire panoramic images and a content management software application, SceneCenter, that allows the presentation and exploration of such panoramas. Spheron Vr AG, Germany, has developed the SceneCam and SceneCenter software application. This technology is currently available for police services to purchase for crime scene documentation. The SceneCam (Figure 1.7) produces a spherical panorama which captures a FOV of 180^{o} vertically x 360^{o} horizontally. The system consists of three main components; a camera head and lens, a tripod, and a portable Toughbook computer.

The SceneCam utilised in this investigation consists of a fisheye Nikon 16 mm f/2.8 D lens and a CCD (Charge Coupled Device) with a tri-linear RGB (red, green and blue) chip which produces 50 MP (megapixel) images as a continuous set of vertical scan lines. The camera head is situated atop a high precision turntable which rotates the camera head allowing it to capture a full 400^{o} in one scan. Post-production within the software crops the image to 360^{o}, removing the 40^{o} overlap.

The high precision turntable rotates the camera head around its ‘nodal point’ as shown in Figure 1.8. This enables the camera to capture a full view of the cameras surrounding in a single scan rotation. The nodal point is the optical centre of the camera and lens and enables the camera to rotate so that the centre of the camera lens remains at the centre of its rotation circle to prevent parallax error or optical distortion (Jacobs, 2012). Parallax error occurs when the camera does not rotate at its optical centre such that the angle and distance to foreground and background objects differs (Jacobs, 2012). The SceneCam takes spherical panoramas with a high dynamic range (HDR) up to 26 f-stops (Reinhard *et al*., 2012). HDR images capture a range of different light levels and allows capture of bright and dark areas within a scene simultaneously. The SceneCenter software is capable of displaying ‘dynamic’ exposure so the viewer can scroll through exposures.

The SceneCam camera lens and high precision turntable are mounted upon a Manfrotto three-legged tripod (Figure 1.7). The tripod has been adapted with a screw system to securely connect the lens to the tripod to allow the camera to rotate around its axis smoothly. The tripod contains a built in spirit bubble to ensure its placement on various surfaces is level. The camera rotation and movement is operated using a tethered Toughbook portable computer (Panasonic) connected to the camera head via a USB (Universal Serial Bus) cable. The Toughbook stores all of the raw image outputs from the camera. Using the inbuilt software controls, a user can adjust the starting point for a scan and start or stop a scan. There are four different resolution settings that can be chosen for scanning an environment; minimum (1,500 x 750 pixels), medium (3,000 x 1,500 pixels), high (6,000 x 3,000 pixels) and maximum (12,000 x 6,000 pixels). There is a viewing window within the software allowing the captured image to be monitored in real time throughout the duration of the scan. Image files stored on the Toughbook computer are stored as .sph files – this is Spheron’s raw spherical image file. The camera turntable is powered by a rechargeable battery pack, which attaches to one of the tripod legs.

The rotation speed of the camera and capture time of the complete panorama corresponds to the chosen image resolution and the exposure within the environment. A greater resolution will increase the time it takes to scan a scene, and a lower resolution will decrease the time it takes to scan a scene. In addition, darker environments with little light will increase the time taken to scan an environment, whilst scenes that contain more light will take less time.

SceneCenter is a complimentary software application which allows import of the raw .sph files to allow navigation and exploration (Figure 1.9). Using the software a user is able to navigate around the panorama, moving left, right, up and down. In addition the software allows zooming in to obtain more detail from aspects within the panorama. The software allows linking of sphericals to create a navigable tour through a scene in addition to linking other media files using hot spots.

Figure 1.7: SceneCam 360^o camera (Spheron VR AG).

Figure 1.8: Centre of the camera lens is positioned in the centre of the turntable at its optical centre

Figure 1.9: SceneCenter software application allows navigation around a panorama (Spheron VR AG).

1.6 Aim of the Research

The broad aim of this research is to examine and evaluate the use of 360° photographic technology for its use within the criminal investigation process.

1.7 Research objectives

The objectives associated with the thesis aim are:

- To explore the types of panoramic imaging technology which is currently available to police services.
- To investigate the accuracy and precision of panoramic imaging technology for taking measurements of crime scenes.
- To determine whether a 360° camera system can be adapted using an alternate light source to enhance the detection of biological fluids.
- To evaluate how technology exists within the criminal justice system and to determine the extent to which new technology would be integrated.

1.8 Thesis Structure

This section outlines the overarching structure of the thesis chapters providing a brief description of the contents of the thesis. The thesis has been divided into four main sections and each chapter explores a different set of objectives to meet the overall aim of the thesis.

Chapter 1 presents the theory upon which the main body of research is based, exploring criminal investigations and the methodologies used to document crime scenes, both past and present. This chapter presents previous research, which has been conducted in this area and critically evaluates their methods to offer a roadmap to assist Police services in assessing how to best identify the most appropriate piece of equipment for their needs.

Chapter 2 introduces the different approaches used to create panoramas using modern panoramic cameras. This chapter details the different specifications of various panoramic imaging technology and the methods each uses to capture a forensic environment. In addition, laser scanning is discussed as an alternative method for creating panoramas utilising point clouds rather than photographs. This chapter explores and considers the variety of panoramic technologies currently available to police services comparing and contrasting them based upon the manufacturers specifications and the methods used by these systems to create their outputs. Some technologies are explored further in detail in different forensic scenarios and environments to identify and to address any benefits and limitations of these systems. Criteria that need to be carefully considered before inculcating technology into operating procedures are discussed. This chapter intends to better inform prospective end users of the equipment, particularly police services, as to some of the operational challenges associated with such technology. This will allow police organisations to develop a more informed decision when considering the adoption of recording technology fit for the 21st century rigors of the evidential process, and the real time requirements expectations of criminal investigations (e.g. terrorist incidents) conducted across different UK police services simultaneously.

Chapter 3 introduces current methods for accurately and precisely measuring crime scenes as part of the documentation process and the limitations that may be associated with these methods. The chapter introduces an experimental design to identify and determine the accuracy and precision of current methods for taking measurements within crime scenes and subsequently comparing and contrasting these data to measurements taken using 360^{o} photography software. The results are evaluated and discussed with reference to the current knowledge in the field and journal literature.

Chapter 4 examines an investigation into enhancing lighting methods for detecting biological fluids at crime scenes utilising alternate light sources. Modifying a 360^{o} camera using an alternate light source in an attempt to improve the visualisation and documentation of biological fluids within a crime scene. This chapter further describes the methodological approach to adapting the existing 360^{o} camera system and the parameters that were investigated as part of this approach. The results discuss and review the benefits and limitations of the approach used in this study and recommendations are discussed.

Chapter 5 discusses the current methods for presenting forensic evidence in a UK Court of law using paper based presentations and explores the use of modern technology to present evidence within the Criminal Justice System. It explores the extent to which technology has been integrated into the courtrooms currently and considers future plans. Participant questionnaires have been used to facilitate an exploration of police service personnel's experiences with technology integration into their current roles and also within courtrooms. This phenomenological study critically analyses the participant responses to uncover the drivers and indeed barriers associated with technology integration into the Courtrooms of the United Kingdom.

Chapter 6 summarises the main findings of the study and links all of the chapters to the main aim of the thesis. This chapter focuses upon the contribution that the thesis has made to the current literature and discusses any recommendations for police services, which have originated from this research. In addition this chapter also discusses future work that is to be conducted to further extend the knowledge in this area.

Chapter 2: Panoramic Technology for Recording and Presenting Crime Scenes

Preface

Chapter 1 introduced the fundamental aspects of the thesis and purpose of the overall study. Technology development has provided different types of panoramic technology aimed at increasing the efficiency of documenting crime scene environments. There is a plethora of both hardware and software technology available on the market to police services and as a result, it is essential to evaluate the effectiveness of such technologies prior to its adoption for use at crime scenes. In addition it is important to understand the factors, which affect the acceptance and integration of new technology into organisations. This chapter will discuss a range of different panoramic technologies available to police services, discuss the factors that may affect the adoption of technologies, and specifications which need consideration prior to the adoption of these technologies. Importantly, this chapter will compare and contrast some of the discussed technology in the context of different crime scene environments.

2.1 Introduction

2.1.1 Panoramic Imaging Technology

The basic techniques of crime scene documentation have remained consistent for many years but are time consuming, laborious and do not allow for an understanding of spatial relationships between evidence. However, modern panoramic imaging technologies could provide the means to document and present crime scenes more effectively and efficiently (Association of Chief Police Officers, 2012). Technological advancements in digital photography have led to the creation of high-resolution photographic cameras, which are able to capture an entire scene in a very short space of time using panoramas (Strandberg, 2015). Such technology can capture 360^{o} views of crime scene environments allowing the demonstration of spatial relationships more accurately. Panoramas are defined by their large field of view (FOV) and capture more information compared to traditional digital photographs and are omnidirectional, capturing an environment in all directions (Huang *et al.*, 2008; Klette, 2014). The implementation of panoramic imaging technology in police services offers the opportunity to visually present complex crime scene environments.

2.1.2 Panorama Capture Methods

Panoramic imaging systems can capture panoramas using a variety of different methods from capturing multiple images that will be ‘stitched’ or combined to create one single wide-angle image to more recent automated rotating cameras which can record a panorama in one scan (Klette, 2014; Guan, 2011; Huang *et al.*, 2008).

2.1.2.1 Stitching

The simplest and often financially prudent method for creating a panorama consists of capturing a series of overlapping digital photographs which are ‘stitched’ together using software applications (Huang *et al.,* 2008). A digital camera is placed at a single position within a scene and the camera is slowly rotated around a central point, taking photographs at given intervals (e.g. taking one photograph every 60^{o}) as shown in Figure 2.1 (Tung *et al.*, 2015; Guan, 2011). Each subsequent photograph in the sequence of photographs being taken must contain overlapping aspects with corresponding landmarks (Huang *et al.,* 2008; Jacobs, 2012). In addition, all scene conditions must remain constant during the capture of the multiple images to ensure a seamless panorama can be created. For example lighting conditions must remain constant and the position of the camera should not be moved during capture (Huang *et al.,* 2008). ‘Stitching’ is conducted using specialist software applications, which require the identification of common points between two overlapping photographs before merging the two photographs together (Huang *et al.,* 2008; Tung *et al.*, 2015). Multiple photographs may be stitched together to make one rather large photograph (Baxter, 2015) but in order to avoid any distortion of the final image, the original photographs must be taken from the same direction and angle to the scene. As a result, the camera must only be rotated around a central point when capturing the multiple images and the position must not be changed during photographic capture. Creating panoramas using this method requires a previous knowledge of stitching software and the ability to register each photograph. Registering identifies common points in each image, which allows the software to identify overlap between the photographs.

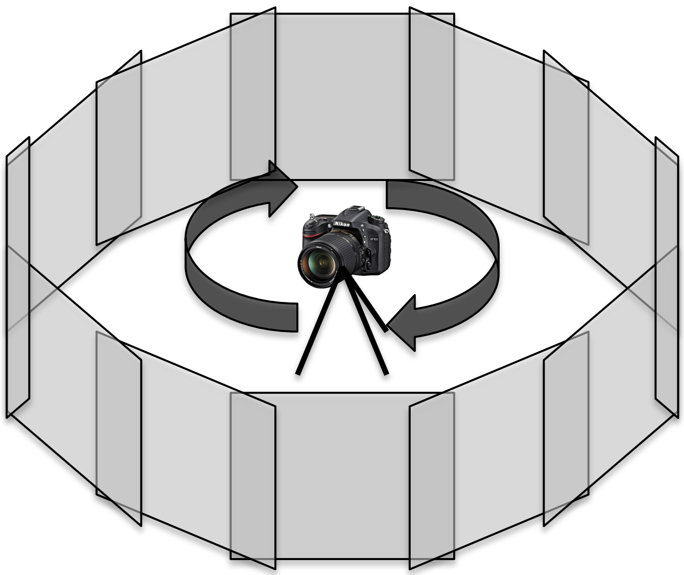


Figure 2.1: Digital camera rotated at varying degrees capturing a photograph at each interval to create a panorama.

2.1.2.2 Automated Panoramic cameras

Development of digital tools for capturing panoramas has introduced more high-end technological solutions, which allow automated capture of panoramas, often capturing the scene in one take. These methods eliminate the requirement for a photographer to rotate a camera at intervals and capture the photographs themselves. However, the automated approach is not possible without some cost implications, making these pieces of equipment more expensive than their manual counterparts.

2.1.2.2.1 Multiple Lens Cameras

Development of camera technology has created panoramic cameras that contain multiple lenses, each covering a portion of the device. Wide angled, fisheye lenses are often used as these offer a greater field of view, reducing the number of lenses required. Using multiple lens cameras, the user can select different exposures, resolutions and capture methods prior to capturing a photograph. The capture procedure using multiple lens cameras consists of selecting the appropriate settings and starting a capture, where the lenses will simultaneously capture a photograph. For example, NCTech have created a panoramic camera called iStar which contains four fisheye lenses situated at 90^{o} to one another as shown in Figure 2.2. This system captures 4 individual images which contain significant overlap. Using complimentary software provided by NCTech the four photographs are registered and automatically stitched together to create a panorama (Guan, 2011).

2.1.2.2.2 Rotating cameras

To remove the requirement for photographic stitching, some manufacturers have developed highly automated panoramic cameras which rotate around a central nodal point to capture the environment in one continuous motion (Figure 2.3). These systems are highly automated and use battery powered turntables to rotate the camera. Using this technique, usually only the two seam edges (i.e. the beginning line of the photograph, and the end line of the photograph) need to be stitched together (Jacobs, 2012) as demonstrated in Figure 2.4. The environment is captured as a photograph as the camera rotates without the requirement for stitching (Guan, 2011).

Figure 2.2: An example of a multiple lens camera system capable of capturing a panoramic image - iStar panoramic camera (NCTech).

Figure 2.3: An example of a rotating single lens camera system capable of capturing a panoramic image in a single pass with no stitching requirement – MK-3 panoramic camera (Panoscan Inc.)

Figure 2.4: Panoramic image captured using a SceneCam (Spheron VR AG) presented as an equirectangular projection demonstrating an overlap on the photograph to ensure the correct positioning for stitching of the photograph beginning and photograph end.

2.1.3 Projection of panoramas

Panoramic photographs often cannot be viewed in the same manner as standard digital photographs due to their FOV and the method with which they are captured (Guan, 2011). Wide angled lenses and fisheye lenses can produce distortion within the image when viewed as a 2D photograph due to their large FOV (Guan, 2011). Panoramas that have not been viewed using the correct software or projected correctly will appear distorted to the viewer as shown in Figure 2.4. Figure 2.4 demonstrates distortion due to the fisheye lens used to capture the photograph. The distortion is evident at the top of the image where the ceilings and walls appear rounded. Most panoramic images will require software in order to correctly view them without any distortion (Guan, 2011). In order to view a panorama correctly without any distortion, the panorama must be projected onto an environment map. An environment map is a geometric shape which the panoramic image is projected onto and thus assists the viewing of the image correctly. Projection is the changing of the panoramic image perspective to present a realistic display of the panorama (Jacobs, 2012). Software image viewers provide the ability to view panoramas as a navigable photorealistic environment without distortion. Most manufacturers provide their own complimentary software application that removes any distortion and presents a method for correctly viewing the panorama (Guan, 2011). Panoramic projections can take different forms consisting of cylindrical, cubic or spherical (Jacobs, 2012).

2.1.3.1 Cylindrical

Cylindrical panoramas are the most commonly used projection in panoramic photography and are produced when the photograph is wrapped around a cylindrical shape, where the viewer is stood in the centre of the cylinder (Jacobs, 2012) (Figure 2.5). The panorama is captured as the camera rotates around a central axis or nodal point (Haeusler and Klette, 2008). Cylindrical panoramas do not show the upper and lower parts of a photograph (so the ceiling and floor are missing), and depict a vertical angle of up to 120^{o} as opposed to 180^{o} like other panoramic projections. Vertical travel within a cylindrical panorama is limited as the ceiling and floor areas are missing and so the viewer is not able to pan up and down as much as panoramas exhibiting the full 180^{o} (Jacobs, 2012). Figure 2.6 presents a cylindrical panorama which has been flattened to allow visualisation of the whole panorama and as a result exhibits distortion of straight lines.

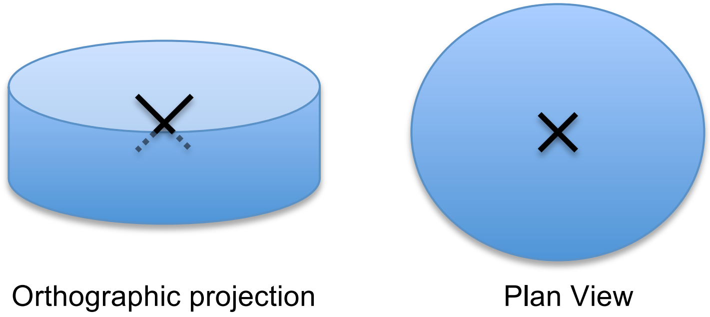


Figure 2.5: Cylindrical projection of a panorama onto a cylinder shape with the viewer standing in the centre. The X denotes the projection centre.

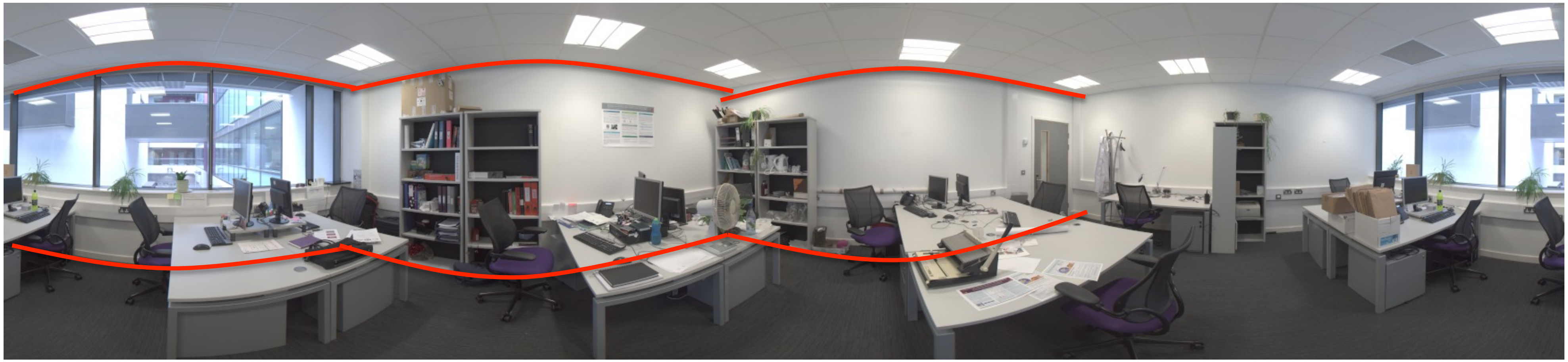


Figure 2.6: Cylindrical panorama demonstrating a limited vertical field of view. The panorama has been flattened to allow visualisation of the whole panorama (equirectangular projection) and therefore demonstrates distortion as demonstrated with the red arc lines.

2.1.3.2 Cubic

Cubic panoramas are produced when multiple photographs are wrapped around a cube shape (Figure 2.7) such that six individual photographs are projected onto six faces of a cube mesh (Bradley *et al.*, 2005) (Figure 2.8). Most cubic panoramas are captured using a specialist camera containing six lenses, one pointing up and the other five are horizontal to the device facing outwards (Bradley *et al.,* 2005; Kangni and Laganiere, 2006). These images need to be stitched together using specialist software to remove any seams and present the panorama as a cube shape (Bradley *et al.,* 2005). Cubic panoramas allow movement in both the horizontal and vertical directions with no limitation on the up and down movement such as that demonstrated in cylindrical panoramas (Jacobs, 2012).

2.1.3.3 Spherical

Spherical panoramas are achieved through the projection of the panorama onto the inside of a sphere, and are viewed such that the user is standing in the centre of a bubble as shown in Figure 2.9 (Jacobs, 2012). The horizontal and vertical viewing capabilities are not restricted in spherical panoramas allowing a viewer the ability to navigate up and down by 180^o and left and right by 360^o, capturing full coverage of an environment as shown in Figure 2.10 (Jacobs, 2012; Guan, 2011).

Panoramic photographs that have been projected correctly allow the user to rotate around 360^o photographs to demonstrate the overall appearance of a scene allowing zooming to visualise detail. Such immersive panoramas allow the user to zoom in and out on areas within the scene, navigate left, right, up and down within the scene. These interactive panoramas are extremely useful for providing the viewer with a better and more comprehensive understanding of a crime scene environment (Fangi, 2013).

Panoramas allow the presentation of a greater volume of information within one photograph and can present a more interactive and immersive experience for the viewer. There are a variety of different commercial software applications available to aid image stitching to generate panoramic images (Fangi, 2013). The majority of manufacturers provide their own viewer software for correctly stitching and viewing the resultant panoramic photographs. In such software, individual panoramas can be linked to one another using ‘hot spots’ to create a virtual tour (Kangni and Laganiere, 2006).

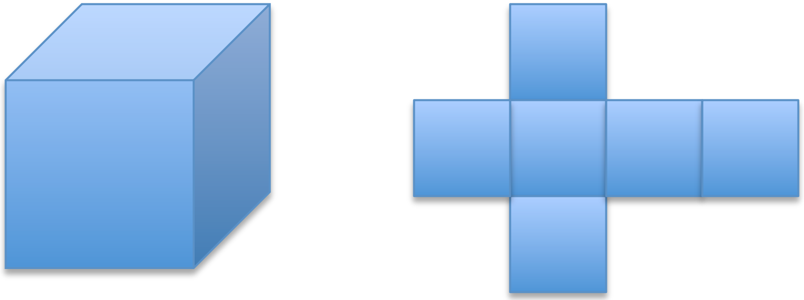


Figure 2.7: Cubic projection of a panorama onto a cube shape.

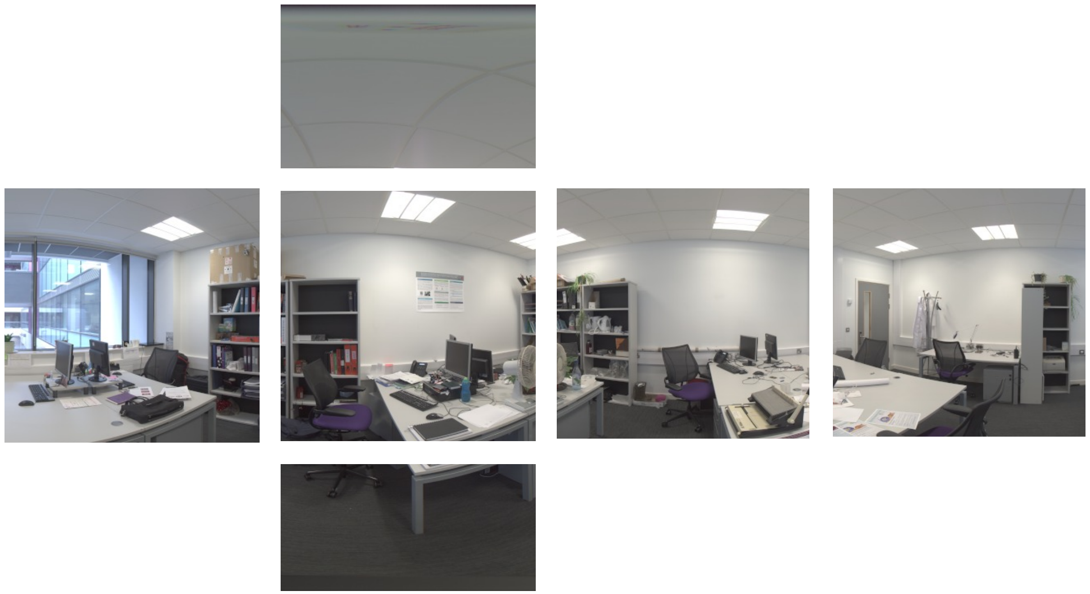


Figure 2.8: Cubic projection of a panorama with each side of the cube saved individually.

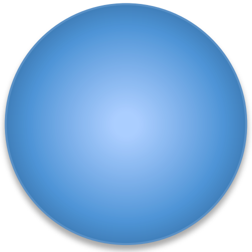
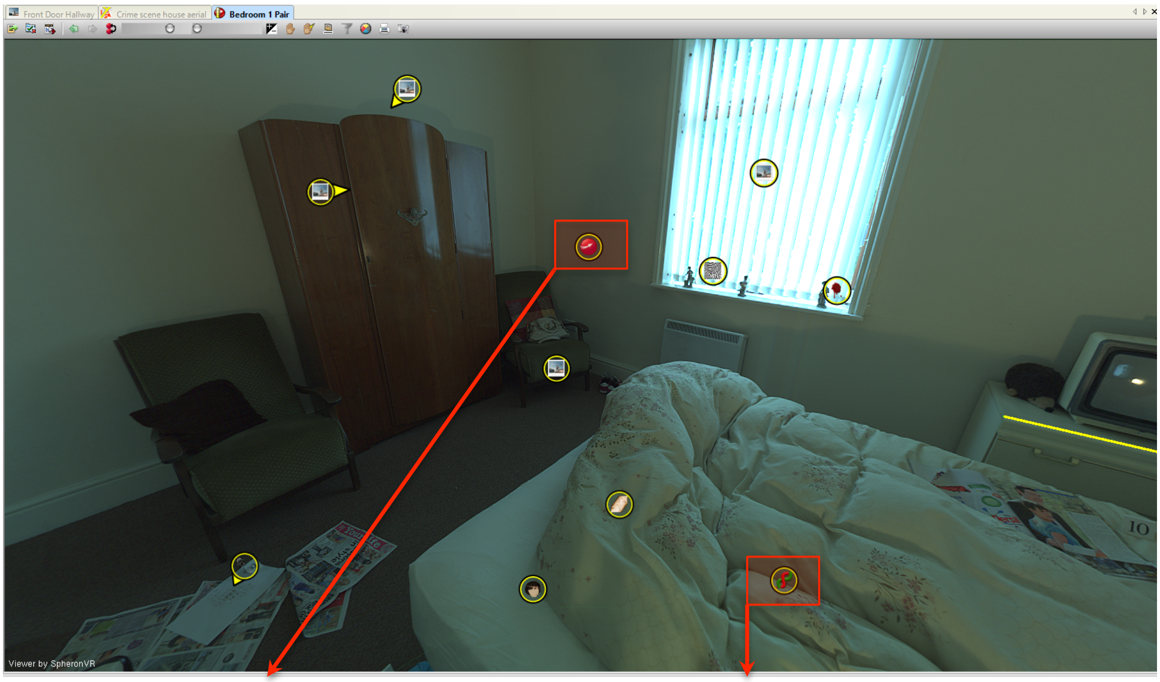


Figure 2.9: Spherical projection of a panorama onto a sphere shape.

Figure 2.10: Spherical projection of a panorama.

2.1.4 Virtual Tours

Several individual panoramas can be linked together to allow movement between different camera capture locations within a scene to create a virtual tour (Kangni and Laganiere, 2006). A virtual tour allows exploration around and through a scene, 'jumping' between panoramas using hot spots. 'Hot spots' are active links between different panoramic images and can be positioned in the relevant location within a panoramic image to guide navigation through a scene as shown in Figure 2.11 (Tung *et al*., 2015). Clicking on a hotspot will 'jump' the user from their current location within a panorama to the next panorama (Jacobs, 2012). Hotspots allow greater interaction with the environment, creating a more immersive experience (Tung *et al*., 2015; Kangni and Laganiere, 2006). In more complex virtual tours, hot spots can also consist of a range of different media formats such as Portable Document Formats (PDF's), Microsoft Word documents, audio files, web links, Joint Photographic Experts Group (JPEG) images, and video files. In addition, where floor plans or aerial plans are integrated into the tour, a user can observe their current location and viewing orientation as demonstrated in Figure 2.12 (Jacobs, 2012; Miller and Marin, 2014). Such a virtual tour retains a photorealistic representation of a scene in addition to presenting spatial relationships and contextual information of objects within the environment (Tung *et al*., 2015). In addition to capturing an environment using panoramic photography methods, more recently 3D laser scanning has been adopted to recreate environments.



Hotspot linking to another 360^o photograph

Hotspot linking to alternative media e.g. photographs, video files, audio files, PDF's.

Figure 2.11: Interactive panorama demonstrating 'hot spots' which allow navigation between different camera locations.

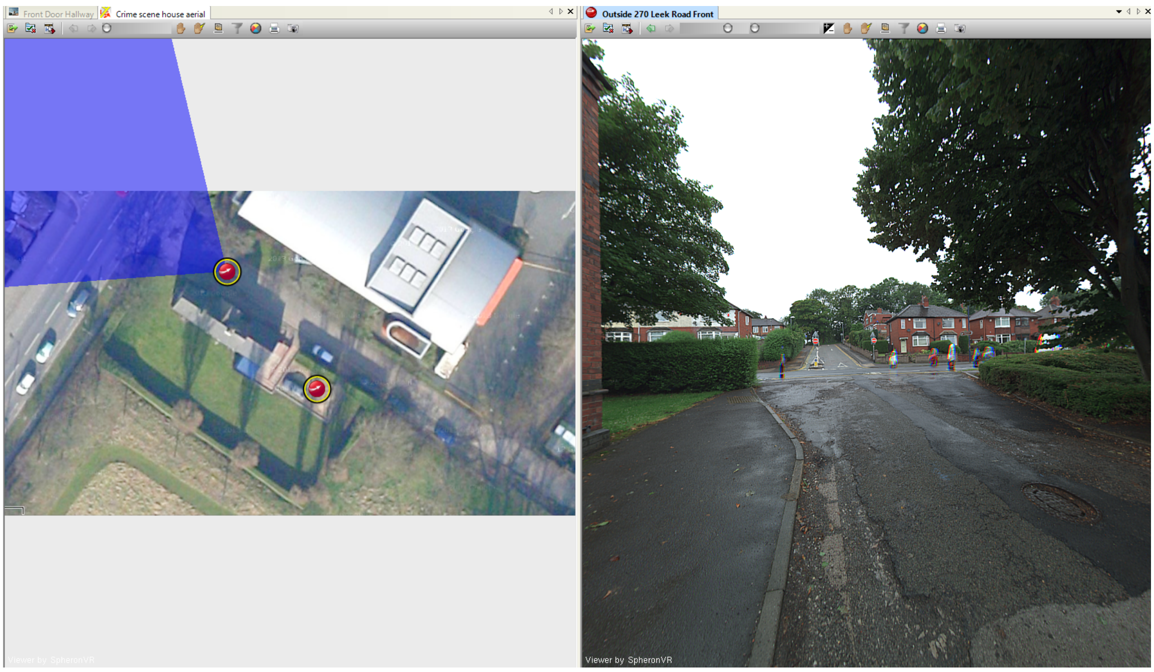


Figure 2.12: Interactive panorama demonstrating an additional aerial plan which allows users to observe the current location of the panorama in relation to the scene and observation of viewing orientation. Left: Aerial view of house demonstrating the viewing orientation of the panorama (Right).

2.1.5 Laser scanners

Additional methods for recording a scene utilise 3D laser scanners, which simultaneously take millions of measurements whilst documenting the scene (Bain, 2017; Mihandoost, 2015). Laser scanners, particularly time of flight scanners, operate using the principle of the speed of light and as a result, distances of objects can be calculated easily using the laser. The scanner emits a pulse of light (a laser), which travels to the nearest surface and is reflected from this surface. A sensor within the scanner detects the reflected radiation from the surface (San Jose Alonso *et al.,* 2011). Mathematical calculations using the speed of light (the laser) and the time it took for the laser to be emitted, reflected back to the sensor and detected can be used to calculate the distance to the object of interest (Sansoni *et al.*, 2009). The laser scanner collects distances and angles which exist between the scanner and objects within its line of sight (Chekole, 2014). As a result, laser-scanning techniques can quickly capture a scene producing highly detailed point cloud data along with millions of measurements (Mihandoost, 2015). Laser scanning enables 3D documentation of a scene and the data captured can be used to create digital reconstructions and simulations of events that may have occurred at a scene (Buck *et al.,* 2013).

Laser scanners determine the distance to objects within 3D space and produces a ‘point’ for every measured object point within an environment. Each ‘point’ represents one point in 3D space. The data produced from laser scanners produces a ‘cloud’ of points in 3D space, which represent visible surfaces to produce an image of an environment composed of millions of data points as shown in Figure 2.13. Laser scanning methods produce a highly detailed and accurate point cloud 3D representation of a scene, which can be ‘walked through’ and viewed at any angle (Pfeifle, 2012).

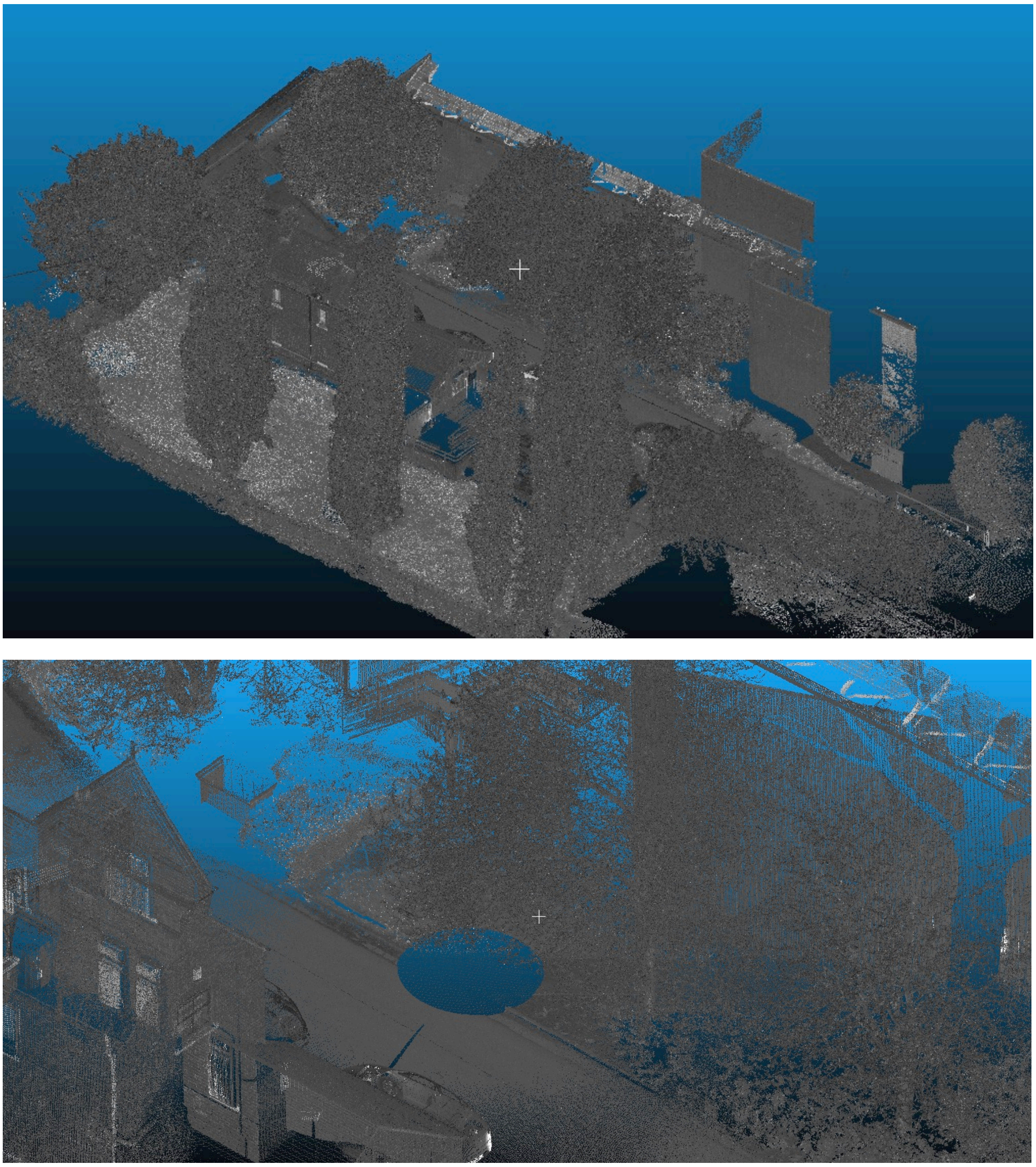


Figure 2.13: Leica Scanstation Laser scan data example comprising millions of data points.

2.1.6 Panoramic recording technology

Such immersive environments provided by panoramic photography and 3D laser scanning are becoming more popular for use within criminal investigations as they provide an opportunity to fully document a scene in a highly detailed manner, which allows the subsequent presentation of an environment in real time. These technologies allow users to visit a scene without having to be physically present at the scene and allow users to view the entire scene as opposed to only the information or evidence deemed relevant at that time. The technology provides a visual presentation tool providing contextual relevance and conveying spatial relationships within a scene; an aspect that still-digital photography cannot offer (Fangi, 2013).

The application of panoramic technology within criminal investigations is relatively novel but products are emerging which are facilitating the need for this technology within crime scene investigations. Panoramic technology has been introduced into police services through a demand for faster and more cost effective technologies. Police services are beginning to take advantage of the opportunities that three-dimensional (3D) technology is providing and have begun adopting technologies such as 360^{o} photography and laser scanning systems (Cavagnini *et al.,* 2009). Such systems produce highly detailed three-dimensional representations of scene and allow the viewer to immerse themselves within a fully navigable environment (Dang *et al.*, 2011).

2.1.7 Rationale

With a multitude of technology available to police services and forensic personnel it is integral that such agencies carefully consider the implications and benefits a particular piece of technology will bring to their organisation. In order to successfully adopt and implement technology it needs to be carefully scrutinised to ensure the adoption of the correct piece of equipment to suit the organisations requirements. Evaluating technology can be a challenging task that requires the investment of a significant amount of time, which police services do not currently have. Crime scenes pose challenging environments, which require extensive documentation and the nature of criminal investigations requires any new technology integration to be seamless and have minimal effect on current working practices or standard operating procedures (SOP’s). Technological glitches at a scene could frustrate, complicate and jeopardise the documentation process and these issues need to be ascertained before police services adopt the technology. Extensive analysis of any technology can aid in minimising any complications or challenges associated with the technology implementation prior to its adoption by any company.

One of the most common experiences with the adoption of new technology without prior research and evaluation involves misuse of the system through underutilisation, whereby a lack of research did not identify that the technology was not suited to the requirements of an organization. This can ultimately lead to the discontinued use of purchased technology due to the lack of comprehensive evaluation prior to adoption and implementation. Panoramic imaging technologies have been extensively used in other fields including architecture, quality control, oil industries and archeology and have been validated for such purposes (National Institute of Justice, 2013; Gledhill *et al*., 2003). However, there is limited validation, comparisons or contrast research into panoramic technology use for documenting crime scenes.

Police and forensic services, much like any company seeking to adopt new technology, need objective information about the technology including the benefits and limitations. An in-depth overview of the technology in an operational environment can provide much needed information, which may not be provided solely from a manufacturers sales pitch. Unbiased and impartial research testing the technology will allow police services and forensic personnel to adopt appropriate technology for them and make a more informed decision about what they require from a piece of equipment to suit their specific needs. Police services do not have the time to comprehensively evaluate and objectively compare different technologies to ascertain the capabilities, benefits and challenges of each of them.

To date only one formal evaluation published in the literature has been conducted, comparing panoramic imaging technologies. A study conducted by the National Institute of Justice (NIJ) in 2013, compared three panoramic imaging technologies based on their manufacturer specifications and analysing their results in different scenes (National Institute of Justice, 2013). More comprehensive comparisons of these types of panoramic imaging technologies are required to ensure police services can make the most informed decision about which technology is most suitable to them. This will prevent adoption of technology that isn’t fit for purpose, reduce the chances of misuse, and reduce underutilisation or even discontinuance of the purchased technology.

Aims and Objectives

The aim of this research was to explore and evaluate the different types of panoramic imaging technology that are currently available to police services for documenting crime scenes.

The objectives to achieve the aim are as follows:

Objectives

- To investigate the different types of panoramic imaging technology which are currently available to police services
- To explore the specifications of each of these technologies and compare and contrast them based on manufacturer specifications
- To investigate the criteria which police services use to assess technology when considering its adoption
- To investigate some panoramic imaging technologies in different environments and compare and contrast their outputs.
- To identify a process to assist police services to make appropriate decisions about which is the most suitable equipment for them to purchase for use in different crime scene environments.

2.2 Methodology

2.2.1 Crime scene recording technology

This research explores the different types of crime scene documentation technologies, in particular panoramic imaging technologies which are currently available for police services to purchase, many of which have already been adopted by police services. In order to determine the different types of panoramic imaging technology which are available to police services literature searching and web searching was conducted, in addition to personal communication with forensic managers from police services across the UK. Each piece of identified technology is discussed describing the technology and its associated features.

2.2.1.1 Technology Specifications

The different types of panoramic imaging technologies identified in *2.2.1 Crime Scene Recording Technology* were tabulated according to criteria which may influence an organization's decision to adopt a particular piece of technology. The identified technologies were compared based on manufacturer specifications that were sought through personal communication with the manufacturers of the technology. Where it was not possible to receive information from the manufacturers, literature and web searching was conducted to obtain information regarding the technology. The technologies were split into panoramic photography technology and 3D laser scanning technology due to their different specifications. The specifications for the photographic technology consisted of lens type, image resolution, field of view (both horizontal and vertical), minimum capture time, storage format, storage device, HDR capabilities, battery life, cost, additional lighting and whether the technology can take measurements. The specifications for the 3D laser scanning technology consist of range, distance accuracy, field of view (both horizontal and vertical), measurement speed, storage device, battery life, cost, additional lighting and the ability to take measurements. The technologies included within this study are discussed in turn.

2.2.1.2 Adoption Criteria

Prior to the purchase and adoption of technology, an organisation must consider many different factors which may influence their purchase choice. An investigation was conducted to determine what police services require from technology and the criteria that they need to consider prior to its adoption. These criteria were determined through discussions with police personnel, forensic managers, College of Policing (CoP) trainers and literature searching and were used to assess the different types of technology discussed in *2.2.1 Crime Scene Recording Technology.* Each technology is discussed in the context of these criteria.

2.2.2 Evaluating crime scene documentation technology in a mock crime scene

Some crime scene documentation technologies were evaluated in different mock crime scene environments. The study did not seek to evaluate and compare the technology against one another but sought to evaluate the specific features and functions of each system to illustrate the capabilities of each.

2.2.2.1 Crime Scene House

The investigation was conducted at a crime facility at the host institution as this facility enabled the same scene to be staged for each technology and allows a comparable evaluation. A double bedroom within this facility was utilised which included fixed and non-fixed items.

2.2.2.1.1 Spheron SceneCam

A Spheron SceneCam was placed in two positions, position 1 and position 2 between the double bed and double wardbrobe within the bedroom environment as demonstrated in Figure 2.14. The camera was calibrated according to the manufacturers instructions (Spheron SceneCam User Manual, 2007) and two 360^{o} panoramas of the environment were taken; one at the cameras lower position (146 cm from the floor to the centre of the camera lens), and one at the cameras highest position (207 cm from the floor to the centre of the camera lens) for both position 1 and position 2. Each panorama was taken at the cameras maximum resolution of 50 MP (megapixels). The room lighting was on and no other artificial lighting was utilised. The resultant panoramas were uploaded onto the complimentary SceneCenter software.

2.2.2.1.2 Leica Scanstation and iStar

A Leica Scanstation was calibrated according to the manufacturers instructions, was placed between the double bed and double wardbrobe within a crime house facility at Staffordshire university to replicate the same positions as used in *2.2.2.1.1 Spheron SceneCam*, as demonstrated in Figure 2.14.

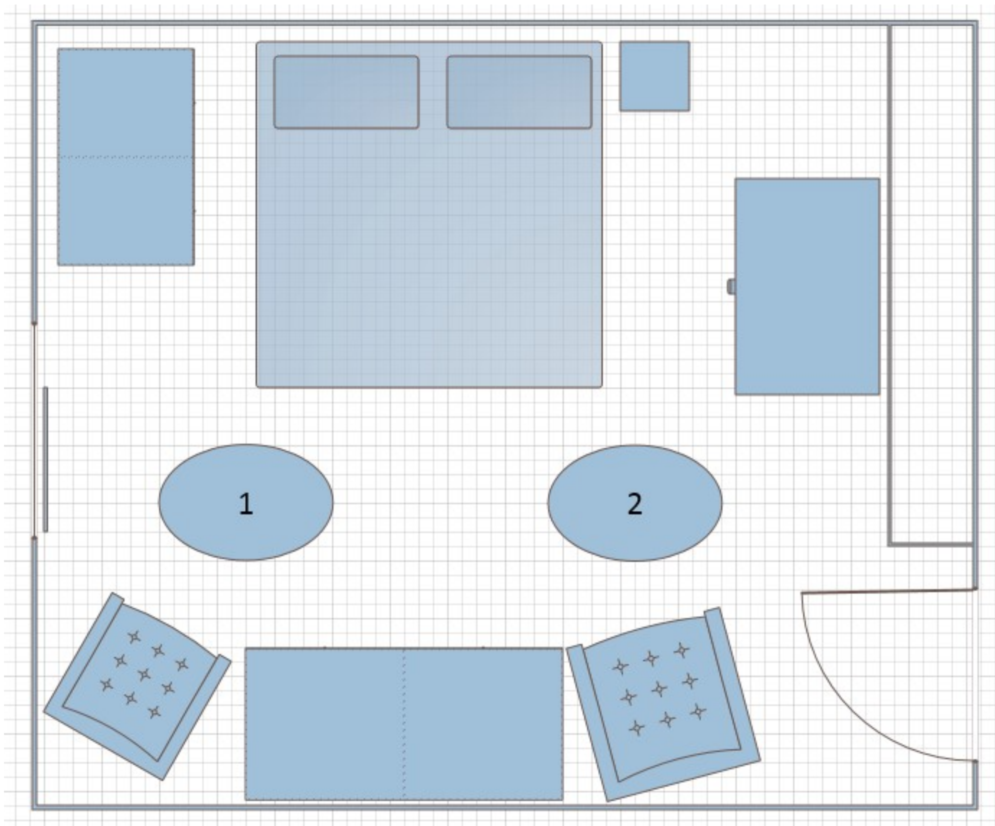


Figure 2.14: SceneCam placement within bedroom environment demonstrating position 1 and position 2 between the double bed and double wardrobe.

The room lighting was on and no other artificial lighting was utilised. In addition, once the Leica ScanStation had captured the environment, an iStar camera system was attached to the same tripod used for the ScanStation and photograhs of the environment were captured using this system. The resultant point cloud was uploaded into the complimentary cyclone software and the iStar photographs were uploaded into NCTechs complimentary software, Immersive Studio.

Each of the technologies were evaluated to determine the extent to which the technology was able to capture the bedroom environment and discusses their specific features for documenting the environment.

2.2.2.2 Fire Investigation

An investigation was conducted to observe how a 360^{o} camera and 3D laser scanner would capture a fire scene. The investigation consisted of recording a scene prior to being burned and then recapturing the scene after burning.

A specialist fire investigation-training site (Gardiners Associates Training and Research Ltd.) was utilised for this investigation as it provided an environment that could be staged as a household interior and allowed for a controlled fire scene to be staged. The environment had been staged by staff at Gardiners associates and mimicked a typical crowded household environment consisting of beds, clothes, television, desk, microwave and chest of drawers (Figure 2.15).

2.2.2.2.1 Pre Burn

2.2.2.2.1.1 Spheron SceneCam

The household environment was photographed using a Spheron SceneCam (Spheron VR AG), which was positioned in two locations within the environment (Figure 2.16). Following calibration of the instrument, two 360 ^{o} scans of the environment were taken; one at the cameras lower position (146 cm from the floor to the centre of the camera lens), and one at the cameras highest position (207 cm from the floor to the centre of the camera lens), according to the manufacturer's instructions (Spheron SceneCam User Manual, 2007). This process was repeated for position 2. The panoramas were uploaded onto the complimentary SceneCenter software and examined to determine the extent to which the fire scene could be successfully captured using this technology.

Figure 2.15: Gardiners Associates Training and Research Ltd. Staged household environment consisting of beds, clothes, television, desk, microwave and chest of drawers.

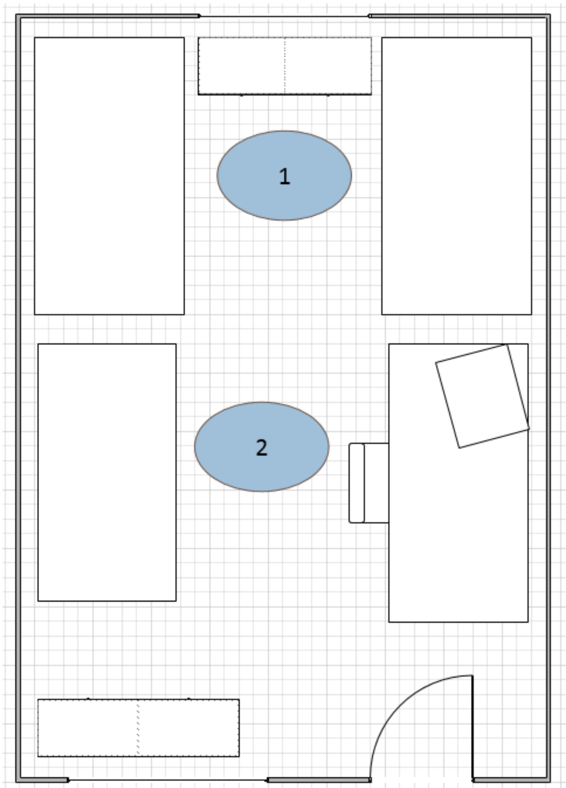


Figure 2.16: Photographs taken using the SceneCam from positions 1 and 2 within the household environment.

2.2.2.2.1.2 FARO Focus X330

The household environment was captured using a FARO Focus X330 (FARO) which was positioned in two locations within the environment; in the approximate same position as the SceneCam, as described in *2.2.2.2.1.1 Spheron SceneCam.* The FARO Focus was used to laser scan the environment. Two processes were undertaken at the scene in order to capture the environment. A laser scan was used to capture point cloud data from the scene, and subsequent photographs using the on-board FARO camera were used to capture colour to add to the laser scan. This process was repeated for position 2 in the environment. The laser scan data was uploaded to the complimentary SCENE software and examined to determine the extent to which the fire scene could be successfully captured using such technology.

2.2.2.2.2 Post Burn

After the environment was burned and the scene had sufficient time to cool (approximately 2 hours) staff at the training site deemed that environment to be safe to enter. The scene was captured using both the SceneCam (Spheron VR AG) and the Focus X330 (FARO) utilising the same procedure and technology placement positions as previously described. Figure 2.17 demonstrates the SceneCam camera placement and subsequent environment capture. The panoramas were uploaded into the complimentary SceneCenter software and the laser scan data uploaded into the complimentary SCENE software by a sales rep who brought along the FARO Focus X330. The panoramas obtained from each technology were evaluated highlighting the benefits and limitations of each technology and examining the usefulness of such technology within fire investigation scenes.

Figure 2.17: Spheron SceneCam placement in the fire investigation scene – post burn.

2.2.2.3 Road Traffic Collisions

An investigation was conducted at a police-training site in Derbyshire to determine the extent to which a SceneCam 360^{o} camera and a Leica ScanStation could accurately capture tyre marks that are often encountered during road traffic collisions (RTC's). Police service personnel produced tyre marks on a tarmac surface using a vehicle at their training site. Tyre marks were marked using standard chalk methods, highlighting key features of the tyre marks such as the start and end point of the tyre mark and the width of the tyre marks.

2.2.2.3.1 Spheron SceneCam

A SceneCam, 360^{o} camera was placed adjacent to the tyre marks, was calibrated and a scan of the environment taken as shown in Figure 2.18. The panorama was captured using the maximum resolution of 50 MP. The panorama was uploaded onto the complimentary SceneCenter software and analysed to determine the extent to which the camera could successfully detect the tyre marks.

2.2.2.3.2 Leica ScanStation

A Leica ScanStation was placed in the same location as the Spheron SceneCam and the environment captured as demonstrated in Figure 2.19. The laser scan data was uploaded into the complimentary Leica Cyclone software and analysed to determine the extent to which the laser scanner could successfully detect the tyre marks.

Figure 2.18: SceneCam set up adjacent to the created tyre marks (right).

Figure 2.19: Leica ScanStation set up adjacent to the created tyre marks (left).

2.3 Results and Discussion

2.3.1 Crime scene recording technology

There are a variety of technologies on sale which purport to capture an environment using panoramic imaging, however, only a select few of these have been adopted for the purposes of crime scene documentation as part of criminal investigations. Police services do not have the time required to conduct such an evaluation or have access to the equipment to provide their own technological assessment.

Many different types of panoramic imaging technologies are available and these represent a spectrum of capabilities. The technologies currently available range from software that allows the user to develop a panoramic image from multiple digital photographs, to hardware and software applications which automatically capture and process data to create a panorama. Other technology can also simultaneously take measurement data whilst capturing the environment (NIST, 2013). Some of the panoramic imaging technologies which are available to police services will be discussed in turn. The technologies discussed within this chapter are not exhaustive of all panoramic imaging technologies available and each manufacturer may offer other panoramic imaging systems which have not been discussed. The main technology items which have been examined within this study are described briefly to include technology components and the basic operation to understand how the technology produces the desired output.

2.3.1.1 CSI:360

CSI:360 has been produced as a division of VPix and consists of a Nikon D600 camera, a rotator, a fisheye lens, tripod and complimentary server based software. The software application can be utilised with any Nikon or Canon cameras. The CSI:360 method requires capture of 4 photographs, 90^{o} apart of any environment. The JPEG images require stitching together to create one panorama which can be uploaded onto the CSI:360 server. Within the CSI:360 server the panoramas views can be linked together. In addition, the software allows the addition of yellow evidence markers to point to evidence within the scene, crime scenes notes and hotspots which demonstrate maps and floor plans, as demonstrated in Figure 2.20.

Figure 2.20: CSI:360 Software (VPix division). Taken from CSI:360.

2.3.1.2 SceneVision Panorama

SceneVision Panorama created by 3rd Tech Inc. consists of a digital camera, tripod, panoramic tripod head, PTGUi software and SceneVision Panorama software. This system utilises 2D photographs captured using a digital camera (Figure 2.21) which is rotated on a panoramic tripod head, capturing multiple images as it rotates around its central axis. The PTGui software aids in creating panoramic images from multiple individual and overlapping images captured using the digital camera. The SceneVision Panorama software (Figure 2.22) generates a virtual tour which can be created by linking multiple panoramic images. In addition, other files can be added into the virtual tour such as sketches, diagrams and still photographs which can be viewed simultaneously alongside the tour. Measurements cannot be taken using this system and tape measurements would still need to be taken manually.

2.3.1.3 Panoscan MK-3

The Panoscan MK-3 is the third generation created by Panoscan in conjunction with Better Light Inc. The capture of a panorama using the Panoscan MK-3 is obtained as the digital camera rotates around its central axis, and eliminates the requirement for stitching multiple images together. The Panoscan MK-3 can accommodate a range of different lenses including a fisheye lens to extend the field of view. Using the complimentary Better Light ViewFinder software multiple panoramic images can be linked to create a virtual tour with additional embedded still photographs. Manual tape measurements would still need to be taken at the crime scene as this technology does not enable measurements to be taken from the photographs. An example of a virtual tour can be seen in Figure 2.23.

Figure 2.21: *SceneVision Panorama compact digital camera and panoramic tripod head. Taken from 3rd Tech Inc.*

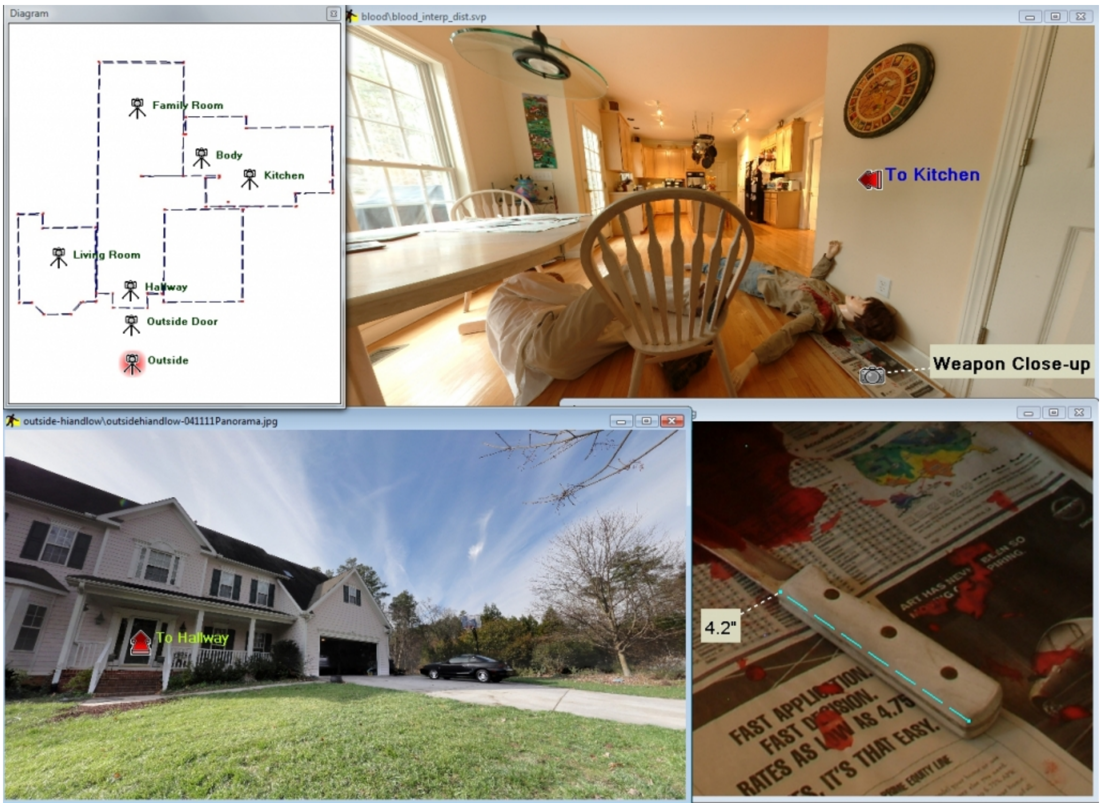


Figure 2.22: SceneVision Panorama software. Taken from 3rd Tech Inc.

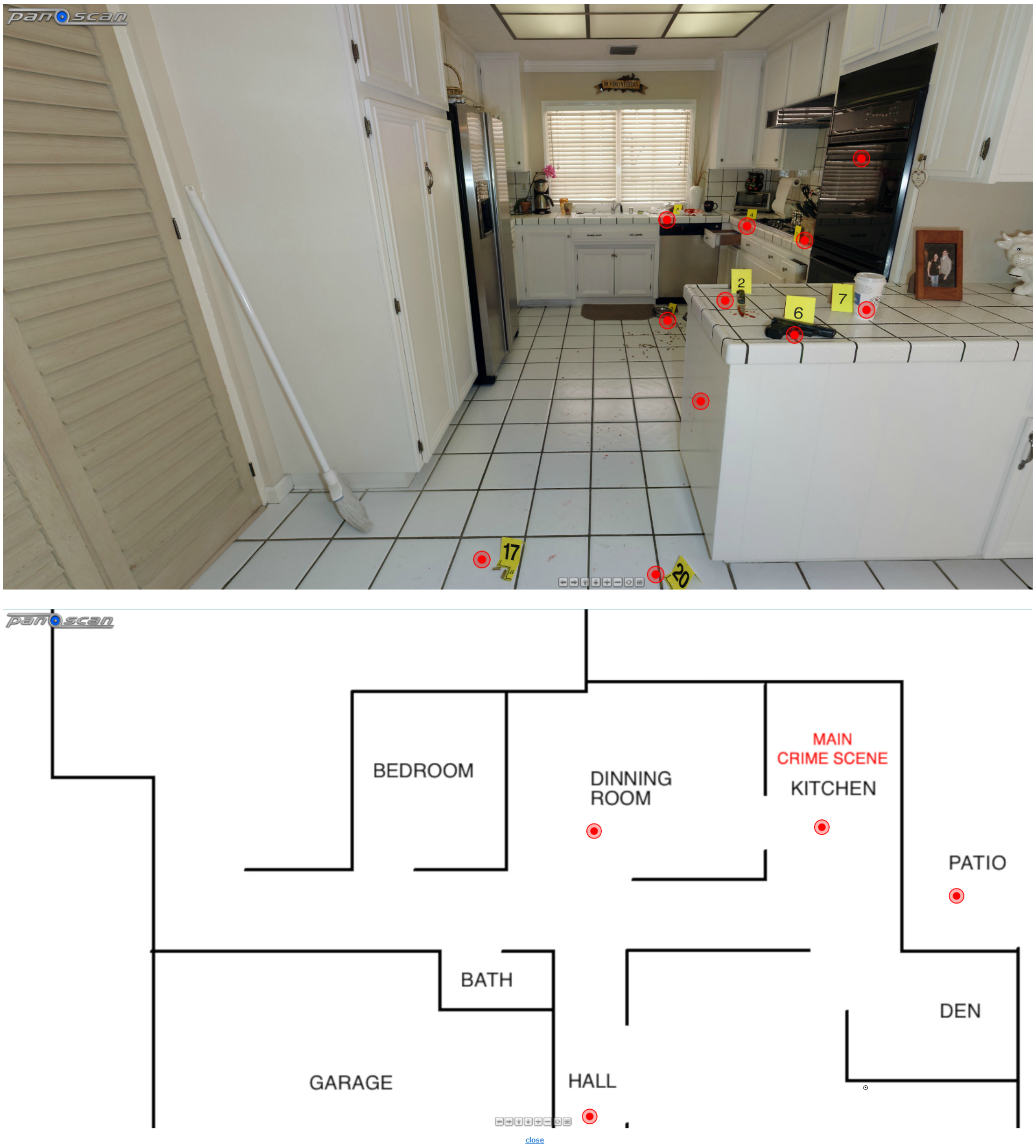


Figure 2.23: Panoscan MK-3 software virtual tour print screens. Top: Kitchen environment showing additional hotspots (red circles) which link to additional information or photographs. Bottom: Floor plan demonstrating where panoramas have been taken from (red circles). Taken from Panoscan.

2.3.1.4 iStar Fusion

The iStar system (Figure 2.2) created by NCTech has been designed for rapid 360° imaging. It is a small, rugged and lightweight system with a footprint of 10 cm x 10 cm. The iStar produces high-resolution 50 MP panoramas with capture times ranging from 5 to 20 seconds depending on the selected resolution. The iStar is operated by a touchscreen on top of the camera system. Panoramas are created using the 4 pre-calibrated lenses each located on one side of the square box. Each lens simultaneously takes a photograph and NCTech's software application Immersive Studio processes and stitches the resultant images (Figure 2.24). Photographs are stored on a Secure Digital Card (SD) card or can be transferred straight onto a Universal Serial Bus (USB) stick. NCTech's complimentary Immersive Studio software allows users to navigate around the panorama and link multiple panoramas to create a virtual tour. Previously the iStar system was incapable of capturing measurements, but more recently the manufacturers have updated their firmware to enable measurements to be taken using Veesus Arena4D Data studio and Arithmetica Spherevision software.

2.3.1.5 FARO Focus^{3D} X 330

The FARO Focus^{3D} X330 (Figure 2.25) is a laser scanner which produces a 3D representation of an environment and has a range of 330 metres. The scanner emits a pulse of light (laser) which travels to the nearest surface and is reflected back to the scanner where a sensor detects the reflected radiation. From this, the laser scanner determines the distances to objects within 3D space and produces a 'point' for every measured object point within the environment. Each 'point' represents one point in 3D space. The resultant point cloud represents visible surfaces within an environment to produce a 3D representation of an environment comprised millions of data points as demonstrated in Figure 2.26.

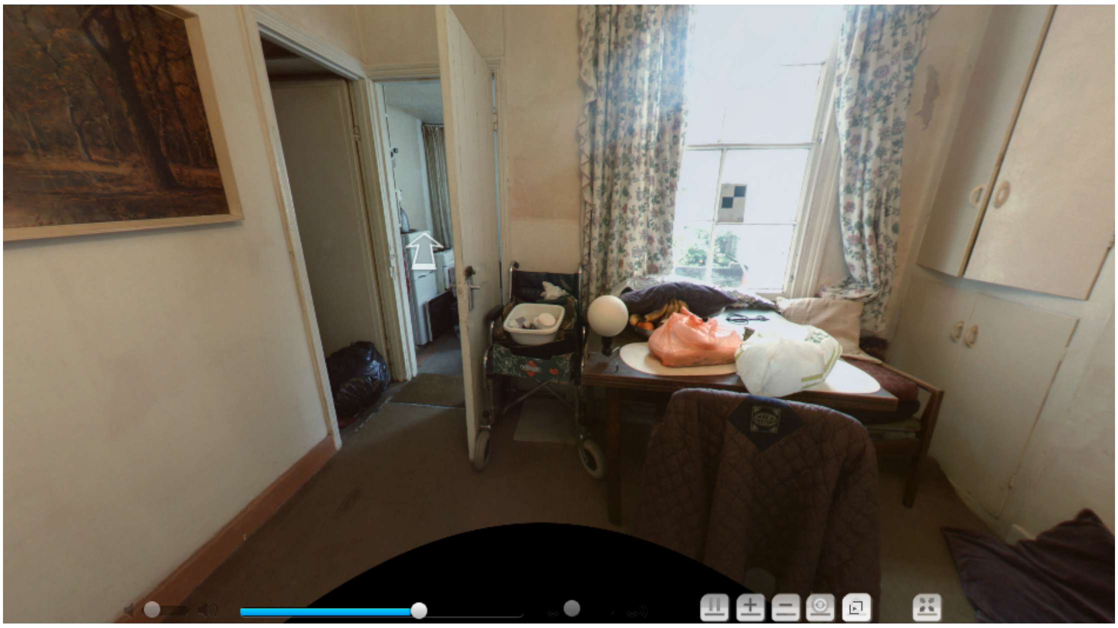


Figure 2.24: NCTech's complimentary software Immersive Studio links multiple panoramic images to create a virtual tour.

Figure 2.25: Faro Focus^{3D} X330 Laser scanner. Taken from FARO.

Figure 2.26: Faro Focus^{3D} X330 Laser scan point cloud data. Taken from FARO.

2.3.1.6 Leica ScanStation

The Leica ScanStation C10 (Figure 2.27) is a laser scanner which produces a 3D representation of an environment. The scanner emits a laser pulse across the environment and receives a reflected signal back to the scanner if the laser reflects off a surface. This builds up a point cloud where each 'point' represents a 3D point in space. The laser scanner measures the distances and angles of the reflected laser. The laser scanner captures a wide field of view and rotates around 360^{o} to capture an environment. A built in camera is used to capture photographs of the environment. Using Leica's complimentary software Cyclone or Truview (Figure 2.28), different laser scanner positions can be registered and linked to allow greater detailed scenes to be created. The photographs can be used to add in colour to the laser scan data.

Figure 2.27: Leica ScanStation C10 laser scanner. Taken from Leica Geosystems.

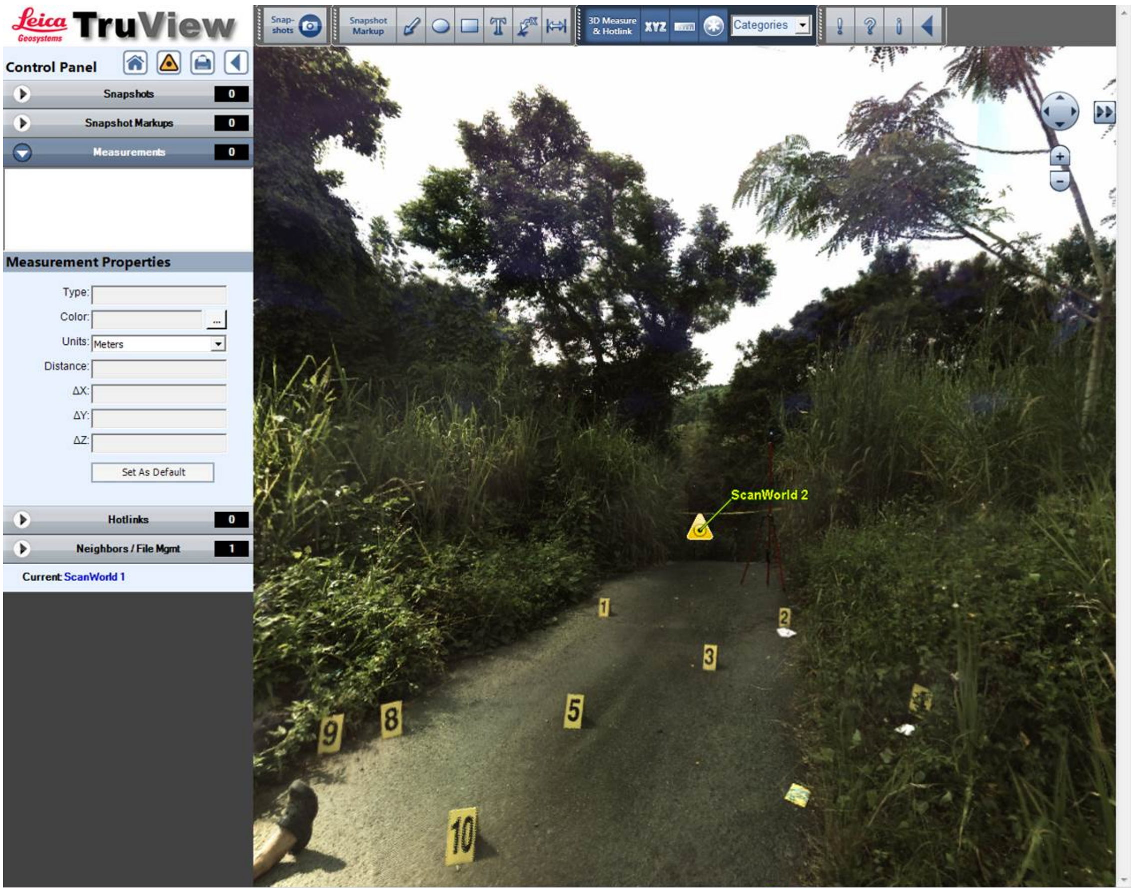


Figure 2.28: Leica ScanStation C10 laser scan data in Truview software with hotspot to another data collection point (yellow triangle). Taken from Leica Geosystems.

2.3.2.1 Technology Specifications

Advancements in technology have enabled some SOCO's to go paperless, through utilisation of modern technology. Table 2.1 details a range of different systems for capturing a crime scene which are available to police forces, ranging from low cost manually operated systems to higher cost high-end automated systems. All of these technologies aim to create the same output; a panoramic representation of an environment, whether through photographic or laser scanning methods. Both panoramic imaging and 3D laser scanning techniques produce a permanent visual record of a scene in its untouched and original state (Strandberg, 2015).

At the lower costing end of the technology spectrum, photographic systems such as CSI:360 and SceneVision Panorama utilise standard Digital Single Lens Reflex (DSLR) cameras as the environment capture method. This is not dissimilar from how crime scenes are currently captured, however, the companies have created their own rotating stage which the camera attaches to and this allows the camera to remain in one position but turn on a central axis. This ensures that 'stitching' of the photographs can occur more smoothly as each photograph was taken from the same orientation and distance within the environment. Additional components can be added to these systems as part of a range of packages sold by the manufacturers; the lens types can be changed on the camera system and additional lighting packages are available to account for low lighting scenes (Sheppard *et al*., 2016).

Note: costs are appropriate at the time of publication

Table 2.1: Photographic technologies available to police services

Photographic Technology											
Technology	**Lens Type**	**Image Resolution**	**Field of View Vertical x Horizontal**	**Minimum Capture Time/ seconds**	**Storage Format**	**Storage Device**	**HDR/ f stops**	**Battery Life/ hours/ shots per charge**	**Cost***	**Additional Lighting**	**Measurements**
CSI:360	Sigma 8mm f/ 3.5 Fisheye Nikon D7200	16MP	180° x 360°	4 shots at 90° intervals	NEF (RAW) or JPEG	USB hiSpeed Card reader SD Card	----	850 shots	£3906.00 US equivalent	Speed Light kit included	Not currently
SceneVision Panorama	Nikon Coolpix P300 (Or comparable)	16MP	Panorama Mode 180° x 360°	Less than 240	JPEG	SD Memory Card	----	240 shots	~£1616 US equivalent**	Flash on Camera	Yes using photogrammetry
Panoscan MK-3	Mamiya 645 format. Fisheye	(9000 x 18000)	180° x 360°	7	TIFF and Adobe PNG	Hard Drive USB 2.0	HDR 12	6	~ £41,500 with software	Optional Lighting Unit	Yes using photogrammetry
iStar Fusion	Fisheye f 2.6 (x4)	50MP (10000 x 5000px)	180° x 360°	5	.nctri	SD Card or USB 2.0 transfer	HDR 3	5-6	£4,750	LED panels	Yes using photogrammetry
Spheron SceneCam	Fisheye f 2.8	50 MP	180° x 360°	7	.sph	USB 2.0	HDR 26	8	~£60,000	Quad column white LED array	Yes using photogrammetry

Laser Scanning Technology									
	Range	**Distance Accuracy**	**Field of View Vertical x Horizontal**	**Measurement Speed/ points per second**	**Storage Device**	**Battery Life /hours**	**Cost**	**Additional Lighting**	**Measurements**
FARO Focus^{3D} X 330	0.6m up to 330 m	+/- 2 mm	180° x 360°	Up to 976,000	SD Card	4.5	~£45,000	Not needed	Yes
Leica Scanstation C10	Up to 300 m	+/- 2 mm	180° x 360°	Up to 50,000	SSD or USB transfer	3.5 (Internal) 6 (External)	~£97,000	Not needed	Yes

* Costs are approximate ** Higher price outside the USA

At the opposite end of the spectrum are the more automated and higher cost photographic systems such as the Panoscan Mk-3, iStar Fusion produced by NCTech, and the SceneCam produced by Spheron VR AG. These systems have been created to eliminate the requirement for manually stitching photographs and the complementary software applications automatically process the images to create spherical panoramas. All three of these systems have been designed so that anybody can operate them, and no previous photographic experience or knowledge is needed, as capturing an environment is a simple button press operation. The Spheron SceneCam has the ability to take measurements of a scene, using photogrammetry, which is the process of taking measurements from a photograph, using triangulation methods. The iStar system previously could not take measurements but software has recently been developed so that measurements can be taken. Photogrammetry as a technique itself is not as accurate as laser scanning systems (Chavalas, 2015).

All of the photographic systems discussed create an end product of full spherical immersive images and produce virtual tours, whereby individual panoramas can be 'linked' so users are able to 'walk through' the scene viewing it from each camera position. Photographs captured with systems such as CSI:360, and SceneVision Panorama require the use of stitching software to allow multiple digital images to be collated to create a panorama. Each manufacturer provides its own software application to allow users to import their photographs and stitch them to create a panorama of a scene. These applications reduce the requirement to have extensive knowledge and experience of software stitching applications, previously needed with other applications. Laser scanning systems such as the Leica ScanStation C10 and FARO Focus X 330 can capture a 360^{o} x 180^{o} view of a scene in the same way that the photographic systems do. Due to the fact that these systems use a laser, the distance range of these systems are far greater than that of the photographic systems, which are limited by their resolution, and the number of pixels used to create a panorama (Chavalas, 2015).

According to the National Institute of Justice (2013) who conducted an evaluation of three panoramic imaging technologies, large featureless environments pose a challenge for the Scenevision and Panoscan systems. The featureless environment interferes with the stitching of images. In such cases the manufacturers suggest small stickers in the featureless areas to create a known point for stitching.

The technologies described have been designed for ease of use, through one button operation to ensure anyone and everyone is able to operate these cameras and as a result offer great flexibility (Strandberg. 2015). The speed at which an entire scene can be captured and how quickly that information can be distributed to relevant personnel is extremely useful for scene of crime officers (Pfeifle. 2012).

2.3.2.2 Adoption Criteria

With a growing trend and governmental drive towards police services adopting and implementing technology it is essential that research is conducted into factors which may affect technology acceptance (Lindsay *et al*., 2011). Technology is being adopted by police services to support policing in different ways depending on the area of acceptance (Ashby and Longley, 2005; Lindsay *et al.,* 2011). Early technology adoption consisted of mobile devices to allow real time transfer of information whilst away from the office such as mobile tablets.

Colvin and Goh (2005) stated that technology has had a significant influence on police practices and the effects of IT on improving policing problem solving skills is favourable (Brown and Brudney, 2003). Despite the significant benefits which technology could provide to police services, there are also factors which may limit the success of technology adoption (Lindsay *et al*., 2011). Technology integration, particularly within police services and law enforcement needs to be implemented with little risk of disruption to existing processes (Association of Chief Police Officers, 2012). In addition, despite the significant advances in technology hardware and software, there is still significant underutilization of such technology systems (Johansen and Swigart, 1996; Venkatesh and Davis, 2000; Association of Chief Police Officers, 2012). An organization may decide to invest in technology to improve the high quality of their services and in some instances to cut costs (Legris *et al*., 2003).

Some of the main factors which need to be considered prior to the adoption of technology include how much the equipment costs, the frequency of use of such equipment and whether it will provide any probative value to the organisation and the crime scene investigations conducted (Koper *et al.,* 2009). In addition organisations need to consider personnel competency, training requirements and additional training costs, and storage space for data. Careful consideration of such criteria should help organisations to determine and justify the expenditure of such technology.

Police services have different goals and requirements and so one particular piece of technology which may provide significant benefits to one police service may not be consistent with requirements from what is required by another different police service. The improvements which may be demonstrated by these technologies will depend upon the specific requirements of that organisation and what the technology will be utilised for. The types of crime that will accommodate such technology may affect the type of technology that is considered, in addition to the perceived frequency of use of such technology.

The very nature of the crime scene documentation process requires that any new element within that process needs to be implemented in a risk free manner without complications (Association of Chief Police Officers. 2012). As a result, agencies need to invest a considerable amount of time evaluating the technologies to determine which is most appropriate to suit their needs – time which they currently don't have. Chan (2005) established a list of requirements that the intended users of a low cost portable system, created for the purpose of documenting crime scene environments, would need to accommodate. These requirements consisted of having a low cost, portable piece of equipment which was easy to use and produced quality images.

SOCO's will ultimately assess their organizational requirements for technology prior to its adoption. An organisation must consider many factors with regards to technology in order to identify a technology which may be more suited to their particular requirements. This will differ for different organisations depending on the intended uses of the system and the organisations desired outputs. The factors which need to be considered are each discussed in turn.

One of perhaps the most important and limiting factors regarding the adoption of technology into an organisation concerns the costing of the equipment. The cost to purchase the technology outright will have significant implications on whether an organisation can afford to purchase the technology. Police services ever constraining budgets often mean that some technology may not fall within their remit for purchase. In addition, organisations must also consider additional costs associated with the purchase of technology which may be associated with optional extras. These optional extras are likely to be other technology items which can adapt the existing technology such as extra lighting systems and different lenses. There may be other finances accompanying the technology through training and maintenance of the technology (Boehler and Marbs, 2003; Forensic Technology Center of Excellence, 2016).

Another crucial consideration with regards to the adoption of technology concerns the accuracy and reported errors associated with the equipment. Measurements that can be taken using such systems must be accurate in order to provide an accurate representation of the environment (Boehler and Marbs, 2003; Forensic Technology Center of Excellence, 2016). In addition, the equipment should have clearly defined levels of accuracy. The weight of the equipment and its associated portability will also significantly effect an organisations decision to purchase technology. SOCO's already have significant volumes of equipment to transport to a crime scene with toolkits which contain a plethora of equipment within hard carry cases (Boehler and Marbs, 2003). The range of capture of a piece of equipment will also need to be considered. This will inform the organisation as to how much of an environment the equipment is able to capture and will determine whether some scenes may require multiple capture points (Boehler and Marbs, 2003; Forensic Technology Center of Excellence, 2016).

Conducting a crime scene examination can be a time consuming aspect of any criminal investigation as it is integral that all information is captured accurately and efficiently. As a result, the time required to capture an environment using new technology, which could be integrated into the crime scene investigation process, must be considered. In such circumstances, the speed of the environment capture is likely to be dependent upon the resolution chosen. Crime scenes, by their nature, should require the highest resolution capture to ensure the documentation of an environment with the greatest level of detail possible (Boehler and Marbs, 2003; Forensic Technology Center of Excellence, 2016). Crime scenes can be encountered within any environment, indoors or outdoors, at any time of the year and therefore in any weather conditions which are beyond a SOCO's control. As a result, the organisation must consider whether the technology is capable of being utilised in all weather conditions, be it bright sunshine, thunderstorms, snow showers, or heavy rainfall.

Modern technological solutions are not possible without their associated large file sizes. As a result organisations must be aware of any additional requirements for additional storage space such as external hard drives or increasing existing hard drive space (Forensic Technology Center of Excellence, 2016). Additional storage options may not be possible without further cost implications.

Panoramic recording technologies such as 360^{o} photography or 3D laser scanning capture raw data from the crime scene. Due to the nature of the data captured it often cannot be viewed directly without subsequent post-production using complimentary software applications. In terms of 360^{o} photography the photographs will either require 'stitching' together or automated panoramas require mapping onto geometric shapes to allow undistorted viewing. With regards to 3D laser scanning, the point cloud data requires registering to link multiple scans together and to ensure that each of them has the correct orientation. These processes themselves will add extra time onto the investigation process and therefore must not be neglected (Forensic Technology Center of Excellence, 2016).

The factors which have been described previously are often generic considerations that will be accounted for by organisations prior to the purchase and integration of technology. This study also investigated more specific factors which organisations may wish to consider prior to the purchase of technology, particularly within forensic environments. These factors were collated through personal communications with forensic managers and college of policing staff when asked what information they would want to know about a piece of equipment prior to its consideration for purchase. Discussions with police services and college of policing trainers identified some of the operational criteria which need to be considered with regards to technology as follows.

With regards to panoramic imaging technology the following criteria were identified:

- The equipment's ability to easily take panoramas in confined locations, for example vehicle interiors. i.e. a car or van.

- The equipment's ability to really zoom in on minute detail. A Senior Investigating Officer (SIO) may want to read something on a document or newspaper clearly without excessive pixilation.

- Low light and ISO capabilities for very dimly lit scenes

- The ability to use the equipment with Unmanned Aerial Vehicles (UAV's) or drones. In such instances can the equipment be easily mounted to a UAV or drone.

- The ability to use the equipment in covert environments without drawing attention to oneself

- Does the equipment have High Dynamic Range (HDR) capabilities?

- The ease of stitching (if required) and if so are there clear instructions on the use of the procedures required for stitching. Does the stitching require technical knowledge in order to use the software or does it consist of more simple drag and drop methods.

- Can the outputs from the technology be easily played on a variety of devices such as fixed computers, laptops, tablets, and phones? The compatibility of the technological outputs requires consideration as this may limit its potential uses or benefits.

One factor, which may not be considered by manufacturers of technology for police services, concerns the compatibility of such technology into current police networks and infrastructure. Current police networks are highly secure to avoid loss or manipulation of highly sensitive data. Technology adoption will be easier if the technology can easily integrate with existing police operating systems, rather than requiring additional external software to be installed. In these circumstances, the nature of secure police systems does not allow for easy installation of external software.

Cost was one of the most important considerations identified by forensic managers and college of policing staff who would also have to consider what piece of technology would be the best value for money. Discussions highlighted whether more expensive items of equipment would be best purchased by a pooled resource for a whole region or collaboration between police organisations. In such situations, rather than dismissing the technology due to its high cost, resources could be pooled to collaboratively purchase such technology should it suit the requirements of the organisations.

It is important to understand the factors which may affect why people accept or reject technology and many authors have researched such effects using the technology acceptance model (TAM). Davis *et al.* (1989) researched predictors to demonstrate how organizations accept and adopt technology which ultimately consist of perceived usefulness and perceived ease of use of the technology in question. Perceived usefulness has been defined as the perceived extent to which a system will enhance an individual's job performance (Venkatesh and Davis, 2000). Perceived ease of use has been defined as the perceived extent to which a system will be free of effort (Venkatesh and Davis, 2000).

Manufacturer sales pitches are likely to paint their technology under the best light and results are often captured using best-case scenarios – a sterile environment which has often been manufactured to demonstrate the technology. This is not representative of real world environments which will be encountered, particularly within the context of criminal investigations – crime scenes are often beyond sterile. Equipment outputs will ultimately depend on the conditions and environment at the time which will encompass many different factors such as the size of the scene, the weather conditions, and the nature of the evidence contained within the environment. As a result it is advisable that a technology be evaluated within different scenarios and environments to ascertain its limitations and advantages within different environments which are likely to be encountered within criminal investigations. Police services do not have the time or resources to trial technology and evaluate its use within different environments.

As a result, this study investigates some of the technologies previously described in different mock crime scenes to evaluate their respective capabilities including the determination of any limitations and benefits of the technology in each scenario.

2.3.3 Evaluating crime scene documentation technology in a mock crime scene

Operational conditions at a crime scene vary greatly depending on the nature of the crime type and the environment itself. As a result a piece of technology which may be appropriate in one environment may not be appropriate within another. For example, confined spaces or very small scenes may not be suitable for large pieces of equipment. Police services will encounter a range of different crime scene types and environments and there are many aspects within crime scene documentation which needs to be conducted. If the technology can accommodate multiple aspects of crime scene documentation it is more likely to be adopted as it can aid in multiple aspects of criminal investigations.

The evaluation of the technologies within these investigations does not attempt to comparatively evaluate the technology against one another but instead sought to evaluate the specific features and functions of each system to illustrate the capabilities of each.

2.3.3.1 Crime scene house

2.3.3.1.1 Spheron SceneCam

The panoramas were examined using the SceneCenter software to determine the extent to which the camera could successfully document the double bedroom environment. An equirectangular projection of the bedroom environment captured using the SceneCam is demonstrated in Figure 2.29.

To access the panoramas demonstrating the double bedroom environment please refer to the supplementary USB card and open the file entitled Chapter 2 – Double bedroom environment. Within this file please select the 'Start' file. This will open the SceneCase with the panorama.

The SceneCam was able to successfully document the bedroom environment capturing the majority of the scene. The camera system does not have the ability to capture anything out of its line of sight and in this instance was not able to capture anything along the floor line to the right hand side of the double bed in Position 1. This was attributed to the initial positioning of the camera within the environment and as a result the camera placement needs to be carefully considered by the SOCO capturing the scene to ensure that the maximum amount of information and detail can be captured from that scene. In this instance, in order to capture the area not covered by the first panorama, a second panorama was also captured from Position 2 situated to the right hand side of the bed.

The set up of the SceneCam consists of linking 4 separate components; the camera head, the tripod, the battery pack and the portable computer. The set up of the equipment takes approximately 2 minutes and this time could be reduced with repeated and familiar use with the technology. Capture of an environment has been designed so that it is easy to use, following step-by-step instructions within the software contained on the portable computer. The software instructs the user to calibrate the camera by attaching the lens cap and informs the user as to when this process has finished by informing the user that the process has finished and asking them to remove the lens cap. The system is ready to capture an environment after the user has selected the required resolution and informed the software as to whether an additional lighting system ‘ScanLight’ has been attached.

In Figure 2.29 the window area looks overexposed due to the bright sunlight entering the scene and ‘bleaching out’ this area. Due to the HDR abilities of the camera, a user is able to dynamically scroll through the different exposure levels captured during the initial photography of the environment, allowing correct exposure viewing of the window. The bedroom environment contains a mirror which in this instance, did not present any challenges. Had the camera been placed directly in front of the mirror the resultant panorama would contain a reflection of the camera within the mirror.

The SceneCam is unable to capture anything under the tripod area as demonstrated in Figure 2.30 and Figure 2.31. As a result it may be necessary to place the camera in an additional location within the environment to ensure capture of this area, or alternatively capture a still digital photograph of underneath the tripod and hotspot this as additional information within the complimentary SceneCenter software.

Figure 2.29: Equirectangular projection of the bedroom environment 360° panorama captured using the Spheron SceneCam

Figure 2.30: The SceneCam is unable to capture anything past the base of the panoramic head within its field of view as demonstrated by the red triangle.

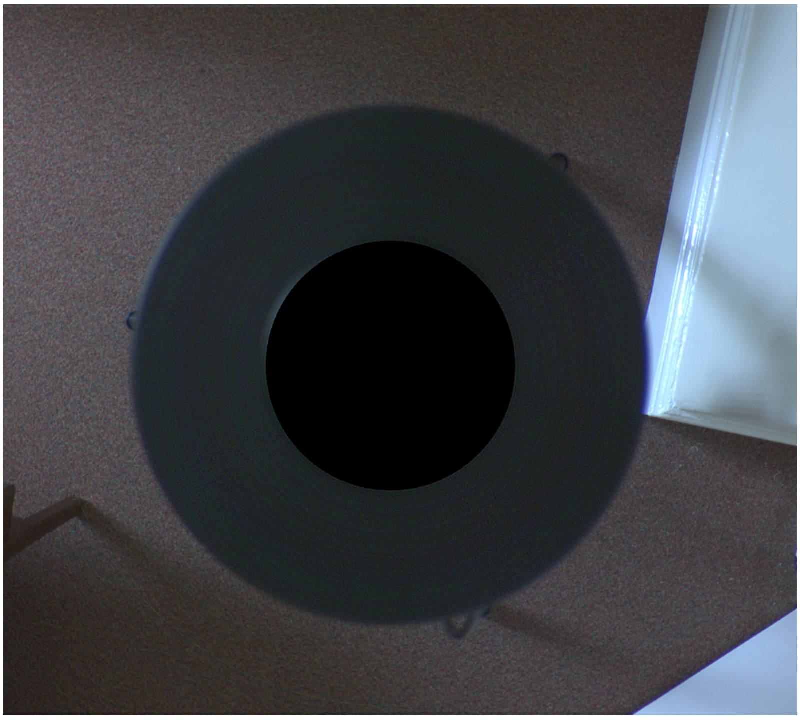


Figure 2.31: The SceneCam is unable to capture under the tripod area and is observed as a grey circle

2.3.3.1.2 Leica ScanStation and iStar

The laser scan data produced using the Leica ScanStation was examined using the Leica Cyclone software to determine the extent to which the laser scanner could successfully document the double bedroom environment. 360^{o} panoramas of the bedroom environment captured using the iStar photographic camera are demonstrated in Figure 2.32. The panoramas have been placed into the viewing software and as a result are not distorted and only show a portion of the scene at one time due to the large field of view.

To access the laser scan data demonstrating the double bedroom environment please refer to the supplementary USB card and open the file entitled Chapter 2 – Double bedroom environment – Laser Scanner.

The ScanStation was able to successfully document the bedroom environment capturing the majority of the scene as demonstrated in Figure 2.33. Unlike camera technology, a laser scanner is capable of capturing data which captures a greater area size and therefore was able to capture point cloud data outside of the bedroom environment, such as through the window. The Leica ScanStation is capable of taking measurements within a scene utilising TruView software application. Figure 2.34 demonstrates capturing a measurement using the laser scan data. Taking a measurement requires the user to select a 3D ‘point’ in space which represents a surface.

In addition, the Leica scanner is unable to capture some data below the scanner itself and this can result in ‘holes’ or missing data points which create circles within the scan data, as demonstrated in Figure 2.33 on the right. These circles can be minimised by moving the laser scanner and capturing the area from another position to reduce the volume of missing data.

Figure 2.32: 360^o navigable panoramas of the bedroom environment captured using the NCTech iStar

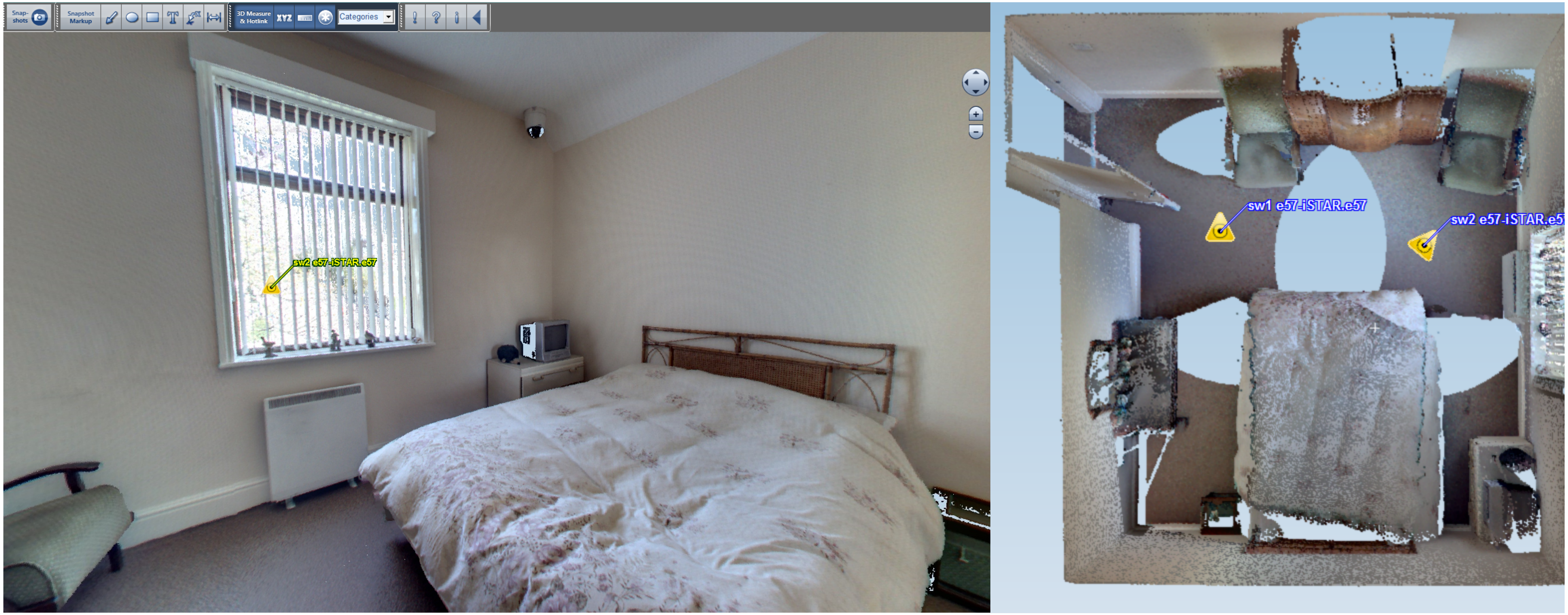


Figure 2.33: Leica ScanStation laser data of the bedroom environment. Left: Laser scan data coloured with the iStar camera. Right: Laser scan data birds eye view. Yellow triangles demonstrate the Leica scan positions.

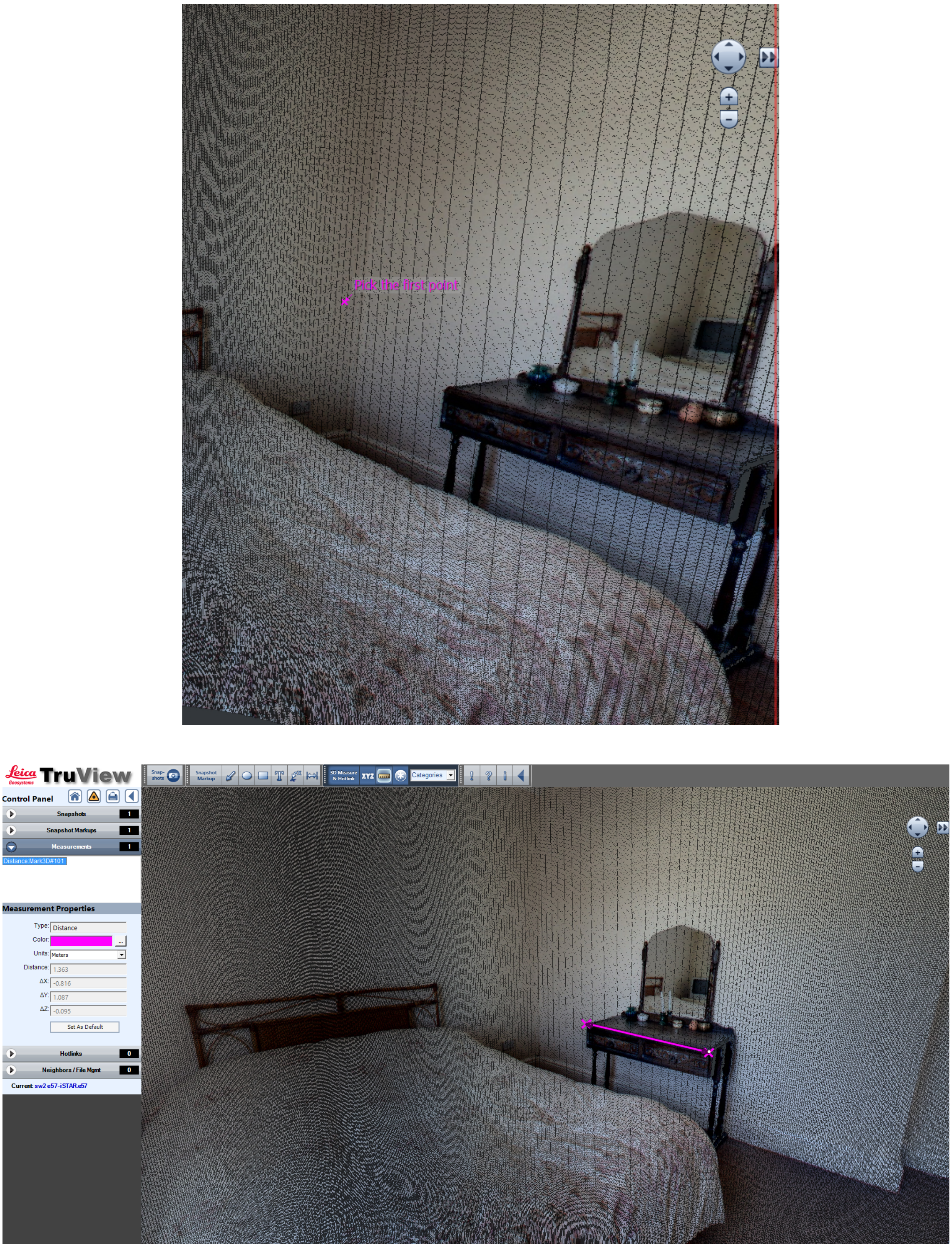


Figure 2.34: Taking a measurement within the TrueView complimentary software application utilising the Leica ScanStation point cloud data.

2.3.3.2 Fire Investigation Scene

The household environment was documented prior to any burning to document the scene as it was at the time and this would allow for comparison to the post burn scene documentation. Fire scenes often present complex crime scene environments to document using traditional methods using digital SLR cameras. The dark nature of fire scenes, due to the soot covered environment, present complexities when photographing the scene. Different exposures or aperture settings and a flash may be required in order to successfully capture the environment. However, it can take time to correctly capture the environment with the correct exposure to obtain the most information from the fire scene.

A laser scan produced by the FARO Focus^{3D} X 330 can be seen in Figure 2.35. The laser scan shown in Figure 2.35 demonstrates the data captured using the FARO laser scanner and the FARO's on board camera which has added colour into the laser scan data. There are areas within the laser scan which appear as dark black areas, such as the windows. Windows are a transparent surface which a laser will project straight through and therefore will not return a signal. Such surfaces produce problems for the laser scanner whereby data can be missing from the 3D point cloud. Where no response is detected by the scanner no value for that particular 3D point in space can be produced and therefore these areas are viewed as dark black areas or missing areas of detail within the scan (Yang and Wang, 2008; Huynh, 2010; Ch'ng *et al*., 2013; Forensic Technology Center of Excellence, 2016). The same environment captured using the SceneCam is shown in Figure 2.36. Figure 2.37 demonstrates a panoramic image of the same environment.

Note: Distortion is present in both Figure 2.35 and Figure 2.36 due to projection of the data. Both panoramas demonstrate a large field of view which is not possible to view as a whole without flattening out the panorama, as demonstrated in these figures. Viewing of the panoramas in their complimentary software applications would remove any distortion present.

To access the panoramas demonstrating the fire investigation scene pre burn please refer to the supplementary USB card and open the file entitled Chapter 2. Fire Investigation Scene. Within this file please select the 'Start' file. This will open the SceneCase with the pre and post burn panoramas. Select Pre Burn.

Figure 2.35: FARO® Focus X330 Laser Scan Data of the before site - Coloured with the onboard camera (Coloured point cloud)

Figure 2.36: Spheron SceneCam 360^0 panorama of the before site. (Photograph).

To access the panoramas demonstrating the fire investigation scene post burn please refer to the supplementary USB card and open the file entitled Chapter 2. Fire Investigation Scene. Within this file please select the 'Start' file. This will open the SceneCase with the pre and post burn panoramas. Select Post Burn.

The SceneCam and FARO Focus^{3D} X330 were used to capture the fire scene after it had been burned. The data obtained for each technology is discussed. Figure 2.37 demonstrates a panorama of the laser scan data intensities using the IR setting on the FARO Focus^{3D} X 330. This figure demonstrates distortion as it has been presented as a whole panorama by flattening. The resulting point cloud data is not viewed as such and therefore does not present distortion. The Focus^{3D} X 330 was capable of successfully recording the fire scene, even capturing the broken glass window which was a result of the fire damage. Due to the dark nature of the fire environment, the FARO utilised IR mode to capture the scene successfully. However, in this instance no colour data could be captured from the scene which may have aided in the identification of features within the environment.

The complimentary SCENE software application provided with the FARO laser scanner enables a viewer to navigate themselves around the point cloud data. Unlike most fixed panoramas, laser scan data allows a more detailed interrogation of the data, whereby a user is able to change their perspective within the environment to demonstrate alternative viewpoints, rather than being fixed to one viewpoint as demonstrated in Figure 2.38. This can be particularly useful for situations where it is necessary to determine the perspective of eyewitnesses within an environment to refute or corroborate eye-witness testimony.

Figure 2.37: FARO® Focus X330 Greyscale Laser Scan Data presented as a panorama which has been flattened and demonstrates some distortion.

Figure 2.38: FARO® Focus X330 Laser Scan Data in SCENE software showing different perspectives, looking inwards onto the environment from the outside.

Figure 2.39 presents a panorama of the fire scene captured using the Spheron SceneCam. The panorama itself looks very dark as it presents a JPEG version of the .sph file created which is not dynamic. Using the complimentary SceneCenter software the exposure levels can be dynamically increased and decreased to allow a lighter view of the already dark fire scene as demonstrated in Figure 2.40. The SceneCam was able to successfully capture the fire scene using the HDR capabilities.

Figure 2.39: Spheron SceneCam 360^0 panorama of the after burn. (Photograph)

Figure 2.40: Screenshots of the panorama taken using the Spheron SceneCam demonstrating the high dynamic range ability of the camera system. Top to bottom: changing exposure levels to increase the light within the scene.

2.3.3.3 Road Traffic Collisions

Road traffic collisions (RTC's) present challenges for crime scene documentation. These can often encompass large areas of motorway or great stretches of dual carriageways. Such large areas needs to be documented quickly and efficiently to ensure the road can be reopened to the public as soon as possible to prevent any inconvenience. The nature of a road traffic collision can generate vast amounts of evidence which can be spread across large distances. For example, vehicle parts or debris which may have travelled a distance away from the initial impact point. An investigation was conducted into the documentation of tyre marks at road traffic collisions. With regards to the tyre marks on the road, these are marked out using chalk based spray paints which are visible in the laser scans and mark out particular points on the tyre mark.

To access the panoramas demonstrating the tyre mark detection please refer to the supplementary USB card and open the file entitled Chapter 2 Road Traffic Collision – Tyre mark detection. Within this file please select the 'Start' file. This will open the SceneCase with the panoramas.

The SceneCam was capable of successfully capturing the end point of the tyre marks and the main tread pattern of the tyre marks as demonstrated in Figure 2.41. Figure 2.41 demonstrates the SceneCam capture of a tyre mark with different coloured chalk marks to emphasise the location of the tyre mark on the tarmac surface.

Although the SceneCam was able to successfully detect the tyre marks, the lighting conditions throughout the capture process did effect the image quality which made it difficult to distinguish some parts of the tyre mark successfully, as demonstrated in Figure 2.42. The SceneCam system is a photographic system which can be affected by lighting within the environment to be captured. Due to the fact that this investigation was conducted in an exterior location, the lighting conditions were changeable due to cloud coverage. It is evident from the panorama captured that the lighting conditions were changing throughout the panorama capture process. The changes in light are demonstrated by the light and darker bands within the image. The panorama captured in this investigation utilised the maximum resolution scan of 50 MP to ensure maximum detail of the tyre marks could be recorded. As a result, the camera took approximately 12 minutes to capture the scene, and rotate a full 400^o. To aid with the lighting conditions and to aim to prevent such drastic light changes, the panorama could have been captured using a lower resolution, but could risk loss of clarity or detail within the image. In these circumstances, particularly for road traffic collisions, the investigating officer would need to consider the lighting conditions and the level of clarity required from the scene as the lighting conditions cannot be guaranteed.

Figure 2.41: SceneCam capture of a tyre mark showing different coloured chalk outlines to emphasise the location of the tyre mark.

Figure 2.42: SceneCam capture of tyre mark demonstrating changeable light conditions within the exterior environment which can effect visualisation of some parts of the tyre marks. Indicated with the red circle.

Laser scanners have been adopted for more complex crime scenes, such as road traffic collisions where significant numbers of measurements need to be recorded, due to its speed of capture in comparison to manual recording of measurements, which can be slow (Komar *et al.,* 2012). As a result of utilising laser-scanning technology at road traffic collision scenes, an average of 39 minutes per accident was saved as estimated by the UK Government (Pfeifle. 2012).

Where laser scanners are used in combination with panoramic photography techniques, the point cloud data can be overlayed with the panoramic photograph taken from the same perspective as the scan. This serves to give the point cloud data colour values that are representative of the actual scene as opposed to an intensity map (Miller and Marin, 2014). Discussions with Derbyshire Constabulary highlighted issues with their current methods for documenting road traffic collisions, whereby the laser scanner they were using was not able to successfully capture the complete tyre marks.

The road traffic collision investigators discussed the inherent merits of utilising laser scanners for the documentation of road traffic collisions describing their quick and highly accurate capture of such environments which is necessary in order to reopen roads as soon as possible to maintain a flow of traffic. However, surfaces which appear dark, such as black or transparent, shiny surfaces can present problems for the laser system. Dark, shiny, semi transparent surfaces and reflective, adsorptive and dispersive surfaces produce problems with 3D laser scanners whereby they may not be detected by the optical sensors within the laser scanner and therefore can leave 'holes' in the point cloud (Yang and Wang, 2008; Huynh, 2010; Ch'ng *et al*., 2013). Black and/or dark coloured surfaces are less reflective surfaces and therefore can produce errors in laser scan data whereby the surface is not correctly or completely captured (Forensic Technology Center of Excellence, 2016). This can be problematic in RTC's due to the dark nature of road surfaces. In addition, black coloured cars can also prove problematic due to their reflective and dark coloured nature. In these instances the laser is absorbed rather than reflected back to the scanner and therefore no response is received and consequently no 3D point in space can be generated for such an area.

In some situations the errors exhibited whereby reflective surfaces are encountered, which produce missing data points within the point cloud, can be negated if the object is temporarily coated with a unique material such as tempera paint (Trucco *et* *al*., 1994; Boehler and Marbs, 2003). New techniques have been developed to attempt to decrease the negative effects these types of surfaces have on the laser scanners such as fine particle dust sprays. The fine particle dust spray is deposited onto the problem surface and this in turn allows the laser pulse to reflect off the dust particle and provide the optical sensor within a response for that surface. However, It may not always possible to coat surfaces as suggested particularly within a forensic context whereby evidence must not be altered.

2.3.4 Advantages of 3D panoramic imaging technology

Traditional methods of investigating crime scenes involve capturing a scene and those items within that scene which the investigator deems relevant at the time of the investigation. 360^{o} photography and 3D laser scanning methods can eliminate the 'what is relevant at the time' issue as the whole environment is captured in a single scan. This technology has been developed to make criminal investigations more efficient and they can speed up the crime scene documentation process significantly (Crambitt and Grissim, 2010). In addition, each of them has the ability to transmit the data on a real time basis, so personnel not at the scene can quickly view the scene as it is captured.

Laser scanning and panoramic photography methods are often considered to be two completely separate entities and they are in respect of their methods for capturing an environment. However, one of the major advantages of both the 360^{o} photography technology and the 3D laser scanning technology is that they are complimentary to one another and can be used together to create highly accurate and highly detailed crime scene reconstructions (Strandberg, 2015). The Leica Scanstation C10 and FARO X 330 laser scanners can be used to create point cloud data of a scene but can also utilise other photographic systems to provide colour to the data. Utilising the highly accurate point cloud data from the laser scanner and the highly detailed colour panoramas from the photographic equipment, a highly accurate and very detailed visual representation of a scene could be created (Boehler and Marbs, 2003).

Laser scanners have been utilised within science disciplines for many years in surveying, archaeological and heritage sites (Mihandoost, 2015). 3D documentation technology becomes particularly useful in hazardous or unsafe environments that may pose a threat to scene of crime officers (Mihandoost, 2015) For example, fire investigation scenes where the building has lost its structural integrity, or Chemical, Biological, Radiological or Nuclear (CBRN) environments.

Panoramic imaging technologies provide the ability to retrospectively re-enter and re-examine a crime scene utilising the virtual tour software applications. This is extremely useful in situations where it may not be possible to re-examine a crime scene, particularly months after the initial incident occurred. The immersive nature of these environments and the ability to transmit data real time provides a more efficient and effective method for communicating a crime scene (National Institute of Justice, 2013).

2.3.5 Limitations of 3D panoramic imaging technology

As with any new technology integration, there are limitations that have to be considered before adoption. Due to the costs of some pieces of equipment a decision to implement technology must be based upon criteria demonstrating effectiveness and value for money. Police services must assess whether the technology will be cost effective and how frequently it will be utilised to justify its purchase. In addition forces need to consider whether it will be compatible with already enforced operational systems or whether this new piece of technology will become an add on to existing systems.

There are limitations associated with the capture methods during documentation which can also prove problematic with standard digital photography methods. Movement during capture can cause blurring of features within panoramic images and occurs as ‘ghost’ images in laser scan data (National Institute of Justice, 2013).

Light conditions within a scene will affect different equipment in different ways. Capturing panoramic images on a bright sunny day could result in overexposure in some areas of the photograph and shadowy, dark areas in other areas of the panorama. Some technology such as the SceneCam (Spheron VR AG) utilizes HDR range which provides a solution to over and under exposed areas within an image. Standard digital photographic methods allow the varying of shutter speeds and aperture settings on the camera to ensure correct lighting exposure for capture.

Reflective surfaces can produce issues whereby the capture technology may be visible within the image. An evaluation of three panoramic imaging technologies was conducted by The National Institute of Justice (2013) presented limitations with laser scanners, such as the Leica ScanStation, whereby some reflective or black surfaces produced issues in the point cloud resulting in dark areas within the point cloud data. Environmental conditions need to be considered as some equipment may be affected by changes in temperature. For example, the Leica ScanStation may require time to warm up in colder climates (National Institute of Justice, 2013). Camera systems can be affected by humidity which can cause the lenses to fog up when the camera is colder than the outside air temperature.

2.4 Conclusions

The adoption and implementation of technology must be appropriately considered prior to its purchase and integration into the forensic evidential workstream. The nature of criminal investigations and crime scene documentation in particular, concerning the time sensitive and ephemeral nature of evidence requires any new technology implementation to be risk free.

The adoption of technology, and in particular deliberation over which technology to use, needs to be considered and an assessment made as to whether it will facilitate Police services requirements and produce minimised risk to current procedures, operations and outcomes. The adoption of these technologies can be affected by many factors, ultimately the cost of the equipment and how they will be used operationally within a service for major and volume crime scenes. Future advancements in the portability, cost, speed of capture and the accuracy of these systems will facilitate the increase in adoption. These methods for documenting crime scenes will not replace current digital imaging processes at crime scenes, such as close up photographs of evidence, but these newer systems will be a welcome addition to more complex crime scenes. Police services will be required to evaluate their specific requirements and needs for technology as well as their financial resources available which will allow them to make an informed decision as to the most appropriate equipment to suit their needs.

Prior to the adoption of technology a police service needs to undertake thorough research to determine what benefits it could bring to their current processes and whether there will be any barriers to its adoption, or whether it will satisfy all their criteria. With the continuous development of technology, it is inevitable that the future is set to be digital. Advancements in technology bring a reduction in the cost in accessing this technology, enabling more individuals, from professionals to those non specialised users to have access (Tokuda *et al.,* 2013).

This chapter creates a framework and has discussed the factors police services can use to consider the appropriate types of technology to suit the requirements of their organisation before they can viably purchase panoramic imaging technology. Results from this investigation provide police services with an impartial and unbiased evaluation of such technology. This study has explored the strengths and weaknesses of such equipment and indicated the potential value for use by police services.

Chapter 3: A Comparative Study of the Accuracy of Photogrammetric Methods using Panoramic Photography in a Forensic Context

Preface

Having discussed the many factors which need to be considered prior to the adoption and integration of technology into police services' current practices in the previous chapter, this chapter will evaluate one of these specific criteria; accuracy. The accuracy with which a piece of technology is able to document and measure a crime scene will affect the consideration to adopt that piece of technology as this information is integral to criminal investigations particularly with regards to the admissibility of such evidence in a courtroom.

3.1 Introduction

3.1.1 Crime Scene Documentation

One of the most important aspects of conducting a criminal investigation involves comprehensively recording and documenting the crime scene, given that the process can ultimately determine the success of the subsequent investigation (Gee *et al.,* 2010). Crime scenes often present unstable and short-lived environments, containing ephemeral evidence, which can prove difficult for Scene of Crime Officers (SOCO's) to document efficiently (Komar *et al.,* 2012). The documentation process is often laborious and time-consuming (Elkins *et al.,* 2015), as the resultant documentation must provide a thorough and permanent record of the scene, comprising written, graphical, photographic, and video evidence of all contextual information (TWGCSI, 2000; Carrier and Spafford, 2003) from the scene in its original untouched state (Strandberg, 2015). The documentation process ensures that the maximum relevant information is obtained and recorded so that the opportunity is not lost when the scene becomes disturbed during the subsequent investigation (Chan, 2005). Thorough documentation of a crime scene is conducted to gather all information regarding the case or scene as it was at the time of the investigation as it is not possible to return to the scene of the crime after the investigation.

3.1.2 Crime Scene Sketch Plans and Measurements

A crime scene sketch is a permanent hand drawn plan of a crime scene environment, which visualises the position and location of objects and evidence within a scene (Chan, 2005; Dutelle, 2013) as shown in Figure 1.1 in Chapter 1. A sketch helps to establish the precise location, distances and relationship of evidence to other evidence within the scene (Dutelle, 2013; Forensic Science Regulator, 2016). The position and location of evidence within a scene is crucial to an investigation, and the subsequent interpretation of the evidence (Bevel, 1991) and their locations can aid in reconstructing a sequence of events (Mihandoost, 2015). The sketch provides a complimentary aid to digital photographs and can help to clarify spatial relationships, distances and evidence dimensions which are not possible to gauge through digital photographs (Dutelle, 2013; Maksymowicz *et al.,* 2014; Tung *et al.,* 2015). Sketches visually convey the layout and measurements of a crime scene in a simplistic format to allow SOCO's to recall events in the future and to present the scene to individuals/ persons who were not present at the crime scene (Chan, 2005; Dutelle, 2013; National Forensic Science Technology Center, 2013). The most common form of sketch is drawn as a bird's eye view or overhead projection sketch, which presents the objects and evidence within the scene from the perspective as if the investigator was looking down on the scene from above.

Measurements of objects, evidence locations and heights within a scene are frequently taken using a tape measure (Howard *et al.,* 2000), which are deemed an 'adequate' method for measuring a crime scene 'in situ' (Gardner and Bevel, 2009). Dimensions of objects within a scene will be recorded along with the precise location of evidence within the scene. Measurements of evidence positions within a scene are often measured from two known positions of origin, or reference points such as walls to an approximate centre of mass of the evidence as shown in Figure 3.1. These measurements will often be taken from the closest fixed reference point.

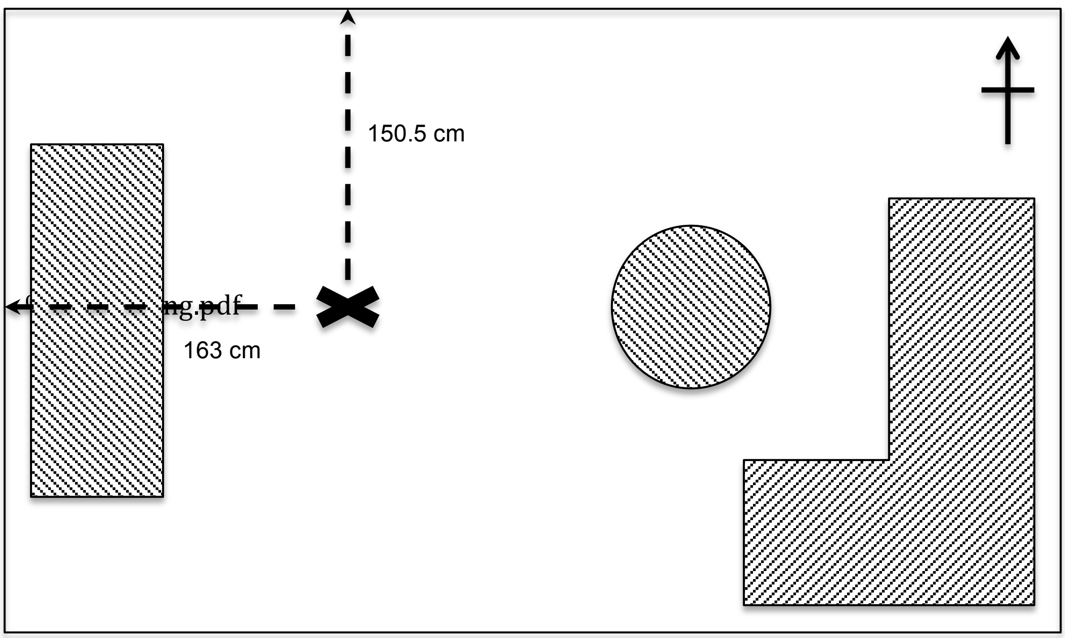


Figure 3.1: Measuring an item of evidence from two fixed points, in this case, walls

Measurements of the evidence or object within the scene is taken from the two fixed reference points including taking the height measurement to show how far off the ground the object was found (National Forensic Science Technology Center, 2013). All measurements taken at the crime scene are considered to be approximate, as potential rounding errors may inhibit the ability to take accurate measurements (Dutelle, 2013). To avoid potential courtroom questioning with regards to the accuracy of measurements taken at a scene, sketches are annotated with 'Not to Scale' (Dutelle, 2013; National Forensic Science Technology Center, 2013).

Currently in the United Kingdom (UK), SOCOs are assessed on their overall ability to examine and process a crime scene through competency testing provided using the National Occupational Standards in addition to face-to-face Crime Scene Investigation competency tests provided by the College of Policing (CoP). According to UK Forensic Investigation Managers and Forensic Trainers, there is currently no proficiency test or other measure of competency currently employed to assess SOCO's ability to take accurate measurements of crime scenes (Moore, 2015; Bell, 2015). Currently, SOCO's will measure a crime scene manually using a tape measure. More complex crime scenes such as Road Traffic Collisions (RTC's) often involve using a laser measure to capture measurement data (Parnell, 2015).

3.1.3 Crime Scene Reconstruction

The interpretation of a scene and establishing a possible sequence of events can prove a critical aspect within a criminal investigation, and can be used to support or refute an individual's account of what allegedly occurred at the scene, or theories about what may have happened (Bevel, 1991; Mihandoost, 2015). Crime scene interpretation, or reconstruction, involves interpreting the scene in its undisturbed state and considering all aspects of the scene to aid in understanding a sequence of events, which may have occurred. In addition to photographs, sketches and expert testimony, reconstruction can help to explain to other persons who were not at the scene, particularly judges and juries in the courtroom, what is likely to have occurred at the crime scene. This can assist the jurors in arriving at an informed decision about what may have occurred at the scene based on all of the evidence available to them and it is therefore essential that such information be accurately recorded (Mihandoost, 2015).

3.1.4 Technology Development

Technology is becoming more abundant within criminal investigations, particularly for visualising and presenting crime scene environments (Noond *et al.*, 2002; Fowle and Schofield, 2011). It may be necessary to effectively communicate the crime scene environment and the distribution of evidence (Tung *et al.,* 2015) to other individuals who were not present at the scene (Schofield and Fowle, 2013). Such communication may be presented using two-dimensional (2D) photographs, sketches, or more recently, using 360° visualisation technology and three-dimensional (3D) modelling or reconstruction technology (Tung *et al.,* 2015). The adoption of such new technologies within police services is therefore further driven by the need to improve efficiency and effectiveness both for forensic scientists, police and the jury within the criminal justice system (CJS) (Koper *et al.*, 2015). Such technology produces 3D representations of crime scenes, providing spatial perception, and the opportunity for the viewer to navigate themselves throughout the scene in a highly detailed immersive environment (Dang *et al.,* 2011). This is not possible with 2D photography.

Technology, which allows 3D representations of scenes to be documented in greater detail and shorter time frames, is being utilised more by police services across the world for documenting crime scenes (Mihandoost, 2015). This technology can potentially make the crime scene documentation process more efficient and quicker (Crambitt and Grissim, 2010). 3D documentation technology was originally developed for use in engineering, gaming, architecture and archaeology disciplines for the purpose of documenting complex environments but its uses continue to expand (Shanbari *et al.*, 2016). With the continual requirement to provide more effective and accurate methods for documenting scenes (Koper *et al.,* 2015) manufacturers are constantly producing new hardware and software programs, which can document environments. Criminal investigations require the documentation of complex environments quickly and accurately and as a result 3D documentation technology has moved into the forensic science disciplines and is now allowing crime scene investigators to navigate around and through a 3D scene, without having to be physically present at the scene (Schofield, 2011; Mihandoost, 2015).

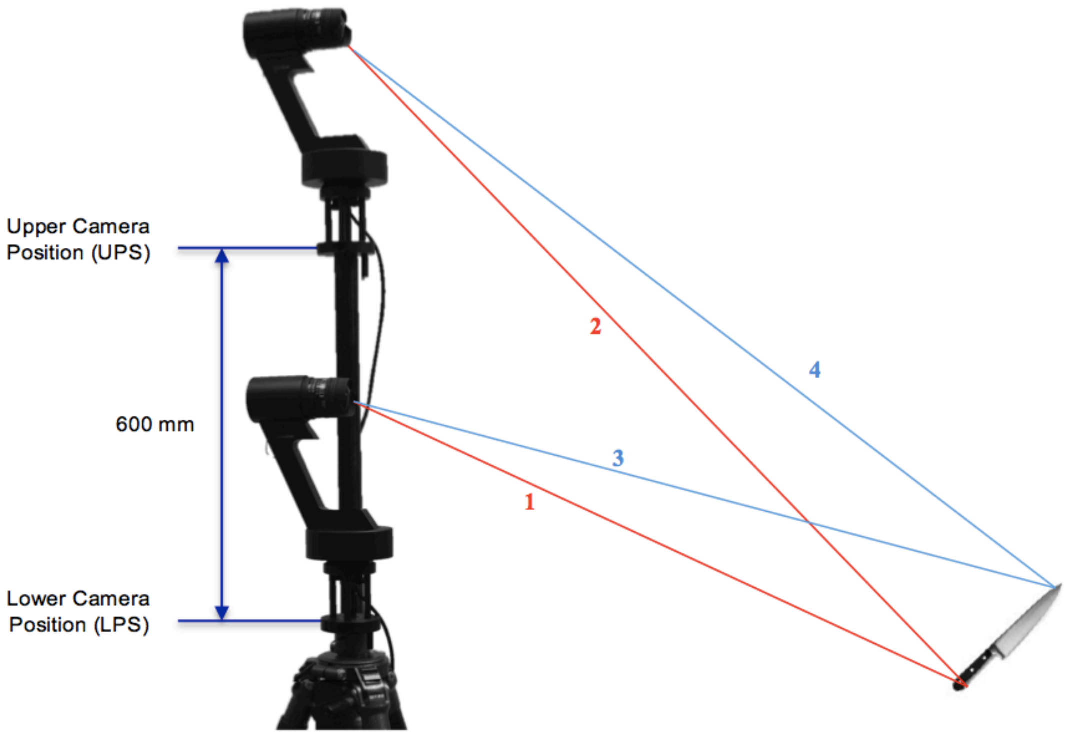
Manufacturers have developed both photographic methods and laser scanning methods for documenting crime scene environments, both which provide very different outputs; JPEGS's or e57 files (Galvin, 2009) but ultimately aim to produce the same 3D reconstruction of an environment.

3.1.5 Measuring an environment using 3D technology

3.1.5.1 360^{o} Photography

Photogrammetry software applications provide the opportunity to take measurements from 360^{o} photographs (Hua *et al.,* 2008). Photogrammetry essentially means taking 3D measurements from 2D photographs (Shanbari *et al*., 2016). The American Society for Photogrammetry and Remote Sensing (ASPRS) define photogrammetry as the "art, science and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images" (ASPRS Manuals, 1980, 1998; Ghosh, 2005). Photogrammetry allows an individual to measure and obtain information regarding properties of objects and items within a scene without actual physical contact with those objects or items (Schenk, 2005). The word photogrammetry is derived from Greek and originates from 'phot' meaning light, 'gramma' meaning drawn and 'metron' meaning to measure (Ghosh, 2005). Photogrammetry utilises mathematical algorithms to derive the size and location of objects from single images, stereo images or multiple images (Mihandoost, 2015).

Photogrammetry allows measurements to be taken from photographs using triangulation methods, which derive the shape and location of features using 3D coordinates (X, Y and Z) (Schenk, 2005). This process requires two or more photographic images to be taken from different positions or viewing directions within a scene (Huang *et al.,* 2008) as shown in Figure 3.2.



Operation:

1. User selects the first point to measure from in the lower camera position (handle of knife)
2. User selects the same identical first point to measure from in the higher camera position (handle of knife)
3. User selects the second point to measure to in the lower camera positions (blade end of knife)
4. User selects the same identical second point to measure to in the higher camera position (blade end of knife)

   A measurement of the length of the knife will be quoted by the software application.

Figure 3.2: Photogrammetry Principle for SceneCam (Spheron VR AG)

Photogrammetry allows SOCO's to take measurements of objects within a scene from the 360^{o} photographs, without having to be physically present at the scene in a non-invasive manner, having previously captured the data (Ghosh, 2005). Measurements of any object or distance can be obtained from the photographs at anytime following the scene documentation and this can prove very useful later in the subsequent investigation process. Traditional methods of investigating crime scenes involve capturing a scene and those items within that scene which the investigator deems to be relevant at the time of the investigation. In this instance an item, which was not deemed relevant, may not have been captured and there is no way to return to the scene to investigate further. Research has demonstrated that the investigators level of experience and expertise is correlated to what is deemed evidential within a scene (Baber and Butler, 2012) and will be subjective between investigators (Eyre *et al.,* 2014). Panoramic photography and 3D laser scanning methods can eliminate this 'what is relevant at the time' issue as the whole environment is captured in a single scan (Eyre *et al.*, 2014).

This study sought to assist police services in evaluating the technology allowing them to make more informed decisions when considering their options for crime scene documentation. One of the most important aspects for validating this type of technology involves the accuracy of the measurements obtained from it, amongst others. This study seeks to validate the accuracy of measurements and the differences that arise between two different methods for capturing measurements; traditional tape measurements and on screen using a photogrammetry software application. The accuracy as defined by the International Organisation for Standardisation (ISO) is the "closeness of agreement between a measurement quantity value and a true quantity value of a measurand" (Wang *et al.,* 2012; ISO VIM). There is a clear need to validate the measurements which can be obtained using this type of technology and disseminating the results to the forensic science community.

3.1.5.2 Laser Scanning

Additional methods for recording a scene utilise 3D laser scanners, which simultaneously take millions of measurements whilst documenting the scene (Mihandoost, 2015). The most common laser scanners operate using the 'time of flight' principle to calculate the distance of an object from the scanner. The scanner emits a laser, which travels to the nearest surface and is reflected from this surface. The reflected radiation travels back to the scanner where it is detected by a sensor (San Jose Alonso *et al.,* 2011). Mathematical calculations using the speed of light (the laser) and the time it took for the laser to be emitted, reflected back and detected can be used to calculate the distance to the object of interest (Sansoni *et al.*, 2009). As a result, laser-scanning techniques can quickly capture a scene producing highly detailed point cloud data along with millions of measurements (Mihandoost, 2015). Laser scanning enables 3D documentation of a scene and the data captured can be used to create digital reconstructions and simulations of events that may have occurred at a scene (Buck *et al.,* 2013).

Laser scanners have been utilised within science disciplines for many years in surveying, archaeological and heritage sites (Mihandoost, 2015). 3D documentation technology becomes particularly useful in hazardous or unsafe environments that may pose a threat to SOCO's (Mihandoost, 2015). For example, fire investigation scenes where the building has lost its structural integrity, or CBRN (Chemical, Biological, Radiological or Nuclear) environments. Both panoramic imaging and 3D laser scanning techniques produce a permanent visual record of a scene in its untouched and original state (Strandberg, 2015).

3.1.6 Accuracy and Validation

The required measurement accuracy and precision will need to be determined prior to the investigation as this will ultimately determine the techniques that can be used at the scene (Makysmowicz *et al.*, 2014; Shanbari *et al.*, 2016). The accuracy of measurements taken using a tape measure or photogrammetry software applications are not only dependent on the accuracy of the instrument, but also rely on the competency of the user. The accuracy of the instrument is frequently reported by the manufacturer. However, details of the experimental work used to support the margin of error are often not transparent, and therefore it is difficult to establish the reliability of such data. Currently the accepted limits of accuracy for taking measurements at a crime scene vary throughout the world. For example, in the UK there is no published accepted limit of accuracy (Moore, 2015), whereas in the United States the accepted limit of accuracy is +/- 0.25 inch (6.35mm) as defined by the National Institute for Standards and Technology (NIST) (National Forensic Technology Center, 2013). In addition, in Canada there is no set official measurement standard or limit of accuracy (Mullins, 2016). However, as part of the ISO 17020 accreditation competency testing is required for all work conducted at the crime scene. Under the scope of ISO 17020, all measuring devices will need to be calibrated within known tolerances in order to meet the required standard, and measurements will be required to have a clearly defined limit of accuracy (Forensic Science Regulator, 2016).

Police services have to consider many factors when considering the adoption and integration of technology into their current practices. Some of the main considerations are how much the equipment costs, how often it will be utilised for cases and whether it will provide any probative value to the organisation and the crime scene investigations conducted (Koper *et al.,* 2015). The accuracy with which new technology is able to document crime scenes and measure is integral to criminal investigations, particularly where admissibility of evidence in a courtroom is concerned (Mullins, 2016).

The very nature of the crime scene documentation process requires that any new element within that process needs to be implemented in a risk free manner without complications (Association of Chief Police Officers. 2012). Police services often do not have the time or financial resources to conduct research investigating which technology is available to them that may aid in the investigation process and police are therefore not able to maximise the opportunities that technology could provide them (Association of Chief Police Officers, 2012).

There is limited research into the accuracy of these crime scene documentation technologies and validation of them for use in a courtroom. Mihandoost (2015) and Mullins (2016) described a clear void in the literature concerning accuracy validation with regards to measurements of laser scanning systems for use in forensic applications. Some authors have also noted a lack in validation of the accuracy of measurements taken using laser scanners and have conducted their own research into validation of such technology (Boehler and Marbs, 2003; Mihandoost, 2015; Hakim and Liscio, 2015; Johnson and Liscio, 2015; Dustin and Liscio, 2016). Research conducted by Mihandoost (2015) compared and validated two software programs; FARO's SCENE software application and 3rd Tech's SceneVision 3D. The research compared the accuracy of measurements taken using the software applications to those taken using traditional methods using a tape measure.

Statistical analysis was conducted where the manual measurements were subtracted from the measurements taken using the software applications, to determine whether the measurement results were within the NIST guidelines, +/- 0.25 inches, for admissibility in court. Differences between the software programs were found to be within NIST guidelines and statistical analysis results show that test results were significant but not practical differences in measurements. In addition Mihandoost (2015) demonstrated that the SCENE software was found to be slightly more accurate than the SceneVision 3D application. Limitations of this study include the generalization of crime scenes and the measurements taken in the field.

It is important to investigate the accuracy with which photogrammetry software applications are able to record measurements compared to tape measures, which are established within Courts of Law. Without robust and independent study it is not possible to reliably implement their use as part of crime scene documentation. Inaccuracies within crime scene documentation could have profound effects on the interpretation of casework, as described. This investigation has examined the accuracy with which a photogrammetry software application was able to measure items within a mock crime scene, and to evaluate practicalities associated with the use of such technology. The results of this study and their interpretation are likely to be of interest and benefit to any person(s) involved in crime scene work, and will help those involved to make an informed choice when considering options for crime scene documentation.

Aims and Objectives

The aim of this research is to compare the measurement capabilities and accuracy of two different methods of measuring crime scenes; using a tape measure, and a 360^{o} camera with complimentary photogrammetry software application.

The general objectives to realise the aim are as follows:

- The accuracy of measurements taken of one centimetre grid squares using a steel ruler and photogrammetry software application will be compared to assess any measurements errors.
- The accuracy of measuring a blank interior wall without any detailed points will be investigated and compared to manual laser measurements.
- The accuracy with which participants are able to take measurements of items within a mock crime scene manually using a tape measure will be examined and compared to measurements taken by participants using a photogrammetry software application.
- The maximum range or limit at which measurements can be taken using the SceneCam and SceneCenter software application will be investigated and the accuracy of such measurements will be compared to manual tape measurements.
- Measurement accuracy of manual tape measuring and photogrammetry software will be compared for both interior and exterior environments where the lighting conditions are likely to differ.
- The investigation sought to identify whether the resolution of the resultant panoramas has any effect on the accuracy of the measurements taken and to what extent, if any, these have on the measurements.

3.2 Method

3.2.1 Accuracy testing with known measurements

A steel ruler was used to measure the length of grid squares on a sheet of A4 1 cm grid paper. The first 1 cm grid square was measured horizontally across the graph paper. The measurement was recorded and the process repeated ten times. Two adjacent 1 cm grid squares were measured together and the measurement recorded with ten repeats being taken (Figure 3.3). This process was repeated until ten adjacent grid squares had been measured together. This procedure was also repeated for measurements taken vertically down the paper from 1 cm to 10 cm.

A sheet of A4 1 cm grid paper was adhered to the approximate centre of a white painted interior wall. The wall was photographed using a Spheron SceneCam (Spheron VR AG). The camera was positioned at the approximate centre of the room (1.5 m from the wall of interest) and following calibration of the instrument, two 360^{o} panoramas of the environment were taken; one at the cameras lower position, and one at the cameras highest positions, according to the manufacturers instructions (Spheron SceneCam User Manual, 2007). The resultant panoramas were uploaded onto the complimentary SceneCenter software. A measurement of the first 1 cm grid square was taken using the software, the measurement was recorded and the process repeated ten times. Subsequently, two adjacent grid squares were measured together; the measurement was recorded and repeated ten times. This process was repeated until ten grid squares had been measured together. In addition, the process was repeated so that measurements of the grid squares had been taken for grid 1- 10 vertically down the graph paper with ten repeat measurements being taken for each grid square.

3.2.1.1 Data Analysis

A Kolmogorov Smirnov test was used to determine the distribution of the measurements taken using the steel ruler and the software application. A Mann Whitney U-test was used to determine whether there were any statistically significant differences between the measurements of the graph paper compared with the measurements of the graph paper taken using a photogrammetry software application. Effect size was calculated according to Cohen's r (Coolican, 2009). All statistical testing was carried out using SPSS version 23 (IBM SPSS).

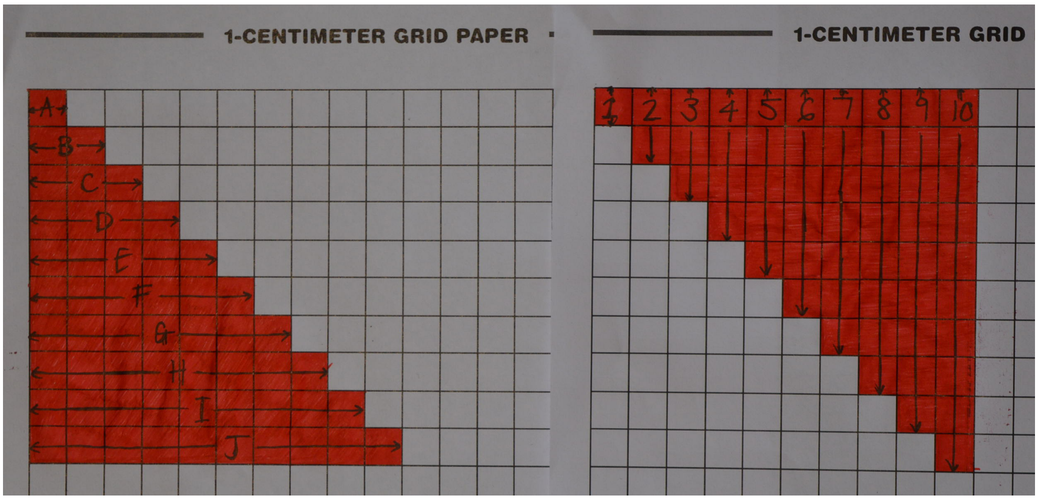


Figure 3.3: Left: Horizontal grid square measurements taken. Right: Vertical grid square measurements taken

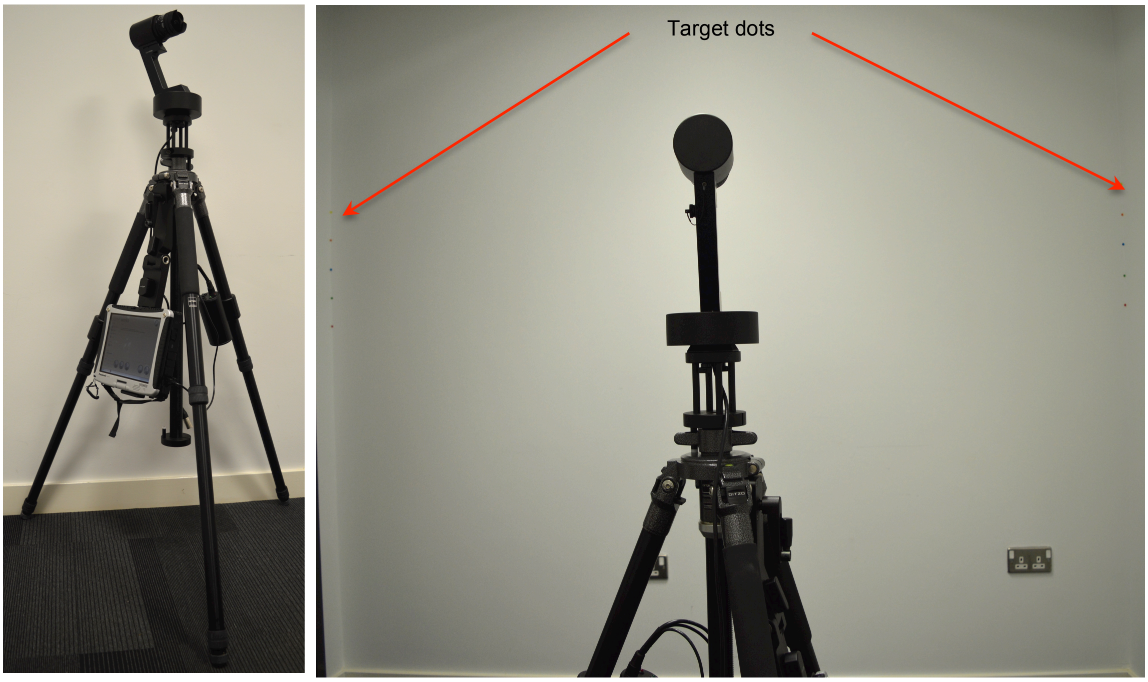


Figure 3.4: Left: Spheron SceneCam. Right: Spheron SceneCam facing the wall of interest with the target dots on each wall corner

3.2.2 Measuring a single blank wall

A DeWalt DW03050 Laser Distance Measure was used to measure the length of a white painted interior wall ten times. The device had a typical measuring tolerance when applied to 100% target reflectivity, such as white painted walls, as used in this study, of +/- 1.5 mm. These tolerances are applicable between 0.05 m to 10 m with a confidence level of 95% (DeWalt Instruction Manual, 2016). The same white painted interior wall was photographed using a Spheron SceneCam (Spheron VR AG) which was positioned in the approximate centre of the room (1.50 m from the wall of interest) as shown in Figure 3.4. Following calibration of the instrument, two 360^{o} panoramas of the environment were taken; one at the cameras lower position (146 cm from the floor to the centre of the camera lens), and one at the cameras highest position (207 cm from the floor to the centre of the camera lens), according to the manufacturers instructions (Spheron SceneCam User Manual, 2007). Each panorama was taken at the maximum resolution of 50 MP (megapixels) with the room lighting on and no other artificial lighting present. The resultant panoramas were uploaded onto the complimentary SceneCenter software. No lens distortion correction was necessary because the system employs an algorithm which automatically corrects any distortion from the fisheye lens. The resolution of the white wall image was 2,828 x 2,724 pixels. The researcher obtained ten repeat measurements of the length of the wall using the SceneCenter software along the ceiling and floor line. The height of the wall was sectioned into five areas, shown in Figure 3.5. The lines shown in Figure 3.5 were annotated onto the photograph after it was taken and are for the purpose of demonstrating the five separated areas. These were not physically drawn onto the wall. Measurements were taken horizontally across the length of the wall and for each of the five areas ten repeat measurements were taken.

Five pairs of 8 mm diameter sticky paper dots; yellow, orange, blue, green and red, were applied to two opposite corners of the white painted wall of interest (Figure 3.6). A DeWalt DW088K cross line laser was used to ensure that the positioning of the dot pairs were level across the wall. The dot pairs were positioned to replicate the same five areas used in the previous study (Figure 3.5). Using a Spheron SceneCam, the environment was photographed in the same manner as in the previous study and the resultant panoramas uploaded onto the complimentary software. Measurements were taken across the wall horizontally between each set of dot pair using the software application, placing the cursor in the approximate centre of the target dots. Ten repeat measurements were taken for each of the five dot pairs.

In addition to the target dots, a DeWalt DW088K cross line laser was also used to provide an alternative reference point for the measurements to be taken from. The cross line laser was placed onto the wall directly opposite the wall of interest and a laser line projected across the wall of interest (Figure 3.7). Utilising the same method as in the previous investigations, the environment was photographed and measurements were taken across the wall using the laser line as a reference point. Ten repeat measurements were recorded across the wall.

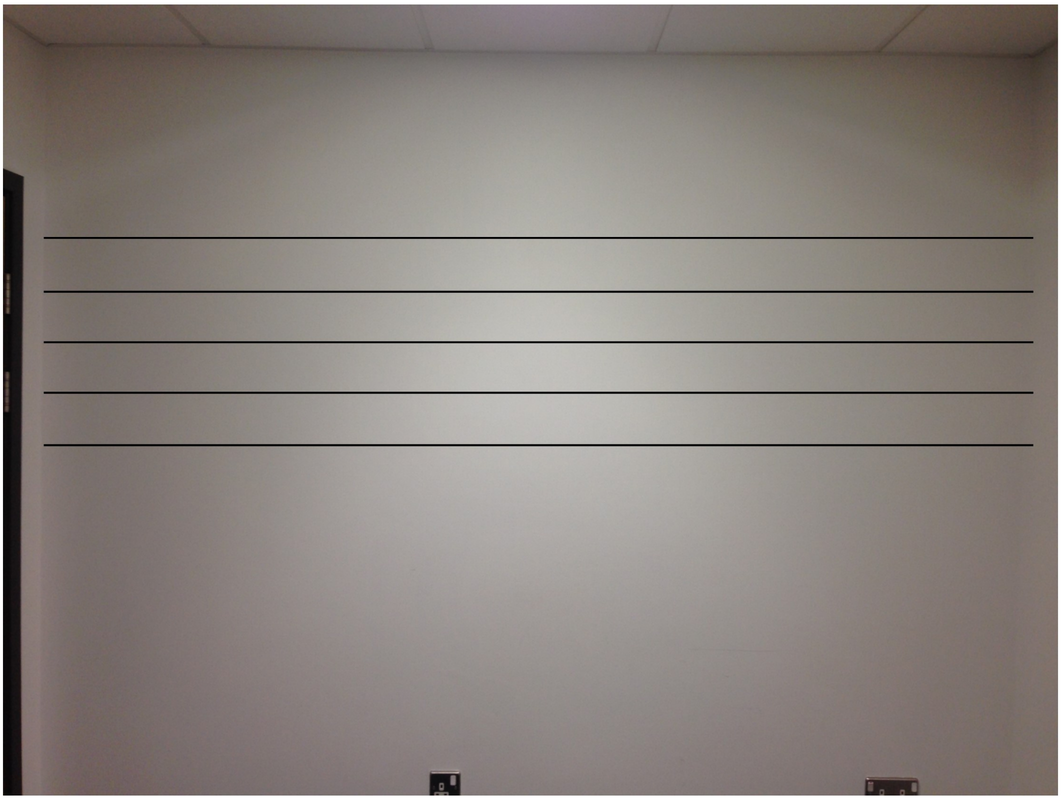


Figure 3.5: Wall sectioned into five areas. Lines just to show the sections and were not drawn onto the wall.

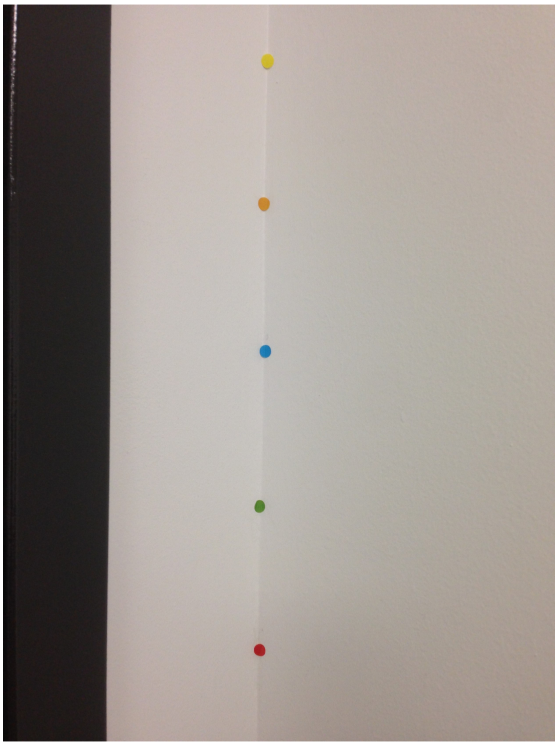


Figure 3.6: Target dots placed in the corner of the room

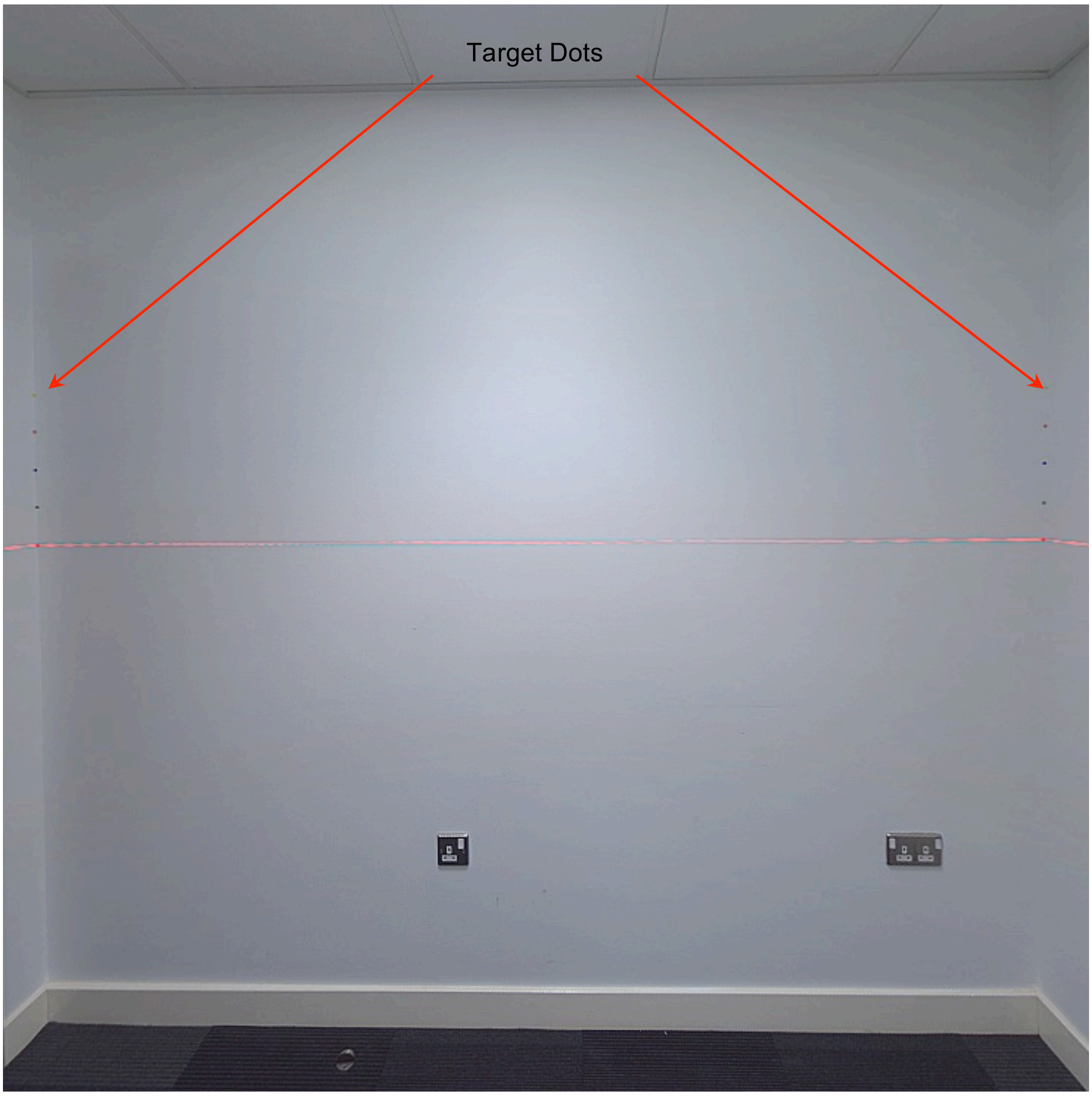
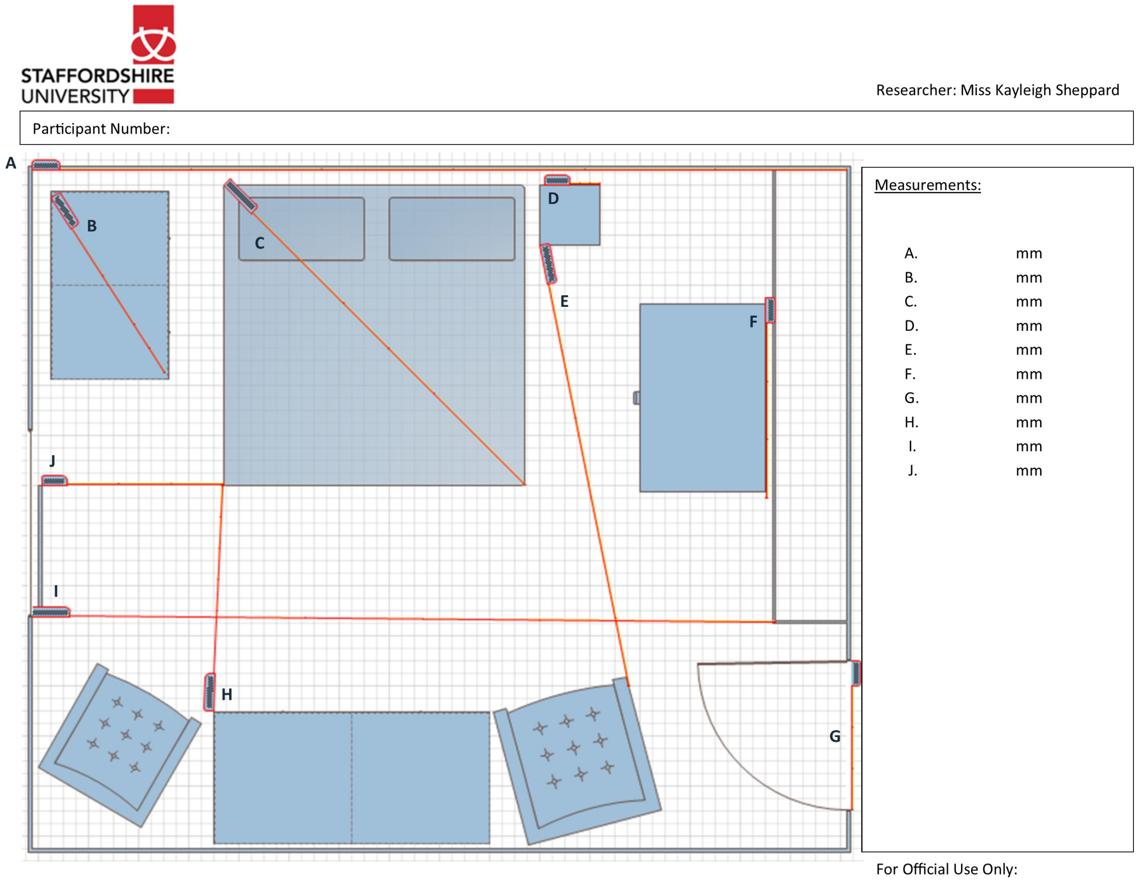


Figure 3.7: Target dots adhered to each corner of the wall and laser level line projected across the wall intersecting through the red coloured target dots

3.2.3 Measuring the scene using a tape measure

The investigation was conducted at a scene of crime facility at the host institution, as this facility enabled the same scene to be staged for each participant. A room within this facility was arranged to replicate a typical double bedroom, which included fixed and non-fixed items, which the participants could measure. The positions of the non-fixed items was standardised by marking out their locations on the floor using Ultraviolet (UV) permanent marker. A plan of the room detailing the ten items to be measured is shown in Figure 3.8.

Using a DeWalt DW03050 Laser distance measure measurements of the ten fixed and non-fixed items were taken and repeated ten times for each measurement A-J. The mean value for each fixed and non-fixed item was used as the control measurement. The laser distance measure was placed with its base against the start point of the item to be measured as shown in Figure 3.9. The laser was switched on and directed towards the end point of the item to be measured and the reading recorded. Artificial markers were used for items that had no obvious distance endpoints. In these instances, the laser distance measure was positioned at the start point of the item to be measured, and a cardboard sheet was positioned at the end point acting as the artificial marker, thus providing an ‘end’ to the laser and allowing a measurement to be taken and recorded.



Measurements A-J consist of:
A – North wall length, corner to corner
B – Top of chest of drawers, measured diagonally from one corner to its opposite corner
C – Width of double bed mattress, measured diagonally across from top corner to bottom corner
D – Length of bedside table
E – Distance along the floor from the leg base of bedside table to the leg base of a chair
F – Length of dressing table
G – Width of inside doorframe
H – Distance along the floor from base of the wardrobe to the leg of the bed
I – Room width measured along the floor, base board to base board
J – Distance along the floor between the baseboard of the radiator to the leg of the bed.

Figure 3.8: Room plan given to participants showing measurements A-J

Figure 3.9: Laser measure base placed at the start point of the item to be measured

3.2.4 Measuring the scene using photogrammetry software

Ten Higher Education students; 3 male and 7 female, aged 20 - 39 years of age, were recruited from the host institution. The participant group comprised final year BSc (Hons) undergraduate and MSci students from Forensic awards, and PhD students from the School of Sciences (some of whom had previously studied Forensic Science). Participants were briefed on the aims of the investigation, and asked to sign a consent form in line with the ethical requirements of the institution. Participants were provided with a plan of the room in hard copy (Figure 3.8) and were asked to record measurements of the ten fixed and non-fixed items using an 8 m Draper 25 mm wide tape measure. The plan was then taken from the participant, and they were asked to complete a distraction task, to help prevent them from remembering the measurements from the scene. The distraction tasks included mathematical calculations such as multiplication, division, subtraction, addition, and counting backwards from 30. Participants were then given an identical room plan and asked to take the same ten measurements, but in a different order. The process was repeated until each participant had measured each of the fixed and non-fixed items ten times.

The bedroom environment was photographed using a Spheron SceneCam (Spheron VR AG). The SceneCam was placed in four different positions within the bedroom to ensure that all ten measurements were visible within the 360^{o} photographs (Figure 3.10). The resultant panoramas were uploaded onto the SceneCenter software. All participants were asked to take measurements of the ten fixed and non-fixed items (Figure 3.8) using the SceneCenter software application. Participants took measurements using a computer mouse to mark out the start and end points of each fixed and non-fixed item. When using the SceneCenter software to take measurements participants were instructed to position the cursor in the approximate centre of the target dots. Participants were asked to record the measurement quoted by the software on an identical plan of the room to that used in the previous study. The plan was taken from the participant following the completion of measuring the ten fixed and non-fixed items. Distraction tasks were not deemed to be necessary in this instance because records of previous marker positions or measurements were not retained; upon completion they were deleted from the software by the researcher to allow the participant to start a fresh blank plan. This process was repeated until each participant had measured each of the fixed and non-fixed items ten times. Blank room plans were provided for each repeat.

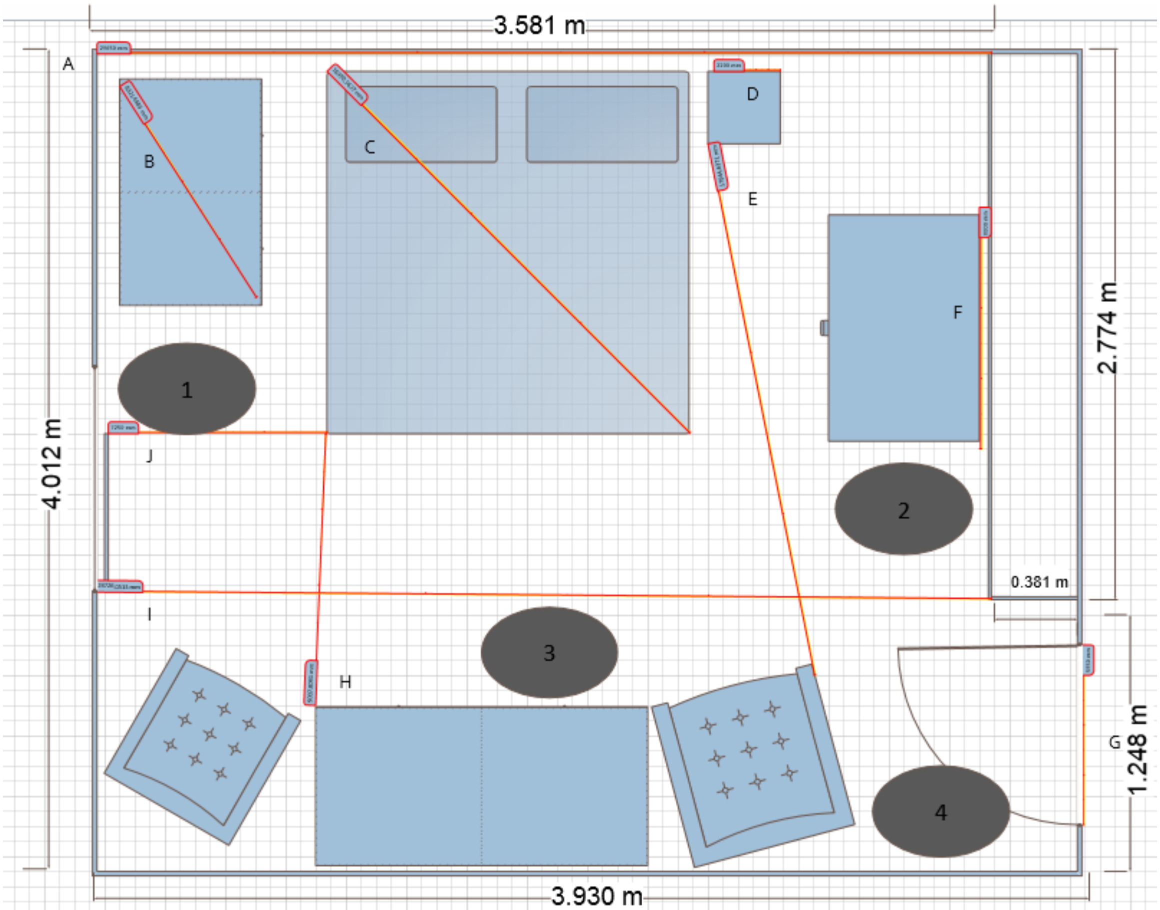


Figure 3.10: Room plan showing the positions 1-4 of the camera for capturing the environment and the bedroom dimensions.

3.2.4.1 Data Analysis

The distribution of the data sets was determined using a Kolmogorov Smirnov test (Gray and Kinnear, 2011). A Friedman test (Gray and Kinnear, 2011) was used to establish the existence, if any, of significant differences between the control, tape and software measurements for each of the ten fixed and non-fixed items. An alpha level of 0.05 was used. Pairwise comparisons of each data set pair were completed using Wilcoxon Signed Rank tests. For the Wilcoxon Signed Rank test (Gray and Kinnear, 2011) a Bonferroni correction was applied to the alpha level by dividing the original alpha level of 0.05 by 3 (0.016). Effect size was calculated according to Cohen's r (Coolican, 2009). All statistical testing was carried out using SPSS version 23 (IBM SPSS).

3.2.5 Measurement Range

An investigation was conducted to determine how far away from the camera measurements could be taken and whether measurements taken from a scene recorded indoors were different to measurements taken from a scene recorded outdoors. To determine whether there were differences between the measurements taken from an indoor (interior) and outdoor (exterior) environment, measurements were taken using the software application of the base of identical orange traffic cones. These software measurements were also compared to tape measurements. The main differences which could be exhibited in each of the different environments concerned lighting conditions, whereby lighting in the indoor environment could be controlled, lighting in the outdoor environment was subject to weather conditions at the time of the investigation.

3.2.5.1 Exterior Environment

The investigation was conducted at a car park at the host institution, (UK, ST4 2DF) as this environment provided a large flat area, which could be used to clearly mark out seventeen 1 metre concentric circles from a central position.

Using high visibility brick line string, (Blue Spot 34630 500ft Brick Line) a noose was formed at the loose end and a piece of white Crayola™ chalk inserted and tightened. Using an 8 m Draper 25 mm wide tape measure 1 m intervals were measured from the noose end of the string and the string was marked at each 1 m interval using black permanent marker pen. This was continued until seventeen metres had been marked onto the string.

A purpose built triangular wooden base was utilised for this study. The wooden base contained three recessed grooves, one for each of the tripod feet to sit into, and a central pivot point (Figure 3.11). The central pivot point; a bolt screwed into the centre of the wooden base, comprised a cradle to hold a DeWalt DW03050 Laser Distance Measure, which rotated about the central axis.

The wooden base was placed onto Tarmac floor in the car park in an area, which allowed for the greatest movement around it, to allow for seventeen 1 m concentric circles to be drawn on the tarmac covering a span of thirty-four meters. Taking the first 1 m marked out on the string this point was affixed to the central pivot point, 0. The string was pulled taut and the chalk placed upright to allow the chalk to mark the floor. The researcher walked around the central point in a clockwise motion, drawing a chalk line on the tarmac until a full circle had been completed. Following the completion of one full circle, the string was removed from the bolt and extended to the 2-metre mark. The same procedure was used to mark out another circle on the tarmac but in this instance 2 meters away from the central point. This process was repeated until seventeen concentric circles, all approximately 1 metre apart had been drawn around the central wooden base.

Orange traffic cones measuring 13 cm (width) x 17 cm (height) were placed onto each 1 m concentric circle line. The cones were intentionally placed in a curved manner so that each cone base was clearly visible from the central point and was not blocked from view by the previous cone (Figure 3.12). In addition, cones were also placed at 0.5 m intervals between the 8 m and 17 m lines to include cones at 8.5, 9.5, 10.5, 11.5, 12.5, 13.5, 14.5, 15.5 and 16.5 m intervals (Figure 3.13).

A DeWalt DW03050 Laser Distance Measure was used to measure the distance from the central point to the central base of the cones. The laser distance measure was placed into the wooden base and pivoted so that the laser projected was aimed at the base of the first 1 m cone. The measurement was read and the cone position readjusted to ensure it was placed at the 1 m mark away from the central point. (The chalk lines were only a rough visual representation of the meter line). Once the cone was placed accurately to the meter mark, the position of the cone was fixed to the tarmac using Duct Tape™. An approximate 5 cm strip of Duct Tape™ was torn from the roll and used to temporarily adhere the cone to the tarmac to prevent displacement in the wind (Figure 3.13). Once fixed in position, a laser measure was used to take a reading of the distance from the central point, to the central base of the first 1 m cone. The measurement was recorded and repeated ten times and a mean value calculated. This process was repeated for each of the cones so that all had been fixed to the tarmac and all distances from the central point had been recorded. The base of each cone was measured using a steel rule and the measurement recorded. This was repeated ten times for each cone and a mean value was calculated which would be used as a control measurement.

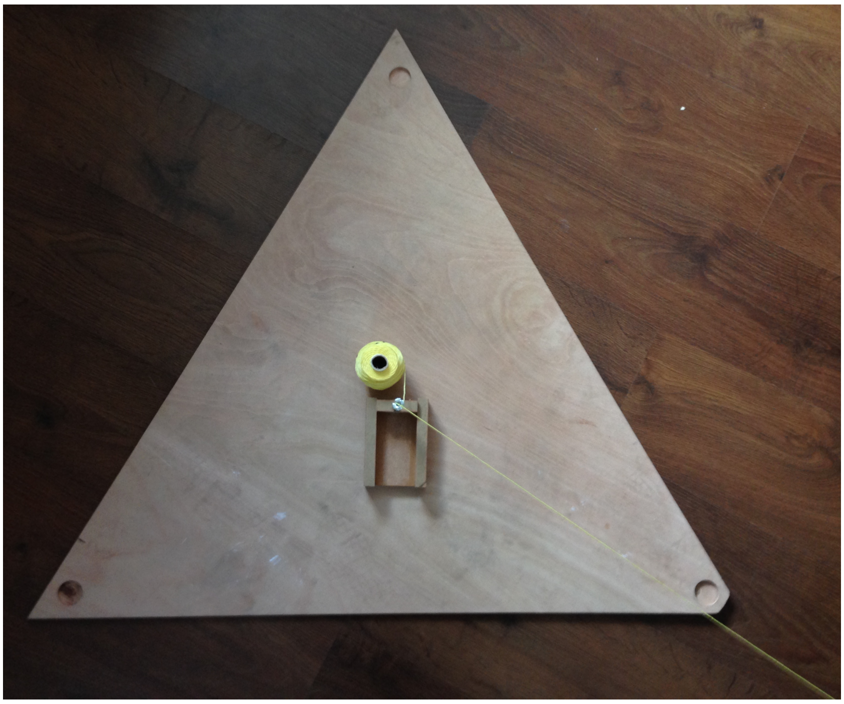


Figure 3.11: Purpose built triangular platform

Figure 3.12: 17 m concentric circles. Cones placed on each 1 metre line in a curved manner

Figure 3.13: Cone positions. Left: 0.5 m interval cones. Right: 1 m interval cones.

A Spheron SceneCam (Spheron VR AG) was placed into the central wooden base. Following calibration of the instrument, two scans of the environment were taken; one at the cameras lower position, and one at the cameras highest position according to the manufacturers instructions. The two panoramas were uploaded into the complementary SceneCenter software. The base of each cone was measured by the researcher using the SceneCenter software by selecting the start and end points for the base of each cone. The measurement quoted by the software was recorded until all seventeen 1 m interval and 0.5 m interval cone measurements had been recorded. This was repeated ten times for each cone.

3.2.5.1.1 Data Analysis

The distribution of the data sets was determined using a Shapiro Wilk test (Gray and Kinnear, 2011). A Mann Whitney U-test was used to determine whether there were any significant differences between the steel ruler cone base measurements and the software cone base measurements. Effect sizes were calculated according to Cohen's r (Coolican, 2009). All statistical testing was carried out using SPSS version 23 (IBM SPSS).

3.2.5.2 Interior Environment

The investigation was conducted within a Sports Hall at the host institution (UK, ST4 2DF) as this environment provided a large open interior area where cones could be placed up to a maximum of 12 metres away from a central point and guaranteed flat floor surface. From the centre of the sports hall, and the centre of a purpose built wooden platform, an 8 m Draper 25 mm wide tape measure was placed down on the floor 90^{o} to the central wooden base. At each 1 m mark on the tape measure an orange traffic cone measuring 13 cm (width) x 17 cm (height) was placed so that the front of the cone, facing the central point, was on the 1 m mark. This was repeated until cones had been placed up to 12 metres away from the central point. Each successive cone was placed so that the previous cone was not blocking its view from the central position. Cones were also placed at 0.5 m intervals from 9.5 – 11.5 metres (Figure 3.14).

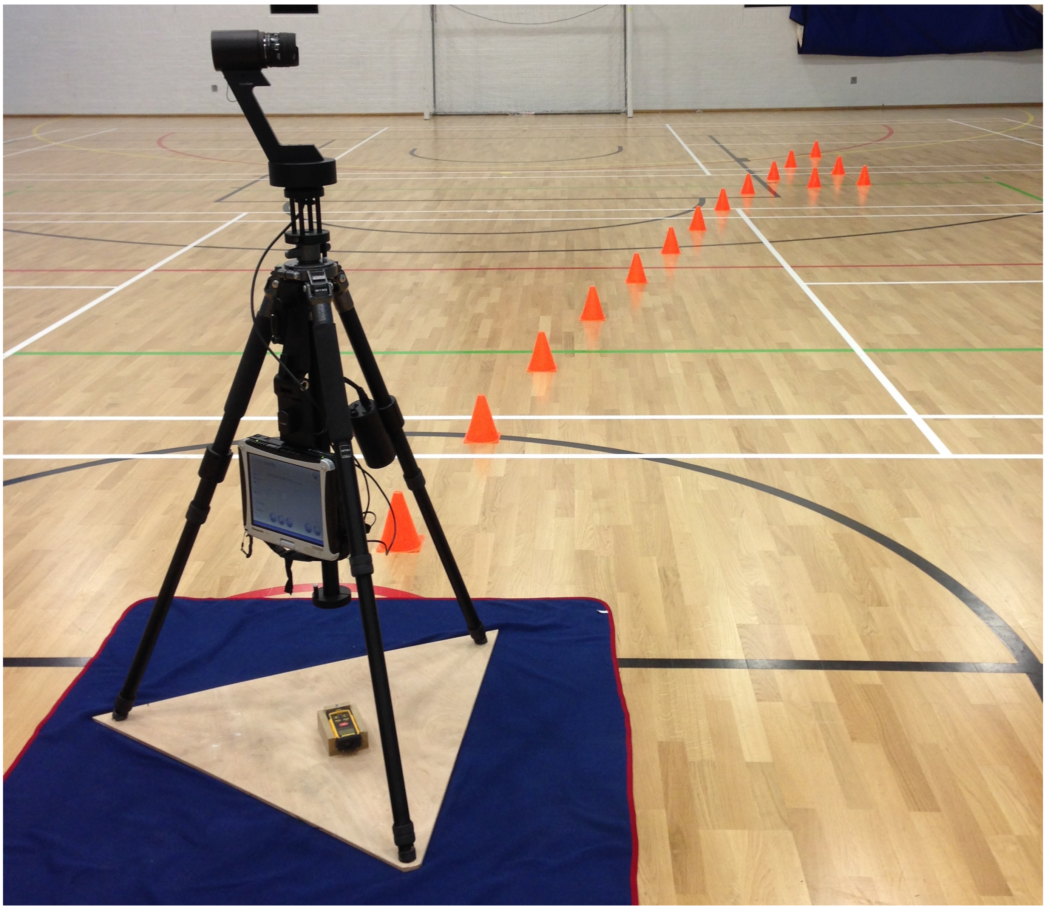


Figure 3.14: Cone placement at 1 metre and 0.5 metre intervals from the central point (camera).

A DeWalt DW03050 Laser Distance Measure was used to measure the distance from the centre of the wooden base to the central base of the cones. A DeWalt laser distance measure was placed into the wooden base and pivoted so that the laser projected from it targeted the base of the 1 m cone. The measurement was taken and the cone moved closer or further away from the central point to ensure it was positioned as close to the 1 m distance away from the central point as possible.

Once the cone was in position, a laser measure was used to take a reading of the distance from the central point, to the central point on the base of the first 1 m cone. The measurement was recorded and repeated ten times and a mean value calculated. This process was repeated so that all distances from the central point to the centre of all cones had been recorded.

A Spheron SceneCam (Spheron VR AG) was placed into the central position utilising the triangular wooden platform. Following calibration of the instrument, two scans of the environment were taken; one at the cameras lower position, and one at the cameras highest position. The two panoramas were uploaded into the complementary SceneCenter software. The width of the base of each cone was measured by the researcher using the SceneCenter software by selecting the start and end points for the base of each cone. The measurement quoted by the software was recorded until all seventeen 1 m interval and 0.5 m interval cone measurements had been recorded. This was repeated ten times for each cone.

The base of each cone was also physically measured using a steel ruler and the measurement recorded. This was repeated ten times for each cone and a mean value was calculated which was used as a control measurement.

3.2.5.2.1 Data Analysis

The distribution of the data sets was determined using a Shapiro Wilk test (Gray and Kinnear, 2011). A Mann Whitney U-test was used to determine whether there were any significant differences between the steel ruler cone base measurements and the software cone base measurements. Effect sizes were calculated according to Cohen’s r (Coolican, 2009). All statistical testing was carried out using SPSS version 23 (IBM SPSS).

3.2.5.3 Comparison of Exterior and Interior Environments

The cone base measurements obtained using the software application for the exterior (3.2.5.1) and the interior (3.2.5.2) environments were compared to determine whether the environment had any effect on the resultant measurements obtained. A Shapiro Wilk test was used to determine the distribution of the data sets. A Mann Whitney U-test was used to determine whether there were significant differences between the exterior and interior environment.

3.2.6 Resolution

Utilising the procedure above, additional scans and photographs were taken using a SceneCam. A SceneCam was placed in the central position utilising the wooden base and was calibrated. One scan was taken at the cameras lower position, and one at the cameras highest position. This was repeated for each camera resolution; low (1,500 x 750 pixels), medium (3,000 x 1,500 pixels), high (6,000 x 3,000 pixels) and maximum (12,000 x 6,000 pixels). Using the Toughbook supplied with the SceneCam, each resolution was selected on the screen, separately and a scan of the environment taken. For each camera resolution panorama, measurements of the base of the cones were taken using the complimentary software.

3.2.6.1 Data Analysis

The distribution of the data sets was determined using a Shapiro Wilk test (Gray and Kinnear, 2011). A Kruskal Wallis test was used to compare each of the measurements obtained at different camera resolutions; low, medium, high and maximum, against one another and against the control measurements. An alpha level of 0.05 was used. Post hoc pairwise comparisons using a Mann Whitney U-test were conducted to identify where significant differences were occurring. A Bonferroni correction was applied to the alpha level by dividing the original alpha level of 0.05 by 6 (0.0083) (to account for the different resolution comparisons). Effect size was calculated according to Cohen's r (Coolican, 2009). All statistical testing was carried out using SPSS version 23 (IBM SPSS). The measurement accuracy was analysed for each separate resolution to determine whether the distance away from the camera had an effect on the measurement.

3.3 Results and Discussion

3.3.1 Accuracy testing with known measurements

Table 3.1 presents the deviation and relative standard deviation (RSD) values for the grid square measurements.

Table 3.1: Deviation and relative standard deviation values for the grid square measurements.

Grid Square	Ruler Deviation	Ruler Relative Standard Deviation (RSD)	Software Deviation	Software Relative Standard Deviation (RSD)
A	0	0	0.000	0
B	0	0	0.0063	31.622
C	0	0	7.31E-18	2.44E-14
D	0	0	7.31E-18	1.83E-14
E	0	0	7.31E-18	1.46E-14
F	0	0	1.46E-17	2.44E-14
G	0	0	1.46E-17	2.09E-14
H	0	0	1.46E-17	1.83E-14
I	0	0	1.46E-17	1.63E-14
J	0	0	1.46E-17	1.46E-14

The deviation of the ruler for each grid square measurement was 0 showing that the measurement of each grid square was highly accurate and very precise with each repeat measurement being taken. There appeared to be a deviation with the software measurements, however, these values were all 0.00, and so the differences between each repeat measurement were negligible.

Figure 3.15 presents the mean measurements for the horizontal and vertical grid squares 1-10 taken using the steel ruler plotted against the measurements taken using a software application from a 360^{o} panorama. A steel ruler provided a more rigid measuring device than fabric tape measures that are more flexible and could produce more varied measurements. Figure 3.15 clearly illustrates that all but the first grid square mean measurements are the same for both the tape measure and the software for both the horizontal and vertical measurements. The software in this case, proved to be highly accurate, with standard deviation values of +\- 0.00 to 2 d.p. (decimal places) and produced the same measurement values as the control tape measurements. The first grid square measurement produced a different result using the software application, and did not quote 0.01 m, but was only able to quote this measurement as <2 cm. This is possibly to be due to a unit limit within the software application.

Practically, this feature within the software will limit the potential uses of this technology, as it will not be suitable for measuring any items that are less than 2 cm in length, width or height. As a result, this technology would not be suitable for analysing blood spatter at crime scenes as many blood drops could be less than 2 cm in diameter.

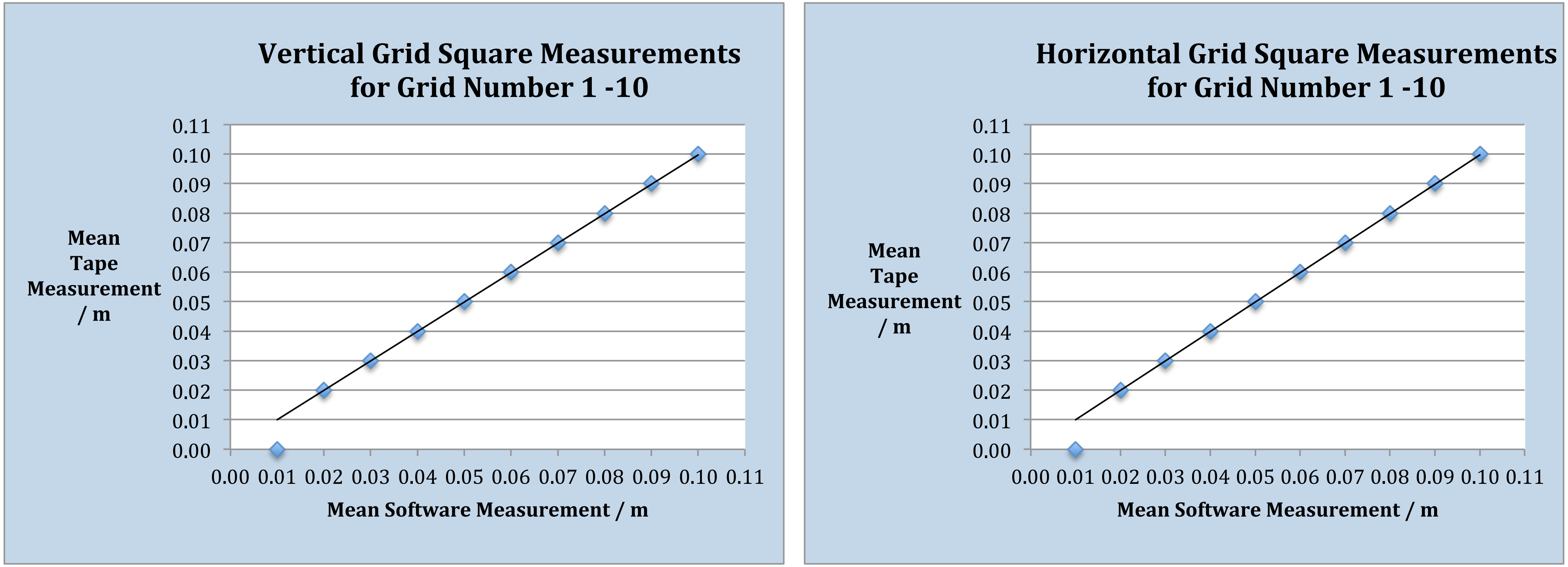


Figure 3.15: Mean measurements for horizontal (left) and vertical (right) grid squares 1-10 respectively. Measured using a tape measure and software application, with line of equality

3.3.1.1 Data Analysis

Due to the absence of normally distributed data sets, a Mann Whitney U test was used. Results suggest that there were no statistically significant differences between the measurements of the graph paper and the measurements of the graph paper taken using the photogrammetry software ($p > 0.05$) for all of the grid squares, 1-10 and for the vertical and horizontal measurements. Effect sizes were not calculated as there were no differences between the data sets and therefore the measurements obtained with the photogrammetry software were the same as the mean. No statistically significant differences and little or no deviation demonstrated that the photogrammetry software application and 360^{o} camera system was very accurate for measuring these fixed points as the measurements produced were the same as those of the steel ruler/graph paper.

3.3.2 Measuring a single blank wall

The control mean wall measurement was 2.70 m, with a standard deviation of 0.00088. Table 3.2 presents the measurements taken using the SceneCenter software for the ceiling, floor and five sections across the wall.

Table 3.2: Measurements taken using the SceneCenter software at the ceiling, floor and five sections across the wall

Repeat Number	Ceiling Measurement / m	Floor Measurement / m	Blank Wall Measurements / m				
			1	2	3	4	5
1	2.66	2.66	3.37	3.47	3.41	3.17	2.54
2	2.66	2.65	3.29	3.15	2.90	2.85	2.65
3	2.66	2.66	2.97	2.95	2.87	2.81	2.52
4	2.66	2.65	3.25	3.10	2.73	2.35	2.12
5	2.66	2.66	3.58	4.00	3.74	3.08	2.44
6	2.65	2.66	4.64	5.07	4.30	3.69	3.28
7	2.66	2.65	4.37	4.09	3.62	2.70	2.31
8	2.65	2.67	5.07	5.33	4.76	4.33	3.38
9	2.65	2.65	5.71	6.05	6.72	6.03	3.77
10	2.66	2.66	5.03	6.25	8.39	5.70	4.24
Mean	2.66	2.66	4.13	4.35	4.34	3.67	2.93
Relative Standard Deviation (RSD) %	0.18	0.25	23.24	28.51	42.63	34.88	23.89

The mean wall measurements taken from the ceiling and floor lines were 2.66 m, which were consistent and 4 cm away from the control measurement of 2.70 m. The RSD values were very small, with results of 0.18 and 0.25 for the ceiling and floor lines respectively, providing evidence of a high level of consistency. Consistency between the control and ceiling/floor measurements were attributed to the presence of clear reference points visible in the ceiling/floor corners of the wall. The ability to locate clear reference points allowed the researcher to assign start and end points, which resulted in accurate measurements being obtained.

Mean measurements taken across the wall ranged from 2.93 m – 4.35 m, with high RSD values, which were up to 42.63 %. The high RSD values were due to the range of measurements taken, which varied from 2.12 – 8.39 m. One of the causes for this significant deviation is likely to have originated from the photogrammetric process, whereby the software cannot rebuild depth as a result of blank featureless textures or shadows produced in the corners of rooms, associated with blank walls (Clarke, 1994; Mallison and Wings, 2014) such as that used in this study. The corners of the wall that were not associated with the ceiling or floor lines were less visible, and therefore it was more difficult to assign start and end points. This problem was magnified by the operation of the software, which automatically zooms into the region of interest in order for the user to select the exact pixel for the start and end points. This means that when the end point is selected the user was unaware of the allocated starting point. This often meant that there was little consistency in the heights of the start and end points, which caused inaccurate measurements to be obtained (Figure 3.16). This also explained why the ceiling and floor lines were easier to measure and gave more accurate measurements, given that the allocated start and end points were level.

For use in documenting crime scene environments, measurements, which have no clearly defined start and end points, may cause the accuracy of a users measurement to diminish. This investigation has shown that there was little consistency between the start and end point heights for a measurement taken across the wall. As such a SOCO trying to capture measurements of blank walls cannot guarantee the placement of the cursor in the same position each time, even with significant training. The automatic zoom ability of the software application when taking a measurement hinders the users ability to determine where their first point was placed which can result in off level measurements. Due to this, a SOCO would not be able to take accurate measurements of items which had no clearly defined start and end points.

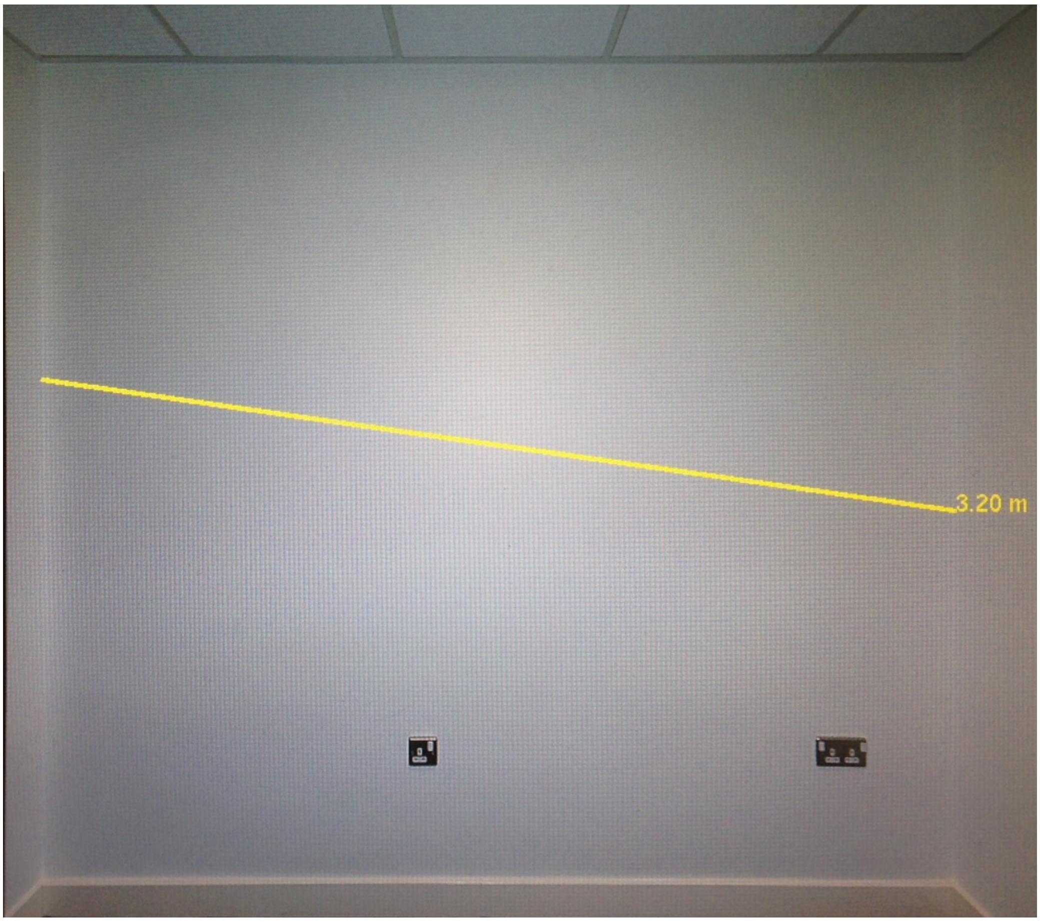


Figure 3.16: Height of start and end points for measurements inconsistent resulting in off-level measurement being taken

In order to address the difficulties in assigning start and end points five pairs of 8 mm diameter paper dots were applied to two opposite corners of the wall. Table 3.3 shows the measurements taken on the SceneCenter software using the target dots compared against those taken in the previous study without the target dots.

Table 3.3: Measurements taken without a reference point (blank wall measurements) compared with those taken using target dots

Repeat Number	Blank Wall Cluster Measurements / m					Target Dots Measurements / m				
	1	2	3	4	5	1	2	3	4	5
1	3.37	3.47	3.41	3.17	2.54	2.68	2.68	2.68	2.68	2.68
2	3.29	3.15	2.90	2.85	2.65	2.68	2.68	2.68	2.68	2.68
3	2.97	2.95	2.87	2.81	2.52	2.68	2.68	2.68	2.68	2.68
4	3.25	3.10	2.73	2.35	2.12	2.68	2.68	2.68	2.68	2.68
5	3.58	4.00	3.74	3.08	2.44	2.68	2.68	2.68	2.68	2.68
6	4.64	5.07	4.30	3.69	3.28	2.68	2.68	2.68	2.68	2.68
7	4.37	4.09	3.62	2.70	2.31	2.68	2.68	2.68	2.68	2.68
8	5.07	5.33	4.76	4.33	3.38	2.67	2.68	2.68	2.68	2.68
9	5.71	6.05	6.72	6.03	3.77	2.68	2.68	2.68	2.68	2.68
10	5.03	6.25	8.39	5.70	4.24	2.68	2.68	2.68	2.68	2.68
Mean	4.13	4.35	4.34	3.67	2.93	2.68	2.68	2.68	2.68	2.68
Relative Standard Deviation (RSD) %	23.24	28.51	42.63	34.88	23.89	0.11	0	0	0	0

Table 3.3 demonstrates that the target dots facilitated reproducible and more accurate results, as shown by the mean wall measurements of 2.68 m. The target dot data also resulted in significantly lower RSD's than measurements taken without the dots, to the extent that measurements of 4/5 sections of the wall had a RSD of 0 %. Artificial targets are often used in photogrammetry to improve the accuracy of measurements taken (Clarke, 1994) but Clarke's study had not used a crime scene context. Given the size and shape of the target dots there was the potential for error within cursor placement, despite the instruction to participants to aim for the approximate centre. An alternative approach could have utilised crosshair markers, or two pieces of tape, situated at right angles to signify endpoint targets. This approach may be considered for future practice.

At a crime scene it may not be possible to use the target dot approach, as there may be issues with contamination as a result of sticking dots to walls, and therefore a laser line was also used to provide an alternative reference point for the measurements to be taken from. Table 3.4 shows the measurements taken on the SceneCenter software using the laser line, compared against measurements taken without the reference line.

Table 3.4: Measurements taken without a reference point (blank wall measurements) compared with those taken using a laser level line.

Repeat Number	Blank Wall Measurement / m	Cross Line Laser Measurement / m
1	2.56	2.68
2	2.63	2.68
3	3.25	2.68
4	2.75	2.68
5	3.30	2.69
6	2.79	2.68
7	3.22	2.68
8	3.39	2.68
9	3.47	2.68
10	3.25	2.68
Mean	3.061	2.681
Relative Standard Deviation (RSD) %	10.52	0.11

Table 3.4 demonstrates the ability of the laser line to produce more accurate and reproducible measurements using the software, as shown by the mean wall measurement of 2.681 m, compared to those taken without any reference point, which had a mean wall measurement of 3.061 m. The blank wall measurement had a significantly higher RSD value of 10.52 % compared to the cross line laser measurement RSD value of 0.11 %. It was not necessary to repeat this process across different sections of the wall, because the purpose of the study was to examine the level of consistency of the measurements taken using the laser level line. The target dot study had demonstrated that the important feature was the presence of clear start and end reference points, which the laser level line had simply replicated in a non-invasive manner. The presence of these artificial reference points allowed the researcher to clearly assign start and end points to the measurements, and this resulted in more accurate measurements being obtained.

In practice, the use of target dots and/or a laser line would provide clearly defined reference points, which would facilitate the capture of more accurate measurements for items that were lacking in definition such as blank featureless walls. This investigation demonstrated the ability of the target dots and the laser line to considerably improve the accuracy of measurements that did not previously have clearly defined start and end points. In such instances, where clearly defined reference points are not available, such as blank walls, SOCO's should utilise either the target dots or a laser line to ensure that accurate measurements are captured. The improved accuracy of measurements taken using the target dots for distances within a scene with no clearly defined reference points should negate the added time onto the investigation. The two methods give the investigator a choice of technique to use at a crime scene. Some scenes may not facilitate the use of target dots as these have to be adhered to the environment and could contaminate the scene so the laser line provides a non-invasive alternative method. Currently the laser line approach requires the user to set up the laser line within the scene. However, development of this technique could seek to adapt the existing camera technology to include a laser line which would be projected onto the surrounding environment simultaneously to capturing a scan.

3.3.3 Measuring a scene using a tape measure

Participant measurements can be observed in Appendix 3. A variety of ten fixed and non-fixed items provided different sizes and shapes for the participants to measure. Also, some of the items were considered easier to measure than others. For example, measurement 'I' (Figure 3.8) was the width of the room across the floor space, which was easy to achieve given that the start and end points were easy to identify and there were no obstructions. On the other hand, measurement 'A' (Figure 3.8) required participants to measure the width of the wall above the existing furniture, which was physically difficult to achieve as a single participant using a tape measure.

Table 3.5 shows the mean control measurements and RSD values for the fixed and non-fixed items, A to J. The RSD values were very small ranging from 0.0104 – 0.2985, providing evidence of a high level of consistency. The method utilised in this investigation to capture the control measurements for items which did not have a clearly defined end point could have been a small contributor to error within the control measurements. The researcher could not guarantee that the cardboard did not move between measurements being taken or that it was at the correct end point for the item to be measured. However, the small RSD values for the control measurements would suggest a high level of consistency between the readings taken but cannot guarantee that each of these was the correct measurement. As a result, there is the likelihood that some of the participant measurements may be closer to the true measurement of the item than those demonstrated in the results. It must be noted however, that all participants measurements were compared to the control and therefore any errors will be consistent between all participants.

3.3.4 Measuring the scene using photogrammetry software

In order to take measurements using the software the camera in the scene had to be able to capture the start and end points of the items to be measured. In this study the camera was placed in four different positions, which facilitated the capture of start and end points for all ten fixed and non-fixed items. This meant that the minimum and maximum distances to the objects of interest in the field of view from each of the camera positions were different, as shown in table 3.6. Figure 3.17 demonstrates that the position of the camera significantly impacted upon the actual measurements that were obtained from the software. For example, the control measurement for item B was 888 mm, yet at position 1 the mean measurement was 870 mm, at position 2 it was 865 mm, at position 3 it was 852 mm, and at position 4 it was 858 mm. Analysis of the error bars for item B would also support a significant deviation of measurements. This trend was apparent for all of the fixed and non-fixed items. As with the earlier study measuring the blank wall, the accuracy of the resultant measurement taken using the software application was dependent upon the users' accuracy in identifying consistent start and end points. Some of the fixed items had bevelled edges or rounded corners, and as a result participants were likely to have chosen different start and end points to measure, resulting in significant deviations. An alternative explanation is that if an object is photographed at close range with full image resolution one might expect a more accurate measurement than an object photographed at long range, which may also have contributed to differences between the control measurements and those taken using the software application.

To access the panoramas demonstrating Position 1-4 for the measurements taken using the software application please refer to the supplementary USB card and open the file entitled Chapter 3 – Participant Software measurements. Within this file please select the 'Start' file. This will open the SceneCase with the panoramas.

Table 3.5: Mean and relative standard deviation values for control measurements A to J.

	Measurement									
Control	A	B	C	D	E	F	G	H	I	J
Mean/ mm	3578	888	2415	341	2881	921	789	1661	3526	1058
RSD (%)	0.0195	0.1869	0.1583	0.2985	0.0104	0.2126	0.0506	0.0538	0.0376	0.0755

Table 3.6: The minimum and maximum distances to the measurements of interest in the field of view from each of the camera positions.

Camera Position	Measurement	Minimum Distance from camera (mm)	Maximum Distance from camera (mm)
1	A	1534	3446
	B	775	1521
	C	1476	2151
	F	2630	2688
	G	3868	4187
	H	741	2101
	I	1305	3277
2	A	2327	3811
	B	2991	3734
	C	666	3156
	D	1897	1960
	E	990	2043
	F	577	1590
	H	1965	2552
3	A	3290	3643
	B	2520	3313
	C	1286	2974
	F	2047	2713
	G	2252	2514
	H	929	1119
	I	1517	2194
	J	1311	2016
4	A	3518	4649
	B	3816	4564
	C	1683	3991
	D	3059	3065
	E	469	3126
	F	1851	2646
	G	848	932
	J	2578	3573

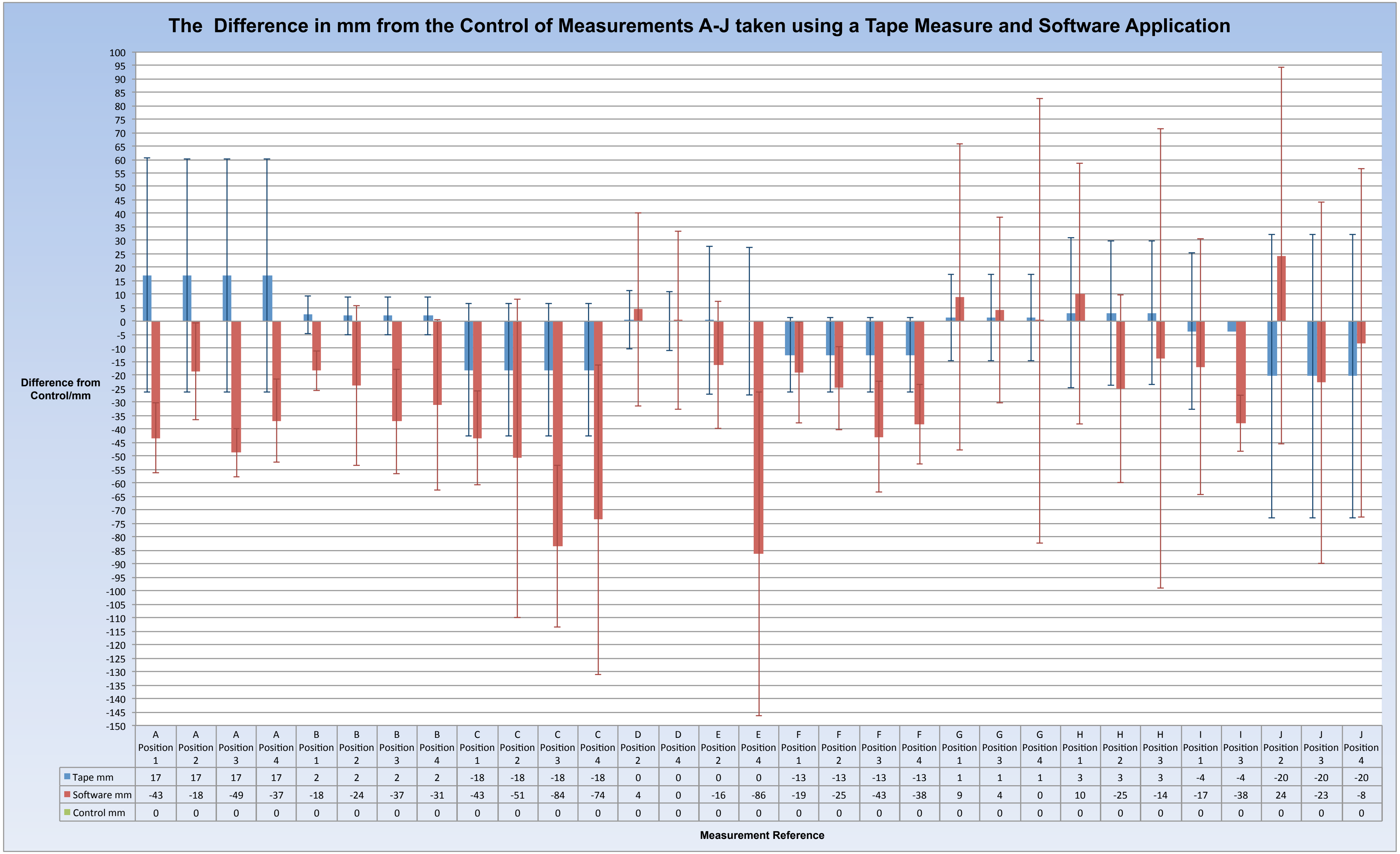


Figure 3.17: Graph to show how measurements taken using a Tape measure and SceneCenter Software differ in millimetres from the Control taken using a Laser Measure

Taking measurements with the tape measure required participants to be in front of the item to assign appropriate start and end points. Figure 3.17 demonstrates that the tape measurements ranged from 0.4 – 20 mm difference from the control. The deviation from the control was dependent on the measurement itself. For example, analysis of the error bar for item A shows a significant deviation from the control measurement, the highest shown for any of the tape measurements, with a standard deviation of +/- 43.40 mm. The control measurement was 3578 mm whereas the mean tape measurement was 3596 mm, showing a difference of 18 mm. This large deviation was likely to have originated from the difficulty of measuring the width of the wall around and above the existing furniture. In this instance, the software was capable of producing less of a deviation, as the item to be measured was considered easier with the software application, which didn't require participants to navigate around furniture.

All of the tape measurements for the ten fixed and non-fixed items showed deviation from the control. The size of the deviation appeared to be dependent on the size and difficulty of the fixed or non-fixed item to be measured. Items B, D, F and G were smaller measurements and were considered easier to measure compared with the rest of the fixed and non-fixed items. Figure 3.17 demonstrates that these items had the smallest standard deviation when compared to the larger fixed and non-fixed items. Standard deviation values of +/- 7.022 mm, +/- 10.872 mm, +/- 13.825 mm and +/- 15.95 mm for items B, D, F and G respectively. Items B, D and F also had bevelled edges or rounded corners, and as a result the deviation within these measurements was likely to have originated from the participants choosing different start and end points to measure.

Measurements taken using the tape measure generally produced smaller standard deviation values compared to the software, which produced higher standard deviation values. This was likely to have originated from the participants' ability to easily and consistently assign accurate start and end points to the measurement whilst stood directly in front of the item to be measured. Using the software it is likely to be more difficult to consistently replicate the same start and end points for each fixed and non-fixed item when selecting them freehand with the computer mouse and attempting to select exactly the same pixel each time. In addition, the accuracy of measurements is dependent upon the start and end points selected and how much detail is present at this point within the panorama. Hard detail points, such as a table top are easier to select than softer points, such as a wall corner where shadows could obscure any detail.

Software measurements demonstrated inaccuracies when compared to the control tape measurements. For some measurements, the software demonstrated substantial inaccuracies, for example measurement E position 4. User inaccuracies are likely to have originated from a lack of training and familiarity with the operation of the software. As a result, significant training prior to the use of the software application must be given to users who will be taking measurements on the software. Repeated use and familiarity with the operation of the software is likely to provide users with a more comprehensive understanding of the software and knowledge of how to capture more accurate measurements. Training and practice with the software may allow the user to gain experience with identifying the same start and end points for measurements and should increase their accuracy.

3.3.4.1 Data Analysis

A Friedman test was used due to the absence of normally distributed data sets. The results suggested that there were statistically significant differences between the control, tape and software measurements for each of the ten fixed and non-fixed items ($p \leq 0.05$). Pairwise comparisons of each data set demonstrated that there were statistically significant differences between the majority of the data sets, as shown in Table 3.7. Significant differences were more prominent between the software and control measurements than measurements taken with the tape measure. This was attributed to the users' ability to accurately assign start and end points to the fixed and non-fixed items, and the ability to accurately repeat this in the same manner each time with the tape measure. User inaccuracies in identifying the same start and end point between the two pairs of images is likely to cause measurement differences whereby the software interpreted the measurement to be more distant and therefore quoted a longer measurement, as shown in Figure 3.18.

Effect sizes were calculated using Cohen's r and ranged from very small (r = 0.005) to large (r = 0.620), according to Cohen's criteria, over the ten fixed and non-fixed items. Statistically significant differences were apparent between the control and tape measurements, with very small to medium effect sizes (0.005 – 0.485) and therefore the differences were negligible given that they were only millimetre differences. Differences between the software and control measurements demonstrated small to large effect sizes (0.029 – 0.616), with the majority of differences amounting to a couple of centimetres, and in an extreme case the difference was 86 mm, as shown in Figure 3.17 Item E position 4. The substantial difference in measurement between the tape and software measurement is likely to have originated from the user operation of the software and the lack of training for taking measurements using the software. Such a substantial difference in the accuracy of this measurement (a difference of 86 mm or 8.6 cm) could have profound effects on the interpretation of a scene and interpreting spatial interactions with other evidence. The calibration accuracy of the lens could also have an affect on the accuracy of measurements, however, the lens is calibrated during manufacture and as such the user has no control over this. Accuracy results demonstrated by the software as previously discussed in *3.3.1 Accuracy testing with known measurements* were highly accurate with standard deviation values of +\- 0.00. The accuracy demonstrated here is likely to have been due to the training, knowledge and prior repeated use of the software by the researcher and the clearly defined start and end points present on the grid square paper.

Table 3.7: P Values and Effect sizes for pairwise comparisons of the control, tape and software measurements.

Item	Position	Tape vs. Software		Software vs. Control		Control vs. Tape	
		P value	Effect Size / r	P value	Effect Size / r	P Value	Effect Size / r
A	1	< 0.001*	0.576	< 0.001*	0.616	< 0.001*	0.268
	2	< 0.001*	0.452	< 0.001*	0.525	< 0.001*	0.278
	3	< 0.001*	0.599	< 0.001*	0.615	< 0.001*	0.278
	4	< 0.001*	0.567	< 0.001*	0.615	< 0.001*	0.278
B	1	< 0.001*	0.620	< 0.001*	0.615	< 0.001*	0.260
	2	< 0.001*	0.570	< 0.001*	0.549	< 0.001*	0.260
	3	< 0.001*	0.607	< 0.001*	0.604	< 0.001*	0.260
	4	< 0.001*	0.542	< 0.001*	0.536	< 0.001*	0.260
C	1	< 0.001*	0.499	< 0.001*	0.611	< 0.001*	0.450
	2	< 0.001*	0.485	< 0.001*	0.584	< 0.001*	0.450
	3	< 0.001*	0.595	< 0.001*	0.613	< 0.001*	0.450
	4	< 0.001*	0.546	< 0.001*	0.582	< 0.001*	0.450
D	2	< 0.001*	0.267	< 0.001*	0.291	0.003*	0.211
	4	< 0.001*	0.286	< 0.001*	0.316	0.003*	0.211
E	2	< 0.001*	0.418	< 0.001*	0.495	0.342	0.068
	4	< 0.001*	0.559	< 0.001*	0.586	0.005*	0.208
F	1	0.002*	0.222	< 0.001*	0.547	< 0.001*	0.485
	2	< 0.001*	0.375	< 0.001*	0.573	< 0.001*	0.485
	3	< 0.001*	0.553	< 0.001*	0.605	< 0.001*	0.485
	4	< 0.001*	0.545	< 0.001*	0.610	< 0.001*	0.485
G	1	< 0.001*	0.266	< 0.001*	0.274	0.628	0.037
	3	0.080	0.133	0.043*	0.154	0.662	0.033
	4	0.120	0.190	0.002*	0.238	0.020*	0.175
H	1	0.103	0.122	0.127	0.114	0.946	0.005
	2	< 0.001*	0.431	< 0.001*	0.480	0.561	0.041
	3	0.003	0.212	0.018*	0.168	0.561	0.041
I	1	< 0.001*	0.361	< 0.001*	0.482	0.567	0.043
	3	< 0.001*	0.531	< 0.001*	0.614	0.567	0.043
J	2	< 0.001*	0.353	< 0.001*	0.260	< 0.001*	0.316
	3	0.509	0.053	0.436	0.062	< 0.001*	0.296
	4	0.069	0.130	0.682	0.029	< 0.001*	0.316

** = statistically significant differences*   [grey] *= large effect size*

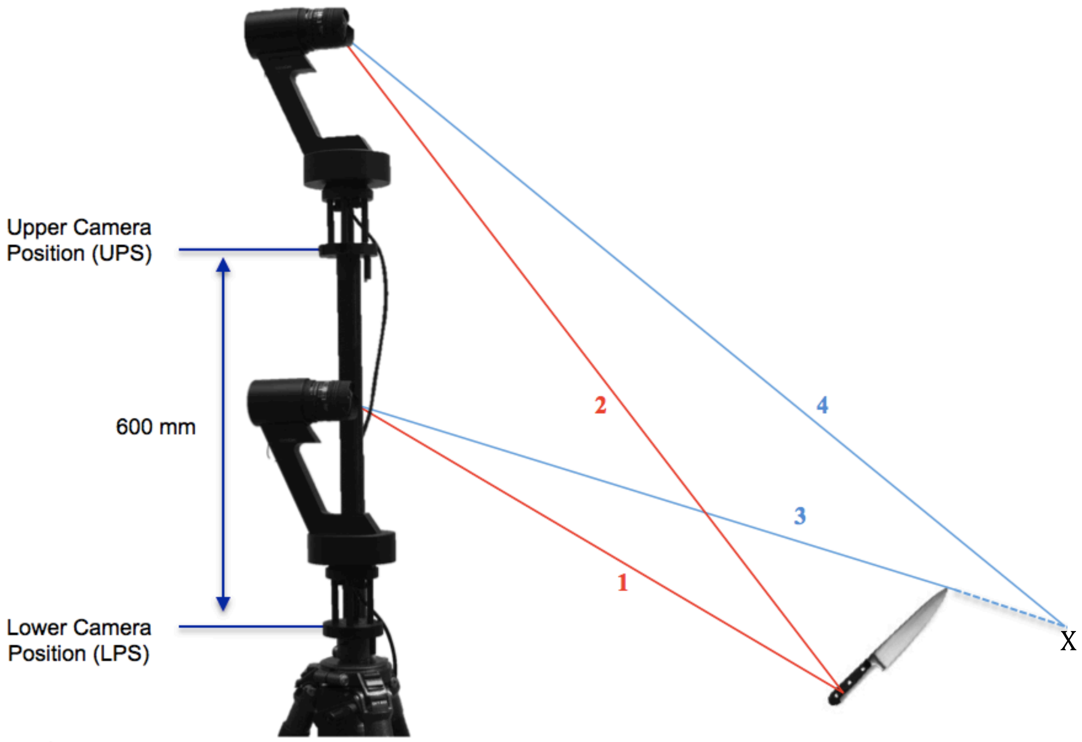


Figure 3.18: User point and click error where the same feature is misidentified between images causing the software to interpret that the object is further away.

Currently, measurements taken at crime scenes are assumed to be approximate values, and in the UK there is no published accepted limit of accuracy for measuring crime scenes (Moore, 2015). However, the accepted limit of accuracy in the United States of America is 0.25 inches (6.35 mm) (NFSTC, 2013). This may be problematic in practice due to differences in the relative sizes of items, which may be measured at a scene. For example, a 0.25 inch limit of accuracy over a 10 metre span may be considered negligible. However, a 0.25 inch limit of accuracy over a 0.5 inch measurement is half of its original size, which may be considered significant. This problem may be alleviated with the use of a percentage of the original measurement which will standardise the limit to account for the overall size of the measurement itself.

Both the tape and the software have advantages and limitations. Tape measurements have to be taken at the scene at the time of the incident, and as a result the SOCO is limited to only those measurements that were taken at the time, and cannot revisit the scene to take further measurements. The software application presents advantages over the tape in this aspect, whereby the user has the ability to take any measurement (providing it is in the line of sight of the camera) within the scene at anytime, even when the crime scene no longer exists. To ensure that all items of evidence are in the camera's line of sight, multiple scans may be necessary from different positions within the scene. Tape measurements introduced human error in the form of transcribing errors, misreading the tape measure, and using incorrect units. The software application removed these potential errors, but can introduce other errors and inaccuracies when users are not competent in its use, or where clear reference points are not available as evidenced within this work. The accuracy of the measurements taken using the software is in part a function of the resolution of the images being used, and as a result all panoramas were taken at their maximum resolution of 50 MP. However, measuring a large object appearing very small in an image is similarly likely to produce inaccurate data, even for a high-resolution image. This is because it is the resolution of the object where the measurements must take place that will determine the accuracy with which measurements can be taken. For example – if an object were photographed at close range with full image resolution one would expect a highly accurate measurement.

This investigation has demonstrated the level of accuracy when using a tape measure in a forensic context is dependent on the ability of the user. The software measurements were more precise and were more reproducible, assuming the user selected the same pixels, but inaccuracies arose from the lack of user knowledge of the software operation. As a result it is a necessity that significant training be given to individuals using this technology, to ensure that they are competent in taking accurate measurements. In line with the requirements of ISO 17020 the limits of accuracy need to be defined regardless of the method used to obtain measurements, and this chapter details a methodological approach, which could be used to determine the levels of accuracy associated with devices used to measure items within a crime scene. The approach described in this chapter may also be useful as part of competency testing.

It has previously been identified that there is a clear void in the literature with regards to validating the accuracy of modern measurement devices for use in criminal investigations. Some authors have attempted to validate direct measurements taken from laser scanners (Boehler and Marbs, 2003; Hakim and Liscio, 2015; Johnson and Liscio, 2015). For example, Mihandoost (2015) conducted research into the accuracy of two laser-scanning systems in comparison to the NIST guidelines suggesting the limit of accuracy of measurements to be +/- 0.25 inches but little more research has been conducted into other technology, which is available to police services, particularly photogrammetric applications. In order for technology to be integrated and to be used to its full potential these systems need to be accurate in taking measurements as it is integral to the investigation process but also for use later in court. The forensic science community has not previously investigated the accuracy of such a 360^{o} camera and content management system, yet many of these systems or similar are being used routinely in criminal investigations.

3.3.5 Measurement Range

3.3.5.1 Exterior environment

Table 3.8 presents the laser distance measurements for each of the cones 1-17, showing the true distance of each cone from the central pivot point.

Table 3.8: Laser distance measurements for cones 1 to 17.

Cone Number	Mean Laser Distance Measurement from tripod centre (m)	Standard Deviation	Relative Standard Deviation / %
1.0	1.0053	0.001418	0.1410
2.0	2.0086	0.000966	0.0481
3.0	2.9923	0.000823	0.0275
4.0	3.9735	0.000527	0.0133
5.0	4.9717	0.000675	0.0209
6.0	5.9773	0.001252	0.0096
7.0	6.9720	0.000667	0.0158
8.0	8.0304	0.001265	0.0087
8.5	8.5001	0.000738	0.0086
9.0	8.9557	0.001160	0.0129
9.5	9.5105	0.001581	0.0166
10.0	9.9877	0.000675	0.0068
10.5	10.5034	0.000966	0.0092
11.0	10.9861	0.000738	0.0067
11.5	11.5073	0.001059	0.0092
12.0	11.9933	0.001160	0.0097
12.5	12.5010	0.000667	0.0053
13.0	12.9966	0.001265	0.0097
13.5	13.5006	0.000516	0.0038
14.0	14.0034	0.000699	0.0050
14.5	14.5028	0.001317	0.0091
15.0	15.0057	0.001636	0.0110
15.5	15.5029	0.000876	0.0056
16.0	16.0087	0.001060	0.0067
17.0	16.9973	0.001160	0.0068

The mean laser distance measurements from tripod presented in Table 3.8 demonstrate how close to the metre or half a meter point each cone was placed. Further reference to the cones will be Cone 1 which is 1 m away from the central point, Cone 2, which is 2 m away from the central point and so on.

The mean control measurement for the base of the cones was 13.2 cm, with a standard deviation of 0. Table 3.9 presents the mean cone base measurements taken using the SceneCenter software for cones 1 -10 placed respectively at 1 -10 meters away from the central position compared to the mean tape measurements. The software measurements were quoted by the software in metres but for the purposes of comparison with the tape measurements these have been converted into centimetres.

Table 3.9: Mean tape and mean software measurements obtained for cones 1 to 10 with centimetre difference and percentage error - Exterior environment

	Cone Base Measurement			
Cone Number	Mean Tape Measurement / cm	Mean Software Measurement / cm	Difference / cm	% Error
1.0	13.20	13.00	0.20	1.52
2.0	13.20	13.00	0.20	1.52
3.0	13.20	13.00	0.20	1.52
4.0	13.20	13.00	0.20	1.52
5.0	13.20	13.00	0.20	1.52
6.0	13.20	13.00	0.20	1.52
7.0	13.20	13.00	0.20	1.52
8.0	13.20	12.80	0.40	3.03
9.0	13.20	12.90	0.30	2.27
9.5	13.20	13.20	0.00	0.00
10.0	--	--	--	--
11.0	--	--	--	--
12.0	--	--	--	--
13.0	--	--	--	--
14.0	--	--	--	--
15.0	--	--	--	--
16.0	--	--	--	--
17.0	--	--	--	--

-- Denotes an occasion where the software was unable to produce a measurement

The mean tape measurements for the cone base remained a constant 13.20 cm for each cone due to the cones being identical. The mean cone base software measurement remained 0.130 m (13.00 cm) for cones 1-7 but fluctuated to 0.128, 0.129 and 0.132 for cones 8, 9 and 9.5 respectively. The standard deviation of cones 1-7 was very small with a value of 0. The calculated percentage error for cones 1- 7 was 1.52 % - the cone tape measurement was 13.20 cm and the software measurement being 13.00 cm – a difference of 2 mm. The software quotes all measurements with meter units, so 13.00 cm is quoted by the software as 0.13 m. The 2 mm difference presented by the software and the control measurements could be a result of the unit limit within the software. For example, if the software quotes its measurements to meter units it can only present 2 decimal places and as a result internal rounding could prevent millimeter accuracy. If an item were measured within the software which actually measures 13.20 cm this would be 0.132 m within the software. However, the software only quotes its measurements to 2 decimal places and can only present a measurement of 0.13, rounding down. If a measurement of 0.136 m was taken, this would be rounded to 0.14 m. As a result the unit limit is also the software's limit of accuracy and immediately adds a +/- 1 cm accuracy range due to rounding errors.

As Table 3.9 shows, the software application was unable to measure anything on or past the 10 m point. This is due to an internal limit within the software which has been set to ensure measurements cannot be taken past the ten meter point as the accuracy of the system diminishes past this point and accuracy cannot be guaranteed. This 10 m limit presents implications for crime scene applications, whereby scenes greater than 10 m will require multiple 360^{o} photographs to be taken in order to capture the full environment, and enable accurate measurements to be taken. This in itself will add time onto the investigation process and is an aspect, which needs to be considered when documenting crime scenes using this equipment. Although this will increase the investigation time, this method will still provide a more efficient and quicker solution than manual tape measurements in addition to capturing a 360^{o} photograph of the crime scene simultaneously whilst allowing measurements to be taken of any item within its line of sight at anytime after the investigation.

Figure 3.19 shows the camera position in the centre and the 10 concentric circles. The figure has been colour coded to denote the accuracy of the measurements taken as the distance from the camera increases.

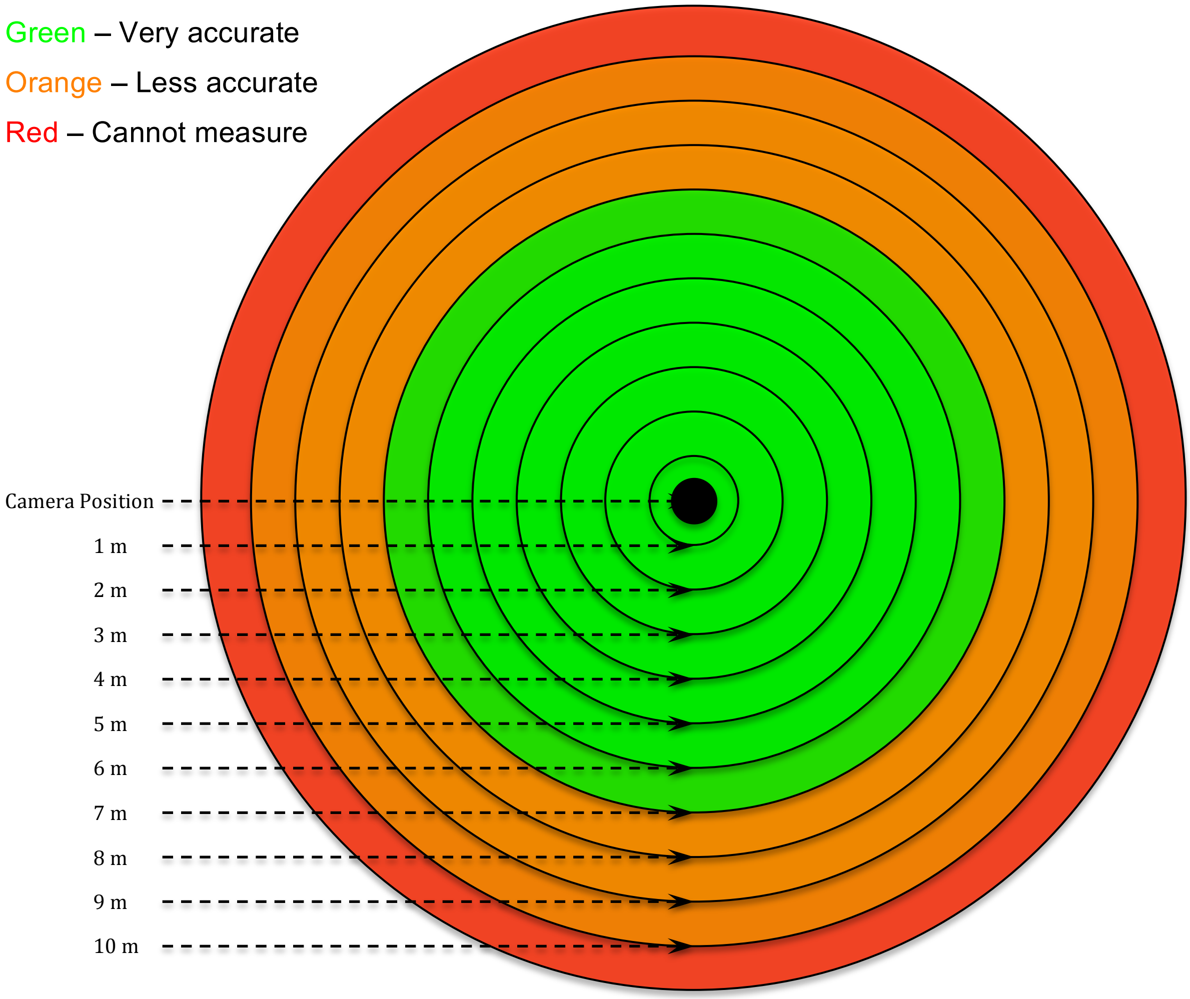


Figure 3.19: Accuracy of measurements taken using the SceneCam and SceneCenter software up to its 10 metre measurement limit.

3.3.5.1.2 Data Analysis

Due to the absence of normally distributed data sets, a Mann Whitney U test was used to determine whether any statistically significant differences were present between the base cone measurements using a tape measure and the software application. The results suggest that there were no statistically significant differences between the cone tape measurements and software measurements ($p > 0.05$). Table 3.10 demonstrates the p values to show that there were no statistically significant difference and their effect size.

Table 3.10: P Values and Effect sizes for the control cone base measurements compared with software cone base measurements for the exterior environment

Cone Number	Control Cone Base Measurement VS Software Cone Base Measurement	
	P value	Effect Size
1	1.000	0.000
2	1.000	0.000
3	1.000	0.000
4	1.000	0.000
5	1.000	0.000
6	1.000	0.000
7	1.000	0.000
8	0.146	0.325
8	0.317	0.224
9	0.543	0.136
9.5	0.146	0.325

** = statistically significant differences*   *= large effect size*

There were no statistically significant differences between the control measurements and software measurements for cones 1 - 9.5. With no statistically significant differences, the software measurements in this case appeared to be as accurate as the tape measurements. Although the accuracy of the two methods appears to be similar, the software method provided significant advantages over the tape method whereby FIs have the ability to take on the spot measurements of the scene, whilst no longer at the scene, more quickly. This has significant advantages where any item from the scene could be measured in the software later in the investigation, perhaps an item that was not deemed relevant at the time of the investigation. Tape measurements would often not allow for the investigator to return to the scene and take the measurement.

3.3.5.2 Interior Environment

The mean control measurement for the base of the cones was 13.2 cm, with a standard deviation of 0. Table 3.11 presents the mean cone base measurements taken using the SceneCenter software for cones 1 -10 placed respectively at 1 -10 meters away from the central position compared to the mean tape measurements. The measurements quoted by the software are presented in metres but for the purpose of comparison with the tape measurements, these have been converted into centimetres.

Table 3.11: Mean Tape and Mean Software measurements obtained for cones 1-10 with centimetre difference and % error – Interior Environment

	Cone Base Measurement			
Cone Number	Mean Tape Measurement / cm	Mean Software Measurement / cm	Difference / cm	% Error
1	13.20	13.00	0.20	1.52
2	13.20	12.90	0.30	2.27
3	13.20	13.00	0.20	1.52
4	13.20	12.90	0.30	2.27
5	13.20	12.60	0.60	4.55
6	13.20	12.80	0.40	3.03
7	13.20	12.60	0.60	4.55
8	13.20	12.70	0.50	3.79
9	13.20	12.40	0.80	6.06
9.5	13.20	13.60	0.40	3.03
10	--	--	--	--

Due to previously determining the measurement range to be a maximum of 10 metres, this investigation only utilised ten 1-metre apart cones. Table 3.11 demonstrates the measurements obtained using the software application for the base of cones 1-10 compared to the control cone base measurement of 13.20 cm. The table demonstrates that all of the software cone base measurements from 1-9.5

fluctuated from the control measurement, with accuracy of the measurements diminishing the further away from the central point that the cone became. When compared to the control measurements differences ranged from 0.20 to 0.80 cm. The calculated percentage error for cones 1 – 9.5 range from 1.52 % to 6.06 % showing the percentage or error increasing the further away the cone or measurement becomes. This demonstrated that the accuracy of the measurement diminished as the cone became further away from the central position. In this case, due to the internal unit limit of the software, previously described in 2.3.5.1, the overall cone base measurements using the software would round to 0.12 or 0.14 m giving an overall difference range of +/- 1 cm. As a result of rounding within the software all measurements will have a limit of accuracy of +/- 1 cm.

3.3.5.2.1 Data Analysis

Due to the absence of normally distributed data sets, a Mann Whitney U-test was used to determine whether any statistically significant differences were present between the base cone measurements using a tape measure and the software application in an interior environment. The results suggest that there were statistically significant differences between some of the cone tape and software measurements ($p \leq 0.05$), but the majority of the data sets did not demonstrate statistically significant differences ($p > 0.05$). Table 3.12 demonstrates where the statistically significant differences occurred and what their effect size was.

Effect sizes were calculated using Cohen's r and ranged from very small ($r = 0.000$) to large ($r = 0.588$), according to Cohen's guidelines, for cones 1 – 9.5. Statistically significant differences were apparent between the control measurements and software measurements for Cone 5, Cone 7 and Cone 9, with large effect sizes; 0.487, 0.487, and 0.588 respectively. Significant differences were more apparent between the cones, which were placed further away from the central position; Cones 5, 7 and 9. As a result, and due to the cone base measurements being the same with a tape measure, we can conclude that the accuracy of the software is likely to deteriorate the further away from the central point the measurement becomes As discussed earlier, the rounding within the software means that all measurements will have a limit of accuracy of +/- 1 cm.

Table 3.12: P values and effect sizes for the Control cone base measurements compared with software cone base measurement for the interior environment

Cone Number	Control Cone Base Measurement VS Software Cone Base Measurement	
	P value	Effect Size
1	1.000	0.000
2	0.317	0.224
3	1.000	0.000
4	0.317	0.224
5	0.029*	0.487
6	0.146	0.325
7	0.029*	0.487
8	0.134	0.335
9	0.009*	0.588
9.5	1.000	0.000

** = statistically significant differences*   *= large effect size*

The accuracy of this technology is frequently reported by the manufacturer. However, details of the experimental work used to support the margin of error are often not transparent, and therefore it is difficult to establish the reliability of such data. This research has experimentally proved that the technology is accurate to +/- 1 cm within a 10-metre radius. The accuracy of the system is not readily available to the public. For a photogrammetry application, +/- 1 cm is very good in terms of accuracy considering the limit that the pixels within the image present. In comparison, laser scanners are known to be more accurate than photogrammetry applications and can have accuracy limits of +/- 6mm, when used correctly (Shanbari *et al*., 2016). Some authors have differentiated the effectiveness and accuracy of laser scanning to photogrammetry applications whilst others suggest a complementary approach using both methods simultaneously to exploit the advantages of each technique (Barazetti *et al.,* 2012; Buck *et al*., 2011; Buck *et al.*, 2013). Barazzetti *et al.* (2012) stated that although laser scanning is better for measuring surfaces in space, photogrammetry is a more appropriate method for capturing smaller details, highlighting the complementarity of techniques to achieve the best possible reconstruction of scenes.

Considerable research has been conducted into the accuracy of laser scanning systems for crime scene documentation. Boehler and Marbs (2003) conducted a large-scale comparison of the accuracy of measurements taken using 13 laser scanning systems, scanning different surface types and materials at different ranges. Laser scanners can provide larger ranges than the Spheron SceneCam system, which has a maximum measurement range of 10 metres. However, these laser scanning systems can come at a much higher cost (Shanbari *et al.*, 2016). Boehler and Marbs (2003) determined that laser scanners can show significant errors under certain conditions and as a result other aspects of the laser scanner should be taken into consideration as well. For example, some laser scanning systems have issues when trying to scan black areas, as the laser is absorbed and not returned to the scanner. This can be problematic when trying to capture black cars, the road surface or wet road surfaces at vehicle collision scenes. Areas that are not captured by the laser scanner produces missing data within the point cloud and objects directly in the lasers line of sight can produce shadows or occlusions where information behind cannot be captured by the laser scanner (Shanbari *et al.,* 2016).

3.3.5.3 Comparison of Exterior and Interior environments

The data obtained from both the exterior and interior environments were compared to determine whether the different environment had an effect on the accuracy of the resultant measurements. The main differences between the two environments concerned the lighting conditions, whereby lighting could be controlled in the indoor environment but where lighting in the outdoor environment was subject to weather conditions at the time of the investigation.

Due to the absence of normally distributed data sets, a Mann Whitney U test was used to determine whether any statistically significant differences were present between the measurements taken on the software indoors or those taken outdoors. The statistical analysis was conducted to determine whether an exterior or interior environment affected the resultant cone measurements. Table 3.13 demonstrates where the statistically significant differences occurred and what their effect size was.

Table 3.13: P values and effect sizes for the comparison of the exterior and interior cone base measurements

Cone Number	Exterior Cone Base Measurement VS Interior Cone Base Measurement	
	P value	Effect Size
1	1.000	0.000
2	0.739	0.224
3	1.000	0.000
4	0.739	0.224
5	0.143	0.487
6	0.481	0.325
7	0.143	0.487
8	0.684	0.121
9	0.043*	0.505
9.5	0.353	0.240

** = statistically significant differences* *= large effect size*

Effect sizes were calculated using Cohen's r and ranged from very small (r = 0.000) to large (r = 0.505), according to Cohen's guidelines, for cones 1 – 9.5. The results suggest that the majority of the data showed no statistically significant differences between the exterior and interior measurements ($p \geq 0.05$). Therefore, in these cases, the environment had no statistically significant affect on the cone base measurements. Results demonstrated that a statistically significant difference ($p \leq 0.043$) between the exterior and interior environment was apparent for Cone 9 ($p \leq 0.05$) with a large effect size (r = 0.505).

Due to the lack of statistically significant differences one can conclude that the environment; exterior and interior has very little effect, if any, on the resultant measurements and therefore the environment should not be considered a factor to consider when taking measurements using this equipment. The lighting conditions in each environment did not adversely affect the resultant measurements.

3.3.6 Resolution

Table 3.14 presents the measurements obtained for the base of the cones using the software application for cones 1-10 at low, medium, high and maximum camera resolutions. The resolution of the image refers to the number of pixels within that image. The pixel numbers for each of the resolutions are: Low (1,500 x 750 pixels), Medium (3,000 x 1,500 pixels), High (6,000 x 3,000 pixels) and Maximum (12,000 x 6,000 pixels).

It is clear to see in Table 3.14 how the measurement accuracy declines as the cone number increases, and therefore as the distance away from the camera increases. The control cone measurement was 13.20 cm. The software produced measurements of 12.90 cm, 12.70 cm, 13.00 cm and 13.00 cm for Cone 1 at low, medium, high and maximum resolutions, respectively. Although differences to the control are apparent, these were only small with a maximum difference of 0.05 cm (5 mm). For Cone 1, the measurements taken at the High and Maximum resolutions produced the most accurate measurements out of all of the resolutions. In addition, the high and maximum resolutions maintained greater accuracy throughout all of the cone measurements when compared with the low and medium resolution scans.

Resolution of a camera refers to the cameras ability to classify and effectively present information such as detail and textures within an image. The greater the number of pixels within an image, the more detailed the picture information and therefore the higher the resolution. The higher the resolution the smaller the angle of separation between adjacent pixels. Higher resolution images result in more pixels covering a particular area and therefore more detail (Eismann *et al.,* 2010; Jacobs, 2012). Figure 3.20 shows the same scene but each taken at a different resolutions; low, medium, high and maximum, using the SceneCam. Observing these images at first glance, there may not seem like there is any noticeable difference, only that the low resolution one may be more blurry than the others. Figure 3.21 demonstrates taking a measurement at the cone base at each resolution option to convey the extent to which the software allows zooming in. The greater resolutions provide the ability to zoom in to a greater extent than the lower resolutions because the higher resolutions contain a greater number of pixels and more detail can be generated as a result. As a result, higher resolutions provide a closer view of the object to be measured with more detail for selecting the exact points to measure to and from.

Table 3.14: Mean Cone Base Measurements for Low, Medium, High and Maximum resolution panoramas

Resolution	Mean Cone Base Measurement / cm										
	1	2	3	4	5	6	7	8	9	9.5	9.75
Low	12.9	13.0	13.2	13.8	12.9	14.6	16.8	23.5	29.5	29.6	18.3
Medium	12.7	12.8	12.7	12.7	12.7	12.5	12.7	14.1	21.3	15.7	16.5
High	13.0	13.0	13.0	13.0	13.0	12.4	12.5	12.9	12.4	13.7	12.6
Maximum	13.0	12.9	13.0	12.9	12.6	12.8	12.6	12.7	12.4	13.6	12.0
Control	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2

Figure 3.20: Different resolution panoramas taken using the SceneCam. Left to right: Low, medium, high and maximum resolution.

Figure 3.21: The extent to which the software zooms in prior to taking measurements at each resolution setting. Left to right: Low, medium, high and maximum resolution.

The higher resolution panoramas produced more accurate results and this can be attributed to the greater detail within the image. The higher resolution images; maximum resolution demonstrated 12,000 x 6,000 pixels and the high resolution demonstrated 6,000 x 3,000 pixels. These higher resolution images contain more pixels per inch (PPI) of the overall image. As a result, more pixels cover a particular area of detail within the image and allow a greater choice of pixels and detail when selecting an exact pixel to measure from. For example, when measuring the cone base from edge to edge, a maximum resolution image allows a greater array of pixels to select allowing the user to determine the exact corner of the cone base. A low-resolution image will have fewer pixels representing a particular area and so one whole corner of the cone base and some of the floor could be one pixel, limiting the area for selection to generate a measurement. The measurements taken will use the centre of the selected pixel and in this case, the measurement could seem greater than it is due to the lack of detail. In such conditions, the selection of the correct pixel makes a comparatively larger difference on the resultant measurements.

The accuracy of calculated distances will ultimately depend on two fundamental factors. The first factor is the calibration accuracy of the lens, which will have been conducted during manufacture, and the user will have little control over. The second factor concerns the user accuracy of feature identification and the ability to correctly select the two points (or pixels) to measure from (Hu *et al.*, 2008).

3.3.6.1 Data Analysis

Due to the absence of normally distributed data, non-parametric statistical tests were used to determine whether any statistically significant differences were apparent between the data sets. Table 3.15 presents the p values for the comparisons of the cone measurements for each of the resolutions, low, medium, high and maximum respectively. Results from a Kruskal Wallis test showed that some of the resolutions demonstrated the presence of statistically significant differences ($p < 0.05$) as shown in Table 3.15.

Table 3.15: P values for the comparison of Low, Medium, High and Maximum resolution photographs – cone base measurements

Cone Number	Measurements of Cones compared for low, medium, high, and maximum resolution to the control P value
1	0.090
2	0.675
3	0.069
4	0.456
5	0.503
6	0.039*
7	0.074
8	0.000*
9	0.011*
9.5	0.258

** = statistically significant differences*

The statistically significant differences were apparent between the resolutions for Cone 6, 8 and 9. Post hoc pairwise comparisons were conducted to determine which resolutions were significantly different. Table 3.16 presents the pairwise comparisons conducted and their p values and effect sizes.

Table 3.16: P values and effect sizes for the comparison of the exterior and interior cone base measurements for each pair comparison for resolution

Cone Number	Resolution of Images	Exterior Cone Base Measurement VS Interior Cone Base Measurement	
		P value	Effect Size
6	Low Vs. Medium	0.048*	0.440
	Low Vs. High	0.023*	0.509
	Low Vs. Maximum	0.062	0.417
	Medium Vs. High	0.737	0.417
	Medium Vs. Maximum	0.298	0.233
	High Vs. Maximum	0.075	0.398
8	Low Vs. Medium	0.002*	0.688
	Low Vs. High	0.000*	0.824
	Low Vs. Maximum	0.000*	0.847
	Medium Vs. High	0.644	0.103
	Medium Vs. Maximum	0.514	0.146
	High Vs. Maximum	0.476	0.159
9	Low Vs. Medium	0.285	0.252
	Low Vs. High	0.067	0.432
	Low Vs. Maximum	0.067	0.432
	Medium Vs. High	0.005*	0.621
	Medium Vs. Maximum	0.005*	0.621
	High Vs. Maximum	0.562	0.130

** = Statistically significant differences* *= large effect size*

Results showed that the differences were mainly occurring between the low resolution and the high/maximum resolutions. This result demonstrates that the larger differences were occurring between the highest and lowest resolution images. The accuracy of measurements taken between these two resolutions is likely to be different due to the number of pixels covering a particular area of detail within the image. The lower resolution image will contain fewer pixels covering the corner of the orange cone, whereas the maximum resolution image will have a greater number of pixels covering the same corner of the orange cone. This will allow the user to select a pixel, which covers the very corner of the cone more accurately. With the lower resolution image, the user may have to select between two pixels that cover the corner of the cone due to the lower number of pixels covering the area, and this could reduce the accuracy of any measurement (Figure 3.22). Practically, if SOCO's are to use this equipment for taking measurements, it would be advisable to capture the scene at the maximum resolution possible to ensure the most accurate measurements can be taken owing to the greater level of detail attributed to the greater number of pixels covering a particular area to be measured.

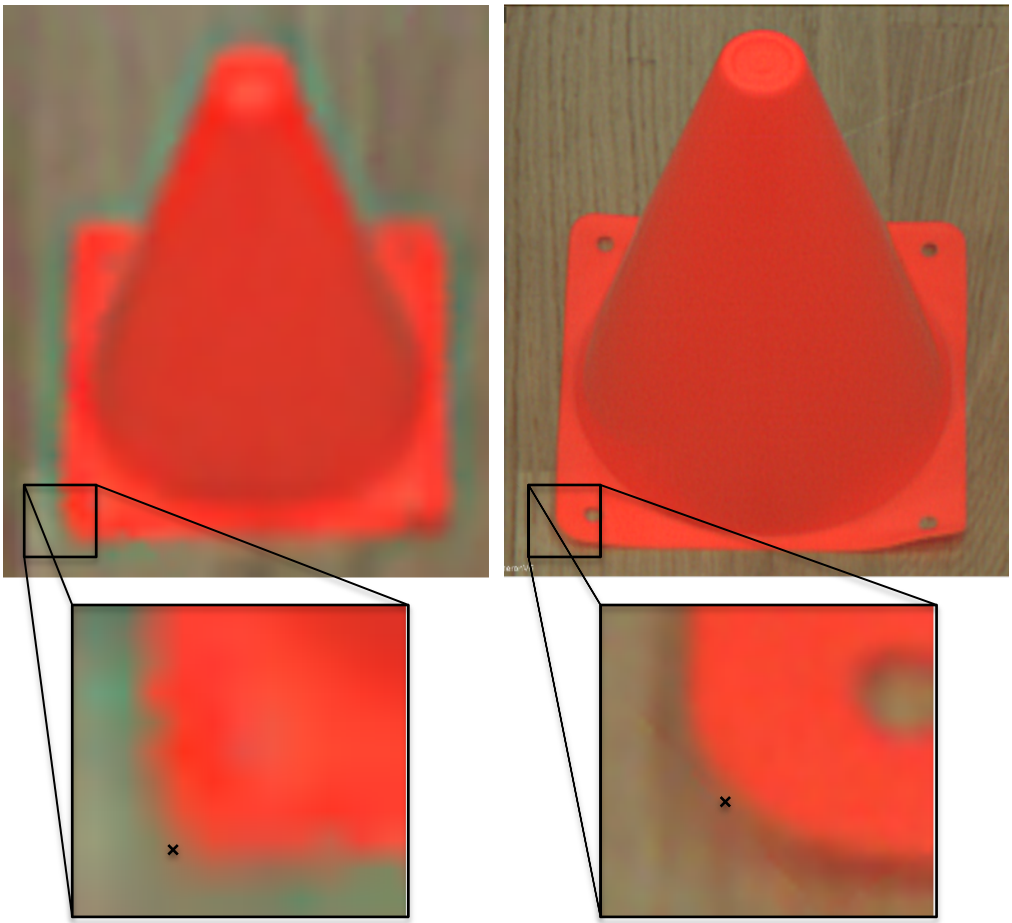


Figure 3.22: Left: Low resolution image capturing the corner of the orange cone with less pixels and therefore less detail. Right: Maximum resolution image capturing the corner of the orange cone with more pixels and therefore more detail.

3.4 Conclusions

3.4.1 Accuracy testing with known measurements

The data showed no statistically significant differences and little or no deviation with the grid square measurements and demonstrated that the photogrammetry software application and 360^{o} camera was accurate for measuring these fixed points as the measurements produced were the same as those of the control tape measure. This investigation highlighted a potential unit limit within the software application, whereby the software quoted any measurement below 2 cm as <2 cm and did not specifically produce a numerical value.

3.4.2 Measuring a scene

This investigation has demonstrated that by utilising target dots to aid with taking measurements with photogrammetry applications where there are featureless walls present facilitated reproducible and more accurate results than by solely measuring blank, featureless walls. Crime scene environments may not allow the use of target dots (potential contamination issues), therefore a laser line could be utilised, which has also been shown to significantly improve reproducibility and accuracy of the measurements made.

3.4.3 Measuring the scene using photogrammetry software

Statistically significant differences were identified between the control measurements, tape measuring and the software measurements ($p \leq 0.05$), particularly between the control and the software measurements ($p \leq 0.016$). Participant derived measurements with the tape measure proved to be more accurate than the software measurements, which ranged from 0.0% to 4.48% differences. The size and shape of the measured items are likely to influence a person's ability to record accurate measurements of them, and each method tested offered advantages and should be used in conjunction. For example, in situations where measurements were considered to be more difficult to take with a tape measure, such as the length of a wall, the software application provided a solution to capture the measurement more easily. In such situations, tape measuring a wall length above and around existing furniture can prove difficult for one person. The use of the software application to take this measurement removes the requirement to measure above and around existing furniture, as the user is only required to 'virtually' select the start and end points to measure. For smaller items with more complex shapes, such as 'bedside tables', it would prove beneficial to use a tape measure in a forensic environment. This study shows the importance of the appropriate use of complimentary measurement techniques in order to accurately capture data that can assist downstream in a forensic-Police enquiry.

The position of the camera within an environment can significantly impact the actual measurements which are obtained using the software with significant deviations in the measurements taken for the same items from four different camera positions. The deviations in measurements between the different camera positions could be attributed to the distance between the camera and the object to be measured. If an object is photographed at close range with full image resolution one might expect a more accurate measurement than an object photographed at long range, which may account for the differences in measurements at different camera positions.

3.4.4 Measurement Range

The software application was unable to measure anything on or past the 10-metre point. This is due to an internal limit within the software, which has been set to ensure measurements cannot be taken past this point as the accuracy of the system diminishes past this point and accuracy cannot be guaranteed. In the context of forensic science and criminal investigations this internal limit has been set to ensure the validity of the system and to prevent the measurement accuracy being called into question in a Court of law. However, the 10 metre limits also present implications for crime scene applications, whereby scenes greater than a 10 metre radius which need measuring will require multiple 360^o photographs to be taken in order to capture the full environment and ensure accurate measurements can be taken. This in itself will add time onto the investigation process and is an aspect to be considered when documenting crime scenes using this technology. Although this will increase the investigation time, this method will still offer a more efficient and quicker solution than manual measurements with the added addition of capturing a 360^o photograph of the crime scene simultaneously. In addition, the accuracy of the measurements diminished the further away from the central point that the measurement became. This could have significant implications on the result of the measurements and therefore an investigation. A rounding effect of the measurements within the software is also likely to produce a limit of accuracy of +/- 1 cm.

3.4.5 Exterior and Interior Environments

Due to the lack of statistically significant differences it can be concluded that the environment; exterior and interior has little effect, if any, on the resultant measurements and therefore the environment should not be considered a factor to consider when taking measurements using this equipment.

3.4.6 Resolution

The resolution of the images had a significant effect upon the accuracy of the measurements with the higher resolution panoramas, producing results of greater accuracy. It was concluded that this greater accuracy at higher resolutions could be attributed to the more defined detail within the image. The higher resolution images contained more pixels per inch of the overall image. As a result, more pixels cover a particular area of detail within the image and allowed a greater choice of pixels and detail when selecting an exact pixel from which to measure. Lower resolution images contained less pixels per inch of the overall image and therefore one pixel could cover far more of a particular area, allowing less detail when selecting an exact pixel to measure from, as the pixel may contain more of the scene. In such conditions, the selection of the correct pixel makes a comparatively larger difference on the resultant measurements.

The accuracy of calculated distances will ultimately depend on two fundamental factors. The first factor is the calibration accuracy of the lens, which will have been conducted during manufacture, and the user will have little control over but should be aware of. The second factor concerns the user accuracy of feature identification and the ability to correctly select the two points (or pixels) to measure from (Hu *et al.*, 2008).

Chapter 4: The Adaptation of a 360^{o} Camera Utilising Alternate Light Sources (ALS) for the Detection of Biological Fluids at Crime Scenes

Preface

Chapter 3 examined the accuracy and precision with which measurements could be taken using the SceneCam and SceneCenter software to validate the technique for use in crime scene documentation. Chapter 3 demonstrated the importance of the appropriate use of complimentary measurement techniques in order to accurately capture data that can assist downstream in a forensic-Police enquiry. In order to facilitate continued use of a particular piece of technology, it is important that it can demonstrate the ability to aid organisations in different environments, or situations and in this case different crime scene environments. Technology development continues to adapt existing technology to provide solutions to current issues and improve the scope of use for technology. This chapter explores the adaptation of the SceneCam utilising alternate light sources to aid in the simultaneous detection and visualisation of biological fluids, which may be encountered at crime scenes to demonstrate the flexibility of such technology for use in multiple disciplines (Linking to specifications in Chapter 2).

4.1 Introduction

Biological fluids, such as blood, semen, saliva, vaginal secretions and urine, are commonly encountered evidence types that can be recovered at crime scenes. They serve as invaluable evidence types given that they contain DNA evidence that may be used to identify individuals present at the scene, including both suspect and victim. Identifying the location and distribution of biological staining within a crime scene can be crucial to the investigation as the location and identity of the fluid may aid Scene of Crime Officers (SOCO's) in reconstructing a sequence of events and determining what may have occurred at the scene (Virkler and Lednev, 2009; Anantrasirichai *et al.*, 2012). Due to the ephemeral nature of this type of evidence, it is fundamental that the evidence is documented extensively and recovered quickly and efficiently. Locating biological fluids can prove a challenging task for FI's as many stains are invisible to the naked eye or are similar in appearance to other extant substances (Vandenberg and Oorschot, 2006; Magalhaes *et al.*, 2015).

4.1.1 Alternate Light Sources

An Alternate Light Source (ALS) typically allows the selection of different wavelengths of light (~ 300 nm (Ultraviolet - UV) – 900 nm (Infrared - IR)) to help visualise evidence, otherwise invisible to the naked eye, based on the response received from the object of interest. An ALS can consist of a light emitting diode (LED) or a laser light source (McClintock, 2014). LED sources often exhibit a range of wavelengths and laser light sources are monochromatic; they exhibit a single wavelength (Auvdel, 1987; James *et al.*, 2005). These wavelengths can be changed within the devices themselves to enable enhancement of different biological fluids. ALS's offer powerful methods that can allow the enhancement and presumptive detection of trace evidence likely to be present at crime scenes (Mahajan *et al.*, 2015) and are one of the simplest methods available for the detection of biological fluids (Miranda *et al.*, 2014). Owing to both their simplicity and non-destructive or non-invasive nature they have been extensively utilised in criminal investigations to aid FI's in determining the location of trace evidence at crime scenes, particularly where limited sample quantities are exhibited (Lennard and Stoilovic, 2004; Powers and Lloyd, 2004; Virkler and Lednev, 2009).

4.1.2 The Electromagnetic Spectrum

Electromagnetic Radiation (EMR) is a form of energy comprising both electrical and magnetic energy and moves through space as waves (Lennard and Stoilovic, 2004). Figure 4.1 depicts a typical wavelength design. Wavelength (λ) is the distance between the peaks of each single wave; crest to crest and is measured in nanometers (nm) (Marin and Buszka, 2013). Frequency, f, is the number of waves (crests) which pass a fixed point per second (Hz) (Marin and Buszka, 2013).

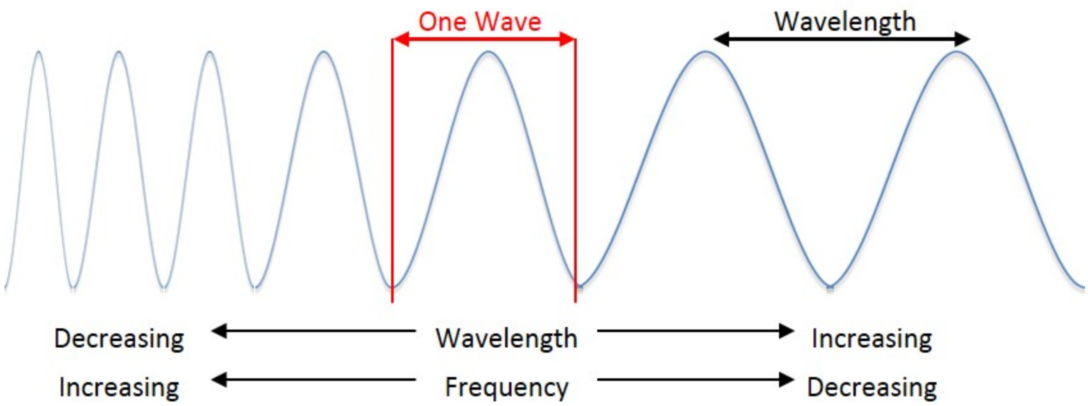


Figure 4.1: A diagram showing the composition of electromagnetic waves

The electromagnetic spectrum is illustrated on a linear scale with increasing wavelength (Figure 4.2) (Breeding, 2008). Electromagnetic radiation exhibits a wave like form and can be divided into different categories; gamma rays, and X-rays, which have a short wavelength; UV radiation, visible light, IR radiation, thermal radiation, radio waves and microwaves, which have a longer wavelength (Marin and Buszka, 2013; Robinson, 2016). Light is a form of electromagnetic radiation and can be in the form of sunlight or artificial light (Baxter Jr, 2015).

The visible range of the electromagnetic spectrum forms only a very small part of the entire spectrum and is the only part that the human eye can physically see without a sensor aid (Fardo and Patrick, 2009; Marin and Buszka, 2013; Baxter Jr, 2015). Visible or white light comprises the colours violet, blue, green, yellow, orange and red and exhibits wavelengths between 400 nm and 700 nm (Lennard and Stoilovic, 2004; Fardo and Patrick, 2009; Marin and Buszka, 2013; The different colours exhibited by the visible spectrum correspond to different wavelengths and frequencies (Figure 4.2). For example, blue light has a shorter wavelength but higher frequency and greater energy than red light, which in contrast has a longer wavelength and lower frequency (Marin and Buszka, 2013). Light below the visible spectrum less than 400 nm is the UV region, which exhibits wavelengths of 100-400 nm (Robinson, 2016). Light above the visible spectrum greater than 700 nm is the IR region (Robinson, 2016). Both UV and IR radiation are not visible to the naked eye and a detector is required to aid visualisation (Lennard and Stoilovic, 2004).

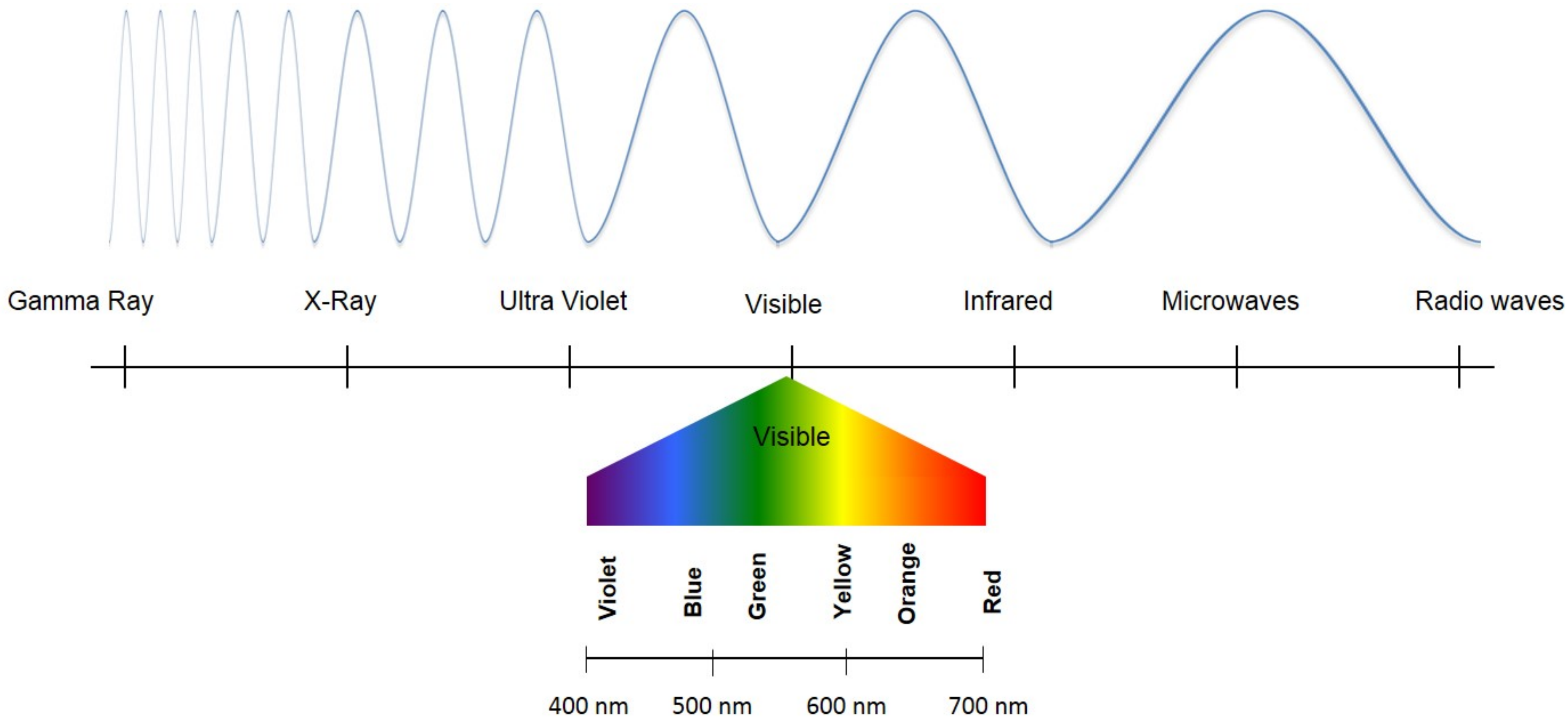


Figure 4.2: The Electromagnetic Spectrum

4.1.3 Using Alternate Light Sources to Detect Biological Fluids at Crime Scenes

An UV source or an ALS emitting blue light can induce fluorescence of naturally occurring chemicals present in particular biological fluids such as semen and saliva (Auvdel, 1987; Lee and Khoo, 2010). UV light exhibits wavelengths between 100 and 400 nm on the electromagnetic spectrum (Robinson, 2016). Different substrates or surfaces that the biological fluid is deposited on may obscure the visualisation of the target staining, as the surface itself may have inherent fluorescent properties and therefore the background could fluoresce and mask the target staining (Auvdel, 1987; Lloyd, 1977; Kobus *et al.*, 2002; Marin and Buszka, 2013). Other light sources enhance the contrast of the evidence against the background to visualise the biological evidence (Lennard and Stoilovic, 2004; Bell, 2012; Marin and Buszka, 2013).

Fluorescence is an emission of light, which occurs when light of a short wavelength is absorbed by a material, and subsequently emitted at a longer wavelength and this phenomenon is referred to as a Stokes Shift (Kobus *et al,* 2002; Wawryk and Odell, 2005; Virkler and Lednev, 2009; Marin and Buszka, 2013; McClintock, 2014). The emitted light has a weak intensity in comparison to the incident light (Lennard and Stoilovic, 2004) and as a result it is necessary to observe any fluorescence through a barrier filter and goggles (Kobus *et al.,* 2002; Lennard and Stoilovic, 2004; Marin and Buszka, 2013). Barrier filters and goggles block out any incident light from the source allowing only selected fluorescent emissions from the target evidence to pass and minimises background fluorescence (Kobus *et al.,* 2002; Marin and Buszka, 2013). This allows visualisation of only the fluorescence emitted by the target evidence (McClintock, 2014). For example if the visible light beam is blue, a yellow or orange filter will block the intense blue light but will allow the weak fluorescence to pass through and be visualised (Robinson, 2016) as shown in Figure 4.3.

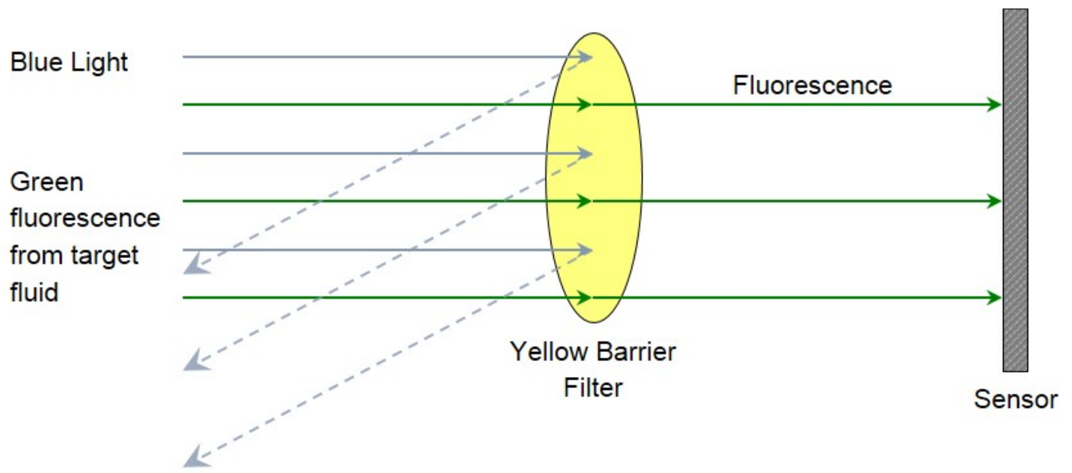


Figure 4.3: Band pass filter operation. Yellow barrier filter blocking out the blue light, allowing only the fluorescence from the target fluid to reach the sensor.

Fluorescence occurs instantaneously upon illumination by a light source and ceases immediately when the light source is removed (Baxter Jr, 2015). Fluorescence can be induced in a material by more than one particular wavelength (Su, 2015). Tuneable light sources allow a SOCO to select the wavelength of light required to induce fluorescence from the target evidence and change barrier filters to enhance the evidence against its background (Marin and Buszka, 2013). Different wavelengths and barrier filters can be combined to create the optimum combination that will allow the stain to be enhanced and visualised (Marin and Buszka, 2013).

Wawryk and Odell (2005) conducted research into the detection of biological stains and other stains on skin, observing fluorescence induced by an ALS. In their research various body fluids, lubricants and moisturisers were placed onto volunteers forearms and the area illuminated using an ALS with wavelengths between 370 and 500 nm. Results produced from investigations conducted by Wawryk and Odell (2005) found that no fluorescence was visible from any of the substances in the majority of volunteers but semen and urine did fluoresce faintly when more powerful light sources were used. As a comparison, the researchers applied semen to cloth and results showed fluorescence at expected wavelengths. Warwyk and Odell (2005) demonstrated that ALS's are useful for the identification of stains on clothing but are still limited in their detection of stains on skin.

Research has been conducted into the effects of light sources for the detection of biological fluids. It is critical for any subsequent DNA analysis that the methods used to locate biological fluids is non-destructive. Nicholson *et al*. (2005) conducted research to determine the effects of UV light on DNA analysis. Concerns have been raised as to the effects of UV exposure to the often limited biological material contained in many biological samples. Results indicated that DNA analysis was most affected by long exposure times to UV, approximately three minutes. This prolonged exposure resulted in poor recovery of DNA and increased allelic dropout, which is thought to have been due to degradation of the biological sample (Nicholson *et al*., 2005). Research conducted by Anderson and Bramble (1997) demonstrated that exposure to 255 nm light for thirty seconds or more damaged DNA so much that no DNA was detected during subsequent analysis (Virkler and Lednev, 2009). High doses of UV radiation can cause structural disintegration of DNA (Chen *et al*., 2017). As a result, light sources which exhibit UV wavelengths needs to be used with caution to prevent any damage to DNA within the forensic evidence (Virkler and Lednev, 2009).

4.1.3.1 Semen

Semen is one of the biological fluids that is commonly encountered at crime scenes and is more commonly found at scenes where sexual assault has occurred. Semen is known to fluoresce when exposed to certain wavelengths of light (Magalhaes *et al*., 2015). Stoilovic (1991) demonstrated that the fluorescence excitation spectrum of dried semen was broad and fluorescence could be induced with excitation wavelengths between 300 to 480 nm (Vandenberg and Oorschot, 2006).

A Woods Lamp (WL) is a device which can emit wavelengths from 320-400 nm and has been utilised extensively for the detection of semen at crime scenes (Virkler and Lednev, 2009; Nelson and Santucci, 2002). In 1919, the Woods Lamp was reported to have fluoresced semen but the effectiveness of this light source has since been challenged with some authors deeming it to be ineffective due to false positives (Magalhaes *et al.*, 2015; Fiedler *et al.,* 2008). Research has suggested that when the WL was tested against other fluids such as lotions, false positives were produced and in cases where semen was present, the lamp had failed to detect it (Santucci *et al.*, 1999; Magalhaes *et al.*, 2015).

Kobus *et al.* (2002) identified that the most significant factor when detecting semen stains using ALS's to induce fluorescence, was the nature of the material on which a stain had been deposited. Results demonstrated a high degree of difficulty in detecting semen stains on materials which were dark in colour, highly absorbent, or made of a material which itself was naturally fluorescent. Issues also arose in the detection of semen in situations involving detergents and fabric conditioners which are known to contain organic compounds, such as brighteners, some of which have fluorescent properties and cause materials to fluoresce under UV light, thus masking the biological staining (Auvdel, 1987; Lloyd, 1977; Vandenberg and Oorschot, 2006).

4.1.3.2 Saliva

Saliva is an important piece of biological evidence at crime scenes, and is more predominant in cases where biting, sucking, kissing or licking has occurred and could leave DNA evidence behind (Nanda *et al.,* 2011). As a result, it is essential that any saliva evidence is detected and documented. Due to its inherent properties, saliva can prove a difficult biological fluid to detect as it can appear almost invisible to the naked eye (Camilleri *et al.,* 2006; McClintock, 2014). ALS's can provide methods for the detection and visualisation of saliva (Camirelli *et al.,* 2006; Vandenberg and Oorschot, 2006). Under UV light saliva stains appear as bluish white staining (Virkler and Lednev, 2009). Saliva is harder to detect than semen due to the lack of particulates within the saliva sample (Virkler and Lednev, 2009) and is known to fluoresce at a lower intensity than semen (Camirelli *et al.*, 2006).

Camilleri *et al.* (2006) found that the optimal contrast for the visualisation of saliva stains on white cotton surfaces was achieved through an excitation wavelength of 470 nm using interference goggles of 555 nm when using a Polilight. Results showed that fabric type had no influence on the detection of the saliva stains but different fabric colours and designs did obscure the saliva stains fluorescence. A study conducted by Soukos *et al.* (2000) demonstrated an excitation peak for saliva at 282 nm however the study only limited the wavelength band to 200 – 320 nm. Auvdel (1987) used an argon ion laser to successfully locate saliva samples using wavelengths which ranged between 454.5- 514.5 nm. Auvdel reported that the use of an argon ion laser increased the detection rate of saliva by 9 % when compared to detection rates utilising a UV light source (Auvdel, 1987; Vandenberg and Oorschot, 2006). It was believed that the increase in success rate using the laser was attributed in part to the lasers higher intensity of radiation when compared to the light source (Auvdel, 1987; Vandenberg and Oorschot, 2006).

4.1.3.3 Blood

Blood is one of the most common biological fluids encountered at crime scenes and the subsequent visualisation and documentation of bloodstains is an integral aspect of criminal investigations (De Forest *et al.,* 2009). Bloodstains can be encountered at a range of different crime scenes relating to different crime types e.g. shooting, assault, aggravated burglary, suicides, and unexpected deaths. Identifying the location and identity of bloodstaining is integral for reconstructing the crime scene and determining the sequence of events, which may have occurred (Bevel and Gardner, 2012). The detection of bloodstains at a crime scene can be dependent upon the type of substrate onto which the fluid has been deposited (Barni *et al.,* 2007; De Forest *et al.*, 2009). Dark surfaces can prove problematic when visualising blood stains which are already dark to the observer due to the lack of contrast (Shaler, 2002; McQuistin, 2006; De Forest *et al.,* 2009). Methods for the enhancement and visualisation of bloodstains can include presumptive tests such as chemical enhancement, light source enhancement and IR photography. Chemical methods can include the use of Luminol or BlueStar. These methods rely on a chemiluminescent reaction whereby haemoglobin and derivatives within blood enhance the oxidation of the chemical reagent; Luminol or Bluestar, and emit light (Virkler and Lednev, 2009) as demonstrated in Figure 4.4.

Chemiluminescence is the emission of light produced as a result of a chemical reaction (Barni *et al.,* 2007; Baxter Jr, 2015). In the presence of human or animal blood, the light emitted from the chemiluminescent reaction of Luminol based reagents ranges from blue-violet to blue-green exhibiting a wavelength of approximately 455 nm (Hetzel, 1991; Barni *et al.,* 2007). The suspected area is sprayed with the aqueous solution and observed for a chemiluminescent reaction (Hetzel, 1991). Luminol appears to be one of the most popular chemiluminescent reagents due to the lack of false positives and false negatives produced when compared to other reagents (Quickenden and Creamer, 2001; Luczak *et al.*, 2006; Barni *et al.,* 2007). This method however has proved to be destructive to any DNA present and over spraying of the target area can dilute the bloodstains (Bray *et al.*, 2004; Quinones *et al.*, 2006). In addition, the Luminol based reagents are sensitive to ambient light and must therefore be used in complete darkness (Barni *et al.,* 2007). Other chemiluminescent reagents have been trialled over Luminol due to the potential irritant and harmful effects, which this reagent provides, including the Luminol based reagent BlueStar that has less harmful effects (Barni *et al.*, 2007).

Photographing chemiluminescent reactions can prove challenging due to the short lived nature of the reaction and the low light levels which require long photographic exposures in order to capture the chemiluminescence (Hetzel, 1991; Courtney *et al*., 1996; Cheyne, 2011; Marsh, 2014).

In 2007, Lin *et al.* suggested using IR light as a non-destructive means for identifying latent bloodstains. Infrared radiation/light is invisible to the naked eye and to camera Charged Couple Device (CCD) sensors. As a result it is necessary to have a camera sensor that is sensitive to IR radiation (*See 4.1.4 Photographing Biological Fluids subjected to Alternate Light Sources*). Research conducted by Lin *et al.* (2007) detected dilute bloodstains on black fabrics subjected to IR light and photographed using a digital camera with an IR sensitive CCD. This method allowed quick searching of a crime scene for bloodstains whilst preserving any DNA present (Lin *et al.,* 2007). This technique was ineffective on certain fabric types such as black fabric samples, but has proven to be a beneficial method due to its non-destructive nature (Lin *et al.,* 2007). Raymond and Hall (1986) also demonstrated that the success rate for the detection of bloodstains using IR photography was dependent upon the substrate on which the fluid had been deposited. Albanese and Montes (2011) demonstrated that using near infrared (NIR) bloodstains could be detected up to dilutions of 1/16 on black fabrics. Research has since demonstrated that IR is a valuable tool for evaluating bloodstains on dark surfaces (Gardner, 2012). Light source enhancement and IR photography provide significant advantages over chemical enhancement methods as they provide a non-destructive and non-invasive method for the detection of blood at crime scenes whereby no chemical alteration is required to visualise the bloodstain (De Forest *et al.,* 2009).

Figure 4.4: Luminol chemiluminescent reaction on blood. Taken from Gardner (2012).

4.1.4 Photographing Biological Fluids subjected to Alternate Light Sources

Once visualised, it is integral that the biological fluid evidence is thoroughly documented in a manner that captures its location and distribution as it was at the time of the investigation. Digital photography allows the SOCO to document both the scene and the evidence and present it to a judge and jury in a courtroom in a simple and detailed manner (Marin and Buszka, 2013). Standard digital cameras have a lower dynamic range than the human eye and as a result photographs can appear under or overexposed in comparison. Evidence that has been enhanced using ALS's needs to be efficiently recorded as seen by the SOCO. Where ALS photography is utilised, fluorescence filters can be fitted over the existing camera lens to block the excitation wavelength of light and allow the camera to capture a response from the target substrate (Albanese and Montes, 2011). The use of an ALS can increase the time taken to process the crime scene. 360^{o} photography can capture a full panorama of a scene in one scan, conveying spatial relationships of evidence within the scene, ensuring the entire scene is captured rather than only those items deemed relevant at the time by the SOCO.

Digital cameras record an environment by capturing the light that is either transmitted or reflected into the camera sensor called a Charged Couple Device (CCD) (Albanese and Montes, 2011). The CCD sensor is located behind the focussing mirror and a filter is located between the sensor and the lens, often referred to as a 'hot mirror' (Albanese and Montes, 2011; Marin and Buszka, 2013) as shown in Figure 4.5. The hot mirror is present within the camera as it acts as a barrier to the sensor, protecting it from dust that can collect when lenses are changed frequently (Marin and Buszka, 2013). A hot mirror's purpose is to block out particular wavelengths of light, which could affect the quality of the resultant photograph particularly infrared light (Albanese and Montes, 2011; Marin and Buszka, 2013). Most camera hot mirrors are designed to block out radiation in the UV (350 nm and below) and IR (750 nm and above) ranges whilst allowing visible light to pass and be recorded on the sensor, forming an image (Marin and Buszka, 2013).

Particularly where IR photography is concerned, it may be necessary to remove the hot mirror from the sensor to allow the camera to capture radiation from the IR radiation source. In addition, it may be necessary to capture UV responses. Removal of the hot mirror enables the camera to become a 'full spectrum' camera whereby it can detect radiation across the whole of the spectrum, as UV and IR are invisible to the naked eye (Robinson, 2016). Marin and Buszka *(*2013) stated that as of 2013 there were no commercially manufactured cameras, which had the hot mirror, removed. A camera, which had the hot mirror removed; the Fuji S3 Fine Pix Pro IRUV, was in production by Fujifilm for a short period of time but has since been discontinued. In 2015, Fujifilm released a newly optimised full spectrum mirrorless digital camera, capable of photographing both UV and IR wavelengths; the Fujifilm X-T1 IR.

Where ALS photography is utilised filters can be fitted onto the existing lens to block specific wavelengths of light allowing the camera to capture a response from a substance based on the radiation being used (Lennard and Stoilovic, 2004; Albanese and Montes, 2011). Filters that are placed over the camera lens are referred to as barrier filters (Lennard and Stoilovic, 2004). Barrier filters block the reflected light which originated from the incident light source, allowing only the fluorescent response light to pass through and be captured with the camera (Kobus *et al.*, 2002; Gardner, 2005; Marin and Buszka, 2013; Su, 2015). The selection of an appropriate filter can be chosen using a colour wheel whereby opposite colours on the wheel are complimentary and will enhance the contrast of the evidence against its background (Lennard and Stoilovic, 2004; Baxter Jr, 2015) as shown in Figure 4.6. For example, if a blue light source was being used to detect the biological fluid, an orange filter would be needed for the camera lens. Different coloured barrier filters will block out different wavelengths of light and it is important to select a wavelength and corresponding barrier filter to allow visualisation of the evidence (Su, 2015). The wrong barrier filter may allow the incident light to pass through the filter into the camera sensor and this can mask any target fluorescence.

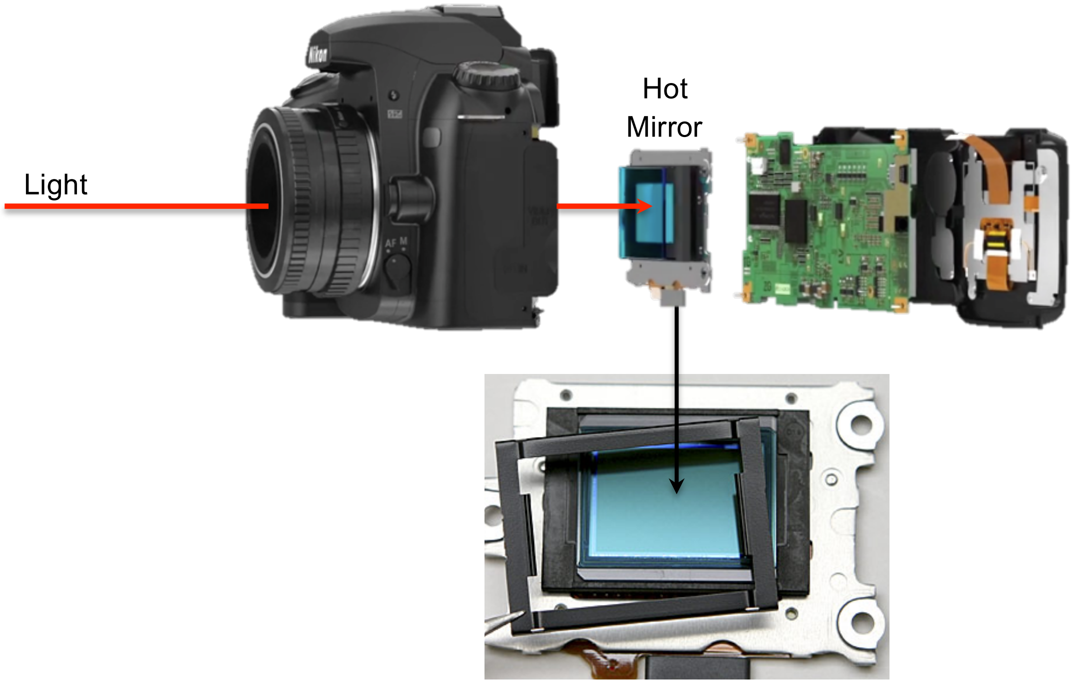


Figure 4.5: Hot mirror to block IR/UV light situated within a digital single lens reflex (DSLR) camera. Adapted from Life Pixel Infrared (2017).

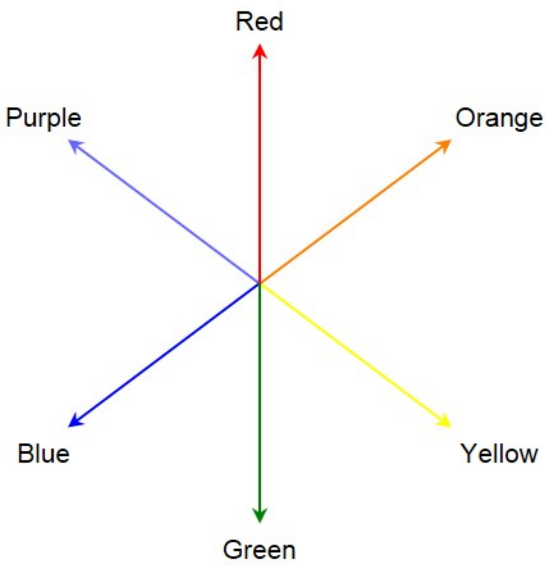


Figure 4.6: The colour wheel for the selection of appropriate barrier filters.

4.1.4.1 High Dynamic Range Imaging

Standard digital cameras have a lower dynamic range than that present in the real world and as a result photographs can appear under or overexposed in comparison with what the human eye can detect. Dynamic range can be defined as the ratio between the lightest (white) and darkest (black) pixel within an image (Reinhard *et al.*, 2012; Mantuik *et al.,* 2016). Multiple exposures of the same image can be combined into one High Dynamic Range (HDR) image (Albanese and Montes, 2011; Reinhard *et al.,* 2012; Anantrasirichai *et al.,* 2012). HDR images contain pixels, which represent a greater range of colours and more accurate luminance levels which appear more realistic (Albanese and Montes, 2011; Mantuik *et al.,* 2016). Classic HDR methods combine several low dynamic range (LDR) images of varying exposures to create one HDR image which selects the best exposure for each pixel and recreates the image (Mertens *et al.*, 2009; Albanese and Montes, 2011; Hafner and Weickert, 2015). To photograph detail in dark areas, high exposures are required and to capture detail in bright areas, which may become 'bleached out', low exposures are needed. As a result it is often impossible to capture both of theses aspects within one single photograph using a standard digital camera, as they are LDR (Narasimha and Batur, 2015). HDR images represent a greater range of luminance levels and can visualise both very bright areas such as direct sunlight, to very dark areas such as shade in one photograph (Albanese and Montes, 2011; Narasimha and Batur, 2015). Often HDR images cannot be displayed on standard monitors that provide limited contrast and colour reproduction and therefore the HDR images need compressing. This can be achieved through tone mapping which aims to preserve the original scene appearance, maintaining the contrast and colour representation through combining multiple LDR images together (Narasimha and Batur, 2015; Mantuik *et al.,* 2016). In contrast, real time automatic HDR photography captures a fully HDR image automatically as shown in Figure 4.7.

Evidence that has been enhanced using ALS needs to be efficiently recorded as seen by the SOCO. Where ALS photography is utilised filters can be fitted over the existing camera lens to block specific wavelengths of light (as detailed in *4.1.4 Photographing Biological Fluids subjected to Alternate Light Sources)* allowing the camera to capture a response from a substrate based on the light being used (Albanese and Montes, 2011). The addition of an ALS can complicate biological fluid documentation further and increase the time taken to process the crime scene.

Figure 4.7: Real time High Dynamic Range Image. The same identical image with light levels being increased to allow visualisation of different aspects of the scene. Top to bottom: Low light, medium light, increased light.

4.1.5 Rationale

Current methods for utilising ALS techniques require the SOCO to search the crime scene at close range (e.g. 30 cm distance) from the surface, which can be a time consuming task depending on the complexity of the environment. Issues may arise during close range searching, particularly where large crime scene environments are concerned, whereby the SOCO could be searching for long periods of time without any indication as to where biological fluids could be present. Once the stained location is determined, the evidence will be documented and photographed accordingly, further extending the investigation time prior to the evidence having been collected and analysed. As DNA analysis times have dropped from days to hours to facilitate the identification and capture of a suspect, it would be ironic if initially identifying the presence of the biological fluid were the absolute limiting factor of DNA analysis. Current methods for photographing a response from biological fluids when using an ALS require the SOCO to select the correct exposure in order to successfully capture a fluorescent response. This process will have to be repeated for multiple biological stains, adding further time onto the investigation process. 360^{o} photography with HDR can capture a complete 360^{o} view of an environment in addition to accounting for multiple exposures. Utilising a system which integrates an ALS within 360^{o} HDR photography could not only allow the detection of biological fluids at larger crime scenes, but could dramatically reduce the time it takes to identify, document, collect and analyse the evidence. The success of this study would allow a more dynamic recording of the spatial placement of biological fluids and allow other evidence types found to be placed in context – a difficult process to do with only still photography.

Aims and Objectives

The aim of this research is to investigate the detection and visualisation of human blood, semen and saliva on different substrates using a 360^{o} camera and an alternate light source and a 360^{o} camera and Class 4 laser light.

The objectives associated with the aim are as follows: -

- To determine the feasibility and practicality of adapting a 360^{o} camera to include a blue Crime Lite XL at 420-470 nm and a camera filter to aid the detection of blood, semen and saliva at a scene.
- To determine the effect of substrate type on the detection and visualisation of blood, semen and saliva using 360^{o} photography and an alternate light source.
- To determine the effect of different volumes of blood, semen and saliva on the detection and visualisation using 360^{o} photography and an alternate light source.
- To determine the effect of the distance between samples of blood, semen and saliva on the detection and visualisation using 360^{o} photography and an alternate light source.
- To determine the effect of substrate type on the detection and visualisation of blood, semen and saliva using 360^{o} photography and a laser light system.
- To determine the effect of different wavelengths of laser light; 405 nm, 445 nm, and 532 nm, on the detection and visualisation of blood, semen and saliva using 360^{o} photography and a laser light system.
- To determine the effect of different intensities of laser light; low, medium and high, on the detection and visualisation of blood, semen and saliva using 360^{o} photography and a laser light system.

4.2 Methodology

4.2.1 LED light source detection and visualisation of biological fluids

4.2.1.1 Collection of biological fluids

In line with ethical requirements of the host institution and in accordance with health and safety procedures, human semen was obtained from one male donor, aged 26. Semen also known as ejaculate contains spermatozoa, seminal fluid and other biological products. For the purpose of this study whole semen was used. Human saliva and blood was obtained from a female donor aged 24. Blood was obtained through venipuncture by a Phlebotomist using a syringe and butterfly needle and collected into a Vacutainer® (Becton Dickinson) without anticoagulant present. Semen and saliva samples were collected into separate 100 ml Thermo Scientific™ Sterilin™ Polystyrene Containers and labelled accordingly. All biological fluid samples were collected on the morning of the study and were immediately stored in a fridge at 3^{o}C until required. White cotton (199 g/m^2), dark blue cotton (367 g/m^2), HP premium matte polypropylene white plotter paper (140 g/m^2), and coloured cardboard (160 g/m^2; red, orange, yellow, green, blue and violet in colour) were utilised as the substrates for fluid deposition. The white cotton, dark blue cotton and white plotter paper substrates were cut into approximate 10 cm x 10 cm square swatches and the coloured cardboard substrate was cut into approximate 5 cm x 5 cm square swatches. Different coloured cardboard was used to try and replicate the variety of colours of painted or wallpapered environments encountered in a typical room or scene. The coloured cardboard swatches enabled consistency between biological fluid tests.

4.2.1.2 Deposition of Biological Fluids

Using Biohit Proline® automated pipettes, 5, 50, 100, 150, 200 and 250 µL of each biological fluid was deposited onto each substrate type. The pipette was held directly above the substrate and the biological fluid deposited at a 90^{o} angle to the substrate, as shown in Figure 4.8. A series of between 1 and 4 drops of biological fluid were deposited onto multiple swatches as shown in Figure 4.9. For the coloured cardboard swatches, one single drop of each biological fluid was deposited. Samples were left to dry under ambient conditions (approximately 18^{o}C) for 24 hours. A specialist ‘trauma room’ at the host institution was utilised for this investigation as it provided an environment which limited contamination from other biological fluids, and allowed for complete darkness. Walls in this room were covered with lining paper to remove the reflectivity and to ensure that the walls were more representative of common household environments. All swatches were adhered to the wall lining paper using double-sided sticky tape, in the approximate centre of one wall. The order with which each swatch was adhered to the wall was determined using a random number generator in Microsoft Excel.

4.2.1.3 Detection and Visualisation of Semen and Saliva

The environment was illuminated using a Crime Lite XL (420-470 nm) (Foster + Freeman Ltd.) and photographed using a SceneCam 360^{o} camera (Spheron VR AG). A Crime Lite XL was held above and behind the camera lens as shown in Figure 4.10. The camera was initially positioned 30 cm away from the swatches. The camera was calibrated according to the manufacturers instructions (Spheron SceneCam User Manual, 2007).

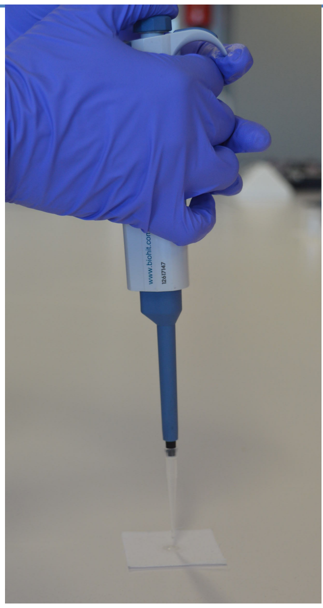


Figure 4.8: Biohit Proline automated pipette held at a 90^{o} angle to the substrate.

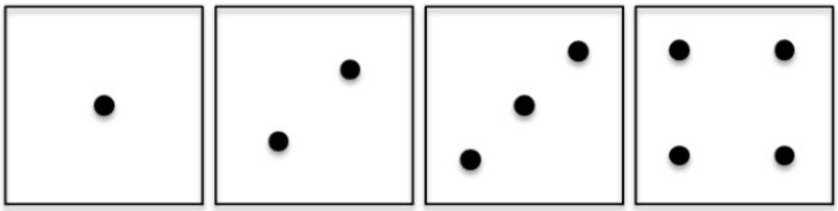


Figure 4.9: Drops of biological fluid deposited onto swatches

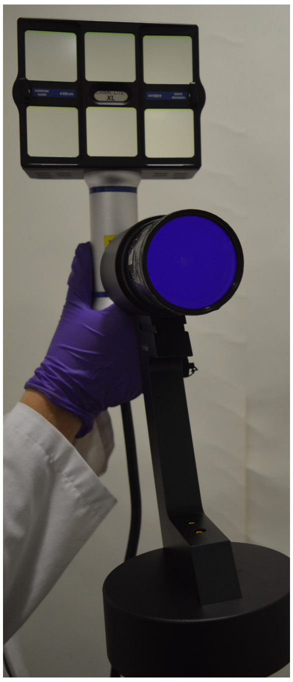


Figure 4.10: The Crime Lite XLs position in relation to the SceneCam.

A 495 nm (GG495) longpass camera filter (62 mm) was adhered, using Duct Tape™, over the existing fisheye lens on the 360° camera, to allow induced fluorescence to be observed (Figure 4.11).

This process was repeated for 60, 90, 150 and 300 cm working distances, for each substrate and biological fluid type. The resulting panoramas were uploaded into the complimentary SceneCenter software. No photographs were enhanced or treated with Photoshop or any other digital image manipulation software.

4.2.1.4 Detection and Visualisation of Blood

The environment was photographed using a SceneCam 360° camera (Spheron VR AG). The camera was positioned 30 cm away from the swatches. The camera was calibrated according to the manufacturers instructions (Spheron SceneCam User Manual, 2007).

A solution of BlueStar® Forensic was prepared according to the manufacturers instructions. Two BlueStar® Forensic tablets (one beige and one white) were added to 175 ml distilled water in a spray bottle, the bottle sealed and stirred gently by swirling for two minutes until dissolution was noted. Just before the camera lens approached the swatches, the samples were sprayed with the BlueStar® Forensic in a sweeping motion at a distance of 30 cm. Due to the close proximity with which BlueStar® Forensic is required to be sprayed onto the target material, this study was only conducted at a 30 cm distance from the swatches. The resulting panoramas were uploaded into the complimentary SceneCenter software. No photographs were enhanced or treated with Photoshop or any other digital image manipulation software.

4.2.2 Participant Detection of Biological Fluids

The panoramas were initially monitored to determine whether the ALS and 360° camera combination could detect any biological staining on the four substrate types. Once it had been established that each of the biological fluids could be successfully located using the ALS and camera combination, the accuracy of the technique was investigated using the following approach.

Ten participants; 4 male and 6 female, aged between 26 and 44 years of age, were recruited from the host institution. Participants were briefed on the aims of the investigation and were asked to sign a consent form in line with the ethical requirements of the institution. Participants were provided with an answer booklet, which had each numbered panorama and the distribution of the substrate swatches (Figure 4.12). Participants were required to replicate a pattern of biological fluid drops corresponding to the swatches in the 360^{o} panoramas. Participants were told not to draw anything that was not circular in shape and were informed that they could use the HDR in the software to increase or decrease the light intensity to aid the visualisation of the biological fluids. The panorama order was randomised and the default titles removed and replaced with numbers.

The total number of drops identified by each participant was calculated by counting the number of drops they had drawn (Figure 4.13) and this was compared against the total number of drops which were originally deposited.

Figure 4.11: GG495 camera filter attached to the already existing fisheye lens of the SceneCam

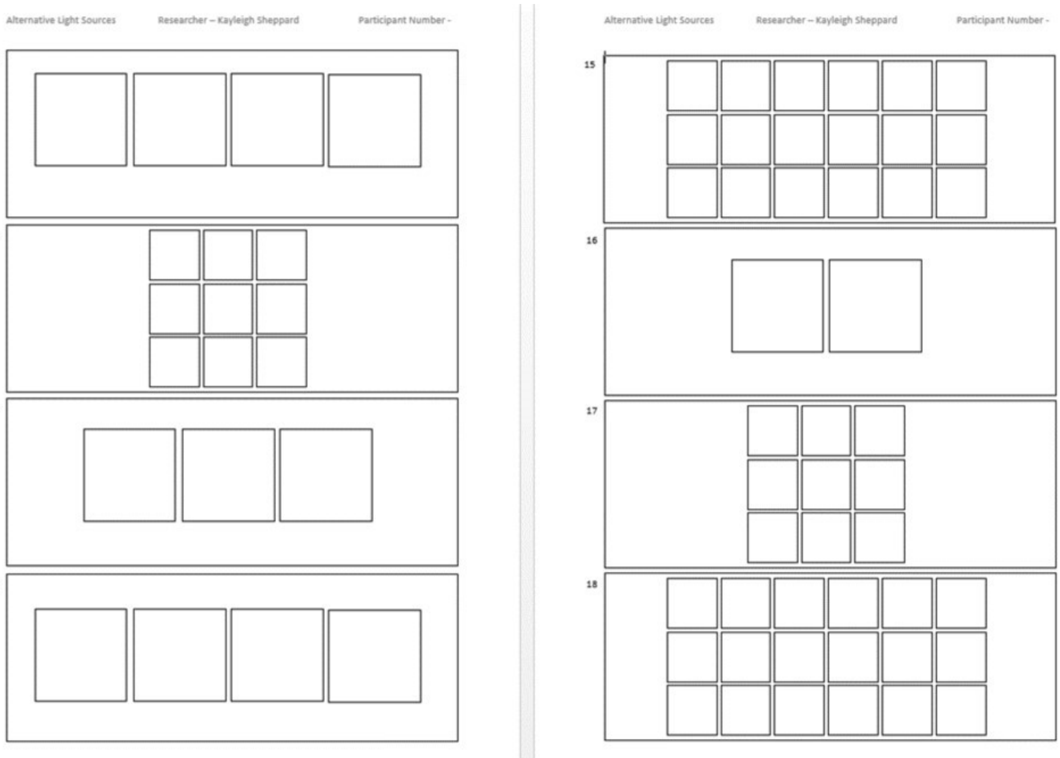


Figure 4.12: A sample two pages of a blank answer booklet for participants to complete

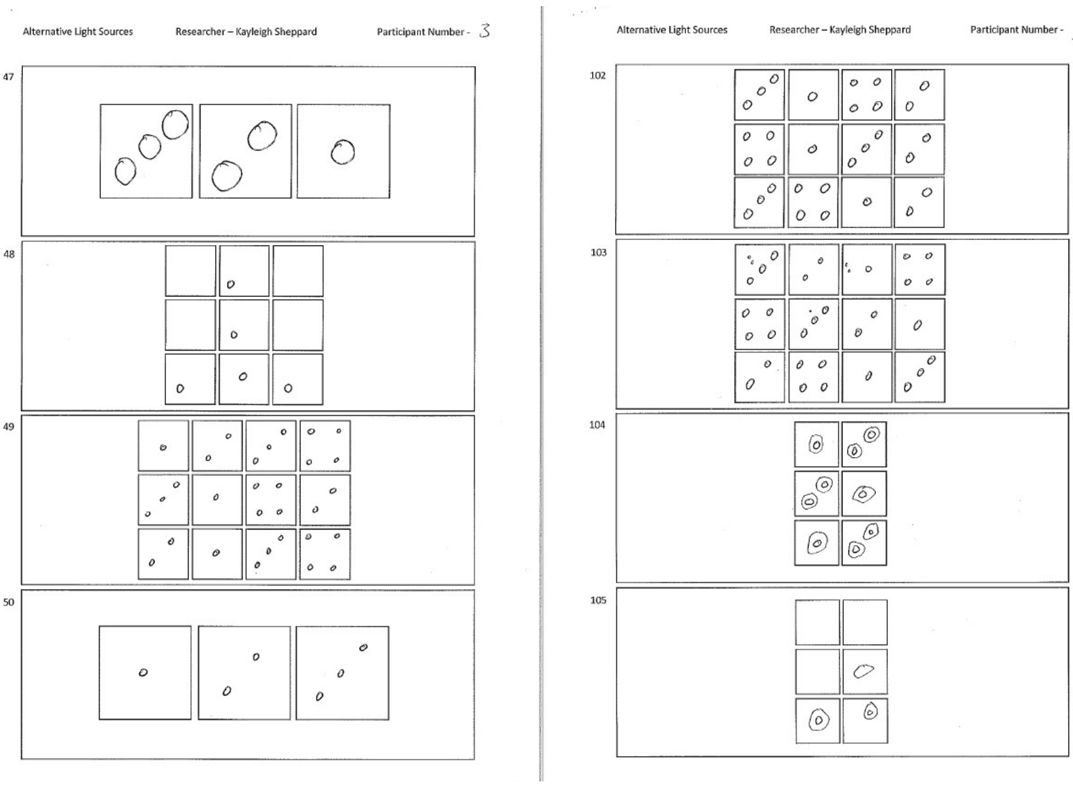


Figure 4.13: An example of a completed answer booklet

4.2.3 Laser Detection and Visualisation of Biological Fluids

4.2.3.1 Collection of Biological Fluids

The same method used in *4.2.1 Collection of biological fluids*, was used to collect semen and saliva in this investigation. Blood was obtained from a different male donor by 'finger pricking' using an Accu-check lancet system. The donor's finger was pierced using a sterile, single use lancet and blood was deposited directly onto each of the substrates. White cotton (199 g/m^2), dark blue cotton (367 g/m^2), and coloured cardboard (160 g/m^2; red, orange, yellow, green, blue and violet in colour) were utilised as the substrates for fluid deposition. The white cotton, dark blue cotton and coloured cardboard substrates were cut into approximate 5 cm x 5 cm square swatches.

4.2.3.2 Deposition of Biological Fluids

Using Biohit Proline® automated pipettes, 5 and 250 µL of each biological fluid was deposited onto each substrate type. The pipette was held directly above the substrate and the biological fluid deposited at a 90^o angle to the substrate, as shown in Figure 4.8. A single drop of biological fluid was deposited onto each swatch. Samples were left to dry under ambient conditions (approximately 18^{o}C) for 24 hours. A specialist 'trauma room' at the host institution was utilised for this investigation as it provided an environment which limited contamination from other biological fluids, and allowed for complete darkness. Walls in this room were covered with lining paper to remove the reflectivity and to ensure that the walls were more representative of common household environments. All swatches were adhered to the wall lining paper using double-sided sticky tape, in the approximate centre of one wall. Swatches were placed in rows according to biological fluid type and volume as shown in Figure 4.14.

4.2.3.3 Detection and Visualisation of Blood, Semen and Saliva

The environment was illuminated using a Triple Laser (Tech-Long Industry Ltd.) (Figure 4.15) and photographed using a SceneCam 360^o camera (Spheron VR AG). The camera was placed 1.5 m away from the wall of interest and calibrated according to the manufacturers instructions (Spheron SceneCam User Manual, 2007). The Triple laser was held to the right hand side of the camera lens as shown in Figure 4.16. Three different wavelengths of light; 405 nm (purple light), 445 nm (blue light) and 532 nm (green light) were examined in this investigation. For each wavelength, three different intensities were also examined; low, medium and high.

The 405 nm wavelength was selected first by turning the power key on the laser device to the correct wavelength setting. A dial on the side of the laser box allows the power intensity to be altered. For the first panorama the power intensity was low, the second panorama medium and the third panorama high. This process was repeated for both 445 nm and 532 nm wavelengths, changing the power intensity for each subsequent panorama.

Each wavelength of laser required a different camera filter to be fitted over the existing camera lens in order to capture any fluorescent response. When the 405 nm and 445 nm wavelength laser lights were used a 495 nm (GG495) longpass camera filter (62 mm) was adhered, using Duct Tape^{TM}, over the existing fisheye lens on the 360^{o} camera, to allow induced fluorescence to be observed (Figure 4.16). For the 532 nm wavelength laser light, an orange 180- 532 nm (NoIR Laser Shields) (OD 7+ % VLT) longpass camera filter (72mm) was adhered using Duct Tape^{TM}, over the existing fisheye lens on the 360^{o} camera, to allow induced fluorescence to be observed (Figure 4.17).

The resulting panoramas were uploaded into the complimentary SceneCenter software. No photographs were enhanced or treated with Photoshop or any other digital image manipulation software. The panoramas were initially monitored to determine whether the laser light system and 360^{o} camera combination could detect any biological staining on the three substrate types.

Figure 4.14: Layout of the swatches. Left to right: Blood (finger prick spot), Semen 5 µL, Semen 250 µL, Saliva 5 µL and Saliva 250 µL

Figure 4.15: Triple Laser (Tech-Long Industry Ltd.) UK.

Figure 4.16: The lasers position in relation to the SceneCam.

Figure 4.17: Left: GG495 yellow camera filter attached to the already existing fisheye lens of the SceneCam. Right: Orange 180-532 nm camera filter attached to the already existing fisheye lens of the SceneCam.

4.3 Results and Discussion

This is the first report demonstrating the successful location and visualisation of biological fluids using a 360° camera system adapted using an ALS.

4.3.1 Semen and Saliva

The location and documentation of semen and saliva using the blue Crime Lite XL and 360° camera technique on each substrate type are discussed in turn. Where contrast of biological stains were observed this was achieved using the 455 nm excitation wavelength and a 495 nm (GG495) longpass camera filter (62 mm).

4.3.1.1 White Cotton

The semen stains deposited onto the white cotton substrate appeared barely visible to the naked eye when examined under natural light. Using the Blue Crime Lite XL at 455 nm excitation wavelength the semen demonstrated fluorescence, which is consistent with recommended best practice (Stoilovic, 1991; Kobus *et al.*, 2002; Vandenberg and Oorschot, 2006). The fluorescence was successfully documented by the 360° camera as shown in Figure 4.18.

The camera system and ALS technique was able to successfully detect semen stains on the white cotton substrate to volumes as small as 5 µL. This was possible for all of the distances studied. Figure 4.19 demonstrates the semen fluorescence detected by the 360° camera and Blue Crime Lite XL for all volumes at 30 cm and 90 cm distances.

Similarly to semen, saliva appeared barely visible to the naked eye under natural lighting, but was successfully visualised and documented for some of the samples of saliva using a Blue Crime Lite XL and 360° camera. Recommended best practice utilised 455 nm such as that which the blue Crime Lite XL provides (Carter-Snell and Soylts, 2005). The fluorescence demonstrated by a saliva stain is demonstrated in Figure 4.20.

Saliva staining was successfully located in the majority of cases using a blue Crime Lite XL, but visualisation was only possible with larger volume stains (150 µL, 200 µL and 250 µL) as shown in Figure 4.21. This was consistent with results observed by Camilleri *et al.* (2006). Smaller volume stains were more difficult to detect, which could be attributed to the lack of solid particles within the saliva sample (Virkler and Lednev, 2009; Miranda *et al.*, 2014). In addition, detection of saliva on the white cotton substrate was difficult due to the porous nature of the surface type. As a result, the saliva was absorbed into the material rather than drying on the surface, leaving little surface fluorescence. The fluorescence from the biological fluid could also have been masked by background fluorescence from the white cotton material. When subjected to blue or UV light, white materials can exhibit fluorescence due to the presence of naturally occurring organic compounds within the material, or optical brighteners present in detergents (Auvdel, 1987; Kobus *et al.*, 2002). Background fluorescence from the substrate can mask the target fluorescence, increasing the difficulty in detecting the biological fluid (Sterzik *et al.*, 2016).

To access the panoramas demonstrating semen and saliva on white cotton please refer to the supplementary USB card and open the file entitled Chapter 4.3.1.1 – White cotton semen and saliva panoramas. Within this file please select the 'Start' file. This will open the SceneCase with the panoramas.

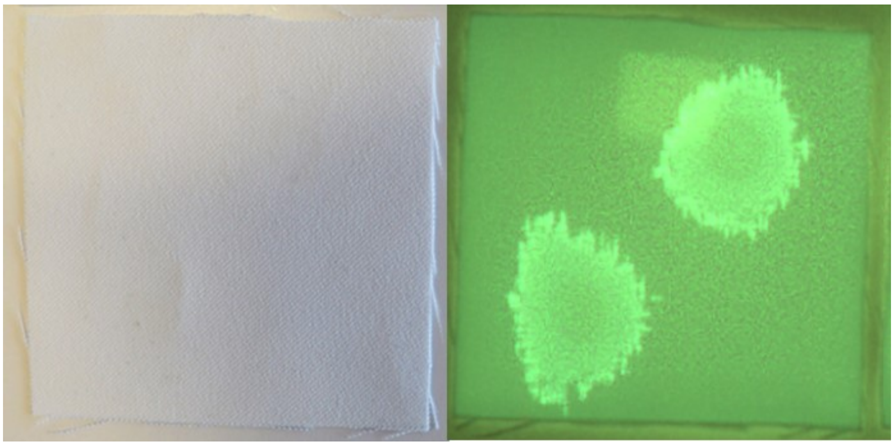


Figure 4.18: 200 µL Semen staining on white cotton swatch 10 cm x 10 cm Left: semen exposed to natural light. Right: semen exposed to a blue Crime Lite XL

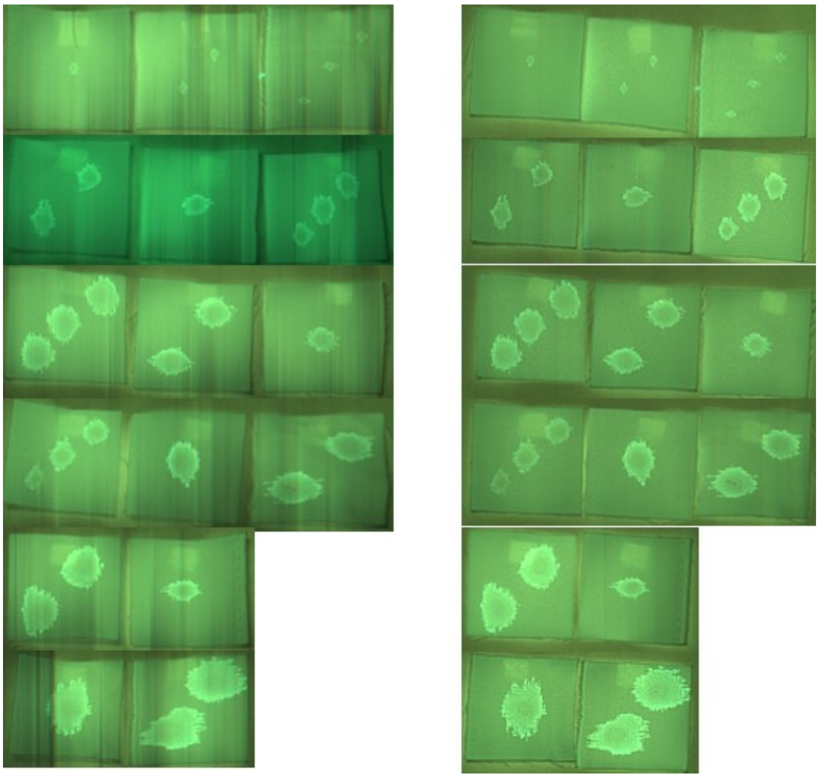


Figure 4.19: All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 µL – semen successfully detected on white cotton using a blue Crime Lite XL at 30 cm (left), 90 cm (right)

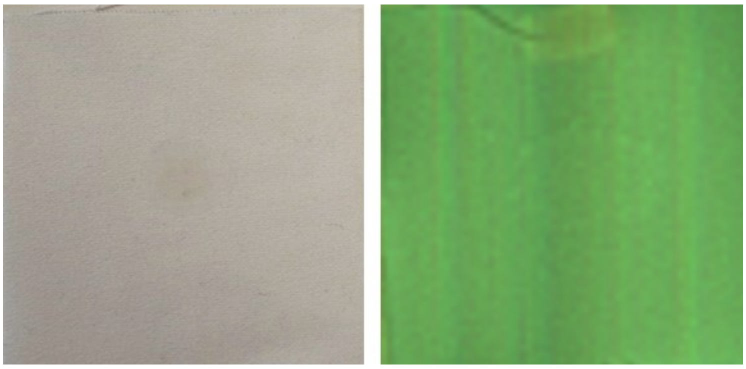


Figure 4.20: 200 μL Saliva staining on a white cotton swatch 10 cm x 10 cm. Left: saliva exposed to natural light. Right: saliva exposed to a blue Crime Lite XL

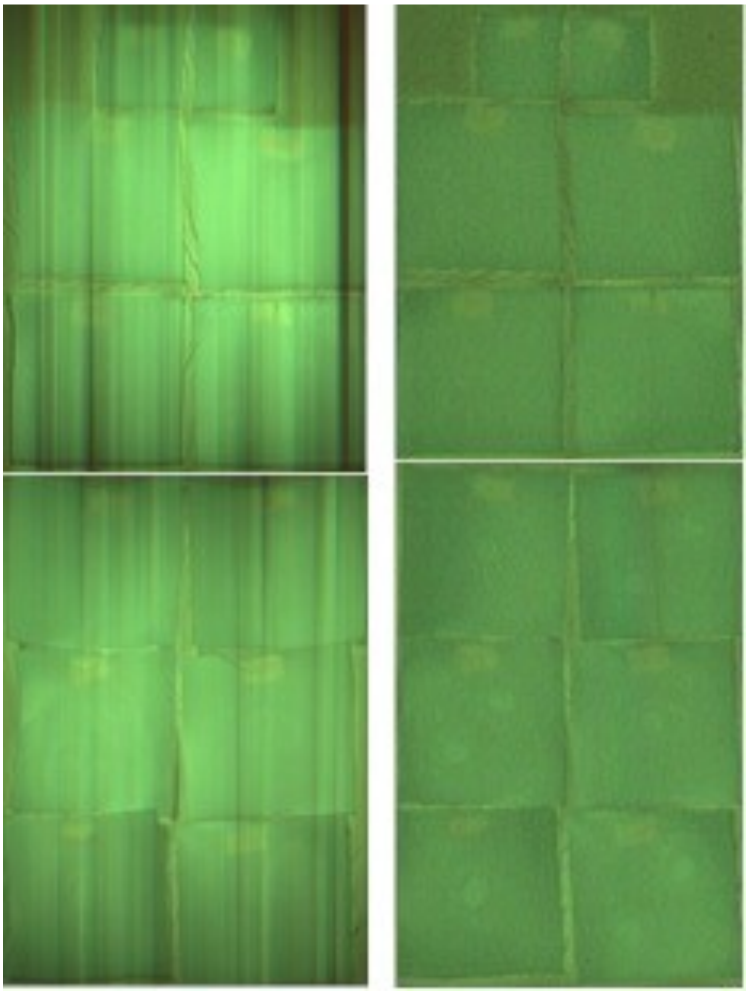


Figure 4.21: All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 μL – larger saliva stains successfully detected on white cotton using a blue Crime Lite XL at 30 cm (left), 300 cm (right)

4.3.1.2 Dark Blue Cotton

Semen was detected under natural light immediately after deposition on the dark blue cotton. Following a 24-hour drying period, the biological staining had dried, and less staining was still visible under natural light. These stains could be successfully located and documented using a blue Crime Lite XL and 360° camera, as shown in Figure 4.22.

Unlike the white cotton, which can contain naturally fluorescent organic compounds, the dark cotton was less likely to contain these substances and mask fluorescence from the semen stains. In this study, the dark cotton was not found to fluoresce itself, but this material presented other problems for locating and detecting the semen stains. The dark material could absorb the excitation light and reduce the chance of detecting the biological fluid (Su, 2015). These results were consistent with research conducted by Kobus *et al.* (2002) and Fiedler *et al.* (2008), which reported a high degree of difficulty in detecting semen on materials, which were dark in colour or highly absorbent.

As shown in Figure 4.22 (right), not all of the biological fluid droplets were consistent in terms of their visibility using the blue Crime Lite XL. This was likely to have been due to incomplete deposition, perhaps due to air bubbles produced during deposition. In addition the variability in the visualisation of semen stains could be attributed to the absorbency of the substrate used. In some instances, the semen could have sat on the surface of the substrate and in others, particularly the larger volumes; some of the semen could have been absorbed into the substrate leaving little fluid on the surface to produce a fluorescent response. Whilst these results are consistent with other authors, Kobus *et al*. (2002) noted no difference in the appearance of semen stain fluorescence using a Polilight on different levels of absorbent materials.

Those stains that could be detected by the camera were detectable up to a maximum distance of 300 cm away from the staining, as shown in Figure 4.23. As the camera and ALS moved further away from the staining, the semen stains became harder to detect and proved more challenging to document.

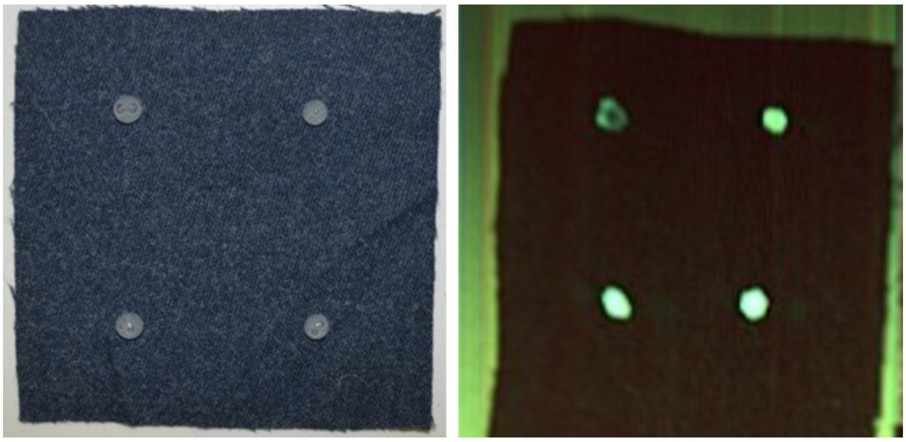


Figure 4.22: 200 µL semen staining on a dark blue cotton swatch 10 cm x 10 cm. Left: semen exposed to natural light. Right: semen exposed to a blue Crime Lite XL

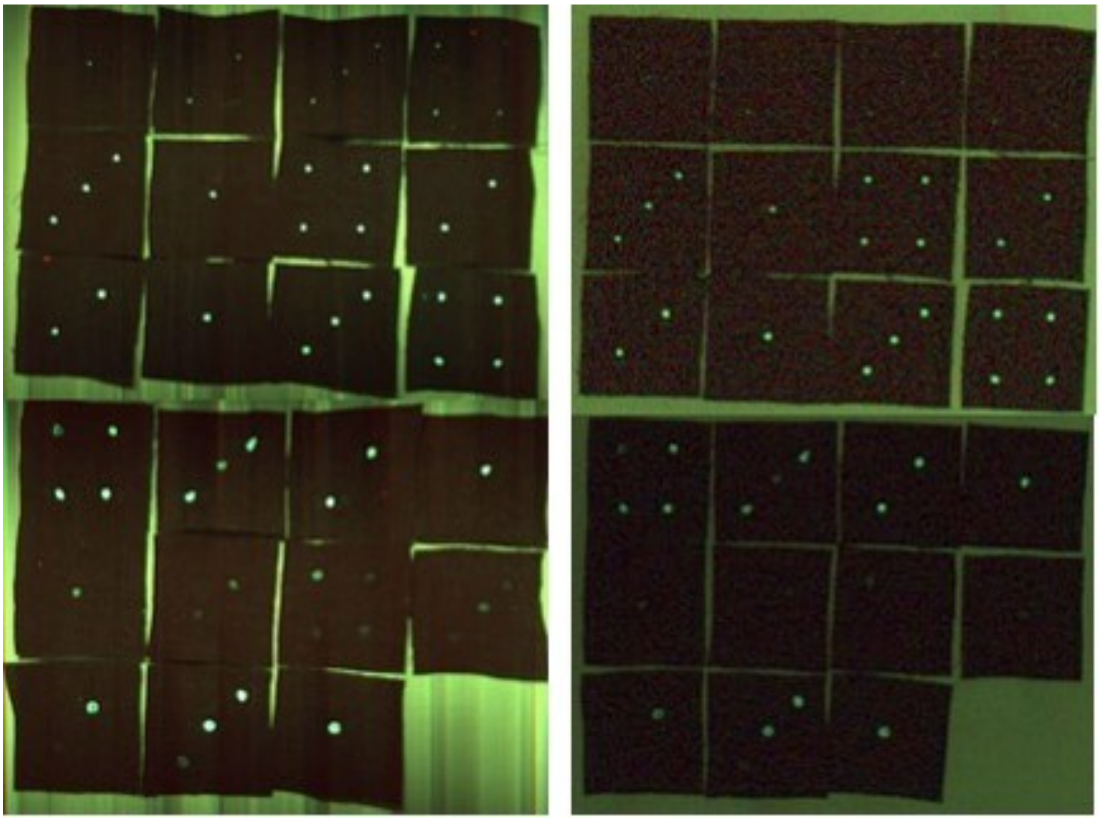


Figure 4.23: All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 µL – semen successfully detected on dark blue cotton using a blue Crime Lite XL at 30 cm (left), 300 cm (right)

Saliva, which is virtually colourless in presentation, proved more difficult to detect on the dark blue cotton substrate than semen. In many cases, the saliva stains were not enhanced using the ALS, and remained invisible to the naked eye, as shown in Figure 4.24. The saliva stains exhibited little response or fluorescence. This could be attributed to the absorbent nature of the substrate whereby saliva was absorbed further into the material whilst drying, as opposed to drying on the surface of the substrate (Miranda *et al.*, 2014). Kobus *et al*. (2002) found that the visualisation of saliva samples was dependent upon the absorbency of the material and better visualisation was achieved for those saliva samples which sat directly on top of the surface without being absorbed (Vandenberg and Oorschot, 2006).

The majority of the saliva stains were not detected on the dark blue cotton fabric using a blue Crime Lite XL for all volumes and distances examined, as shown in Figure 4.25, with only one or two drops actually being detected. In these few cases, the fluorescence demonstrated by the stains was very low intensity, which made the stains more difficult to detect. The limited detection of saliva on this substrate could be attributed to the porous nature of the material, whereby the saliva absorbed into the fabric, and due to the lack of solid particles within the saliva, as previously described (Camilleri *et al.*, 2006; Miranda *et al.*, 2014).

The samples of saliva were rapidly absorbed into the white and dark blue cotton substrates once deposited. In some of the tests conducted on these materials the biological fluid was undetectable, or the fluorescence observed was weak in intensity. The absorption of the biological fluid into the substrate inhibited the ability to detect the fluorescence of the fluid in some cases. The smaller volumes of biological fluid deposited had a tendency to sit on the surface of the substrate without being absorbed, making the stains easier to detect. In contrast, the semen samples were easier to detect on the same substrates, and this could have been attributed to the higher viscosity of the semen, which allowed the fluid to sit on the surface of the substrate once deposited, as shown in Figure 4.21 (left). This is consistent with results demonstrated by Vandenberg and Oorschot (2006). Where a fluorescent response was not observed the presence of a biological fluid cannot be excluded and further testing would be required (Kobus *et al.*, 2002).

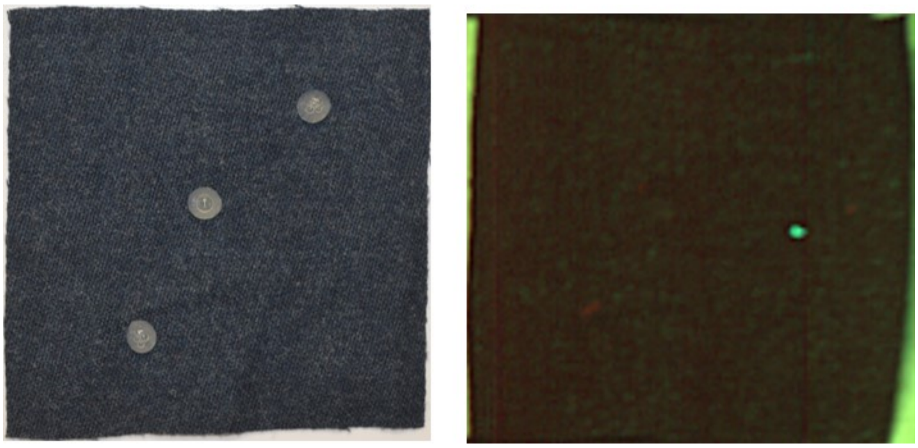


Figure 4.24: 200 µL Saliva staining on dark blue cotton swatch 10 cm x 10 cm. Left: saliva exposed to natural light. Right: saliva exposed to a blue Crime Lite XL

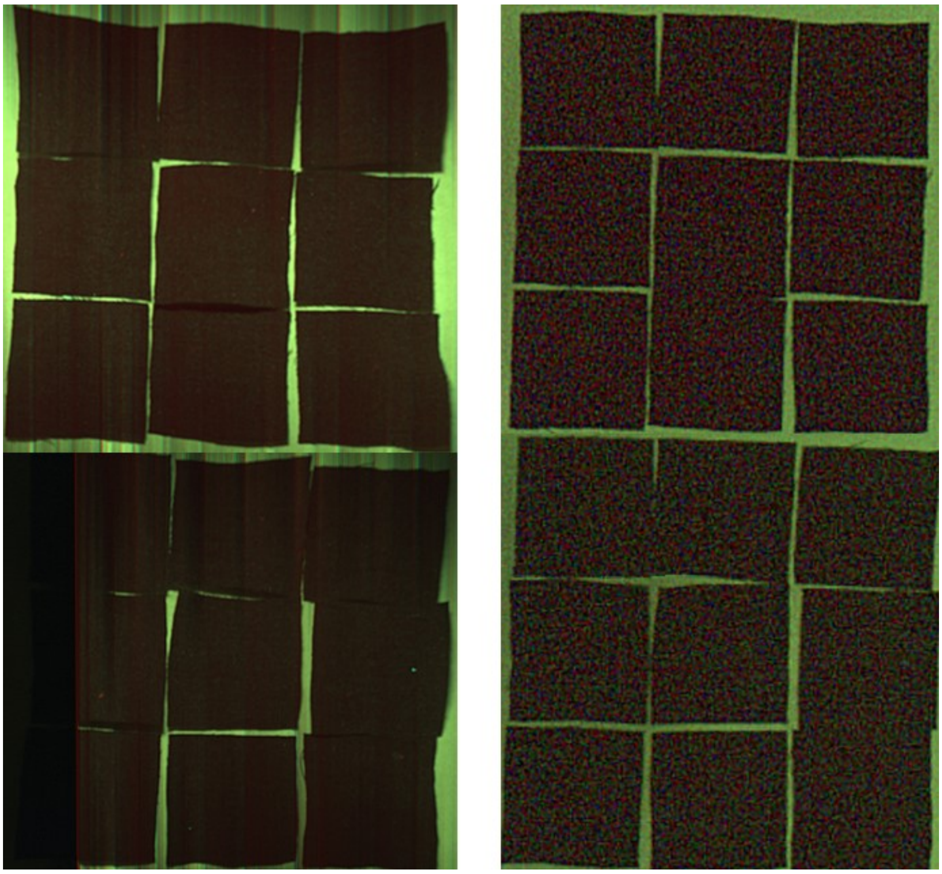


Figure 4.25: All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 µL unsuccessfully detected for saliva on dark blue cotton using a blue Crime Lite XL at 30 cm (left), 300 cm (right)

To access the panoramas of semen and saliva on dark blue cotton please refer to the supplementary USB card and open the file entitled Chapter 4.3.1.2 – Dark blue cotton semen and saliva panoramas. Within this file please select the 'Start' file. This will open the SceneCase with the panoramas.

4.3.1.3 White Plotter Paper

The semen stains deposited onto the white plotter paper substrate were visible when examined under natural light. When subjected to a blue Crime Lite XL, the semen demonstrated high intensity fluorescence, which was successfully documented using the 360^{o} camera system, as shown in figure 4.26. The camera system and ALS technique was able to successfully detect semen stains on the white plotter paper to volumes as small as 5 µL. This was possible for all of the distances at which the stains were studied. The fluorescence observed by the semen on the white plotter paper substrate appeared to exhibit high intensity fluorescence. Figure 4.27 demonstrates the semen fluorescence detected by the 360^{o} camera and blue Crime Lite XL for all volumes at 30 cm and 300 cm distances.

Saliva deposited onto the white plotter paper substrate was visible under natural light, but was visualised more easily using a blue Crime Lite XL. The saliva stains were successfully located and documented using the 360^{o} camera, as shown in Figure 4.28. The camera system and ALS technique was able to successfully detect saliva stains on the white plotter paper to volumes as small as 5 µL, although the smaller volumes were more difficult to visualise and document with the 360^{o} camera system. Documentation of the smaller volume stains became more difficult as the working distance increased. Figure 4.29 demonstrates the saliva fluorescence detected by the 360^{o} camera and blue Crime Lite XL for all volumes at 30 cm and 90 cm distances.

For the saliva stains, the identified fluorescence was concentrated around the outer edges of the saliva stain with very little fluorescence in the centre of the stain. Saliva exhibited low intensity fluorescence when compared to the fluorescence exhibited by the semen on the white plotter paper substrate, as shown in Figure 4.30. The fluorescence exhibited by the saliva is attributed to an aromatic amino acid and fluorophore, Tryptophan, found in alpha amylase (Soukos *et al*., 2000; Nanda *et al*., 2011). The fluorescence observed by the semen stains occurred across the entirety of the stain, which was likely to be attributed to the presence of conjugated choline and flavin proteins within the semen (Kobus *et al.*, 2002). Knowledge about the different responses biological fluids have to certain wavelengths of excitation light can aid in estimating but not distinguishing between semen and saliva fluids (Seidl *et al.*, 2008). However, the definitive nature of a fluorescent area cannot be determined solely through visual inspection and any fluorescent areas will require further confirmatory testing to ascertain the identity of the fluid (Lennard and Stoilovic, 2004; Lincoln *et al.*, 2006).

To access the panoramas of semen and saliva on white plotter paper please refer to the supplementary USB card and open the file entitled Chapter 4.3.1.3 – white plotter paper semen and saliva panoramas. Within this file please select the 'Start' file. This will open the SceneCase with the panoramas.

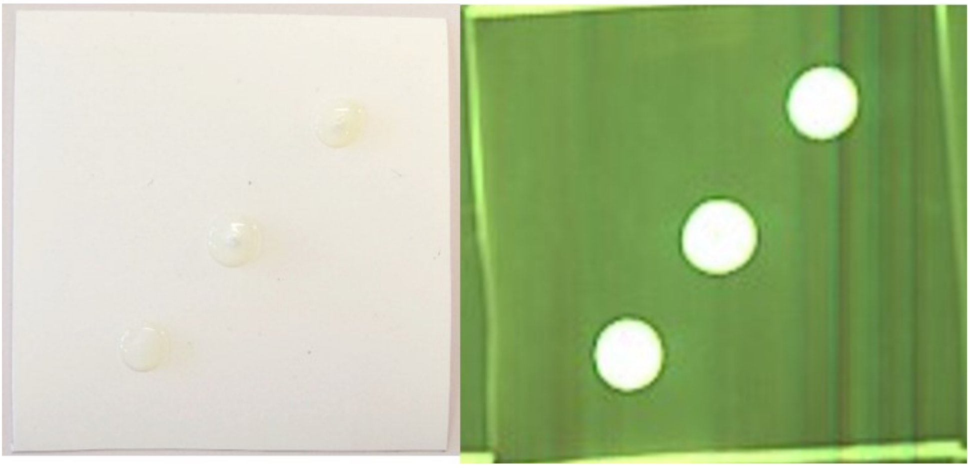


Figure 4.26: 200 µL Semen staining on white plotter paper   10 cm x 10 cm
Left: semen exposed to natural light. Right: semen exposed to a blue Crime Lite XL

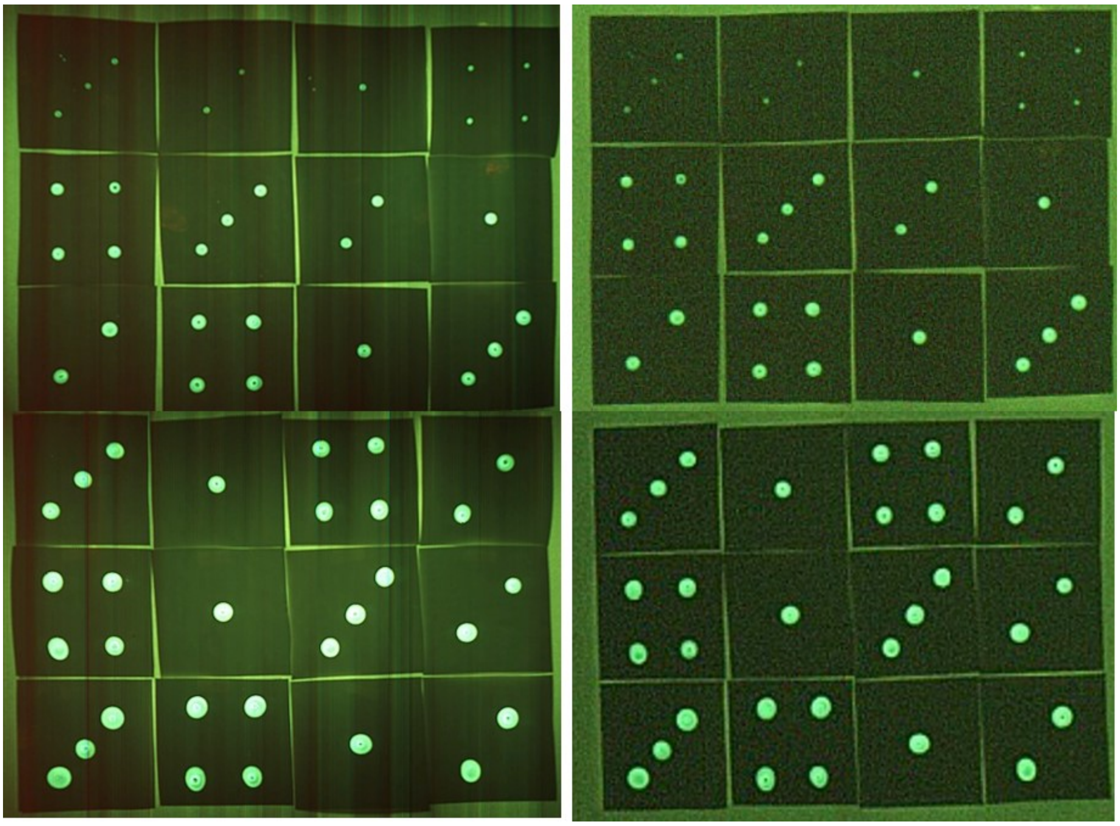


Figure 4.27: All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 µL – semen successfully detected on white plotter paper using a blue Crime Lite XL at 30 cm (left), 300 cm (right)

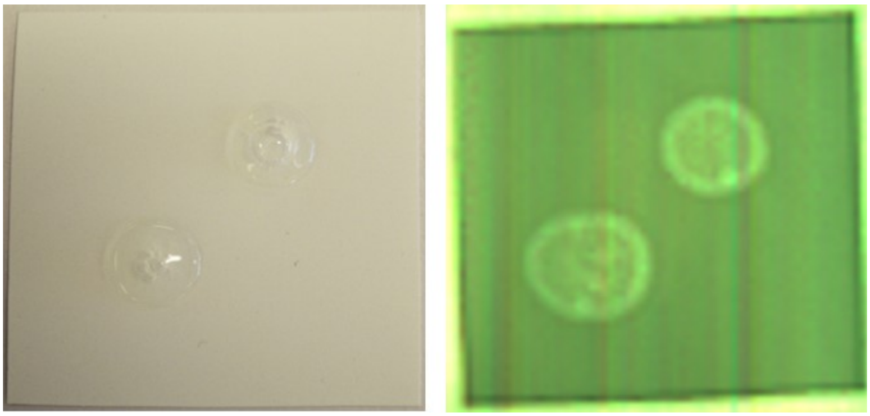


Figure 4.28: 200 µL Saliva staining on White Plotter paper 10 cm x 10 cm. Left: saliva exposed to natural light. Right: saliva exposed to a blue Crime Lite XL

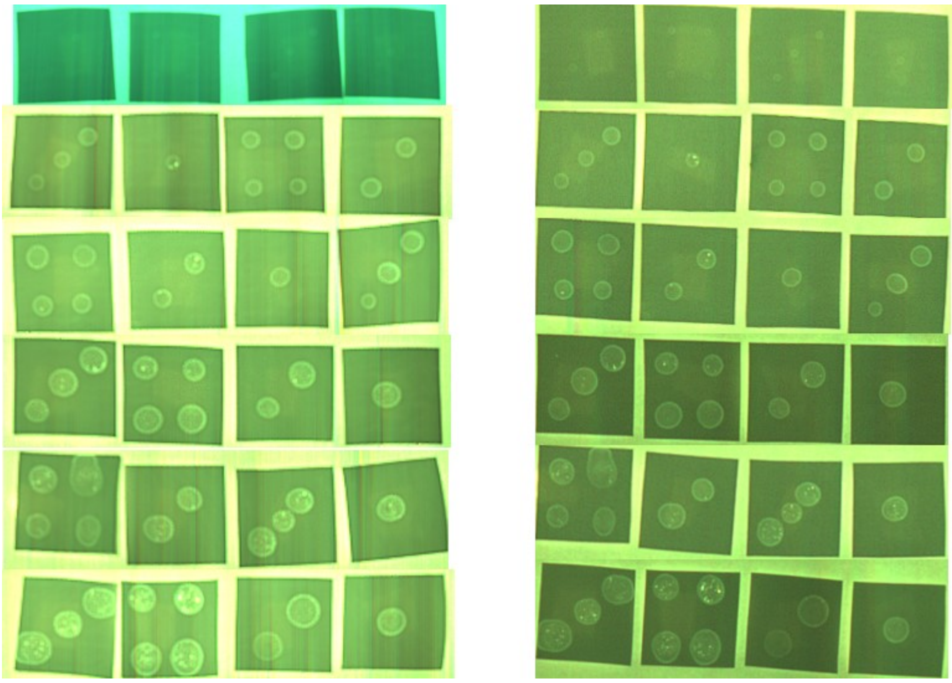


Figure 4.29: All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 µL – saliva successfully detected on white plotter paper using a Blue Crime Lite XL at 30 cm (left), 90 cm (right)

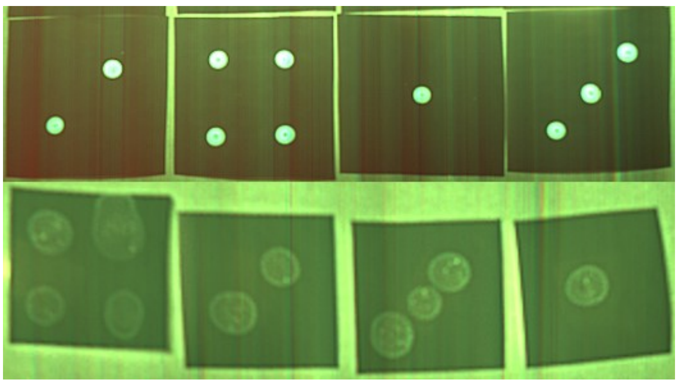


Figure 4.30: 200 µL stains on white plotter paper substrate exposed to a blue Crime Lite. Top: semen. Bottom: saliva

4.3.1.4 Coloured Cardboard

The semen stains deposited onto the coloured cardboard substrate were visible as circular dry marks when examined under natural light. When subjected to a blue Crime Lite XL, the semen demonstrated high intensity fluorescence, which was successfully documented using the 360^{o} camera system, as shown in Figure 4.31.

In some cases the yellow cardboard produced limited results, particularly for the smaller volumes, where the background fluorescence from the yellow cardboard masked the fluorescence from the semen stains. In these cases the HDR of the SceneCam enabled fluorescence previously masked by the background to be visualised successfully. The intensity of the light source on the stains did have an effect on the fluorescence detected by the 360^{o} camera system. However, the unique HDR capabilities of the optical system allowed visualisation of the biological fluids even when this appeared to be masked by background fluorescence from the substrate, as shown in Figure 4.31 (Top). Photographing fluorescence from biological fluids using a digital camera can prove difficult when background fluorescence is present due to the masking, and may require a series of different photographs to be taken at multiple exposures to try and reduce the fluorescent response from the background and enhance the target fluorescence. In this study, the unique addition of the HDR resulted in noticeably greater contrast between the staining and the background, allowing greater visibility of the stains, as shown in Figure 4.32. The HDR controls within the complementary software allows the luminance levels to be increased or decreased without digitally altering or manipulating the image, as the camera accounted for all the different light levels and exposures as it scanned at the time of image acquisition.

Albanese and Montes (2011) explored the use of HDR photography with NIR light to detect bloodstains on dark fabrics. This process involved taking multiple photographs at multiple exposures and combining them using Adobe Photoshop and Photomatix to produce a tone mapped image. Their research demonstrated the successful detection of bloodstains using NIR but an increased visibility of bloodstains using the combined NIR and HDR photography. The HDR technique presented in this chapter occurs in real time; as the camera scans the environment it captures up to 26 f-stops accounting for the different levels of light within the environment. This offers a quicker and more automated method than that presented by Albanese and Montes (2011), which required the photographer to capture identical photographs using different exposure levels in order to combine the images to create a superior photograph with the best light levels available.

To access the panoramas demonstrating semen and saliva on coloured cardboard please refer to the supplementary USB card and open the file entitled Chapter 4.3.1.4 – Coloured Cardboard semen and saliva panoramas. Within this file please select the 'Start' file. This will open the SceneCase with the panoramas.

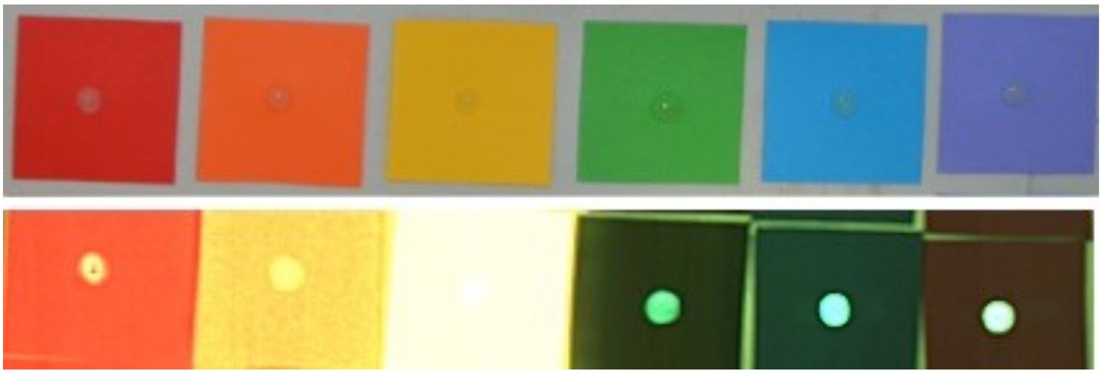


Figure 4.31: 200 µL Semen staining on coloured cardboard substrate 5 cm x 5 cm Top: semen exposed to natural light. Bottom: semen exposed to a blue Crime Lite XL

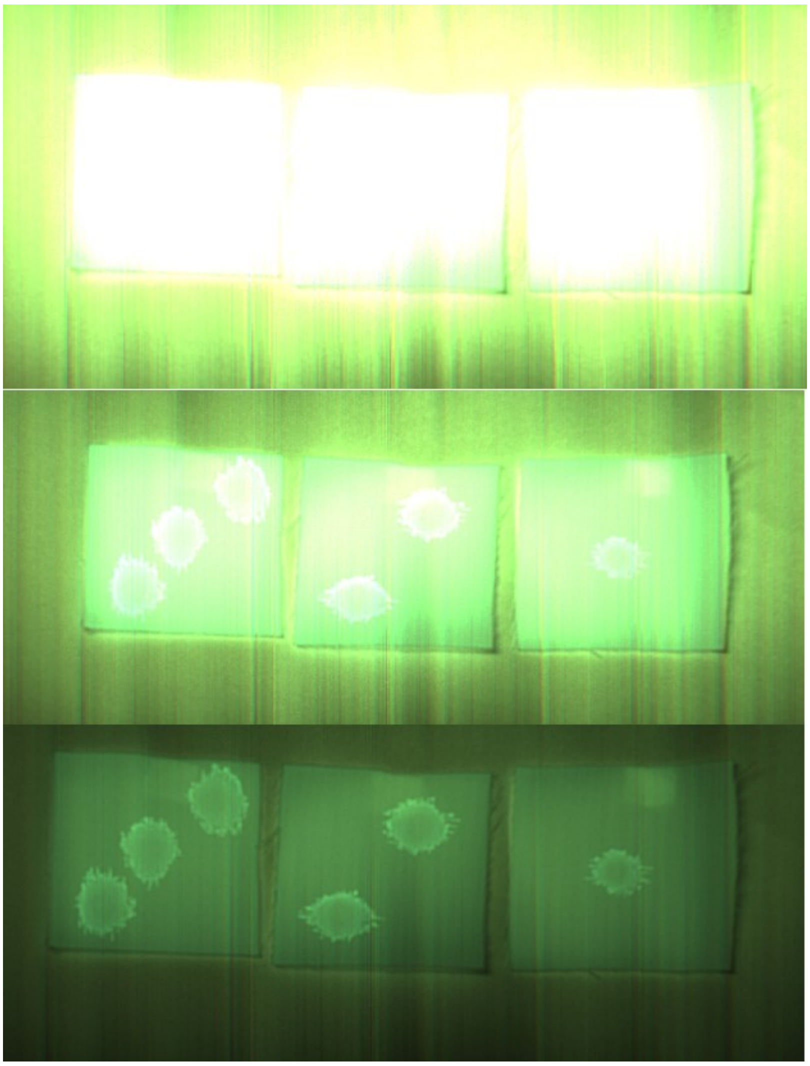


Figure 4.32: Real time HDR applied to the detection of semen stains on white cotton. Top: default exposure with masked fluorescence. Middle: lowered exposure showing semen fluorescence. Bottom: lowered exposure further to fully observe the shape and contrast of the semen stains.

The majority of the semen stains deposited onto the coloured cardboard substrate were successfully visualised and documented by the Crime Light XL and 360^{o} camera system. This was successful for most volumes at all distances examined, as shown in Figure 4.33. At greater distances the smaller volumes, such as 5 µL, became more difficult or impossible to detect.

The 360^{o} camera and light source were moved further away from the stained swatches to determine whether the distance had any effect on the ability of the camera to document the staining. The distance of the camera and light source technique had no effect on the resultant fluorescence of the biological staining, but the larger distances meant the 360° camera could not document some of the smaller volumes (5 µL and 50 µL) of biological fluids successfully. The resolution of the camera will become a limiting factor for the detection of the biological staining as the camera and light source distance increases. Further investigation can be conducted to determine the effects that the resolution will have on the documentation of the biological fluids. As the camera moves further away from the target staining the area covered by a single pixel becomes larger, limiting the detail that can be captured (Figure 4.34) as discussed in *Chapter 3 Section 3.3.6 Resolution*. De Forest *et al.* (2009) identified that the result of zooming in on an image compromised the ability to resolve smaller volume stains. In this study the camera resolution did not compromise the ability to locate the staining due to the limit of the room size of 300 cm. At significantly greater distances however, it is expected that the resolution will become a limiting factor for the successful documentation of biological staining.

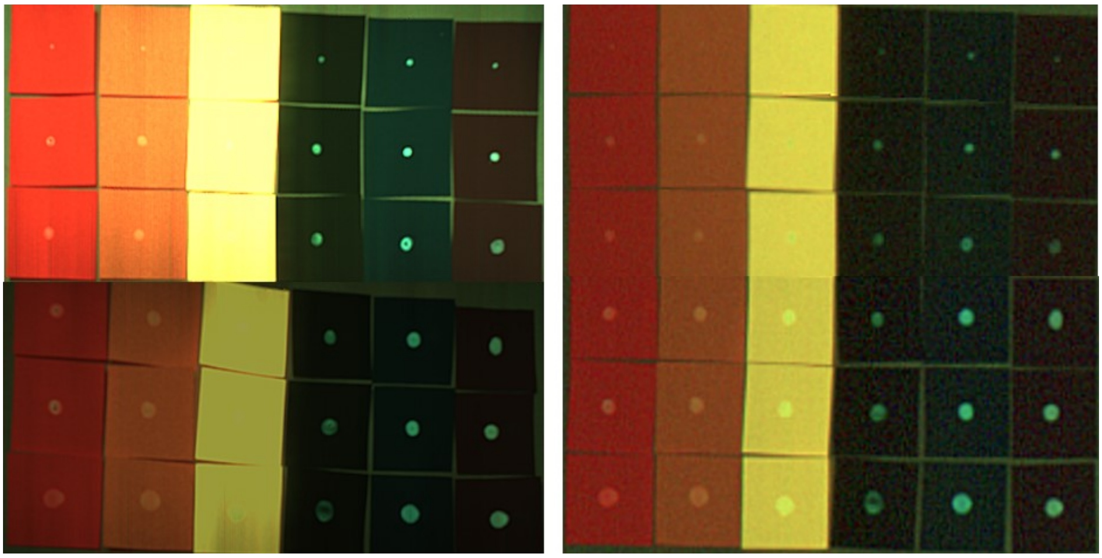


Figure 4.33: All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 µL – semen fluid successfully detected on coloured cardboard using a blue Crime Lite XL at 30 cm (left), 300 cm (right)

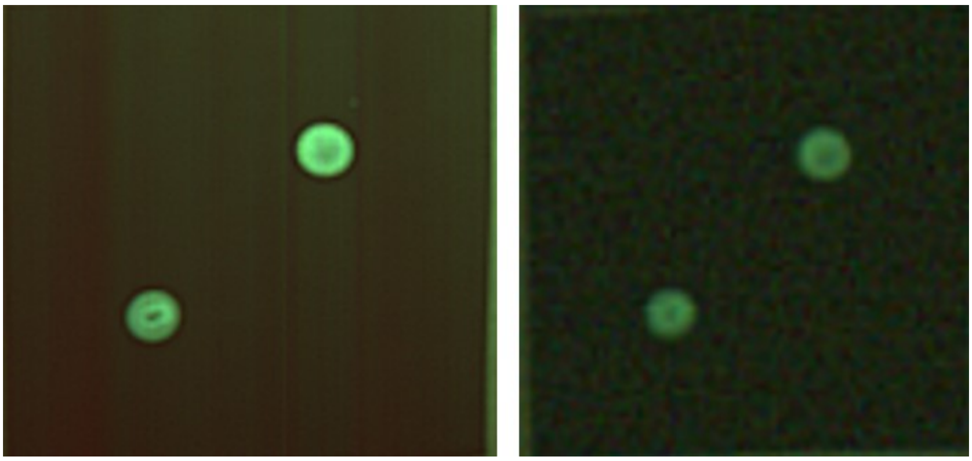


Figure 4.34: 100 µL Semen stains on white plotter paper substrate exposed to a blue Crime Lite XL. Resolution difference: (Left) 30 cm. (Right) 300 cm camera distance from semen stain

The saliva stains deposited onto the coloured cardboard substrate were visible as circular dry marks when examined under natural light. When subjected to a blue Crime Lite XL, the saliva demonstrated high intensity fluorescence, which was successfully documented in the majority of cases using the 360^{o} camera system, as shown in Figure 4.35. The majority of the saliva stains were successfully documented at all distances, particularly the larger volume stains, as shown in Figure 4.36.

In some cases the yellow cardboard produced limited results, particularly for the smaller volumes, where the background fluorescence from the yellow cardboard masked the fluorescence from the semen stains. In these cases the HDR of the SceneCam enabled fluorescence previously masked by the background to be visualised successfully, as previously described and demonstrated in Figure 4.37.

The green coloured cardboard substrate proved more challenging for the detection of the saliva stains, particularly for the smaller volumes such as 5 µL. This could be attributed to the dark nature of the substrate absorbing the incident light coupled with the fact that saliva lacks particulates.

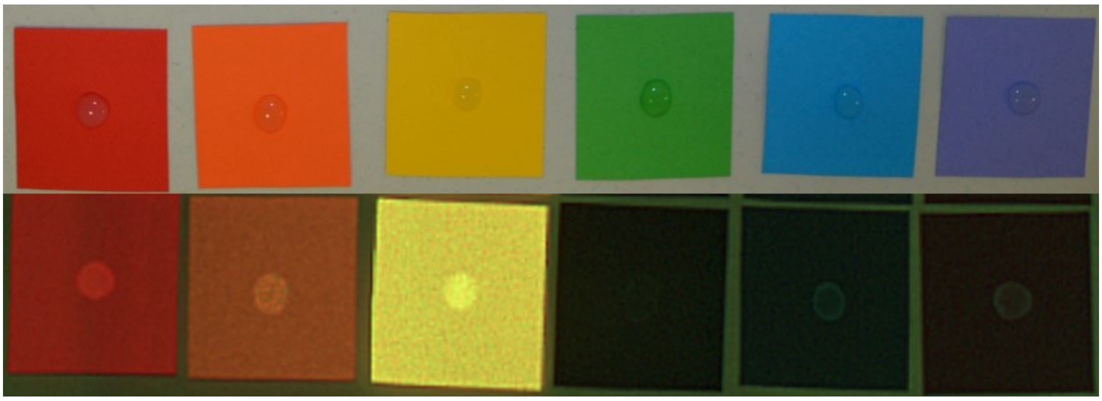


Figure 4.35: 250 μL Saliva staining on coloured cardboard substrate 5 cm x 5 cm Top: saliva exposed to natural light. Bottom: saliva exposed to a blue Crime Lite XL

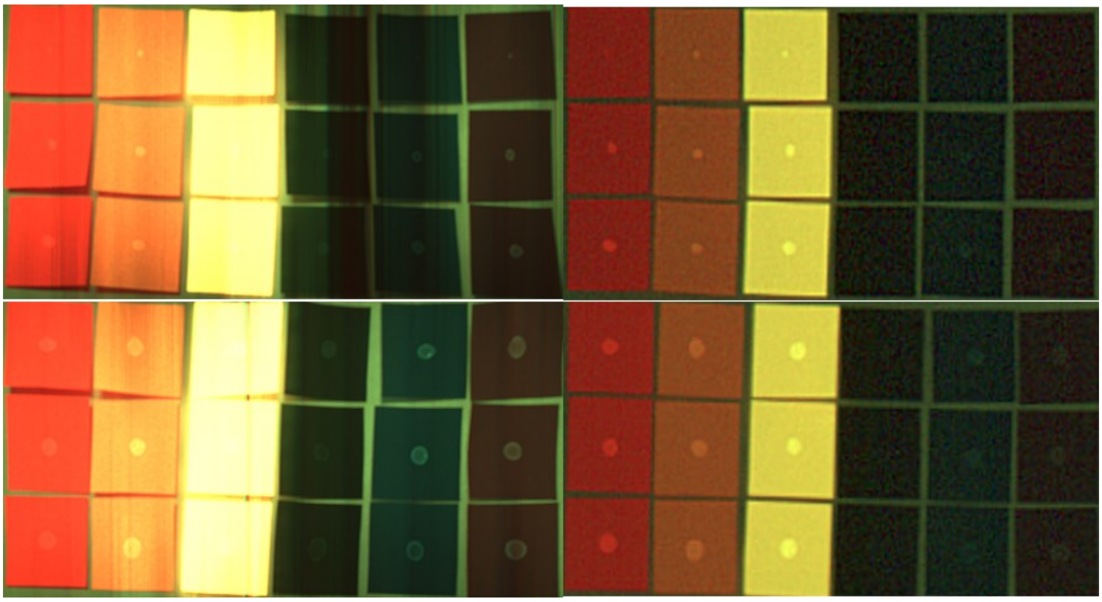


Figure 4.36: All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 μL – saliva successfully detected on coloured cardboard using a blue Crime Lite XL at 30 cm (left), 300 cm (right)

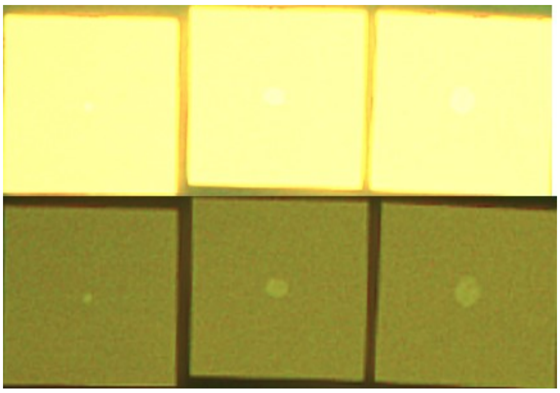


Figure 4.37: Top: 5, 50 and 100 μL increased light and background fluorescence masking target fluorescence from saliva stains. Bottom: 5, 50 and 100 μL decreased light using HDR to reduce background fluorescence to reveal saliva stains.

Although semen and saliva samples were successfully located and visualised using an ALS and 360^{o} camera these biological fluids were not detected in all cases. Some substrates presented challenges for the location and visualisation of these biological fluids.

The white plotter paper substrate allowed for the successful location and visualisation of all saliva and semen samples deposited for all volumes and distances investigated. The successful detection and visualisation of semen and saliva on white plotter paper can be attributed to the non-porous nature of the substrate. The biological fluids were able to sit on the surface of the substrate and were not absorbed into it, allowing more biological fluid to absorb the incident light and produce a fluorescent response. The strong fluorescence demonstrated by semen and saliva in this case concurs with results demonstrated by Kobus *et al.* (2002) who reported a strong fluorescent response from semen which remained on the surface of low absorbency fabrics. The semen samples exhibited higher intensity fluorescence than the saliva samples, which was more concentrated around the outer edges of the stain. This made it easier to detect the fluorescence demonstrated by the semen in this instance.

The coloured cardboard substrate allowed for the successful detection and visualisation of the majority of semen and saliva samples. Particular colours such as yellow inherently fluoresced and masked potential fluorescence from the target staining. The HDR ability of the camera however, managed to visualise some of the samples but this was not possible in all cases, particularly for the smaller volume stains.

The dark blue cotton presented challenges for the location and visualisation of both semen and saliva. The absorbent nature of the material meant that smaller volumes were impossible to detect, due to the majority of the target fluid having been absorbed into the substrate, leaving little material on the surface to exhibit fluorescence. In addition, the dark nature of the dark blue cotton could have meant that the fabric absorbed the incident light and limited any chance of detecting the biological fluid (Fiedler *et al*., 2008; Su, 2015).

The white cotton presented challenges due to the natural fluorescent properties of the cotton attributed to optical brighteners which could be present (Auvdel, 1987). The HDR capabilities of the 360^{o} camera presents a unique opportunity to capture the fluorescent response from the target biological fluid in situations where the substrate may mask any target fluorescence. This potentially eliminates the requirement to use a variety of filters and wavelengths of light to attempt to remove any background fluorescence in order to capture the target fluorescence.

In this study the colour of the substrate which the biological fluid was deposited onto had an effect on the detectability of the biological fluid staining as also reported by Vandenberg *et al*. (2006), Kobus *et al.* (2002) and Su (2015). Substrates which were darker in colour limited the detection of any biological fluid and substrates which contained optical brighteners masked any target fluorescence from the biological fluid (Lennard and Stoilovic, 2004). In such situations the HDR of the 360^{o} camera provided a unique automatic method for reducing the light intensity and revealing fluorescence from the target stain which was previously masked by the background fluorescence.

4.3.1.5 Distinguishing between biological fluids

Although both semen and saliva could be detected and visualised using the blue crime lite XL and a 360^{o} camera, it was difficult to distinguish between the two biological fluids. Semen exhibits higher intensity fluorescence than saliva, as evidenced in Figure 4.30. However, this method could not be used to differentiate between the two types of biological fluids. In this instance, both fluids were visualised differently but other conditions or environments might not present them in such a way. Instead, this method is intended for use as a screening tool to identify the location of any biological fluid and to capture the response using a 360^{o} camera. Vandenberg and Oorschot (2006) concluded that the Polilight (Rofin, Australia Pty Ltd.), a similar light source to that used in this study, was only valuable as a screening tool and it too could not be used to differentiate between different stains. In such instances, further confirmatory testing would have to be conducted in order to determine the nature and origin of such staining.

4.3.1.6 Increasing working distance

At a greater working distance, the intensity of the light source may become a limiting factor. A high powered light source will be more likely to induce a fluorescent response from staining at greater distances than a low powered light source. As a result the intensity and power from the light source must be considered before embarking on this work. In this study, the intensity of the light source was inconsequential and did not affect the ability to induce a fluorescent response from the biological staining. The Crime Lite XL provides 96 high intensity LEDs that, in this case, was sufficient for illuminating an entire internal wall at a distance of up to 3 metres. However, the exhibited fluorescence by the biological fluid had clearer visibility the closer the light source was to the substrates. In contrast, for substrates that exhibited background fluorescence, greater visibility was observed when distance was present between the light source and the substrate. This could be attributed to the particular high intensity light source that was being utilised in this investigation. Research conducted by Lincoln *et al.* (2006) demonstrated how the distance between the light source and the object affects the visibility of the fluorescence. Their research demonstrated that the visibility of fluorescence increased as the distance of the light source from the substrate decreased.

Due to the high intensity illumination provided by the Crime Lite XL, some ambient lighting within the environment did not prove problematic. Some ambient lighting was present during this investigation, whereby lighting from a laptop connected to the camera was present and lighting from the adjacent room. These other light sources did not seem to affect the enhancement of the biological staining, and as a result we can conclude that it is not essential to block out all light within the scene. This provides significant benefits over methods that require complete darkness in order to successfully detect biological staining. De Forest *et al.* (2009) came to the same conclusion where it was not necessary to block out all ambient light from a scene.

4.3.1.7 Other artefacts

The camera system adapted with the ALS was capable of detecting other artefacts in addition to the biological fluids on the materials, as shown in Figure 4.38. Fibres and other small particles were enhanced by the light source and produced a fluorescent response. As a result this technique, with appropriate lighting and filters, could also be used as a screening method for other types of evidence, including hairs and fibres, in addition to biological fluids. De Forest *et al*. (2009) found that the light sources used in their study also detected other artefacts such as fibres on the material.

This study has clearly demonstrated that the 360^{o} camera and ALS combination could successfully detect and document biological staining on different substrates at different distances from the substrate. As a result, this technique could provide a more effective method for locating biological fluids than current methods, which utilise low power ALS's which require the investigator to close range search a crime scene. This technique could eliminate the need for close range blind searching of a crime scene and direct an investigators attention to target staining more quickly. The opportunity to rapidly and covertly screen a crime scene for biological fluids will facilitate simultaneous location and visualisation of evidence.

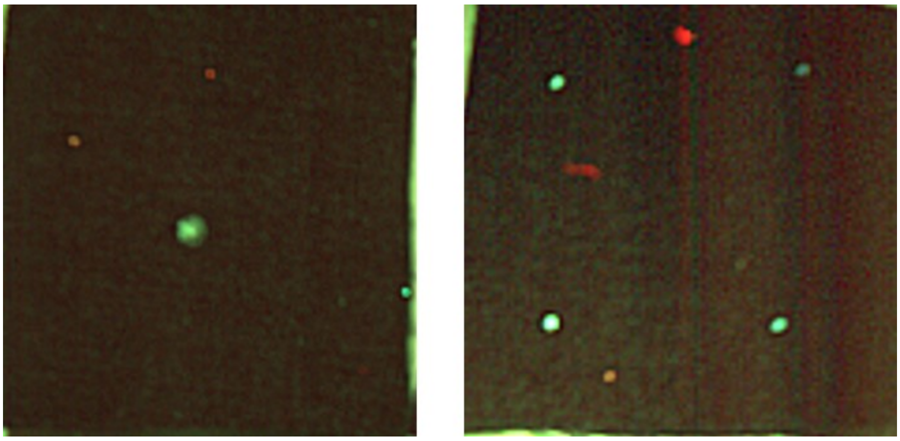


Figure 4.38: Artefacts such as fibres identified on the substrate.

4.3.2 Blood

The visualisation and documentation of blood using BlueStar® Forensic and a 360° camera technique on each substrate are discussed in turn.

4.3.2.1 White Cotton

The bloodstains deposited onto the white cotton substrate were highly visible when examined under natural light, as shown in Figure 4.39 (left). However, after subsequent application of BlueStar® Forensic, the 360° camera was unable to successfully detect the bloodstains on the white cotton surface, as shown in Figure 4.39 (right).

4.3.2.2 Dark Blue Cotton

The bloodstains deposited onto the dark blue cotton substrate were barely visible when examined under natural light, as shown in Figure 4.40 (left). However, after subsequent application of BlueStar® Forensic, the 360° camera was unable to successfully detect the bloodstains on the dark blue cotton surface, as shown in Figure 4.40 (right).

4.3.2.3 Coloured Cardboard

The bloodstains deposited onto the coloured cardboard substrate were highly visible when examined under natural light, as shown in Figure 4.41 (left). However, after subsequent application of BlueStar® Forensic, the 360° camera was unable to successfully detect the bloodstains on the coloured cardboard, as shown in Figure 4.41 (right).

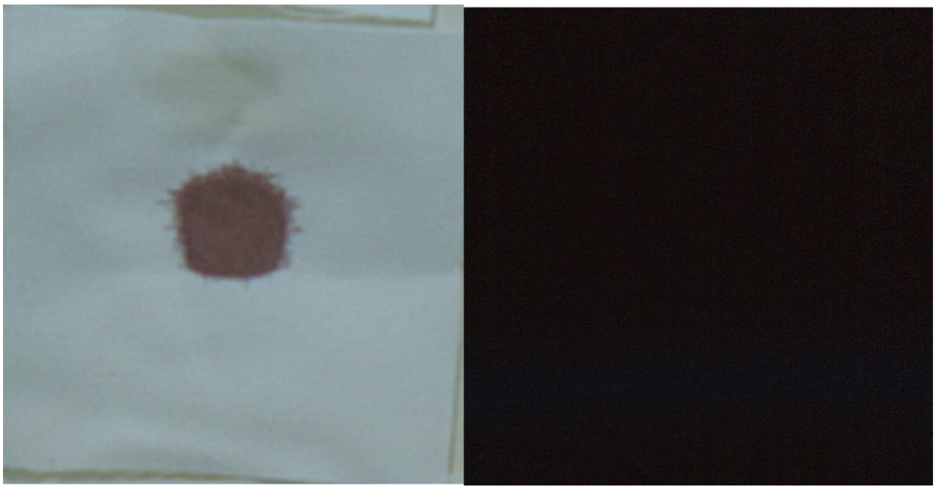


Figure 4.39: 200 µL Blood staining on white cotton swatch 10 cm x 10 cm
Left: Blood exposed to natural light. Right: Blood applied with BlueStar® Forensic

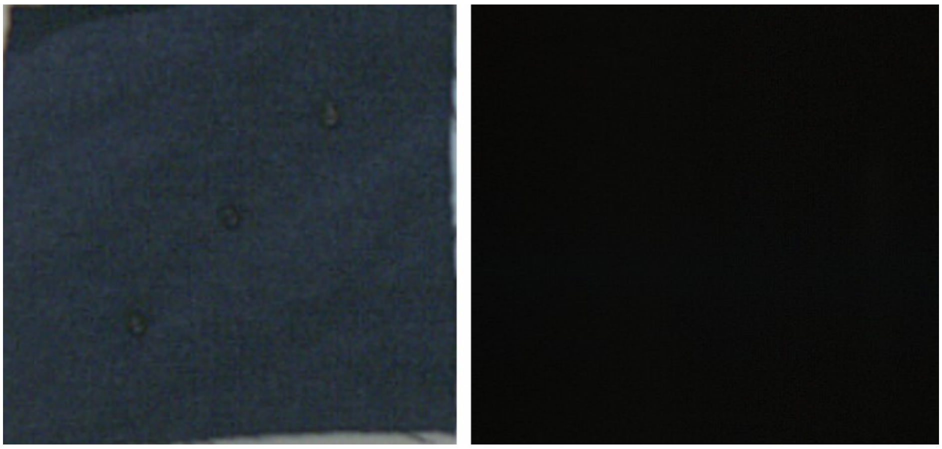


Figure 4.40: 100 µL Blood staining on dark blue cotton swatch 10 cm x 10 cm
Left: Blood exposed to natural light. Right: Blood applied with BlueStar® Forensic

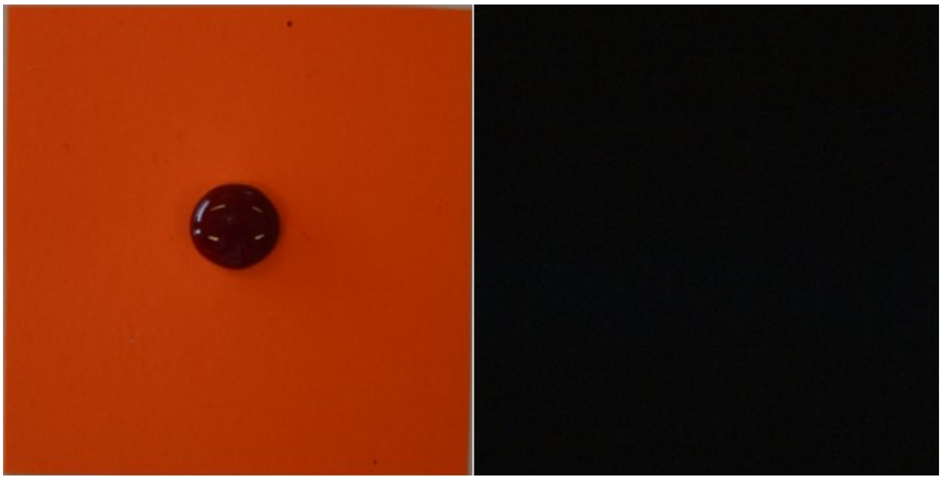


Figure 4.41: 200 µL Blood staining on coloured cardboard swatch 5 cm x 5 cm
Left: Blood exposed to natural light. Right: Blood applied with BlueStar® Forensic

For all substrate types, capturing the chemiluminescent response exhibited by the blood drops applied with BlueStar® Forensic using the 360° camera proved impossible. The chemiluminescent response exhibited by the blood was very short lived (Hetzel, 1991) and as a result, the 360° was unable to capture any response. In order to capture the greatest level of detail within the photographs, each scan was set to a maximum resolution but this increased the time taken to complete a scan and decreased the rotation speed of the lens. To counteract this, a low-resolution scan was used which would increase the speed of the capture, by increasing the rotation speed of the lens. Unfortunately even with the increased camera speed, the 360° camera system was still unable to capture the chemiluminescent response exhibited by the bloodstains. The researcher did observe a slight luminescent response from the bloodstains with the naked eye, but as previously mentioned the response was very short lived. In this instance, the 360° camera system did not provide any benefits to current methods of photography where chemiluminescent reactions are utilised.

Recommended best practice for the photography of chemiluminescent reactions requires optimum exposure and aperture settings to achieve the best photograph of the fluorescent response (Cheyne, 2011). In these instances, a long shutter speed and exposure is used to ensure the response is captured (Hetzel, 1991; Courtney *et al.*, 1996; Cheyne, 2011). Some authors also recommend that HDR be used to aid in the capture of the reaction (Marsh, 2014). Due to the automated nature of the 360° camera used in this investigation, it was not possible to adjust the exposure and aperture settings in order to photograph the chemiluminescent response.

4.3.2.4 Infrared Photography of Bloodstains

Although chemiluminescent reactions have been utilised extensively within criminal investigations for the detection of blood, technology development and research has demonstrated that more innovative and non-invasive methods are available for the detection of blood at crime scenes. These methods involve using Infrared light (IR) for the detection of bloodstains (Lin *et al.*, 2007; De Broux *et al.*, 2007). Infrared light is found on the electromagnetic spectrum at 760 nm – 1500 nm (Marin and Buszka, 2013). IR methods offer significant advantages over LED’s when dark surfaces are present and rely on the ability to create contrast of the background substrate to the biological fluid (Marin and Buszka, 2013; DeForest *et al.,* 2016). IR is useful in situations where the biological fluid of interest may be similar in colour to the background material, which it is deposited onto such as dark surfaces (Raymond and Hall, 1986; Farrar *et al*., 201; DeForest *et al*., 2016) (Figure 4.42).

IR photography of bloodstains has proved to be a more successful method for the detection of blood on surfaces as the IR changes the contrast of the blood against its background to improve its visualisation and does not rely on a chemical reaction (Perkins, 2005; Farrar *et al*., 2012; DeForest *et al.,* 2016). IR capture of the bloodstained samples was planned, however later exploration into the 360^{o} camera lens components meant that this was no longer possible. As described in *Section 4.1.5 Photographing Biological Fluids subjected to Alternate Light Sources,* cameras need to be adapted in order to capture radiation in the IR or UV regions by removing the hot mirror. It was not possible in this case to remove the hot mirror from the camera lens (Figure 4.43) and therefore was not possible to conduct any investigations regarding IR for the detection of bloodstains.

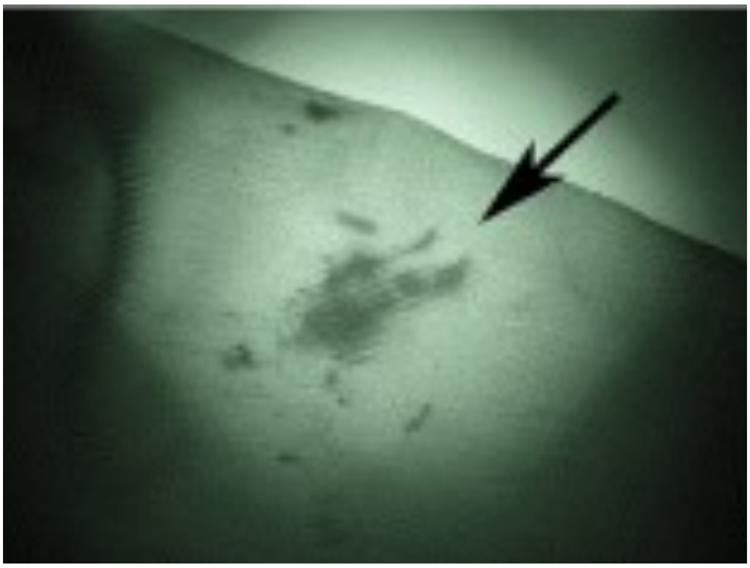


Figure 4.42: Infrared Detection of Bloodstains. IR illumination allows visualisation of bloodstaining on a dark substrate. Taken from: Lin et al. (2007).

Figure 4.43: Hot mirror installed in the 360^o camera to prevent IR/UV interference which can reduce photograph quality.

4.3.3 Participant Detection of Biological Fluids

The number of drops of semen drawn by the participants can be found in Table 4.1.

The results in table 4.1 suggest that semen can be located and visualised on white cotton with a high degree of accuracy, given that all 10 participants identified 99 semen drops on the white cotton substrate (100% of semen drops identified given that 99 drops were deposited in total). For the white plotter paper substrate, 9 participants identified 300 drops of semen and 1 participant identified 304 drops. A total of 300 drops of semen were deposited onto the plotter paper and so participant 7 identified 4 more drops than were originally deposited. Despite the apparent high level of accuracy evidenced by the remaining participants, participant 7 could have identified artefacts on the substrate, which were not the target biological fluid. The authors were not concerned by this result, given that the technique had been able to locate and visualise the known semen samples, and accept that during casework, further analysis of any located sample would have to commence in order to identify the source of the biological fluid.

A reduced level of accuracy was exhibited on the dark blue cotton and cardboard substrates compared to the white cotton and white paper substrates. Participants detected between 238 and 305 drops of the 280 drops of semen that were initially deposited onto the dark blue cotton substrate. Participant 6 identified 25 more drops than were initially deposited and this could be attributed to artefacts present on the substrate, such as fibres or other particles, which fluoresced.

Participants' detection of semen drops on the coloured cardboard ranged from 160 drops to 180 drops out of the 180 semen drops initially deposited. Just one participant identified all 180 drops of semen. The reduction in the level of accuracy was attributed to the substrate type. The yellow cardboard in particular demonstrated background fluorescence that masked the fluorescence from the semen stains, making them harder or impossible to detect. In addition, the increased working distances made the smaller volumes harder to detect and thus some participants were not able to detect the semen in these cases.

The number of drops of saliva drawn by the participants can be found in Table 4.2.

Table 4.1: The number of semen drops identified on each of the substrates by each participant

Substrate Type	Participant Number 1	2	3	4	5	6	7	8	9	10	Total Number of Drops Deposited	Average number of drops detected by all participants	Percentage of drops detected by all participants / %
	Number of semen drops identified by participants												
White Cotton	99	99	99	99	99	99	99	99	99	99	99	99	100
Dark Blue Cotton	270	264	263	238	271	305	249	252	258	259	280	262.9	93.89
White Plotter Paper	300	300	300	300	300	300	304	300	300	300	300	300.4	100.13
Coloured Cardboard	176	174	173	178	175	180	173	160	172	162	180	172.3	95.72

Table 4.2: The number of saliva drops identified on each of the substrates by each participant

Substrate Type	1	2	3	4	5	6	7	8	9	10	**Total Number of Drops Deposited**	**Average number of drops detected by all participants**	**Percentage of drops detected by all participants / %**
	Participant Number												
	Number of semen drops identified by participants												
White Cotton	32	31	20	35	37	26	31	15	30	24	90	28.1	31.22
Dark Blue Cotton	3	5	21	6	4	100	7	0	1	3	180	15.0	8.33
White Plotter Paper	180	178	178	178	180	180	178	176	180	178	180	178.6	99.22
Coloured Cardboard	166	150	166	151	166	178	165	158	163	119	180	158.2	87.88

In comparison to semen, considerably less accuracy was demonstrated by participants during the location and visualisation of saliva. Four participants were able to identify all 180 saliva drops on the white plotter paper substrate, with 5 participants missing 2 drops initially deposited, and one participant failing to detect 4 drops (1.11% missed), as shown in table 4.2. The majority of participants identified >87% of the total number of drops initially deposited on coloured cardboard. Participant 10 only managed to identify 66 % of saliva drops on the coloured cardboard, which could be attributed to its colour, and the yellow substrate demonstrating background fluorescence, masking the fluorescence of the saliva. In addition, saliva can be more difficult to detect due to a less intense fluorescent response caused by a lack of solid particles within the biological fluid (Virkler and Lednev, 2009; Miranda *et al.,* 2014).

The level of accuracy associated with locating and visualising saliva stains on white cotton was significantly reduced, with only 33 % of the total drops deposited being successfully identified. The reduced level of accuracy associated with the detection of saliva on white cottons was likely to have been due to the inherent fluorescence observed by the substrate, thus masking the fluorescence from the saliva (Kobus *et al.*, 2002; Camilleri *et al.*, 2006).

Very few participants were able to detect saliva stains on dark blue cotton. This could be attributed to the porous nature of the substrate whereby the saliva was absorbed into the substrate rather than drying on the surface, leaving little surface reflectance (Kobus *et al.*, 2002; Miranda *et al.*, 2014; Sterzik *et al.*, 2016). The difficulty in detection of saliva could also be due to the very weak nature of saliva fluorescence (Camilleri *et al.*, 2006).

The results of this research have demonstrated a variation in the ability to locate and visualise semen and saliva on a variety of substrates using a non-destructive technique; 360° photography combined with an alternate light source. Further investigation observing a broader range of substrates is planned to determine the optimum conditions and limitations of this combined technique and its applications for casework, particularly in the presence of alternative agents, which may also fluoresce, and therefore introduce false positive results. In addition, the author recommends the investigation of other biological fluids, such as vaginal secretions and urine, to determine the optimum conditions for their successful location and visualisation.

4.3.4 Limitations

Limitations associated with this research include the size of the environment used. The room dimensions only allowed for the camera to be placed at a maximum distance of 3 m away from the substrates however, this would be appropriate for the majority of crime scenes encountered. The results proved that some of the biological fluids, depending on the surface they were deposited onto, could be successfully documented using the camera system up to 3 m away. As a result, this method could be easily utilised in environments that measure 3 m x 3 m with the camera positioned in the centre.

This research was conducted in a sterile, controlled environment, which does not represent common household environments where crimes are likely to be committed. As a result, no false positive results were obtained in this study and a more representative approach, investigating false positives from alternative agents that may fluoresce would need to be investigated. In addition, only one donor for saliva was utilised in this study and further work would utilise more donors. Research has previously demonstrated that saliva fluorescence can vary between different donors as well as within individuals, fluctuating at different times within a day, which is thought to be attributed to different protein contents within the saliva sample (Nanda *et al.*, 2011).

As previously described in *Chapter 3.3.1 Accuracy testing with known measurements*, the SceneCenter software is unable to measure any distance less than 2 cm. The software allows the user to select the exact pixels to measure but any item which is smaller than 2 cm will only ever be quoted as < 2 cm on the software application. This limits the potential applications for such technology. With regards to biological fluids, which are relatively small in volume when encountered at crime scenes, these fluids would not be able to be measured using the software, meaning measurements would still have to be taken at the scene. Particularly where blood pattern analysis is concerned, measurements can be taken of the blood stains and estimations based on their size and location can be used to estimate a point of impact. Therefore, due to the internal unit limit set within the software this technology would be unsuitable for use at crime scenes for capturing blood patterns – photography could be taken but any subsequent measurements could not.

4.3.5 Laser Light

The use of LED's in forensic science crime scene investigations is well established due to their low power multispectral wavelength allowing a number of body fluids to be potentially identified simultaneously. However their limited power output requires the operator to be close to the item being examined. Lasers offer a more powerful tool coupled with specific wavelength outputs (monochromatic) (Breeding, 2008) but they have not been commonly used in crime scenes due to their cost and the need for extra care with eye protection and extraneous reflected beams when using Class 4 lasers. Research into the feasibility of lasers for detecting biological fluids has provided systems which are lower cost and more portable than their earlier heavy and cumbersome counterparts (Auvdel, 1987). In recent years their reduced cost and size coupled with their ability to examine larger areas within crime scenes has seen a resurgence in interest by the forensic community.

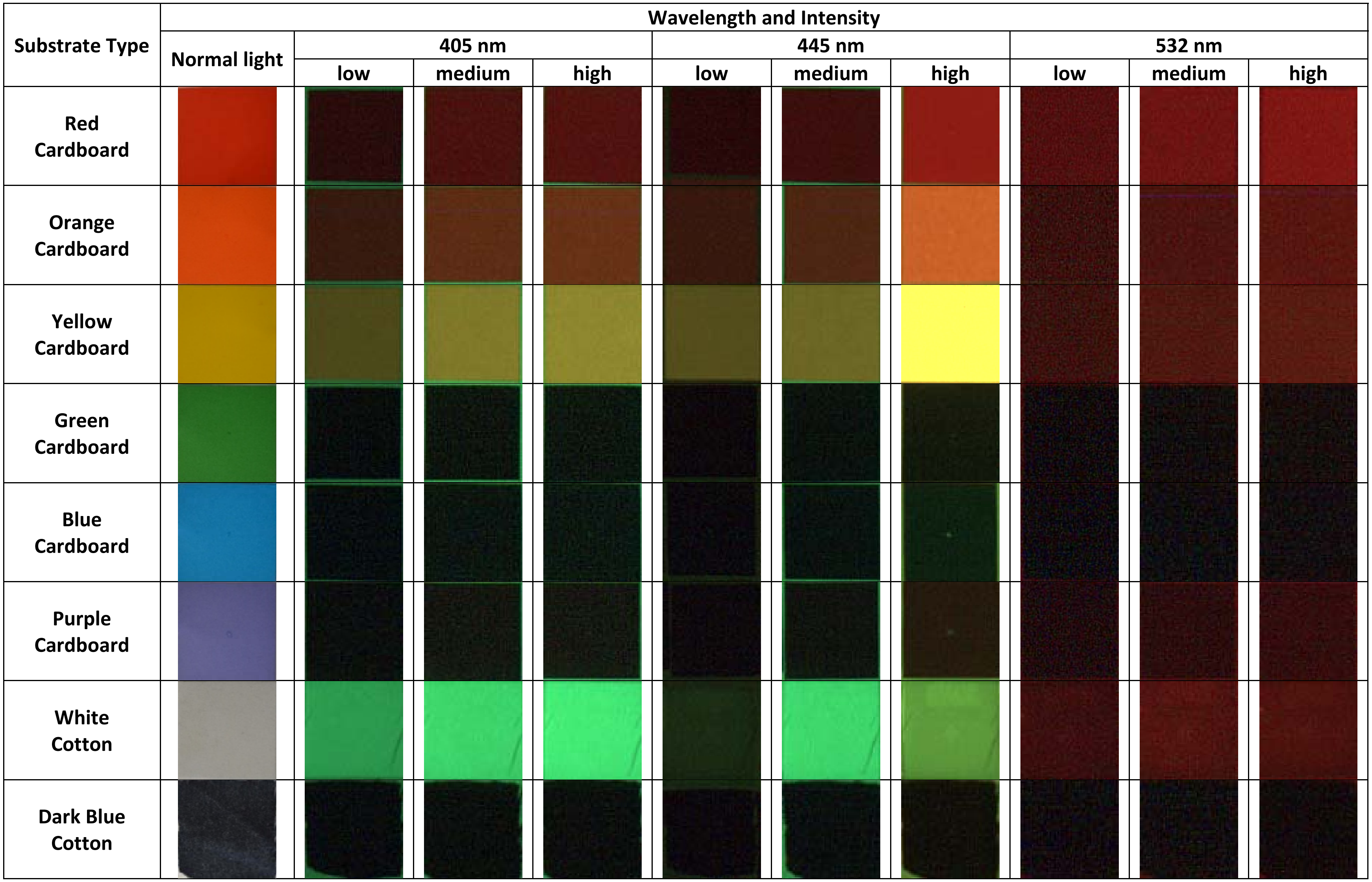
This is the first report demonstrating the successful location and visualisation of biological fluids using a 360^{o} camera system and laser light sources. The location and visualisation of blood, semen and saliva using a Triple Laser (Tech-Long Industry Ltd.) and 360^{o} camera, SceneCam (Spheron VR AG) technique on each substrate type using 405 nm, 445 nm and 532 nm wavelengths are discussed in turn.

To access the panoramas of semen, saliva and blood on all substrate types at each wavelength and intensity please refer to the supplementary USB card and open the files entitled 'Chapter 4.3.5 – 405 nm low, medium and high intensities', 'Chapter 4.3.5 – 445 nm low, medium and high intensities' and 'Chapter 4.3.5 – 532 nm low, medium and high intensities'. Within these files please select the 'Start' file. This will open the SceneCase with the panoramas.

4.3.5.1 Semen

The semen stains deposited onto each substrate appeared barely visible when examined under natural light. The visualisation of 5 μL semen staining using the 360^{o} camera showing all substrate types, wavelengths and intensities can be found in Figure 4.44. Figure 4.44 demonstrates the 360^{o} camera capture of any fluorescent response exhibited by the 5 μL semen samples on each substrate type at each wavelengths and power intensity. The 445 nm wavelength at the highest power intensity provided the best visualisation of the semen on most substrate types, compared with the other wavelengths used. The location and visualisation of the small volume (5 µL) semen stains was difficult on most substrates at all wavelengths; 405 nm, 445 nm and 532 nm. The small volume utilised could have absorbed into the surface of the substrates, particularly the porous fabrics, such as white cotton and dark blue cotton, leaving little biological fluid on the surface to induce a fluorescent response.

Figure 4.44: 360º visualisation of 5 µL semen staining on all substrate types at wavelengths 405 nm, 445 nm, 532 nm and the variable low, medium and high intensities



At higher intensities the yellow cardboard substrate demonstrated significant background fluorescence this masking the potential for any target fluorescence from the semen sample. For the small 5 µL volume, the HDR on the 360^{o} camera did not reduce the background fluorescence to reveal the biological fluid and as a result the semen could not be visualised on the yellow cardboard.

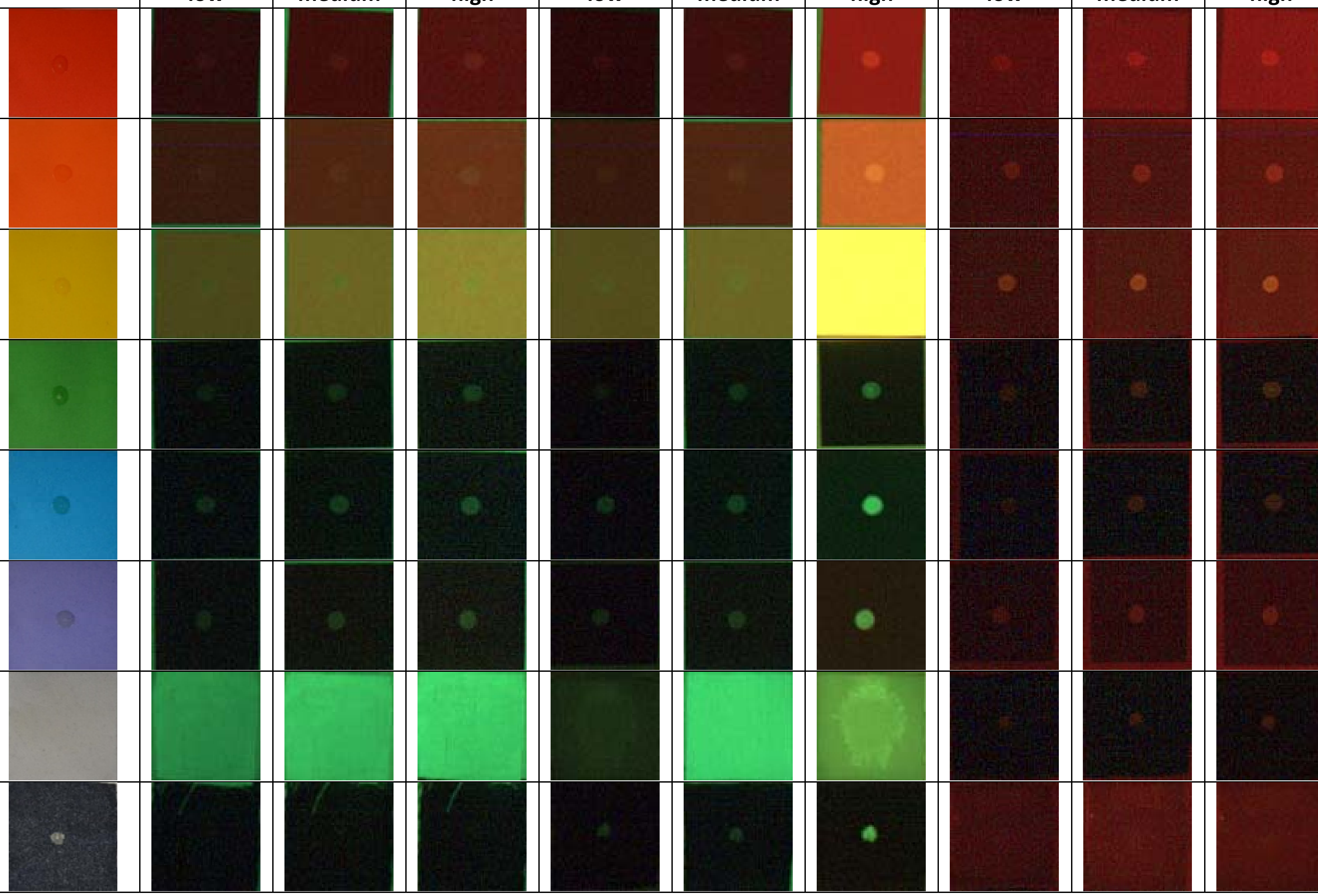
The white cotton substrate proved difficult for the detection and visualisation of small volumes of semen due to the inherent natural fluorescent properties of the optical brighteners contained within the material (Auvdel, 1987). Using the 405 nm and 445 nm wavelengths the white background was highly fluorescent. However, using the 445 nm wavelength at the highest power intensity, semen at 5 µL was detected. Using this wavelength and power intensity, there was no, or little background fluorescence from the white cotton substrate to mask the target fluorescence from the semen. In addition, semen could also be detected using the 532 nm wavelength at all power intensities, although the lowest power intensity response was very faint.

The dark blue cotton substrate proved problematic for detecting and visualising the semen at 5 µL volumes. The dark nature of the dark blue cotton can affect visualisation of biological fluids using alternate light or laser sources due to the substrate absorbing the light (Su, 2015). The white cotton substrate also proved difficult for the visualisation of semen but this was attributed to the natural fluorescent properties of optical brighteners likely to exist within the material (Auvdel, 1987).

The visualisation of 250 µL semen staining using the 360^{o} camera showing all the substrate types, wavelengths and intensities can be found in Figure 4.45. Figure 4.45 demonstrates the 360^{o} camera capture of any fluorescent response exhibited by the 250 µL semen samples on each substrate type at each wavelength and power intensity.

Figure 4.45: 360º visualisation of 250 µL semen staining on all substrate types at wavelengths 405 nm, 445 nm, 532 nm and the variable low, medium and high intensities

Substrate Type	Wavelength and Intensity									
	Normal Light	405 nm			445 nm			532 nm		
		low	medium	high	low	medium	high	low	medium	high
Red Cardboard										
Orange Cardboard										
Yellow Cardboard										
Green Cardboard										
Blue Cardboard										
Purple Cardboard										
White Cotton										
Dark Blue Cotton										



Due to the larger volume size, 250 µL was easier to detect and visualise using the laser light. Using the 405 nm wavelength, the majority of the semen drops were detectable using the laser light and 360^{o} camera. All of the semen drops on the coloured cardboard were detected successfully, with greater visibility of the stains using the higher intensity. However, the white cotton substrate provided a difficult surface for the detection of semen stains which could not be successfully visualised using the laser light or 360^{o} camera. In comparison to the coloured cardboard substrate which is non-porous, the cotton substrates were porous and therefore the semen could have been absorbed into the fabric limiting the surface fluorescence available. In contrast to the results obtained from the 5 µL semen stains, the 250 µL semen stains were successfully detected and visualised using the laser light and 360^{o} camera. The porous nature of the substrate absorbs the biological fluid, as shown with the unsuccessful detection of 5 µL of semen, however the larger volumes allow some of the drop to sit on the surface of the substrate without being absorbed which allows the biological fluid remaining on the surface to fluoresce.

Using the 445 nm wavelength at the low and high power intensities, all semen stains could be successfully detected on all of the substrates using the laser light and 360^{o} camera. Using the 445 nm wavelength at the medium intensity all semen stains were successfully detected on the coloured cardboard and dark blue cotton substrates. The semen stain on the white cotton substrate was not detected due to the fluorescence detected from the background which can be attributed to optical brighteners present in the substrate. All of the semen drops on the coloured cardboard were detected successfully with greater visibility using the higher intensities.

The 532 nm wavelength appeared to be the most consistent wavelength, demonstrating how changing the intensity had little effect on the detection and visualisation of the semen stains. This wavelength produced a clear contrast between the background and the biological fluid enabling successful detection and visualisation by the laser and 360^{o} camera. All semen stains were successfully detected and visualised on all substrate types using the 532 nm wavelength and at all power intensities; low, medium and high.

4.3.5.2 Saliva

The saliva stains deposited onto each substrate appeared barely visible when examined under natural light. The visualisation of 5 µL saliva staining using the 360^{o} camera showing all substrate types, wavelengths and intensities can be found in Figure 4.46.

The detection and visualisation of the 5 µL saliva samples proved difficult using the laser light at all wavelengths; 405 nm, 445 nm and 532 nm and at all power intensities; low, medium and high. The lack of saliva detection in this case could be attributed to the small sample volume which was utilised and the lack of solid particles within the saliva leaving little sample material for the laser light to induce any fluorescent response (Camilleri *et al.*, 2006; Miranda *et al.*, 2014). In addition, the small sample volume may have been absorbed into the material of each substrate whilst drying as opposed to drying on the surface of the substrate (Miranda *et al.*, 2014). Although a fluorescent response was not observed by any of the saliva samples using the laser light, in this instance, the presence of a biological fluid cannot be excluded and further testing would be required (Kobus *et al.,* 2002).

The visualisation of 250 µL saliva staining using the 360^{o} camera showing all substrate types, wavelengths and intensities can be found in Figure 4.47. In contrast to the more successful visualisation of semen at greater stain volumes, the greater volume of saliva had little effect on the detection and visualisation using the laser light and 360^{o} camera. The red and orange cardboard substrates were the best substrate for the successful detection and visualisation of saliva samples at 250 µL as these could be detected at all wavelengths; 405 nm, 445 nm and 532 nm and power intensities; low, medium and high studied. The saliva samples were not successfully detected using any of the wavelength and intensity combinations for the dark blue and white cotton substrates. The white cotton substrate exhibited significant background fluorescence which masked any possible target fluorescence from the saliva.

The HDR ability that the 360^{o} camera provides had little or no effect on the detection and visualisation of saliva in most instances, on the different substrates. The HDR allows control of the light intensity within the image, which can enhance the detection of the biological fluid in some instances, as demonstrated in *Chapter 4.3.1.4 Coloured Cardboard.*

Figure 4.46: 360º visualisation of 5 µL saliva staining on all substrate types at wavelengths 405 nm, 445 nm, 532 nm and the variable low, medium and high intensities

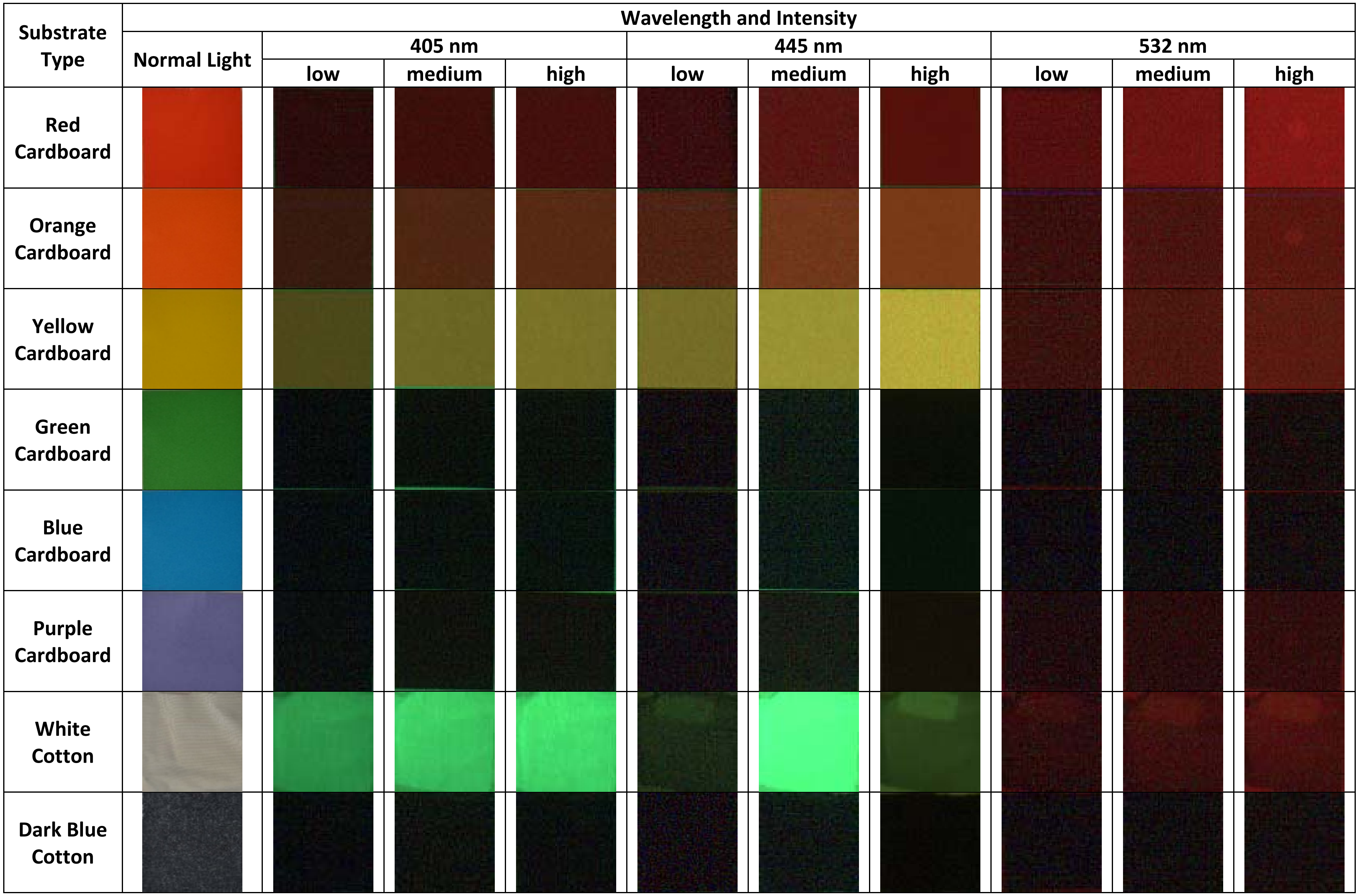
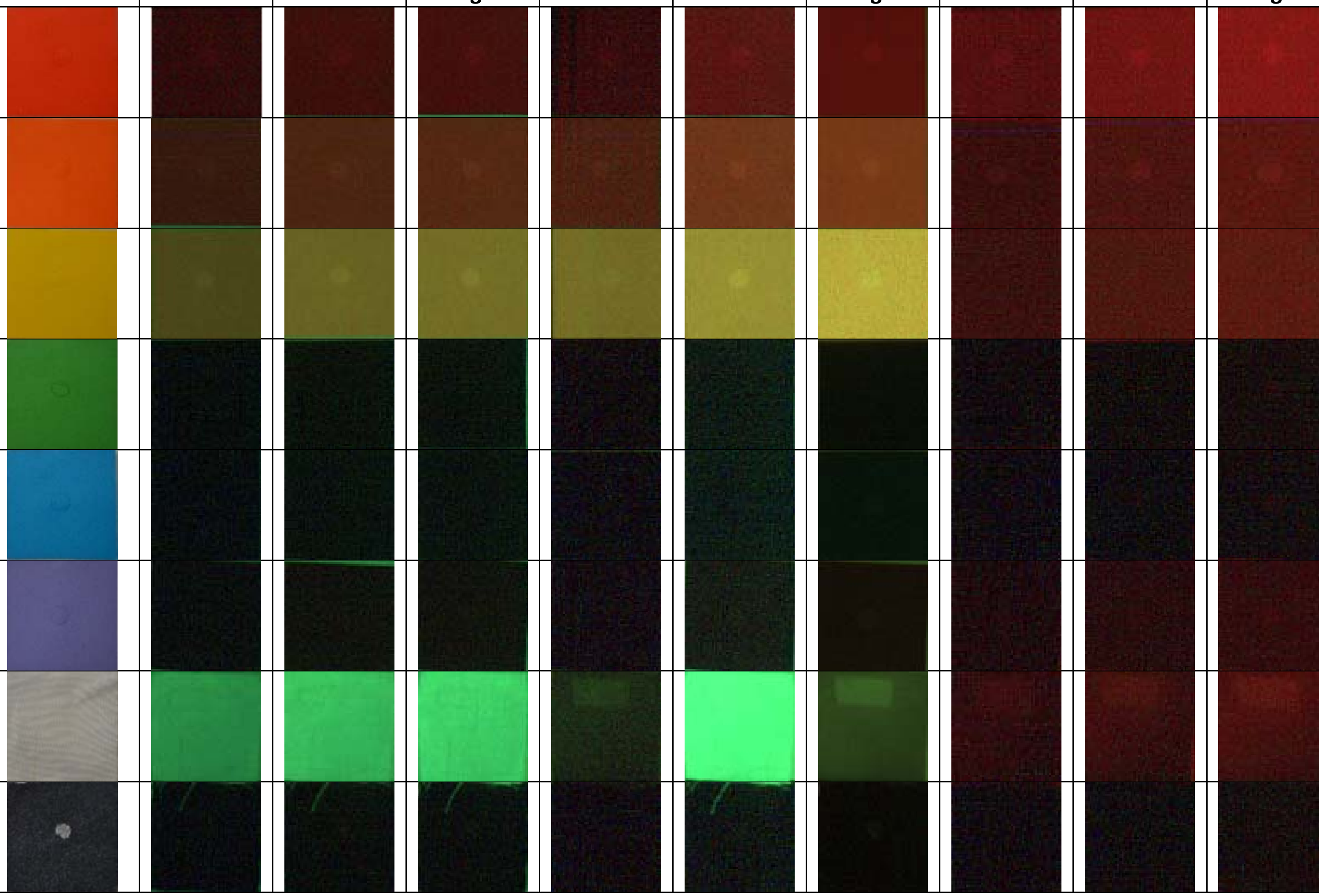


Figure 4.47: 360º visualisation of 250 µL saliva staining on all substrate types at wavelengths 405 nm, 445 nm, 532 nm and the variable low, medium and high intensities



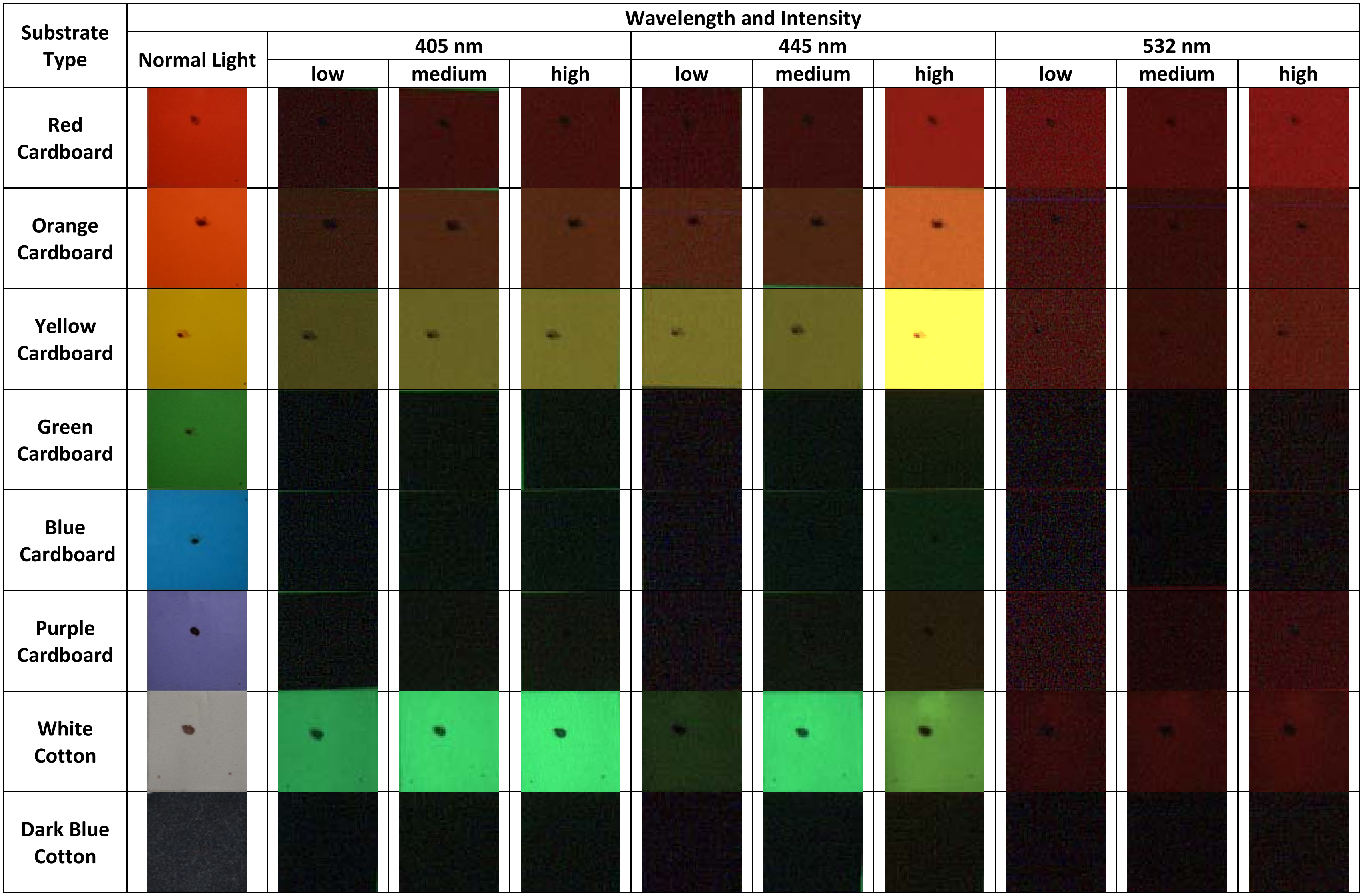
Substrate Type	Wavelength and Intensity									
	Normal Light	405 nm			445 nm			532 nm		
		low	medium	high	low	medium	high	low	medium	high
Red Cardboard										
Orange Cardboard										
Yellow Cardboard										
Green Cardboard										
Blue Cardboard										
Purple Cardboard										
White Cotton										
Dark Blue Cotton										

4.3.5.3 Blood

Blood samples were visible on all substrate types excluding the dark blue cotton under natural light. The visualisation of 5 μL blood staining using the 360^o camera showing all substrate types, wavelengths and intensities can be found in Figure 4.48. The visualisation of the blood was not significantly enhanced using the laser light source and 360^o camera. In most cases, the use of the laser light reduced the detection of any blood present.

Using the 445 nm wavelength at the highest power intensity, blood was clearly visible on both the purple and blue cardboard substrate. The blood deposited onto the blue cardboard was not visible using any other wavelengths or power intensities. Although visible, there was little change in contrast of the background to the biological fluid. In this instance, the laser light and 360^o camera system did not provide any benefits over current methods for detecting bloodstains but provided non destructive benefits over the detection of bloodstains using chemical methods.

Figure 4.48: 360º visualisation of blood staining on all substrate types at wavelengths 405 nm, 445 nm, 532 nm and the variable low, medium and high intensities



4.3.5.4 Limitations of this study

This research did not seek to identify the effect of distances of the laser from the biological fluid staining on the ability to successfully detect and visualise the biological staining. To avoid close range searching at crime scenes, research would need to be conducted investigating the effects of the laser light source distance from the target staining and a limit of detection.

This research was conducted in a sterile, controlled environment, which does not represent common household environments where crimes are likely to be committed. As a result, no false positive results were obtained in this study and a more representative approach, investigating false positives from alternative agents that may fluoresce would need to be investigated.

4.4 Conclusion

Both laser light and LED light sources provide a non-destructive screening method for the detection of biological fluids making them preferable over their chemical screening counterparts (Auvdel, 1987). This research did not investigate the differences and similarities between the LED light source and the laser light but many studies have previously compared the relative merits of each. Research conducted by Auvdel (1987) evaluated the detection capabilities of laser and UV methods for detecting biological fluids. The research demonstrated that the laser was shown to be a more effective method for detecting biological stains than the UV method. However, Auvdel (1987) stated that a higher success rate for the detection of biological stains was achieved through a combination of both laser and UV light sources. In contrast, James *et al.* (2005) stated that alternate light sources such as high intensity lights and laser lights are comparable in their ability to detect biological fluids and that the choice of which to adopt is based upon costs, portability and ease of use, for example.

This study has demonstrated that light and laser light sources using differing wavelengths can be used to successfully identify and subsequently capture biological fluids using a 360^{o} camera. The 360^{o} capture of the scene gives contextual and spatial information about the nature of biological fluid deposition in a crime scene. The success of this study provides the opportunity to allow a more dynamic recording of the spatial placement of biological fluids and allows fluids found to be placed in context – a significant improvement over still digital photography.

The results of this research have demonstrated a variation in the ability to locate and visualise semen and saliva on a variety of substrates. Results demonstrated that semen fluorescence is more intense than that exhibited by saliva, which can make saliva more difficult to detect. The weak intensity of the fluorescence exhibited by saliva can be attributed to the lack of solid particles within the saliva sample. Substrate type and colour had a significant effect on the detection of the biological fluid, with limited fluid detection on darker substrates. The porous nature of the white and dark blue cotton substrates meant the biological fluid was absorbed into the substrate rather than drying on the surface, leaving little surface fluorescence. Some substrates have inherent photo luminescent properties and can mask fluorescence from biological fluids, making them harder to detect.

These techniques act solely as presumptive screening methods and can be used to inform and direct an investigator to the locations of biological staining during documentation of the scene. The techniques cannot differentiate between biological fluids and therefore any fluorescent areas would require further confirmatory testing to identify the fluid in question. In addition, where a fluorescent response is not observed, the presence of a biological fluid cannot be entirely excluded. Further investigation is required to observe a broader range of substrates to determine the optimum conditions and limitations of this combined technique and its application for casework, particularly in the presence of alternative agents, which may also fluoresce, and therefore introduce false positive results.

The unique real-time HDR ability of the SceneCam significantly enhanced the detection of biological fluids where background fluorescence masked target fluorescence. These preliminary results are presented as a proof of concept for combining 360^{o} photography using HDR and an alternate light/laser source for the detection of biological stains, within a scene, in real time, whilst conveying spatial relationships of staining to other evidence. This technique presents the opportunity to rapidly screen a crime scene for biological fluids and will facilitate simultaneous location and visualisation of biological evidence in addition to capturing a complete 360^{o} view of the scene. The examination process and post processing of the panoramas is likely to take more time than traditional examination methods. However, the combined 360^{o} camera and ALS technique provides complete interactive panoramas of the scene, in addition to capturing the locations and spatial relationships of biological fluids and allowing exploration of the scene at anytime, from any location.

Chapter 5: Technology within the UK Criminal Justice System

Preface

The previous chapters have explored and considered the variety of panoramic imaging technologies available to police services and determined some of the criteria used to assess the suitability of technology into standard operating procedures prior to the integration into organisations. The accuracy and precision of one panoramic imaging technology was investigated in addition to determining the feasibility of adapting current 360^{o} imaging technology to enhance current lighting methods for visualising and documenting biological fluids within crime scenes. The adoption of these types of recording technology is not solely dependent upon user requirements and costs. To ensure technology can be used to its utmost potential it needs to be able to fulfil all the requirements of the organisation seeking to adopt it and be utilised throughout the entire criminal investigation, from crime scene to courtroom. As a result it is necessary to discover how courts adapt to integrate new technology to discover whether the implementation of such crime scene documentation technology is possible.

5.1 Introduction

The delivery of forensic evidence in a UK Court of law currently involves arduous descriptions of events and evidence from an investigation, which can be a time consuming and laborious task (Schofield, 2016). Verbal descriptions can present problems whereby laypersons may misinterpret or not be able to fully comprehend the information being described to them (Schofield and Fowle, 2013). Conveying evidence from a scene, which both experts and laypersons can fully understand, remains an ever-difficult task (Chan, 2005). The most commonly used methods for delivering evidence to the court involves verbal statements, printed photographs and sketches of the scene, and these have remained standard for most courtrooms (Lederer, 1994; McCracken, 1999). It has often been questioned as to whether these methods of delivery provide the most effective method for communicating complex information to a jury. A survey conducted by the American Bar Association (2013) previously demonstrated that significant volumes of technical information or complex facts can not only overwhelm the jury but also often confuses them, leaving them feeling bored and frustrated (Kuehn, 1999; Schofield, 2009). In turn this can present difficulties in absorbing and retaining information (Krieger, 1992). Evidence becomes meaningless if it cannot be understood and conveyed effectively. As Lederer states "Communication is at the heart of litigation; everything else is secondary" (Lederer, 1994).

5.1.1 Current Methods for the presentation of evidence

Scientific advances in technology development over recent years have provided advanced methods for recording, visualising and presenting evidence (Shelton, 2008; Schofield, 2016). Past courtroom evidence presentation methods were limited to sketches, photographs and verbal descriptions, which at the time were appropriate and effective methods for conveying evidence (Lederer, 1994). However, these methods lack flexibility and the ability to deliver the information in a fully understandable manner. Basic demonstrative exhibits in the courtroom were time consuming, expensive, and limited in the their ability to be edited (Manlowe, 2005).

With technology continuing to develop, courtrooms have had to become more accommodating towards its use and integration of technology to prevent inefficiencies. The opportunities which technology can provide include the ability to speed up processes, allow documents to be searched for quickly, greater communication between individuals and the ability to collaborate and disseminated information to ultimately improve efficiency (Obrien and Marakas, 2010; Manker, 2015).

The majority of courtrooms have begun to integrate basic courtroom technology such as tablets and TV screens with a limited number integrating more high-end technological solutions such as CG presentations (Chan, 2005). Technology development has enabled the use of technology within the courtroom to change dramatically over the past 20 years with numerous hardware and software products being introduced to aid in the delivery of complex scientific evidence and create a more efficient Criminal Justice System (CJS) (Manlowe, 2005).

5.1.2 Visual Presentation Methods

Visual methods for presenting information have become more common in recent years and individuals are accustomed to having information accessible to them 24 hours a day, 365 days a year using visual media such as laptops, tablets and smartphones (Pointe, 2002; Manlowe, 2005). As a result, these individuals are used to receiving high impact information in relatively short periods of time. The range of technologies now available to police services and the courtrooms has expanded and as a result courtrooms are turning into cinematic display environments (Heintz, 2002; Schofield, 2009; Schofield, 2016). Due to the increase in the adoption of technology for use in criminal investigations, which were once expensive and far fetched, the price of these systems has significantly decreased, making them a more viable and affordable option than their previous counterparts. In addition, these products have become far easier to use and extensive computing knowledge is not required in order to use them (Manlowe, 2005).

Complex information from a criminal investigation needs to be delivered in an understandable manner to non-scientists (Schofield and Fowle, 2013; Tung *et al.,* 2015; Schofield, 2016) and the outcome of the trial could depend on the juror’s comprehension of the evidence presented to them. The juror’s ability to view the presentation is key to the success of an argument (Manlowe, 2005). The influence of the presentation method of evidence on juror’s comprehension has been extensively researched (Tung *et al.,* 2015). The attention span of an average member of a jury is approximately 7 minutes (Devine *et al.*, 2001; Schofield, 2009) and as a result complex information needs to be delivered in the quickest and most efficient manner. Many scientific studies have been conducted to determine the most effective methods for presenting evidence to ensure jurors can understand and recall the evidence (Tung *et al.*, 2015). When presented with oral evidence, jurors experienced difficulties in maintaining concentration (Tung *et al.,* 2015) and when compared with other methods, only 10% of the verbal evidence described to them was retained (Selbak, 1994). Substantial research demonstrates that visual methods for the delivery of evidence within a courtroom provides significant improvements in juror comprehension and recollection of information (Krieger, 1992; Selbak 1994; O Flaherty, 1996; Schofield and Fowle, 2013).

Visual methods of delivery can consist of images, graphics, scene reconstructions or animations and are often referred to as demonstrative evidence, that is evidence, which is demonstrated through means other than verbal descriptions (Schofield and Fowle, 2013). Visualisation seeks to represent data in a more comprehensible and understandable manner (Schofield and Fowle, 2013). Selbak (1994) demonstrated that visual methods for delivering evidence provided greater stimulation for the jury members. A study conducted in the UK by a crash investigation and training unit investigated the effect of the evidence presentation on juror's performance. Three groups were given information in the form of textual descriptions, images and a combination of text and images, respectively (Doyle, 1997; Schofield *et al*., 2000). The group who received solely textual descriptions did not perform as well as the other two groups.

The Weiss McGrath report demonstrated that when presented with verbal descriptions jurors would only retain 10% of the information after 72 hours. In contrast, and further demonstrating the advantage of visual presentation methods over verbal descriptions, jurors shown a visual presentation retained 20% of the information. The most effective method to increase juror retention was found to be a combination of both verbal descriptions and visual presentations, where jurors presented with the combination presentation of evidence were able to successfully recall 65% of the information after 72 hours (Weiss and McGrath, 1963; Manlowe, 2005). The data obtained from the Weiss McGrath report can be seen in Figure 5.1.

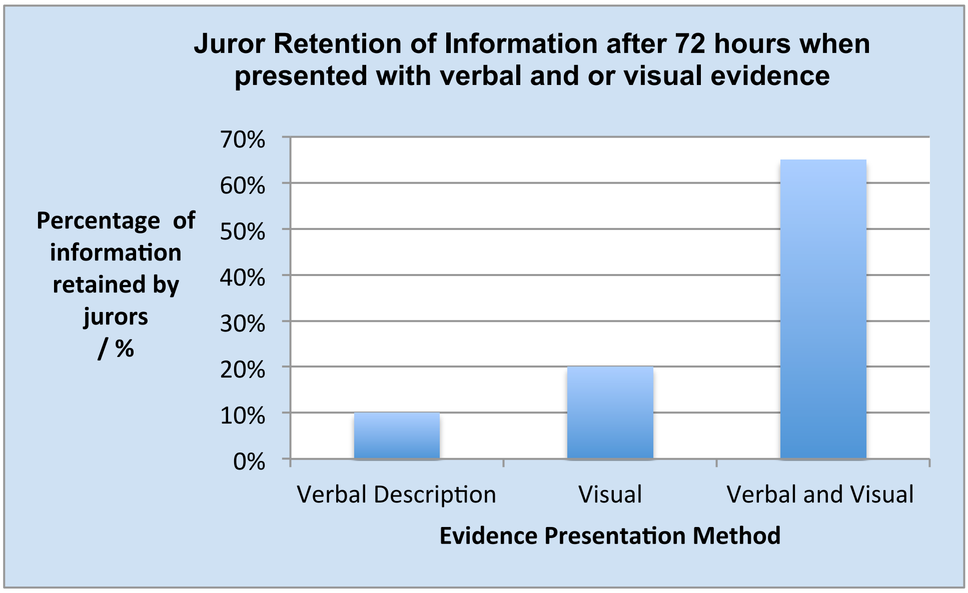


Figure 5.1: Data generated from the Weiss McGrath report demonstrating the retention of information of jurors based on the method of delivering the evidence.

Figure 5.1 conveys the information described in the preceding paragraph in a simpler and more understandable manner. Berkoff (1994) also demonstrated how visual presentation provides a more effective method for the presentation of evidence than verbal methods. In agreement with the Weiss McGrath report, verbal communication is most effective when combined with visual presentation methods (O Flaherty, 1996) with visual aids enhancing verbal testimonies (Nelson and Simek, 2013). The human brain begins to process information primarily through the eyes and so the interpretation of images occurs much more quickly than with textual information (Schofield and Fowle, 2013). The visual presentation of evidence is a more direct method and reduces the number of mental steps jurors take in order to comprehend the information being presented to them (Heintz, 2002). Visual evidence presentation has proved to be more engaging and entertaining than verbal methods. Research has demonstrated that the use of visualisation as a method of presenting evidence makes complex information easier for the jury to understand and relate to (Schofield, 2009). As a result, it has been suggested that cases could potentially be shorter and thus save the courts money, when evidence is presented using both oral and visual presentation methods. Some authors report that technology within the courtroom could save a quarter to a third of the time taken for a traditional trial, without the use of technology (Lederer, 2004).

5.1.3 Technology in the Courtroom

Forensic scientists must strive continuously to develop new and improved ways of presenting complex evidence. Technology has developed considerably over the past 20 years and has provided more advanced digital presentation tools to the expert. Forensic scientists and Scene of Crime Officer's viewpoint on the use of CG displays in the courtroom is changing due to the increasing requirement to communicate complex data to laypersons. Courtroom technology can be defined as "any system or method that uses technology in the form of electronic equipment to provide a clear benefit to the judicial process" (Gruen, 2003).

Schofield (2011) discovered that courtroom environments are slowly adapting to the advances in technology and are using equipment to present visual media displays in the courtroom. Traditional visual methods for presenting evidence in court were thought to be inadequate and as a result experts have sought more effective methods to present complex evidence. A number of courtrooms around the world have seen the presentation of forensic evidence using reconstructed virtual environments. The application of CG displays or virtual reality (VR) reconstructions within courtroom environments is relatively new, particularly within the UK. The introduction of CG displays and VR has been developed through the necessity to improve the jurors understanding of complex evidence without technical, jargon filled explanations. It is thought that jurors place more credibility on what they can see and touch (Schofield, 2009; Berg, 2000). Three-dimensional (3D) graphical technologies such as CG reconstructions or VR environments present unique opportunities to visually illustrate a scene with the ability to 'walk through' and interact with the environment and this can be more compelling for juries (Agosto *et al.,* 2008; Mullins, 2016).

Some authors have described the relative merits of these visual methods for presenting evidence but are aware of the implications they could have on a case. Schofield and Fowle (2013) asked whether the decisions that are made in courtrooms are affected by the manner in which the evidence is presented. Manlowe (2005) details the practical considerations, which need to be made before introducing visual presentations into the courtroom. Lowman (2010) described how visual presentations are only effective if the right pictorial representation is chosen and can demonstrate useful information (Schofield and Fowle, 2013). As a result, visual methods for presenting evidence need to be demonstrated in a manner that the jury can understand and the expert witnesses should carefully scrutinise the presentations to ensure they convey the correct information without confusing the jury.

The state of courtroom technology integration differs significantly around the world, with various forms of technology being integrated aiming to improve case efficiency (Reiling, 2010; Manker, 2015; Lederer, 2017). However, technology integration can present both improvements and risks (Lederer, 2017).

5.1.3.1 United States of America (USA)

The USA is at the forefront of technology use within the courtroom and currently sets the precedent for the rest of the world. In 1993 the most technologically equipped courtroom in America; Courtroom 21 (Figure 5.2), was introduced and has demonstrated the significant advantages that technology can provide to the courtroom (Lederer, 2004). Courtroom 21 acts as both an experimental test bed for various technologies as well as a fully operational model of integrated commercially available technology (Lederer, 1994). The fully functional model courtroom setting can be examined to determine the technological solutions to suit the unique needs of judges, lawyers and expert witnesses (Lederer, 1994) and is constantly updated to ensure it is technologically current. This courtroom enables those who have no experience with such systems, or those who are in the early integration stage, such as the United Kingdom (UK), to learn from the mistakes or barriers encountered during their installation.

The first major use of CG evidence in court was at the Delta 191 trial. On August 2nd 1985, Delta Flight 191 carrying one hundred and twenty-eight passengers and eight Delta crew members crash-landed following violent winds (Marcotte, 1989; Selbak, 1994; Schofield and Fowle, 2013). Law suits were filed over who would pay the millions of dollars worth of damage for wrongful deaths, loss of aircraft and other damages. The governments defence presentation involved a 45-minute CG animation, which illustrated its theory of events that took place on the day of the crash landing. This case was thought to be a monumental turning point in the use of CG animations due to the sheer length and sophistication of the presentation. This trial marked a new beginning for the use of CG animations as demonstrative evidence within a court and as a result of its huge success other judges and courtrooms began to accept the technology (Selbak, 1994).

Figure 5.2: Courtroom 21 Project: McGlothlin Courtroom at William and Mary Law School

Although technology use in US courtrooms has improved significantly since the early 2000's, many attorneys and judges have been reluctant to integrate technology into their courtrooms. Despite the advantages that this technology can provide to trials, many legal professionals are reluctant to accept the technology (Manker, 2015). Reluctance to accept technology into the courtrooms could be attributed to a lack of familiarity with the technology and fear of the technology failing (Manker, 2015). Where technology has been adopted into the courtroom it has revolutionised judicial practices, changed the administration of justice and has improved and hastened trials (Wiggins, 2006; Manker, 2015; Lederer, 2017).

5.1.3.2 United Kingdom (UK)

The integration of technology within UK courtrooms is still in its infancy and is a significantly slower process than USA or Australia. Con O'Carrol, Director of Procurement strategy, Department of Justice and Equality (UK) quoted that progress within the UK criminal justice system with regards to the introduction of technology is 'glacially slow'. Lederer (1994) explained that the slow integration of technology into the criminal justice system could be due to the lack of skills and deficient technology within the courtroom to deal with such technology.

As part of a strategic new plan introduced in 2014, the UK Criminal Justice System was due to be transformed through digital technology. The plan which was introduced by Matthew Coats, sought to make courtrooms 'digital by default' with an end to the reliance on paper by 2016 and to provide "swifter justice" through the digital dissemination of information (Ministry of Justice, 2013). The CPS and courts print approximately 160 million sheets of paper for case files every year (Loveday Ryder – criminal justice system efficiency programme director). The ultimate aim of the reform is to digitise the entire UK Criminal justice system by 2020 and simplify processes. The driving force for the introduction of this new plan was to create a more efficient criminal justice system. Damien Green, Criminal Justice Minister stated that he wants to "see a Criminal justice system where information is captured once by a police officer responding to a crime and then flows though the system to the court stage without duplication or reworking". Most forces now transfer 90% of case files electronically to the CPS. There is much more that can and will be changed in the near future, with police having the ability to access real time intelligence and build case files from the street. Although technology use in the courtroom is slow to progress, technology integration within police services is becoming commonplace and will drive the need for more efficient technology in the courts. Without the technology in place in the courtroom to allow the presentation of such data, the evidence becomes worthless.

In 2013, Birmingham's Magistrates Court produced the UK's first digital concept court (Figure 5.3), a courtroom that trialled technology to aid in the speed and efficiency of trials. In this courtroom laptops have been adopted by case lawyers to store electronic case files as opposed to large paper folders. An application called 'Click Share' allows the sharing of files with other members of the courtroom, who will be able to see the same information on their screens – like screen mirroring. Mrs Greta Band, Bench chairman at Birmingham Bench, stated, "courts need to move into the 21st century in terms of using technology." When questioned on the digital concept court she remarked, "If it can work here, it can work anywhere. Digital courts are certainly the way forward."

One of the most extensive and first recorded use of digital technology in the UK courtroom was for the Soham murders of 2002. The trial of Ian Huntley, arrested for the murders of Holly Wells and Jessica Chapman, was highly publicised and involved the presentation of complex forensic evidence using a CG presentation. Mike Dixon and Stephen Cole who worked in West Yorkshire Police's digital imaging unit produced one of the first fully interactive courtroom presentations in the UK. A digital versatile disc or digital video disc (DVD) presentation was created for the trial encompassing all relevant case material. The jury members were able to view the entirety of the major scenes within the investigation on screens within the courtroom through 360^{o} panoramas, photographs, maps, plans and 3D reconstructions, created by the investigation team (Gower, 2004; Khalil, 2005). The presentation methods were praised by numerous individuals in the case including Sir Ronnie Flanagan. Chief Constable Sir Ronnie stated "using the technology represented a very significant saving of time and enabled everyone in the court to fully appreciate all aspects of the prosecutions case".

Figure 5.3: Top: Justice Minister Damian Green at the digital centre in Birmingham Magistrates Court. Bottom: Birmingham's Digital Concept Courtroom Bench each individual with his or her own screen and a TV screen on the wall with a live link for presenting evidence.

A research project conducted in collaboration with Greater Manchester Police explored the use of virtual reality to create 3D reconstructions of crime scenes. Howard *et al*. (2000) proved that the system they introduced made it far easier for the court to understand the evidence being presented to them and substantially shortened the length of trials. In 2014, a Birmingham trial became the first Crown court to use 360^{o} panoramas in a murder trial. A jury in Birmingham was one of the first to experience a virtual 'walk through' of a scene for a murder trial, created using an iSTAR® panoramic camera (NCTech). Warwickshire Police use an iSTAR® camera to document serious road traffic collisions (RTCs) in a highly accurate and detailed manner. The panoramas presented to the jury helped to secure a conviction of Scott Melville aged 38, who murdered partially sighted pensioner Sydney Pavier, aged 91. Principal Crown advocate of the Crown Prosecution Service, Peter Grieves Smith commended the technology used stating "It was invaluable footage that greatly assisted the jury in understanding the layout of the property. It will surely become the norm to use this in the future in the prosecution of complex and grave crime". Judge Burbidge QC also commended Warwickshire Police for their professional pursuit of justice in this case.

5.1.4 Persuasive Impact of Computer Generated Presentations

Substantial research has demonstrated the successes of visual presentations over verbal evidence descriptions, but careful scrutiny over the impact that these visual methods have on the jury and on the case must be considered (Lederer, 1994; Schofield, 2009). Although visual presentations offer advantages through increased juror retention and comprehension of the evidence, it is thought that the vividness of such visual methods could make them more persuasive than verbal methods (Marder, 2011). Many lawyers are advocates for the use of graphical evidence due to its persuasive impact and when used appropriately technology in the courtroom can be a powerful addition to a trial (Manlowe, 2005). Nevertheless, some legal representatives are concerned that these methods can be too persuasive and introduce too much empathy (Lederer, 1994; Narayanan, 2001).

Research has also demonstrated the negative effects on the use of CG technology within the courtroom concerning the decrease in the mental resources of the viewer so that they are not able to critically review what they are viewing (Schofield and Fowle, 2013). Animations or reconstructions, which have been recorded from a particular viewpoint, could lead the court to believe a particular event happened in a way that may be greatly removed from the truth and could cause viewers to place undue reliance on the evidence – "seeing is believing" (Galves, 2000; Girvan, 2001; Schofield, 2009). Its persuasive nature can lead a jury to blindly believe and accept evidence that has been presented by a computer, regardless of its accuracy (Selbak, 1994; Schofield and Fowle, 2013). In addition, animations, which have been altered, could remove the severity of an event (Narayanan, 2001). As a result, the use of visual presentation using CG could have profound implications on the case outcome if the jurors instantly believe what they are seeing (Krieger, 1992) and place undue reliance on the evidence presented (Fiedler, 2003). Evidence presented in such a way must remain scientifically accurate and truthfully reflect the scientific data and augment witness testimony (Manker, 2015). Technology should not be blindly relied upon however, and technology for the sake of technology could have profound effects on the trial outcome (Lederer, 1994). The evidence needs to describe the incident and what occurred but also needs to be easily understood. One author commented on the consequences on the misuse of CG presentations in the courtroom stating: "Rather than an award of loss of money judgement, the defendant in a criminal prosecution is subject to a loss of liberty" (Bardelli, 1994, O Flaherty, 1996).

The digital age has enabled significant technological development of computer technology and as a result jurors can believe and put undue reliance on the fact that computers are credible. The blind belief that computers tell the truth is further exaggerated by television programs about policing and forensic science, such as Crime Scene Investigation (CSI), which "have given people unrealistic expectations of what can be performed and the time frame in which this can be achieved" (Hempel, 2003; Chan, 2005). This is known as the 'CSI effect', which exaggerates the portrayal of forensic science, introducing futuristic technology, which may not yet exist. Many legal representatives have claimed that television programs such as CSI have caused jurors to wrongfully acquit guilty defendants when no scientific evidence has been presented.

A survey conducted by Shelton *et al.* (2011) explored prospective jurors expectations and demands for scientific evidence with regards to the 'CSI Effect'. Results from the survey demonstrated that 58.3% of jurors expected to see a form of scientific evidence in every criminal case with 42.1 % of jurors expecting to see DNA evidence in every criminal case. Results also demonstrated that juror's expectations for scientific evidence varied depending on the type of crime. Juror's expectation for scientific evidence was high for murder cases, with 74.6% of jurors expecting to see DNA evidence. Shelton *et al.* (2011) demonstrated that although CSI viewers had higher expectations for scientific evidence, this had no bearing on the respondent's ability to convict. Ruling out the potential of the CSI effect, it is thought that a more broad tech effect exists as a result of changes in our culture, the rapid advances in science and information technology and jurors perceptions of increased scientific evidence capabilities. Jurors of today have become more technologically sophisticated and as a result of day-to-day technology use, develop an expectation that the criminal justice system will follow suit (Schofield and Fowle, 2013).

As a result, CG presentations should only be allowed in the courtroom after having been closely scrutinised by the courts and CPS. Prior to the adoption of technology, the tool should be carefully and critically evaluated to determine whether it would actually aid the jury in performing their role (Marder, 2001). In some cases, the evidence presented might constitute unfair prejudice whereby jury members believe that computers are superior and cannot lie (Lederer, 1994). The probative value of the evidence and the manner with which it is presented must be carefully considered before being admitted to court.

5.1.5 Admissibility of Evidence in the Courtroom

Technology integration into courtrooms raises concerns with regards to the admissibility of evidence (Wiggins, 2006). Courtrooms have standard procedures in place to determine the admissibility of evidence within a courtroom. Admissibility is the process of determining what evidence and expert testimony will be heard by a courtroom. Standards that include variations of 'general acceptance' whereby the scientific method used is generally acceptable to a significant proportion of the scientific discipline. Other methods for determining the admissibility of evidence fall to the judge who acts as a 'gatekeeper' to determine whether scientific evidence and testimony is to be admitted to the court (Mirakovits, 2016). These existing procedures are constantly being challenged by new technology. The introduction of digital photography raised questions about the authenticity of the images based on the fact that they could be more easily altered than their traditional film based counterparts (House of Lords, 1998; Staggs, 2005). In addition, concerns have been expressed about the security and authenticity of evidence presented through digital means. Digital data has the potential to be hacked or manipulated by unauthorised users which can compromise the evidence quality (Witkowski, 2002; Wiggins, 2006; Mankoff *et al.,* 2010; Kleve *et al*., 2011; Rahman, 2012; Haider, 2014; Manker, 2015). The standards set out by the courts assure the accuracy and integrity of the evidence being submitted. Digital imagery is commonly accepted into courtrooms due to Scientific Working Group on Information Technology (SWGIT) guidelines for the admissibility of images in the courtroom (SWGIT, 2001).

CG presentations present new issues with regards to the admissibility of this evidence in courtrooms but so far have been treated like any other digital evidence within a court environment (Schofield and Goodwin, 2007; Schofield, 2009; Schofield, 2016). The future use of CG may present challenges with regards to the admissibility of evidence in the courtroom and new guidelines may have to be developed to account for this. With regards to the criteria for excluding CG animation evidence The Federal Rule of Evidence 403 provides the best rationale. Rule 403 states "although relevant, evidence may be excluded if its probative value is substantially outweighed by the danger of unfair prejudice, confusion of the issues, or misleading the jury, or by considerations of undue delay, waste of time, or needless presentation of cumulative evidence" (Selbak, 1994). In order to be used any CG evidence must demonstrate that the probative value of the evidence outweighs any danger of unfair prejudice. In order to be admitted to court CG evidence must also satisfy Federal rules of evidence 803 (24), 901, 401, 402 and 702 (Selbak, 1994). There are some judges in the UK who may look to the USA for guidance in considering issues of admissibility given that they are pioneering the field with regards to the use of technology in the courtroom. In the UK the admissibility of evidence is defined within the Civil Procedure Rules (CPRs) but ultimately the court must determine the probative value of such evidence balanced alongside the cost of producing the evidence and any prejudicial effects the evidence may have on the case (Clifford and Kinloch, 2008).

5.1.6 Rationale

The past use of basic visual aids has been limited to techniques such as hand drawn sketches, charts and photographs. Although very effective and useful at the time, they may be limited by their flexibility. In recent years advances in computer hardware and software has enabled production of CG presentations, which can improve the juror's ability to understand complex concepts. Traditional methods encompass huge volumes of paper and hardcopy files – courtroom technology can improve service delivery and enhance courtroom efficiency (Wiggins, 2006).

With police services rapidly integrating novel documentation technology, such as 360^{o} photography and laser scanning, the courtrooms are under significant pressure to embrace this technology and provide the facilities to allow the successful presentation of this visual evidence in a courtroom. There has been an associated cultural shift towards the adoption of technology in courtrooms although this is only in its infancy and requires significant advancement (Antweil *et al.,* 2011; Manker, 2015). There is a requirement to bridge the existing gap between the use of technology at crime scenes and subsequently in the courtroom. Cortini and Lanzard (2014) described how the changes brought about by the digitisation of the criminal justice system have been overlooked despite their relevance for the potential successful integration into courtrooms (Cortini and Cordella, 2015).

Results from this research may add to the existing body of knowledge on the use of technology in courtrooms. Both legal professionals and police service personnel may benefit from a more comprehensive understanding of the current use of technology in the courtroom, the advantages which technology can provide to their case, and the barriers which have been affecting the adoption of technology into courtrooms. Exploration of some of the factors that may contribute to the so far limited adoption of IT in courtrooms could provide knowledge and recommendations, which can aid in the improvement of technology implementation into courtrooms. It is hoped that this research study will provide a basis to influence additional and future research investigating courtroom acceptance and implementation of technology to enhance the breadth of knowledge regarding this topic.

Aims and Objectives

The aim of this study was to explore the current situation regarding technology use in the courtroom and explore barriers and facilitators to its greater and effective use.

The objectives associated with the aim are as follows:-

- To establish the state of current literature associated with the use of technology in courtrooms
- To obtain information regarding the experiences of some UK police service personnel with regards to presenting digital evidence in courtrooms
- To identify the types of technology that are currently being utilised in some courtrooms in the UK
- To seek the opinions of some police service personnel with regards to technology use in the courtrooms
- To provide a starting point exploring technology use in UK courtrooms

5.2 Methodology

5.2.1 Participant Questionnaires

A qualitative phenomenological research study was conducted to explore the life experiences of police service personnel, including vehicle collision investigators and forensic photographers/imaging technicians, regarding the current use of information technology in courtrooms and in their presentation of evidence. A snowball sample of 21 police service personnel were recruited for participation within this study. Snowball sampling is a technique whereby existing participants recruit future participants through referral amongst their acquaintances or contacts (Berg, 1988). Participants were chosen from the UK and Australia. Potential participants known to meet the selection criteria; they are a police service personnel actively involved in crime scene or vehicle collision investigations and are required to present evidence in a court of law as an expert witness, were initially contacted by email. Potential participants were sent invitation emails enquiring as to whether they wished to participate in a research study exploring the current use of technology in courtrooms. The email also asked if they could recommend other colleagues who also met the selection criteria who may be willing to take part in the study.

Those participants who were willing to participate in this research study were emailed a consent form to obtain consent from them to participate in the study, in line with the ethical requirements of the host institution (Appendix 5.A1). The consent form outlined the guidelines of the study and the ethical guidelines adhered to throughout the duration of the study. Participants were informed that participation was voluntary and that they could withdraw from the study at anytime. Participants were also informed that their identities would be kept confidential and any identifying information would be excluded from the study such that any quotes would be anonymous and participant responses were assigned a number rather than referring by name. Participation in this study was unlikely to cause participants any discomfort as they were not obligated to answer all questions and could leave any questions with which they were not comfortable. In addition, participation in this study did not pose a risk to individuals' safety.

Participants who consented to participation in the study were emailed a semi structured, open-ended questionnaire and were asked to type their responses below the relevant question and email the answered questionnaire back to the researcher. The presentation of questions was carefully considered prior to the questionnaire being disseminated to respondents. Open answer responses were selected, as this would allow the respondent to explain their experiences. Participants were able to complete the questionnaire in their own time and were permitted to stop at any point.

Participants were provided with the following questions:-

1. What is your job title and role within the Criminal Justice System
2. As part of your role are you required to present evidence in a courtroom?
3. Can you tell me what, if any, technology has been integrated into the courtroom?
4. What has your experience been in terms of the introduction of new technology into the courtroom?
5. Have there been any difficulties with technology being integrated into the courtroom?
    a. With the implementation of technology with existing and current courtroom systems
    b. And whether there have been barriers, if any, to the adoption of such technology?
    c. If there hasn't, why do you think this is?
6. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Please explain.
7. What has your experience been with the presentation of evidence in court? Please explain.
8. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.
    a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes?
    b. Have you ever had to present this type of evidence in court? Please explain.
9. What has the response been to this method of presenting evidence
    a. From the judges?
    b. Barristers?

c. The jury members

Is the courtroom fully equipped to allow you to present this type of evidence? Please explain.

10. Do you feel there is anything, which needs improvement? Please explain.
11. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

5.2.2 Data Analysis

Thematic analysis based on Mankers (2015) methodology, originally adapted from Guest, MacQueen and Nameys (2012) methodology was used to analyse the data that was collected from the 21 participants. The data analysis consisted of breaking down and coding the text responses obtained from the participant’s questionnaires, to identify themes and to construct thematic networks. A computer software program NVivo was used to store, organise and code the open-ended data collected from participants. Participant text responses were re-structured within an Excel spread sheet and the data set uploaded into NVivo software. The data was explored using the NVivo software through word frequency queries to analyse the most frequently used words in the participant data. From this possible emerging themes were identified and were analysed. Emerging themes were coded using specific keywords or nodes that had been previously identified by the researcher. Nodes were created based on these recurring themes and any responses were coded at the relevant nodes. Nodes were created for each question with potential answers that participants could respond with. For example, for question 11 which asked the participants “What has the response been to this method of presenting evidence,” potential responses from participants could suggest a good response, a bad response, little response, no response, or not applicable. These identified nodes would allow the researcher to link a node to the relevant response from participants. Within the NVivo software, the researcher could search nodes and easily identify all participants who had the same response. This was used to analyse the different themes identified within the participant data. As the analysis of the data progressed some new nodes were identified and these were checked against all other participants.

The coding process was based on a predetermined set of thematic categories such as courtroom technology, ease of use, implementation, limited use, recommendations, advantages, and disadvantages. These thematic categories served as the basis for the manual coding of the data and themes were abstracted from coded text segments. Some of the thematic categories were further broken down to include additional related categories. For example, courtroom technology was further broken down to include specific categories such as television screens, audio-visual technology, computers, 360^{o} photography, and laser scanning. The participant responses were analysed, described and tables created which documented the number of respondents to have reported such a response.

5.3 Results and Discussion

5.3.1 Participant Questionnaires

The purpose of this qualitative phenomenological research study was to explore and describe experiences of police service personnel with regards to the current use of technology within the courtroom. The research design was intended to reveal the meanings that underpinned participants' perceptions towards courtroom technology (Tracy, 2013; Manker, 2015). This method of study was conducted due to the nature of the data, which was being collected; 'experiences of individuals'. A phenomenological approach can produce rich descriptions and reactions to events and phenomena, which can aid the researcher in understanding the essence of participants' experiences (Vagle, 2014; Manker, 2015). From this the researcher could analyse holistic information regarding the perceptions, beliefs and experiences with regards to courtroom technology among individuals who work within the criminal justice system.

Methods used for seeking potential respondents for the questionnaire included contacting known networks through personal communication via email. These potential respondents passed the questionnaire onto their colleagues (snowball sampling) and other contacts that they thought may be interested in helping with this research study. In addition, one potential respondent enquired as to whether the details surrounding the research study could be posted onto an online police forum where interested individuals could email the researcher who would send the consent form and questionnaire directly to the interested individual. As a result, some participants originated through this method of participation.

The participants utilised for inclusion in this study were chosen because these participants had responded to the initial email communication asking them to kindly complete a questionnaire seeking to explore technology use within courtrooms. These participants were approached due to the nature of their work; being part of a police service in either forensic investigations or vehicle collisions, and who often present evidence in the courtroom. Police service personnel were the targeted respondents for this study as they are beginning to adopt novel technology for documenting crime scenes which is likely to need presentation in a courtroom, as discussed in *Chapter 1.*

Questions posed to participants aimed to explore their experiences with the use of technology in the courtroom and as a result questions were designed as open ended to allow a deeper exploration of the topic and to gain a better understanding of the concepts under investigation. It was not possible to conduct face to face interviews as previously designed due to the extraction time required for the interviews and the limited time that active serving police personnel have and the costs associated with travel to each participant. As a result participants were required to complete a series of questions in the form of a questionnaire, which could be emailed to them to complete in their own time.

5.3.2 Data Analysis

The results obtained from the questionnaires were presented based on the key themes, which arose from the data. The raw questionnaire responses can be found in Appendix 5.A2. The results presented include tables and direct quotes from the participant responses. Results from the questionnaires will be discussed based on responses from participants, which have been grouped into country, consisting of the UK and Australia. Individuals were also chosen from Australia due to the similarities between the UK CJS, with Australia having adopted the UK's criminal procedure rules and very similar forensic systems in addition to the diversity of researching another country (Marcus and Waye, 2004). In splitting the responses by geography, the research can be compared and contrasted based on the country. In addition, results from this research will be compared and contrasted to other research studies found in the literature, particularly focusing on the USA. It is important to note that the participant responses identified within this research are not expressing the opinions of the general population for the whole country and is limited to only those individuals within this study.

5.3.2.1 Current methods for presenting forensic evidence in a UK Court of Law

In order to identify the current forensic evidence presentation methods, participants were asked to describe how forensic evidence is currently being presented in courtrooms and whether, in their opinion, they thought that anything needs to be changed.

Participant 2 described their experience with presenting complex forensic evidence in court stating: "A bad, but typical, example: I was presenting evidence on blood spatter in court. The jury were looking at photocopies taken from the album of blood spatter on a door. So I had to ask the jury to accept that there were better quality images where the spatter could be seen and I was able to interpret the pattern. Not only does this allow a barrister to claim I was making it up but, it is much easier to explain something if people can see it."

Participant 3 commented how they currently present evidence in the courtroom stating: "I generally present a jury bundle as photographs and a plan, all printed on paper." The participant then went on to comment on how they thought, "courts need to catch up, but for most cases, a simple 2D plan and photographs is more than sufficient. There is the ability to produce flashy reconstruction DVD's but I think there is a huge danger of a reconstruction showing things that did not happen, putting images to the court and jury that may only be a representation of a possible scenario rather than what is definite. This is particularly true for collision investigation where there are often unknowns and using a computer model cannot be certain that is what happened. Videos shown are talked through as they are run."

In agreement participant 4 also commented on paper methods for presenting evidence discussing: "Currently the evidence I give tends to be oral backed up with 2D paper plans and photographs, whereas it could be interactive 3D 'fly-through' models etc. There is nothing essentially wrong with simple technology, a photograph is easy to refer to and can be very simply referred to, likewise a 2D plan, however they tend to be clumsy and fill the witness box with paper that is pointed to in front of the witness and this is never conveyed to the jury." Paper files in the courtroom (Figure 5.4) are still heavily relied upon, with the UK's Crown Prosecution Service (CPS) producing roughly 160 million sheets of paper every year (Ministry of Justice, 2013). Participant 4 also commented on how this could be improved; "If, maybe through the use of tablets, or some form of interactive media, this could be displayed on screen, then the witnesses' thoughts and explanations may be better conveyed to the jury".

Participant 5 described how "to date, I haven't used any visual aids/props. Generally I will have compiled a report, which contains photographs and a scale plan, but as part of the wider investigation there may be digital data such as CCTV footage, 3D laser scans and animated reconstructions. My evidence is given orally and the relevant sections of the jury bundle referred to for context .I have presented a case involving CCTV footage which was, as mentioned above, played on too small a screen for the jurors to see properly therefore making it difficult for them to understand the intricacies of what it showed. The footage itself had to be provided in a format that could be played in a DVD player present in the courtroom, leading to an overall reduction in quality. In another case I had to show each individual juror an original printed photograph from the report I had brought with me as those provided in their bundle were of such poor quality that the subject of my oral evidence was not clearly visible to them."

Figure 5.4: Legal professionals paper files used in Edinburgh's High Court. Taken from Channel 4: Murder Trial Documentary (2012).

The majority of participants described how “primarily evidence is verbal, [and that the] presentation of photographs are by way of rather dodgy photocopied versions lovingly prepared by the CPS”. Participant 7 commented, “we occasionally use video footage, which has to be converted to DVD format to play at court – assuming the usher knows how to work it.” In agreement, participant 9 also described the use of 2D plans, photo albums and if applicable DVD’s of video footage. Speaking on presenting such evidence in court participant 9 stated: “all of this is presented at court in a simple way with the only technology being a DVD player attached to the screen they already have for presenting video witness evidence.”

In contrast some participants noted the lack of technology integration into the courtroom for the presentation of forensic evidence. Participant 8 states: “the court process has changed very little in the 12 years I have been a collision investigator whilst the equipment we use and evidence we produce has changed exponentially.” This emphasises the fact that whilst police services have been more accommodating towards the integration of technology into their current practices and crime scene investigations, courtrooms have been slower to adopt technology which would allow for the presentation of such evidence in the courtroom.

Participant 15 made reference to the introduction of technology into the courtroom stating how it can “depend very much on the attitudes of the judge, prosecutors and investigators. Some are technologically averse whilst others are happy to accommodate new technology.”

5.3.2.2 Current methods used by Police Services to record crime scene environments

In line with the contents of this thesis, participants were asked what technology they currently use for recording crime scenes in order to identify the extent to which police services have adopted technology for such purposes. Table 5.1 demonstrates the number of participants who reported using a type of technology, listed in the table, to record crime scene environments.

Table 5.1: Types of technology reported by participants that are currently used to record crime scene environments

Technology type used to record crime scene environments	Number of participants reporting using this technology to record crime scene environments	Percentage of participants reporting using this technology to record crime scene environments/ %
3D Laser scanning	9	43
3D Laser scanning and 360° photography	8	38
Standard DSLR Photography	6	29
Video Footage	4	19
Total Station	2	10
3D Printing	2	10
360° Photography	1	5
GPS Plot Data	1	5
3D Modelling	1	5

Eighteen participants within this study (86 %) have used either 360° photography or 3D laser scanning methods for recording crime scene environments with eight participants using a combined method of both 3D laser scanning and 360° photography. Participant 1 described how "our department uses both 360° imaging and scanning on a regular basis. A lot of the time that data may not be used, however, both methods capture the entire scene and not just a few points chosen by the investigator and will remain on record/stored for 10 years."

Participant 3 described the type of technology they currently use and what exactly they use the technology for stating; "We use 3D laser scanners for all our collisions. We use a Reigl VZ4000 360° laser scanner. We use it as a survey tool to enable us to measure any aspect of the scene, and to produce scale plans from the survey data using plan-drawing software. We do not use it to produce 360° images, we still take conventional photographs alongside the scanner." Although this high tech recording technology has been adopted by some police services, it is important to note that in the majority, if not all, cases it has not replaced traditional methods of capturing a crime scene using contemporaneous notes, sketches and digital photography. The new technology methods presented offer a complimentary approach to recording crime scene environments, whilst allowing the complete 360^{o} capture of an entire scene.

Participant 5 also described having a Reigl VZ400 3D laser scanner since 2012 in addition to utilising a FARO Focus 3D laser scanner. These are "predominantly used for indoor crime scene work when assisting the major crime department." This participant also inferred that "[the 3D laser scanner] does not however decrease the time spent at a scene in my experience." Participant 11 agreed: "it is a myth that this truly speeds up evidence/data capture. What it does do is increase the quality of the evidence capture at the close scene – but if you have a very large scene – no, this takes the same time or even longer to capture data." Although the technology may not speed up the crime scene documentation process they do offer a unique advantage in the increased quality of the data captured compared with standard digital photography.

The capture of crime scenes by police services also utilised "360^{o} photography through panoramic digital photography mounts with a digital SLR" (Participant 21). Commenting on the use of 360^{o} photography and 3D laser scanning methods for the purposes of crime scene reconstructions, participant 15 stated: "by capturing crime scenes and evidence within the context of this reconstruction, we are able to glean additional information and learn new facts not otherwise able to be deduced."

Six participants (29 %) described how their police service utilises traditional digital photography for capturing crime scenes. Some participants commented how even after having utilised 360^{o} photography and/or 3D laser scanning, traditional methods for documenting the evidence were also used. The new technological methods are used to compliment traditional methods. Participant 3 commented: "We do not use it [laser scanning] to produce 360 images, we still take conventional photographs alongside the laser scan data."

Three participants (14 %) described using video to capture a crime scene as part of the documentation process. All three participants who commented on using video footage also described how the footage "has to be converted to DVD format" to enable play in the courtroom. Participant 7 commented: "we occasionally use video footage, which has to be converted to DVD format to play at court – assuming the usher knows how to work it."

Two participants (10 %) described the use of alternative methods for presenting evidence in the courtroom using 3D printing methods. Participant 16 described what their organisation uses 3D printing to accomplish: “Some photographic/video evidence is not shown in court as it is deemed prejudicial e.g. graphic crime scene photographs or photographs of injuries, I believe sometimes it is important this evidence is shown in order to give a comprehensive account of the events that occurred. We are now using technology to work around this by introducing 3D printed evidence to the court room that accurately depict injury evidence etc. with a more neutral tone, eliminating the prejudicial aspect of graphic imagery whilst clearly depicting the events/consequences.”

5.3.2.3 Participant experiences with presenting 360° photography and 3D laser scanning data in the courtroom

Having ascertained the types of technology that police services are currently using to record crime scene environments, participants were asked whether they have ever had to present this type of evidence within the courtroom and to explain their experience of this.

Participant 1 described how “I was the first to show 360° panoramas along with point cloud data. I had to explain to the court what it was and how it was used prior to the case commencing.” We have presented this type of evidence now in live court 3 times and received no criticism. There have been at least another 3 cases where we have produced it but not required to show it. It does require some advanced preparation and several visits to the court room to be used, to make sure it all works.!”

Eighteen participants (86 %) described how they currently utilised 360° photography and/or 3D laser scanning methods for recording the crime scene but due to the limitations of the court facilities some participants were unable to present such evidence in a courtroom. Those participants who described such an experience stated that they would use the 3D laser scan data to subsequently make 2D plans which would be printed on paper for the purposes of the court. Participant 4 expressed their opinion on having to print 2D plans as opposed to using the 3D data in court stating that it is “a travesty really when you consider what capability this data offers.” In agreement, participant 5 stated that it is “unfortunate as the benefits of the data cloud as a contextual visual aid are unrivalled.” In situations where the 3D data was allowed, it was only accepted into the court as a 3D animated ‘fly-through' played directly from a DVD. Participant 8 stated that using this DVD method "it was not possible to move through the scene in real time."

Participant 15 described how they present this type of 360^{o} photography and/or 3D laser scan data in courtrooms "for the purposes of viewing/demonstrating a crime scene and for conducting specific analysis of the data to reach a conclusion." However the participant continued to describe how "there are a number of technical and institutional challenges in presenting this evidence. Typically I have found that this evidence is readily accepted by the court and well understood by jurors, judges and lawyers. Defence, however, can seize on the technical aspects in an attempt to create doubt and confusion." In contrast, courtrooms in America have already begun routinely presenting 360^{o} photography and/or 3D laser scan data in courtrooms (Figure 5.5).

With regards to their experiences with presenting panoramic imaging technology data to the courtroom participants were asked to provide their opinion about the possible advantages and disadvantages associated with presenting evidence using these technologies. Participant 1 described how presenting evidence using panoramic visual means can be refreshing due to the fact that "a picture paints a thousand words and by their nature courts are stuffy and boring with lots of evidence being read out. Provided there are large viewing or multiple screens around the courtroom, then visual evidence is perfect for court." Participant 5 stated that the "overriding advantage is the quality of the product and its ability to replace a scene visit by letting the jurors visit remotely and repeatedly." In turn, this saves money, which would previously have been required to transport the jury to the crime scene. Participant 14 and 15 respectively described how the presentation of evidence using new technologies such as 360 photograph or laser scan data is "more visually appealing and juries can review the presented evidence" and that it is "much more effective and allows the expert to clearly demonstrate aspects of the crime scene or analysis."

Figure 5.5: Presentation of 3D evidence. Prosecutors demonstrated 3D laser scan data including cutaway details of Justin Harris's SUV during Harris' murder trial at the Glynn County Courthouse in Brunswick on Friday 28th October 2016. (Screen Capture from WSB-TV).

Participants divulged the perceived disadvantages of using this technology for presenting evidence in court. Participant 1 commented on the frustrations of presenting such evidence when the technology refuses to work at the time and described their embarrassment when the judge became impatient. Technological failure is one of the most common concerns with regards to technology use. Participant 6 commented: “I can only see the benefits so long as everything works. Some people prefer a written report. Either way it only assists and the quality of the evidential speaker is for me crucial.” Participant 14 stated that the disadvantages to presenting evidence in this manner “would be coming too dependent on presentation of evidence this way and cases breaking down or being delayed due to technical failures.” Participant 3 described how “the police are trying to do more with less and do not have the funds to do this properly and will rely on what still works i.e. paper. Paper also still works as it does not rely on good WIFI, correct plug leads, sufficient battery power, lost passwords and the multitude of other issues that accompany IT.” Of all the participants included within this phenomenological study, participant 3 was the only participant to provide their opinion with regards to paper methods still working and being more reliable than its technology counterpart as it is not reliant on issues which accompany such technology.

Other participants described the dangers of presenting evidence in this manner suggesting how it can “place a lot of emphasis on certain bits of evidence which can distract the jury from key evidence that isn’t part of glossy displays.” Participant 4 stated: “if there are elements missing and the reconstruction is somewhat subjective then its use is, in my view, dangerous. If you show a jury a nice video they may well be tempted to believe what they are being shown, accepting that it is fact, when in reality it is simply what the person using the system wants them to see; nobody is immune to the power of suggestion.” In agreement, Participant 10 commented how “extreme caution has to be placed on the manner in which this type of evidence is presented in order that the jury are not misled.” Many authors have previously researched the negative effects of visual panoramic methods for presenting evidence in courtrooms, demonstrating how its persuasive nature can lead a jury to blindly believe and accept what is being presented by a computer (Selbak, 1994; Schofield and Fowle, 2013). This can constitute unfair prejudice and as a result the probative value of presenting evidence in such a manner must be carefully considered prior to admittance to court (Lederer, 1994).

In addition to the persuasive impact that this evidence presentation method can have on the members of the court, participants also described the training requirements in order to competently use this technology to successfully present evidence in the courtroom. Participant 5 stated: "the user would need to be competent otherwise delays would be likely. There may also be difficulty in reproducing and documenting the views shown to a jury." In addition to having the training knowledge to operate the technology, having the specialised technology available within the courtroom presents challenges, when expert witness are required to provide their own laptops as described by Participant 16. Participant 15 described how the techniques used to capture the panoramic data "opens up avenues for defence to attack the data and create doubt, due to the technical aspects of the evidence."

The perceived advantages and disadvantages of presenting forensic evidence using such technological methods requires careful consideration and a requirement to determine the probative value of presenting evidence in such a manner prior to its admittance in the courtroom. Utilising panoramic methods for presenting evidence may not be required in all instances and is likely to depend upon the severity of the case or crime type and the nature of the evidence which is required for presentation. Some cases will not require such highly technological solutions which may be too complex for the necessities of a specific case. Particularly whilst technology integration into courtrooms is in its early stages and is not yet routinely utilised, technological failure will remain concern for some courtroom personnel.

5.3.2.4 Judge, jury and barrister responses to 360^{o} photography and 3D laser scanning methods of presenting forensic evidence

For those participants who had presented 360^{o} photography and/or 3D laser scanning forensic evidence in court, they were asked what the responses from the judge, jury and barristers were to this method of presenting evidence.

5.3.2.4.1 Judges responses to the 360^{o} photography and 3D laser scanning evidence

When asked what the response from Judges has been to these methods of presenting evidence, all participants who responded stated how the feedback received was positive. Participant 1 commented how the judge "praised for the ingenuity and tech know how" and "the court appeared to be receptive to seeing panoramic images and one particular judge praised the police for using it in his court during his summing up. If it's relevant then use it" whilst participant 15 stated that feedback about the technology was "generally very positive and well received. Most judges are interested and accommodating." Participant 19 raised a point about the acceptance of the evidence commenting that the response from judges regarding the technology was very receptive when [the] evidence [was] allowed."

It is important to consider that these particular responses obtained from the participants described the opinion of this one particular individual, describing an event at one specific time. The response obtained could be one of many 'good' and/or 'bad' experiences with presenting evidence using technology in the courtroom and in this instance the participant has simply recollected the good experience. These quotes portray one recollection, which could be amongst many that haven't been described. It was also evident from the participant responses with regards to this question that these were the participant's perceived opinions of what the judge, jury and barristers may have thought about the technology. The participant had not conducted a scientific experiment to investigate different judges, juries and barristers' opinions and attitudes, specifically asking their opinions with regards to evidence being presented using panoramic imaging technology. This can be observed through the participant responses. For example, participant 13 responded to this question as follows; "I am not given any response during evidence by any of these parties nor are they in a position to do so." The majority of participants who responded with their perceived evaluation on the judge, jury or barristers opinion on technology preceded their statement with "I am aware", "from what I have heard" and "I think [judges and juries] both see the benefits".

5.3.2.4.2 Barristers responses to the 360^{o} photography and 3D laser scanning evidence

Participant responses differed however, when asked to comment on the response to this technology from barristers. Participant 1 described how the barristers "use it [the technology] to show the scene to the court, then 'walk witnesses through' as they give evidence." In contrast, Participant 2 commented on how there had been a "mixed response. Some love it and some prefer to use their oratory skills." Participant 8 commented on how both judges and barristers "see the benefits of this new technology, for example to test witness accounts by repositioning them in the scan to ascertain their actual view of the incident". This is not physically possible with standard photographs, where jury members or witnesses would have to imagine a different viewpoint. Participant 15 also received positive feedback from barristers claiming that the "prosecution are generally very interested in having the evidence viewed whilst defence lawyers are also interested in querying the data when attempting to put their arguments forward." In agreement participant 19 had similar responses from barristers with prosecutors responses being "extremely positive" and defence being "extremely sceptical".

5.3.2.4.3 Jury members responses to the 360^{o} photography and 3D laser scanning evidence

Participants were asked to comment on the jury members responses to viewing forensic evidence which had been presented using 360^{o} photography and/or 3D laser scanning. Of all the participants who could respond to this question, they all described how feedback was positive. Participant 1 stated that; "in all my cases, they [the jury] appeared very attentive." Participant 3 earlier commented on how they use the 3D data to create 2D scale plans which are printed for the courtroom and commented how "everyone understands paper plans and photos." A picture is worth a thousand words and substantial research has demonstrated that visual methods for the delivery of evidence within a courtroom provides significant improvements in juror comprehension and recollection of information (Krieger, 1992, Selbak 1994; O Flaherty, 1996; Schofield and Fowle, 2013). Visual evidence presentation has proved to be more engaging and entertaining than verbal methods.

Participant 5 commented that positive feedback was obtained by jury members but that "due to the limitations of the court facilities [they] generally use the information within the scan data to create a 2D scale plan of the scene. The closest we have come to scan data being presented to a jury is by way of a video file being created of a predetermined 'fly-through' of the scene. I believe this was well received by all involved and consequently no scene visit was required by the jury." Participant 15 had presented 3D laser scan data in court and stated how "juror feedback has indicated that the 3d reconstruction data has been of immense use and they have enjoyed being exposed to it."

In other instances, participant responses claimed that they are not in a position to ask the jury for feedback on their response to technological presentation of evidence. This further emphasises the point raised in *5.3.2.3.1 Judges responses to the 360^{o} photography and 3D laser scanning evidence* with regards to most participant responses being their opinion on the perceived feedback from individuals within the courtroom environment and not having originated from scientific research.

5.3.2.5 Is the courtroom equipped to allow the presentation of 360^{o} photography and 3D laser scanning?

Participants were asked to comment on whether the courtroom was fully equipped to allow them to present 360^{o} photography and 3D laser scanning forensic evidence. 52 % of participants expressed how they thought the courtrooms were equipped enough for them to present such evidence. Participant 1 responded to whether the courtrooms were fully equipped to allow the presentation of such evidence stating: "in most cases yes, providing there is a laptop connection point and that the viewing screens are large enough." Participant 3 discussed how the courtroom they visited had WIFI, which allows the court to display anything that someone puts onto a computer. Participant 6 also thought the courtrooms were equipped to allow this presentation method for evidence but commented on how this "would vary on the location and type of court – crown to magistrate to coroners" depending on the type of case on trial. In Participant 7's experience "all courts have several 40" TV screens located all around the court, from memory about 6 screens. It would be much better if each juror or interested party had a tablet or personal screen but that'll never happen. Some court rooms have a HDMI input lead so it can connect to a laptop but it doesn't connect audio so it needs a separate cable etc. for that." Courtrooms in America have already begun installing multiple screens for the jurors (Figure 5.6). Participant 19 thought, "some courtrooms are well equipped, older rooms not very well equipped, if equipped at all." Participant 4 claimed how they had "not had the opportunity to use this form of evidence capture in the courtroom to its full potential" but stated how "it has been exceptionally well received by Senior Investigating Officers and in the preparation of cases. With the increase of cases being captured on dash mounted CCTV systems the use of point cloud data will mean the use of 3D laser scanning becomes essential."

Other participants disagreed and described how they thought the courtrooms were not fully equipped to allow them to present 360^{o} photography and 3D laser scanning forensic evidence. In Participant 5's experience "the courtroom does not offer a direct link for a laptop to be utilised. This is necessary as the volume of data involved with a scan project is vast, far in excess of the capacity of a data disc." With new technological methods for capturing vast amounts of data surrounding a crime scene environment, file sizes increase and as a result the space to store them is also required. Participant 15 also thought that the courtrooms were not fully equipped to allow the presentation of this evidence describing: "most courtrooms only have a single screen which is often not enough. A computer must also be brought along by the expert presenting the evidence. Some courtrooms have been able to be fitted with customised AV equipment, however these are only the most significant of cases. Typically, new technology is welcomed however displaying and using it in a useful way in the physical courtroom is a challenge. Enabling all parties in a trial to view the 3D data simultaneously and clearly in a courtroom is not possible in some courtrooms with limited AV equipment, whilst other specialised courtrooms offer each individual their own screen. Generally advance liaison with the courtroom clerks is required to test and ensure that the systems will operate correctly in the course of a trial. Another issue is ensuring that whatever new technology is used will be able to be accessed outside of police systems by the defence or jury, and that each juror can receive the same experiences in using the technology."

Figure 5.6: American courtrooms have already installed individual TV screens for jurors so that they can easily view evidence presented to them.

5.3.2.6: Theme 1 - Current Technology in the Courtroom

The results from the thematic analysis using NVivo identified the following main themes: current courtroom technology, a lack of technology in the courtroom, difficulties associated with the integration of technology into the courtroom, barriers to the adoption of technology into the courtroom, the improvements and/or changes required, the future of technology in the courtroom. These themes were coded within NVivo as nodes which were attributed to the participant's responses. Word frequency queries within NVivo allowed further exploration within each of these main nodes, to identify further sub themes. For example, under current courtroom technology, sub nodes such as: Television screens, DVD players, paper, audio-visual systems, live links, WIFI, projectors and PC's were identified as sub themes which were linked to current courtroom technology. Participant responses, which identified any of the sub themes, were coded at the relevant node.

The first theme identified from the participant data was related to the different types of technology in the courtroom, which participants had personally used or seen being used in trials. The types of technology identified by participants can be found in Table 5.2. The majority of participants had been exposed to courtroom technology at some stage or had used technology to present evidence in the courtroom and these experiences differed significantly. Participants in this study originated from different counties from across the UK and different areas across Australia. As a result, the progress of technology implementation into courtrooms may differ throughout the country and also between countries, which could account for the differences in experiences with relation to courtroom technology.

Table 5.2: Types of technology reported by participants that are currently situated within the courtroom

Current Technology reported by participants in the Courtroom	Number of participants reporting presence of equipment in the courtroom	Percentage of participants reporting presence of equipment in the courtroom / %
Television Screens (TV)	13	62
DVD Players/ CCTV viewing facilities	9	43
Basic Multimedia PC's/ Laptops	6	29
Paper Files/ Printed Photographs	4	19
Basic Audio Visual Systems	3	14
Live Links	2	10
WIFI	2	10
Projectors	1	5
Specialist software to view 3D data	1	5

Note: Participants who reported a particular piece of technology having been in the courtroom have been included in the results, but this does not signify that the technology was not there for those participants who didn't report it. It could just be that at that particular time when the question was asked the participant simply did not make reference to it.

The types of technology identified by participants that had, in their experience, been implemented into the courtrooms consisted of Television (TV) screens, WIFI, DVD players, laptops or tablets and other audio-visual equipment. Those courtrooms that have initiated technology implementation into trials are still in their infancy and have implemented what many participants claimed to be "basic and limited audio visual technology". Eight participants (38 %) from the UK identified that large TV screens had been installed into the courtroom. Participant 3 explained that from their experience, the courtroom had installed "large TV screens which link up via WIFI to laptops which the barristers use, so any media on the laptop can be played to the whole court". Eight participants (38 %) identified the use of DVD players in the courtroom, particularly for viewing Closed Circuit Television (CCTV) footage on large screens. TV screens have been implemented into courtrooms; participants highlighted how any other technology currently integrated into the courtroom was "very limited or little". The use of TV screens should make the evidence easier to understand by jurors who are accustomed to receiving information using such methods (Marder, 2001).

Two participants (10 %) identified the use of live links or videoconferencing, which allows expert witnesses to present their testimony off site. This is particularly useful for police officers that can remain working at the police station until they are called forward to present evidence. At this point, the officer will use a designated video conferencing room that has been set up with a video camera and audio facilities to enable a video connection with the courtroom. This videoconferencing technology is already being used between custody suites and the courtroom to arrange suitable dates for a defendant’s trial. In these instances, the judges are able to communicate directly with the defendant without having to transport the defendant unnecessarily to the courtroom, which can cost substantial amounts of money. It is thought that remote testimony presentation may shorten witness testimony (Marder, 2001). The participant results in this instance with regards to the use of live links or videoconferencing were limited. Only two participants quoted observing the use of such technology within the courtroom. Live links have already proven to be a cost effective method; videoconferencing can save time and money transporting defendants to the courtroom location for hearings (Ward, 2016).

With the government drive to transform courtrooms using modern technology to improve the effectiveness and speed of the criminal justice system, the researchers would have expected more participants to have commented on their observation of live link technology integrated into the courtroom setting. The lack of participants having observed such a phenomena (2 out of 21 participants (10 %)) could be attributed to the fact that some participants may simply not have recalled such an observation at the particular time of completing the questionnaire, and therefore it may be that more participants have observed live link technology but were unable to recollect this at the time of participation. In addition, the use of live link technology will ultimately be dependent on both the nature of the trial taking place and the particular courtroom being used for the trial. Six participants observed the use of basic multimedia PC’s or laptops within the courtroom environment. Four participants described how the current technology within the courtroom is limited to that of traditional paper files and printed albums of photographs.

It appeared that the current situation with regards to the implementation of technology into the courtroom was similar in Australia with two participants describing the use of TV screens in the courtroom most often used for presenting DVD footage. Participant 19 described how “some courtrooms have audio visual capabilities. The newer courtrooms have individual screens for each jury member, older courts may have one TV screen”. It is clear that some courtrooms in Australia are more advanced than other courtrooms, with some implementing more technology, such as individual screens for the jury to view evidence.

From those participants who took part in this study, the main theme identified was the lack of technology integration into the courtroom environment. However, this was the general consensus opinion of only those participants who have taken part in this study and cannot be generalised across the whole country. These respondents experiences with the lack of technology could be influenced by many different factors, such as where in the country they presented their evidence, what courtroom, and what case they attended to present evidence. All of these factors could have an influence on the respondents experience with technology at the time that they were referring to. For example, the case that they were presenting evidence at that time may not have required the use of such technology and therefore the respondent would not have seen it in use. In addition, although legislation is being implemented to oversee the update of courtrooms by 2020 using digital tools to facilitate delivery of justice, courtrooms across the country will no doubt be at different stages in the implementation process, depending on finances and the time constraints with on-going trials. In addition, a particular courtroom within a court may be designated as a digital courtroom which contains the technology available to present evidence digitally, however, if the participant had attended a case in another courtroom they would have the opinion that the courtroom lacked technology integration.

Manker (2015) conducted similar research investigating the life experiences of attorneys and judges with regards to technology use in state courtrooms in America. When participants were questioned on the current use of technology within the courtrooms in Mankers’ research, it was found that 15 out of 22 participants (68%) were found to use presentation software to present their evidence in the courtroom. Ten participants (45%) used videos in the courtroom and 9 used overhead or digital projectors. These were the most common forms of technology used within the courtroom according to attorneys and judges from the state of Virginia. Technology, in its different forms, is being integrated into courtrooms across the world, if only in its infancy but can set precedents for future adoption of more complex technology.

Marder (2001) described how technology of the future could involve jurors having a laptop computer in the courtroom, which contained all of the relevant case files, currently produced as large paper folders.

5.3.2.7: Theme 2 - Lack of Technology in the Courtroom

Participants were asked about their experiences in terms of the introduction of new technology into the courtroom. As part of the UK Digital Reform, courtrooms were required to become 'Digital by Default' by 2016, in an effort to become completely paperless (Ministry of Justice, 2014). In 2013, Birmingham's Magistrates court trialled novel technology to become the UK's first digital concept court. This involved the introduction of large TV screens within the courtroom, video live links for remote expert witness testimony, and 'click share' that allows the sharing of documents between different personnel's screens. Following the successes of the digital concept court, and as part of the digital reform, other courtrooms across the country were to follow suit and implement basic equipment to aid in the presentation of visual evidence in the courtroom. A question was posed to participants to discover the extent to which this has been implemented and to explore their experiences with the implementation of any new technology into the courtroom.

Some participants expressed how in their opinions very little technology had actually been implemented into the courtrooms and how they considered courtrooms to be very slow to implement new technology. Participant 2 stated "there has been little investment by the courts in modern technology". With regards to the implementation of technology into courtrooms, Participant 4 stated that "generally there hasn't been any and under investment seems to have been the greatest problem." It was evident that some participants were frustrated at the lack of technology integration into the courtroom particularly when the technology is routinely available to them for the documentation of crime scenes. Participant 4 commented "We have the opportunity to bring 3D interactive virtual scenes to the courtroom for example, however the limited computing power available means that this is impossible". In this instance, police services are adopting novel technology for documenting scenes but the courtrooms do not currently have the capability to present this data, often resorting to tried and tested paper methods, which are now out-dated.

It was identified by these participants that the type of court and crime is a factor, which determined whether any technology was implemented, and the type of technology that was implemented. Participant 6 explained that the majority of their cases are produced for the coroner's courts who are yet to embrace new evidential technology. It was also noted, however, that although slow to embrace technology, in the majority of cases at the coroners court, it is not needed.

The UK National Audit Office conducted an investigation to determine the current situation of courtrooms in terms of the digital reform. Results demonstrated how some parts of the criminal justice system are still heavily paper based and this creates inefficiencies in itself. The reforms, which have been deemed as ambitious, are designed to reduce the reliance on paper and enable more digital working but the time frames, which were originally employed, were overambitious (National Audit Office, 2016).

5.3.2.8: Theme 3 - Difficulties associated with the integration of technology into the courtroom

Another recurring theme that emerged from the participant data with regards to difficulties associated with the integration of technology into the courtroom was that even the basic equipment already installed in the courtroom presents problems. Participant 2 described; "I would want basic scene photographs to be shown on screens to the jury that allow zooming and good definition. In fact a photographic 5 x 7 (cm) album is placed on a copier and poor quality copies are produced on normal A4 paper. This lacks the fine detail often required to see evidence such as blood spatter or a fingerprint". Participant 3 added "people always seem to be finding their feet when trying to play digital evidence, making things connect and work. Also the actual devices are not always reliable". Participant 4 claimed "the current systems seem incapable of keeping up with the advance on modern technologies or simply do not work more often than not." It is clear from the participant responses that there are critical issues regarding the equipment currently installed in the courtrooms and the effective operation of these. Prior to any new technology being installed into the courtroom it is essential that any pre-existing issues be resolved to prevent further IT frustrations. Judges and lawyers within the courtroom will be less inclined to adopt further technology into the court prior to all current problems being resolved.

Many participants commented on how the crown prosecution service (CPS) require a standard DVD to be created which comprises all case information consisting of scene photographs, sketches, computer animations and reconstructions. Participant 5 commented on how they would "ideally like to be able to link a laptop to the monitors within the courtroom in order to project 3D models and move around them in real time instead of having to create a generic video file to be played on the DVD player".

Many participants described how a lack of training and knowledge about current technology installed in the courtroom could prevent further investment into technology. Participant 5 commented on how "the court clerk always seems to have difficulty getting the existing system to work correctly, albeit a DVD player. It is a great source of frustration for all involved." Until current technological issues encountered using basic courtroom technology can be rectified further disturbance will be likely with additional modern technology.

5.3.2.9: Theme 4 - Barriers to the adoption of technology into the courtroom

There will always be barriers, which prevent the adoption of technology, not just within the criminal justice system but also in other professional fields. Many individuals perceive technology to be a threat to their existing jobs and do not trust the security of modern technology. Particularly within a courtroom setting, it can be frustrating when technology being used to present evidence does not work correctly and technical issues can extend trial times. The barriers identified by participants to the adoption of technology in the courtroom can be found in Table 5.3.

Table 5.3: Barriers reported by participants to the adoption of technology in the courtroom

Barriers to the adoption of technology reported by participants	Number of participants reporting such barriers to the adoption of technology in the courtroom	Percentage of participants reporting such barriers to the adoption of technology in the courtroom / %
Lack of investment/Funding	5	24
Current basic technology doesn't work	4	19
Courtrooms are ill-equipped to interact with Police Investigators technology	3	14
Reluctance of Judges	2	10
Lack of Training	1	5
Lack of Knowledge about systems	1	5
CPS resistant to change	1	5
Reluctance of Investigators	1	5
Reluctance of Lawyers	1	5
Finding time to update full time courtrooms	1	5

Five participants (24 %) described that "a lack of investment" and the cost to implement technology appeared to the greatest barrier to its adoption in the courtroom. Participant 4 commented "Under investment seems to have been the greatest problem; we have the opportunity to bring 3D interactive virtual scenes to the courtroom for example, however the limited computing power available means that this is impossible and there is little or no will on the part of the Ministry of Justice (MoJ) to invest in this technology". The greatest barrier to the adoption of technology within businesses, not just the CJS is costing, and publicly funded legal services and the justice system have ever more constraining budgets. Manker (2015) conducted a phenomenological research study and found that participants considered cost of equipment to be the main reason for the limited use of technology in courtrooms. Although technology may be expensive to purchase in the first instance, the significant returns, which could be observed, should outweigh the initial expenditure. For example, technology aided trials may aid juries in understanding the evidence more quickly and reaching a verdict more quickly, thus bringing the case to a close more quickly, reducing case costs and allowing more trials to be conducted concurrently (Marder, 2001). In addition, there are benefits that cannot be quantified, such as juror satisfaction and engagement through the use of technology over laborious descriptions.

Participant 2 described how “efforts are being made by the Police. CPS protocol is resistant to change and it also requires funding”. Money appears to be one of the most prevalent barriers to the adoption of technology into the courtroom as well as the fear of the IT failing. Participant 3 commented, “I have seen judges get frustrated when the IT all fails”. If current systems will not work, individuals within the criminal justice system, particularly judges, will be less likely to integrate more technology into the courtroom for fear of further frustration and time spent rectifying problems. The perceived reluctance of judges to accept technology could be attributed to the fact that at this stage they are observing technology at its simplest form, for example the introduction of laptops, tablets, flat screen televisions and occasionally these are not working. These basic technological issues may be affecting their trust and confidence in the use of these basic systems so how do we expect them to trust even more fundamentally important technology without which the case could flounder.

Participant 5 described a barrier being “that the facility does not exist and I assume that is a monetary issue. Regardless, until the improvement of the visual aids for the jury i.e. much larger or closer/individual monitors are implemented even the products we provide at the moment are of limited use in the courtroom”. There is still far more technology which needs to be implemented into the courtroom to ensure a seamless integration between the technology police personnel use to document scenes and the ability to present these to the jury in the courtroom.

It was clear from the participant responses and their experiences that they believe there is a clear lack of technology integration into the courtrooms, regardless of the Ministry of Justice legislation to transform all courtrooms into ‘digital by default’ by 2016. Participants described a lack of investment as one of the main reasons for the slow progression of technology integration into the courtroom and the frustrations already apparent with current technology installed in the courtroom. There seems to be both practical and institutional barriers, which are affecting further integration of technology into the courtroom. Participant 4 commented, “Like all areas of public service this has been underfunded by the current government. Enhanced IT whilst potentially preferable to providing a better CJS might not be essential to providing a functioning CJS. Whether a good quality or high volume justice system is the desired outcome is no doubt a whole subject for debate in itself".

Barriers to the adoption of technology can include a resistance to change or a lack of acceptance. Unfamiliarity with technology can contribute to a resistance against the use of technology, not just within courtrooms (Pointe, 2002). Manker (2005) discovered that attorneys were reluctant to embrace new technology as they were set in their ways and didn't want to learn anything new. Many participants in Mankers' (2005) study described technology as cumbersome and a waste of time. Reluctance to adopt new technology can arise from tradition and fear. Some judges, lawyers and police officers may have spent the majority of their career in the traditional courtrooms that were established without the use of technology and as a result are hesitant to change procedures, which in their opinion have worked for years (Marder, 2001). Participant 15 commented on the reluctance of individuals to accept new technology; " barriers include reluctance of some judges, investigators and lawyers to consider or implement newer technologies into their investigation or courtroom presentation". However, participant 15 did continue to mention about cultural shifts; " these challenges are reducing as time progresses and the technologies are increasingly established and the general paradigm is altered." Fear of technology and change also presents a barrier to the adoption of technology, particularly the risks associated with such technological change. Some changes may be successful, and others may not, but until these changes are made, it is impossible to know the outcomes of the technology use and what it can provide to the courtroom (Marder, 2001). In addition, the CJS and CPS can look to other legal systems across the world to aid in the successful integration of technology, learning from others previous mistakes, particularly that of the Courtroom 21 Project in America.

Marder (2001) expressed concerns about dividing jurors with the use of technology, creating a larger digital divide between those jury members who are technologically savvy and those who are not. Those jury members who have not been exposed to technology may feel that they are at a disadvantage and the technology itself may confuse them prior to the evidence even having been presented. Marder concluded that a multifaceted approach would allow for a smooth transition process whereby old and new technology could co exist.

A report by the Ministry of Justice (2016) explains how the entire UK criminal justice system is being digitised to modernise courts using £700 million government funding. The funding aims to create a new online system that will link courts together – a common platform. The majority of participants described a lack of funding as one of the main barriers preventing the adoption of technology into the courtroom. The digitisation of the UK criminal justice system is due to be completed in 2019, and an influx of funding should enable more rapid adoption of technology into the courtrooms.

Courtroom equipment such as TV screens or video links may not always be available in the court or may break down. In 2014, 13 cases in Crown Court and 275 in Magistrates were postponed because of problems with the technology. The National Audit Office (2016) reported that the police had so little faith in the courts equipment that they hired their own at a cost of £500 a day. Participant 3 suggested that a potential barrier to the lack of technology integration within courtrooms could be attributed to a lack of knowledge. Rt Hon Sir Brian Leveson highlighted the requirement for judges, court staff and those individuals who have regular access to such technology to be sufficiently trained in the use of any new technologies which are to be implemented into the courtroom. In addition, staff should received subsequent refresher training to maintain sufficient knowledge and ensure existing technology can be used to its full potential (Leveson, 2015). In addition, technical assistance is required to be on hand more readily than it is currently to prevent underutilisation of technology due to delays exhibited through technological failures such as incompatible systems, or defective equipment (Leveson, 2015). Leveson found that many judges are in favour of exploiting technology in order to aid in the efficiency of the criminal justice system but had doubts regarding the ability to adapt current technology and its capacity to undertake its current duties (Leveson, 2015). Issues regarding the compatibility of technology in the courtroom and a lack of staff training are not contained to the UK. A report generated by the Attorney General of New South Wales, Australia, identified the same issues arising from technology in the courtroom (NSW Attorney General's Department, 2013; Leveson, 2015).

5.3.2.10: Theme 5- Improvements/Changes required

One of the main themes identified by participants was the current lack of technology use within the courtroom. Participants were asked whether they thought the presentation of evidence required any improvements or changes. Table 5.4 demonstrates the key improvements or changes which participants identified which they believe are necessary for the courtroom.

Table 5.4: Improvements and/or changes required within the courtroom reported by participants

Improvements and/or changes required reported by participants	Number of participants reporting such improvements and/or changes required in the courtroom	Percentage of participants reporting such improvements and/or changes required in the courtroom / %
Technology Upgrade	8	38
No Change Necessary	7	33
Individual Screens/Tablets	7	33
Increased AV Capabilities	3	14
Standardisation of Formats	1	5
More Training Required	1	5
Laptop Links	1	5
More Freedom for Experts	1	5

Eight participants (38 %) identified that the courtrooms require a significant technology upgrade in order to cope with the ever-increasing demand of technology. Participant 1 commented: “The majority of courtrooms need a radical update. I’d hope that those being built now incorporate the required technology; however I wouldn’t count on it”. In agreement, Participant 2 stated “the courts need full modernising” and participant 4 commented how “the basic court infrastructure needs upgrading to allow it to handle the significant increase in demand that comes with the use of 3D animations software”. With police services adopting modern technology to aid with the documentation and recovery of evidence from crime scenes, the courtrooms must adopt technology, which allows the presentation of such evidence, or the evidence captured by investigators becomes futile. Participant 6 commented how “courts need to catch up with investigative technologies in some instances.”

In contrast to participants who felt that the courtrooms need modernising with more novel technology, seven participants commented that no change in the courtroom was necessary with regards to technology. Participant 16 commented, “I think current methods are sufficient and like I said anything more complicated we provide our own laptop for”. Thirty-nine percent of participants thought that jurors should have individual screens or tablets whilst in the courtroom. Currently most courtrooms only have a few television screens located around the courtroom, positioned so that the judge and jury can easily view them. However, this is not always the case and although projected towards the jury, many are placed over the other side of the courtroom, which can make it difficult for the jury members to make out any detail being shown on the screens. Participant 5 stated how the courtrooms could be improved through the use of “larger screens or preferably individual tablets/monitors for jurors”. Participant 15 also described how “most courtrooms would significantly benefit from increased AV capabilities, as well as catering to the needs of jurors to have access to screens, iPads etc.” Many courtrooms in the USA have already installed multiple computer screens or individual tablets for the jury so that evidence is more easily viewed (Wiggins, 2006; Schofield, 2016).

Results demonstrated that participants believe that the courtrooms require increased audio-visual capabilities, with three participants identifying this change. Participant 2 commented: “The courts need full modernising with audio-visual displays. CPS protocol needs to change from requiring a signed photographic album to that of an electronic presentation. A basic Microsoft PowerPoint would be a good starting point”.

One participant (5 %) identified that the courtrooms need a standardisation of file formats. Participant 18 stated: “ A standardisation of digital formats used in the courtrooms. This would help in the preparation of evidence knowing which format to use when supplying evidence, to police and the courts. The most common remark we get from police and the courts regarding digital file formats is ‘can you supply or convert this or these files to a usable format, we just need it to be playable in court’”. Participants from both the UK and Australia identified the need for file format standardisation. Documentation technology currently used by police services is incompatible with current system file formats installed in the courtroom and time is required to re format files to allow them to be ‘playable in court’. The CPS often requires police services to place all crime scene files onto DVD’s as standard video files or media player to allow them to be played on the basic equipment installed in the courtroom.

5.3.2.11: Theme 6: Courtrooms of the future

With the current rate of technology development, participants were asked about their thoughts on where courtrooms will be in the future with regards to the use of technology. Technology development has produced technology such as virtual reality, which transports an individual to a scene, allowing them to view it in 3D and navigate through a scene. Research has been conducted to investigate the use of VR courtrooms, whereby jurors will wear VR headsets and be transported to the crime scene, allowing them to explore a scene (Bailenson *et al.*, 2006; Schofield, 2007). Some participants mentioned the use of VR explaining how this is a potential future development of technology use within the courtroom. Table 5.5 demonstrates some of the responses identified by participants when asked where they see courtrooms of the future. Five participants identified how the courtrooms would be completely digital, ending the reliance on paper files.

Table 5.5: How participant's perceived courtrooms of the future

How participants perceived courtrooms of the future	Number of participants reporting aspects of courtrooms of the future	Percentage of participants reporting aspects of courtrooms of the future / %
Completely Digital	5	24
Paperless	3	14
3D Presentations	2	10
3D Virtual Reality	2	10
No different to what they	2	10
Remote Transmission of	2	10
Virtual Courts	1	5
Interactive Whiteboards	1	5

Two participants (10 %) identified that more 3D presentations would be used and others identified the use of 3D Virtual Reality. In contrast, two participants stated how the courtrooms of the future would be no different to what they are now. Participant 10 commented: "the justice system works very slowly and changes very rarely". Participant 19 agreed that courtrooms are "notoriously slow to respond to 'new' technology". As part of the digital reform courtrooms are beginning to adopt technology to digitise the criminal justice system (Ministry of Justice, 2013). The digitisation of the criminal justice system is essential in order for it to remain effective in a modern technologically governed society.

Two participants (10 %) mentioned the use of VR in the courtrooms of the future whereby juries could be transported to the crime scene through VR headsets. Participant 4 commented on the benefits that VR would provide to the courtroom: "When presenting evidence in an innovative way it generally means in a way that is better for the jury to understand, and that means clarity". Participant 16 commented on the advantages of VR in the courtroom: "This will provide the ability for jurors, judges and the coroner to revisit a scene without leaving the courtroom and see things from the perspective of various people involved (victim, accused, witnesses)." Many participants commented on the benefits that VR could provide allowing a jury to explore a scene in 3D as if there were there, however other participants commented on how VR was "still a long way off from being used for evidence". Issues regarding the persuasive impact of demonstrative evidence have already been explicitly expressed with regards to 360^{o} photography and laser scanning (Narayanan, 2001). There are individuals who express more concern about the persuasive impact of VR on the jury. The persuasive nature of CG evidence can lead a jury to blindly believe and accept the evidence (Schofield and Fowle, 2013) regardless of its accuracy (Selbak, 1994). As a result, the use of visual presentation using CG could have profound implications on the case outcome if the jurors instantly believe what they are seeing. Evidence presented in such a way must remain scientifically accurate and truthfully reflect the scientific data and augment witness testimony (Manker, 2015). Participant 21 commented on courtrooms of the future and the use of VR stating: "the probity value is yet to be determined, in addition to juries not being allowed on many occasions to witness certain graphic images for fear of being overly influenced. Virtual reality would compound this." Participant 7 also commented on issues associated with VR in the courtroom: "it may be perceived as entertainment rather than a judicial process". The ultimate aim in the courtroom is to present the evidence to a jury in a way that can be easily understood so that they can make a decision based on that evidence. Technology is a means to present this evidence and the variety of technology available is ultimately aimed at presenting the evidence in the best way to ensure the jury can easily comprehend the information being presented to them. As participant 5 commented: "The aim is surely to assist the jury with understanding the complexities of the crime scene and to do that they need to be able to visualise the location and the evidence identified within it so I believe the future of a courtroom will be to provide this as realistically as possible.” Participant 5 doesn’t state what technology will be used to provide this experience to the jury only that the visual evidence will need to be as realistic as possible. Participant 5 then comments on the issues regarding visual evidence presentation in the future: “There will however be a fine line between giving a jury enough information with which to make an informed decision and traumatising them in vivid technicolour.” Technology should not be adopted for the sake of it as this could have profound effects on the trials outcome. Any evidence presented in a courtroom needs to describe the incident that occurred in a manner which is easily understandable.

The success of any future visual evidence within the courtroom ultimately depends upon the courtrooms ability to accommodate such technology. Chan (2005) demonstrated that the courtroom was insufficiently equipped to display the presentation they had created and as a result, expert witnesses were required to transport their own equipment to the court in order to display the presentation. Until courtrooms rectify issues with the already existing limited and basic technology currently installed in courtrooms, VR seems a distant prospect.

The responses obtained by participants in this study are not representative of the whole population and as such results cannot be generalised for the whole population. Further research would be required to gather a larger data sample to be able to make general statements about the whole population. This study provides an insight into the opinions and experiences of a small proportion of individuals who work within police services and who frequently present evidence in a courtroom environment - an environment which has remained paper based for many years and is now seeking to adopt technology to aid in providing a more efficient criminal justice system.

The UK National Audit office (2016) has identified that courtrooms have been slow to adopt technology and still heavily rely on paper files, which has worked for many years. The reason paper files have worked for many years could be attributed to the fact that people like to have something in their hands that they can see in front of them. Paper files and photographs allow a jury to look closely and examine what they are being shown as opposed to having documents and photographs projected onto a screen which may be half way over the other side of the courtroom that they cannot clearly see. However, printing photographs often leads to a loss in clarity and detail, which could make it more difficult to interpret what they are seeing. Often it is the case that something may be visible on screen in a digital photograph that is not visible once recreated through print.

There are currently 43 police services within the UK as demonstrated in Figure 5.7. The 15 police services that were represented from this study are found in Figure 5.7. Each police service region has their own policy and procedures for conducting criminal investigations and as such different individuals within the same police service would follow the same procedures. As a result, had this study asked other participants who originated from the same police service, it is likely that due to the operations of that particular police service, their methods for capturing crime scene environments would be the same in addition to the methods used to present evidence in court. This research covered over one third of the total 43 police services within the UK. To date, there is no current literature which has investigated police officers opinions and experiences regarding the use of technology to present complex crime scene evidence within UK courtrooms.

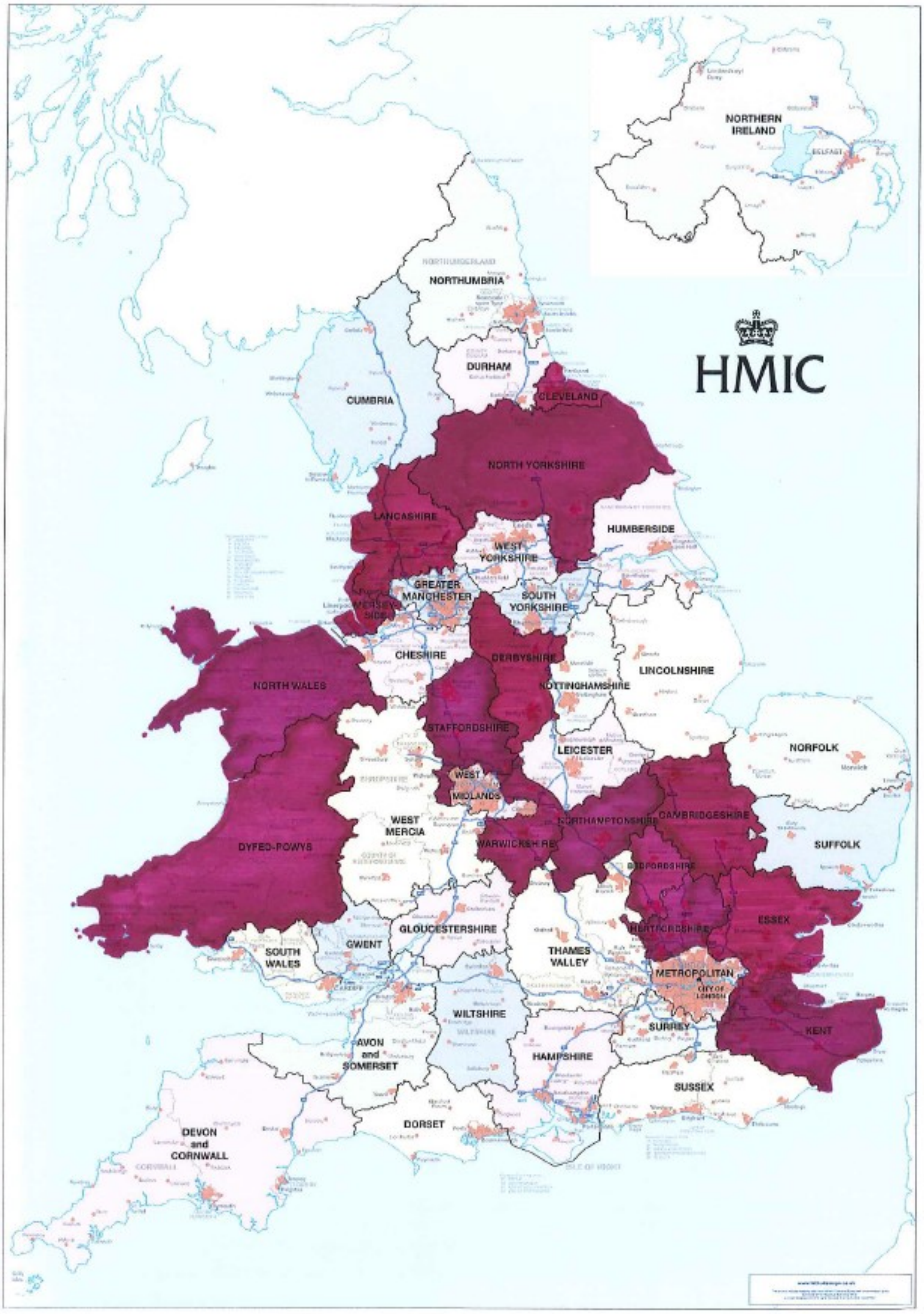


Figure 5.7: Map to show the 15 police service regions represented by the participants who completed the questionnaire (highlighted in purple). Adapted from original by HMIC.

5.3.3 Assumptions of the research study

Several assumptions were made for this research study. It was assumed that the police service personnel had some experience with the use of technology in the courtroom. As such, not all participants may have had previous experience with technology in the courtroom and as such would be unable to answer the questions in the manner previously assumed.

Another assumption was that the questionnaires would allow adequate exploration of police service personnel's experiences with regards to technology use in the courtroom and to ascertain reasons why there may be a limited use of technology in courtrooms. The method used to collect data in this case may have limited that ability to adequately explore the police service personnels' experiences due to the fact that the questionnaire did not allow for further explanation or prompt by the researcher as it would do in interviews (Turner, 2010). Participants responses to questions are likely to change based on different stimuli, such as the context of the request and their mood, in addition to what information they can recall from memory at that particular time and as a result participants may not recollect a particular experience or event at that particular time and as a result may not mention it (Saris and Gallhofer, 2014).

5.3.4 Questionnaire Design

The study design utilised questionnaires and it was assumed that the questions were worded in a manner that could be understood and accurately interpreted by the participants and that participants would answer all questions honestly and openly given that privacy and confidentiality was assured. The presentation of the questions was carefully considered prior to the questionnaire being disseminated to respondents. However, the presentation of such questions could still have caused participants to misinterpret the response required from the researcher. A question can be posed in many different ways depending on the response required. Open answer responses were chosen as this would allow the respondent to explain their experiences. In this case, closed questions would have limited the exploration of their experiences and answers and were not used as a result. Closed requests for answers contain categories or scales whereas open requests for answers do not require such parameters and allow the respondents to give their own answer (Saris and Gallhofer, 2014). Open answer requests allow the respondent to follow their own thoughts and do not force the respondent into the frame of the reference of the researcher as suggested by Krosnick and Fabrigar (1997). The effect of the researcher on the end result questions is also avoided through utilisation of open answer request however, not all responses from open-ended questions can be trusted at face value (Krosnick and Fabrigar, 1997; Saris and Gallhofer, 2014).

Questionnaires were conducted whereby respondents had to fill in the forms themselves without the presence of an interviewer. There are advantages and disadvantages for the use of questionnaires as opposed to telephone or face-to-face interviews. One of the disadvantages to the use of questionnaires which may have affected the results obtained in this study relates to the lack of control the interviewer had over the way the respondents answered the questions. Without interviewer presence respondents could skip questions or answer questions in a basic and standard manner without further elaboration (Saris and Gallhofer, 2014). In addition, the interviewer was not able to aid respondents with difficult questions or elaborate by reformulating questions to ensure participants understanding (Van der Zouwen and Dijkstra, 1996). However, although it may aid the participant, reformulating the questions would not allow comparisons to be made if the questions posed to each participant were not the same (Saris and Gallhofer, 2014). Advantages of using questionnaires to obtain participant opinion data ensured that participants did not have any time pressures that would have been associated with face-to-face interviews.

5.3.5 Limitations

There were some limitations associated with this phenomenological research study. The data collection method used questionnaires rather than face-to-face interviews due to the abstraction costs associated with using actively serving police personnel. This method of data collection provided some advantages whereby participants did not feel pressured into providing immediate responses to questions posed. However, this also meant that the researcher was not in the room with the participants and so could not gauge the emotional state or the non-verbal response of the participant at the time of answering question (Saris and Gallhofer, 2014; Manker, 2015). In addition, this method meant that the researcher did not have the opportunity to encourage a response from the participant if they seemed reluctant to answer or to ask for elaboration if short responses were given. As a result, the respondent could have skipped questions counting as a non-response to the researcher. Missing values or answers could have a disrupting effect on the analysis of the data and therefore present data that is not representative of the target population (Saris and Gallhofer, 2014).

Social desirability bias may have existed within the study and may have influenced participant's responses to questions. This is a type of bias associated with social science whereby participants can have a tendency to respond to questions in a manner that will be viewed favourably or make a good impression (Saris and Gallhofer, 2014; Manker, 2015). As a result participants may be inclined to over exaggerate 'good behaviour' or under report 'bad behaviour' and may not respond honestly and openly as previously assumed. The effect of social desirability is reduced in situations where an interviewer is not present, such as in this study (Saris and Gallhofer, 2014).

5.4 Conclusion

Whilst technology in the 21st Century has revolutionised our daily activities, from mobile phones, to notebooks and tablet PC's, the Courts have been reluctant to embrace it to aid in criminal cases, and still heavily rely on mounds of paper files. However, it is inevitable that courts will, in the not so distant future, have to adopt the use of technology for presenting evidence in order to remain efficient and up to date in a digital age. With the Ministry of Justice (MoJ) driving the adoption of technology and providing significant funding to ensure the uptake of technology by courtrooms, it is inevitable that courtrooms will become 'digital by default'. This will provide a more efficient CJS and allow information transfer to become more seamless.

American courtrooms have pioneered the integration of technology into their trials which has now become commonplace. Similarly to the UK, there are still courtrooms in the USA that are yet to fully integrate technology into their trials due to funding issues or reluctance from judges. Technology adoption in UK courtrooms has been significantly slower than the USA. Trials at different courtrooms across the country have demonstrated the benefits that technology in the courtroom can provide and the aim is to drive the adoption and integration of further technology into all courtrooms across the UK. The courtrooms, CPS and police have been moving at different speeds in terms of the digitisation of processes and the MoJ aims to develop joined up working to ensure all relevant parties are at the same stage. An inspection conducted by the National Audit Office (2016) identified little evidence of agencies identifying the financial savings made through digitisation of current processes. Steps have been made towards modernising the CJS however the Ministry of Justices' vision to provide a digital end-to-end common platform within the criminal justice system is still some way from becoming a reality.

Results from the literature survey and participant questionnaires provides support for the need for improved and expanded courtroom technology in order to significantly advance the efficiency of trials and present complex comprehensible evidence. Study results indicate that many of the participants had previous exposure to a sort of courtroom technology but the courtrooms examined did not have consistent equipment. The majority of participants commented on such technology as television screens DVD players, and basic audio visual capabilities with some participants commenting on how paper files were still being used. There is a significant cultural and social shift that is required as individuals within the CJS are currently hindering the adoption of technology into courtrooms. Reluctance from individuals to integrate technology originates from a lack of knowledge and frustration at current technology that doesn't work. An unfamiliarity with the technology has contributed to resistance among criminal justice system personnel (Pointe, 2002; Manker, 2015). In addition, systems, which have already been adopted, do not talk to each other which can waste resources and frustrate users. Until these imperfections are rectified, there is likely to be further reluctance and complications of technology integration into the courtroom. A lack of training and cost of implementation appear to also contribute to the lack of integration thus far. Training of individuals with regards to the use of courtroom technology is essential for the effective application of such technology and a lack of such training contributes to a reluctance to its acceptance or use (Bellone, 2007; Dixon, 2012; Manker, 2015). In addition to further funding required to ensure successful integration of modern technology into courtrooms, implications for positive social change are required to also increase the adoption rate of technology.

A recommendation for the implementation of further technology into the courtroom concerns its introduction in a balanced manner. One participant commented on their concerns associated with the introduction of technology into the courtroom: "misrepresentation of evidence and presentation animations could wrongly lead a trial. Extreme caution has to be placed on the manner in which this type of evidence is presented in order that the jury are not misled". There are other authors who also emphasise the careful scrutiny associated with such technology integration and the evaluation required to determine whether such additions will aid the jury in performing their role and increase trial efficiency (Selbak, 1994; Galves, 2000; Girvan, 2001; Narayanan, 2001; Marder, 2001; Schofield, 2009; Schofield and Fowle, 2013). Technology integration is not without its challenges. Many individuals are concerned about the security risks associated with transferring information and evidence digitally. These negative effects demonstrate the requirement for the careful implementation of technology with minimal disruption to current procedures.

Further reluctance to adopt visual technology arises from the persuasive impact that these demonstrations may have on the jury and on the case outcome. Schofield and Fowle (2013) identified how further research is required to establish an acceptable framework for visual presentations of evidence to identify suitability for the jury. As of yet, there is no established framework for the acceptance of visual presentations, which are commonly treated like other digital evidence with regards to its admissibility (Wang, 2011; Schofield and Fowle, 2013). In addition, judges often appear to be the ultimate authority on whether a presentation is admitted into the courtroom (Selbak, 1994).

Further research must be conducted to determine the most appropriate methods for integrating new technology into the courtroom with minimal disruption to current procedures. Technological failures in the courtroom can extend the time of trials and can cause the judge to lose confidence in the equipment. In addition staff who are well versed and trained in the operation of such equipment need to be on hand within the courtroom to prevent frustrations when IT fails to work. This will not only prevent frustrations with regards to technology use in the courtroom but it should also speed up the trials. This will also alleviate concerns by judges and lawyers who feel it is a requirement that they have the technical skills to be able to operate such equipment. Legal professionals can be reluctant to adopt new technology after developing their skills without the use of such technology (Bellone, 2007; Dixon, 2012). Training for judges and lawyers on the adoption of technology will give them knowledge about such systems and may reduce their fears associated with current courtroom technology.

The Committee of Public Accounts (2014) (House of Commons, 2014) identified that “there has been slow progress in improving IT, and there were still too many disparate systems, which failed to operate together” as one of the long-standing problems associated with the criminal justice system. Police service personnel agree that progress of technology implementation into courtrooms is ‘glacially’ slow.

The Ministry of Justice (2016) is investing £700 million into modernising the courts, transforming the way in which they operate through the adoption of technology to provide a more efficient criminal justice system. The reform will modernise courtrooms using modern technology including WIFI, video link systems and new equipment for presenting digital evidence. Some courtrooms across the UK are making greater use of technology than others, but the current reform program should address these issues, funding more courtrooms to integrate technology. The nature of some court estates wont allow the facilitation of technology adoption due to listed buildings but it would be expected that any new courtrooms being built would have technology installed as standard during its construction to minimise disruption. In order to facilitate the successful integration and maintenance of technology within the courtroom a significant cultural change is required and will only prove successful if all parties involved actively seek to change or become willing to embrace such systems.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

The overarching purpose of this study was to determine the relative importance and potential of new panoramic imaging technologies which could provide more innovative and appropriate methods for documenting, managing and presenting crime scenes. This thesis has explored the potential of panoramic imaging technology and crime scene management software to assist and develop the way in which criminal investigations are conducted and investigated. This research has summarised several purpose-built crime scene documentation technologies which are currently available to police services, and has evaluated the accuracy and precision of measurements which can be taken using one of these panoramic imaging technologies to determine its applicability to criminal investigations. The thesis has also considered the additional uses of panoramic imaging technology within criminal investigations by adapting a 360^{o} panoramic camera to integrate an alternate light source for the detection and visualisation of biological fluids to fulfil alternative aspects of crime scene examinations. Finally, the thesis has explored the extent to which technology has been integrated within the criminal justice system, particularly focusing upon technology use and adoption within courtroom environments and exploring the barriers which may affect successful use of technology in courtrooms. The research also highlights the difficulties associated with technology adoption into organisations, particularly focusing upon police organisations which have strict standard operating procedures.

This research is significant because it provides new insights into the development of crime scene documentation and the subsequent adoption and implementation of panoramic imaging technology into existing police processes and standard operating procedures. In addition, the research examines the implications for organisations associated with limited technology evaluation and correct determination of user requirements prior to technology adoption. Further study focusing on alternative implications within policing is recommended. This chapter summarises the main insights from the research conducted within this thesis and discusses the contributions which the research makes to knowledge. This chapter concludes with some of the other questions which have arisen due to this research and the implications for policy and practice as well as recommendations for future research.

The extant literature on crime scene documentation leads one to conclude that current methods for documenting crime scenes are no longer sufficient and lack the ability to successfully convey spatial relationships of evidence within a scene. Development and advancement of technology has brought a reduction in the cost of accessing technology, enabling more individuals, from professionals to non-specialised users to have access (Tokuda *et al.,* 2013). With a plethora of technology currently available to police services it is imperative that thorough research is conducted to determine the advantages and limitations of such technologies and to determine the probative value of such technology to an organisation.

This thesis scrutinised the current methods for investigating and documenting crime scenes, determined the limitations associated with such approaches and developed an understanding of how technology has developed to produce new, more immersive and detailed methods for documenting crime scenes using panoramic imaging technology. The thesis explores the different types of panoramic imaging technology available to police services and develops an understanding regarding the operation of such technology. This can present difficulties for police services when considering the purchase and use of such technologies. With declining budgets, Police services do not have the time and financial resources to extensively evaluate technology prior to its adoption. Thorough research evaluating the technology would allow Police services to make more informed decisions about the adoption of technology that is fit for purpose and cost effective. The results from the research determine that police organisations must consider their operational requirements and determine exactly what purpose technology will serve if implemented into current standard operating procedures. Organisations must evaluate their specific needs, operations and financial resources. Furthermore, given that the panoramic imaging technology utilised within this study was not exhaustive, it is suggested that further studies could explore other types of panoramic imaging technology available to police services, to allow a more comprehensive record of the alternative types of accessible technology. Chapter 2 presents a series of criteria which should be considered when an organisation is seeking to adopt technology into their current practices and it is recommended that organisations use this information as a basis for evaluating their specific requirements for technology in order to ensure a more informed decision can be achieved allowing full justification of its subsequent purchase.

This research highlighted that one of the most important considerations Police organisations must make regarding technology adoption is cost (Koper *et al.,* 2009). Second to cost concerns the validation of such technology to determine its probative value within criminal investigations. One such validation focuses upon the accuracy and precision of the technology and in this instance focused upon the accuracy and precision of measurements that could be taken using photogrammetric methods. Accuracy and precision of capture and measurements using the technology's hardware and software are essential factors for the successful integration of such equipment within the criminal justice system. Measurements, which could be taken using the SceneCam and complimentary SceneCenter software application, were examined and compared to traditional manual measurement methods using a tape measure. Results from this study demonstrated that the software application measurements were more reproducible than the manual approach, and this offered greater flexibility with regards to the time and location of the documentation process in a crime scene. The size and shape of the measured items are also likely to influence a person's ability to record accurate measurements of them, and each method tested offered advantages and should be used in conjunction. For example, in situations where measurements were considered to be more difficult to take with a tape measure, such as the length of a wall, the software application can provide a solution to capture the measurement more easily. For smaller items with more complex shapes, such as bedside tables, it may prove beneficial to use a tape measure in a forensic environment. This study demonstrates the importance of the appropriate use of complimentary measurement techniques in order to accurately capture data that can assist in a forensic-Police enquiry. In addition, this study highlighted a potential unit limit within the software application, whereby the software quoted any measurement below 2cm as <2 cm and did not specifically produce a numerical value for the measurement. Practically, this feature within the software will limit the potential applications within criminal investigations as it will not be suitable for measuring any items that are less than 2 cm in length, width or height. As a result, this technology would not be suitable for analysing and measuring blood spatter at crime scenes, for example.

Additional uses for the panoramic imaging technology were considered focusing upon the ability to successfully locate and visualise human biological fluids on different substrates utilising an alternate light source (ALS). The successful adaptation of such technology would allow the technology to be utilised for multiple purposes to document a range of different crime scenes and may further justify its purchase. This study determined that the 360^{o} camera system was adapted using a blue Crime Lite XL to successfully detect semen and saliva at different volumes (from 5 to 250 μL) at a range of distances (from 30 cm to 300 cm). The ability to successfully locate and visualise human biological fluids on different substrates provided the opportunity to allow a more dynamic recording of the spatial placement of biological fluids and allowed fluids located to be placed in context; this is a significant improvement over 'still' digital photography. This technique presented the opportunity to presumptively screen a crime scene for human biological fluids and facilitates simultaneous location and visualisation of biological evidence in addition to capturing a complete 360^{o} view of the entire crime scene for contextual purposes of placing other evidence types (e.g. footwear, finger marks). The results of this research have also demonstrated that it is possible to locate undiluted biological fluids.

This study provides a snapshot of how technology has begun being integrated into the criminal justice system process, initially within police services for documenting and recording crime scene environments, to use for presentation of evidence within courtrooms. Although technology is well adopted within Police services, there is further need for police organisations to evaluate their specific requirements to ensure adoption of fit for purpose and cost effective technology. Regarding the use of technology within courtrooms, the literature suggests that changes are required to enable routine use of technology (Manker, 2015). Basic technology is being installed into courtrooms, such as television screens, WIFI and video live links. However, there are often times within trials when the technology will not work and the technical staff is not available to fix the problem, leaving judges frustrated. Respondents of the questionnaire had different experiences with the use of technology within courtrooms for the presentation of evidence, with some police personnel having routinely utilised panoramic recording technology for presenting evidence, whilst others described the difficulties in demonstrating such evidence when the technology does not currently exist within the courtroom to allow its presentation. The full potential of panoramic imaging for presenting complex forensic evidence is yet to be fully established and until its use becomes routine within courtrooms, it cannot be used to its full potential or purpose within such an environment or discipline.

This study makes major contributions to the knowledge about technology within the criminal justice system, focusing on panoramic imaging technology that can be used for documenting crime scenes. Concurrently, it has only begun to scratch the surface regarding technology within courtrooms and the alternate uses of such technology within forensic science. As an exploratory study, this work presents some exciting insights as to how panoramic imaging technology can be adapted to provide alternative uses for such a system and aiding with other aspects of forensic science and policing. These insights provide motivation for further research to be conducted, using this study as a starting point and a tool that can aid further research in this area.

6.2 Further research

As with many studies, this study raises further questions and throughout the thesis a number of them have been mentioned. Many of these questions and other areas of follow up research are presented below. The questions raised are intended to aid in setting a research agenda for technology use within criminal investigations.

Given the changing nature of technology, a series of longitudinal studies, based on this research, would document further panoramic imaging technologies available to police services and evaluate the advantages and disadvantages associated with such technology. The development of research investigations that involve both the practitioner and the researcher are imperative, and in some instances manufacturers. Police services do not have the time or financial resources to conduct in depth, evaluative research such as that conducted within the thesis to determine the most appropriate type of technology for use by their organisation, and this will differ between departments and within counties, as their operational requirements will also differ. In some circumstances it may be required that manufacturers and practitioner organisations work alongside one another to allow manufacture of equipment which is both fit for purpose and cost effective. The collection and comparison of additional case studies from a range of contexts and environments is important. The development of more outcomes based, measurement studies to encourage comparative studies should also be encouraged. Further validation of technology could be investigated using the methodology proposed in this thesis; this will ensure that a thorough and detailed investigation can be conducted to determine the accuracy of further technology.

With regards to the successful adaptation of a 360^o camera system utilising an alternate light source, future research would consider utilising more wavelengths of light to determine the optimum lighting conditions required to induce a fluorescent response from the target biological fluid. Further investigation observing a broader range of substrates is planned to determine the optimum conditions and limitations of this combined technique and its applications for casework, particularly in the presence of alternative agents, which may also fluoresce, and therefore introduce false positive results. Alternative agents known to induce false positive results are documented in the literature (Vandenberg and Oorschot, 2006; Marin and Buszka, 2013) and therefore it would be expected that the introduction of such agents into the existing methodology would produce similar results. In addition, it is recommended that other biological fluids be investigated, such as vaginal secretions, urine and sweat, to determine the optimum conditions for their successful location and visualisation. In addition, it would be useful to establish the sensitivity of this approach using diluted samples, which could be more reflective of casework samples. It would also be useful to monitor the effectiveness of the approach over time and this could form the basis of further work.

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Appendix

Appendix 1

Sheppard, K., Cassella, J.P., Fieldhouse, S. (2017) A Comparative study of photogrammetric methods using panoramic photography in a forensic context. *Forensic Science International.* 273. 29-38.

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A comparative study of photogrammetric methods using panoramic photography in a forensic context

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ABSTRACT

Taking measurements of a scene is an integral aspect of the crime scene documentation process, and accepted limits of accuracy for taking measurements at a crime scene vary throughout the world. In the UK, there is no published accepted limit of accuracy, whereas the United States has an accepted limit of accuracy of 0.25 inch. As part of the International organisation for Standardisation 17020 accreditation competency testing is required for all work conducted at the crime scene. As part of this, all measuring devices need to be calibrated within known tolerances in order to meet the required standard, and measurements will be required to have a clearly defined limit of accuracy. This investigation sought to compare measurement capabilities of two different methods for measuring crime scenes; using a tape measure, and a 360° camera with complimentary photogrammetry software application. Participants measured ten fixed and non-fixed items using both methods and these were compared to control measurements taken using a laser distance measure. Statistical analysis using a Wilcoxon Signed Rank test demonstrated statistically significant differences between the tape, software and control measurements. The majority of the differences were negligible, amounting to millimetre differences. The tape measure was found to be more accurate than the software application, which offered greater precision. Measurement errors were attributed to human error in understanding the operation of the software, suggesting that training be given before using the software to take measurements. Transcription errors were present with the tape measure approach. Measurements taken using the photogrammetry software were more reproducible than the tape measure approach, and offered flexibility with regards to the time and location of the documentation process, unlike manual tape measuring.

1. Introduction

One of the most important aspects of conducting a criminal investigation involves comprehensively recording and documenting the crime scene, given that the process can ultimately determine the success of the subsequent investigation [1]. Crime scenes often present unstable and short-lived environments, containing ephemeral evidence, which can prove difficult for Scene of Crime Officers (SOCO's) to document efficiently [2]. The documentation process is often laborious and time-consuming [3], as the resultant documentation must provide a thorough and permanent record of the scene, comprising written, graphical, photographic, and video evidence of all contextual information [4,5]. This may require effective communication of the crime scene environment and the distribution of evidence to other individuals who were not present at the scene [6]. Communication may be via 2D photographs, sketches, or more recently, using 360° visualisation technology and 3D modelling [7]. The adoption of such new technologies within police services is therefore further driven by the need to improve efficiency and effectiveness both for forensic scientists, police and the jury within the criminal justice system [8]. Such technology produces three-dimensional representations of crime scenes, providing spatial perception, and the opportunity for the viewer to navigate themselves throughout the scene in a highly detailed immersive environment [9]. This is not possible with 2D photography.

During scene documentation measurements of objects and evidence within the scene are taken, which establish their precise location and relationship to one another [10]. The position and location of evidence is crucial to an investigation because it can help to reconstruct a sequence of events, which may be used to

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support or refute an individual's account of what happened at the scene, or theories about what may have happened. It is therefore essential that such information be accurately recorded. Measurements are frequently taken using a tape measure [11], which are deemed 'adequate' for measuring a crime scene 'in situ' [12]. With 360° technology the user has the ability to take measurements from digital images using photogrammetry software applications. Photogrammetry allows measurements to be taken from photographs using triangulation methods, which derive the location of features using 3D coordinates (X, Y and Z) [13]. The process requires two or more photographic images to be taken from different positions or viewing directions within a scene [14]. The accuracy of measurements taken using a tape measure or photogrammetry software applications are not only dependent on the accuracy of the instrument, but also rely on the competency of the user. The accuracy of the instrument is frequently reported by the manufacturer. However, details of the experimental work used to support the margin of error are often not transparent, and therefore it is difficult to establish the reliability of such data.

Currently the accepted limits of accuracy vary throughout the world. For example, in the UK there is no published accepted limit of accuracy, whereas in the United States the accepted limit of accuracy is 0.25 inch [15]. However, as part of the International Organisation for Standardisation (ISO) 17020 accreditation competency testing is required for all work conducted at the crime scene. Under the scope of IS0 17020, all measuring devices will need to be calibrated within known tolerances in order to meet the required standard, and measurements will be required to have a clearly defined limit of accuracy [16].

It is important to investigate the accuracy with which photogrammetry software applications are able to record measurements compared to tape measures, which are established within Courts of Law. Without robust and independent study it is not possible to reliably implement their use as part of crime scene documentation. Inaccuracies within crime scene documentation could have profound effects on the interpretation of casework, as described. This investigation has examined the accuracy with which a photogrammetry software application was able to measure items within a mock crime scene, and to evaluate practicalities associated with the use of such technology. The results of this study and their interpretation are likely to be of interest and benefit to any person(s) involved in crime scene work, and will help those involved to make an informed choice when considering options for crime scene documentation.

2. Method

2.1. Measuring a single blank wall

A white painted interior wall was measured ten times using a DeWalt DW03050 Laser Distance Measure. The device had a typical measuring tolerance when applied to 100% target reflectivity (such as white painted walls) of +/−1.5 mm. These tolerances apply between 0.05 m–10 m, with a confidence level of 95% [17]. The same wall was then photographed with a Spheron SceneCam (Spheron VR AG), which was positioned in the approximate centre of the room (1.50 m from the wall of interest). The Spheron SceneCam (Fig. 1) utilised in this investigation consists of a fisheye Nikon 16 mm f/2.8 D lens and a CCD (Charge Coupled Device) with a tri-linear RGB chip which produced 50 MP (megapixel) images. The resolution of the white wall image was 2828 × 2724 pixels.

Following calibration of the instrument, two 360° scans of the environment were taken; one at the cameras lower position (146 cm from the floor to the centre of the camera lens), and one at the cameras highest position (207 cm from the floor to the centre of the camera lens), according to the manufacturer's instructions [18]. The panoramas were uploaded onto the complimentary Scene-Center software, and measurements were taken by the researcher along the ceiling and floor line. The height of the wall was sectioned into five areas, as shown in Fig. 2. For each of the five areas ten repeat measurements were taken. No lens distortion correction was necessary because the system employs an algorithm which automatically corrects any distortion from the fisheye lens. This means that the user is only required to select the distance endpoints under study.

Five pairs of 8 mm diameter paper dots were applied to two opposite corners of the wall (Fig. 3). The pairs were positioned to replicate the five areas used in the previous study (Fig. 2). A DeWalt DW088K cross line laser was used to ensure that the position of the dot pairs were level. All photographs and measurements were taken using a Spheron SceneCam and ten repeat measurements

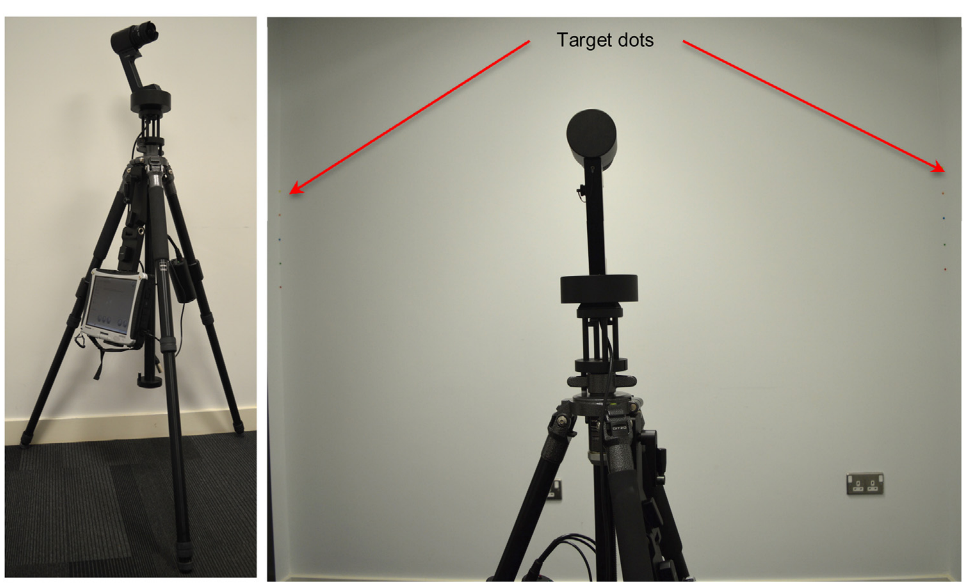

Fig. 1. Left: Spheron SceneCam. Right: Spheron SceneCam facing the wall of interest with the target dots on each wall corner.

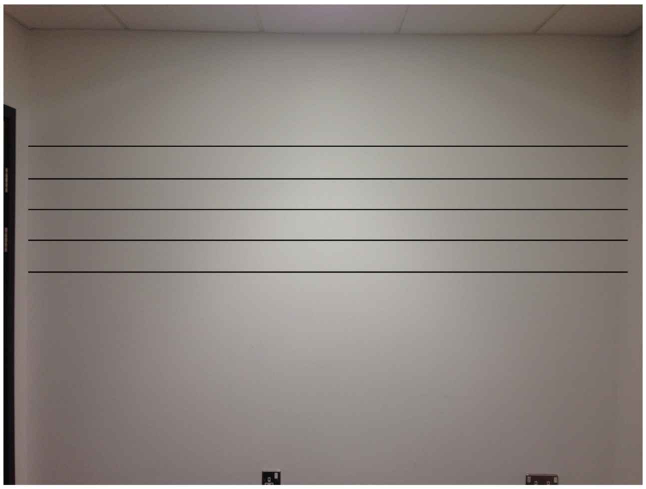

Fig. 2. Wall sectioned into five areas. Lines just show the sections and were not drawn onto the wall.

were taken. When using the SceneCenter software the cursor was positioned in the approximate centre of the target dots.

A DeWalt DW088K Cross line laser (Fig. 4) was also used to provide an alternative reference point for the measurements to be taken from. The cross line laser was placed onto the wall directly opposite the wall of interest and a laser line projected onto the wall of interest (Fig. 5). Photographs and measurements were taken as described.

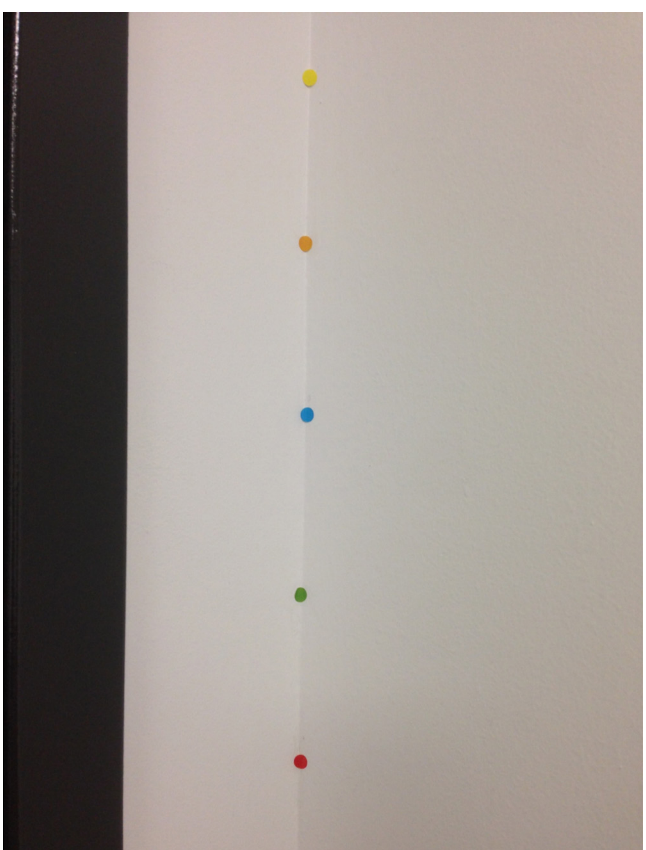

Fig. 3. Target dots placed in the corner of the room.

2.2. Measuring the scene

The investigation was conducted at a scene of crime training facility at the host institution, the room was arranged to replicate a typical double bedroom. The same scene was staged for each participant, with fixed and non-fixed items, which the participants could measure. The position of the non-fixed items was standardised by marking out their locations on the floor using UV permanent marker. A plan of the room detailing the ten measurements taken is shown in Fig. 6.

Measurements of the fixed and non-fixed items (Fig. 6) were taken using a DeWalt DW03050 Laser Distance Measure. This was repeated ten times for each measurement. The mean value was used as the control measurement. Artificial markers were used for items that had no obvious distance endpoints. In this instance the laser distance measure was positioned at the start point, and a cardboard sheet was positioned at the end point, thus providing an 'end' to the laser, and allowing a measurement to be taken.

Ten Higher Education students (3 male and 7 female, aged 20–39 years) were recruited from the host institution. The participant group comprised final year BSc undergraduate and MSci students from Forensic awards, and PhD students from the School of Sciences (some of whom had previously studied Forensic Science). Participants were briefed on the aims of the investigation. Participants were provided with a plan of the room in hard copy (Fig. 6) and were asked to record measurements of the ten fixed and non-fixed items using an 8 m Draper 25 mm wide tape measure. The plan was then taken from the participant, and they were asked to complete a distraction task, to help prevent them from remembering the measurements from the scene. The distraction tasks included mathematical calculations such as multiplication, division, subtraction, addition, and counting backwards from 30. Participants were then given an identical room plan and asked to take the same ten measurements, but in a different order. The process was repeated until each participant had measured each of the fixed and non-fixed items (Fig. 6) ten times.

The bedroom environment was photographed using a Spheron SceneCam (Spheron VR). The SceneCam was placed in four different positions within the bedroom to ensure that all ten measurements were visible within the 360° photographs (Fig. 7). The resultant panoramas were uploaded onto the SceneCenter software. All participants were asked to take measurements of the ten fixed and non-fixed items on the SceneCenter software application. When using the SceneCenter software participants were instructed to position the cursor in the approximate centre of the target dots. Participants were asked to record the measurement quoted by the software on an identical plan of the room to that used in the previous study. Distraction tasks were not deemed to be necessary because records of previous marker positions or measurements were not retained. The process was repeated until each participant had measured each of the fixed and non-fixed items ten times. Blank room plans were provided for each repeat.

The distribution of the data sets was determined using a Kolmogorov Smirnov test [19]. A Friedman test [20] was used to establish the existence of statistically significant differences between the control, tape and software measurements for each of the ten fixed and non-fixed items. An alpha level of 0.05 was used. Pairwise comparisons of each data set pair were completed using Wilcoxon Signed Rank tests. For the Wilcoxon Signed Rank test [20] a Bonferroni correction was applied to the alpha level by dividing the original alpha level of 0.05 by 3 (0.016). Effect size was calculated according to Cohen's r [20]. All statistical testing was carried out using SPSS version 23 (IBM SPSS).

Fig. 4. DeWalt DW088K Cross line laser.

3. Results and discussion

3.1. Measuring a single blank wall

The control mean wall measurement was 2.70 m, with a standard deviation of 0.00088. Table 1 presents the measurements taken using the SceneCenter software for the ceiling, floor and five sections across the wall.

The mean wall measurements taken from the ceiling and floor lines were 2.66 m, which were consistent and 4 cm away from the control measurement of 2.70 m. The RSD values were very small, with results of 0.18 and 0.25 for the ceiling and floor lines respectively, providing evidence of a high level of consistency. Consistency between the control and ceiling/floor measurements were attributed to the presence of clear reference points visible in the ceiling/floor corners of the wall. The ability to locate clear reference points resulted in accurate measurements being obtained.

Mean measurements taken across the wall ranged from 2.93 m–4.35 m, with high RSD values, which were up to 42.63. The high RSD values were due to the range of measurements taken, which varied from 2.12–8.39 m. One of the causes for this significant deviation is likely to have originated from the photogrammetric process, whereby the software cannot rebuild depth as a result of blank featureless textures or shadows produced in the corners of rooms associated with blank walls [21], such as that used in this study. The corners of the wall that were not associated with the ceiling or floor lines were less visible, and therefore it was more difficult to assign start and end points. This problem was magnified by the operation of the software, which automatically zooms into the region of interest in order for the user to select the exact pixel for the start and end points. This means that when the end point is selected the user is unaware of the allocated starting point. This often meant that there was little consistency in the heights of the start and end points, which caused inaccurate measurements to be obtained. This also explained why the ceiling and floor lines were easier to measure and gave more accurate results, given that the allocated start and end points were level.

In order to address the difficulties in assigning start and end points five pairs of 8 mm diameter paper dots were applied to two opposite corners of the wall. Table 2 shows the measurements taken on the SceneCenter software using the target dots compared against those taken in the previous study without the target dots.

Table 2 demonstrates that the target dots facilitated reproducible and more accurate results, as shown by the mean wall measurements of 2.68 m. The target dot data also resulted in significantly lower RSD's than measurements taken without the dots, to the extent that measurements of 4/5 sections of the wall had a RSD of 0. Artificial targets are often used in photogrammetry to improve the accuracy of measurements taken [22], but this study had not used a crime scene context. The authors accept that given the size and shape of the target dots there was the potential for error within cursor placement, despite the instruction to participants to aim for the approximate centre. An alternative approach could have utilised crosshair markers, or two pieces of tape, situated at right angles to signify endpoint targets. This approach may be considered for future practice.

At a crime scene it may not be possible to use the target dot approach, and therefore a laser line was also used to provide an alternative reference point for the measurements to be taken from. Table 3 shows the measurements taken on the SceneCenter software using the laser line, compared against measurements taken without the reference line.

Table 3 demonstrates the ability of the laser line to produce more accurate and reproducible measurements using the software, as shown by the mean wall measurement of 2.681 m, compared to those taken without any reference point, which had a mean wall measurement of 3.061 m. The blank wall measurement had a significantly higher RSD value of 10.52 compared to the cross line laser measurement RSD value of 0.11. The target dot study had demonstrated that the important feature was the presence of clear start and end reference points, which the laser level line had simply replicated in a non-invasive manner. The presence of these artificial reference points allowed the researcher to clearly assign start and end points to the measurements, and this resulted in more accurate measurements being obtained.

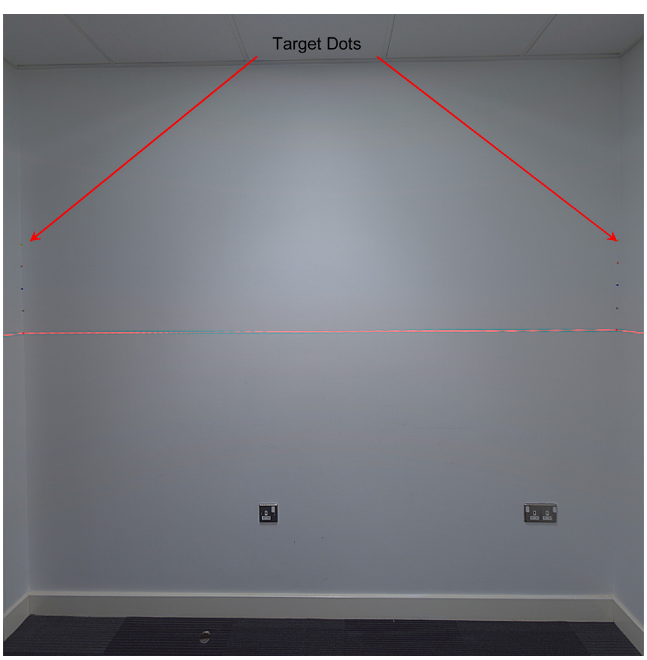

Fig. 5. Target dots adhered to each corner of the wall and laser level line projected across the wall intersecting through the red coloured target dots.

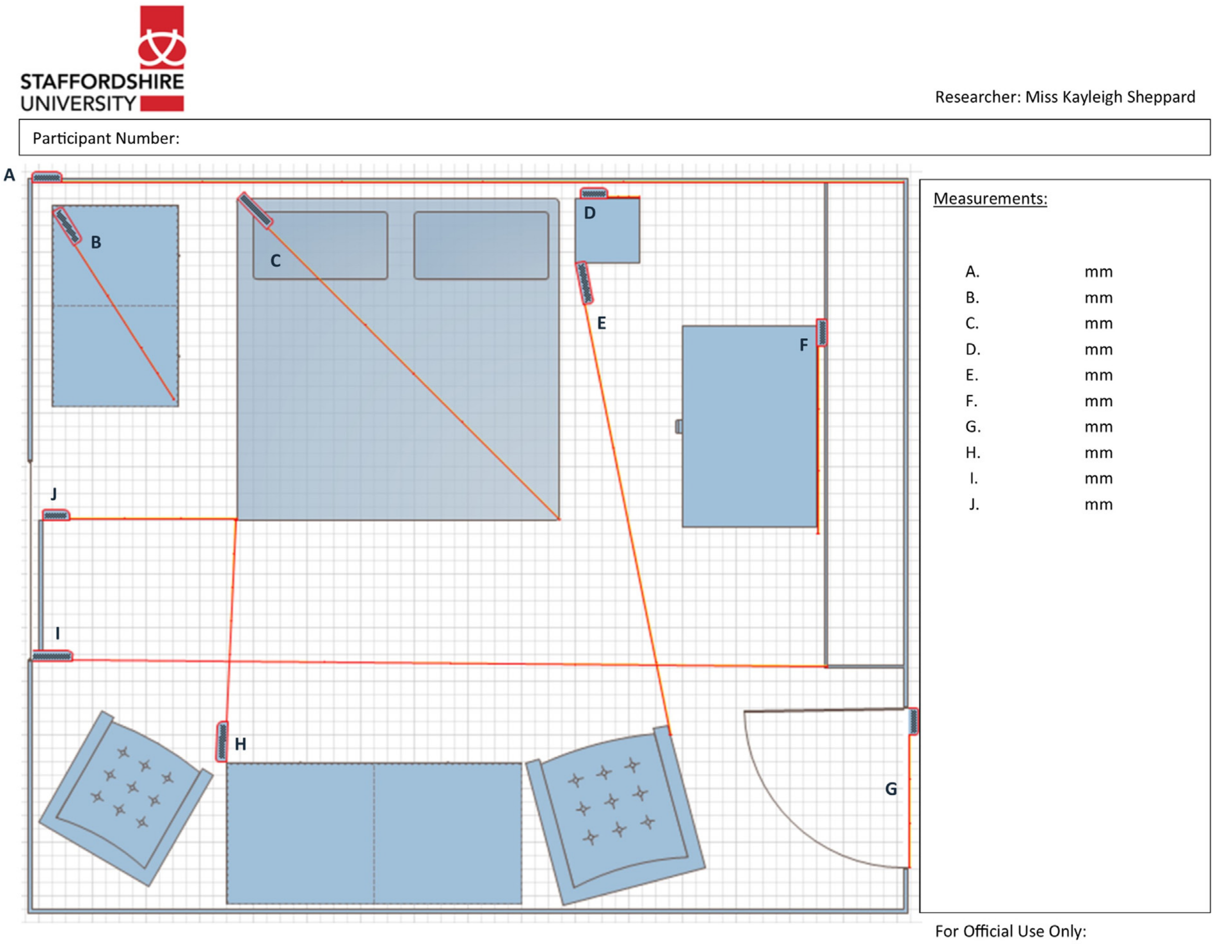

Fig. 6. Room plan given to participants showing measurements A–J.
Measurements A–J consist of:
A—North wall length, corner to corner
B—Top of chest of drawers, measured diagonally from one corner to its opposite corner
C—Width of double bed mattress, measured diagonally across from top corner to bottom corner
D—Length of bedside table
E—Distance along the floor from the leg base of bedside table to the leg base of a chair
F—Length of dressing table
G—Width of inside doorframe
H—Distance along the floor from base of the wardrobe to the leg of the bed
I—Room width measured along the floor, base board to base board
J—Distance along the floor between the baseboard of the radiator to the leg of the bed.

3.2. Measuring the scene

A variety of ten fixed and non-fixed items provided different sizes and shapes for the participants to measure. Also, some of the items were easier to measure than others. For example, measurement I (Fig. 6) was the width of the room across the floor space, which was easy to achieve given that the start and end points were easy to identify. On the other hand, measurement A (Fig. 6) required participants to measure the width of the wall above the existing furniture, which was physically difficult to achieve as a single participant using a tape measure.

Table 4 shows the mean control measurements and RSD values for the items, A–J. The RSD values were very small ranging from 0.0104–0.2985, providing evidence of a high level of consistency.

In order to take measurements using the software the camera in the scene had to be able to capture the start and end points of the items to be measured. In this study the camera was placed in four different positions, which facilitated the capture of start and end points for all ten fixed and non-fixed items. This meant that the minimum and maximum distances to the objects of interest in the field of view from each of the camera positions were different, as shown in Table 5. Fig. 8 demonstrates that the position of the camera significantly impacted upon the actual measurements that were obtained from the software. For example, the control measurement for item B was 889 mm, yet at position 1 the mean measurement was 870 mm, at position 2 it was 865 mm, at position 3 it was 852 mm, and at position 4 it was 858 mm. Analysis of the error bars for item B would also support a significant deviation of measurements. This trend was apparent for all of the fixed and non-fixed items. As with the earlier study measuring the blank wall, the accuracy of the resultant measurement taken using the software application was dependent upon the users' accuracy in identifying consistent start and end points. Some of the fixed items had bevelled edges or rounded corners, and as a result participants were likely to have chosen different start and end points to measure, resulting in significant deviations. An alternative explanation is that if an object is photographed at close range with full image resolution one might expect a more accurate measurement than an object photographed at long range, which

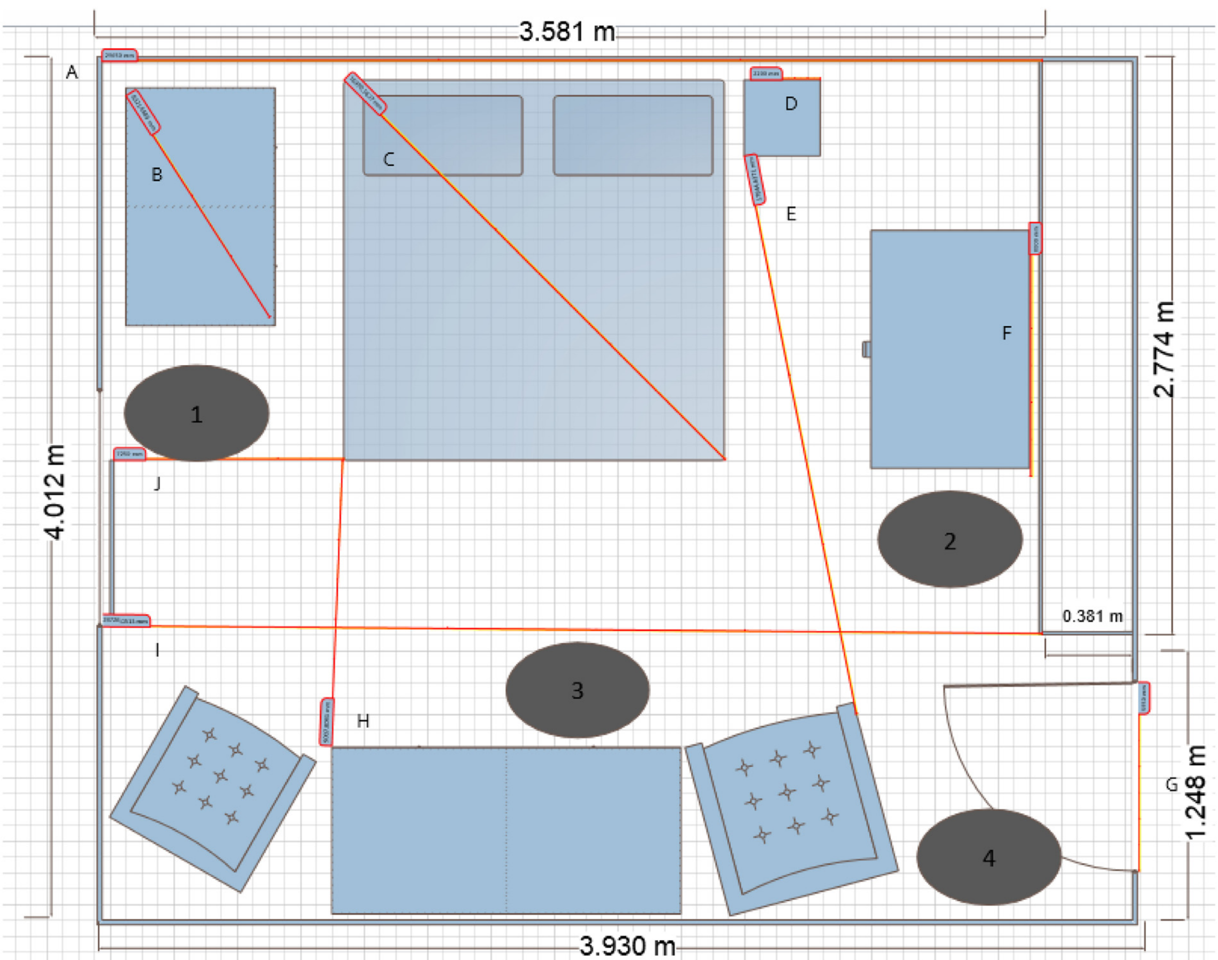

Fig. 7. Room plan showing the positions 1–4 of the camera for capturing the environment and the bedroom dimensions.

Table 1
Measurements taken using the SceneCam software at the ceiling, floor and sections across the wall.

Repeat number	Ceiling measurement/m	Floor measurement/m	Blank wall measurements/m Section across the wall				
			1	2	3	4	5
1	2.66	2.66	3.37	3.47	3.41	3.17	2.54
2	2.66	2.65	3.29	3.15	2.90	2.85	2.65
3	2.66	2.66	2.97	2.95	2.87	2.81	2.52
4	2.66	2.65	3.25	3.10	2.73	2.35	2.12
5	2.66	2.66	3.58	4.00	3.74	3.08	2.44
6	2.65	2.66	4.64	5.07	4.30	3.69	3.28
7	2.66	2.65	4.37	4.09	3.62	2.70	2.31
8	2.65	2.67	5.07	5.33	4.76	4.33	3.38
9	2.65	2.65	5.71	6.05	6.72	6.03	3.77
10	2.66	2.66	5.03	6.25	8.39	5.70	4.24
Mean	2.66	2.66	4.13	4.35	4.34	3.67	2.93
Relative Standard Deviation (RSD) %	0.18	0.25	23.24	28.51	42.63	34.88	23.89

may also have contributed to differences between the control measurements and those taken using the software application.

Taking measurements with the tape measure required participants to be in front of the item to assign appropriate start and end points. Fig. 8 demonstrates that the tape measurements ranged from 0.4–20 mm difference from the control. The deviation from the control was dependent on the measurement itself. For example, analysis of the error bar for item A shows a significant deviation from the control measurement, the highest shown for any of the tape measurements, with a standard deviation of +/−43.40 mm. The control measurement was 3579 mm whereas the mean tape measurement was 3596 mm, showing a difference of 17 mm. This large deviation was likely to have originated from the difficulty of measuring the width of the wall around and above the existing furniture. In this instance, the software was capable of producing less deviation, as the item to be measured was considered easier with the software application, which didn't require participants to navigate around furniture.

All of the tape measurements for the ten items showed deviation from the control. The size of the deviation appeared to be

Table 2
Measurements taken without a reference point (Blank Wall Measurements) compared with those taken using Target Dots.

Repeat number	Blank wall cluster measurements/m					Target dots measurements/m				
	1	2	3	4	5	1	2	3	4	5
1	3.37	3.47	3.41	3.17	2.54	2.68	2.68	2.68	2.68	2.68
2	3.29	3.15	2.90	2.85	2.65	2.68	2.68	2.68	2.68	2.68
3	2.97	2.95	2.87	2.81	2.52	2.68	2.68	2.68	2.68	2.68
4	3.25	3.10	2.73	2.35	2.12	2.68	2.68	2.68	2.68	2.68
5	3.58	4.00	3.74	3.08	2.44	2.68	2.68	2.68	2.68	2.68
6	4.64	5.07	4.30	3.69	3.28	2.68	2.68	2.68	2.68	2.68
7	4.37	4.09	3.62	2.70	2.31	2.68	2.68	2.68	2.68	2.68
8	5.07	5.33	4.76	4.33	3.38	2.67	2.68	2.68	2.68	2.68
9	5.71	6.05	6.72	6.03	3.77	2.68	2.68	2.68	2.68	2.68
10	5.03	6.25	8.39	5.70	4.24	2.68	2.68	2.68	2.68	2.68
Mean	4.13	4.35	4.34	3.67	2.93	2.68	2.68	2.68	2.68	2.68
Relative Standard Deviation (RSD) %	23.24	28.51	42.63	34.88	23.89	0.11	0	0	0	0

Table 3
Measurements taken without a reference point (Blank Wall Measurements) compared with those taken using a laser line.

Repeat number	Blank wall measurement/m	Cross line laser measurement/m
1	2.56	2.68
2	2.63	2.68
3	3.25	2.68
4	2.75	2.68
5	3.30	2.69
6	2.79	2.68
7	3.22	2.68
8	3.39	2.68
9	3.47	2.68
10	3.25	2.68
Mean	3.061	2.681
Relative Standard Deviation (RSD) %	10.52	0.11

Table 4
Mean and relative standard deviation values for control measurements A–J.

	Control measurement									
	A	B	C	D	E	F	G	H	I	J
Mean/mm	3579	889	2416	342	2882	921	789	1661	3527	1059
RSD (%)	0.0195	0.1869	0.1583	0.2985	0.0104	0.2126	0.0506	0.0538	0.0376	0.0755

dependent on the size and difficulty of the item to be measured. Items B, D, F and G were smaller measurements and were considered easier to measure compared with the others. Fig. 8 demonstrates that these items had the smallest standard deviation when compared to the larger fixed and non-fixed items. Standard deviation values of +/−7.022 mm, +/−10.872 mm, +/−13.825 mm and +/−15.95 mm for items B, D, F and G respectively. Items B, D and F also had bevelled edges or rounded corners, and as a result the deviation within these measurements was likely to have originated from the participants choosing different start and end points to measure.

Measurements taken using the tape measure generally produced smaller standard deviation values compared to the software. This was likely to have originated from the participants' ability to easily and consistently assign accurate start and end points to the measurement. Using the software it is probably more difficult to consistently replicate the same start and end points for each item when selecting them freehand with the computer mouse. In addition, the accuracy of measurements is dependent upon the start and end points selected and how much detail is present at this point within the panorama. Hard detail points, such as a table top are easier to select than softer points, such as a wall corner.

A Friedman test was used due to the absence of normally distributed data sets. The results suggested that there were statistically significant differences between the control, tape and software measurements for each of the ten fixed and non-fixed items ($p \leq 0.05$). Pairwise comparisons of each data set demonstrated that there were statistically significant differences between the majority of the data sets, as shown in Table 6. Significant differences were more prominent between the software and control measurements than measurements taken with the tape measure. This was attributed to the users' ability to accurately assign start and end points to the items, and the ability to accurately repeat this in the same manner each time with the tape measure.

Effect sizes were calculated using Cohen's r and ranged from very small ($r = 0.005$) to large ($r = 0.620$), according to Cohen's guidelines, over the ten fixed and non-fixed items.

Statistically significant differences were apparent between the control and tape measurements, with very small to medium effect sizes (0.005–0.485) and therefore the differences were negligible given that they were only millimetre differences. Differences

Table 5
The minimum and maximum distances to the measurements of interest in the field of view from each of the camera positions.

Camera position	Measurement	Minimum distance from camera (mm)	Maximum distance from camera (mm)
1	A	1534	3446
	B	775	1521
	C	1476	2151
	F	2630	2688
	G	3868	4187
	H	741	2101
	I	1305	3277
2	A	2327	3811
	B	2991	3734
	C	666	3156
	D	1897	1960
	E	990	2043
	F	577	1590
	H	1965	2552
3	A	3290	3643
	B	2520	3313
	C	1286	2974
	F	2047	2713
	G	2252	2514
	H	929	1119
	I	1517	2194
	J	1311	2016
4	A	3518	4649
	B	3816	4564
	C	1683	3991
	D	3059	3065
	E	469	3126
	F	1851	2646
	G	848	932
	J	2578	3573

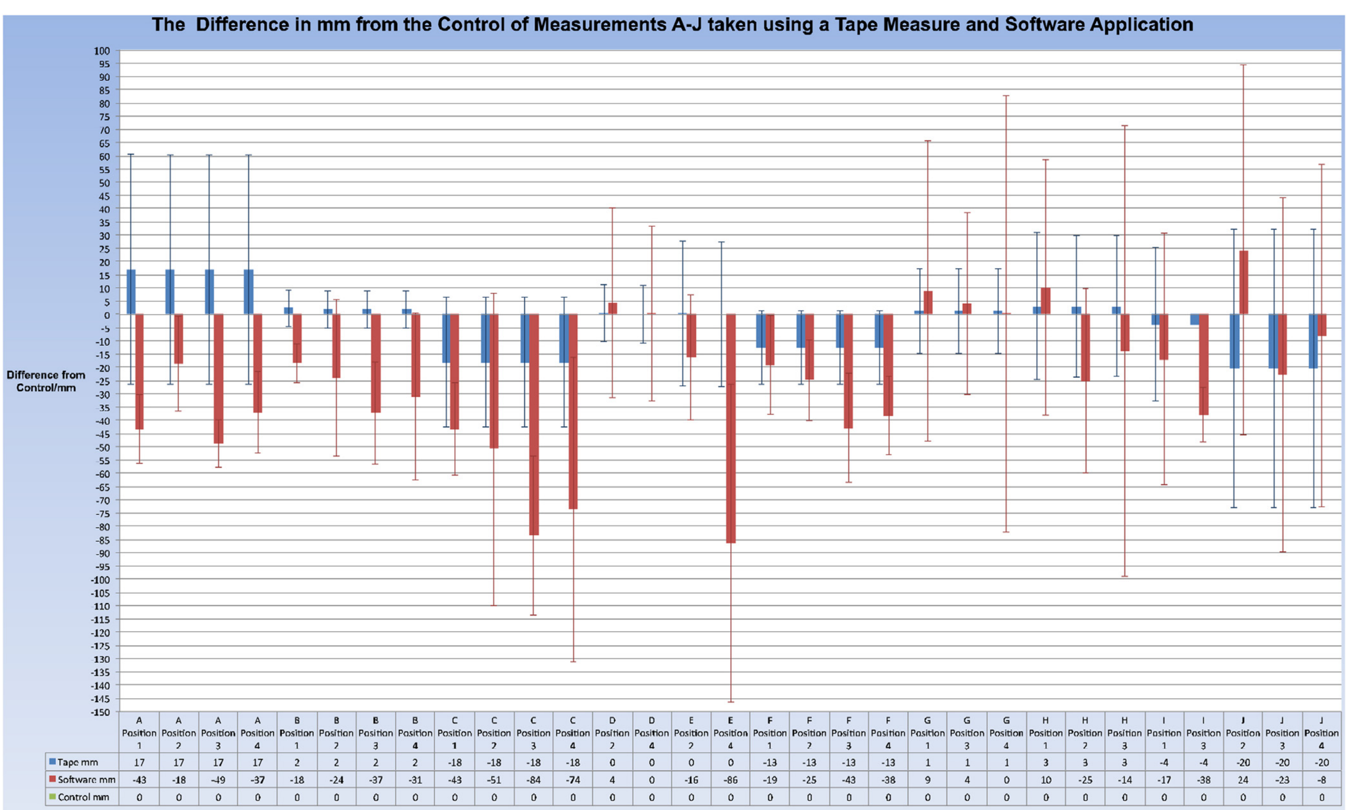

Fig. 8. Differences from the control for the tape and software measurements for items A–J.

Table 6
P values and effect sizes for pairwise comparisons of the control, tape and software measurement.

Item	Position	Tape vs. Software		Software vs. Control		Control vs. Tape	
		P value	Effect size/r	P value	Effect size/r	P value	Effect size/r
A	1	<0.001[a]	0.576[b]	<0.001[a]	0.616[b]	<0.001[a]	0.268
	2	<0.001[a]	0.452	<0.001[a]	0.525[b]	<0.001[a]	0.278
	3	<0.001[a]	0.599[b]	<0.001[a]	0.615[b]	<0.001[a]	0.278
	4	<0.001[a]	0.567[b]	<0.001[a]	0.615[b]	<0.001[a]	0.278
B	1	<0.001[a]	0.620[b]	<0.001[a]	0.615[b]	<0.001[a]	0.260
	2	<0.001[a]	0.570[b]	<0.001[a]	0.549[b]	<0.001[a]	0.260
	3	<0.001[a]	0.607[b]	<0.001[a]	0.604[b]	<0.001[a]	0.260
	4	<0.001[a]	0.542[b]	<0.001[a]	0.536[b]	<0.001[a]	0.260
C	1	<0.001[a]	0.499	<0.001[a]	0.611[b]	<0.001[a]	0.450
	2	<0.001[a]	0.485	<0.001[a]	0.584[b]	<0.001[a]	0.450
	3	<0.001[a]	0.595[b]	<0.001[a]	0.613[b]	<0.001[a]	0.450
	4	<0.001[a]	0.546[b]	<0.001[a]	0.582[b]	<0.001[a]	0.450
D	2	<0.001[a]	0.267	<0.001[a]	0.291	0.003[a]	0.211
	4	<0.001[a]	0.286	<0.001[a]	0.316	0.003[a]	0.211
E	2	<0.001[a]	0.418	<0.001[a]	0.495	0.342	0.068
	4	<0.001[a]	0.559[b]	<0.001[a]	0.586[b]	0.005[a]	0.208
F	1	0.002[a]	0.222	<0.001[a]	0.547[b]	<0.001[a]	0.485
	2	<0.001[a]	0.375	<0.001[a]	0.573[b]	<0.001[a]	0.485
	3	<0.001[a]	0.553[b]	<0.001[a]	0.605[b]	<0.001[a]	0.485
	4	<0.001[a]	0.545[b]	<0.001[a]	0.610[b]	<0.001[a]	0.485
G	1	<0.001[a]	0.266	<0.001[a]	0.274	0.628	0.037
	3	0.080	0.133	0.043[a]	0.154	0.662	0.033
	4	0.120	0.190	0.002[a]	0.238	0.020[a]	0.175
H	1	0.103	0.122	0.127	0.114	0.946	0.005
	2	<0.001[a]	0.431	<0.001[a]	0.480	0.561	0.041
	3	0.003[a]	0.212	0.018[a]	0.168	0.561	0.041
I	1	<0.001[a]	0.361	<0.001[a]	0.482	0.567	0.043
	3	<0.001[a]	0.531	<0.001[a]	0.614[b]	0.567	0.043
J	2	<0.001[a]	0.353	<0.001[a]	0.260	<0.001[a]	0.316
	3	0.509	0.053	0.436	0.062	<0.001[a]	0.296
	4	0.069	0.130	0.682	0.029	<0.001[a]	0.316

[a] = Statistically significant differences.
[b] = large effect size.

between the software and control measurements demonstrated small to large effect sizes (0.029–0.616), with the majority of differences amounting to a couple of centimetres, and in an extreme case the difference was 86 mm, as shown in Fig. 8 Item E position 4.

Currently, measurements taken at crime scenes are assumed to be approximate values, and in the UK there is no published accepted limit of accuracy for measuring crime scenes. However, the accepted limit of accuracy in the United States of America is 0.25 inches (6.35 mm). This may be problematic in practice due to differences in the relative sizes of items, which may be measured at a scene. For example, a 0.25 inch limit of accuracy over a 10 m span may be considered negligible. However, a 0.25 inch limit of accuracy over a 0.5 inch measurement is half of its original size, which may be considered significant. This problem may be alleviated with the use of a percentage of the original measurement.

Both the tape and the software have advantages and limitations. Tape measurements have to be taken at the scene at the time of the incident, and as a result the SOCO cannot revisit the scene to take further measurements. The software application presents advantages over the tape in this aspect. Tape measurements introduce human error in the form of transcribing errors, misreading the tape measure, and using incorrect units. The software application removes these potential errors, but can introduce other errors and inaccuracies when users are not competent in its use, or where clear reference points are not available. The accuracy of the measurements taken using the software is in part a function of the resolution of the images being used, and as a result all panoramas were taken at their maximum resolution of 50 MP. However, measuring a large object appearing very small in an image is similarly likely to produce inaccurate data, even for a high resolution image. This is because it is the resolution of the object where the measurements must take place that will determine the accuracy with which measurements can be taken. For example—if an object is photographed at close range with full image resolution one would expect a highly accurate measurement.

The investigation has demonstrated the level of accuracy when using a tape measure is dependent on the ability of the user. The software measurements were more precise and were more repeatable, but inaccuracies arose from the lack of user knowledge of the software operation. As a result it is a necessity that significant training be given to individuals using this technology. In line with the requirements of ISO 17020 the limits of accuracy need to be defined regardless of the method used to obtain measurements, and this paper details a methodological approach, which could be used to determine the levels of accuracy associated with devices used to measure items within a crime scene. The approach described in this paper may also be useful as part of competency testing.

4. Conclusion

This investigation has demonstrated that by utilising target dots to aid with taking measurements with photogrammetry applications where there are blank walls present facilitated reproducible and more accurate results than by solely measuring blank, featureless walls. Crime scene environments may not allow the use of target dots (potential contamination issues), therefore a laser line could be utilised, which has also been shown to significantly improve reproducibility and accuracy of the measurements made. Statistically significant differences were found between the control, tape and the software measurements ($p \leq 0.05$), particularly between the control and the software measurements ($p \leq 0.016$). Participant derived measurements with the tape measure proved to be more accurate than the software measurements, ranging from 0.0% to 4.48% differences. The size and shape of the measured items are likely to influence a person's ability to record accurate measurements of them, and each method tested offered advantages and should be used in conjunction. For example, in situations where measurements were considered to be more difficult to take with a tape measure, such as the length of a wall, the software application can provide a solution to capture the measurement more easily. For smaller items with more complex shapes, such as bedside tables, it may prove beneficial to use a tape measure in a forensic environment. This study shows the importance of the appropriate use of complimentary measurement techniques in order to accurately capture data that can assist in a forensic-Police enquiry.

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Appendix 2

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The adaptation of a 360° camera utilising an alternate light source (ALS) for the detection of biological fluids at crime scenes

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ABSTRACT

One of the most important and commonly encountered evidence types that can be recovered at crime scenes are biological fluids. Due to the ephemeral nature of biological fluids and the valuable DNA that they can contain, it is fundamental that these are documented extensively and recovered rapidly. Locating and identifying biological fluids can prove a challenging task but can aid in reconstructing a sequence of events. Alternate light sources (ALS) offer powerful non-invasive methods for locating and enhancing biological fluids utilising different wavelengths of light. Current methods for locating biological fluids using ALS's may be time consuming, as they often require close range searching of potentially large crime scenes. Subsequent documentation using digital cameras and alternate light sources can increase the investigation time and due to the cameras low dynamic range, photographs can appear under or over exposed. This study presents a technique, which allows the simultaneous detection and visualisation of semen and saliva utilising a SceneCam 360° camera (Spheron VR AG), which was adapted to integrate a blue Crime Lite XL (Foster + Freeman). This technique was investigated using different volumes of semen and saliva, on porous and non-porous substrates, and the ability to detect these at incremental distances from the substrate. Substrate type and colour had a significant effect on the detection of the biological fluid, with limited fluid detection on darker substrates. The unique real-time High Dynamic range (HDR) ability of the SceneCam significantly enhanced the detection of biological fluids where background fluorescence masked target fluorescence. These preliminary results are presented as a proof of concept for combining 360° photography using HDR and an ALS for the detection of biological stains, within a scene, in real time, whilst conveying spatial relationships of staining to other evidence. This technique presents the opportunity to presumptively screen a crime scene for biological fluids and will facilitate simultaneous location and visualisation of biological evidence.

1. Introduction

Biological fluids, such as blood, semen, saliva, vaginal secretions and urine, are a commonly encountered evidence type that can be recovered at crime scenes. They serve as an invaluable evidence type given that they contain valuable DNA evidence that may be used to identify individuals present at the scene, including both suspect and victim. Identifying the location and distribution of biological staining within a crime scene is crucial to the investigation, as the location and identity of the fluid can aid Forensic Investigators (FI) in reconstructing a sequence of events, and determining what may have occurred at the scene [1]. Due to the ephemeral nature of this type of evidence, it is fundamental that the evidence is documented extensively and recovered quickly and efficiently. Locating biological fluids can prove a challenging task for FI's as many stains are invisible to the naked eye or are similar in appearance to other extant substances. In these circumstances filtered light analysis can provide an investigator with an effective means of locating and presumptively differentiating between some biological fluids [2], and some biological fluids with similarly appearing extant substances, given that such substances often respond differently to varied wavelengths of light. This type of analysis is non-contact, unlike alternative presumptive tests, such as the Kastle-Meyer test for blood, or the acid phosphatase test for semen, which interact with constituents found in biological fluids. Confirmatory tests are used to confirm the presence of a particular biological fluid [1].

Filtered light analysis is frequently deployed at scenes of crime using Alternate Light Sources (ALS), which typically allow the selection of different wavelengths of light between approximately 300–900 nm. For example, semen is reported to fluoresce at an excitation wavelength of 455 nm, although the substrate will affect the efficacy of this approach [3–5]. Camerilli et al. [6] found that the optimal contrast for the visualisation of saliva stains could be achieved at an excitation wavelength of 470 nm, although the colour and design of the fabric type could affect the fluorescence of the stain. In addition to biological

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1355-0306/

fluids, ALS's may offer powerful methods that can allow the enhancement and presumptive detection of trace evidence likely to be present at crime scenes, for example fibres [7]. Given their simplicity, non-destructive and/or non-invasive nature, they have been extensively utilised in criminal investigations, particularly where limited sample quantities are exhibited [1,8]. Conversely, this approach can be time consuming depending on the complexity and size of the environment. The FI could be searching for long periods of time without any indication as to where biological fluids could be present. The light intensity of the ALS will also affect its ability to locate and presumptively test for biological fluids. For example, the sensitivity of the approach is likely to decrease as the distance between the light source and biological fluid increases [9], meaning that often, searching for biological fluids using ALS' is close range and thus time consuming.

Once visualised using an ALS, it is integral that the evidence is thoroughly documented in a manner that captures its distribution and location as it was at the time of the investigation. Digital photography allows the FI to document both the scene and the evidence and present it to a judge and jury in a courtroom in a simple and detailed manner [10]. Where ALS photography is utilised, fluorescence filters can be fitted over the existing standard digital camera lens to block the excitation wavelength of light and allow the camera to capture a response from the target substrate [11]. Current methods for photographing a response from biological fluids when using an ALS require the FI to select the correct exposure in order to successfully capture a (fluorescent) response. This process will have to be repeated for multiple biological stains, adding further time onto the investigation process. Also, given that the FI is often working at close range, the photographs that are taken to capture any existing stains will need to be taken at equally close distances.

The area that may be captured by a digital camera is limited to the field of view of its accompanying lens. For example, a fish eye lens can facilitate the capture of an 180° horizontal field of view. Alternatively, 360° photography can capture a full panorama, and ensures the entire area (crime scene) is captured rather than only those items deemed relevant at the time by the FI [12]. 360° photography can be achieved using a standard digital camera, which requires the user to facilitate 'stitching' the images together, using appropriate software applications or manual overlays. Automated 360° photography systems eliminate the requirement for manual stitching, and allow information about spatial relationships of evidence within a scene to be extracted [13]. Also, digital cameras generally have a lower dynamic range than the human eye, and as a result photographs can appear under or overexposed in comparison. In contrast, many 360° photography systems facilitate the capture of images in High Dynamic Range (HDR), which alleviates such issues of over or under exposure. Dynamic range can be defined as the ratio between the lightest (white) and darkest (black) pixel within an image. HDR images contain pixels which represent a greater range of colours and more accurate luminance levels, which appear more realistic [11,14]. Despite their reported advantages, 360° photography systems are considerably costlier in terms of equipment purchase, maintenance and training compared to conventional digital photography. Such systems may be less portable and practical to use in some crime environments, e.g. confined spaces.

Utilising a system which integrates an ALS within 360° HDR photography could not only allow for the detection of biological fluids at larger crime scenes, but could dramatically reduce the time taken to identify, document, collect and analyse such evidence. The aim of this study was to investigate the detection and visualisation of biological fluids on various substrates using a 360° photography system combined with an ALS.

2. Method

In line with ethical requirements of the host institution and in accordance with health and safety procedures, human semen was obtained from one male donor, aged 26. Human saliva was obtained from a female donor aged 24. Biological fluid samples were collected into separate 100 ml Thermo Scientific™ Sterilin™ Polystyrene Containers and labelled accordingly. All biological fluid samples were collected on the morning of the study and were immediately stored in a fridge at 3 °C until required. White cotton, dark blue cotton, HP premium matte polypropylene white plotter paper (140 g/m^2), and coloured cardboard (160 g/m^2; red, orange, yellow, green, blue and violet in colour) were utilised as the substrates for fluid deposition. The white cotton, dark blue cotton and white plotter paper substrates were cut into approximate 10 cm × 10 cm square swatches and the coloured cardboard substrate was cut into approximate 5 cm × 5 cm square swatches.

Using Biohit Proline® automated pipettes, 5, 50, 100, 150, 200 and 250 μl of the biological fluid were deposited onto each substrate type. The pipette was held directly above the substrate and the biological fluid deposited at a 90° angle to the substrate. A series of between 1 and 4 drops of biological fluid were deposited onto multiple swatches

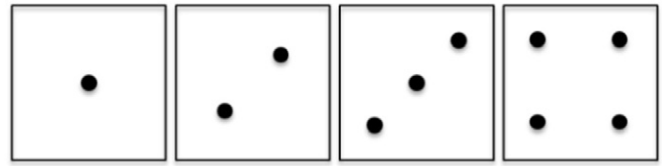

Fig. 1. Drops of biological fluid deposited onto swatches.

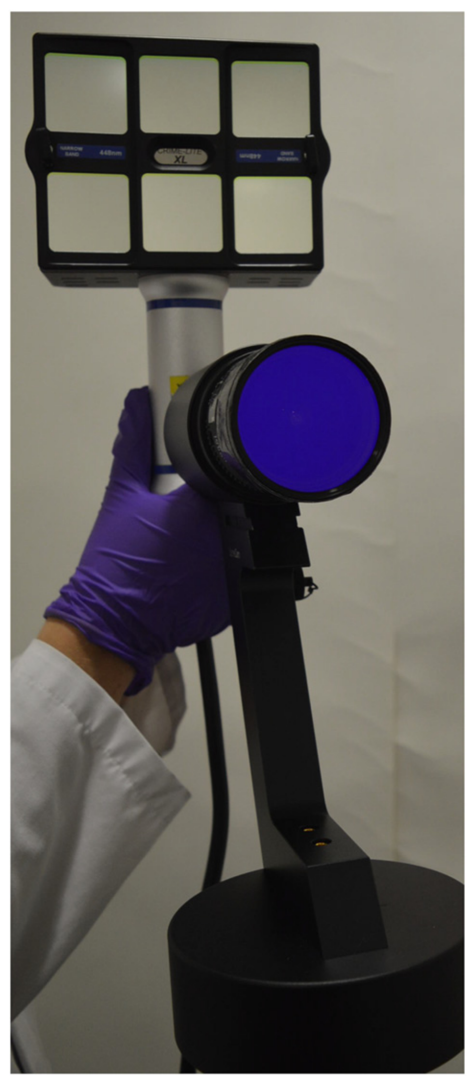

Fig. 2. The Crime Lite XLs position in relation to the SceneCam.

Fig. 3. GG495 camera filter attached to the already existing fisheye lens of the SceneCam.

as shown in Fig. 1. For the coloured cardboard swatches, one single drop of each biological fluid was deposited. Samples were left to dry under ambient conditions (approximately 18 °C) for 24 h.

A specialist 'trauma room' at the host institution was utilised for this investigation as it provided an environment, which limited contamination from other biological fluids, and allowed for complete darkness. Walls in this room were covered with lining paper to remove the reflectivity and to ensure that the walls were more representative of common household environments. All swatches were adhered to the wall lining paper using double-sided sticky tape, in the approximate centre of one wall. The order with which each swatch was adhered to the wall was determined using a random number generator in Microsoft Excel.

The environment was illuminated using a Crime Lite XL (420–470 nm) (Foster + Freeman Ltd.) and photographed using a SceneCam 360° camera (Spheron VR). A Crime Lite XL was held above and behind the camera lens as shown in Fig. 2. The camera was initially positioned 30 cm away from the swatches. The camera was calibrated according to the manufacturers instructions (Spheron SceneCam User Manual, 2007).

A 495 nm (GG495) longpass camera filter (62 mm) was adhered, using Duct Tape™, over the existing fisheye lens on the 360° camera, to allow induced fluorescence to be observed (Fig. 3).

This process was repeated for 60, 90, 150 and 300 cm working distances, for each substrate and biological fluid type. The resulting panoramas were uploaded into the complimentary SceneCenter software. No photographs were enhanced or treated with Photoshop or any other digital image manipulation software.

2.1. Detection of biological fluids

The panoramas were initially monitored to determine whether the ALS and 360° camera combination could detect any biological staining on the four substrate types. Once it had been established that each of the biological fluids could be successfully located using the ALS and camera combination, the accuracy of the technique was investigated using the following approach.

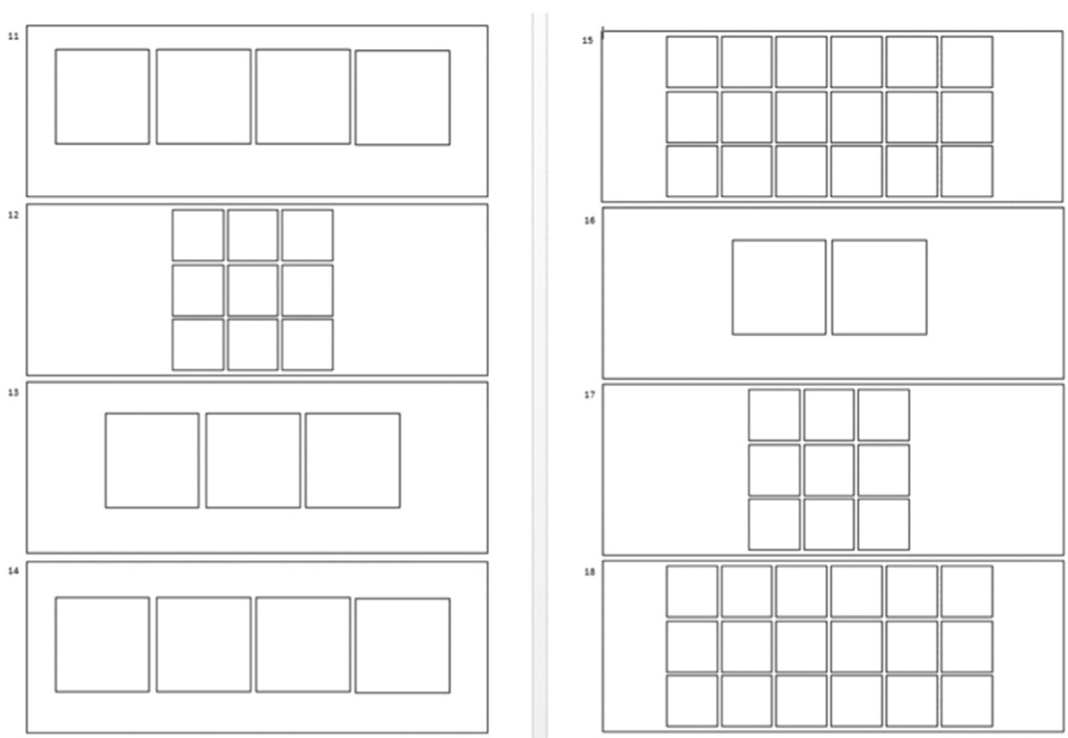

Fig. 4. Answer booklet for participants to complete.

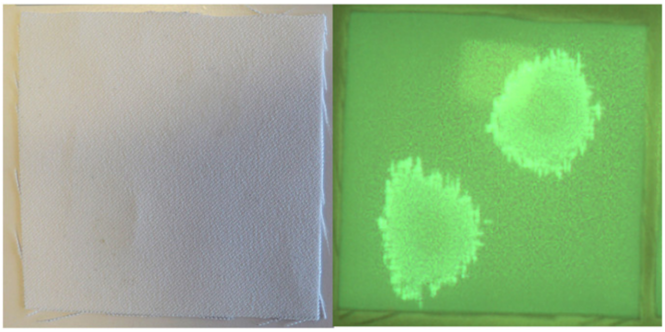

Fig. 5. 200 μl semen staining on white cotton swatch 10 cm × 10 cm Left: semen exposed to natural light. Right: semen exposed to a blue Crime Lite XL.

Ten participants; 4 male and 6 female, aged between 26 and 44 years of age, were recruited from the host institution. Participants were briefed on the aims of the investigation and were asked to sign a consent form in line with the ethical requirements of the institution. Participants were provided with an answer booklet, which had each numbered panorama and the distribution of the substrate swatches (Fig. 4). Participants were required to replicate a pattern of biological fluid drops corresponding to the swatches in the 360° panoramas. Participants were told not to draw anything that was not circular in shape and were informed that they could use the HDR in the software to increase or decrease the light intensity to aid the visualisation of the biological fluids. The panorama order was randomised and the default titles removed and replaced with numbers.

The total number of drops identified by each participant was calculated by counting the number of drops they had drawn.

3. Results and discussion

This is the first report demonstrating the successful location and visualisation of biological fluids at small volumes using a 360° camera system adapted using an alternate light source.

The location and documentation of semen and saliva using the blue Crime Lite XL and 360° camera technique on each substrate type are discussed in turn. Where contrast of biological stains were observed this was achieved using the 455 nm excitation wavelength and a 495 nm (GG495) longpass camera filter (62 mm).

3.1. White cotton

The semen stains deposited onto the white cotton substrate appeared barely visible when examined under natural light. Using the Blue Crime Lite XL at 455 nm excitation wavelength the semen demonstrated fluorescence, which is consistent with recommended best practice [3–5]. The fluorescence was successfully documented by the 360° camera as shown in Fig. 5.

The camera system and ALS technique was able to successfully detect semen stains on the white cotton substrate to volumes as small as 5 μl. This was possible for all of the distances studied. Fig. 6 demonstrates the semen fluorescence detected by the 360° camera and Blue Crime Lite XL for all volumes at 30 cm and 90 cm distances.

Similarly to semen, saliva appeared barely visible to the naked eye under natural lighting, but was successfully visualised and documented for some of the samples of saliva using a Blue Crime Lite XL and 360° camera. Recommended best practice utilised 455 nm such as that which the blue Crime Lite XL provides [15]. The fluorescence demonstrated by a saliva stain is demonstrated in Fig. 7.

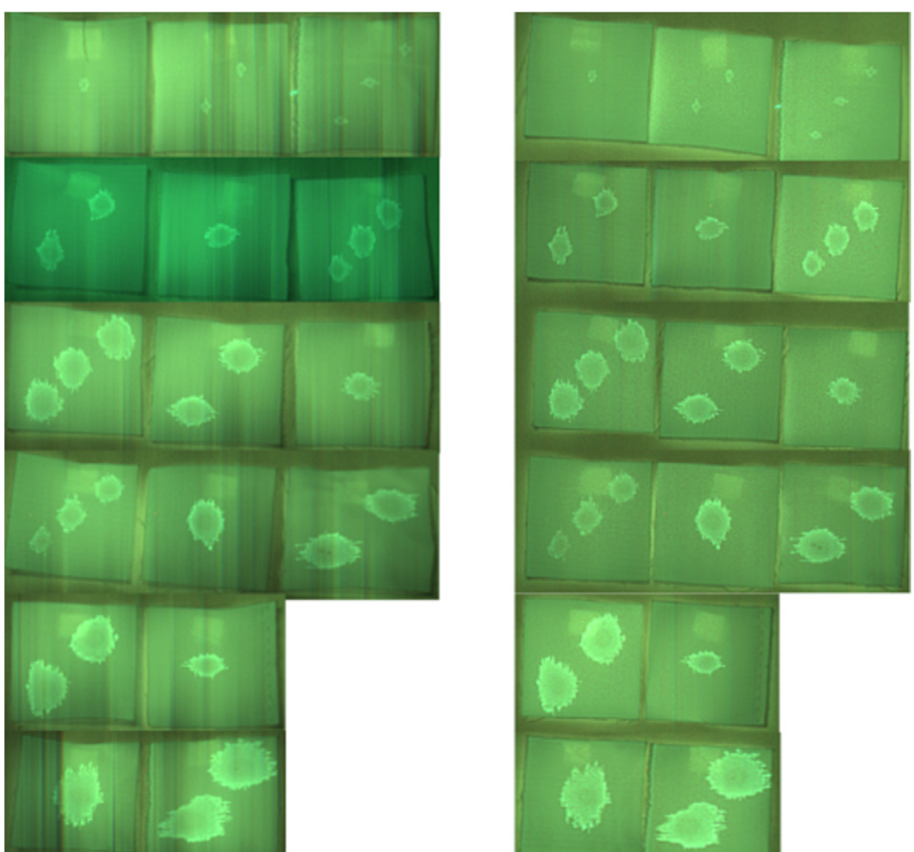

Fig. 6. All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 μl– semen successfully detected on white cotton using a blue Crime Lite XL at 30 cm (left), 90 cm (right).

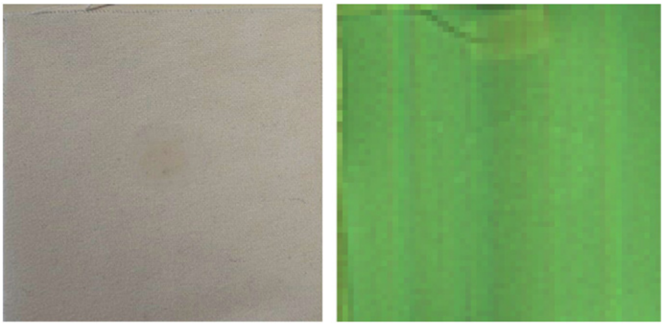

Fig. 7. 200 μl Saliva staining on a white cotton swatch 10 cm × 10 cm. Left: saliva exposed to natural light. Right: saliva exposed to a blue Crime Lite XL.

Saliva staining was successfully located in the majority of cases using a blue Crime Lite XL, but visualisation was only possible with larger volume stains as shown in Fig. 8. This was consistent with results observed by Camilleri et al. [6]. Smaller volume stains were more difficult to detect, which could be attributed to the lack of solid particles within the saliva sample [1,3]. In addition, detection of saliva on the white cotton substrate was difficult due to the porous nature of the surface type. As a result, the saliva was absorbed into the material rather than drying on the surface, leaving little surface fluorescence. The fluorescence from the biological fluid could also have been masked by background fluorescence from the white cotton material. When subjected to blue or ultra-violet light (UV), white materials can exhibit fluorescence due to the presence of naturally occurring organic compounds within the material, or optical brighteners present in detergents [3]. Background fluorescence from the substrate can mask the target fluorescence, increasing the difficulty in detecting the biological fluid [16].

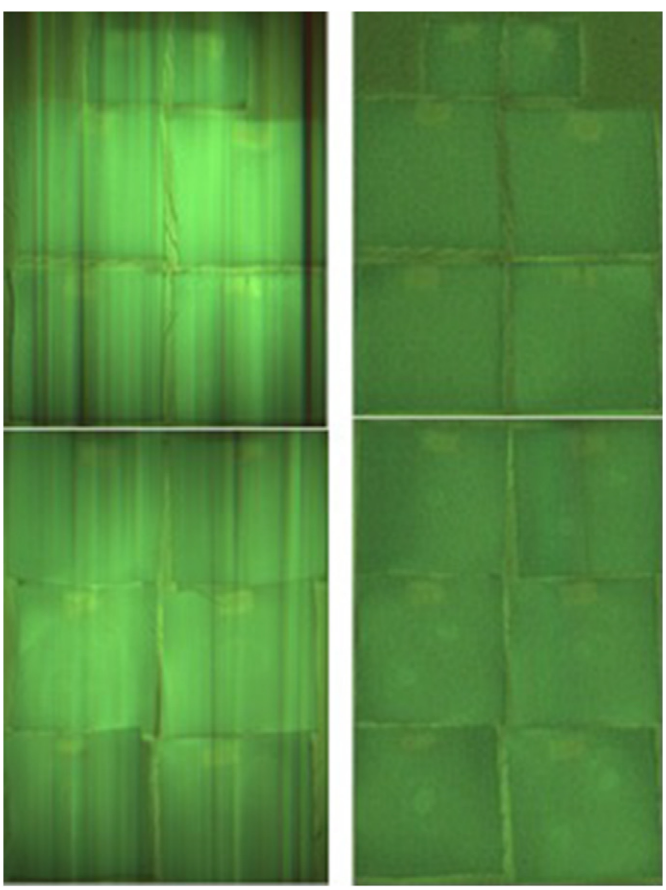

Fig. 8. All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 μl– larger saliva stains successfully detected on white cotton using a blue Crime Lite XL at 30 cm (left), 300 cm (right).

3.2. Dark blue cotton

Semen was detected under natural light immediately after deposition on the dark blue cotton. Following a 24-hour drying period only some staining was still visible under natural light. These stains could be successfully located and documented using a blue Crime Lite XL and 360° camera, as shown in Fig. 9.

Unlike the white cotton, which can contain naturally fluorescent organic compounds, the dark cotton was less likely to contain these substances and mask fluorescence from the semen stains. In this study, the dark cotton was not found to fluoresce itself, but this material presented other problems in the location and detection of the semen stains. The dark material could absorb excited and emission fluorescence from some of the biological stains, making them less visible. These results were consistent with research conducted by Kobus et al. [3] and Fiedler et al. [17] which reported a high degree of difficulty in detecting semen on materials, which were dark in colour, highly absorbent, or made of material which itself is naturally fluorescent, such as white cotton.

As shown in Fig. 9 (right), not all of the biological fluid droplets were consistent in terms of their visibility using the blue Crime Lite XL. This was likely to have been due to incomplete deposition, perhaps due to air bubbles produced during deposition. However, those stains that could be detected by the camera were detectable up to a maximum distance of 300 cm away from the staining, as shown in Fig. 10. As the camera and ALS moved further away from the staining, the semen stains became harder to detect and proved more challenging to document.

Saliva, which is virtually colourless in composition, proved more difficult to detect on the dark blue cotton substrate than semen. In many cases, the saliva stains were not enhanced using the ALS, and remained invisible to the naked eye, as shown in Fig. 11. The saliva stains exhibited little response or fluorescence. This could be attributed to the absorbent nature of the substrate whereby saliva was absorbed further into the material whilst drying, as opposed to drying on the surface of the substrate [2].

The majority of the saliva stains were impossible to detect on the dark blue cotton fabric using a blue Crime Lite XL for all volumes and distances examined, as shown in Fig. 12, with only one or two drops actually being detected. In these few cases, the fluorescence demonstrated by the stains was very low intensity, which made the stains more difficult to detect. The limited detection of saliva on this substrate could be attributed to the porous nature of the material, whereby the saliva absorbed into the fabric, and due to the lack of solid particles within the saliva, as previously described in 3.1 [3, 6].

The samples of saliva were rapidly absorbed into the white and dark blue cotton substrates once deposited. In some of the tests conducted on these materials the biological fluid was undetectable, or the fluorescence observed was weak in intensity. The absorption of the biological

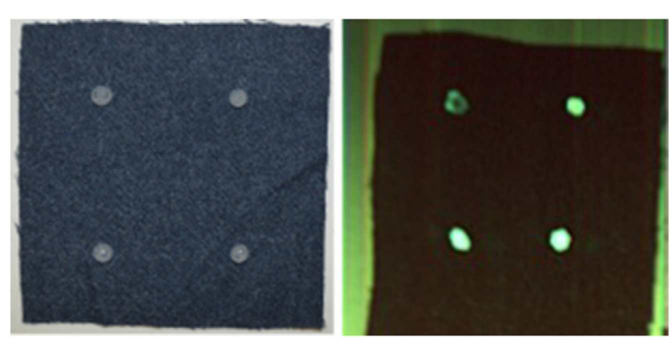

Fig. 9. 200 μl semen staining on a dark blue cotton swatch 10 cm × 10 cm. Left: semen exposed to natural light. Right: semen exposed to a blue Crime Lite XL.

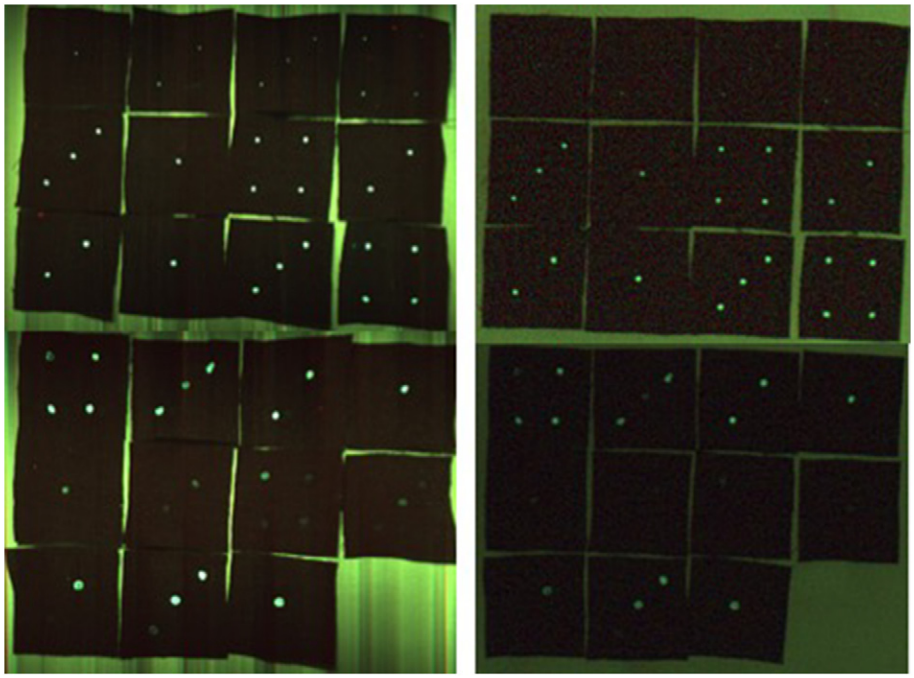

Fig. 10. All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 µl– semen successfully detected on dark blue cotton using a blue Crime Lite XL at 30 cm (left), 300 cm (right).

fluid into the substrate inhibited the ability to detect the fluorescence of the fluid in some cases. The smaller volumes of biological fluid deposited had a tendency to sit on the surface of the substrate without being absorbed, making the stains easier to detect. In contrast, the semen samples were easier to detect on the same substrates, and this could have been attributed to the higher viscosity of the semen, which allowed the fluid to sit on the surface of the substrate once deposited, as shown in Fig. 9. This is consistent with results demonstrated by Vandenberg and Oorschot [5]. Where a fluorescent response was not observed the presence of a biological fluid cannot be excluded and further testing would be required [3].

3.3. White plotter paper

The semen stains deposited onto the white plotter paper substrate were visible when examined under natural light. When subjected to a blue Crime Lite XL, the semen demonstrated high intensity fluorescence, which was successfully documented using the 360° camera system, as shown in Fig. 13.

The camera system and ALS technique was able to successfully detect semen stains on the white plotter paper to volumes as small as 5 µl. This was possible for all of the distances studied. The fluorescence observed by the semen on the white plotter paper substrate appeared to exhibit high intensity fluorescence. Fig. 14 demonstrates the semen fluorescence detected by the 360° camera and blue Crime Lite XL for all volumes at 30 cm and 300 cm distances.

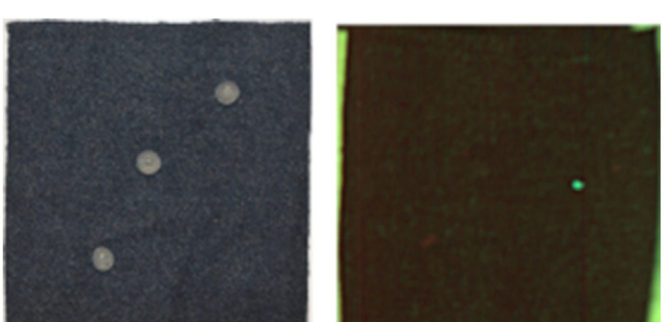

Fig. 11. 200 µl Saliva staining on dark blue cotton swatch 10 cm × 10 cm. Left: saliva exposed to natural light. Right: saliva exposed to a blue Crime Lite XL.

Saliva deposited onto the white plotter paper substrate was visible under natural light, but was visualised more easily using a blue Crime Lite XL. The saliva stains were successfully located and documented using the 360° camera, as shown in Fig. 15.

The camera system and ALS technique was able to successfully detect saliva stains on the white plotter paper to volumes as small as 5 µl, although the smaller volumes were more difficult to visualise and document with the 360° camera system. Documentation of the smaller volume stains became more difficult as the working distance increased. Fig. 16 demonstrates the saliva fluorescence detected by the 360° camera and blue Crime Lite XL for all volumes at 30 cm and 90 cm distances.

For the saliva stains, the identified fluorescence was concentrated around the outer edges of the saliva stain with very little fluorescence in the centre of the stain. Saliva exhibited low intensity fluorescence when compared to the fluorescence exhibited by the semen on the white plotter paper substrate, as shown in Fig. 17. The fluorescence observed by the semen stains occurred across the entirety of the stain, which was likely to be attributed to the presence of conjugated choline and flavin proteins within the semen [3]. Knowledge about the different responses biological fluids have to certain wavelengths of excitation light can aid in estimating but not determining between semen and saliva fluids [18]. However, the definitive nature of a fluorescent area cannot be determined solely through visual inspection and any fluorescent areas will require further confirmatory testing to ascertain the identity of the fluid [8,9].

3.4. Coloured cardboard

The semen stains deposited onto the coloured cardboard substrate were visible when examined under natural light. When subjected to a blue Crime Lite XL, the semen demonstrated high intensity fluorescence, which was successfully documented using the 360° camera system, as shown in Fig. 18.

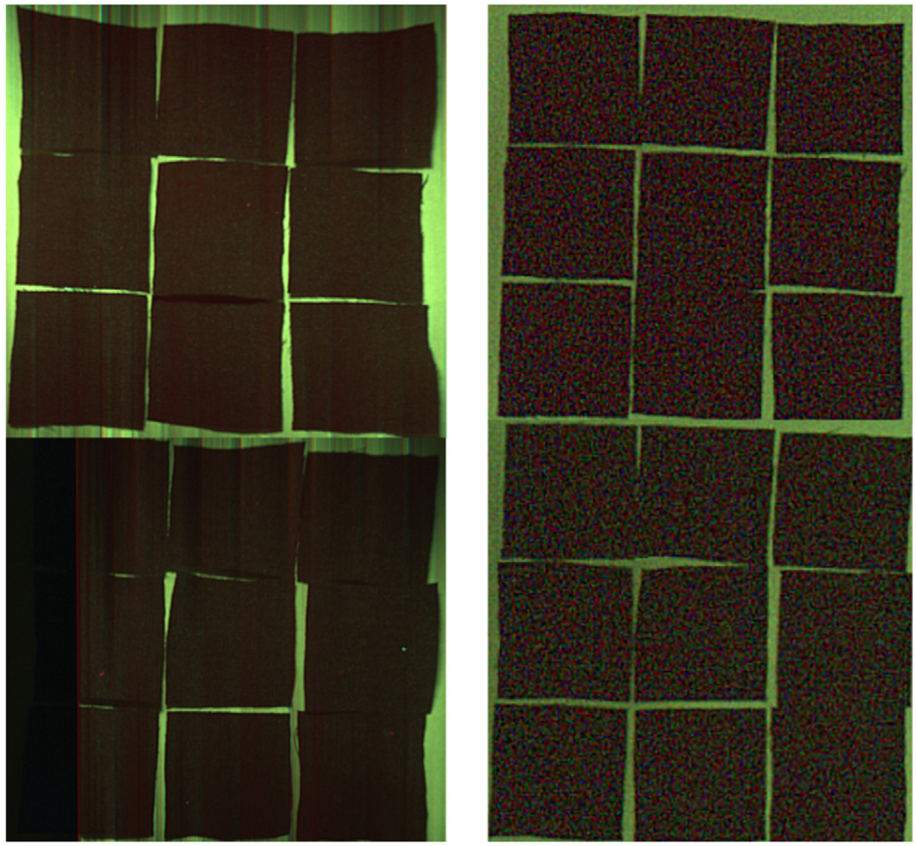

Fig. 12. All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 μl unsuccessfully detected for saliva on dark blue cotton using a blue Crime Lite XL at 30 cm (left), 300 cm (right).

In some cases the yellow cardboard produced limited results, particularly for the smaller volumes, where the background fluorescence from the yellow cardboard masked the fluorescence from the semen stains. In these cases the HDR of the SceneCam enabled fluorescence previously masked by the background to be visualised successfully. The intensity of the light source on the stains did have an effect on the fluorescence detected by the 360° camera system. However, the unique HDR capabilities of the optical system allowed visualisation of the biological fluids even when this appeared to be masked by background fluorescence from the substrate, as shown in Fig. 19 (Top). Photographing fluorescence from biological fluids using a digital camera can prove difficult when background fluorescence is present due to the masking, and may require a series of different photographs to be taken at multiple exposures to try and reduce the fluorescent response from the background and enhance the target fluorescence. In this study, the unique addition of the HDR resulted in noticeably greater contrast between the staining and the background, allowing greater visibility of

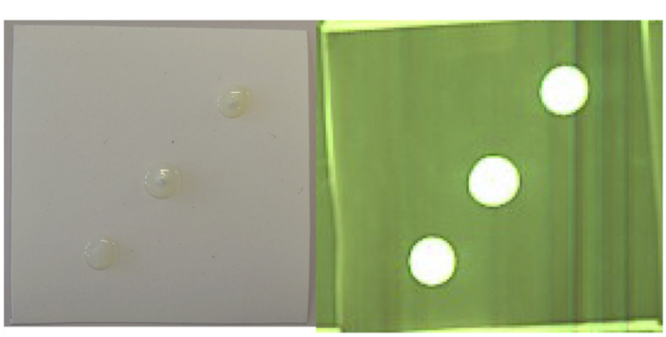

Fig. 13. 200 μl Semen staining on white plotter paper 10 cm × 10 cm Left: semen exposed to natural light. Right: semen exposed to a blue Crime Lite XL.

the stains, as shown in Fig. 19. The HDR controls within the complementary software allows the luminance levels to be increased or decreased without digitally altering or manipulating the image, as the camera accounted for all the different light levels and exposures as it scanned at the time of image acquisition.

The majority of the semen stains deposited onto the coloured cardboard substrate were successfully visualised and documented by the Crime Light XL and 360° camera system. This was successful for most volumes at all distances examined, as shown in Fig. 20. At greater distances the smaller volumes, such as 5 μl, became more difficult or impossible to detect.

The 360° camera and light source were moved further away from the stained swatches to determine whether the distance had any effect on the ability of the camera to document the staining. The distance of the camera and light source technique had no effect on the resultant fluorescence of the biological staining, but the larger distances meant the 360° camera could not document some of the smaller volumes (5 μl and 50 μl) of biological fluids successfully. The resolution of the camera will become a limiting factor for the detection of the biological staining as the camera and light source distance increases. Further investigation can be conducted to determine the effects that the resolution will have on the documentation of the biological fluids. As the camera moves further away from the target staining the area covered by a single pixel becomes larger, limiting the detail that can be captured (Fig. 21). De Forest et al. [7] identified that the result of zooming in on an image compromised the ability to resolve smaller volume stains. In this study the camera resolution did not compromise the ability to locate the staining due to the limit of the room size of 300 cm. At significantly greater distances however, it is expected that the resolution will become a limiting factor for the successful documentation of biological staining. This study has demonstrated that the 360° camera and alternative light source combination could successfully detect and document

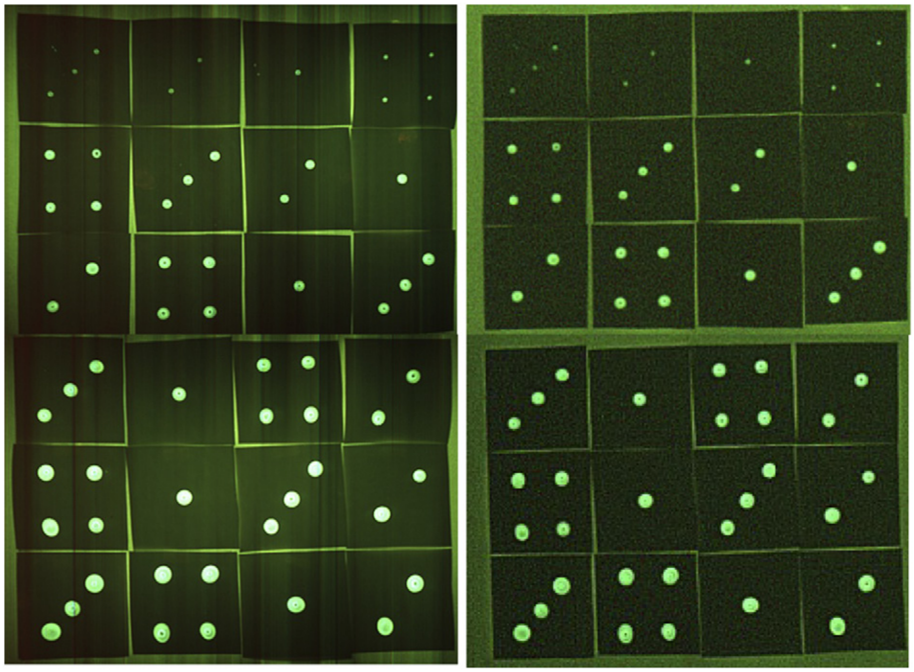

Fig. 14. All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 μl– semen successfully detected on white plotter paper using a blue Crime Lite XL at 30 cm (left), 300 cm (right).

biological staining on different substrates at different distances from the substrate. As a result, this technique could provide a more effective method for locating biological fluids than current methods, whereby close range searching is conducted. This technique could eliminate the need for close range blind searching of a crime scene and direct an investigators attention to target staining more quickly. The opportunity to rapidly screen a crime scene for biological fluids will facilitate simultaneous location and visualisation of evidence.

At a greater working distance, the intensity of the light source may become a limiting factor. A high powered light source will be more likely to induce a fluorescent response from staining at greater distances than a low powered light source. As a result the intensity and power from the light source must be considered before embarking on this work. In this study, the intensity of the light source was inconsequential and did not affect the ability to induce a fluorescent response from the biological staining. The Crime Lite XL provides 96 high intensity LEDs that, in this case, was sufficient for illuminating an entire internal wall at a distance of up to 3 m. Due to the high intensity illumination provided by the Crime Lite XL, some ambient lighting within the environment did not prove problematic. Some ambient lighting was present during this investigation, whereby lighting from a laptop connected to the camera was present and lighting from the adjacent room. These other

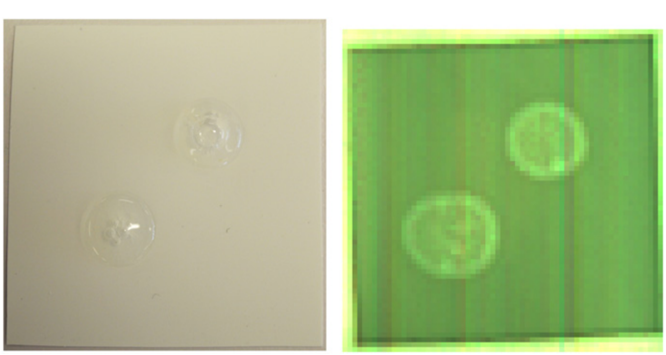

Fig. 15. 200 μl Saliva staining on White Plotter paper 10 cm × 10 cm. Left: saliva exposed to natural light. Right: saliva exposed to a blue Crime Lite XL.

light sources did not seem to affect the enhancement of the biological staining, and as a result we can conclude that it is not essential to block out all light within the scene. This provides significant benefits over methods that require complete darkness in order to successfully detect biological staining. De Forest et al. [7] came to the same conclusion where it was not necessary to block out all ambient light from a scene.

3.5. Other artefacts

The camera system adapted with the ALS was capable of detecting other artefacts in addition to the biological fluids on the materials, as shown in Fig. 22. Fibres and other small particles were enhanced by the light source and produced a fluorescent response. As a result this technique, with appropriate lighting and filters, could also be used as a screening method for other types of evidence, including hairs and fibres, in addition to biological fluids. De Forest et al., [7] found that the light sources used in their study also detected other artefacts such as fibres on the material.

3.6. Participant detection of biological fluids

The percentage of drops of semen and saliva drawn by the participants can be found in Fig. 23.

The results in Fig. 23 suggest that semen can be located and visualised on white cotton with a high degree of accuracy, given that all 10 participants identified 99 semen drops on the white cotton substrate (100% of semen drops identified given that 99 drops were deposited in total). For the white plotter paper substrate, 9 participants identified 300 drops of semen (100%) and 1 participant inaccurately identified 304 drops. Despite the apparent high level of accuracy evidenced by the remaining participants, this participant could have identified artefacts on the substrate which were not the target biological fluid. The authors were not concerned by this result, given that the technique had been able to locate and visualise the known semen samples, and accept that during casework, further analysis of any located sample would have to commence in order to identify the source of the biological fluid.

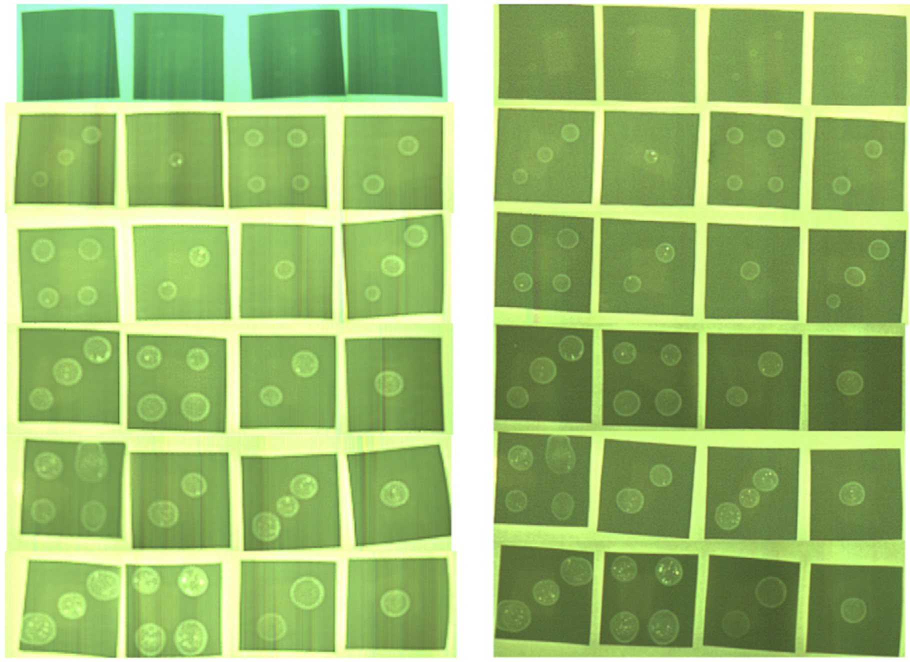

Fig. 16. All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 μl– saliva successfully detected on white plotter paper using a Blue Crime Lite XL at 30 cm (left), 90 cm (right).

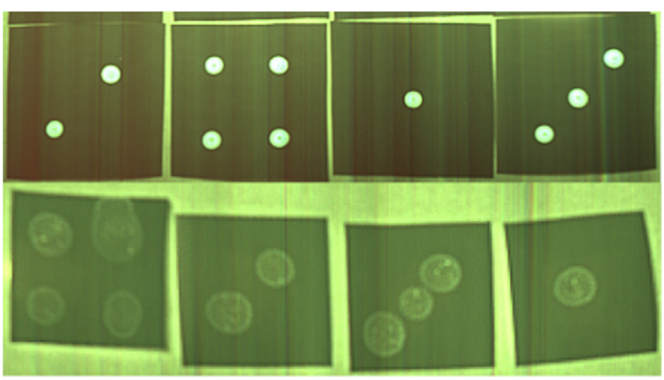

Fig. 17. 200 μl stains on white plotter paper substrate exposed to a blue Crime Lite Top: semen. Bottom: saliva.

A reduced level of accuracy was exhibited on the dark blue cotton and cardboard substrates compared to the white cotton and white paper substrates. Participants detected between 238 and 305 drops of the 280 drops of semen that were initially deposited onto the dark blue cotton substrate (85% and 108% respectively). Participant 6 identified 25 more drops than were initially deposited and this could be attributed to artefacts present on the substrate, such as fibres or other particles, which fluoresced.

Participants' detection of semen drops on the coloured cardboard ranged from 160 drops (89%) to 180 drops out of the 180 semen drops initially deposited (100%). Just one participant identified 100% of the deposited drops of semen. The reduction in the level of accuracy was attributed to the substrate type. The yellow cardboard in particular demonstrated background fluorescence, which masked the fluorescence from the semen, stains, making them harder or impossible to detect. In addition, the increased working distances made the smaller volumes harder to detect and thus some participants were not able to detect the semen in these cases.

In comparison to semen, considerably less accuracy was demonstrated by participants during the location and visualisation of saliva. Four participants were able to identify 100% of saliva drops on the white plotter paper substrate, with 5 participants missing 2 drops initially deposited, and one participant failing to detect 4 drops (1.11% missed), as shown in Fig. 23. The majority of participants identified >87% of the total number of drops initially deposited on coloured cardboard. One participant only managed to identify 66% of saliva drops on the coloured cardboard (participant 10), which could be attributed to its colour, and the yellow substrate demonstrating background fluorescence, masking the fluorescence of the saliva. In addition, saliva can be

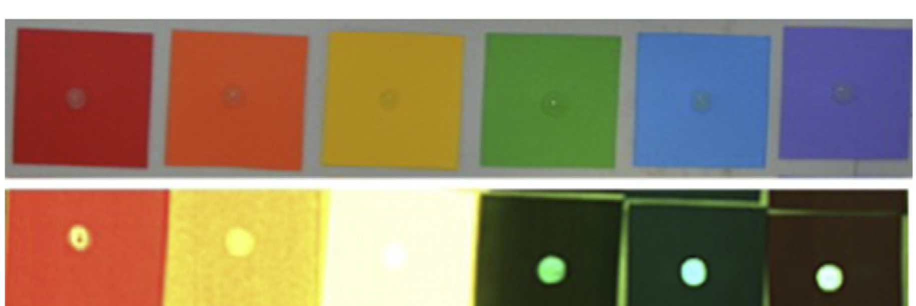

Fig. 18. 200 μl Semen staining on coloured cardboard substrate 5 cm × 5 cm Top: semen exposed to natural light. Bottom: semen exposed to a blue Crime Lite XL.

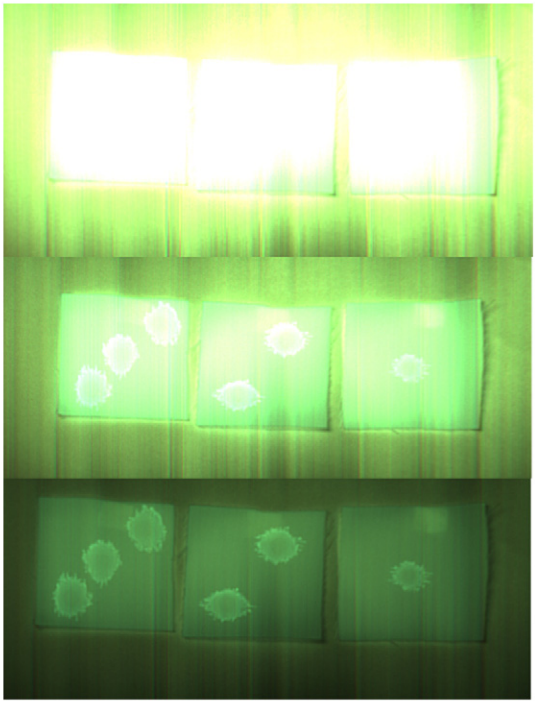

Fig. 19. Real time HDR applied to the detection of semen stains on white cotton. Top: default exposure with masked fluorescence. Middle: lowered exposure showing semen fluorescence. Bottom: lowered exposure further to fully observe the shape and contrast of the semen stains.

more difficult to detect due to a less intense fluorescent response caused by a lack of solid particles within the biological fluid [1,3].

The level of accuracy associated with locating and visualising saliva stains on white cotton was significantly reduced, with only 33% of the total drops deposited being successfully identified. The reduced level of accuracy associated with the detection of saliva on white cottons is likely to have been due to the inherent fluorescence observed by the substrate, thus masking the fluorescence from the saliva [3,6].

Very few participants were able to detect saliva stains on dark blue cotton. This could be attributed to the porous nature of the substrate whereby the saliva was absorbed into the substrate rather than drying on the surface, leaving little surface reflectance [2,3,16]. The difficulty in detection of saliva could also be due to the very weak nature of saliva fluorescence [11].

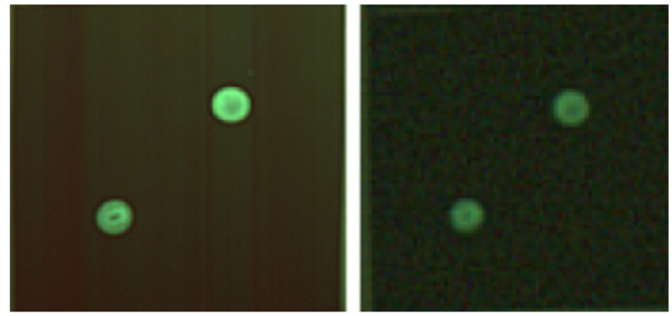

Fig. 21. 100 μl Semen stains on white plotter paper substrate exposed to a blue Crime Lite XL. Resolution difference: (Left) 30 cm. (Right) 300 cm camera distance from semen stain.

The results of this research have demonstrated a variation in the ability to locate and visualise semen and saliva on a variety of substrates using a non-destructive technique; 360° photography combined with an alternate light source. Further investigation observing a broader range of substrates is planned to determine the optimum conditions and limitations of this combined technique and its applications for casework, particularly in the presence of alternative agents, which may also fluoresce, and therefore introduce false positive results. Alternative agents known to induce false positive results are documented in the literature [5,9], and therefore the authors would expect the introduction of such agents into the existing methodology to result in similar results. In addition, the authors recommend the investigation of other biological fluids, such as vaginal secretions and urine, to determine the optimum conditions for their successful location and visualisation. The results of this paper have demonstrated that it is possible to locate such undiluted biological fluids. The authors recognise that it would be useful to establish the sensitivity of this approach using diluted samples, which could be more reflective of casework samples. It would also be useful to monitor the effectiveness of the approach over time. This will form the basis of further work.

4. Conclusion

The results of this research have demonstrated a variation in the ability to locate and visualise semen and saliva on a variety of substrates. Results demonstrated that semen fluorescence is more intense than that exhibited by saliva, which can make saliva more difficult to detect. The weak intensity of the fluorescence exhibited by saliva can be attributed to the lack of solid particles within the saliva sample. Substrate type and colour had a significant effect on the detection of the biological fluid, with limited fluid detection on darker substrates. The porous

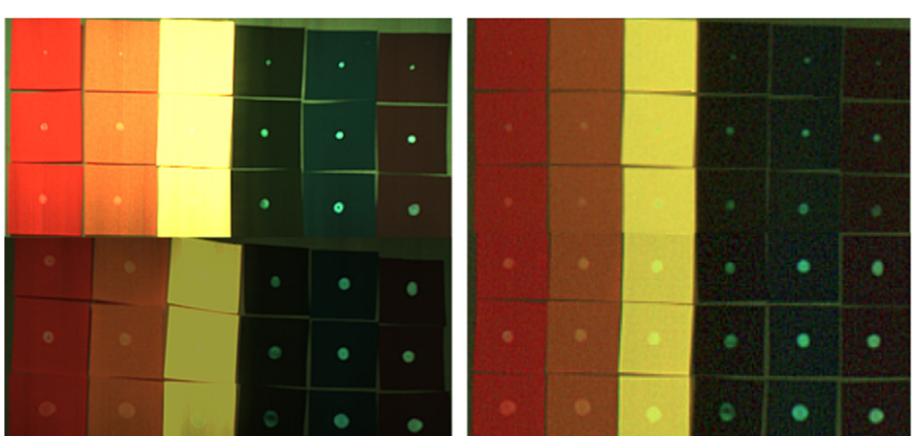

Fig. 20. All volumes (from top to bottom), 5, 50, 100, 150, 200 and 250 μl– semen successfully detected on coloured cardboard using a blue Crime Lite XL at 30 cm (left), 300 cm (right).

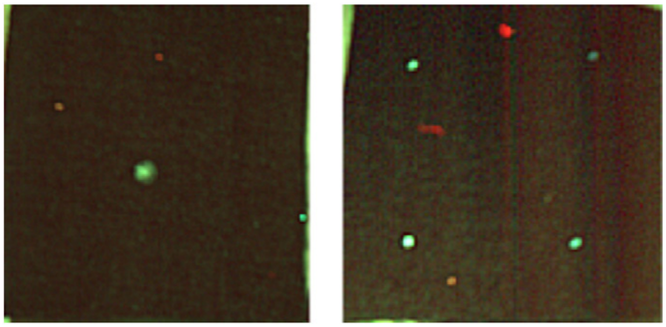

Fig. 22. Artefacts such as fibres identified on the substrate.

nature of the white and dark blue cotton substrates meant the biological fluid was absorbed into the substrate rather than drying on the surface, leaving little surface fluorescence. Some substrates have inherent photo luminescent properties and can mask fluorescence from biological fluids, making them harder to detect. This technique acts solely as a screening method and can be used to inform and direct an investigator to the locations of biological staining during documentation of the scene. This technique cannot differentiate between biological fluids and any fluorescent areas will require further confirmatory testing to identify the fluid in question. In addition, where a fluorescent response is not observed, the presence of a biological fluid cannot be excluded. Further investigation is required to observe a broader range of substrates to determine the optimum conditions and limitations of this combined technique and its application for casework, particularly in the presence of alternative agents, which may also fluoresce, and therefore introduce false positive results. The unique real-time HDR ability of the SceneCam significantly enhanced the detection of biological fluids where background fluorescence masked target fluorescence. These preliminary results are presented as a proof of concept for combining 360° photography using HDR and an alternate light source for the detection of biological stains, within a scene, in real time, whilst conveying spatial relationships of staining to other evidence. This technique presents the opportunity to rapidly screen a crime scene for biological fluids and will facilitate simultaneous location and visualisation of biological evidence.

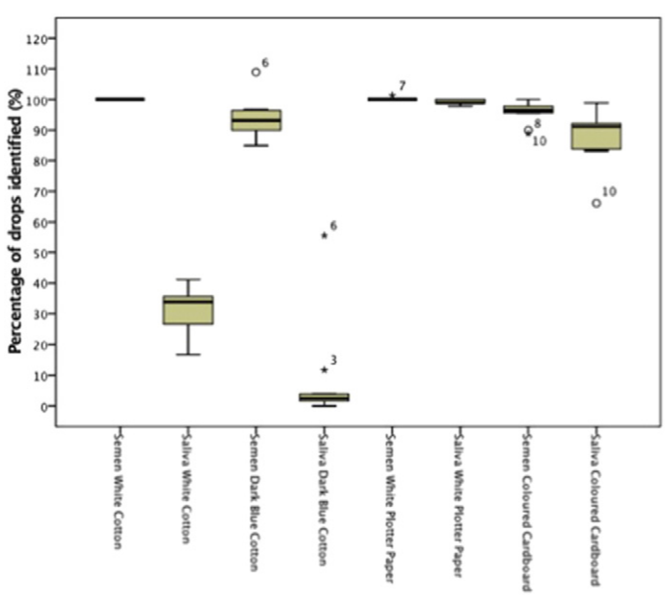

Fig. 23. Boxplot to show the percentage of semen and saliva drops identified by 10 participants on four different substrates. Numbers denote the participant number for those that have been identified as outliers. Symbols – circle denotes an outlier, star denotes extreme outliers, which have been defined by SPSS as 1.5 × Interquartile range.

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Appendix 3

3.A1 – Participants crime scene house measurements for items A-J using the SceneCenter software application

Participant Number	Camera Position	Measurement Reference and Participant Measurement/ mm										Repetition
		A	B	C	D	E	F	G	H	I	J	
1	1	3540	870	2380			890	1020	1690	3490		1
1	1	3530	870	2370			890	800		3500		2
1	1	3540	870	2360			890	920		3490		3
1	1	4770	870	2380			890	700		3500		4
1	1	3550	870	2390			890	740		3510		5
1	1	7840	870	2380			890	810		3500		6
1	1	3540	870	2380			890	870		3500		7
1	1	3540	870	2370			890	800		3510		8
1	1	7830	870	2370			890	850		3490		9
1	1	3530	870	2370			890	830		3500		10
1	2	3560	860	2370	330	2850	890		1640		1080	1
1	2	3580	860	2360	330	2870	890		1640		1090	2
1	2	3550	840	2350	330	2860	880		1620		1010	3
1	2	3570	870	2350	330	2870	880		1630		1050	4
1	2	3570	890	2350	330	2880	880		1650		1060	5
1	2	3560	860	2370	330	2860	890		1630		1070	6
1	2	3560	880	2360	330	2870	890		1620		1060	7
1	2	3560	880	2350	330	2870	890		1640		1090	8
1	2	3560	880	2350	330	2860	890		1640		1070	9
1	2	3560	870	2350	330	2870	880		1610		1050	10
1	3	3530	840	2350			870	780	1670	3490	1070	1

1	3	3530	840	2320		880	780	1020	3490	1070	2
1	3	3530	850	2330		870	780	1680	3480	1050	3
1	3	3540	860	2340		870	790	1660	3480	1060	4
1	3	3530	840	2320		880	780	1660	3490	1060	5
1	3	3530	830	2350		880	820	1050	3490	1050	6
1	3	3530	850	2380		870	800	1680	3480	1060	7
1	3	3540	850	2340		870	800	1630	3490	1060	8
1	3	3540	850	2360		870	780	1670	3490	1060	9
1	3	3530	830	2340		870	780	1650	3490	1050	10
1	4	3550	880	2350	320	870	740			1060	1
1	4	3550	870	2380	320	870	1030			1060	2
1	4	3540	880	2340	330	870	760			1040	3
1	4	3550	860	2330	330	880	840			1080	4
1	4	3560	850	2390	320	880	880			1070	5
1	4	3540	880	2360	320	870	990			1040	6
1	4	3550	900	2360	330	870	1090			1030	7
1	4	3530	850	2340	320	880	670			1070	8
1	4	3540	860	2310	330	870	660			1020	9
1	4	3550	870	2370	330	870	780			1040	10
4	1	3540	870	2370		900		1680	3510		1
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4	1	3540	870	2370		880	1040	1640	3520		3
4	1	3530	870	2370		910	890	1630	3490		4
4	1	3540	870	2360		910	1410	1620	3520		5
4	1	3540	870	2370		900	1270	1640	3490		6

4	1	3530	860	2270			940	770	1590	3570		7
4	1	3530	870	2370			900	1280	1620	3510		8
4	1	3530	870	2360			900	1290	1640	3510		9
4	1	3540	830	2350			880	1670	1630	3490		10
4	2	3560	850	2360	330	2850	890		1640		970	1
4	2	3560	890	2370	330	2860	900		1620		950	2
4	2	3570	900	2340	320	2850	890		1630		930	3
4	2	3560	860	2330	330	2850	890		1600		940	4
4	2	3570	870	2350	330	2860	900		1600		930	5
4	2	3560	880	2360	320	2840	900		1620		1330	6
4	2	3580	680	2280	330	2920	900		1560		960	7
4	2	3550	880	2450	350	2880	880		1620		1100	8
4	2	3560	850	2390	350	2850	900		1640		1100	9
4	2	3570	760	2400	440	2910	890		1760		1200	10
4	3	3530	870	2330			890	790	1630	3470	930	1
4	3	3520	860	2320			870	780	1630	3480	920	2
4	3	3520	840	2370			900	790	1620	3490	940	3
4	3	3530	850	2390			860	780	1620	3490	940	4
4	3	3530	830	2340			880	780	1640	3490	920	5
4	3	3540	840	2360			840	780	1630	3490	930	6
4	3	3540	830	2300			840	790	1620	3490	910	7
4	3	3530	850	2340			880	780	1620	3490	940	8
4	3	3520	850	2300			880	780	1620	3490	920	9
4	3	3540	810	2300			880	790	1630	3490	900	10
4	4	3540	880	2320	340	2790	880	640			1090	1

4	4	3520	850	2330	340	2800	880	750			1080	2
4	4	3560	760	2230	330	2780	880	730			920	3
4	4	3520	850	2350	320	2810	890	840			1050	4
4	4	3540	860	2310	330	2740	890	730			1100	5
4	4	3570	820	2290	330	2790	870	850			1050	6
4	4	3550	880	2330	330	2760	870	800			1100	7
4	4	3550	900	2310	390	2790	870	780			1070	8
4	4	3560	860	2450	350	2770	890	770			1080	9
4	4	3530	740	2250	330	2800	880	970			900	10
5	1	3540	880	2380			910		1690	3520		1
5	1	3540	880	2380			910		1670	3500		2
5	1	3540	880	2380			910		1660	3520		3
5	1	3530	880	2380			900		1670	3530		4
5	1	3540	880	2380			910		1650	3510		5
5	1	3540	880	2380			910		1650	3510		6
5	1	3530	880	2380			910		1650	3500		7
5	1	3530	870	2390			900		1650	3490		8
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12	2	3560	860	2360	330	2860	890		1650		1020	3
12	2	3560	850	2350	330	2850	880		1650		1090	4
12	2	3570	860	2420	330	2850	890		1610		1030	5
12	2	3550	860	2380	330	2860	880		1610		1090	6
12	2	3560	890	2360	330	2840	880		1620		1020	7
12	2	3580	880	2330	330	2850	890		1620		1050	8
12	2	3550	870	2330	330	2860	890		1640		1040	9
12	2	3560	840	2360	330	2850	890		1640		1080	10
12	3	3530	840	2340			850	780	1610	3490		1
12	3	3520	860	2320			860	770	1590	3480		2
12	3	3530	860	2320			850	780	1740	3480		3
12	3	3520	880	2350			870	770	1620	3490		4
12	3	3520	840	2330			870	780	1620	3490		5
12	3	3530	820	2300			860	780	1660	3490		6
12	3	3530	810	2310			870	780	1680	3490		7
12	3	3520	850	2340			880	780	1650	3490		8
12	3	3520	830	2320			870	770	1610	3480		9
12	3	3530	840	2320			840	770	1730	3480		10
12	4	3550	870	2360	320	2770	890	1040			990	1
12	4	3530	850	2330	320	2780	870	780			810	2
12	4	3530	840	2350	330	2810	870	770			970	3
12	4	3520	890	2320	320	2800	870	770			910	4
12	4	3550	830	2370	320	2790	890	770			1070	5
12	4	3520	810	2290	330	2780	870	780			1020	6

12	4	3560	860	2390	330	2810	860	780	1040	7
12	4	3550	840	2390	330	2780	870	780	1080	8
12	4	3550	840	2340	320	2820	870	780	1090	9
12	4	3540	840	2340	330	2810	880	780	1000	10

Appendix 3

3.A2 – Participants crime scene house measurements for items A-J using a tape measure

	Measurement Reference and Participant Measurement / mm										
Participant	A	B	C	D	E	F	G	H	I	J	Repetition
Control	3579	888	2423	340	2882	922	789	1660	3526	1060	1
Control	3580	891	2411	342	2882	919	789	1661	3525	1060	2
Control	3579	886	2417	340	2882	923	790	1663	3526	1059	3
Control	3579	891	2416	342	2881	920	789	1662	3527	1058	4
Control	3580	887	2410	342	2882	921	790	1660	3528	1058	5
Control	3578	887	2417	342	2882	923	789	1660	3530	1058	6
Control	3578	889	2417	341	2882	922	789	1661	3526	1058	7
Control	3579	890	2415	343	2882	925	789	1661	3527	1058	8
Control	3578	889	2411	341	2882	918	789	1661	3526	1059	9
Control	3579	890	2419	343	2882	921	789	1661	3527	1058	10
Mean	3578.90	888.80	2415.60	341.60	2881.90	921.40	789.20	1661.00	3526.80	1058.60	
SD	0.74	1.75	4.03	1.07	0.32	2.07	0.42	0.94	1.40	0.84	
Standard Error	0.23	0.55	1.28	0.34	0.10	0.65	0.13	0.30	0.44	0.27	
Relative Standard Deviation	0.02	0.20	0.17	0.31	0.01	0.22	0.05	0.06	0.04	0.08	
P1	3588	890	2420	345	2860	925	805	1680	3530	1140	1
P1	3590	890	2425	347	2858	928	920	1680	3528	1160	2
P1	3589	900	2410	347	2860	928	792	1675	3528	1165	3
P1	3588	894	2415	345	2860	927	792	1672	3528	1160	4
P1	3590	892	2420	346	2858	929	791	1680	3528	1160	5
P1	3597	890	2410	345	2858	928	793	1680	3527	1165	6
P1	3585	890	2412	347	2860	928	793	1675	3525	1160	7
P1	3592	891	2410	345	2860	928	792	1680	3526	1164	8
P1	3591	890	2415	345	2861	927	792	1672	3524	1165	9

P1	3589	890	2412	345	2860	928	790	1680	3526	1162	10
Mean	3589.90	891.70	2414.90	345.70	2859.50	927.60	806.00	1677.40	3527.00	1160.10	
SD	3.14	3.20	5.20	0.95	1.08	1.07	40.28	3.50	1.76	7.42	
Standard Error	0.99	1.01	1.64	0.30	0.34	0.34	12.74	1.11	0.56	2.34	
Relative Standard Deviation	0.09	0.36	0.22	0.27	0.04	0.12	5.00	0.21	0.05	0.64	
P4	3610	910	2325	345	2890	900	790	1680	3520	1000	1
P4	3640	905	2395	345	2905	905	785	1665	3525	990	2
P4	3625	901	2345	345	2890	900	785	1645	3525	990	3
P4	3640	900	2365	343	2870	905	785	1650	3530	990	4
P4	3625	910	2420	344	2880	905	785	1650	3530	909	5
P4	3620	895	2380	344	2875	905	785	1650	3525	985	6
P4	3625	900	2380	344	2875	905	785	1655	3525	980	7
P4	3635	910	2380	344	2875	905	785	1650	3530	985	8
P4	3630	900	2375	344	2875	905	785	1655	3525	985	9
P4	3620	905	2335	344	2880	905	785	1650	3525	980	10
Mean	3627.00	903.60	2370.00	344.20	2881.50	904.00	785.50	1655.00	3526.00	979.40	
SD	9.49	5.23	28.58	0.63	10.55	2.11	1.58	10.27	3.16	25.41	
Standard Error	3.00	1.65	9.04	0.20	3.34	0.67	0.50	3.25	1.00	8.04	
Relative Standard Deviation	0.26	0.58	1.21	0.18	0.37	0.23	0.20	0.62	0.09	2.59	
P5	3500	890	935	340	2870	910	790	1640	3530	1040	1
P5	3530	890	2380	350	2860	910	790	1650	3470	1040	2
P5	3540	890	2400	350	2870	910	780	1640	3530	1040	3
P5	3570	890	2400	350	2860	910	780	1610	3530	1040	4
P5	3580	890	2410	345	2860	910	780	1630	3480	1040	5

P5	3580	890	2410	350	2860	920	790	1640	3530	1040	6
P5	3580	890	2370	345	2860	920	790	1635	3530	1040	7
P5	3595	890	2410	342	2860	920	790	1640	3530	1040	8
P5	3590	880	2400	345	2860	920	790	1635	3530	1040	9
P5	3580	890	2380	345	2860	930	790	1640	3530	1040	10
Mean	3564.50	889.00	2249.50	346.20	2862.00	916.00	787.00	1636.00	3519.00	1040.00	
SD	30.77	3.16	462.09	3.65	4.22	6.99	4.83	10.49	23.31	0.00	
Standard Error	9.73	1.00	146.12	1.15	1.33	2.21	1.53	3.32	7.37	0.00	
Relative Standard Deviation	0.86	0.36	20.54	1.05	0.15	0.76	0.61	0.64	0.66	0.00	
P6	3590	890	2400	343	287	915	788	1667	3525	1050	1
P6	3586	890	2407	343	2873	917	788	1668	3524	1044	2
P6	3583	890	2413	343	2873	950	789	1643	3528	1075	3
P6	3581	890	2422	343	2874	950	789	1664	3524	1078	4
P6	3581	890	2422	343	2873	915	789	1665	3524	1078	5
P6	3584	890	2422	343	2873	915	789	1664	3527	1074	6
P6	3584	890	2422	343	2873	915	789	1664	3522	1074	7
P6	3583	890	2419	343	2873	915	789	1664	3524	1074	8
P6	3583	890	2422	343	2873	915	789	1664	3523	1074	9
P6	3584	890	2422	343	2873	915	789	1664	3524	1074	10
Mean	3583.90	890.00	2417.10	343.00	2614.50	922.20	788.80	1662.70	3524.50	1069.50	
SD	2.60	0.00	7.88	0.00	817.80	14.67	0.42	7.07	1.78	12.05	
Standard Error	0.82	0.00	2.49	0.00	258.61	4.64	0.13	2.24	0.56	3.81	
Relative Standard Deviation	0.07	0.00	0.33	0.00	31.28	1.59	0.05	0.43	0.05	1.13	
P7	3680	890	2420	340	2900	920	790	1690	3540	1030	1

P7	3660	890	2420	350	2910	890	790	1680	3540	1040	2
P7	3630	920	2420	340	2910	890	790	1680	3540	1050	3
P7	3560	900	2420	340	2900	890	790	1680	3540	1050	4
P7	3650	900	2410	340	2900	890	790	1680	3540	1050	5
P7	3650	890	2410	340	2900	890	790	1680	3550	1050	6
P7	3650	900	2410	340	2900	890	790	1680	3590	1050	7
P7	3654	900	2400	340	2900	890	790	1680	3540	1050	8
P7	3650	900	2400	340	2900	890	790	1780	3540	1060	9
P7	3660	900	2400	240	2900	890	790	1680	3540	1050	10
Mean	3644.40	899.00	2411.00	331.00	2902.00	893.00	790.00	1691.00	3546.00	1048.00	
SD	32.15	8.76	8.76	32.13	4.22	9.49	0.00	31.43	15.78	7.89	
Standard Error	10.17	2.77	2.77	10.16	1.33	3.00	0.00	9.94	4.99	2.49	
Relative Standard Deviation	0.88	0.97	0.36	9.71	0.15	1.06	0.00	1.86	0.44	0.75	
P8	3700	900	2390	340	2890	920	810	1670	3090	1060	1
P8	3600	890	2400	340	2890	920	800	1640	3060	1050	2
P8	3540	2380	2390	340	2900	890	800	1630	3070	1030	3
P8	3700	890	2370	340	2900	890	800	1680	3070	1030	4
P8	3600	890	2300	340	2890	890	800	1650	3070	1030	5
P8	1600	890	3350	340	2890	890	800	1670	3090	1030	6
P8	1600	890	2360	340	2890	890	800	1670	3070	1030	7
P8	1600	890	2370	340	2890	890	800	1700	3070	1030	8
P8	3600	890	2370	340	2890	890	3070	1700	800	1030	9
P8	3600	890	3350	340	2890	890	800	1700	1070	1030	10
Mean	3014.00	1040.00	2565.00	340.00	2892.00	896.00	1028.00	1671.00	2646.00	1035.00	
SD	976.94	470.84	414.63	0.00	4.22	12.65	717.49	25.14	904.07	10.80	

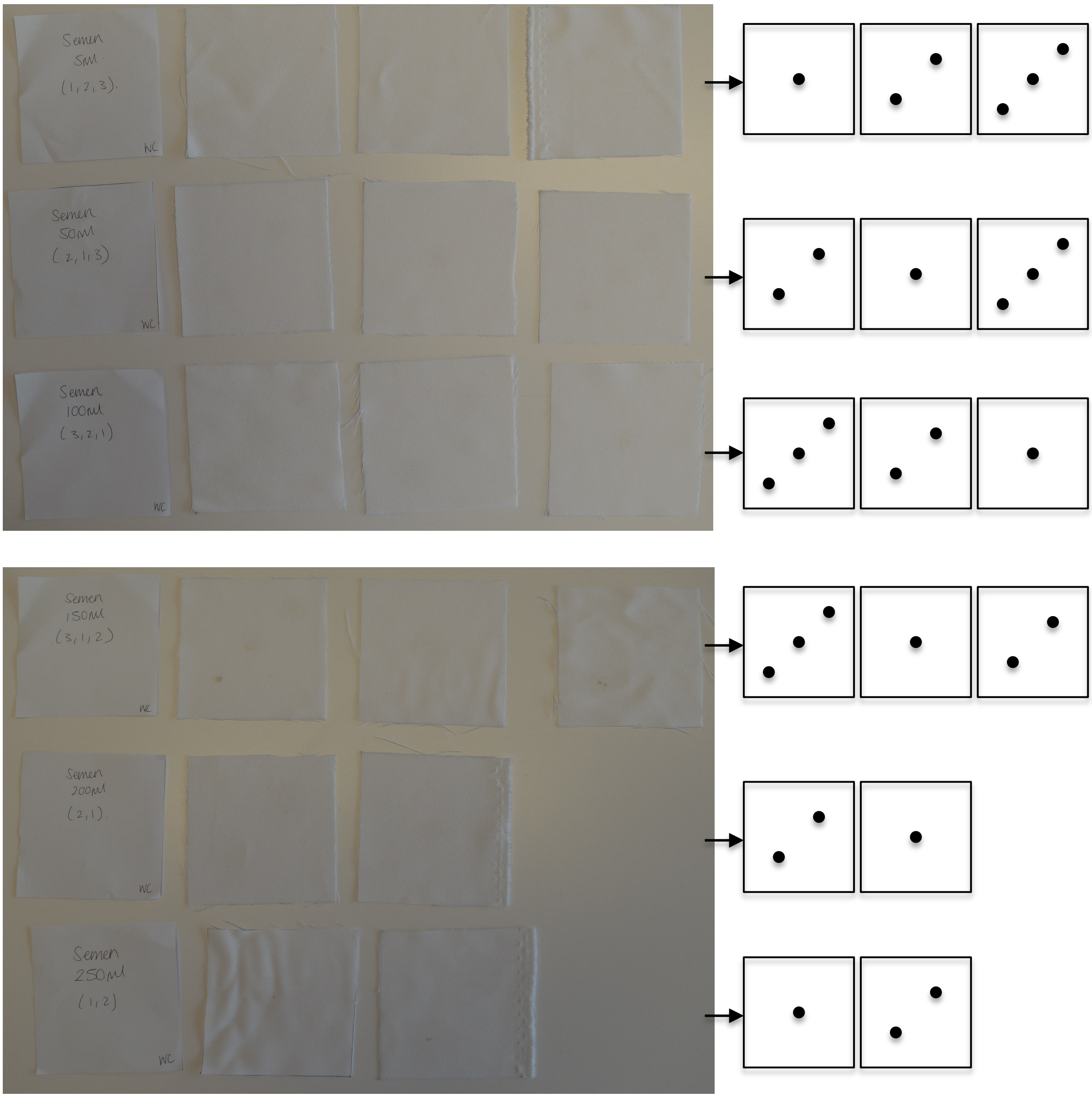
Standard Error	308.93	148.89	131.12	0.00	1.33	4.00	226.89	7.95	285.89	3.42	
Relative Standard Deviation	32.41	45.27	16.16	0.00	0.15	1.41	69.79	1.50	34.17	1.04	
P9	3590	890	2370	340	2890	925	790	1670	3540	1060	1
P9	3590	890	2390	343	2910	925	785	1680	3530	1050	2
P9	3580	890	2370	343	2880	920	790	1670	3430	1040	3
P9	3630	890	2380	340	2880	920	785	1670	3540	1030	4
P9	3590	890	2380	340	2890	920	785	1670	3520	1030	5
P9	3620	890	2380	340	2890	920	785	1670	3560	1030	6
P9	3620	890	2380	340	2920	920	785	1670	3590	1030	7
P9	3620	890	2380	340	2890	920	785	1690	3520	1020	8
P9	3620	890	2380	340	2890	920	785	1690	3530	1030	9
P9	3610	890	2390	340	2880	920	785	1670	3540	1030	10
Mean	3607.00	890.00	2380.00	340.60	2892.00	921.00	786.00	1675.00	3530.00	1035.00	
SD	17.67	0.00	6.67	1.26	13.17	2.11	2.11	8.50	40.82	11.79	
Standard Error	5.59	0.00	2.11	0.40	4.16	0.67	0.67	2.69	12.91	3.73	
Relative Standard Deviation	0.49	0.00	0.28	0.37	0.46	0.23	0.27	0.51	1.16	1.14	
P10	3694	889	2349	349	2900	920	790	1674	3525	1019	1
P10	3500	884	2400	341	2800	890	777	1618	3518	1021	2
P10	3572	890	2419	340	2897	910	780	1640	3512	1022	3
P10	3571	890	2368	341	2887	910	780	1618	3518	1022	4
P10	3577	887	2360	341	2899	890	778	1634	3507	1011	5
P10	3580	885	2389	340	2891	894	778	1655	3514	1014	6
P10	3585	889	2414	341	2890	900	779	1620	3510	1013	7
P10	3583	889	2390	340	2892	900	778	1634	3511	1130	8

P10	3576	890	2450	342	2890	896	776	1648	3511	105	9
P10	3579	889	2400	342	2889	895	780	1638	3510	1022	10
Mean	3581.70	888.20	2393.90	341.70	2883.50	900.50	779.60	1637.90	3513.60	937.90	
SD	46.63	2.15	30.06	2.67	29.67	9.86	3.89	17.78	5.32	294.79	
Standard Error	14.75	0.68	9.50	0.84	9.38	3.12	1.23	5.62	1.68	93.22	
Relative Standard Deviation	1.30	0.24	1.26	0.78	1.03	1.09	0.50	1.09	0.15	31.43	
P11	3490	890	2440	340	2930	900	790	1630	3340	910	1
P11	3580	890	2420	340	2810	910	790	1630	350	1010	2
P11	3560	890	2420	350	2900	900	790	1620	3500	1000	3
P11	3570	890	2420	350	2900	910	790	2900	3500	9800	4
P11	3560	890	2410	350	2900	910	790	1610	3500	980	5
P11	3560	890	2420	350	2900	910	790	1640	3500	980	6
P11	3560	890	2410	350	2900	910	790	1630	3500	980	7
P11	3560	890	2420	350	2900	910	790	1640	3500	990	8
P11	3560	890	2420	350	2910	910	790	1640	3500	980	9
P11	356	890	2380	350	2900	910	310	1640	3500	980	10
Mean	3235.60	890.00	2416.00	348.00	2895.00	908.00	742.00	1758.00	3169.00	1861.00	
SD	1012.08	0.00	15.06	4.22	31.36	4.22	151.79	401.38	991.77	2789.61	
Standard Error	320.05	0.00	4.76	1.33	9.92	1.33	48.00	126.93	313.63	882.15	
Relative Standard Deviation	31.28	0.00	0.62	1.21	1.08	0.46	20.46	22.83	31.30	149.90	
P12	3530	880	2410	340	2900	900	790	1700	3520	1000	1
P12	3780	880	2400	340	2900	900	790	1700	3520	1000	2
P12	3570	880	2400	340	2900	900	790	1700	3530	1000	3
P12	3570	880	2400	340	2900	900	780	1700	3540	1000	4

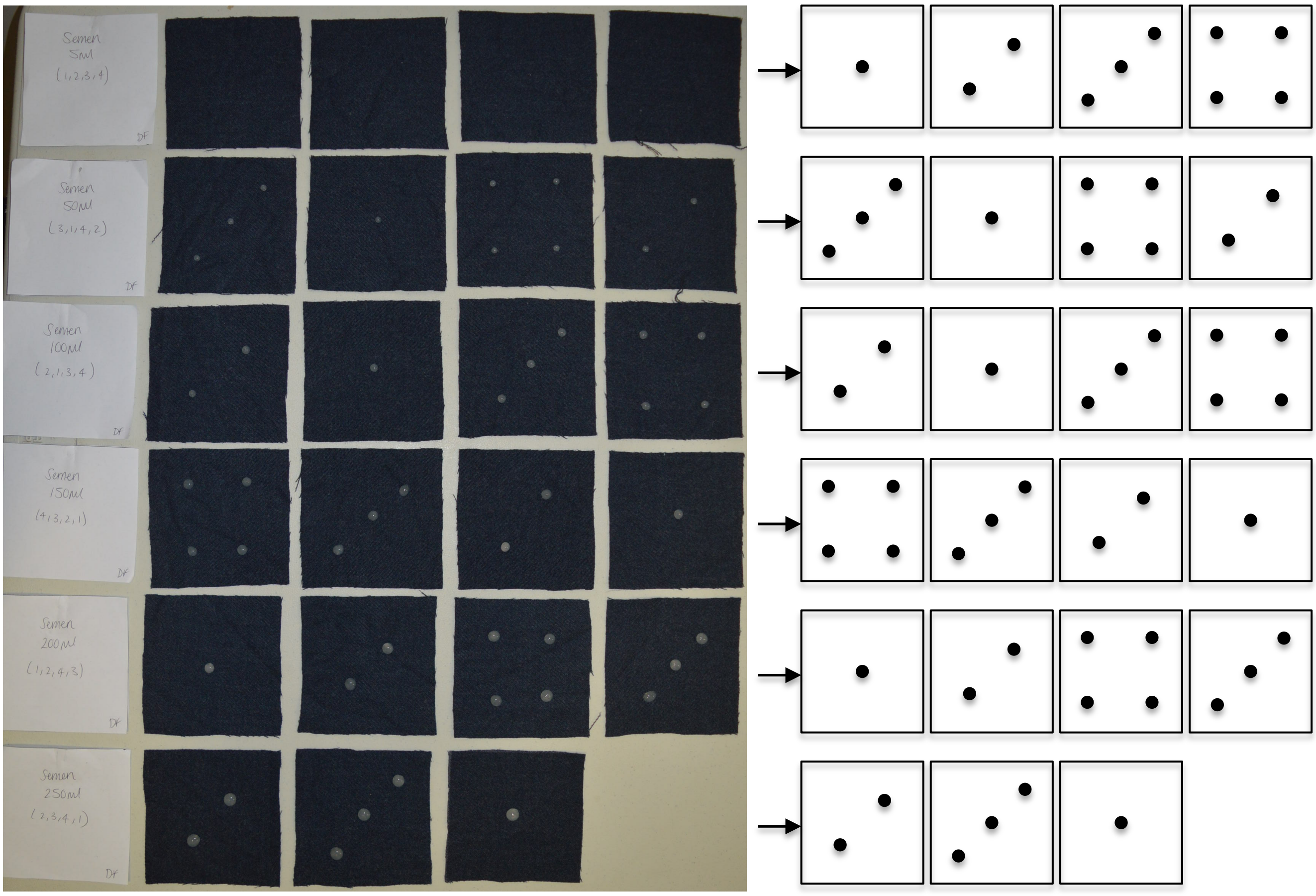
P12	3570	880	2400	340	2900	900	790	1700	3540	1000	5
P12	3570	880	2400	340	2900	900	780	1700	3540	1000	6
P12	3570	880	2400	340	2900	900	790	1700	3540	1000	7
P12	3570	880	2400	340	2900	900	790	1700	3540	1000	8
P12	3570	880	2400	340	2700	900	7900	1700	3540	1000	9
P12	3570	880	2400	340	2900	900	790	1700	3540	1000	10
Mean	3587.00	880.00	2401.00	340.00	2880.00	900.00	1499.00	1700.00	3535.00	1000.00	
SD	68.97	0.00	3.16	0.00	63.25	0.00	2249.09	0.00	8.50	0.00	
Standard Error	21.81	0.00	1.00	0.00	20.00	0.00	711.22	0.00	2.69	0.00	
Relative Standard Deviation	1.92	0.00	0.13	0.00	2.20	0.00	150.04	0.00	0.24	0.00	

Appendix 4

4.A1 – Figure to show the distribution of semen drops on white cotton swatches. Top to Bottom – 5, 50, 100, 150, 200 and 250 μL respectively.

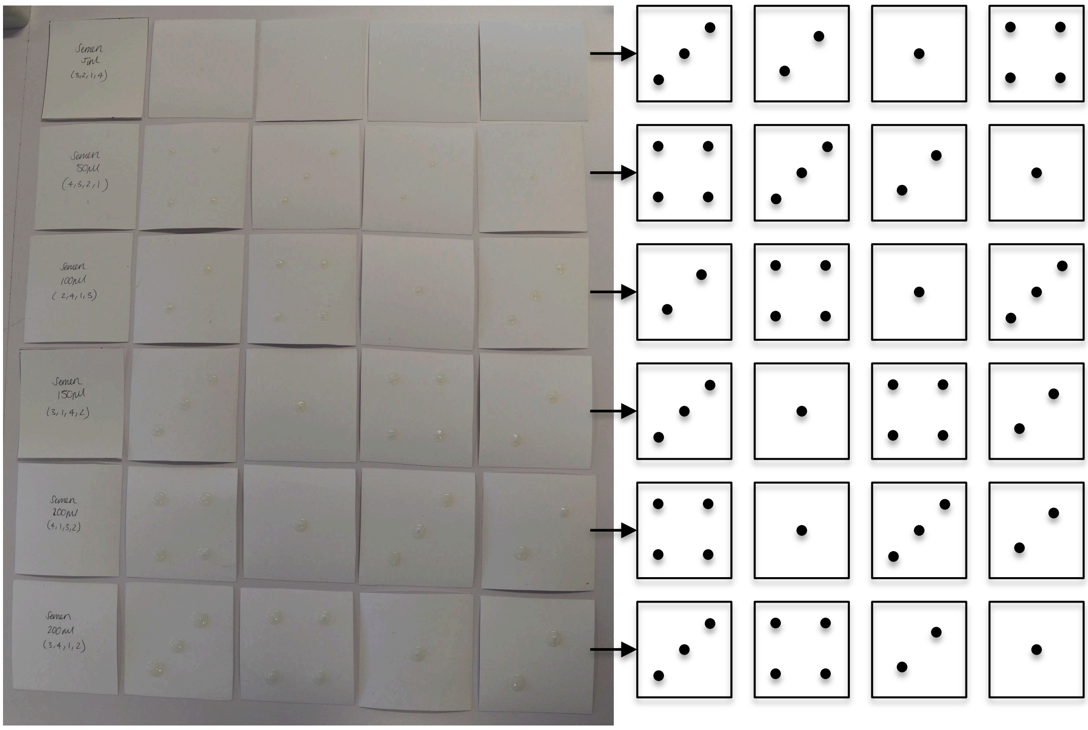


4.A2 – Figure to show the distribution of semen drops on dark cotton swatches. Top to Bottom – 5, 50, 100, 150, 200 and 250 µL respectively.

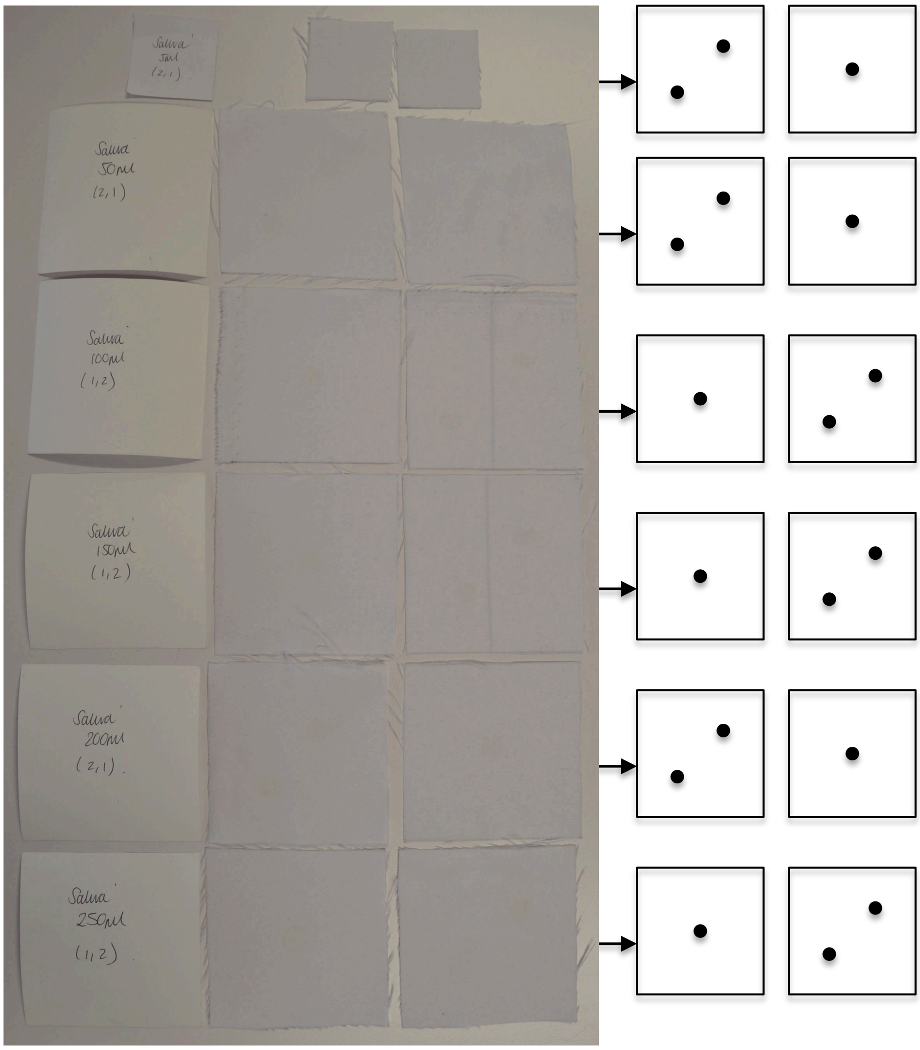


4.A3 - Figure to show the distribution of semen drops on coloured cardboard. Top to Bottom – 5, 50, 100, 150, 200 and 250 μL respectively

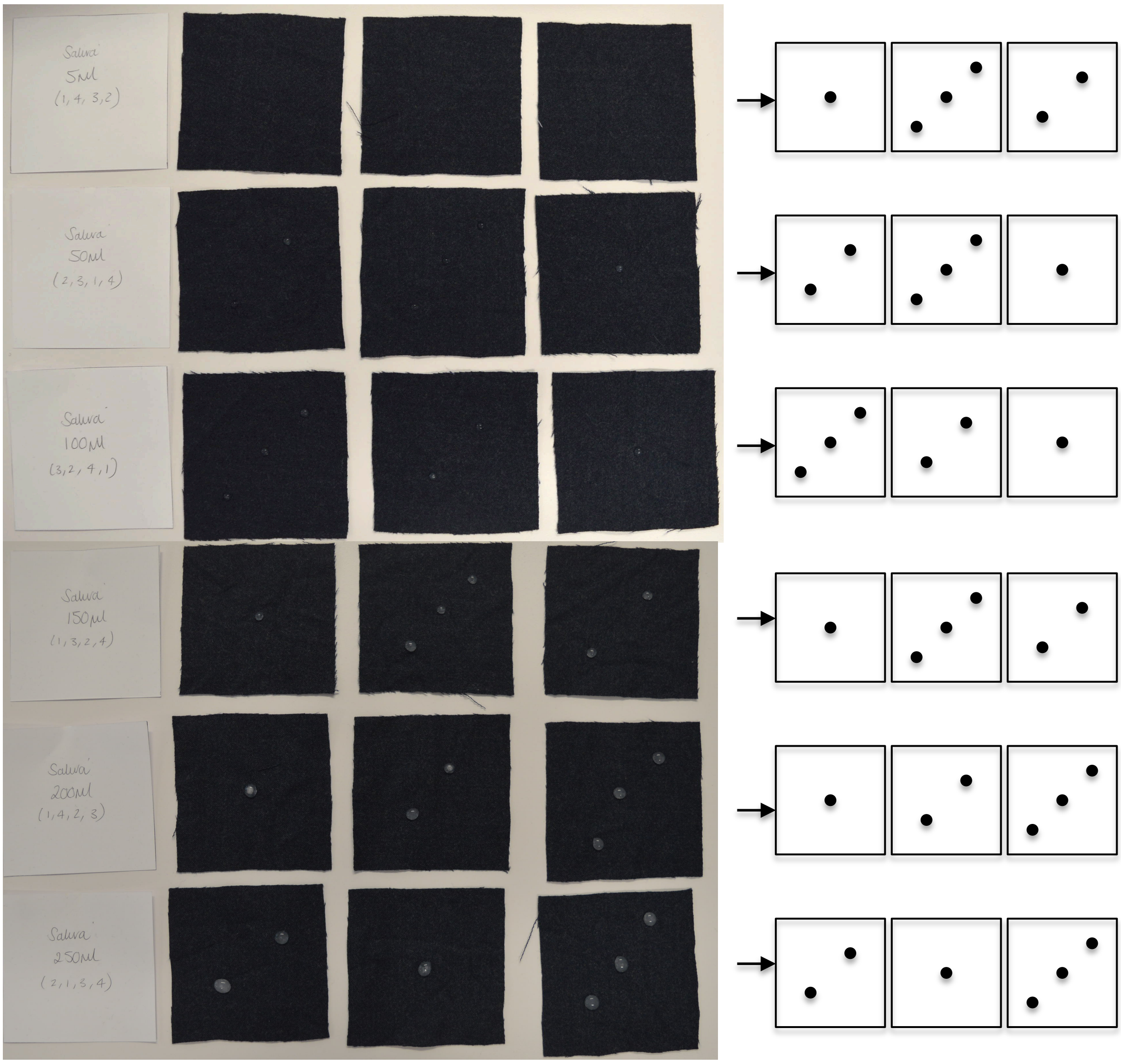
4.A4 - Figure to show the distribution of semen drops on white plotter paper. Top to Bottom – 5, 50, 100, 150, 200 and 250 μL respectively



4.A5 - Figure to show the distribution of saliva drops on white cotton swatches. Top to Bottom – 5, 50, 100, 150, 200 and 250 μL respectively

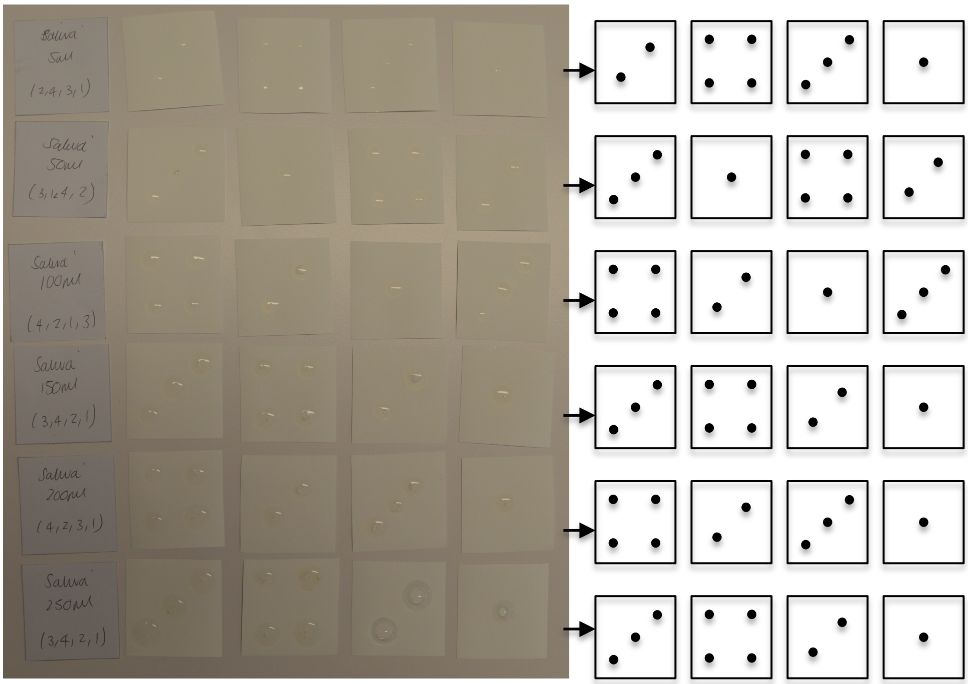


4.A6 - Figure to show the distribution of saliva drops on dark cotton swatches. Top to Bottom – 5, 50, 100, 150, 200 and 250 µL respectively

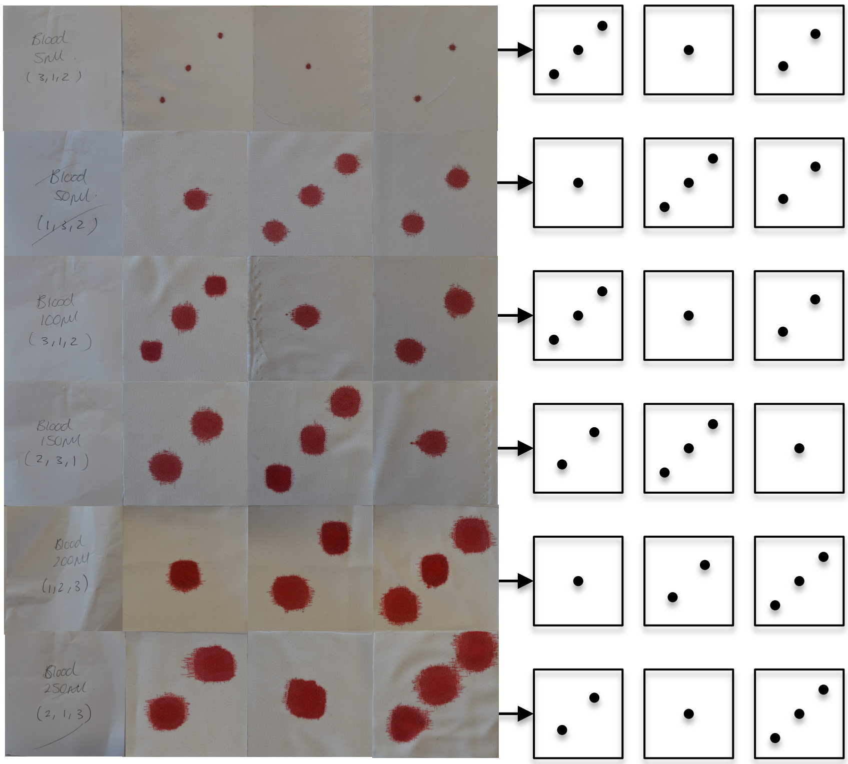


4.A7 - Figure to show the distribution of saliva drops on coloured cardboard. Top to Bottom – 5, 50, 100, 150, 200 and 250 μL respectively

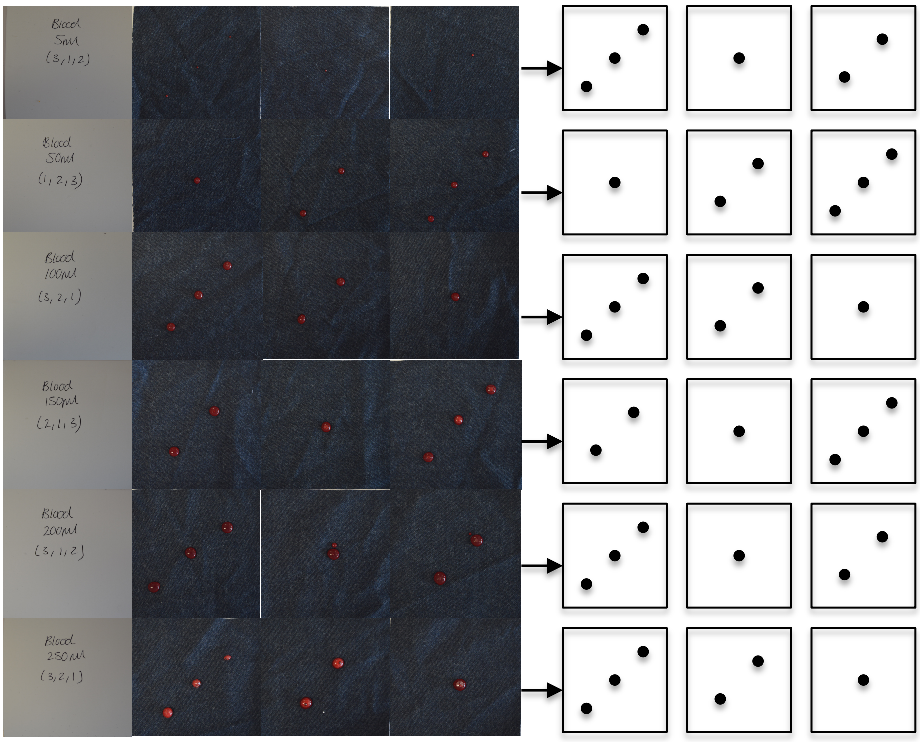
4.A8 - Figure to show the distribution of saliva drops on white plotter paper. Top to Bottom – 5, 50, 100, 150, 200 and 250 μL respectively



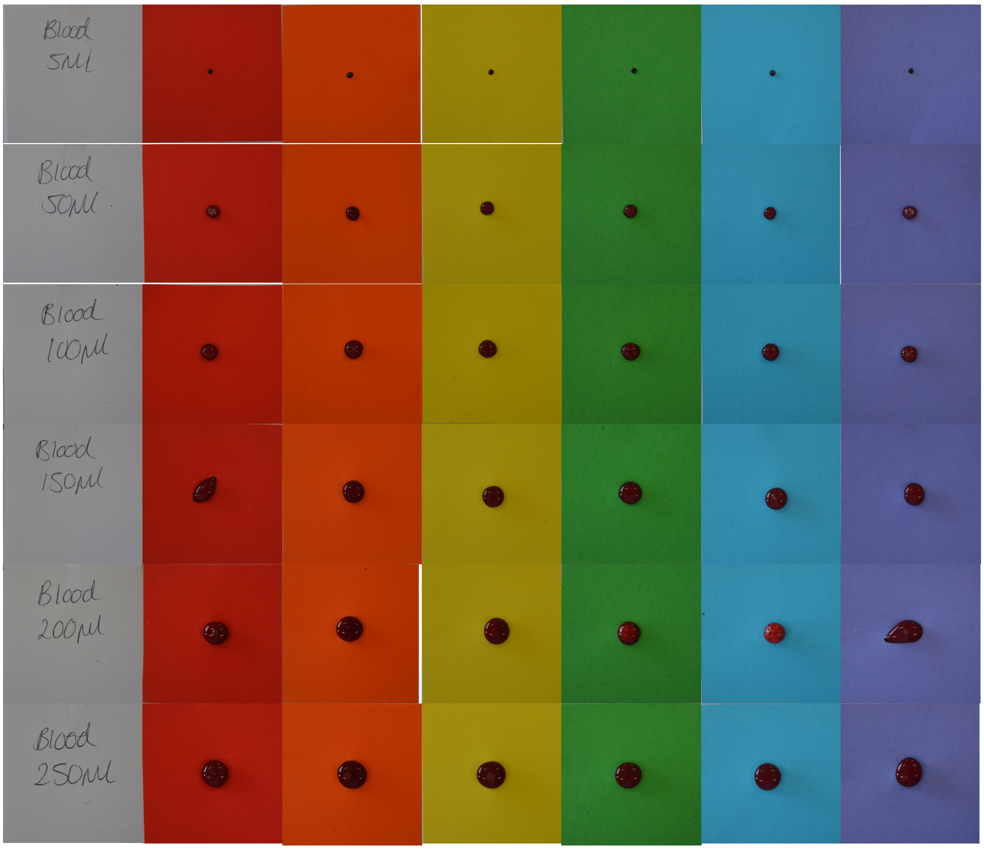
4.A9 - Figure to show the distribution of blood drops on white cotton swatches. Top to Bottom – 5, 50, 100, 150, 200 and 250 µL respectively



4.A10 - Figure to show the distribution of blood drops on dark cotton swatches. Top to Bottom – 5, 50, 100, 150, 200 and 250 µL respectively



4.A11 - Figure to show the distribution of blood drops on coloured cardboard. Top to Bottom – 5, 50, 100, 150, 200 and 250 μL respectively



Appendix 4

4.A12 – Information sheet and Consent Form for participation in detecting biological fluids

STAFFORDSHIRE UNIVERSITY

Information Sheet

<u>An investigation into whether a 360-degree panoramic camera system can be adapted using Alternative Light Sources for the detection of body fluids including blood, semen and saliva within crime scenes.</u>

Aims of the Research

Crime scene environments can encompass a range of different evidence types which need to be accurately documented quickly and efficiently. Biological evidence such as blood, semen and saliva are among the most important pieces of evidence within a crime scene investigation. Biological fluids, particularly semen and saliva can often be naked to the invisible eye and this can make them problematic to locate.

Screening techniques utilising Forensic or Alternative Light Sources (ALS) can be used to locate biological evidence within a scene and present a non-invasive method for the detection of biological fluids. Alternative Light Sources are an illumination system adapted for use in forensic investigation and often comprise of high intensity filtered lamps.

ALS can either make the evidence fluoresce or enhance the contrast of the evidence against the background. Since body fluids such as semen and saliva naturally fluoresce, alternative light sources can be utilised to aid their detection within a scene and offers a unique and non-invasive method of detection compared with other contact methods. The use of alternative light sources allows an investigator to narrow down areas of interest based on locating the staining. Combining this with the use of a 360-degree camera is a new method and could potentially speed up the location process.

More specifically the research seeks to:

a) Identify whether a 360-degree automated camera can detect blood, semen and saliva, using a range of alternative light sources.

Invitation

You are being invited to consider taking part in the research study - *An investigation into whether a 360-degree panoramic camera system can be adapted using Alternative Light Sources for the detection of body fluids including blood, semen and saliva within crime scenes.*

This project is being undertaken by Kayleigh Sheppard, a PhD Researcher from Staffordshire University.

Before you decide whether or not you wish to take part, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with friends and relatives if you wish. Ask us if there is anything that is unclear or if you would like more information. For more information please email Kayleigh Sheppard at Kayleigh.sheppard@staffs.ac.uk or call 01782294863.

Do I have to take part?

You are free to decide whether you wish to take part or not. If you do decide to take part you will be asked to sign two consent forms, one is for you to keep and the other is for our records. You are free to withdraw from this study at any time and without giving reasons. We will keep no records of your withdrawal. Any data collected up until this point will be included in the research, however this will consist of graphs, tables and drawings which you created but these will not be identifiable to you.

What will happen if I take part?
If you agree to participate in the research study and are in good health, you will be asked to sign a consent form and disclose that you are able to complete a short task requiring you to draw what you can see. You are free to withdraw at any stage during the process. If you do decide to withdraw we will remove and dispose of your personal information within this project.

How will information about me be used?
No personal information about yourself will be disclosed at any point in the project and you will only be referred to as a number within the research e.g. participant 1, 2, 3 etc.

How will the researcher ensure that the data is confidential and that the subject will not be identified from the data gathered from the research project?

At no point will drawings made by you be used to identify you. All responses used within reports will be anonymised and it will not be possible to identify you through these drawings. You will not be identifiable as you personally but a number will be assigned to you and you shall be referred to as participant 1, 2, 3 etc.

Signed consent forms will be stored by the principal supervisor in their office, which is accessible only be members of University staff.

Who will have access to this data, and for what purposes?
Only the researcher and project supervisors will have access to the participants consent forms. The participant will not be identified within the research, as the data being produced from this will be anonymised. Data generated from this research and in the thesis will be displayed using graphs and tables and will be in the public domain as part of the thesis submission. You will not be identified in this research and will be referred to as a number.

How will the data be stored, for how long, and how will it be discarded?
In the final project submission the individual will not be identified, and any consent forms will be held by the researcher and will be disposed of after ten years. Anonymised data will appear in the researcher's thesis. This will remain indefinitely in the public domain. In particular, the thesis is likely to be scrutinized by examiners (including external examiners) for the purpose of assessment and by students in subsequent years for educational purposes

Are there any potential risks or hazards associated with this project which may cause harm to the subject or the researcher, in addition to any discomfort, distress or inconvenience to them, together with any ethical problems or considerations that the researcher considers to be important or difficult in the proposed project?

There are no other ethical issues to consider and no associated risks involved with taking part in this study.

What if there is a problem?
If you have a concern about any aspect of this study, you may wish to speak to the researcher(s) who will do their best to answer your questions. You should contact Kayleigh Sheppard at Kayleigh.sheppard@staffs.ac.uk or 01782 294863. Alternatively, if you do not wish to contact the researcher(s) you may contact the Principle supervisor Professor John Cassella at j.p.cassella@staffs.ac.uk.

CONSENT FORM

Title of Project:

An investigation into whether a 360-degree panoramic camera system can be adapted using Alternative Light Sources for the detection of body fluids including blood, semen and saliva within crime scenes.

Name and contact details of Principal Researcher: Kayleigh Sheppard – Kayleigh.sheppard@staffs.ac.uk

Please tick box if you agree with the statement

1. I confirm that I have read and understood the information sheet provided for the above study and have had the opportunity to ask questions ☐

2. I agree to take part in this study and as a result am agreeing to take part in a short study which will require me to draw what I see from photographs given to me ☐

3 I understand that my participation is voluntary and that I am free to withdraw at any time without providing reasons and without my rights being affected ☐

4. I understand that you will keep no record of my withdrawal and any personal details collected up to the point of withdrawal will be removed. Any data collected up until this point will be included in the research, however, as stated within the information sheet this will consist of graphs, tables and drawings which you created but these will not be identifiable to you. ☐

5. I understand that data collected about me during this study will be anonymised before it is submitted for publication. ☐

6. I understand that all personal details about the subjects will be stored separately from the derived data in a secure approved location. ☐

I hereby give my full consent to take part in the research as described in the information sheet.

____________________	____________________	____________________
Name of participant	Date	Signature
_Kayleigh Sheppard_____	____________________	____________________
Researcher	Date	Signature

Researcher – Kayleigh Sheppard – kayleighsheppard@staffs.ac.uk
Principle Supervisor – Professor John Cassella – j.p.cassella@staffs.ac.uk

Date: Participant Number -
1 for participant, 1 for researcher

Appendix 5

5.A1 – Consent Forms for participation in this study

CONSENT FORM

Title of Project:
An investigation into whether a 360-degree panoramic camera system can be adapted using Alternative Light Sources for the detection of body fluids including blood, semen and saliva within crime scenes.

Name and contact details of Principal Researcher: Kayleigh Sheppard – Kayleigh.sheppard@staffs.ac.uk

Please tick box if you agree with the statement

1. I confirm that I have read and understood the information sheet provided for the above study and have had the opportunity to ask questions ☐

2. I agree to take part in this study and as a result am agreeing to take part in a short study which will require me to draw what I see from photographs given to me ☐

3 I understand that my participation is voluntary and that I am free to withdraw at any time without providing reasons and without my rights being affected ☐

4. I understand that you will keep no record of my withdrawal and any personal details collected up to the point of withdrawal will be removed. Any data collected up until this point will be included in the research, however, as stated within the information sheet this will consist of graphs, tables and drawings which you created but these will not be identifiable to you. ☐

5. I understand that data collected about me during this study will be anonymised before it is submitted for publication. ☐

6. I understand that all personal details about the subjects will be stored separately from the derived data in a secure approved location. ☐

I hereby give my full consent to take part in the research as described in the information sheet.

____________________	____________________	____________________
Name of participant	Date	Signature
_Kayleigh Sheppard_____	____________________	____________________
Researcher	Date	Signature

Researcher – Kayleigh Sheppard – kayleighsheppard@staffs.ac.uk
Principle Supervisor – Professor John Cassella – j.p.cassella@staffs.ac.uk

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Date:
1 for participant, 1 for researcher

Participant Number -

5.A2 – Participant raw questionnaire responses.

Participant 1 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   It's going to be an extremely slow process starting with the minor magistrates' courts. In Feb 2015 we were shown the latest tech for the courts in Leamington. It involved a 'red transfer button' connected to various laptops in the room, that basically, when pressed allowed that laptop to mirror on TV screens. Although we send our files electronically, CPS still require paper copies. This amounts to boxes and boxes full of evidence coming into court. Judges & barristers all use their own laptops during trials but still refer to paper copies of statements and reports. I can foresee issues arising from documents not being scanned in. Some basic audio visuals. Large court cases have a separate company that installs superior A/V equipment for the duration of the trial.

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   I was the first to show 360 degree panoramas along with point cloud data. I had to explain to the court what it was and how it was used prior to the case commencing.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   Yes...the seating structure is always the same i.e. where the barristers/solicitors and runners sit, with few or no computer access points.

b. And whether there have been barriers, if any, to the adoption of such technology?

   One reason maybe that judges prefer to sit in a certain court room. With so many cases outstanding, finding down time to update court rooms with tech is an issue.

c. If there hasn't, why do you think this is?

   -

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   A lot of forensic evidence is read and accepted pre-trial. If there are any issues then 'experts' again try to agree pre or during trial. Generally its only images and videos that are shown to the court.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

   The court appeared to be receptive to seeing panoramic images and one particular judge praised the police for using it in his court during his summing up. If it's relevant then use it.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

Our dept. uses both 360 imaging & scanning on a regular basis. A lot of the time that data may not be used, however, both methods capture the entire scene and not just a few points chosen by the investigator and will remain on record/stored for 10yrs.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

We have presented this type of evidence now in live court 3 times and received no criticism. There have been at least another 3 cases where we have produced it but not required to show it. It does require some advanced preparation and several visits to the court room to be used, to make sure it all works..!

8. What has the response been to this method of presenting evidence?

a. From the judges?

Praised for the ingenuity and tech know how.

b. Barristers?

Use it to show the scene to the court, then 'walk-witnesses through' as they give evidence.

c. The jury members

In all my cases, they appeared very attentive.

Is the courtroom fully equipped to allow you to present this type of evidence?

In most cases yes, providing there is a laptop connection point and that the viewing screens are large enough.

9. Do you feel there is anything, which needs improvement? Please explain.

The majority of courtrooms need a radical update. I'd hope that those being built now incorporate the required technology; however I wouldn't count on it.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

Provided there are large viewing or multiple screens around the court room, then visual evidence is perfect for court. A picture paints a thousand words and by their nature courts are stuffy and boring with lots of evidence being read out. It can be refreshing but at the same time infuriating when it simply refuses to work on the day. This has happened to me once and was very embarrassing as judges soon get impatient.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an

example. What is your idea of a courtroom of the future?

-

Participant 2 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   Very little, normally they are brought in for a specific case.

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   There has been little investment by the courts in modern technology.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   Yes, even with the basics it is typically a problem. I would want basic scene photographs to be shown on screens to the jury that allow zooming and good definition. In fact a photographic 5x7 album is placed on a copier and a poor quality copies are produced on normal A4 paper. This lacks the fine detail often required to see evidence such as blood spatter or a fingerprint.

b. And whether there have been barriers, if any, to the adoption of such technology?

   I have asked. Efforts are being made by the Police. CPS protocol is resistant to change. It also requires funding.

c. If there hasn't, why do you think this is?

   Funding and political will.

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   Judge and jury should have individual screens that allow examination of images and other electronic presentations both in the court and jury room. There should be further large screens in the court room for reference by all, including the expert giving evidence.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

   A bad, but typical, example: I was presenting evidence on blood spatter in court. The jury were looking at photocopies taken from the album of blood spatter on a door. The fine spatter pattern could not been seen, it just looked like a white door. So I had to ask the jury to accept there were better quality images where the spatter could be seen and I was able to interpret the pattern. Not only does this allow a barrister to claim I was making it up but, but it is much easier to explain something if people can see it.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

Yes we use 360 and laser scanning.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

No, I Haven't but a few cases I have worked on have used it. We normally have to help set it up.

8. What has the response been to this method of presenting evidence

a. From the judges?

All feedback has been positive

b. Barristers?

Mixed response some love it, some prefer to use their oratory skills.

c. The jury members

I don't know, I never had any feedback.

Is the courtroom fully equipped to allow you to present this type of evidence?

No, most courts have little technology.

9. Do you feel there is anything, which needs improvement? Please explain.

The Courts need full modernising with audio visual displays as previously described.

CPS protocol needs to change from requiring a signed photographic album to that of an electronic presentation. A basic PowerPoint would be a good starting point.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

It is an excellent tool for showing evidence; however it can place a lot of emphasis on certain bits of evidence which can distract a jury from key evidence that isn't part of glossy display.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

I think the courts will be decades behind the technology for years to come apart from special cases when it is essential to the case.

Participant 3 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   Large TV screens which link up via wifi to laptops which the barristers use, so any media on the laptop can be played to the whole court

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   Slow to implement but it is there, Crown Court only that I can comment on.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   Lack of training, people always seem to be finding their feet when trying to play digital evidence, making things connect and work. Also the actual devices are not always reliable.

b. And whether there have been barriers, if any, to the adoption of such technology?

   I have seen judges get frustrated when the IT all fails

c. If there hasn't, why do you think this is?

   -

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   Court needs to catch up, but for most cases, a simple 2D plan and photographs is more than sufficient. There is the ability to produce flashy reconstruction DVD's but I think there is a huge danger of a reconstruction showing things that did not happen, putting images to the court and jury that may only be a representation or a possible scenario rather than what is definite. This is particularly true for collision investigation where there are often unknowns and using a computer model cannot be certain that is what happened.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

   I generally present a jury bundle as photographs and a plan, all printed on paper. Videos are shown and talked through as they are run. There is the technology to create an interactive computer based 3D fly through with interposed images, but this type of presentation requires a high degree of computer skills which I, and most collision investigators do not possess. Most police forces do not have the funds or capability (staff skill or software) to produce these types of presentations. I know the MET have a special unit that can produce these, as I have seen them at their presentation days, but they are a bigger, well funded force with visual imaging units. Most other forces simply cannot do it.

   I think the courts can now facilitate playing any evidence, provided it is on a laptop, but the police cannot at this stage produce the goods

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

YES – we use 3D laser scanners for all our collisions. We use a REIGL VZ400 360 laser scanner. We use it as a survey tool to enable us to measure any aspect of the scene, and to produce scale plans from the survey data using plan drawing software. We do not use it to produce 360 images, we still take conventional photographs alongside the laser scan data.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Yes, but the 3D laser scan data is converted into a 2D plan printed on paper. We have not yet presented a 3D computerised scene at court

8. What has the response been to this method of presenting evidence

a. From the judges?

Everyone understands paper plans and photos.

b. Barristers?

Everyone understands paper plans and photos.

c. The jury members

Everyone understands paper plans and photos.

Is the courtroom fully equipped to allow you to present this type of evidence?

As mentioned before, court has WIFI to display anything that someone puts on a PC.

9. Do you feel there is anything, which needs improvement? Please explain.

Courts are about there with the means to display digital data and images. Issue is the police cannot afford the funds and training and extra staff to produce interactive computerised presentations.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

I think it would be good to be able to do these things, but as always the police (more so than the courts in my opinion) are trying to do more with less and do not have the funds to do this properly and will rely on what still works i.e. paper. Paper also still works as it does not rely on good Wifi, correct plug leads, sufficient battery power, lost passwords and the multitude of other issues that accompany IT.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

More virtual courts, to prevent travelling to the building, more 3D presentations as people become more comfortable with the technology and police forces are able to use it

Participant 4 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

I am, as an expert witness

2. Can you tell me what, if any, technology has been integrated into the courtroom?

I have personally used DVD players in the courtroom for presentation purposes. I am also aware of other limited audio-visual technology such as video links.

3. What has your experience been in terms of the introduction of new technology into the courtroom?

Generally there hasn't been any. Under investment seems to have been the greatest problem; we have the opportunity to bring 3D interactive virtual scenes to the courtroom for example, however the limited computing power available means that this is impossible and there is little or no will on the part of the MoJ to invest in this technology.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

Only that the current systems seem incapable of keeping up with the advance on modern technologies…or simply do not work more often than not.

b. And whether there have been barriers, if any, to the adoption of such technology?

A simple lack of investment.

c. If there hasn't, why do you think this is?

Like all areas of public service this has been underfunded by the current government. Enhanced IT whilst potentially preferable to providing a better CJS might not be essential to providing al functioning CJS…whether a good quality or high volume justice system is the desired outcome is no doubt a whole subject for debate in itself!

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

Currently the evidence I give tends to be oral backed up with 2D paper plans and photographs, whereas it could be interactive 3D 'fly-through' models etc. There is nothing essentially wrong with simple technology, a photograph is easy to refer to and can be very simply referred to, likewise a 2D plan, however they tend to be clumsy and fill the witness box with paper that is pointed to in front of the witness and this is never conveyed to the jury. If, maybe through the use of tablets, or some form of interactive media, this could be displayed on screen, then the witnesses' thoughts and explanations may be better conveyed to the jury.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

I have given detailed evidence on numerous occasions, with varying levels of success. I have used various methods, but knowing the limited resources available I have always tailored my presentation methods to suit. I did once get told by the judge to physically approach the jury to show them a light bulb simply because there was no other way to demonstrate something intricate to them.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

I use 3D laser scanning to record collision scenes.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Due to the limitations of the IT available in the court rooms I have only ever used this evidence capture method to subsequently make a 2D paper plan – a travesty really when you consider what capability this data offers.

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

-

Is the courtroom fully equipped to allow you to present this type of evidence?

I have not had the opportunity to use this form of evidence capture in the courtroom to its full potential – it has been exceptionally well received by Senior Investigating Officers and in the preparation of cases however. With the increase of cases being captured on dash mounted CCTV systems the use of point cloud data will mean the use of 3D laser scanning becomes essential.

9. Do you feel there is anything, which needs improvement? Please explain.

The basic court IT infrastructure needs upgrading to allow it to handle the significant increase in demand that comes with the use of 3D animation software.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

I have found that the use of 'simulation' software must be done carefully. If the data is there to allow it then all well and good, however if there are elements are missing and the reconstruction is somewhat subjective then its use is, in my view, dangerous. If you show a jury a nice video they may well be tempted to believe what they are being shown, accepting that it is fact, when in reality it is simply what the person using the system wants them to see; nobody is immune to the power of suggestion.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

I would hope that VR courtrooms are the future; there is no reason why they could not exist now except for the cost. However, I feel there is always an additional resistance to progress that comes from 'the defence' side of the court room. When presenting evidence in an innovative way it generally means in a way that is better for the jury to understand, and that means clarity – and often clarity comes as the expense of the defence who are there often with the, or so I seems, the sole aim of muddying the waters. Whilst this may seem a vaguely cynical approach I base it on many years of experience, and counter any suggestion that I am wrong by saying that the approach taken in the civil court is often very different where the onus is split more evenly on both sides rather than being biased on one.

Whilst this would not stop the IT infrastructure being put into place, I have found reconstructions being excluded for example, so why not more VR based recreations of the scene as they are prejudicial?!

Participant 5 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

Yes, predominantly Coroners court but also Crown, Mags and Civil.

2. Can you tell me what, if any, technology has been integrated into the courtroom?

No technology is used in my experience of Coroners court.

Magistrates has been limited to a live link between the court and a witness room with monitors positioned for the court.

The Crown court cases I have been involved with have had access to DVD players only with monitors positioned for the judge and jury to view CCTV for example.

3. What has your experience been in terms of the introduction of new technology into the courtroom?

The court clerk always seems to have difficulty getting the existing system to work correctly albeit only a DVD player. It is a great source of frustration for all involved.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

Ideally we would like to be able to link a laptop to the monitors within the courtroom in order to project 3D models and move around them in real time instead of having to create a generic video file to be played on the DVD player.

b. And whether there have been barriers, if any, to the adoption of such technology?

I am only aware of the barrier being that the facility does not exist and I assume this is a monetary issue. Regardless, until the improvement of the visual aids for the jury i.e. much larger or closer/individual monitors are implemented even the products we provide at the moment are of limited use in the courtroom.

c. If there hasn't, why do you think this is?

-

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

As at 5b in terms of digital evidence.

The jury bundle remains a folder of printed (badly photocopied) documents so the photographs are always of a poor quality (sometimes even black and white!), the scale plan not to scale etc. In my opinion it would make perfect sense in this digital age to have a jury bundle on a tablet so the jury could view all the documents/photos clearly and at their convenience throughout the trial.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

I have to present my findings in relation to fatal/serious injury road traffic collisions that I have attended. Generally I will have compiled a report which contains photographs and a scale plan but as part of the wider investigation there may be digital data such as CCTV footage, 3D laser scans and animated reconstructions. My evidence is given orally and the relevant sections of the jury bundle referred to for context. To date, I haven't used any visual aids/props.

I have presented a case involving CCTV footage which was, as mentioned above, played on too small a screen for the jurors to see properly therefore making it difficult for them to understand the intricacies of what it showed. The footage itself had to be provided in a format that could be played in a DVD player present in the courtroom, leading to an overall reduction in quality.

In another case I had to show each individual juror an original printed photograph from the report I had brought with me as those provided in their bundle were of such poor quality that the subject of my oral evidence was not clearly visible to them.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

Yes, we have had Riegl VZ-400 3D laser scanners since 2012. We also utilise a FARO Focus 3D laser scanner which is predominantly used for indoor crime scene work when assisting the major crime dept. With the improvement in the back office processing we use the scanners for our scene measurements now more than ever and there are few scenarios where it is not the tool of choice. It does not however decrease the time spent at a scene in my experience.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

No, due to the limitations of the court facilities we generally use the information within the scan data to create a 2D scale plan of the scene, which is unfortunate as the benefits of the data cloud as a contextual visual aid are unrivalled. The closest we have come to scan data being presented to a jury is by way of a video file being created of a predetermined 'fly through' of the scene. I believe this was well received by all involved and consequently no scene visit was required by the jury.

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

I am only aware of positive feedback stemming from the example given in 8b.

Is the courtroom fully equipped to allow you to present this type of evidence?

As discussed previously, in my experience the courtroom does not offer a direct link for a laptop to be utilised. This is necessary as the volume of data involved with a scan project is vast, far in excess of the capacity of a data disc.

9. Do you feel there is anything, which needs improvement? Please explain.

Laptop link. Larger screens or preferably individual tablets/monitors for jurors.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

I assume this means scan data.

The overriding advantage is the quality of the product and its ability to replace a scene visit by letting the jurors visit remotely and repeatedly.

One disadvantage of giving evidence with an unrestricted data cloud, if this was possible, would be the 'live' navigation of the scene. The user would need to be competent otherwise delays would be likely.

There may also be difficulty in reproducing and documenting the views shown to a jury.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

The aim is surely to assist the jury with understanding the complexities of the crime scene and to do that they need to be able to visualise the location and the evidence identified within it so I believe the future of a courtroom will be to provide this as realistically as possible. There will however be a fine line between giving a jury enough information with which to make an informed decision and traumatising them in vivid technicolour.

I think the documents provided to jurors will eventually (hopefully) be in a digital format.

An interactive whiteboard that could be utilised by experts or witnesses in generally whilst giving evidence would be advantageous to explain key points, especially if the contents could be saved and documented.

Participant 6 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   A little fake – is this my knowledge of court room technology you are after or what I have used in court? I'm aware Dyfed-Powys use Met Police software that I believe is known as FOCUS to present multimedia presentations and data in court, however this software is getting a little dated now. I am waiting to go to crown court to present scanner data using Risolve software from data obtained by our Riegl VZ-400 terrestrial laser scanner. This will include animation from the point cloud that has been exported to windows media player.

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   Very little to date – the majority of our cases are for the coroner in coroners court and they are yet to embrace new evidential technology within their courts as in the main it is not needed.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   -

b. And whether there have been barriers, if any, to the adoption of such technology?

   -

c. If there hasn't, why do you think this is?

   -

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   Again I cannot add much here – we have embraced technology including laser scanning as an investigative tool and no longer prepare paper reports that are now submitted as pdf's. These are then printed elsewhere for coroners court etc.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

   Best answered after my impending crown court appearance.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

See Q3

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

I've prepared an album of screen grabs from Risolve software to present to the jury just as you would conventional photographic albums. The animation is produced on windows media player and will be played via FOCUS presentation software. If the court does need anything more specific the desktop computer and peripherals will have to be taken to court.

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

Unable to comment at this time – hopefully good!!.

Is the courtroom fully equipped to allow you to present this type of evidence?

So I'm led to believe. This would vary on the location and type of court – crown to magistrates to coroners.

9. Do you feel there is anything, which needs improvement? Please explain.

Courts need to catch up with investigative technologies in some instances.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

I can only see benefits so long as everything works. Some people prefer a written report. Either way it only assists and the quality of the evidential speaker is for me crucial.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

They are catching up and a time will come when everything will be fully integrated – however I've 5 years left until I retire so I may not see it!

Participant 7 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   All the time!!!!!

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   -

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   -

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   -

b. And whether there have been barriers, if any, to the adoption of such technology?

   -

c. If there hasn't, why do you think this is?

   -

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   -

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

   Primarily evidence is verbal, presentation of photographs are by way of rather dodgy photocopied versions lovingly prepared by the CPS, we occasionally use video footage, which has to be converted to DVD format to play at court – assuming the usher knows how to work it.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

   Photograph, occasionally GPS plot data (2d survey), usually line and offset measurements and hand written scene notes**.**

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

-

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

-

Is the courtroom fully equipped to allow you to present this type of evidence?

All the courts have several 40” tv screens located all around the court, from memory about 6 screens. – it would be much better if each juror or interested party had a tablet or personal screen but that’ll never happen. Some court rooms have a HDMI input lead so it can connect to a laptop but it doesn’t connect audio so it need a separate cable etc for that.

9. Do you feel there is anything, which needs improvement? Please explain.

As above, if each juror had an ipad or tablet with the photo bundle in, they could look at each image when they wanted and could zoom in on any aspect they were interested in. similarly the judge/barrister could ‘share’ a particular point with everyone by ‘beaming’ particular page or bookmark.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

-

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

Courtroom of the future???? Either judge dread or minority report!!! J joking aside, a more personalised and produced prosecution case would be more impactive and professional – only issue I could foresee is that it may be perceived as entertainment rather than a judicial process.

Participant 8 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

YES

2. Can you tell me what, if any, technology has been integrated into the courtroom?

Very limited, TV/DVD for CCTV

3. What has your experience been in terms of the introduction of new technology into the courtroom?

In my experience the courts have been very slow to embrace new technology for Collision Investigation, particularly around 3D laser scanning and virtual reconstructions

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

YES

b. And whether there have been barriers, if any, to the adoption of such technology?

-

c. If there hasn't, why do you think this is?

I think it is twofold, a lack of knowledge and a lack of money

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

Much better IT required. We are limited to producing paper reports and plans, together with some electronic media in the form of CCTV and DVD's

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

Basically, the court process has changed little in the 12 years I have been a collision investigator whilst the equipment we use and evidence we produce has changed exponentially.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

We use Riegl 3D laser scanners at crash scenes

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Yes, but the 3D animated 'fly through' was played directly from DVD; it was not possible to move through the scene in real time.

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

I think both see the benefits of this new technology, for example to test witness accounts by repositioning them in the scan to ascertain their actual view of the incident.

c. The jury members

Don't know

Is the courtroom fully equipped to allow you to present this type of evidence?

NO

9. Do you feel there is anything, which needs improvement? Please explain.

-

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

It provides the court with more detailed but easier to understand evidence, which can be tested in open court

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

In reality, unless funding becomes available, I can't see much changing!

Participant 9 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

None in Crown Court. We have used power point presentations in one of the three Coroner's Courts we are required to attend, but this has become less and less as the deputies, who don't like using the power points, are taking more cases.

3. What has your experience been in terms of the introduction of new technology into the courtroom?

We haven't had any new technology introduced. Our evidence is presented on paper plans and photo albums. We are not at present using 360 degree photography or laser scanners and we don't do 3D reconstructions. This was briefly looked at many years ago, 10+, at the early stages of 3D animation but not taken up as a usable option in our Force.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

As we are not using the equipment the courtroom hasn't needed to introduce technology.

b. And whether there have been barriers, if any, to the adoption of such technology?

As above

c. If there hasn't, why do you think this is?

As above

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

At present we gather our evidence via digital SLR cameras, digital video cameras, and via standard surveying equipment to produce 2 D plans, photo albums and if applicable DVD's of video footage. All of this is presented at court in a simple way with the only technology being a DVD player attached to the screen they already have for presenting video witness evidence. As we don't gather or create evidence in any other form there is no need for any further technology

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

As above

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

We have no experience of this at this stage

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Not presented, as above

8. What has the response been to this method of presenting evidence

a. From the judges?

N/A

b. Barristers?

N/A

c. The jury members

N/A

Is the courtroom fully equipped to allow you to present this type of evidence?

N/A

9. Do you feel there is anything, which needs improvement? Please explain.

N/A

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

N/A

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

Paperless courtrooms are likely to become the norm in the future, with evidence presented on screens to the court and each jury member having a tablet, or something similar to view evidence on rather than copies of plans and images. As surveying equipment changes and the way the evidence is presented the courts are going to have to move with the times and provide the IT systems required. I don't think we will end up with jury members, judges, barristers and witnesses wearing individual virtual reality headsets to view evidence or 'walk through' scenes, but I suppose that is always a possibility.

Participant 10 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

Yes in all types of Court

2. Can you tell me what, if any, technology has been integrated into the courtroom?

Until recently technology within the Courtroom was very limited. There is now a facility to provide an input computer data and images to multi screens within the Court

3. What has your experience been in terms of the introduction of new technology into the courtroom?

Very poor, until a few years ago we were still recording on tapes (now CD). The Coroners Courts in particular have no facility to view CCTV footage.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

-

b. And whether there have been barriers, if any, to the adoption of such technology?

-

c. If there hasn't, why do you think this is?

As a team we struggle for funding to replace equipment generally. The Court system is quite antiquated and has until recently been unable to provide facilities other than DVD players attached to large television screens to play footage. We certainly would not have considered the possibility of providing any other form of digital data to a jury and Court.

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and

explain what you think needs to be changed (if anything).

In the main we provide evidence using printed photographs and two dimensional scale plans. As a team we feel this is probably the better way of presenting evidence. This may seem outdated on our part but as reconstruction officers we are very conscious that evidence presented to a jury can be easily interpreted as “that’s how it happened”. A good example would be the use of a laser scanned scene with computer animation of the movements of vehicles involved based on limited marks and physical evidence at the scene. Once presented, no matter how inaccurate or vague the jury can easily be misled into believing that the representation of the computer reconstruction is exactly how the collision occurred. We can never be certain as to how a collision occurred as we did not witness the collision.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

The methods we use at this time are robust and can be controlled quite easily, as an example a Barrister advising the jury to only look at one photograph, then move to the next as a point is discussed, this allows the juror time to digest the information, and if necessary annotate the photograph. The use of DVD footage is becoming more common and the courts need to be more conversant with the variants of players needed to present this type of evidence.

From experience some jurors may not be able to see a screen on the far side of the Court clearly due to their own health issues or an obstruction to view. They may also lose interest in footage shown on multiple occasions. You can often see a juror “switch off” when evidence is repeated time and time again.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

Staffordshire were part of the TRL project in the early 2000’s to evaluate the benefits of laser scanning and photogrammetry. As a result we received DfT funding for new GPS and Total Station surveying equipment to assist in the CLEAR project and improve the speed in which we dealt with collision scenes. The Laser Scanning devices were subsequently implemented, despite it being clear that we as scene analysists were often quicker at Total Station surveying than the Laser Scanners.We have tried to persevere with the Laser Scanners but have experienced difficulties with IT infrastructure, obtaining suitable powerful computers to run the cloud point data.

Further issues with the actual scanning of scenes have been experienced. We as a team often work single crewed, the practicalities of the Laser Scanners have been found to be poor due to the numerous set up positions required to gain a full and accurate survey. Whereas the Total Station only needs to be set up once, and is a single team member operation. The scene also does not need to be clear of staff. I appreciate we can invert layers to remove clutter, why introduce a process of editing because the device is not suitable .A further issue is the positioning of vehicles involved in the incident. If a goods vehicle is against a hard shoulder embankment or safety barrier you cannot place the laser scanner against the embankment or barrier to record the side of the vehicle. This prevents data from being recorded accurately. We also feel that the quality of the data provided by the Leica scanner is very pixelated and poor for viewing, and we would not at this stage consider it suitable for presentation as evidence. Despite being issued with the equipment we have failed to provide a representative scene which we would be happy presenting as evidence. It is only recently that the Court infrastructure has had the facility to present this type of evidence, but it has not been trialled with our computers.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

-

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

-

Is the courtroom fully equipped to allow you to present this type of evidence?

The Court is now able to view this type of evidence, we would not however consider using it, until we are satisfied with the quality of the product.

9. Do you feel there is anything, which needs improvement? Please explain.

The Scanners in our team opinion are too bulky for scene use and multiple moves. We have seen hand scanners used for vehicle deformation, but these could not complete a full scene.

The back office processes are too lengthy and provide limited results. We were provided with the scanners in order that we could conduct a scene survey and then complete a 2D scene plan for paper presentation to the Court as we do now. At this time we cannot see a quality or time improvement over our current working practices.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

As outlined above, extreme caution has to be placed on the manner in which this type of evidence is presented in order that the jury are not misled.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

Having now served nearly 27 years the Courtroom has not changed in all those years. The most recent advances in the Courts are the audio recordings have changed to DVD, and we now have the television screens with the multi-port links for presentation of images to the jurors and Court. Kayleigh, I don't want you to think that we are dinosaurs, but the Justice System works very slowly and changes very rarely. We are aware that many forces have embraced the Scanners, and we are personally keen to progress towards Photogrammetry as a tool, as we feel this will be a more practical approach alongside better GPS and Total Station surveying. Our main concerns are also the misrepresentation of evidence and presentation animations which could wrongly lead a trial. While we can never completely dismiss the idea of laser scanning, at this particular time it would not improve our time at scene, or provide greater clarity of evidence.

Participant 11 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   i) I am aware of the presence of television/monitor screens. In a recent court case I noted both CPS (Prosecuting Solicitor Agent) and District Judge now using laptops.

   ii) I also have noted that at two Local Coroners Courts – both coroners using Laptops.

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   Average to Poor.

   Reference i) above: At a recent court case I submitted evidence obtained from a forensic tachograph download. This is produced from the analysing computer as a colour paper printout. The colours, on charts, are important as they identify different activities for various time periods.

   These documents are not produced in a digital form that can be entered into the digital prosecution network directly.

   This is because the analytical computers are not connected to the local police force network and the IT department refuse to acknowledge they are for Police Investigation work so have no means of linking. Documents have to be uniquely printed then scanned.

   Thus the colour print document was submitted and scanned for attachment to the electronic case. Obviously case workers involved at some point failed to realise the importance of the colour as the document had become black and white, which when produced at court made the evidence almost impossible to present.

   Then we came to actually discussing and presenting the evidence in court.

   The closest or nearest monitor to the witness box was behind and to one side.

   The CPS agent produced the document on the screen and initially it was in the wrong format – landscape not portrait – so everything was on it's side.

   This made the CPS look incompetent.

   After faffing a couple of minutes, the document was righted and I was questioned.

   In order to demonstrate the appropriate time on the chart it was necessary to point at the chart – however to do this I had to step out of the witness box (permission had to be asked first), then step down on the level under the screen and at 6' tall I had to bob up and down on tip-toe to reach the screen to point to the relevant evidence.

   I must have looked an idiot myself.I certainly didn't feel professional and at the end of the day this was a simply case with only one exhibit of digital evidence produced

   I question why a small monitor screen and mouse could not be integrated into the witness box or a small laser pointer provided.

   Reference ii) above:

   In Coroners court there are often what's best described as painful silent pauses, whilst the Coroner has to undertake an operation on the lap top – either view a document or activate sound recording.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

-

b. And whether there have been barriers, if any, to the adoption of such technology?

-

c. If there hasn't, why do you think this is?

With regards to the above questions, I think these need to be directed at the court system – it is they, themselves that have to implement this and they have such major questions as finance, modifications of buildings and design etc.

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

My work is currently presented as a report, (between 20-55 pages in length depending on incident) and printed scale plans – predominantly A2 – try to work to A3 but this sometimes produces multiple sheets.

With this system each person who requires a plan can be given a plan (this does need to be asked for prior to court and a late request – often on the day of court itself produces and inordinate amount of work and stress).

Each side that needs to see a copy of the report has one presented or disclosed – however we are now being told that CPS cannot refer to the relevant photos within the body of the report unless they are exhibited and produced as a further separate exhibit.

There are other forces that produce reports without photos and then the person presenting has to flit between two or three documents in order to produce a relevant photo.

The stand point we are at now – works almost 95% efficient.

Sadly change is being brought on us – but without full consultation and again with financial constraints. Computer systems have been bought that allow case files to be built electronically and transferred electronically. This is progress and does save a little time and the constant repetition of certain writings – however – maximum size limitations have been placed on individual documents. Ours sadly exceed those.

We have modified our working practices to try and accommodate the changes – ie publishing to "web only PDF" only to find others in the Criminal Justice System then printing these off and producing poor quality documents.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

-

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

I use laser scanning and have the opportunity to use a 360 degree camera.

However it is a myth that this truly speeds up evidence/data capture.

What it does do is increase the quality of evidence capture at the close scene – but if you have a very large scene – no, this takes the same time or even longer to capture data.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

The evidence is converted back to a paper manual method.

I have not been required to produce a 360 scene photo or "linked / animated walk thorough".

I am aware that we are in possession of a laptop to produce this evidence.

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

Cannot comment.

Is the courtroom fully equipped to allow you to present this type of evidence?

I am aware that laptops can be connected into a system at the court which is linked with the screens present in the court.

9. Do you feel there is anything, which needs improvement? Please explain.

My comments here would relate to the criminal justice system and not the question I believe you ask.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

I have not opinion on this at the moment.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

The advancing pace of future technology at the moment is far outstripping the pace of modernisation within the police service.

I have seen technologies such as GPS linked photogrammetry, aerial borne photogrammetry, and even simply hand held camera photogrammetry that would save more time in recovering data and evidence from scene.

These methods are becoming proven within the surveying and scientific world, however as a police constable, no account of the knowledge that I may have developed within this area is taken into account either by managers or supervisors when asked to consider that progress could be made in this area, and that it would be more economic in terms of monies and time saving, than the current forecasted way forward. That is the failure of a "disciplined" rank structured service – I am told what to do and what not to do and not to think about what could be better because those above me are paid to think.

However those above can be misled or influenced by outside sources acting in "the best interests of the service".

Upward advice and progressive suggestions are ignored and discounted – whilst downward and sometimes, static, un-economic polices are enforced.

The only real way progress will be made is when police forces are merged and become unitary bodies with no more than four or five across the county.

Currently with 43 police forces you have 43 ways of doing things.

Whilst some forces want to / try to work together and link working practises – others flatly refuse even when their working methods have been held to be either very poor and needing improvement, or very good but have to change to the poor way neighbours work because the neighbours are bigger or there are more of them and can exert a greater financial influence.

Participant 12 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   TV/CCTV playback facilities.

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   Very limited. Our files/reports/plans/images etc are currently too large to be used digitally within the court room or via CPS etc.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   Size of data files too large.

b. And whether there have been barriers, if any, to the adoption of such technology?

   As above

c. If there hasn't, why do you think this is?

   n/a

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   All currently paper based. Digital evidence presentation is being considered but currently not an option.

6. What has your experience been with the presentation of evidence in court? Please

explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

Photographs and scale plans are all presented with paper copies being used by the court/jury etc. This can be effective but could also be enhanced if able to present digitally.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

Laser Scanning. Currently using the data to prepare paper plans though. WQe have recently purchased new software ARAS Faro etc and new laptops to process the data. All new and experimental at the moment although reductions in scene time have been recognised this is offset by longer processing times.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Plans – paper scale plans only at this time.

8. What has the response been to this method of presenting evidence

a. From the judges?

Existing methods tried and tested so no resistance

b. Barristers?

-

c. The jury members

-

Is the courtroom fully equipped to allow you to present this type of evidence?

n/a

9. Do you feel there is anything, which needs improvement? Please explain.

Support and IT networks are currently inadequate to handle the data size of files

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

Has potential for future but improvements are required to internal systems, CPS never mind the court room. We also report to Coroners who's courts have not progressed digitally.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

All digital, paperless environment with possibility of providing evidence remotely.

Participant 13 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   yes, crown court, magistrates court and inquests

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   Nothing in coroners and a DVD player and screens in courts

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   Generally not user friendly and is password protected so required a member of court staff to operate it.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   Very slow integration and digital animations not endorsed at all.

b. And whether there have been barriers, if any, to the adoption of such technology?

   -

c. If there hasn't, why do you think this is?

   -

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   Forensic evidence is presented via the investigator through photographs and verbal explanations.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

   mostly presented verbal evidence in the 'box' using albums of images and plans. DVD player used on a couple of occasions.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

   I use a RIEGL 3D laser scanner for scenes and a trimble EDM digital images taken using a digital camera.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Courts still insist on 2D plans so even using scanners etc a 2D plan is still produced.

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

Courts like to see a hard copy and are not comfortable with a 3d scan – I have not been able to use scanner technology in court.

Is the courtroom fully equipped to allow you to present this type of evidence?

again a dvd player is present

9. Do you feel there is anything, which needs improvement? Please explain.

The courts need to start to accept digital and virtual technology

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

Different experts can use the 3D tech in different ways – 3D allows ? to present the evidence

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

courts require joint expert statements now so I think court attendance will not be a regular thing in the future. 3D technology is available but not welcomed by the courts. In the future I believe it will be accepted but we are still only half way there.

Participant 14 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

Court Technology is sadly out-dated and currently relies on recorded discs screened on digital TV's

3. What has your experience been in terms of the introduction of new technology into the courtroom?

Very slow

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

Incompatible systems, discs not able to work or equipment failure

b. And whether there have been barriers, if any, to the adoption of such technology?

Barriers would appear to be cost

c. If there hasn't, why do you think this is?

-

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

Currently we give a verbal account relying on photo booklets and if the equipment is working use of recorded footage. We need to move to a computer based system to keep up with technology used in our field.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

As on the previous answer we still rely on verbal evidence photos and printed plans. Because the courts know no different this hasn't raised any issues but I think this will change.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

We use 360 laser scanners and 360 Photography. We are currently using these for collision scenes but have also been utilised for murder scenes and industrial accidents.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

We have not presented this evidence in court yet.

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

-

Is the courtroom fully equipped to allow you to present this type of evidence?

N/A

9. Do you feel there is anything, which needs improvement? Please explain.

We need to work with the courts to show what we can present and then update technology accordingly

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

The advantages of presenting evidence digitally mean it is more visually appealing juries can review the presented evidence it allows a full overview of a case.
The disadvantage would be coming to dependent on presentation of evidence this way and cases breaking down or being delayed due to technical failures

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

It is anticipated by our local court system that the jury will have tablets to view the evidence instead of a paper system. This will allow them to be led through the evidence but have a ready reference to go back to highlighted sections. From our perspective the way we present evidence will change and will become more of a presentation initially. I envisage with the technology we now have use of with use a cloud based system, we could use the 360 laser technology to walk a jury through the scene using links to highlight evidence or crucial areas. With us having a 360 perspective we could highlight witness viewpoints to show what they could see and link this back to their statements and what they have said.

This is not future technology but what we now have and intend to present.

Participant 15 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

Photographic images (conventional and 360 panoramas), specialist software to view complex 3D data/crime scene reconstructions, 3D laser scan data, 3D modelling, as well as hardware required to view these in the courtroom (high powered computers, display units, etc)

3. What has your experience been in terms of the introduction of new technology into the courtroom?

This can depend very much on the attitudes of the judge, prosecutors and investigators. Some are technology averse whilst others are happy to accommodate new technology. Typically, new technology is welcomed however displaying and using it in a useful way in the physical courtroom is a challenge. Enabling all parties in a trial to view the 3D data simultaneously and clearly in a courtroom is not possible in some courtrooms with limited AV equipment, whilst other specialised courtrooms offer each individual their own screen.

Generally advance liaison with the courtroom clerks is required to test and ensure that the systems will operate correctly in the course of a trial. Another issue is ensuring that whatever new technology is used will be able to be accessed outside of police systems by the defence or jury, and that each juror can receive the same experience in using the technology.

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

-

b. And whether there have been barriers, if any, to the adoption of such technology?

-

c. If there hasn't, why do you think this is?

Yes, as mentioned above there are both practical and institutional barriers. Some courtrooms are ill-equipped to display or interact with the technology effectively to allow their utilisation in court, whilst other technologies are simply difficult to implement in any courtroom environment (such as VR tech). Other barriers include reluctance of some judges, investigators and lawyers to consider or implement newer technologies into their investigation or courtroom presentation. These challenges are reducing as time progresses and the technologies are increasingly established and the general paradigm is altered.

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

It can be difficult when you are restricted to only answering questions you are asked, when those posing the questions have a limited understanding of the technology they are viewing. A greater freedom for experts/practitioners to speak freely and guide the courtroom to a greater understanding would be most useful in criminal trials, where the expert is restricted to directly answering a question and cannot necessarily elaborate further beyond the scope of the question, despite the information's relevance.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

Similar to point 4, there are a number of technical and institutional challenges in presenting this evidence. Typically I have found that this evidence is readily accepted by the court and well understood by jurors, judges and lawyers. Defence however can seize on the technical aspects in an attempt to create doubt and confusion.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

Yes, I primarily use these technologies (3D laser scanning, modelling, 3D printing and 360 photography) for the purposes of crime scene reconstructions. By capturing crime scenes and evidence in 3D to reconstruct a crime scene and further interrogate the available evidence within the context of this reconstruction, we are able to glean additional information and learn new facts not otherwise able to be deduced.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Yes, I have presented this evidence in a number of criminal trials and coronial inquests. This has been both for the purposes of viewing/demonstrating a crime scene and for conducting specific analysis of the data to reach a conclusion.

8. What has the response been to this method of presenting evidence

a. From the judges?

Generally very positive and well received. Most judges are interested and accommodating.

b. Barristers?

Also typically positive. Prosecution are generally very interested in having the evidence viewed whilst defence lawyers are also interested in querying the data when attempting to put their arguments forward.

c. The jury members

Juror feedback has indicated that the 3d reconstruction data has been of immense use and they have enjoyed being exposed to it.

Is the courtroom fully equipped to allow you to present this type of evidence?

No, most courtrooms only have a single screen which is often not enough. A computer must also be brought along by the expert presenting the evidence. Some courtrooms have been able to be fitted with customised AV equipment, however these are only the most significant of cases.

9. Do you feel there is anything, which needs improvement? Please explain.

Most courtrooms would significantly benefit from increased AV capabilities, as well as catering to the needs of jurors to have access to screens, iPads, etc.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

Presenting evidence using new technologies, such as 360 photography or laser scan data, is much more effective and allows the expert to clearly demonstrate aspects of the crime scene or analysis. It also opens up avenues for defence to attack the data and create doubt, due to the technical aspects of the evidence. Thus all bases must be covered when capturing, processing and presenting the evidence.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

Courtrooms will hopefully embrace new technologies and see the importance in aptly equipped courtrooms which allow the effective use of this type of technological evidence. As technologies advance and the type of deliverables also expand it is hopeful that the courtrooms capacity will expand also.

Participant 16 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   Basic multimedia PC's, projectors and television screens

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   Limited, all above was introduced before my time and haven't had any issues personally. Have been aware of some courts having a problem with downloading a particular program for viewing of our products, a basic free program already on most computers, but sometimes people don't know who has the authority to approve the download to court machines and put the whole thing into the "too hard basket".

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   I am aware of a few issues such as that mentioned above, most of our current products can be viewed on any basic computer, anything that requires something more complex we provide our own laptop to connect to their projectors or screens.

b. And whether there have been barriers, if any, to the adoption of such technology?

   I am only aware of that mentioned above.

c. If there hasn't, why do you think this is?

   Generally we design our products for ease of access anywhere including courtrooms.

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   In terms of technology, no, I think current methods are sufficient and like I said anything more complicated we provide our own laptop for. Some photographic/video evidence is not shown in court as it is deemed prejudicial e.g. graphic crime scene photographs or photographs of injuries, I believe sometimes it is important this evidence is shown in order to give a comprehensive account of the events that occurred. We are now using technology to work around this by introducing 3D printed evidence to the court room that accurately depict injury evidence etc. with a more neutral tone, eliminating the prejudicial aspect of graphic imagery whilst clearly depicting the events/consequences.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

   Personally limited and basic, mostly answering questions relating to statements. Generally the evidence I deal with is fairly well accepted at this stage.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser

scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

Yes, I use both panoramic photography and 3D laser scanning technology within my role, as well as other methods of 3D imagery such as structured light 3D scanning and 3D modelling.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Yes but so far limited and well accepted, I am expecting this to change in the future as I become more involved and technology advances.

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

So far well accepted by all, predicting some challengers in the future as explained above.

Is the courtroom fully equipped to allow you to present this type of evidence?

Yes, for the moment. As explained in questions 5 and 6.

9. Do you feel there is anything, which needs improvement? Please explain.

Only that mentioned in questions 5 and 6.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

Advantages – Easy, portable, products designed to play on any computer or device

Disadvantages – Some limitations where specialised technology or software required, mostly able to work around this by providing own laptop in court for the moment.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

The technology is definitely heading towards the use of 3D virtual reality technology within the courtroom. This will provide the ability for jurors, judges and the coroner to revisit a scene without leaving the court room and see things from the perspective of various people involved (victim, accused, witnesses). It will help to corroborate or refute witness accounts, with the jury/judge/coroner able to make that determination for themselves rather than being "told" the outcome based on evidence provided.

Participant 17 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   Viewing DVD/video/files on large screen

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   Nil

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   Not sure

b. And whether there have been barriers, if any, to the adoption of such technology?

   Not sure

c. If there hasn't, why do you think this is?

   Not sure

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   No

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

   I've given evidence in Local court on more than 80 matters, District court on more than 20 matters and Coronial court on 2 matters over a period of 15 years in the 3 different roles I have performed – (1) General duties, (2) Crime Scene Investigator and (3) Forensic Imaging Technician

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

   I have assisted in the capture of crime scene with 360-degree photography (ISRAPS) and Laser scanning.

   I also use surveying equipment to capture scenes and then draw a scaled plan of the scene (survey plan) using AutoCAD

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Yes, several survey plans which I drew up on AutoCAD from scene surveys I completed of fatal/serious injury motor vehicle collisions

8. What has the response been to this method of presenting evidence

a. From the judges?

No issues, positive

b. Barristers?

No issues

c. The jury members

No issues

Is the courtroom fully equipped to allow you to present this type of evidence?

Yes

9. Do you feel there is anything, which needs improvement? Please explain.

No

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

Survey plans are an easy way for people to visualise a crash scene

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

I think courts will just play 360-degree photography or the point cloud data from a 3D scanner on a large screen (No different from what they do now). Easiest way is to have it in a file format (.mp4 file) and play it with VLC media player. Survey plans are printed out at a scale (i.e. 1-50, 1-100, 1-200 or 1-400) and either put up on the large screen or passed around for the jury members to view.

Participant 18 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

N/A

3. What has your experience been in terms of the introduction of new technology into the courtroom?

N/A

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

N/A

b. And whether there have been barriers, if any, to the adoption of such technology?

N/A

c. If there hasn't, why do you think this is?

N/A

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

N/A

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

N/A

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

N/A

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

N/A

8. What has the response been to this method of presenting evidence

a. From the judges?

N/A

b. Barristers?

N/A

c. The jury members

N/A

Is the courtroom fully equipped to allow you to present this type of evidence?

N/A

9. Do you feel there is anything, which needs improvement? Please explain.

   A standardisation of digital formats used in the courtrooms. This would help in the preparation of evidence knowing which format to use when supplying evidence, to Police and courts. The most common remark we get from police and the courts regarding digital file formats is, <u>Can you supply or convert this or these files to a usable format, "We just need it to be playable in court"</u>.

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

    N/A

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

    N/A

Participant 19 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   Some courtrooms have audio visual capabilities, the newer courtrooms have individual screens for each jury member, older courts may have one tv screen.

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   It is a very slow process and dependant on the residing judge/magistrate

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   Some courts are not equipped with facilities enabling the presentation of evidence.

b. And whether there have been barriers, if any, to the adoption of such technology?

   Barriers apart from physical i.e no screens are the residing judge/magistrate

c. If there hasn't, why do you think this is?

   -

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   Older courts need to implement Audio Visual capabilities.

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad

experience – was there technology present to allow you to present this evidence?

When the room is physically equipped and the judge/magistrate accepting the evidence is easily given and readily accepted.

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

Yes, spherical 360 degree scene recording utilising canon 5d and fisheye lens 6 shots around (60 degree increments) one up shot and one down shot.

Yes laser scanning, utilised data from scans to provide reconstruction opinion

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Indirectly yes, presented evidence and opinion resulting from laser scan data

8. What has the response been to this method of presenting evidence

a. From the judges?

Very receptive when evidence allowed

b. Barristers?

Prosecutor: Extremely positive

Defence: Extremely sceptical

c. The jury members

Very receptive.

Is the courtroom fully equipped to allow you to present this type of evidence?

Some, the newer court rooms are well equipped, older rooms not very well equipped if equipped at all

9. Do you feel there is anything, which needs improvement? Please explain.

Older courts need to be equipped with at least basic audio visual capabilities

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

Very positive, essentially doesn't rely on opinion or interpretation when evidence can be visualised.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

Courts and judges/magistrates are notoriously slow to respond to 'new' technology, however if the rooms are equipped to allow current technology to be presented they should be accommodating of new tech.

Participant 20 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

   Only as required – very infrequent

2. Can you tell me what, if any, technology has been integrated into the courtroom?

   Courts adapt to whatever technology is been used

3. What has your experience been in terms of the introduction of new technology into the courtroom?

   All our evidence is introduced into court via other experts in their field e.g Crime Scene/Crash investigators

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

   As stated previously courts adapt to new technology as that is the way it is presented

b. And whether there have been barriers, if any, to the adoption of such technology?

   -

c. If there hasn't, why do you think this is?

   -

5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

   No change required – just the facilities to use new technology

6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

   Do not present evidence at court

7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

   Personally I have not presented evidence of this nature in court. Laser scanning is been implemented but is at an early stage of development. The evidence produced by laser scanning brings the crime scene to life – allowing jurors/lawyers etc. to experience the crime scene as if they were there.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

-

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

From what I have heard it is well liked by all. As mentioned before court rooms will have to adapt to new technologies

Is the courtroom fully equipped to allow you to present this type of evidence?

-

9. Do you feel there is anything, which needs improvement? Please explain.

No

10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

As I don't deliver evidence I cannot comment

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

Better of

Participant 21 – Questionnaire Response

1. As part of your role are you required to present evidence in a courtroom?

Yes

2. Can you tell me what, if any, technology has been integrated into the courtroom?

-

3. What has your experience been in terms of the introduction of new technology into the courtroom?

-

4. Have there been any difficulties with technology being integrated into the courtroom?

a. With the implementation of technology with existing and current courtroom systems

-

b. And whether there have been barriers, if any, to the adoption of such technology?

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c. If there hasn't, why do you think this is?

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5. In terms of the current methods with which forensic evidence is presented in court do you think anything needs to be changed? Describe how it is currently presented and explain what you think needs to be changed (if anything).

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6. What has your experience been with the presentation of evidence in court? Please explain what you presented, how you presented this and whether it was a good or bad experience – was there technology present to allow you to present this evidence?

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7. New technology is becoming available to police services and forensic services for the documentation and presentation of crime scenes. 360-degree photography or laser scanning is being implemented into police services to speed up the data capture as well as to capture more detail and information from the scene.

a. Have you any experience in this area – do you yourself use these methods for documenting crime scenes? Please explain what technology you use and what you use it for.

Yes. 360-degree photography for capturing crime scenes through panoramic digital photographic mounts with a digital slr.

b. Have you ever had to present this type of evidence in court? Please explain if you have or haven't. If you have how, what evidence did you present and how did you present it.

Yes I have presented it successfully

8. What has the response been to this method of presenting evidence

a. From the judges?

-

b. Barristers?

-

c. The jury members

I am not given any response during evidence by any of these parties nor are they in a position to do so.

Is the courtroom fully equipped to allow you to present this type of evidence?

Yes, computer cabling to large tv panels are installed.

9. Do you feel there is anything, which needs improvement? Please explain.

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10. Can you give me your opinion on presenting evidence in this manner? Advantages/Disadvantages.

My evidence is only to present this technology, without it, I would not be presenting anything further.

11. Can you provide me with information about where you think courtrooms will be in the future in terms of technology? With the recent advances of virtual reality as an example. What is your idea of a courtroom of the future?

I think virtual reality is still a long way off from being used for evidence. The probity value is yet to be determined, in addition to juries not being allowed on many occasions to witness certain graphic images for fear of being overly influenced. Virtual reality would compound this. For non-graphic content it may have its place. It may be a useful investigative tool though.