Inter - Observer Error for Area of Origin Analysis Using FARO Zone 3D

Abstract

In a bloodletting incident, the area of origin (AO) of an impact bloodstain pattern is crucial when establishing the sequence of events. The use of laser scanners and other three-dimensional (3D) technologies to document and analyse bloodstains have been the subject of previous papers, especially where AO analysis is concerned. FARO Zone 3D (FZ3D) is a relatively new software programme that can be used for bloodstain AO analysis. FZ3D requires a greater understanding of inter-observer errors associated with AO. This study looked at the inter-observer variation between 21 examiners when repeatedly calculating the AO six times for a single impact pattern on a plain white wall. An impact rig which consisted of a spring tension arm was positioned and fixed 45 cm from the X wall (right wall), and 45 cm from the Y wall (left wall). This experimental design resembles an impact blow for a bloodletting event. The AO was unknown to all examiners, making it a blind study. The collected results were documented in a Microsoft Excel datasheet and later analysed. From previous literature, a 30 cm acceptable allowance was utilised for AO analysis; however, there is currently no accepted standard error for this type of analysis. The overall total 3D mean error for all examiners was 5.62 cm. The maximum error for any one impact analysis was 24.27 cm. The variation of the data, which was collected by all examiners, was documented as X = 1.14 cm, Y = 1.24 cm, Z = 1.68 cm, and the total 3D error = 2.28 cm. The total 3D error for any one examiner and the variance between examiners did not exceed the 30 cm acceptable allowance utilised in previous literature.

Keywords

Bloodstain Pattern Analysis; 3D forensics; FARO Focus S350 Laser scanner; Crime scene reconstruction; Forensic science; Impact pattern; Stringing.

Recently scientists and law enforcement agencies have been introduced to sophisticated technologies, which help in bringing criminals to justice or to prevent an innocent individual from being convicted. Along with the array of recent additions of technology, experts and jurors see a dramatic change in metrological technologies - the scientific study of measurement. Innovations from forensic science research and development are implementing these new techniques for solving crimes and increasing the reliability, efficiency, and validation of forensic testing (1) (2). Laser scanners and software packages have been utilised for bloodstain pattern analysis (BPA). Laser scanning has been recognised for the ability to return to the crime scene months or years after the scene has been released. Laser scanning technology has been accepted in courts worldwide in countries such as Canada, Australia, Germany, The Netherlands, New Zealand, and the United States.

When an object comes into forceful contact with a blood source, blood drops radiate from the source (i.e., the impact location) and disperse into various directions, resulting in a distinct pattern. Circular bloodstains can be generated when a blood drop encounters a surface at 90^o. Otherwise, if a blood drop meets a surface at an angle other than 90^o, a bloodstain that is typically elliptical in shape is formed (1) (2). Elliptical bloodstains usually contain a tail, which indicates the direction in which the bloodstain was travelling prior encountering a surface. The location of where the blood originated can be determined by drawing a line lengthwise along the tail, bisecting the middle of the ellipse. Drawing lines through multiple elliptical stains will result in lines converging in a two-dimensional (2D) area, which has been shown to indicate where the impact occurred (4). This area is recognised as the Area of Convergence (AOC), which runs along the same horizontal plane as the blood spatter. The area of origin (AO) is assumed to be perpendicular to the 2D AOC. The angle at which a blood droplet impacts the surface can be determined by a relationship, first observed by Dr. Victor Balthazard, and subsequently formulated by Dr. Conrad Rizer (3). The angle (θ) can be determined by taking the arcsine of the ratio between the width (W) and length (L) of an individual blood droplet, (θ = sin-1 (W/L). Examiners use this calculation when utilising the traditional stringing method to determine the angle of impact; however, this technique has limitations (5). The stringing method is known to be challenging, time-consuming, and invasive when attaching strings to a surface(s) within a crime scene.

Moreover, this technique can be cumbersome, typically when there are many bloodstains to be strung. Examiners follow a sequential approach, firstly identifying which bloodstains to string to determine the AOC, measuring the location, width, and length of the bloodstains, calculating the angle of impact, and finally identifying the AO (6). A non-invasive alternative technique to manual stringing is the virtual stringing method. The mechanism of virtual stringing is equivalent to manual stringing but transposed onto a computer via software packages (7). There are several software packages such as Faro Scene (8), FARO Zone 3D (FZ3D) (2), HemoSpat (9), and BackTrack (11). The accuracy of these software packages have been independently tested, compared, and validated through published, peer-reviewed scientific articles (1) (2) (4) (8) (9) (10) (11). It must be noted for the purpose of this study FZ3D will be utilised. FZ3D has a vast number of features as well as BPA such as bullet trajectory, vehicle momentum, critical speed yaw, speed from skids, road profile, vehicle crush and many more.

Since the release of FZ3D, there have been no published scientific studies that have explored the inter-observer errors when examiners calculate the AO multiple times for a single impact bloodstain pattern deposited on plain white walls. This study aimed to identify the variance between 21 examiners when analysing an impact bloodstain six times to determine the AO. A 30 cm acceptable error allowance was utilised for AO analysis in this study. To date, there is no standard methodology established for creating bloodstains. Previous researchers have utilised a custom-made mouse trap to create impact bloodstains. The methods for this study were analogous to Griffiths et al. (2) and Liscio et al. (10), which utilised a custom-made impact rig with a spring tension armature to create impact bloodstains.

Methods

21 Examiners were recruited through our own personal connections and social media. All examiners had various knowledge of BPA, ranging from BPA awareness to advanced BPA training. However,

they were all experienced in FZ3D. Although examiners were experienced in FZ3D, a tutorial video was provided along with the point cloud data in ‘Dropbox’. Examiners knew they were analysing the same impact stain as the photograph / point cloud data was the same for the six repeats. Examiners were given 2 months to complete the task. The author provided feedback to the examiners after they had completed the analysis with their results, this being the total 3D error, along with any further feedback. A proportionate ethics form for this study was completed and granted by Staffordshire University.

Two sheets of hardboard 48” X 48” were fixed adjacent to each other to produce a 90^o corner wall. The X-axis was selected as the right wall, Y-axis as the left wall, and the Z-axis was the height from the floor. The 90^o wall replicated a complicated position instead of using a single flat surface. This set-up is illustrated in Figure 1 and Figure 2.

FIGURE 1 Here

Figure 1 - Illustrates the construction of the plain 90^o wall.

FIGURE 2 Here

Figure 2 - Illustrates the impact rig with the position of the 90° wall with the X (right wall) Y (left wall) and Z (floor). The known impact location was 45 cm from the X and Y walls.

A 90^o white wall and a custom-made impact rig, shown in Figure 3, was utilised to create an impact stain. The rig was fixed to the (Z) floor, the centre of impact being 45 cm from the X wall and 45 cm from the Y wall, this being the known AO, illustrated in Figure 2. Although there is a height difference of 5 cm, between the floor and the base of the rig, the checkered target was selected as the 0,0,0 point in the software. A checkered target was positioned to the centre of the impacting dowel (3 cm diameter) located on the rig, allowing measurements of the known area of origin, illustrated in Figure 3.

FIGURE 3 Here

Figure 3 - Illustrates the custom-made impact rig which was utilised to create the 6 repeated impact spatters. The black and white checkered target positioned on the impact rig is the known area of origin.

The temperature of the room was approximately 23 degrees and approximately 30% humidity. The blood was preserved in 1% Sodium Fluoride and Potassium Oxalate, which was then stored at 4ºC in a refrigerator. 5 mL of sheep blood, sourced from the Canadian Food Inspection Agency, was placed onto the checkered target on the impact rig, with a 10 mL disposable resin syringe, ensuring that the blood remained within the limits of the checkered target. The age of the blood was 2 days old, however, the blood was used throughout another project, so it varied from 2 days old to 5 days. As previously stated, the blood was preserved in 1% Sodium Fluoride and Potassium Oxalate, which was then stored at 4ºC in a refrigerator throughout this period. To imitate the temperature of the human body, the sheep blood was stirred for homogeneity while being heated to 37ºC, the temperature was taken with a thermometer. The mechanism of the impact rig consisted of a swinging armature, and when pulled back to 90º from its resting position, the tension in the spring was generated. After release, the armature swung downwards where the impacting head connected with the 5 mL of sheep blood, located on the checkered target to produce an impact spatter, seen in Figure 4. The use of an impact rig allowed for more consistent impact speed and reduced variability of the impact and human intervention. The velocity of the dowel immediately before the point of impact was determined to be an average of 10.45m/s (SD 1.22 and n-value of 571).

FIGURE 4 Here

Figure 4 - Illustrates the impacting head connecting with the 5 mL of sheep blood located on the impact rig to produce an impact spatter on the X and Y walls.

Visual Analysis and Digital Documentation

An impact spatter was produced onto the X and Y walls, and careful inspection of the bloodstains was performed, allowing the examiner to select which bloodstains were appropriate for analysis. All examiners had received a varying level of BPA training; thus, they were encouraged to self-select their stains to reduce bias in this study. For the marking up of individual bloodstains in FZ3D, the software requires high-resolution photographs to mark the ellipses. Clusters of bloodstains were selected, and three black and white checkered targets were placed in a triangle shape around each cluster, with two checkered targets approximately horizontal to one another. This assists in the captured photographs to be scaled and orientated to the laser scanned data by referencing the same markers. For this study, a Canon Powershot S100 camera with a built-in zoom lens was used to capture each cluster of bloodstains, illustrated in Figure 5. The bloodstain photographs had a resolution of 4000 X 2248 pixels. The camera was fixed perpendicular to the surface, similar to previous studies. This approach reduces the amount of error in FZ3D, as the software does not auto-correct perspective distortion. The photograph must be captured "square" to the bloodstain surface, as this will reduce the amount of error caused by a non-orthogonal shot.

FIGURE 5 Here

Figure 5 - Painted plain wall photograph, illustrating three black and white checkered targets placed around the cluster, this assists in the photograph alignment in FZ3D.

Terrestrial Laser Scanner

A FARO Focus S350 laser scanner was utilised, which was placed one meter away from the X and Y walls. This type of scanner emits an infrared laser beam, which can measure the position that a point is located. The scanner records the horizontal and vertical angle of the emitted laser beam along with the intensity of the signal, which is then returned to the device. The laser scanner captures photographs and then stitches them into a panoramic image to colourise the captured data. For every point captured, the laser scanner produces X, Y, and Z positions of any individual point, the intensity of the return signal, and the red, green, and blue pixel information captured by the camera. Depending on the selected resolution setting of the scanner, this could result in millions of points being captured. The FARO S350 laser scanner has an accuracy of ±1 mm, an in-depth description of this scanner and process has been published in previous papers (1) (2) (10).

The laser scanner captured a full 360º scan of the surrounding area with a ¼ resolution and a quality setting of 4X. The output of selecting a ¼ resolution results in a point spacing of 6.13 mm at 10 meters or 0.6 mm at 1 meter, which contributed to the alignment of the scan data with a captured photograph. These settings have been recommended in previous literature (2). Selecting 4X quality relates to how many times the same point is sampled, thus reducing noise in the scan data, and increasing the accuracy of the captured points.

Faro Scene 7.1 processing

The laser scanned data was processed and managed in FARO Scene 7.1. This involved first importing the raw scanned data into the software. A sequential processing stage permitted for the integration of colour and the optimisation of the data format. The ‘Auto clipping boxes’ allowed for the point cloud to be cropped to the area of interest, this being the X, Y, and Z walls. Once this process had been completed, the file was then exported as an e57 file from FARO Scene 7.1 into FZ3D. This processing stage was not conducted by examiners and was already prepared.

FARO Zone 3D

The e57 file was imported into FZ3D, and the global coordinate system assisted with the alignment and rotation of the point cloud. With the assistance of the black and white checkered target located on the impact rig, the centre of the checkered target was selected as the 0,0,0 point (known AO). This point was chosen as it was easier to set the centre of the impact location to 0,0,0, resulting in the errors being directly readable, and it being a relative location. The ‘clip box’ tool was selected to hide the impact rig located on the point cloud. This was visualised as a ‘blind test’, and examiners were unaware of the known AO. The ‘Align 3 – point’ tool allowed for captured photographs to be aligned to the point cloud scanned data. The alignment of the photographs was conducted by selecting three checkered targets that were present on the photograph, with the same three checkered targets located on the scanned point cloud. Four photographs were aligned in total (2 on the X wall and 2 on the Y wall) seen in Figure 6. Captured photographs of the bloodstains were pre-aligned, ready for the examiners to calculate the AO.

FIGURE 6 Here

Figure 6 - Illustrates four photographs aligned to the scanned point cloud.

Within FZ3D, the marking up and alignment of bloodstains depends on the manual and semi-automatic detection tools. Examiners were advised to utilise the semi-automatic edge detection tool; and, if required, the use of the manual adjustment tool, as the edge detection tool sometimes marks bloodstains inaccurately. Examiners utilised the edge detection tool to click on the centre of the bloodstain, where the software will automatically identify the best fit ellipse. If the algorithm failed, examiners adjusted and verified each ellipse mark up to their satisfaction. Figure 7 illustrates an examiner’s prediction of the bloodstain’s backtracked trajectory.

FIGURE 7 Here

Figure 7 - Illustrates a examiners prediction of the back tacked trajectory of a bloodstain.

The software can misinterpret the stain's directionality when using the semi-automatic detection tool. If required, the manual edit tool can be utilised to amend the directionality of the virtual strings. Once the examiner was satisfied with the ellipse mark-up, a straight-line trajectory was created at the calculated angle of impact, which aims in the direction of travel. FZ3D utilises the inverse sine function method to determine the angle of impact. It must be noted that only upwards-moving stains were selected for analysis, due to FZ3D only allowing upward-moving stains to be analysed at this current time. Examiners were able to see the calculated AO in real-time as they marked up the bloodstains. The final AO position was documented in a properties window located on the left side of the screen, seen in Figure 8. All examiners provided calculated X, Y, and Z axis position values into an Excel spreadsheet ready for data analysis.

FIGURE 8 Here

Figure 8 - Calculated AO for one of the impact stains on a plain wall.

Results

A total number of 21 examiners calculated the AO six times for a single impact bloodstain pattern. The standard deviation for all the X, Y, and Z axes data collected by examiners was, X = 1.07 cm, Y = 1.12 cm, and Z = 1.30 cm, and the total 3D error of 1.51 cm. The total error for any one analysis was calculated using the 3D Pythagorean Theorem, where e_x, e_y, and e_z are the errors for each axis, and E is the total error in centimetres. It must be noted, for this study absolute values were used rather than positive or negative values, as this highlights the magnitude of errors without considering which direction from zero the number lies.

The mean absolute errors for the X, Y, and Z axes, and the total 3D error for each examiner are depicted in Figures 9, 10, 11, and 12. Outliers are represented as a (*) on Figures 9, 10, 11, and 12, which were calculated for any one repeat.

The mean absolute errors for all the X-axis (right wall) data collected by examiners (n = 126) was 1.96 cm (ranging from 0.71 cm to 4.41 cm). The mean absolute errors for all the Y-axis (left wall) data collected by examiners (n = 126) was 4.08 cm (ranging from 2.31 cm to 6.13 cm). The mean absolute errors for all the Z-axis (height) data collected by examiners (n = 126) was 2.76 cm (ranging from 1.01 cm to 5.87 cm). The overall total 3D mean error collected by all examiners was 5.62 cm (ranging from 3.52 cm to 8.80 cm). Calculated data for all examiners did not exceed the 30 cm acceptable allowance for AO analysis.

FIGURE 9 Here

Figure 9– Boxplot showing the mean absolute errors in the X axis for each examiners, after calculating the X axis six times.

FIGURE 10 Here

Figure 10 - Boxplot showing the mean absolute errors in the Y axis for each examiners, after calculating the Y axis six times.

FIGURE 11 Here

Figure 11 - Boxplot showing the mean absolute errors in the Z axis for each examiners, after calculating the Z axis six times.

FIGURE 12 Here

Figure 12 – Boxplot showing the total 3D error for each examiners after calculating the AO six times.

The variation for the X, Y and Z axes between examiners was X = 1.14 cm, Y = 1.24 cm, Z = 1.68 cm, and the total 3D error = 2.28 cm. The total 3D error for any one examiner and the variance between examiners did not exceed the 30 cm acceptable allowance utilised in previous literature (1) (2) (4). Range errors for any one analysis for any one examiner for the X, Y, and Z axes, and the total 3D error for all data was documented as X = 0.01 – 6.13 cm, Y = 0.02 – 7.29 cm, Z = 0.02 – 24.08 cm, and the total 3D error = 0.06 – 24.27 cm.

Discussion

In this study, 21 examiners analysed a single bloodstain impact pattern, and the variance was obtained. The variance is the average of the squared differences from the mean. The BPA tool incorporated into FZ3D allowed for the AO to be calculated. To this date, there is no standard for accuracy, and previous researchers have utilised a 30 cm acceptable allowance for error when calculating the AO (2). FZ3D (2), FARO Scene (8), HemoSpat (9), and BackTrack (11) assume a straight-line trajectory, neglecting the influence of gravity and air resistance (12). The algorithm utilised for AO estimation consists of a linear, bloodstain flight path instead of a parabolic flight path. Therefore, the Z-axis may be expected to have a more significant error, which has been shown to be true in several published papers. However, De Bruin identified greater accuracy in the X and Z axes, and more significant errors in the Y axes using BackTrack and HemoSpat (3). At the time of the write up of this study, there are no commercially available BPA software packages that take gravity/ parabolic path into account. Attinger has proposed a method to reconstruct the region of origin of impact blood spatter patterns that consider fluid dynamics and statistical uncertainties in physical sciences (17). Attinger et al. discusses the five aspects of BPA related to fluid dynamics, these being the generation of the drops, their flight in the air, the physical forces driving the motion of blood as a fluid, their impact on solid or liquid surfaces, and the production of stains (18). When comparing the height error obtained in this study, to the height error obtained in previous research using FZ3D, BackTrack, and HemoSpat, the Z values are smaller. Thus, examiners may have selected and marked up bloodstains that they assumed were near or close to the AO. Table 1 highlights data collected by previous authors for the X, Y, and Z absolute errors.

Table 1 – Illustrates data collected by previous authors for the X, Y, and Z absolute errors.

Table 1 HERE

It must be noted that Esaias et al. created impacts stains on a flat wall, resulting in the X-axis being absent. The variance between examiners for the Y wall was 25.7 cm and 2.83 cm for the Z wall. The variation appears to be much greater in Esaias paper compared to this paper. This could be due to the selection of bloodstains that the examiners used (3), it is recommended that bloodstains that are assumed to be near or close to the AO are preferred, due to the reduced influence of gravity and air resistance when airborne. Also, this could be due to the accuracy of ellipse marking. Research has been conducted by Liscio et al. on the accuracy of ellipse marking, which could also increase and decrease the error in the X, Y, and Z axes (16). Depending on how round the stains were and where they were located, the gamma angle can have an influence on the location of the trajectories and influence the AO result.

The mean absolute errors for the X, Y, and Z axes in this study were comparable to (2, 4, 10, 11,12, 13, and 19). The overall total 3D mean error for all examiners (n = 126) was 5.62 cm (ranging from 3.52 cm to 8.80 cm). Previous research by Griffiths et al. reported a 9.77 cm overall total 3D mean error (ranging from 1.97 to 20.62 cm) (2). Liscio reported an overall total 3D mean error of 3.40 cm when 14 examiners analysed a single impact pattern once (10). The overall total 3D mean error for this study was comparable to (2, 10). The variance within all the total 3D error data for this study (n = 126) was 2.28 cm.

The overall standard deviation between examiners was calculated to be X = 1.07 cm, Y = 1.12 cm, Z = 1.30 cm, and the total 3D error of 1.51 cm. Liscio reported a standard deviation for each axes, this being X = 2.5 cm, Y = 2.1 cm, and Z = 3.1 cm (10). Hakim et al. reported a standard deviation for each axes, this being X = 3.49 cm, Y = 1.14 cm, and Z = 9.08 cm (4). The standard deviation for the X, Y and, Z axes in this study, and comparative studies, showed low deviations indicating values were close to the mean. Therefore, these values indicate reproducibility.

In this study, the mean absolute errors for the X, Y, and Z axes were all within the literature error recommendation. De Bruin highlights bloodstain selection is crucial when calculating the AO, and suggests there can be a considerable variation in the deviation between different bloodstains. Bloodstains with smaller deviations contain better stains than higher deviation bloodstains. Smaller deviation bloodstains are those which lie closer to the actual AO than the ‘‘strings’’ corresponding to the stains with higher deviations. De Bruin suggests the lower the bloodstains on the wall, the smaller the deviation from the actual AO (3). Bloodstains that are closest to the presumed location of the blood source should be selected. This reduces the influence of gravity and air resistance, resulting in a more accurate origin height determination. Research has been conducted by Hakim et al. and states that as the distance increases from the X and Y wall the error increases (4). This is due to the influence of gravity and air resistance. Bloodstains with a larger surface area result in less deviation, following a recent study by Reynolds et al. (13). The smaller the bloodstain, the more difficult it is to identify the edges of the bloodstain. Thus, the error in the depicted measurement of the width and length is more substantial. Therefore, selecting bloodstains that are >1.5 mm is recommended. Examiners identify characteristics of bloodstains and often use the tail of the bloodstain as an indicator of the direction the blood travelled before being deposited on a surface. In FZ3D, the mechanism of the edge detection tool consists of clicking the centre of the bloodstain, which automatically identifies the best fit ellipse. If the algorithm failed, examiners adjusted the length of the bloodstain and adjusted the width of the ellipse to the stain. This method is susceptible to human perception, variability, and errors, which could result in errors of the resulting ellipse. Ultimately, it is up to the examiner to accept, reject, or modify the ellipse fit on any bloodstain. However, it must be noted that there was no indication that observer error reduced with each repetition, (i.e., their error did not reduce due to experience). An example of this for examiners 1, 2, 3, and 4 has been illustrated in Figure 13.

Table 2 – Illustrates the total error for examiners 1, 2, 3, and 4, illustrating the error did not reduce with experience.

Table 2 Here

Studies have highlighted that the most common errors associated in blood spatter elliptical marking are the overestimation of bloodstain length resulting in an underestimation of the impact angle (19). Some of the variables in this study were not controlled, such as which bloodstains were marked and used for the analysis. Also, the number of bloodstains used in the analysis and variation of image placement was not analysed specifically but were considered in their totality in the final results.

Capturing clear photographs and the alignment of the photograph to the scanned point cloud data is vital for the marking of bloodstains. The blurring of captured bloodstains results in an additional error in the stains edge identification and increases errors within the X, Y, and Z axes. The camera was fixed perpendicular to the surface, similar to previous studies. For this study, four photographs were aligned to the scan data, and the BPA tool allowed for marking up and calculating the AO, previous researchers utilised a single photograph which resulted in poor AO estimations (4). The researcher shared that bloodstain clusters located in one photograph do not provide enough separation between stains, resulting in the AO being highly sensitive to small variations in trajectory angles. The utilisation of multiple photographs assisted in reducing the standard deviations and increasing the accuracy, allowing for comparable results from previous researchers utilising other virtual stringing software for BPA (4).

The advantages of using the Faro Focus S350 laser scanner and FZ3D software include non-invasive scene processing, quick data processing time, and visual output. The time spent processing/documenting the scene and analysing the impact stain to determine the AO was <1.5 h. Processing the scene involved identifying clusters of bloodstains and the placement of the black and white checkered targets, photographing the bloodstain clusters, and scanning the area. In this study, the processing time took 30 minutes (black and white checkered target placement and photography = 20 minutes, scanning = 10 minutes). Cropping and managing the scanned point cloud data in FARO Scene 7.1 took 15 minutes. The alignment of captured photographs to the scanned point cloud data and calculating the AO for the impact spatter took 45 minutes. Another advantage of FZ3D is the ability to visualise the AO in both 2D and 3D, making it valuable when presenting in court. This software is valuable when visualising the sequence of events, measuring distances from potential evidence to another, and the ability to virtually present the scene without physically attending. Future studies may look at the variation between examiners when analysing impact stains on different wallpaper surfaces, similar to the study of Griffiths et al. (2).

Conclusion

This study aimed to identify the variation between 21 examiners when analysing a single impact bloodstain six times to determine the AO. The results of this study highlight that the bloodstain AO tools within FZ3D are robust with minimal inter-observer errors. The X, Y, and Z mean absolute errors were X = 1.96 cm, Y = 4.08 cm, Z = 2.76 cm, and the overall total 3D mean error was 5.62 cm. The maximum error for any one examiner when calculating the AO was 24.27 cm; this was an outlier within the data when an examiner calculated the AO. The total 3D error for any one examiner did not exceed the 30 cm acceptable allowance recommended in previous research. The variation between examiners was X = 1.14 cm, Y = 1.24 cm, Z = 1.68 cm, and the total 3D error of 2.28 cm, which was also within the 30 cm acceptable allowance. This option appears to be promising for bloodstain pattern analysts. When coupled with the ability to visualise the analysis in the context of a major crime scene, this forms for a powerful tool when used in forensic investigation.

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