SWARM 2017: The 2nd International Symposium on
Swarm Behavior and Bio-Inspired Robotics
October 29-November 1, Kyoto, Japan

Development of 3D Sculpted, Hyper-Realistic Biomimetic Eyes for Humanoid Robots and Medical Ocular Prostheses

Carl Strathearn[1†], Minhua Ma[2]
School of Computing and Digital Technologies, Staffordshire University, UK
Carl.Strathearn@research.staffs.ac.uk, M.Ma@staffs.ac.uk

Abstract. Hyper-realistic Humanoid Bio-robotic Systems (HHBS) are the precise electro-mechanical bodily emulation of natural human being in materiality, form and function. However, the standardised approach of constructing static ocular prosthesis for implementation in modern HHBS design, contradicts innate organic human criterion as the artificial eyes are void of the intricate dynamic fluidic functions of the natural human iris. The aim of this paper is to outline the development and construction process of a pair of realistic artificial humanistic optical retinal sensors that accurately simulate the autonomous fluctuating operations of the human iris in reaction to visceral emotion and photo-luminescent stimuli and retain the optical sensory capability and integral aesthetic materialism of the organic eye. The objective of the auto-dynamic pupillary framework is to advance the external expressive / embodied realism of HHBS towards achieving a more accurate operational and embodied simulation. Prospective future application and advancement of the outlined optical system presents potential implementation in the field of medical ocular prosthetic design, with the aim of enhancing the naturalistic operations of future fabricated human eye replicas, thus conceivably reducing the malaise and discomfiture commonly associated with the archetypical fixed artificial eyes.

Key Words: Ocular prosthesis, Hyper-Realistic Humanoid Bio-Mimetic Robotic Systems, dielectric elastomer, simulacra and simulation, 3D Modelling, uncanny valley.

1. Introduction

Perceptual ocular identification is the foremost primary process of direct interpersonal human contact, preceding other forms of rudimentary conspecific sensory and auditory commutative operations [1]. The upper and mid facial region presents a key locality for anterior facial recognition, expression, and interpretation of emotional signals during face to face contact [2], [3]. A recent study by Kang et al. [4] measuring pupillometry data of inter-human eye contact indicated high levels of responsive pupil mimicry during intermediate communicative exchanges between individuals in the test group. Therefore, it is possible to speculate that irregularities in integral eye form and function appear distinctly prevalent to the average observer during the initial phases of direct reciprocal non-verbal communication. It is at this elementary instant in human intercommunication, that static prosthetic design may instantaneously capitulate to the negative reactions exemplified in the *uncanny valley* hypothesis, as traditional fixed artificial eye structures are void of the fine fluidic nuances which appear visually prevalent in the natural human eye form [5].

2. Dynamic Pupil System Design for HHBS

It is possible to predict a similar adverse emotive reaction during the crucial first stages of personal contact with HHBS, as it becomes discernibly obvious to the observer that the robotic replicant is void of the intricate and variable dynamic key components (notably optical related) that combinate to represent the conventional organic human condition [6] [7]. An example of this process may be observed in Hanson Robotics, humanoid replicant *Sophia*

Ⓒ SWARM 2017 All Rights Reserved.

[8]. The system presents a close approximation to the human female form. However, the robot’s eyes function as a set of camera sensors, utilised in the gathering of visual data. Therefore, the integral operations of the robot’s eyes remain static, as the eye forms operate as partitions to hide camera components, rather than accurately simulate the integral dynamic functions of the human eye [9]. According to the uncanny valley theorem, even the most minuscule visual discrepancies, such as minor static functions or unnatural surficial spasmodic fluctuations, may install an eerie and uncomforting effect on the average observer [10].

Therefore, to avoid compromising the integrity of the HHBS emulative organic naturality and falling into the uncanny valley principle, the system must superlatively perform all key and secondary functions accurately and according to the parameters of the natural human paradigm. Jean Baudrillard, in his philosophical treatise ‘Simulacra and Simulation’ describes this simulative process as: a system which no longer alludes to the underlying symbolic illusionary function, but transcends imitation and impression, formulating a singular spectrum of unequivocal actuality or hyper-real [11].

2.1. Current and Future Application of HHBS

HHBS are still in the early stages of development, however, significant advances in the mechanical and systematic progression of HHBS are becoming prevalent in today’s society [12]. As the technology employed in contemporary robotic character design ameliorates, it vastly increases the potential inauguration of HHBS in future commercial projects [13]. This shift in application is exemplified in the gradual transition of robotic system design, from traditional industrial purpose, to the extensive and variable utilisation in fields such as interactive therapeutic healthcare, public service interfaces, scientific research, autonomous transportation services and medical training devices (robotic patient simulators) [14], [15], [16]. An example of the current progression of HHBS can be observed in the Walt Disney’s patent [17] for a soft body HHBS for physical human/robot interaction. The initiative describes the development of a semi-autonomous HHBS that can safely interact with young people via a control system of embedded touch sensors within the robotic outer skin of the artificial character. The document further details the potential future application of the system in schools, hospitals and workplaces [18]. Therefore, consideration should be given to the surficial appearance and functionality of the system, if it is to effectively integrate and communicate with people without causing feelings of unease [10]. It is in such instances that the application of precise emulative expressive operations may become key, in permitting positive attachments between humans and HHBS in the future [19], [20].

2.2. Dynamic Pupil System for Medical Prosthesis

Similar acute practical and systematic considerations should to be calculated in the development of an internally dynamic artificial ocular prosthetic module, for application in the medical field. For instance, if the fabricated eye dilated out of synchronicity with the remaining biological eye, the simulative organic process becomes dis-configured, resulting in an inaccurate representation of the unified pupillary vision function [6]. Therefore, the system must have the capacity to accurately measure the fluctuating pupil diameter of the remaining biotic eye if the artificial module is to operate with the degree of mimetic precision required to avoid asymmetrical dissonance.

2.3. Pupillary Dilation Response to Emotive Visual Stimuli

Kinner et al. [21] in a scientific study entitled *What our eyes tell us about feelings: Tracking pupillary responses during emotion regulation processes*, investigated the effects of negative, neutral and positive emotive visual stimuli on the pupillary responses of 30 healthy participants, via measuring the rate and distance of pupil dilation of the test group during an image based examination. The outcome of the experiment determined that participants in the test group exhibited considerable fluctuations in pupil response to highly emotive visual stimuli. This result is indicative of a profoundly visceral correlation between the image based information and the cognitive processing of highly emotive stimulus on the subjects pupilar response mechanism, suggesting, variation in pupil dilation is not a singular reaction to alternating light levels, but presents visually responsive dynamic fluctuation to highly emotive based visceral optical stimuli.

Therefore, innate pupillary responses to highly emotive triggers are intrinsic when considering the development of an accurate and naturalistic simulative inner pupil dilation response system. This framework applies to both HHBS and medical ocular prosthetic system design, as a singular photo-sensitive pupil dilation prosthetic, would subsequently be incapable of portraying the expressive ocular visceral-emotion optical reaction of the operator. The outcome of implementing a singular photo-sensitive artificial eye module, may result in an abnormal pupillary feedback, of the dynamic artificial iris against the natural pupil dilation response of the biological eye. In HHBS the application of an emotion based pupillary response system may exceedingly increase the surficial and internal mimetic credibility of the HHBS, as it would permit subtle emotive pupil response triggers proximal to organic human ocular operation.

2.4. Previous HHBS Ocular Models with Pupillary Dilation Systems

Schnuckle [22] demonstrated a method for the development of realistic dilating artificial eyes. The system comprises of a triangular foam formation that when pressed against the inner surface of the internal eye shell, compresses the point of the triangle back and forth against the interior surface, thus, increasing and decreasing the diameter of the foam point creating a fluctuating pupil effect. However, review of the system poses potential issues concerning: 1. The offset of the natural pivot of the eye via an actuator. 2. The extensive space occupied via the forward linear rod mechanism. 3. Intricate and complex mechanical components, which may lead to unstable and unreliable system procedure over time. 4. The unnatural dynamics of the pupil (opposed to the organic kinetics of the human Iris). 5. Anomalous mechanical operations of the artificial eye system at close proximity, due to the nonfluidic nature of the motorised actuator [23]. Prendergast & Reed [24] patented a comparable dynamic ocular system using a mechanical shutter lens framework. However, on examination the system not only suffers similar operational capacity issues as Schnuckle’s model, but the shutter mechanism may present further issues concerning the unnatural functioning of the artificial iris at close inspection, due to the mechanical nature of the shutter mechanism [25].

The University of Nottingham (2013) announced the construction of a prototype artificial human eye model using a dielectric elastomer membrane, for future application in the medical prosthetic industry [26]. The ocular system demonstrates an autonomous capability to contract and expand the artificial iris fluidically under variable light levels. However, the model appears distinctly mechanical and far withdrawn from natural human eye reference in form and aesthetical quality [27]. The system further lacks the capacity to respond the user’s emotive stimuli, thus acting as a singular photo-sensitive prosthetic module. Laponite et al. [28], provided an additional dilating ocular medical retina model, utilising an LCD screen for the projection of an animated iris. However, the LCD screen format lacks the operational definition required to accurately portray the intricate detail and fluidic dilation of the human eye.

2.5. Discussion of Findings

This paper identifies a gap in the current field of HHBS and medical dynamic ocular prosthetic design. This outcome provides evidence for the requirement for a precision artificial eye system.

The following prototype optical system will attempt to address these issues via introducing an emotive-visceral optical dilatation mimetic sensor: with secondary autonomous photo-sensitive pupillary reaction capability; whilst visually adhering to the organic aesthetical formation and kinetic operation of the natural human eye. The HHBS ocular system design will additionally include a hidden camera element for visual data collection.

3. Realistic, Dynamic Pupilar Model Design for HHBS and Prosthetic Eyes

The process for creating an emulative bio-mimetic iris membrane (Fig. 1) commences with a high-resolution virtual image of the natural frontal eye form that is to be replicated. This image is then transformed into a stencil using 3D modelling software and extruded using a depth map, the image can then be imprinted onto the blank eye form produced in 3D graphic design software. The result of this procedure is a very detailed 3D virtual approximation of the original organic iris. The colour image of the iris can then be projected onto the imprinted eye form to ensure an exact fit and precise simulative likeness to the original image.

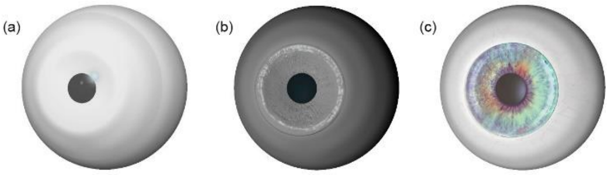

Fig. 1. Virtual modelling technique for developing a precision custom iris form. (a) Basic 3D eye form created in Maya (3D graphics software) using average biological eye parameters. (b) Eye form imported into Mudbox (3D sculpture software) and imprinted with customised stamp tool (iris). (c) Finished eye form with colourised iris.

In Fig. 2, the imprinted eye configuration (a) is exported to a precision 3D printing system (min: 20 micron = 0.02 mm) and printed using SLA resin (b) the material provides a detailed surficial area for the replicated iris print. A silicone mould is then assembled from the 3D printed eye form, this process establishes an accurate negative for making a gelatine positive (c) of the iris. In order to create a precision replicate of the natural iris colour array, a physical copy of the original eye image is printed on gelatine / gel transfer paper using a high-resolution printer (min: 4,800 x 2,400dpi) and layered onto the gelatine positive, this surface sheet is then sealed on the iris form with a coating of crystal clear gelatine compound, amalgamating the layered configuration into a singular flexible arrangement.

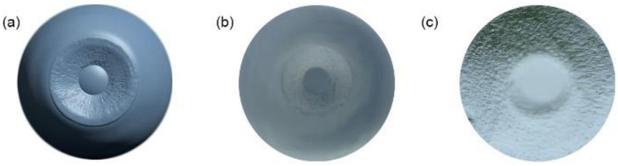

Fig. 2. 3D printing process for resin base form and production of a silicone mould for gelatine iris positive. (a) Eye base form in 3D printing software (b) 3D Printed SLA resin eye (c) Gelatine positive of iris from silicone mould.

3.1. Dielectric Elastomer System: HHBS and Medical Ocular Prosthetic Design

A frontal diagram of auto-kinetic pupillary system is shown in Fig. 3. The kinetic internal dilation system of the artificial eye is calculated on the dielectric elastomer action equation:

$$c = \varepsilon_r \varepsilon_0 \frac{A}{D} \qquad \text{Eq. (1)}$$

where capacitance equals ε_r to the relative permittivity of the foam membrane and ε_0 is the permittivity of space (aperture) in the diaphragm. A is the area of the foam membrane and D is the distance between the upper and lower surficial conductive carbon infused layers.

The dynamic capacity of the electro-active elastomer framework provides an effective fluidic transition, similar to the natural dilation function of the human iris and within a comparable operational range. The gelatine membrane acts are a protective barrier and strengthens the delicate electro-active polymer foam diaphragm. The gelatine iris element can be infused with the carbon particles required for electronic conduction distribution of the carbon gel membrane to expand and contract the foam layer. This application provides an additional conductive surface layer for the dielectric elastomer action, which may result in a reduction of the required operational voltage into the electro-active elastomer membrane.

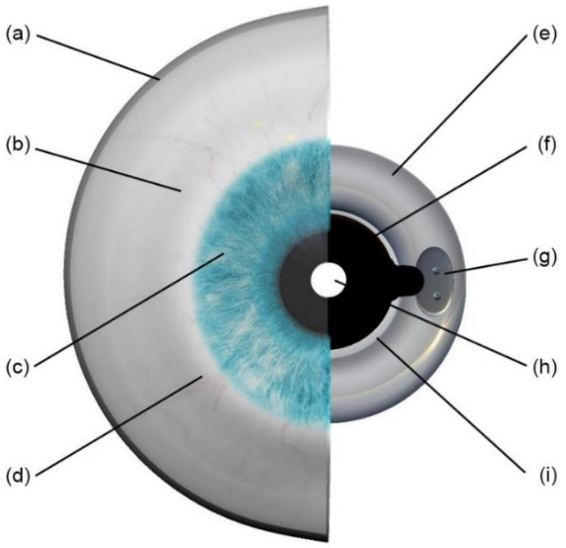

Fig. 3. Frontal diagram of HHBS and Medical Auto-kinetic pupillary system design. (a) Clear cast resin outer shell (b) Silicone sclera skin (c) Gelatine iris (d) Air brushed veining – silicone based paint (e) Laser cut acrylic frame (f) Conductive carbon gel (g) Metal power coupler (h) Aperture (i) Electro-active polymer foam diaphragm

3.2. HHBS Photosensitive / Emotive, Dilation System and Camera Output Model

In the photosensitive binocular design showed in Fig. 4 and 5, the left eye component controls the dynamic operation of the artificial iris for both left and right optical modules. A standard light dependant resistor functions as a simulative retina via determining the contrast in fluctuating light levels. Photo-sensor data can then be inputted into an Arduino micro-controller and used to regulate the positional angle of a micro servo. The micro-servo horn is directly connected to the manual control element of a (QS-500) step-up converter. Thus, as light level frequency is measured via the photo-sensor (input), the control system converts this information into servo positional data (output). This linear process modifies the flow of electricity into the left and right dielectric elastomer membranes, increasing and decreasing the circumference of the aperture (pupil) in reference to the data gathered via the light dependant resistor. A manual electronic resistor control is situated on the power input into the right ocular module, this permits fine tuning of the system, to ensure the synchronicity of both pupillary fluctuations.

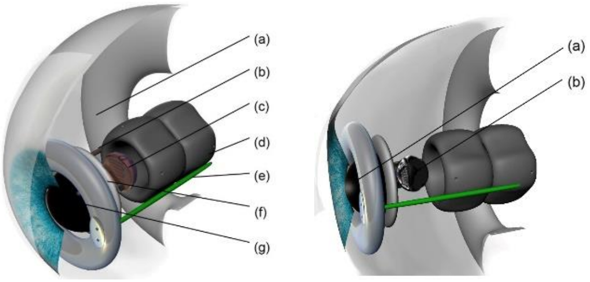

Fig. 4. Left – Right eye photo-sensitive / Camera ocular design for HHBS. Right: (a) Resin eye form (b) Negative power cable (c) Photo-resistor (d) Ball and socket bracket (e) Positive power cable (f) Sensor frame (g) One-way black-out acrylic sphere. Right: (a) 1080p infra-red camera (b) Aperture in EAP membrane and Gelatine iris

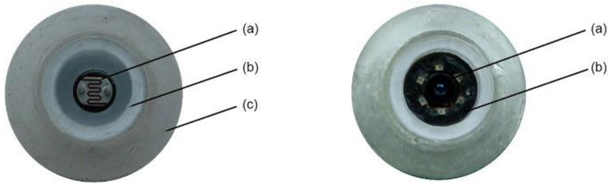

Fig. 5. Left – Right eye photo-sensitive / Camera: ocular internal mechanics prototype for HHBS. Left: (a) photo resistor (b) laser cut dielectric elastomer frame (c) Cast proxy resin eye form. Right: (a) 1080p infra-red camera (b) black silicone sheath.

A relay switch permits the system to transfigure between autonomous photo-reactive mode and high emotional dilation (expressive) operation, managed via the systems integrated programmatical framework. The emotive dilation function therefore over-rides the photo-sensitive device when trigged contiguously with the pre-configured facial expression controls of the HHBS. The robotic right eye module functions as a camera for visual information gathering and motion tracking. This system design permits the optical module to function with the same sensory capacity as contemporary HHBS constructs.

4. Medical Ocular Prosthetic: Photo-sensitive / Visceral-Emotive, Dilation System and Pupil Sensor Glasses

Fig. 6. demonstrates the optical system design for the self-contained dynamic medical prosthetic prototype. The framework utilises a custom micro-controller with input-outputs specifically designed for implementation in the medical prosthetic system. The artificial eye is

powered via a 12v rechargeable battery which serves both the control board and regulates the dynamic operation of the dielectric elastomer membrane. Voltage regulation is controlled directly through a transistor which is digitally operated via the micro-controller's programmatic structure.

The system implements two modes of sensor input, the primary data source is configured through a pupil camera system mounted on a pair of glasses. The camera sensor measures the pupil dilation of the operator's biological eye and sends this data to the artificial eye module to synchronise the ocular prosthetic model with the natural kinetic functions of the natural eye. (Similar pupil dilation detection systems implemented in 2017 by public service providers to measure the health of vehicle operators) [29].

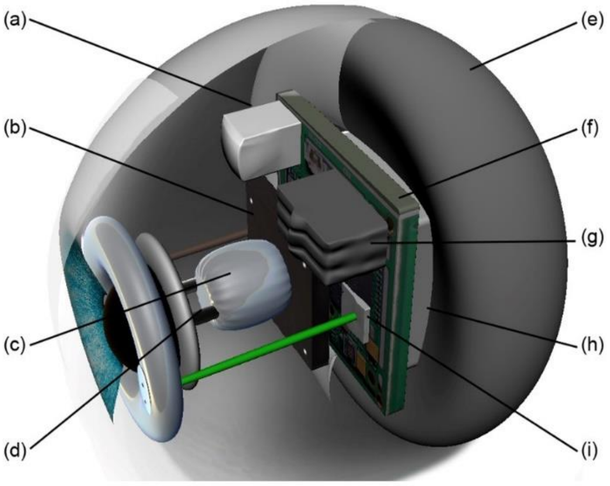

Fig. 6. Diagram of Medical Prosthetic: Auto-kinetic Pupil Module Design. (a) Input receiver (output, glasses sensor) (b) Step up / down boost converter (c) Transistor (d) Photo-resistor input (e) Mouldable back form for precision fit (f) Micro-controller (g) Relay device (h) 12v Battery (i) +/- Power Input

If the ocular prosthetic module loses signal with the primary sensor (glasses) due to proximity issues or battery usage. The photo-sensitive transmitter functions as a sub-system which is automatically activated via a system controlled relay device; transfigured when the receiver registers signal loss. This permits the seamless systematic interchange between the two sensor operations. The purpose of this framework is to continually permit the system to function as a dynamic ocular prosthetic module. It is important to reiterate that the accuracy of pupillary synchronisation will be impacted when registering singular fluctuating light levels using the photo-sensitive resistor as the primary transmission input. The Ocular prosthetic prototype has the potential to be integrated to operate with other medical based control devices that aid in the migration of artificial eye forms [30].

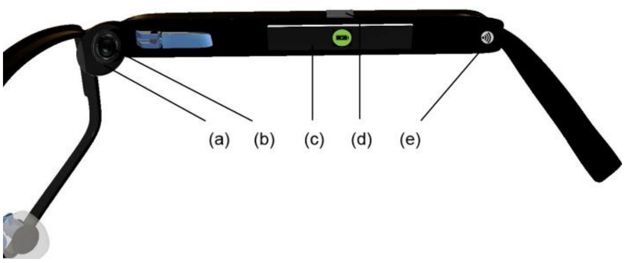

Fig. 7. Diagram of Pupillary Sensor Glasses Control System. (a) Curved lens (b) Camera sensor (c) Rechargeable Battery (d) On / Off power switch (e) Transmitter

The prototype pupil sensor glasses are designed to conceal the camera, transmitter device and battery system via embedding them within the design parameters of the glasses. The glasses feature a small infra-red camera sensor with an arced lens to accurately read the positional movement of the organic iris via the pupil. This data is then inputted into a micro-controller encapsulated in the temple frame of the glasses. The signal is outputted to the transmitter module at the end of the glasses arm and read by the ocular prosthetic module to control the dynamics of the dielectric elastomer.

Fig. 8. Illustration of Finished Pupillary Sensor Glasses Design for Application with Dynamic Prosthetic Eye Module. Top: 3D model of glasses sensor for measurement of biological pupil. Bottom: front view of glasses sensor.

5. Conclusion and Future Work

As advances in computational and mechanical technology progress the simulative realism of artificial bio-mimetic robotic model's closer to actuality, it provides grounding for new and innovative systems to emerge. The variable application and adaptation of these precision bio-mimetic mechanical frameworks, provide potential utilisation across multiple service industries including: medical engineering, home maintenance, child care, entertainment and public assistance. In the future, precision robotic modules may allow individuals with life challenging physical injuries an opportunity to not only gain back their independence, but forgo the inconveniences associated with wearing a static or un-naturalistic prosthesis.

The progression of future prosthetic system design may eventually create life-like synthetic modules indistinguishable from the original natural missing or dysfunctional appendages of the operator, and in some cases, enhance the capabilities of the operator past the constraints of the natural human physical ability. Such provisions may one day allow individuals to work longer, faster and more efficiently without sustaining physical injury or fatigue.

The potential future development and construction of a perfect bio-mimetic robotic humanoid is perceived by many individuals as achieving the holy grail of mankind's technological capability. It is this fascination that has driven the HHBS industry today, and numerous examples of humanoid robotic replicas make international news headlines on a regular basis. It is safe to assume that we are on the verge of entering a new era in bio-robotics. The prescribed fictional mechanical humanoid characters of stage and screen are now making way for actual robots with extensive real-life capabilities. However, if mankind is to effectively integrate and form relationships with HHBS, the replicants have to reflect the same visual-emotive signals we register as measurements of trust, care, love and confidence in other humans. The HHBS ocular prosthesis exemplified in this paper provides a potential step towards achieving a greater simulative embodied realism, which may intercede with our inherent referencing of the human condition and permit us to form stronger relationships with HHBS in the future.

REFERENCES

1. Levy. J, Foulsham. T, Kingstone. A: Monsters are people too: Biology Matters, Vol 9, Issue 1, pp.01-04. (2013) DOI: 10.1098/rsbl.2012.0850

2. Gentile. F, Ales. J, Rossion. B: The Neural Dynamics of Face Perception. Volume 38, Issue 1, (2017) pp.120-139. DOI: 10.1002/hbm.23348

3. Guarnera. M, Hichy. Z, Maura. C, Stefano. C: Facial Expressions and Ability to Recognize Emotions from Eyes or Mouth in Children. European Journal of Psychology: Vol 11, Issue 2 (2015), DOI: 10.5964/EJOP.V11I2.890

4. Kang. O, Wheatley. T: Pupil Dilation Patterns Spontaneously Synchronize Across Individuals During Shared Attention. Journal of Experimental Psychology: Volume 146, Issue 4, pp.569-576 (2017) DOI:10.1037/xge0000271

5. Sansoni. S, Wodehouse. A, McFadyen. A, Buis. A: The Aethetic Appeal of Prosthetic Limbs and the Uncanny Valley: The Role of Personal Characteristics in Attraction: International Journal of Design, Volume 09, Issue 01, pp.67-81. (2015) ISSN 1991-3761

6. Schwind. V, Jager. S: The Uncanny Valley and the Importance of Eye Contact: Journal of Interactive Media: Volume 15, Issue 01 (2016) DOI: https://doi.org/10.1515/icom-2016-0001

7. Looser. E. C, Wheatly. T: The Tipping Point of Animacy, How When and Where We Perceive Life in a Face: Journal for Psychological Science (aps), Volume 21, Issue 12 (2010). DOI:10.1177/0956797610388044

8. Hanson Robotics: Sophia: Retrieved from: http://www.hansonrobotics.com/robot/sophia/ (2017), Accessed (13.04.17)

9. Taylor. H: Could you all in love with this robot. Retrieved from: http://www.cnbc.com/2016/03/16/could-you-fall-in-love-with-this-robot.html. (2016) Accessed (14.04.17)

10. Mori. M: The Uncanny Valley, Energy, Volume 7, Issue 4, pp.33-35 (1970) Trans: MacDorman. K.F & Minato. T: Android Science (2005): Retrieved from. http://www.androidscience.com/theuncannyvalley/proceedings2005/uncannyvalley.html. Accessed 09.04.17.

11. Baudrillard. J: Simulacra and Simulation (1984): Trans, Glaser. S: The University of Michigan Press (1994), pp.02-09. DOI: 10.3998/ mpub.9904

12. Gazeta. R: Russian Android Robot ‘Fedor’ can screw in lightbulbs and do the splits. (2016) Retrieved from http://rbth.com/science_and_tech/2016/12/09/russian-android-robot-fedor-can-screw-in-light-bulbs-and-do-splits_655053. Accessed 14.04.17

13. Hanson. D: Why We Should Build Humanlike Robots, (2011) Retrieved from. http://spectrum.ieee.org/automaton/robotics/humanoids/why-we-should-build-humanlike-robots Accessed 14.04.17

14. Huang. C, Gu. J, Luo. J, Li. H, Zhang. J, Ke. J: Optimal Design of a Robotic Eye based on Spherical Parallel Mechanism by Evolutionary Strategy Algorithm. Information and Automation (ICIA) (2014) IEEE International Conference. DOI: 10.1109/ICInfA.2014.6932797

15. Jiji. J: Robot Run Henn Na Hotel in Nagasaki Enters Guinness Book of World Records: Retrieved from. http://www.japantimes.co.jp/news/2016/11/18/business/nagasakis-robot-staffed-henn-na-hotel-gets-guinness-nod/. (2016): Accessed 14.04.17

16. Moosaei. M, Das. K. S, Popa. O. D, Riek. D. L: Using Facially Expressive Robots to Calibrate Clinical Pain Perception: AMC/IEEE International Conference on Human-Robot Interaction (2017). DOI 10.1145/2909824.3020216

17. Katsu. J, Kim. J, Alspach. N. A: Soft Body Robot for Physical Interaction with Humans. Pub.No.: US 2017/0095925 A1 (2017) Disney Enterprises INC, Burbank, C.A, U.S.A, Appl No 15/047,820, pp.1-34.

18. Katsu. J, Kim. J, Alspach. N. A: Soft Body Robot for Physical Interaction with Humans.: Retrieved from.:http://www.appft.uspto.gov/netacgi/nphParser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearchbool.html&r=1&f=G&l=50&co1=AND&d=PG01&s1=15%2F047820&OS=15/047820&RS=15/047820. (2017). Accessed 18.04.17

19. Suzuki. Y, Galli. L, Ikeda. A, Itakura. S, Kitazaki. M: Measuring Empathy for Human and Robot Hand Pain Using Electroencephalography: Scientific Reports, Volume 5, Article 15924.: (2015)

20. Kret. M. E, De. D. CK: Pupil-mimicry conditions trust in partners: moderation by oxytocin and group membership: Proceedings of the Royal Society: Biological Sciences (2017), DOI:10.1098/rspb.2016.2554.

21. Kinner. V, Kuchinke. L, Dierolf. M. A, Merz. J. C, Otto. T, Wolf. T. O: What our eyes tell us about feelings: Tracking pupillary responses during emotion regulation processes.: Psychophysiology. Issue 54 pp.508-518, (2017). DOI: 10.1111/psyp.12816

22. Schnuckle. G: Expressive eye with dilating and constricting pupils.: Publication Number US 7485025B2. (2006): Retrieved from. https://www.google.com/patents/US7485025. Accessed 09.04.17.

23. Schnuckle. G: Expressive eye with dilating and constricting pupils.: Publication Number US 7485025B2. (2006): Retrieved from. https://patentimages.storage.googleapis.com/US7485025B2/ US07485025-20090203-D00002.png. Accessed 09.04.17

24. Prendergast. K. W, Reed. T. J.: Simulator eye dilation device.: Publication number. US5900923. Retrieved from. http://www.google.co.uk/patents/US5900923.: Accessed 09.04.17

25. Prendergast. K. W, Reed. T. J.: Simulator eye dilation device.: Publication number. US5900923. Retrieved from. http://patentimages.storage.googleapis.com/pages/US5900923-2.png,: Accessed 09.04.17

26. Breedon. J. P, Lowrie. P.J.: Lifelike prosthetic eye: the call for smart materials.: Expert Review of Ophthalmology, Volime 8, Issue 04, pp. 135-137. (2013).: doi.org/10.1586/17469899.2013.814907

27. Nottspost. MB.: New artificial eye developed in Nottingham.: (2013) Retrieved from http://www.nottinghampost.com/new-artificial-eye-developed-nottingham/story-18597186-detail/story.html,: Accessed 16.04.17

28. Lapointe. J, Durette. J.F, Shaat. A, Boulos P.R, Kashyap. R.: A ‘living’ prosthetic iris.: Macmillan Publishers: Eye, Issue 24, pp.1716-1723. (2010)

29. Lilly. B.: Cab Cameras Gain ‘Machine Vision’: New Video Systems Now Able to See Vechicles Lanes, To Better Track Driver Behaviour.: (2017) Retrieved from. http://www.ttnews.com/articles/ basetemplate.aspx?storyid=44855&page=.: Accessed 19.04.17

30. Wolfe. T.B, Faulkner. M.G, Wolfaardt .J.: Development of a shape memory alloy actuator for a robotic eye prosthesis.: Institute of Physics Publishing: Smart Materials and Structures. Issue 14, pp.759-768, (2005). doi:10.1088/0964-1726/14/4/035