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DEVELOPMENT OF EYE TRACKING PROCEDURES USED FOR THE ANALYSIS OF VISUAL BEHAVIOR - STATE OF ART

Lazar Alexandra - Maria[1], Baritz Mihaela Ioana[1]
[1]Product Design, Mechatronics and Environment Department, Transilvania University from Brasov, bd-ul Eroilor nr. 29, 500036 Brasov, Romania, alexandra.lazar@unitbv.ro, mbaritz@unitbv.ro

Abstract: *Eye tracking is widely used by both researchers and professionals in various field. It is an instrument of monitoring the cognitive process of learning, a screening and treatment method and a vast field of research and marketing. Due to the rapid evolution of technology, eye tracking has become one of the most useful and easy to use instruments that can aid in the decoding of languages, development of software and the understanding of human behaviour and its underlying thought processes.This paper is intended as a: a presentation of various research based on eye tracking, a presentation of the methods of measuring ocular movement, a description of the fields of research aided by this method and a description of the main applications and platforms in which information gathered via eye tracking is used.*
Keywords: *eye - tracking, screening, evolution.*

1. INTRODUCTION

The visual system is considered the most important system of the human body after the brain, but the foremost in terms of sensory systems, as 85 percent of the information the organism obtains from the environment is processed through it [1].
Devices used for measuring ocular movements are commonly called eye-trackers [2]. According to previous research, eye tracking is a process that can: monitor ocular movements (in terms of direction and speed), determine the position of the eyeball, identify and monitor the fixation process and the convergence or visual attention towards an object.
As a technology that facilitates understanding of human behaviour and its underlying thought processes, eye tracking is studied and used in various fields, both for fundamental and practical research or for various commercial applications [3]. Monitoring techniques are adapted to various types of eye movement and can: identify and evaluate the eye's position relative to the head, determine the eye's orientation in space or correlate the human body's posture to the direction of glancing [2].
The spectrum of applications in which information gathered by eye tracking is processed and used is in continous development. Therefore, it brings about the necessity of constant enhancing of products, both in development and already launched [4]. Some of the fields which use visual monitoring to identify and interpret facial expressions and ocular movement are: artificial intelligence, correction of visualisation problems, the enhancement of e-learning platform, the improvement of flight or leadership-related military simulations and applications or the development of devices and software for monitoring, diagnosis and fast treatment of various ailments [4].
Since its widespread adoption as an analysis method, eye tracking has also been used in: marketing (visual training, which refers to the application of stimuli and monitoring the consumer's behaviour towards that stimuli and associated products), in neuroscience or in the development of human-machine interfaces. According to [5], eye tracking research provides information regarding the way in which visual attention is distributed and the manner in which a stimulus can determine a partial or total modification of human preference. Recording the precision rate of correct answers is also of significant importance. Generally, eye tracking devices record the participant's view direction as raw data, which is processed and interpreted using specific software and applications [5].
Eye monitoring systems measure their physical rotation and the direction of sight and can therefore "decode" on-line cognitive abilities. In this manner, eye tracking is a valuable method for the observation of cognitive processes [2, 6].

2. THE HUMAN VISUAL SYSTEM

The visual system, according to past research of field professionals, is comprised of three main processing components: the eyeball, the visual transmission pathway and the visual cortex. The lightwaves that enter the eye are converted at the retina in neural signals, which are transported and organised by the visual pathways (the optical nerve and the optical chiasma). These lead the signals towards the visual cortex in the brain, which achieves the superior processing of eyesight (i.e., visual perception). The radiation that enter the eye through the cornea is focused on the retina by the lens while the ciliar body, located “from the root of the iris to the orra serrata” has a role in the “accommodation process” of the lens [6, 7]. The iris, or more specifically the pupil, regulate the intake of light radiation of the eyeball [6]. The choroid, with its heavy vascularisation and intense pigmentation, is the medium that feeds blood into the eye and absorbs the scattered light [6, 7].

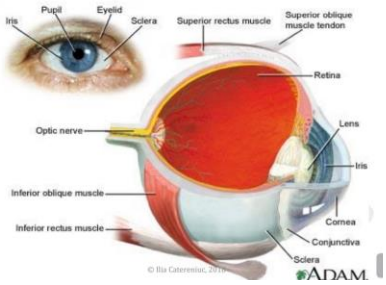


Figure 1 – The anatomy of the eyeball [8]

The interior layer of the retina, which contains the photoreceptors (that detect the impulses of electromagnetic radiation in the visual spectrum), is characterised by the neuron network which processes the impulses. This signals are filtered and transmitted to the neuron layers. Once they reach the visual cortex, these neural signals are fused and interpreted to form the perception image and then stored in the memory layer [6].
The retina contains about 100 to 120 million rods and 7 to 8 million cones, but only about 1 million retinal ganglion cells. The peripherical portion of the retina, which mainly contains rods, has a high photosensitivity when illumination is low [9]. According to research, there three main types of rod cells to which color vision is attributed; they contain photo pigments sensitive to the three fundament light waves (RGB) [10]. Cone cells mainly cover a central portion of retina called fovea centralis and provide acute visual perception when the illumination is high [9].
The visual perception is achieved in three areas of the retina: fovea centralis (in the center of the retina), parafovea (the region around the fovea centralis) and the perifovea (which is outside the parafovea). According to research, the fovea centralis offers the sharpest vision, followed by the parafovea and the perifovea which offer the least visual acuity [11].
In its attempt to see things as clearly as possible, the human organism carries out adjustments of the eyeballs’ position, so that the observed object is in the visual field of sharpest perception (fovea centralis). Researchers have identified and classified various types of ocular movement: some which maintain the fovea on a visual target in the environment (light, jerky search for example), while others that stabilise the eyes while the head in moving (in the process of fixation for example) [2, 11, 12, 13].
Furthermore, studies have shown that different subjects have various distances of sight/perception, which indicates the existence of efficient zones of vision, with information not being gathered during jerky eye movements [11].

3. EYE TRACKING APPLICATIONS

According to research [6], there are numerous fields in which information gathered using eye-tracking is used to enhance various activites or increase the amount and quality of gathered information. So, far eye tracking has also been extensively used in psychology, neuroscience and to study the interaction of humans and computers [6, 11].
Most of the applications are related to information processing, such as: text reading, the perceptive process, testing, musical sheet reading. In these cases, measurements of ocular movement illuminate the fundamental processes and mechanisms involved in reading comprehension [14] and visual perception [15]. On the other hand, the eye tracking techniques implemented by Jacob & Karn [16] and Goldberg & Helfman [17] were aimed at investigating human-machine interaction Hyönä [18] or media communication [11]. Fields of application for eye movement monitoring include branches such as: online advertising and website design, medical research and

product development, evaluation of sports training, enhancing marketing techniques, screening and treatment methods.

Therefore the development of different approaches to the processing and interpretation of data was necessary. The main approaches to data processing are: statistical algorithms, series editing algorithms and visual analysis techniques. Regardless of the method used for interpreting eye tracking data (by visual statistics or data analysis), the volume of data that are generated is very high and has to be taken into consideration [5, 6]. According to Sundstedt [6], recent developments have made eye tracking technology much more user-friendly, although there still limitations in terms of precision. [2] States that eye monitoring systems can be used for diagnosis or interaction.

Diagnosis using eye tracking is carried out using a monitoring device that records ocular movements which are then analysed using procedures developed experimentally. Meanwhile, an interactive system uses the sight direction of the user as a method of interaction with the digital application. In other words, the user's sight can be considered an alternative method of input [6]. [2] Also classifies interactive systems as selective or contigent upon the sight process. In selective systems, the fixation point is a method of input similar to using a mouse to navigate a computer screen, while in contingent systems the virtual environment is modified based on the observer's sight [2, 6].

4. EYE TRACKING METHODS

Numerous types of eye tracking systems have been developed in the past 100 years, since the development of the first reading research devices [6]. There are two techniques used for the study of ocular movement: one that measures the position of the eye relative to the head and one that measures the spatial orientation of the eye. The most common system for measuring the spatial orientation of the eye is video eye tracking using corneal reflexion. The main advantage of this method is that it is unobtrusive and does not disturb the user in any way [6]. Electronical methods are comprised, according to Duchowski [2], of four main categories of techniques for usage or measurement: Electro-OculoGraphy (EOG), Scleral Contact Lens/Search Coil, Photo-OculoGraphy (POG) or Video-OculoGraphy (VOG) and video-based combined pupil or corneal reflexion [2]. According to Young & Sheena [19], in the early 1970s EOG was the most commonly used method to evaluate ocular movement.

The first objective method of measuring eyeball movements, which used corneal reflexion, was proposed in 1901 and patented by Robinson (apud Duchowski [2]) in 1968. To improve the measurement accuracy, o series of techniques were developed in the 1950s that were based on using contact lens. The devices attached to these contact lenses, which varied from small mirror to metal micro-coil, could carry out measurements due to the physical contact between the contact lens and the eyeball. Therefore, they generally offer measurement of high fidelity and accuracy [2].

4.1. Electro - OculoGraphy (EOG)

This method is considered to be the most widely used for eye tracking. It measured the variation of the electrical potential of the skin, by using electrodes positioned around the eyes.

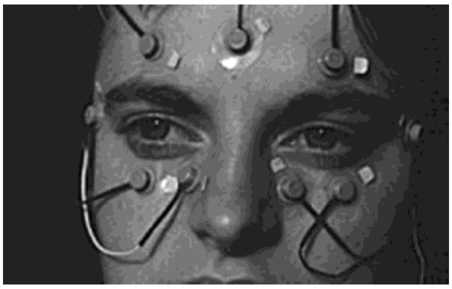
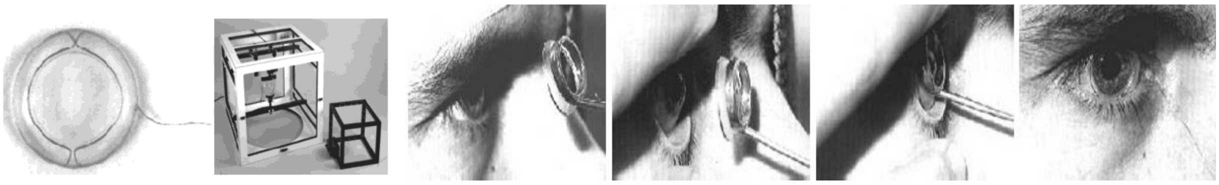


Figure 2 - Example of electro-oculography (EOG) eye movement measurement [2]

According to [2], recorded values of electric potential are in the 15 – 200 μV range, with the systems having a nominal sensitivity of around 20 μV per degree of eye movement. Although still widely in use, this method measures ocular movements relative to the head. Therefore, it can only evaluate the position of the point of fixation (the point at which the user's sight is directed) if at the same time the head's position is also recorded (by using a head-mounted tracking system).

4.2. Scleral Contact Lens / Search Coil

One of the most precise methods for measuring eye movement involves the attachment of an optical or mechanical reference element to a contact lens which is then applied directly to the subject's eyeball [2]. This technique has evolved to the point where a large, modern contact lens that covers the cornea and the sclera is used. To prevent the contact lens slipping, a spindle is attached to it.



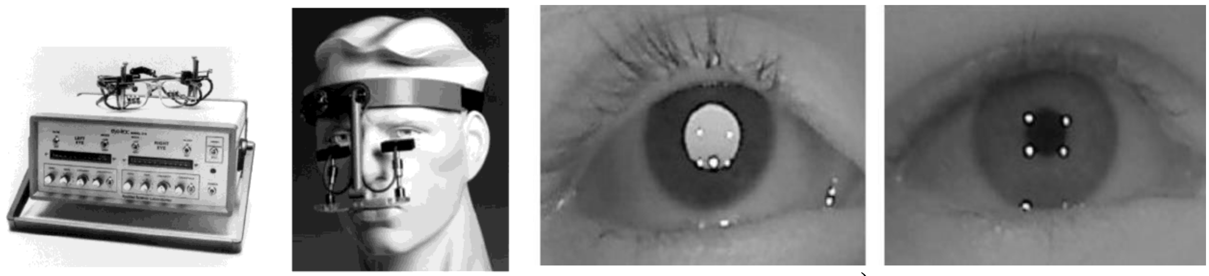
a) b)

Figure 3 – a) Example of search coil embedded in contact lens and electromagnetic field frames for search coil eye movement measurement. b) Example of scleral suction ring insertion for search coil eye movement measurement [2]

Different mechanical or optical devices can be placed on the spindle attached to the lens, with reflectant elements and wire micro-coils being the most popular in magnetico-optical configurations. The working principle involves a coil of metalic wire which moves through an electro-magnetic field. Although this method is the most precise way of tracking ocular movement, with a precision of 5-10 arc seconds for a 5-degree movement [26], it is still the most intrusive. Lens application requires concentration and an experienced examiner, while wearing the lens can cause disconfort to the subject.

4.3. Photo - OculoGraphy (POG) or Video - OculoGraphy (VOG)

In this category are grouped a large variety of techniques for recording eyeball movement, which operate by measuring distinctive features of the eyes during rotation or translation movements, such as: the apparent pupil shape, the limbus position or the corneal refraction of a (usually infrared) light-source (usually infrared) placed nearby.



a) b) c)

Figure 4 – a) Example of infra-red limbus tracker apparatus; b) example of infra-red limbus tracker apparatus, as worn by subject [2]; c) Images of the eye illuminated by the IR sources in bright eye mode (left) and dark eye mode (right) [20]

The recording of ocular movement determined using these techniques can be carried out manually or automatically. Manual evaluation (accomplished with watching the video sequence at a frame-by-frame rate) can lead to errors and is also affected by the temporal sampling rate of the video recording device. Automatic tracking of the limbus area often involves photodiodes (very often emitting infrared light) that are mounted on the frames of glasses.
According to Young & Sheena [19], some of these investigative techniques require pinning the subject's head (by using a head/jaw support or a bite bar) to eliminate possible errors.

4.4. Video - Based Combined Pupil / Corneal Reflection

Most of the eye tracking devices use sequences of digital images to determine the fixation point (the point at which the subject is looking at). Video eye tracking uses video cameras and image processing techniques to determine the fixation point in real time, and can focus on one or both eyes at the time, tracking its or their movements for a specified time. The device can be mounted on a table, on the user's head or glasses frame, dependent on application. The performance of the method has been constantly increasing, with it currently being the most adequate for use in interactive environments.

The reflexion of the light source (usually infrared) on the cornea is measured relative to the center of the pupil. In this manner the method can be used even when the light source is installed further from the subject. For mobile eye tracking systems that are attached to a head-mounted frame, the system cannot compensate for head movements so the evaluation of ocular movement is done in two coordinate systems simultaneously (a fixed and a mobile one).

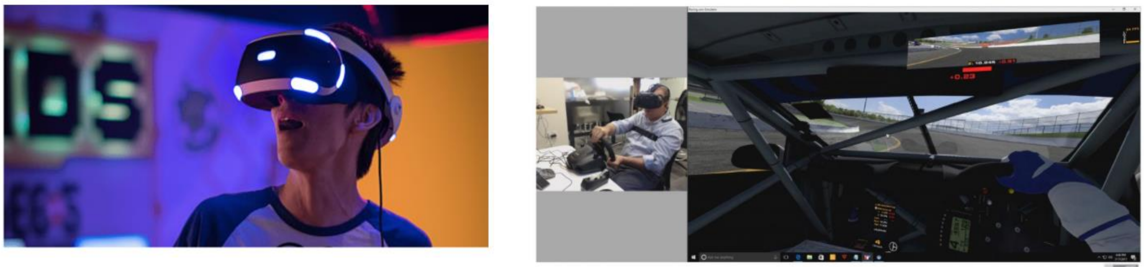


Figure 5 - Examples of eye – tracker devices [21]

One of the major objectives of virtual reality is to present an imaginary in a most convincing and real manner to its users. The discrepancy between the consumers' requirements and the degrees of their accomplishment drives the constant enhancement of these products. Therefore, modern head-mounted devices that use the latest technologies to present captivating vistas are now widely available [22].

5. DEDICATED/ SPECIALIZED SOFTWARE IN EYE - TRACKING

Regardless of the field of application, eye tracking is one of the tools most readily available for software development, enabling applications that can easily run on tablets or smartphones without the need for other sensors or devices [23].
Eye tracking is an important data source for both offline analysis or as input for realtime applications [6].
In the development of a graphical application for eye monitoring, the most important requirement is mapping the eye tracker's coordinates to the correspondent reference frame of the software application. The uncontested importance of eye tracking is therefore apparent in its applications in so many fields, its use in numerous research carried out over the years [2] and in various products launched on the market.

Figure 6 – Domenii in care se utilizeaza eye - tracking [3, 24]

GazeSense ™ is a software for 3D monitoring of eye movement, which offers realtime sight decoding without the need for the subject to wear glasses. Using surveillance cameras, as its developers suggest, enables this product to monitor multiple subjects simultaneously, monitor their attention in realtime and label objects of interest in the environment [3].
Researchers affiliated with the **iMotions** projects have designed and perfected a platform for integrated analysis that has a high accuracy and can support research into human behaviour. According to its creators, **iMotions** can seamlessly integrate and sync multiple biometric sensors, in order to present a wider perspective. Efficient integration of emotion recognition software and various biometric sensor modules that the clients choose to use (for eye tracking, galvanic skin response, EEG or ECG analysis) allows a clearer understanding of human behaviour [8]. Software applications like **iMonitor** can present stimuli in any manner, from images, videos and websites to real-world environments or virtual reality simulations.

6. EYE TRACKING – METHODOLOGIES

Looked at not just as a marketing instrument but as a method for screening and treatment, eye-tracking has a clearly defined role in the evaluation of both children and adults [5].

According to information presented by researchers from Stuttgart, Germany [5], the number of papers, conferences and textbooks on eye tracking has been on an upper trend in the last decade. The first IEEE Symposium on Information Visualisation, which took place in 1995 is considered a landmark event, which created an interest in eye tracking that has only increased with time. Using in a large spectrum of applications, this method leads to new challenges both in the field (like eye tracking in a 3D environments) and inter-disciplinary [5].

Eye tracking devices record the fixation (or ocular convergence) of participants subjects, to various stimuli. The recording rate and data fidelity generally depend upon the devices' characteristics. Modern devices allows recording rates in the range of 60 to 120 Hz, while newest devices can record at frequencies of 240 Hz or even higher. The recording rate is the number of fixations points registered per second [5].

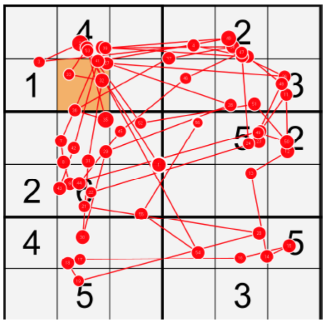


Figure 7 - In typical scanpath visualization, each fixation is indicated by a circle, where the radius corresponds to the fixation duration. Saccades between fixations are represented by connecting lines between these circles [5]

Positioning of the fixation points overlaid over a stimulus is one of the simplest techniques for the visualisation of eye tracking data. This method has been used for dinamic stimuli ever since 1958 [25]. A combined visualisation of fixation data from multiple users and stimuli is commonly called "bee hive". Aggregations of focalisation over time and/or participants are referred to as: attention map, fixation map or heat map. The main purpose of attention maps is to present an overview of ocular movements and to identify the stimuli regions that attract the most attention (called Areas of Interest – AOI) [5].

A paper published in 2011 by researchers from New York University [26] provides two major innovations, as its authors state. The study, whose participants were six 14-month old infants, aimed at testing the feasability of eye tracking in a complex environment. The innovation of this research, as presented by the authors, is the fact that a wireless eye tracking device was used for the first time. This allowed the recording of ocular movement data without hindering the infants in any manner. The study presents a new methodology for analysing visual exploration of infants during spontaneous, natural interactions with caretakers, objects and obstacles [26].

In 2016, another group of researchers [27] studied the manner in which ocular indicators (such as: blinking duration, speed of jerky ocular movements and pupil dilation) were influenced by the variation of cognitive information volume during video gaming. By sistematically modifying the difficulty of a Tetris game (by increasing the speed at which the pieces were falling), the researchers tracked the correlation between ocular values and difficulty variation.

These papers conclude that some ocular movements are correlated with the volume of work (highlighted in these cases by the difficulty of the task to be carried out). As an example, a negative correlation is found between blinking duration or fixation and difficulty, while the maximum speed of jerky ocular movements and pupil dimension are positively correlated with difficulty. Overall, the best predictor for task difficulty is the pupil dimension [27].

The purpose of a study carried out in Germany in 2016 [22] was to analyze eye tracking data in order to evaluate the appearance of effects like tunnel-vision, for various pathologies. This research showed that a significant degradation of visual fixation was present at the periphery of the subjects' fields of vision. The authors establish that there are major differences in terms of the subjects' capacity to concentrate their attention on moving or static targets. Regardless, when participants are tracked, their eyesight is spread over a much higher area in the case of moving targets, with the authors evaluating this data as "counterintuitive". The rate of errors is attributed to the presence of a powerful effect of tunnel-vision induced by the need to follow moving targets. The author state that not only the visual field of participants is effectively reduced, but that it determined an average quality of evaluation. According to the authors, this paper could serve as a basis for future research in this field, as the

information presented can be utilised for future adaptation and improvement of rendering performance, by enhancing the level of visual quality [22].
In 2016, researcher from the University of Georgia and from Massachusetts Institute of Technology [23] carried out a complete tracking of eye movement by using mobile devices (the most common devices available globally nowadays). The authors used GazeCapture and iTracker (which involve neural networks) developed a new system of large-scale eye tracking. The system can run on any modern mobile device and captures 10-15 frames per second in realtime. By making use of a large storage capacity for the variety of data gathered, the authors demonstrate the existence of a pattern that can predict the direction in which eyesight will turn. The experiment was carried out on over 1450 persons and required 2.5 million frames. A significant reduction of errors relative to previous approaches is reported, with error values between 1.71 and 2.53 cm (without device calibration). Errors were reduces to the 1.34 to 2.12 cm range by calibrating the recording devices (mobile phones or tablets). In addition, stored data can be used as a training dataset by the *iTracker* application, in order to improve the accuracy of other experiments [23].

7. CONCLUSIONS

Eye tracking can provide valuable data about the behaviour and preferences of customers or visitor, which are not always apparent to other investigative methods. For example, although face-to-face surveys provide immediate answers, they fail to highlight and make use of information present in the subject's subconscious [28]. The eyes, which are often called a "mirror into the soul", are the link between our inner self and outer environment. For example, changes of the pupil's dimension can show us that the person before us is intrigued, or that they manifest an intense emotional response. The ways in which individuals react to stimuli help marketing experts elaborate atractive strategies, so that the number of customers is constantly increasing. These techniques also allow companies to increase the usability of their web platforms, whose content is designed to attract [28].
Alternative methods of interacting with video games are especially important for disabled persons, for which traditional methods (like using the mouse and keyboard) are far from ideal [6].
To conclude, eye tracking is a vast and dynamic research field, in which software applications able to process larger and larger quantities of data collected from ever more complex hardware systems are developed. The scope of applications and the accuracies obtained are therefore constantly expanding.
In the last years especially, eye tracking applications shine a new light on various behavioural stances and can serve an auxiliary role in various human endeavours (artistical, sports-related and so on), with the aim of improving human performance.

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