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# Application of eye tracking in medicine: A survey, research issues and challenges

Katarzyna Harezlak*, Pawel Kasprowski

*Institute of Informatics, Silesian University of Technology, ul. Akademicka 16, 44-100 Gliwice, Poland*

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ABSTRACT

The performance and quality of medical procedures and treatments are inextricably linked to technological development. The application of more advanced techniques provides the opportunity to gain wider knowledge and deeper understanding of the human body and mind functioning. The eye tracking methods used to register eye movement to find the direction and targets of a person's gaze are well in line with the nature of the topic. By providing methods for capturing and processing images of the eye it has become possible not only to reveal abnormalities in eye functioning but also to conduct cognitive studies focused on learning about peoples' emotions and intentions. The usefulness of the application of eye tracking technology in medicine was proved in many research studies. The aim of this paper is to give an insight into those studies and the way they utilize eye imaging in medical applications. These studies were differentiated taking their purpose and experimental paradigms into account. Additionally, methods for eye movement visualization and metrics for its quantifying were presented. Apart from presenting the state of the art, the aim of the paper was also to point out possible applications of eye tracking in medicine that have not been exhaustively investigated yet, and are going to be a perspective long-term direction of research.



## 1. Introduction

The performance and quality of medical procedures and treatments are inextricably linked to technological development. The application of more advanced techniques provides the opportunity to gain wider knowledge and deeper understanding of the human body and mind functioning. The eye tracking methods used to register eye movement to find the direction and targets of a person's gaze are well in line with the nature of the topic. Such information is useful not only in revealing abnormalities in eye functioning and thus ensuring appropriate therapy but also in cognitive studies focused on learning about peoples' emotions, intentions and how they utilize their knowledge and skills. However, in order to make this reasoning feasible, some data has to be collected by applying an appropriate procedure – adequate to the issue under consideration. There are several decisions which have to be made. One of them concerns the device used for the eye movement registration. Furthermore, an experiment of the type which forces and emphasizes a studied phenomenon, has to be developed. Well-defined test enables obtaining valuable and useful eye movement recordings that can serve for the purpose of this phenomenon analysis. One of its elements is eye movement visualization, which relates gazes to areas of an observed scene and facilitates understanding analyzed processes.

The usefulness of the application of the eye tracking technology in medicine was proved in many research studies. Most of them were devoted to the exploration of the nature of various types of diseases. Nevertheless, there are also works in which eye tracking was used for other purposes, such as therapy or improvement of medical education.

The aim of this paper is to give an insight into those studies and the way they utilize eye imaging in medical applications. At first the eye tracking methods and algorithms, as well as the eye movement characteristic were explained. Attention was especially focused on VOG technique based on eye image processing, commonly used in current eye tracking solutions. Based on this knowledge, the experiments used in the aforementioned studies were described. Although they provided answers for many asked questions, there are still unanswered ones and additional studies are required. The presented survey may prove helpful in this activity.

* Corresponding author.
*E-mail address:* katarzyna.harezlak@polsl.pl (K. Harezlak).

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**Fig. 1.** Eyes of people on image detected with the Viola–Jones algorithm (Jones and Viola, 2003).

## 2. Eye tracking techniques

Some research in tracking eye position and eye movement was presented in the literature already in the previous centuries mostly in psychology and reading (Porterfield, 1737; Dodge, 1900; Huey, 1908; Nixon, 1924). However, owing to the development of eye tracking methods during the last decade, wider exploration of eye movement characteristics has become possible. Over these years techniques for such data collecting significantly changed.

The first, the most accurate and at the same the most intrusive is based on a contact lens equipped with mirrors (Yarbus, 1967) or a magnetic search coil, being inserted in the eye (Kenyon, 1985; Remmel, 1984). In the latter case a thin copper wire is placed in a silicon annulus. The lens is connected to a mechanical or optical device, such as a coil that measures the variation of an electromagnetic field, when a person moves his/her eyes. However, due to the method's invasiveness the length of an experiment has to be limited to 30 min even when the eye is anesthetized, which restricted the usage of the method.

The second technique called Electrooculography (EOG/E.O.G.) utilizes the corneo-retinal standing potential existence between the front and the back of the human eye, measured with usage of skin electrodes placed in the vicinity of the eye. When the eye rotates towards them they become more positive whereas rotation in the opposite direction makes them less positive. This method is also perceived as relatively cumbersome and uncomfortable for the subjects. Another disadvantage is the limitation of its use only for laboratory experiments without the possibility for its application on a daily basis and mobile circumstances.

The third and at the same time the most popular method is video-based eye tracking (VOG) – recording eye movement by means of digital video cameras. Eye-tracking systems capture a sequence of images (Fig. 1). The eye positions and movements are determined by the use of the information obtained from the images captured. Therefore the eye camera has to be positioned in such a way that eyes remain visible in the recording.

VOG eye trackers do not require direct contact with eyes, which makes them more comfortable and less intrusive. Although, until recently relatively complex and very expensive, this technique, due to the technological and image processing algorithms development, has become affordable for the wider research community. However, it must be remembered the accuracy of such eye trackers significantly depends on the resolution of the images they record.

Eye images may be obtained either by utilizing ambient light reflected by the eyes (passive approach) or by the application of an infrared illuminator (active light) (Hansen and Ji, 2010; Lupu et al., 2013). The main disadvantage of the former method is the significant impact of varying ambient light conditions on detecting iris/pupil contours being traced (Fig. 2). The usage of the infrared spectrum strongly alleviated this problem and being invisible, does not distract the user or cause the pupil to contract (Zhu and Ji, 2005).

**Fig. 2.** The same eye image recorded by the same digital camera with and without IR filter (Genius FaceCam 2025 with IR filter switch). It is visible that a pupil is much easier to find on the infra-red image.

The majority of research and industry solutions, for the gaze tracking purpose, apply active light sources, achieving high accuracy rates. Most implementations use Near IR Light Sources with a wavelength approximately 880 nm, almost invisible for the human eye, but still possible to be detected by most commercial cameras (Morimoto and Mimica, 2005). Depending on the light direction it is possible to produce the bright/dark pupil effect. The first of them is achievable when the light source is collinear with the eye visual axis, because a camera registers the light reflected from the retina (so shows a dark pupil) (Fig. 3).

However, there are some challenges, which have to be faced when utilizing VOG methods. They are discussed in subsequent sections, while a more detailed description of the eye gaze tracking techniques may be found in Lupu et al. (2013), Van der Geest and Frens (2002), Chennamma and Yuan (2013), and Ferhat and Vilariño (2016).

### 2.1. Determining position of an eye

A set of eye recordings obtained from an eye tracker is subjected to the advanced image processing aimed at estimating subsequent positions of the eye and the direction of a gaze.

The image-base eye detection and tracking is an extensive topic and different methods have been developed to extract pupil or iris from an eye image, which in the literature are divided into two main groups *appearance-based* and *feature-based* (Chennamma and Yuan, 2013; Feng Lu et al., 2011; Lai et al., 2014; Wang et al., 2016). Additionally, the *model-based* solution was also enumerated in Lupu et al. (2013) and Ferhat and Vilariño (2016) and *hybrid* models in Hansen and Ji (2010) and Ferhat and Vilariño (2016) are mentioned too.

*Appearance-based* methods directly compute features from the appearance of eye images and estimate gaze points using a function mapping them to a region of a given scene. In studies concerning this kind of approach various solutions as such a function are

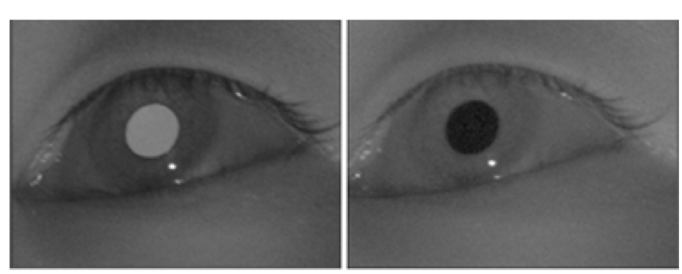

**Fig. 3.** Example of images with a bright pupil and dark one (right), obtained from digital camera.