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Natural Eye Gaze Computer Interaction for Medical Oculography Diagnosis: Current Status and Future Prospects

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Abstract - With recent technological developments, modern computing systems are becoming more and more powerful. Common computers are capable of calculating more than 50,000 million instructions per second. Currently the biggest obstacle in computer usage is slow communication between the human and the computer. With innovation and development of novel (natural based) sensors capable of capturing positions and natural motion of human body a new, natural, way of interacting with computer is enabled.

This paper gives an overview of eye tracking technology, and presents its application in nature based human-computer interaction (HCI) systems by extending standard controllers, such as the keyboard and the mouse. Novel approaches enable HCI closer to the communication patterns of human beings. In addition, the usage of those concepts in applications for eye diseases and disorders diagnostics and rehabilitation is discussed.

Keywords: eye tracking, computer interaction, hci, oculography, medical diagnosis.

I. INTRODUCTION

The use of standard interaction devices (such as mouse and keyboard) for communication between human and computer is already addressed as one of the biggest obstacle in modern computer usage [1], [2]. In this research field even HORIZON 2020, the EU Framework Programme for Research and Innovation, recognized problem and necessity for improvement. In the year of 2014, one of the first opened calls in HORIZON 2020 Programme, is the special topic Multimodal and Natural computer interaction, in the section ICT 2014 - Information and Communications Technologies.

Recent development of intelligent sensors for capturing and recognizing natural human behaviours enabled novel approaches to answer to this problem by making human-computer interaction (HCI) a natural process. During last few years several different controllers emerged as products affordable for general population.

Microsoft Kinect controller is a multi-modal sensor which contains a RGB camera, an infrared (IR) emitter and an IR depth sensor, a multi-array microphone and a 3-axis accelerometer. With all of these inputs Kinect is able to determine its current orientation, to find the location of the sound source and the direction of the audio wave, to identify human in the scene, to find the location of human body parts, to recognize human body poses and gestures [3]. All of the calculations were performed by computer embedded into the device.

The Leap Motion controller is a small USB peripheral device produced by Leap Motion, Inc. This sensor contains two monochromatic IR cameras and three infrared LEDs. With its smaller observation area, higher resolution and acquisition rate the Leap Motion sensor differentiates from the Kinect. Unlike the Kinect, which is more suitable for whole-body tracking, the Leap Motion is used for acquiring positions, orientations and gestures of human hands and fingers in very high resolution and precision [4].

Eye tracking sensor also emerged as one of the most promising device for HCI and similar applications. During last few years several companies developed eye tracking sensors using different technology, however the devices were still too expensive for general public. In year 2013 Tobii announced a new device Tobii EyeX, a high accurate eye tracking device with affordable price for general population. The true benefit of eye tracking is opportunity to gather data for HCI even for the population with disabilities to use their limbs. The other important feature is a capability to use standard interaction methods, using keyboard and mouse, and gain an additional information to enhance the interaction. Based on those advances, the aim of this paper is to address new capabilities for HCI and new approaches for diagnostics and rehabilitation in the field of medical oculography.

II. EYE TRACKING TECHINQUES

The most popular and also commercially available method to measure the rotation of the eye is "corneal-reflection/pupil-centre" [5]. It is an optical tracking method without direct contact to the eye. This method uses benefits of corneal, which reflects a light directed into the eye. In order to decrease dazzling, infrared light is emitted to the eye. Light enters the retina and a large proportion of it is reflected back, making the pupil appear as a bright, well defined disc known as the "bright pupil" effect. This effect is achieved if the infrared light emitter is placed close to the optical axis of the infrared camera

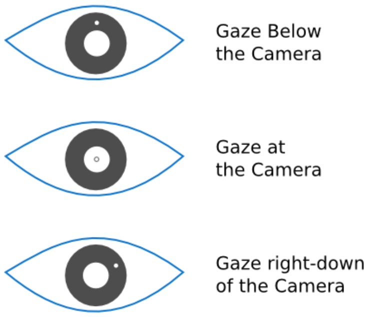


Figure 1. Corneal reflection

device. Setting emitter away from the optical axis will cause the pupil to appear dark. Additional data that can be collected with infrared camera is corneal reflection which is appearing as a small, but sharp glint Figure 1. Based on these two facts and data collected during calibration procedure, a point of regard (gaze point on the surface) or a gaze direction can be calculated using trigonometric calculations.

The complexity of estimation point of regard is depended on number of cameras and light sources. The point of regard can be estimated using one camera and one light source only if the head is completely stationary. Estimation of the point of regard with free head movements is enabled by using one camera and multiple light sources followed with multiple point calibration procedure. Theoretically, it is possible to have one-point calibration procedure to estimate point of regard if multiple cameras and multiple light sources are used. It has been shown that main sources of gaze estimation errors are the discrepancy between the shape of real corneas and the spherical corneal shape assumed in the general theory, and the noise in the estimation of the centres of the pupil and corneal reflections [6].

Limiting factors of the bright pupil method for eye detection are size of the pupil, environmental light and retinal reflection properties. The last one brings most concern and depending on these properties different approach is used, bright pupil or dark pupil technique [7]. This study has found correlation between pupil size and pupil intensity leading to conclusion that subjects with larger pupil sizes are producing higher intensity values. In general, bright pupil method gives higher precision values than dark pupil method. However, it has been shown that dark pupil method provides better results than bright method among ethnic groups, especially for African and Indian population. This bright/dark pupil effect raised the question of how applicable device would be in ethnic diverse country such as South Africa [8].

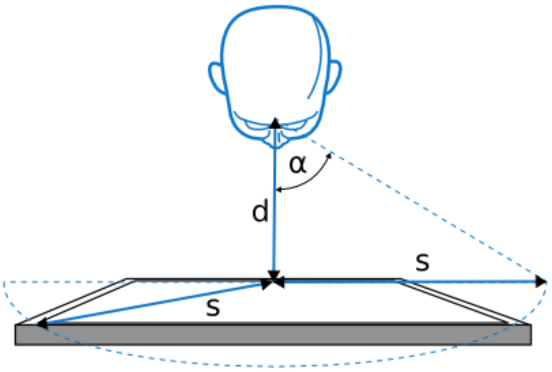


Figure 2. Optimal distance from eye tracker

Before the usage of the eye tracker the calibration procedure is needed to be carried out. During the calibration procedure, the participants are asked to look at the corresponding points also known as the calibration dots displayed on the projected area which is called Active Display Area (monitor, TV screens, projected displays etc.). Number of calibration points and calibration setup affects the accuracy of the results. In general, the more calibration dots, the better the accuracy. Calibration is usually performed on five or nine points. It is very important to have the correct distance to the monitor or the tracked object, otherwise the eye tracker cannot track the entire area. If the monitor or object is placed too close to the participant there is a risk that the gaze data for the corners of the display area of the monitor will not be collected [9]. To calculate optimal distance d from eye tracker following formula is used:

$$d = s / \tan(\alpha), \qquad (1)$$

where s represent the distance from the bottom centre corner of display area to the upper right/left corner, α - optimal gaze angle which value depends on type of eye tracking device (known parameter). During calibration procedure, for each calibration dot an image is taken by the eye tracker, and then analysed to extract parameters for a psychological 3D eye model.

The gaze angle error is expressed as deviation in degrees between two lines where origin is determined by the position of the eye, calculated from images captured by eye tracker. Second point of the first line is determined by the subject’s actual gaze point in the active display area, and the second point of the other line is the gaze point measured by the eye tracker.

Another parameter that effects on accuracy and precision of the eye tracker device is environmental illumination [9]. According to Tobii X2-30 eye tracker specification manual it is clearly visible that best accuracy and precision is achieved at illumination of about 300lx what represents the general ambient light levels in offices, classrooms, laboratories and public areas. Illumination above and below this value reduce precision and accuracy of the eye tracker. The main reason for the error is pupil dilation [10].

Constant exposure to the infrared light emitted by the eye tracker has a tiring effect on the eyes which is another concern to observe. The daily use of this technology could be limited if medical research shows harmful effect on the human eyes. Participants wearing glasses or even sunglasses had a better and enhanced bright pupil detection, only problems occurs during reflection from glasses or strong edges of the glasses [8].

III. Characteristics For Eye tracker Usage

The aim of eye tracking devices is to collect subject's eye activity while they are performing a specific task. The most common types of metrics used in analysis of human behaviour of the eye are fixation and saccades. Fixation are defined as inaction state of the eye above certain period of time. The threshold for this period is time varies typically between 100-200ms. Important attributes that describe fixation are: fixation duration, number of fixations and time to first target fixation. Graphically fixation is presented as circle determined by 2D coordinates with radius defined by duration of fixation. Lines that connect fixation points represent the movement of the eye from one focus to the other and are called saccades. The sequence of fixation and saccades are called a scan path. Collection of scan paths collected for certain period of time represent gaze plot. Generally gaze plots aren't appropriate for analysis for longer duration of time, because graph becomes overwhelmed with plotted data. As common type of visualization for this kind of problem is used heat map. Heat map gives the distribution of density fixation points, which mean heat maps belong to the class of time aggregated diagrams.

Currently eye tracking devices are mostly used in following research fields:

- Psychology studies
- Linguistic studies
- Human-computer interaction research
- Social interaction studies
- Research and studies using simulators
- Copy testing, digital campaigns and TV commercials
- Web and software usability studies of mobile interfaces and devices
- Studies of interactive television, gaming, virtual reality environments and control panels
- Usability studies of physical objects and industrial design
- Real-world interface studies that require a small eye tracker, such as studies of an ATM a ticket machine, or a control pane

IV. Natural Eye Gaze Computer Interaction

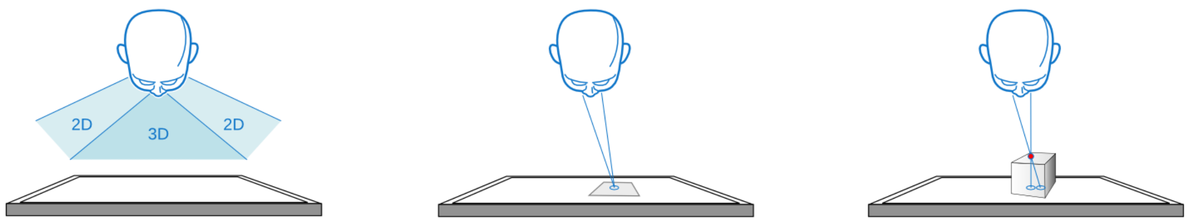
Communication between human and machine goes in two opposite ways - first direction represents visualization of data to be presented by machine to human, the opposite direction goes from human to the machine as commands. To understand how human interact with virtual environment on the computer we need to explain how human perceive a real content in natural environment. Each eye perceive scene from its specific field of view and creates a single 2D image. Left and right eye fields of view intersect in frontal area where two different images are gather for the same scene Figure 3. (a). Using information of left-right eye distance and location of the objects in left/right eye images human brain can calculate depth map (distance of objects in scene).

Interaction with 2D virtual content is enabled by tracking the eye gaze location on the monitor. This location is represent with pixels (x and y coordination of the point) or metrics (mm). Using this information machine can navigate through the content or recognize specific gestures as commands Figure 3. (b).

Unlike the 2D content for interaction with 3D content the depth value is necessary. Depth value can be obtained by extracting two different gaze points of each eye separately Figure 3. With information of 3D position of pupil-centre and 2D gaze point we can calculate gaze vector for each eye. Two vectors should intersect in a single point. This point is a real gaze point and have 3D position Figure 3. (c). This point also represents the focus of the user observation.

The base idea in creation advance HCI is to systematically collect and analyse this eye tracking data to learn behaviours of the user. With this information physical and emotional state of the user can be determined, and intentions detected. This information enables creation of optimal user-specific representation (visualization) of data structures to make interaction with context more natural.

It is important to emphasize that eye tracker cannot be used as primary input device for navigation. It is shown that eye movement input is faster than other current input media [11], [12] but the people are not accustomed to operate only by moving their eyes. Naturally human eye is an input sensor and is not adjusted to trigger actions what leads to conflicts [13]. Usage of the eye tracker for eye-gazed based interaction, problem is in determination of delta time to register input, if this time is too short it leads to Midas-Touch problem and if delta time it too long leads



a) Human perception   b) Interaction with 2D virtual content   c) Interaction with 3D virtual content

Figure 3. Perception and interaction with 2D and 3D virtual content

to tiredness [14]. Adding the fact how we interpret a perceptually uncertain stimulus [15], additionally raises the question of limited usage of the eye tracker.

V. Medical Oculography Diagnostics

Taking into account the speed of sampling eye tracker device and its accuracy under optimal condition of working, it can be used in the field of ophthalmology as the instrument in examining cognitive visual function, vision deficiencies and to study oculomotor behaviour of the eyes. It can be used as instrument that replaces and automate current methodologies that relay on observation and as instrument that provide identification of diseases at a much earlier stage of progression. A lot of research has been done in investigating a relationship of disease on the stability of the eye. It has been shown that there is no difference in fixation stability between 12 young observers at mean age of 22 and 12 older observers at mean age of 70 years old [16]. Fixation stability in patients with age-related macular degeneration has been studied using eye tracker system thankfully its higher digital sampling rate rather than the scanning laser ophthalmoscope. Another benefit was that eye tracker allows non-invasive measurements free of artificial support and diagnosis a patient condition in more natural way than that of the scanning laser ophthalmoscope [17]. Saccadic eye movements during tracking, fixation and resting were investigated in schizophrenic and normal participants. It has been shown that the frequency of saccades was higher in schizophrenic's participants than in normal subjects in all of the experimental conditions [18]. Endeavour on replacement the currently used methodologies that relay on observation with automated ones can be seen more and more frequently in the field of ophthalmology. Such example is current research which goal is to investigate the usage of eye tracker as device for detection of strabismus and amblyopia at early stages of development [18], [19]. A feature of high sampling rate in eye tracking can be used to measure the frequency and amplitude of the nystagmus. The investigation of eye pupil dilation under various stimuli attracted a lot of attention among researchers. This phenomena has been connected with many different human emotional and physical states. The most interesting conclusions are:

- pupil dilation can be used as a measure of attention [20],
- visual detection and recognition responses with pupil dilation [21] and
- pupil dilation during visual emotional stimulations can be a measure of affective states of non-communicative individuals [22], [23].

Eye tracker can be used in research as instrument for studying others eyes diseases and also as instrument for diagnostic irregularities in eyes behaviour which would lead to detailed examination of certain eye disorders. Examination the sensitivity of the eye to the light and glare, colour vision changes, peripheral and central vision are some of the irregularities witch can be detected. After surgery of the eye it is usually necessary to conduct a set of eye exercises which is another potential usage of the eye tracker. This would lead to reduction of the load on the medical personnel to focus their importance on emergency cases.

VI. Conlusion

With new advances in sensor technology a new approaches for HCI can be developed. New controllers should be used in addition with standard HCI input devices (keyboard and mouse). Introduced eye tracking device captures movement of eyes, which is considerably faster than other current input media. However eye tracker cannot be used as primary input device for navigation because people are not accustomed to operate only by moving their eyes and other problems mentioned previously, such as Midas-Touch problem.

Medical usage of eye tracking device is still novel and popular thematic in research. Such technology can approve current methods for oculomotor diagnostics to be carried out automatically. With this advances some eye disorders can be diagnosis in much earlier stages.

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