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Human Computer Interface using Eye Gazing with error fixation in Smooth and Saccadic Eye Movement

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Abstract

Human Computer Interface (HCI) requires proper coordination and definition of features that serve as input to the system. The parameters of a saccadic and smooth eye movement tracking are observed and a comparison is drawn for HCI. This methodology is further incorporated with Pupil, OpenCV and Microsoft Visual Studio for image processing to identify the position of the pupil and observe the pupil movement direction in real-time. Once the direction is identified, it is possible to determine the accurate cruise position which moves towards the target. To quantify the differences between the step-change tracking of saccadic eye movement and incremental tracking of smooth eye movement, the test was conducted on two users. With the help of incremental tracking of smooth eye movement, an accuracy of 90% is achieved. It is found that the incremental tracking requires an average time of 7.21s while the time for step change tracking is just 2.82s. Based on the observations, it is determined that, when compared to the saccadic eye movement tracking, the smooth eye movement tracking is over four times more accurate. Therefore, the smooth eye tracking was found to be more accurate, precise, reliable, and predictable to use with the mouse cursor than the saccadic eye movement tracking.

Keywords: Vestibulo-ocular reflex, image processing, eye tracking, accurate prediction, saccadic eye movement, human computer interface

1. Introduction

In general, the step tracking of saccadic eye movements is done by locating the user's gaze with the help of a camera [1]. However, there are some difficulties faced during this action which results in inaccuracy of information. The major causes of these inaccuracies are as follows:

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1. When the user is controlling the cursor, it will result in calibration drift.
2. Quality of calibration determines the accuracy with which the eyes are tracked.
3. A minimal tolerance is about one-degree with respect to the point position.

Due to the change in head movements [2] and pupil size, calibration drift occurs that modify the calibration validity. Apart from this issue, when vision is fixated on a particular target, tracking the cursor motion will be an open-loop condition [3] in step change. Hence, it proves to be a challenge as the gaze of the user will travel to the destination position from the mouse cursor and the position of the cursor cannot be tracked as it moves. Vestibulo-Ocular Reflex (VOR) [4] results in smooth eye movement and serve as an alternative for closed-loop and slower control, such that it is possible for the user to observe the movement of the cursor as it targets the destination. This level of tracking is possible since it is possible for the user to move the mouse cursor and monitor its trajectory in a smooth manner. In [5] the authors have introduced a VOR-related smooth eye movements tracking system which is made up of a camera mounted on the user's head which ensures that it is possible for the user to focus on the cursor's position. At the same time, the user will also be able to attain high deflection for large scale eye movements. With the help of a head-mounted system, the incremental tracking measurements of both saccadic eye movement and smooth eye movement were compared [6]. Cursor tracking is evaluated based on the measurement of the system and its performance.

2. Related Works

In [7] the authors have explained the importance of human-computer interaction and its involvement in our everyday lives. They have also introduced the applications of eye movements and the crucial role they play in aiding people with disabilities. This research addresses [8] multiple usability problems faced in gaming system, software, operation of mobile devices and web usage. It is possible to control the cursor by means of eye tracking which requires user-interface for effective eye tracking.

2.1 Eye Movement

There are a number of eye movements used in several situations. However, in order to track the movement of the eye with respect to an approaching object [9], vergence movements are used. On seeing an approaching object, the eye will move immediately. While reading and observing fast-moving objects, quicker saccadic movements are used. Similarly, to track objects moving with a slower pace, rapid smooth pursuit movement is required [9]. Smooth and saccade pursuit movements are generally used in previously existing methods for tracking movements of the eye. The VOR output is used to focus on an object even though the head of the person is in motion. In [10] the authors identified that, when compared with saccadic movements, the smooth tracking methodology will yield slower eye movement such as during the process of reading. With the help of VOR, it is possible to make the eye movement [11] to be stable, irrespective of the head movement. The brain reacts with two types of head movements namely translations and rotations [12]. Translational head movements are identified based on the inner ear's otoliths while the semi-circular canals present in the inner ear are used to identify rotational head movements. In the VOR, extra-ocular muscles [13] are used to guide the gaze of the eyes towards stability. The retina will hold a stabilized image during movement of the head due to the working of extra-ocular muscles which enables eye rotation in the direction opposite to that of head movement.

2.2 Eye Tracking

The authors of [14] documented a non-invasive and precise eye tracking methodology with the aid of light reflected from the eye's cornea. A large number of eye tracking methodologies have been built and tested ever since its introduction. Video-oculography and electro-oculography are two such methodologies that are widely in research. Video-oculography is defined by the authors in [15] who use a digital video camera to capture the movement of the eye. In video-oculography, a number of methods are used to observe eye movement like cameras with glasses and head-mounted gears [16]. This will provide a clearer and magnified view of the image, thereby making the process easier to be incorporated in the image processing software. The video camera can also be placed on top of the head similar to that of a web-cam on the desktop computer to capture movement of the eyes. However, this will need more number of image processing methodologies as it first requires detection of the face and eye before extracting movement of the eyes. On the other hand, electro-oculography is a methodology that measures the existence of retinal action potential prevalence because of metability occurrence in the retina [17]. This will lead to negative and positive poles in the retina and cornea, respectively. Hence a minor voltage variation exists between the back and front of the eyes. This can be calculated with the help of electrodes located in pairs at the right, left, below or above the eye. The voltage measured ranges between the values 0.5 and 1.1 mV. Hence it is possible to achieve 70° rotation and will lead to movement signal within the range of 6 and 18 μV [18]. The output thus obtained is then amplified, filtered and further transformed into digital signal. Both the methodologies can be executed using infrared or visible light. Since the pupil appears as a black circle on the image, infrared light along with a mounted camera is required to detect [19-22].

3. Proposed Methodology

When the cursor is in motion, the user can observe it with eye tracking when smooth and slower movements are exploited. Unlike saccadic eye tracking, this provides the user with an enhanced incremental control over the cursor [23]. Smooth eye tracking has a major advantage of providing closed-loop control. In order to move the cursor, the user must look away or take their eyes off with saccadic eye tracking. A large-scale deflection [24] is allowed with smooth eye tracking as the position of the eye is determined with respect to the head instead of the fixed gaze position of the user. Greater robustness, less eye deflection, greater comfort in eye-movement, close-loop tracking, and enhanced accuracy are the major advantages of using the smooth cursor tracking system. Saccadic eye [25] tracking exhibits erratic saccadic movement while continuous incremental movement is observed with great robustness in smooth cursor tracking. Full range of cursor movement can be accessed with smooth eye tracking. While designing the system, it is essential to ensure that the common and standard operating system and the proposed hardware are compatible with each other. With the movement of eyes relative to the head in space, smooth eye tracking [26] and pupil detection [27, 28] are essential to overcome the issues faced by the conventional saccadic eye tracking technique.

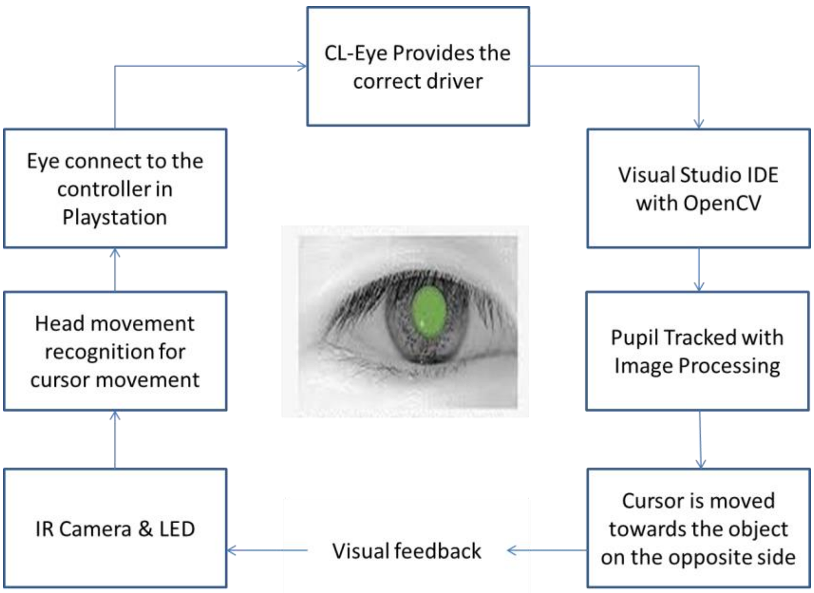

Figure 1. Proposed Architecture and Its Operation Cycle

The processing power of the computer imposes constraint over image processing [29]. The hardware system prioritizes eye safety based on set limits for infrared exposure as well as electrical safety. Movement of the cursor across the computer screen is enabled through eye tracking and smooth head movements. Software and hardware counterparts are equally important in this system. Visual feedback, software and hardware connectivity, pupil detection, and wearable headgear based architecture of the proposed system is presented in figure 1.

4. Hardware Setup

Infrared circuit, headgear, and PlayStation-Eye camera are used in the hardware subsystem by researchers in [30] with a similar general approach. The headgear holds the PlayStation-Eye camera that acquires the pupil movement. Freedom of head movement is achieved using this wearable instrumentation setup. Infrared light is received exclusively by performing certain modifications in the camera. An infrared light source is attached to the headgear with the help of a separate circuit. Universal Serial Bus (USB) is used for establishing connectivity between the computer and the camera. The camera is accessed by third party software programs with the Code Laboratories Eye platform driver, which is a certified hardware driver installed on the computer. Based on the manufacturer specifications, lenses and a built-in infrared light filter are presented in the PlayStation-Eye camera. Videos and infrared images can be captured on close-up by modifying this setup. Using the built in mechanism of the camera, the zoom lens can be altered to achieve a field of view ranging between 56 to 75 degrees.

Basic trigonometry and this data can be used to achieve an optimal focal distance and shortest field of view for eye safety. When compared to the eye size, this value is large. In order to overcome this drawback, a suitable lens is used to replace the lens that is available in the PlayStation-Eye. A lens with a field of view of 23 degrees and 60 mm zoom is selected for the purpose of experimentation. The necessary close-up pictures of the eye can be captured by this lens with this focal distance and field of view. Only infrared light is allowed to pass through the system by inserting a visible light filter between the lens and the image sensor. A floppy disk is used and its magnetic table is cut out to be used as the visible light filter. The infrared image of the eye is obtained from this system. The infrared circuit and PlayStation-Eye camera are supported with a helmet that acts as a headgear. Though the movement of head occurs, the camera is pointed towards the eye continuously. The camera is connected to the headgear with the help of a malleable copper wire. As different people use the headgear, the infrared Light

Emitting Diodes (LEDs) and camera direction can be varied appropriately to suit their individual requirements. Infrared light is provided to the human eyes by means of the infrared circuit. The Pulse Width Modulation (PWM) pins of the ESP8266X Wemos D1 mini microcontroller is connected to two infrared LEDs and a 3.3V power source. The power source is constructed by placing two AA batteries in series. Limited infrared exposure to the eyes is ensured by setting the duty cycle of PWM at 50%. The design prioritizes the exposure limits of eye safety and electrical safety.

5. Experiments and results

A reclined chair at an angle of 100 degree is used for the experimentation. Multiple subjects have individually used the headgear by sitting upright on this chair. Adjustments are made in the chair such that the subjects can place their feet on the ground in a flat and comfortable manner. The distance between the eye level and computer monitor is 60 cm. The position of the cursor is time tracked along with the estimation of characteristics like resolution and accuracy as shown in Fig.2. Both conventional saccadic eye tracking as well as the proposed smooth eye tracking experimentation are performed by maintaining a constant distance and, eye and head position of the user. Before each test, the user is asked to look at the screen of the computer monitor with a normal gaze. This ensures constant position of the eyes and face while performing the experiment. When the user's pupil focuses on the center of the screen, calibration of the position is performed prior to conducting the tests. During the saccadic eye tracking test, the users can move only their eyes while maintaining a steady position of their heads.

The eye and head position of the user is maintained at the same starting position as that of the saccadic test for the smooth eye tracking test. The movement of the cursor requires head movement and hence, during experimentation, the position of the head varies. Recalibration is performed prior to smooth eye tracking experimentation in order to maintain consistency by requiring the user to position their head towards the monitor and look at the center of the screen. The position of the cursor is time tracked along with the estimation of characteristics like resolution and accuracy. The pupil-position data quality is further optimized with the experiment results. Each user is required to wear the headgear with the PlayStation-Eye camera during experimentation. The camera captures the infrared light that falls on the left eye of the user. Time and accuracy characteristics are tested initially while repeating the collection of measurements with respect to the pupil. The experiment and analysis are repeated for 15 iterations before estimating the average value of the results.

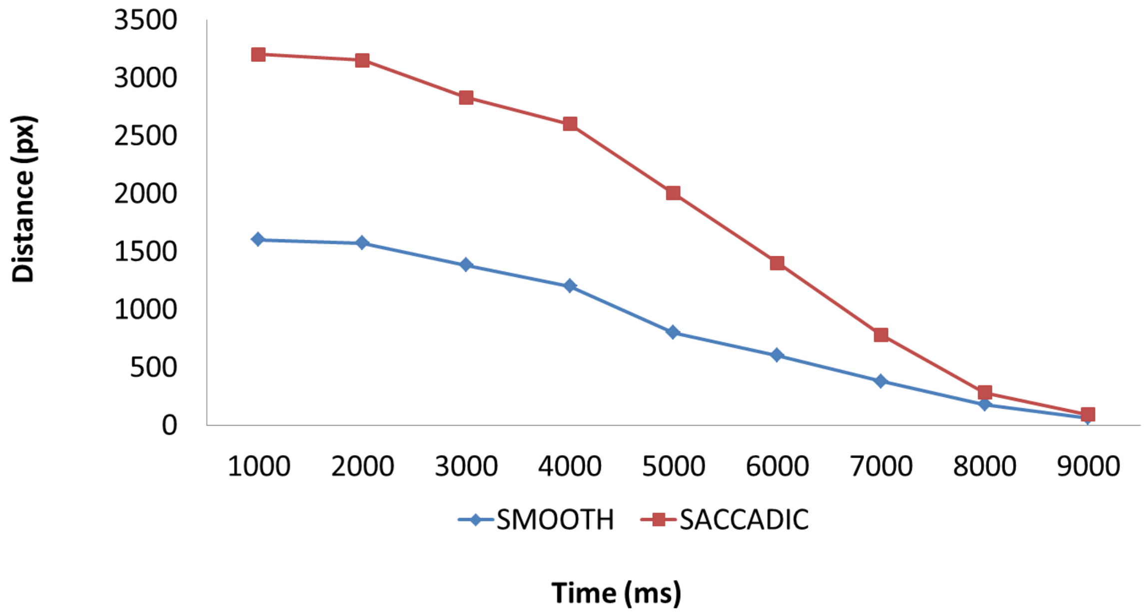

Figure 2. Comparison of time taken to detect objects in smooth and saccadic eye movement

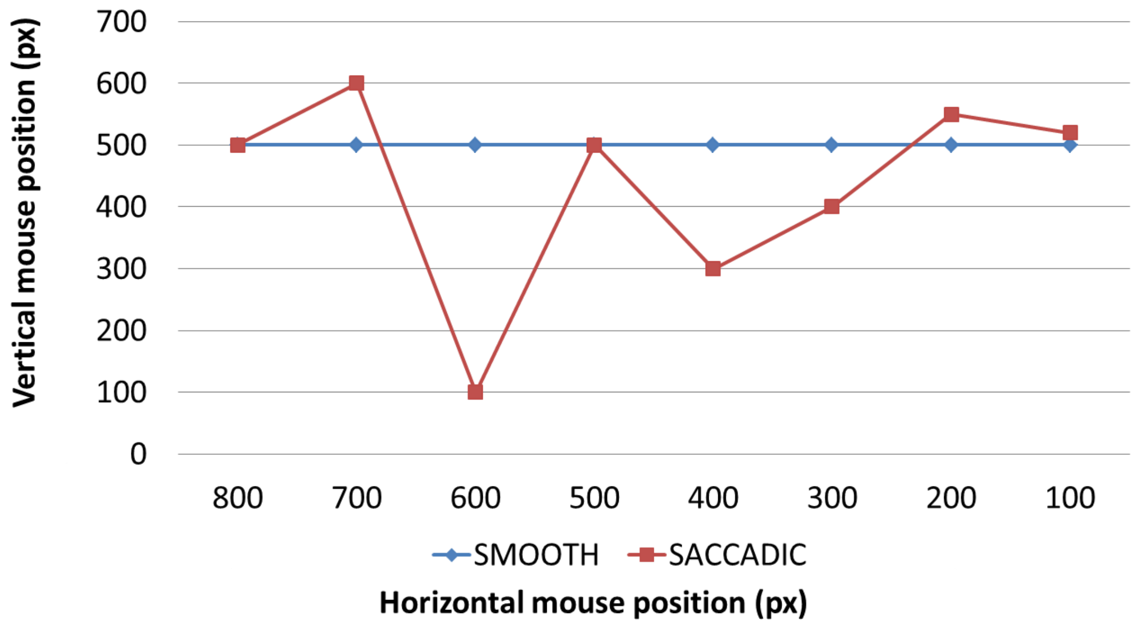

Figure 3. Spatial tracking curve of the cursor for eye movement

It is noticed based on the observations that, the smooth eye movement tracking was over four times more accurate than the saccadic eye movement tracking. The average resolution position was recorded at 0.75 cm distance from the earmark. Moreover, with 3.1 cm as the average position resolution, the saccadic eye movements were tracked and measured. With the help of incremental tracking of smooth eye movement, an accuracy of 90% is achieved while positioning the cursor on the pixel square of dimensions 9x9. When step change tracking saccadic eye movements are considered, it is not possible to place the cursor on the user defined target. It is identified that the incremental tracking requires an average time of 7.21s while the time for step change tracking was 2.82s. However, when compared with the saccadic eye movement tracking, the smooth eye tracking was found to be more accurate, precise, reliable, and predictable to use with the mouse cursor as shown in Figure 3.

6. Conclusion and Future Scope

Eye movement related to vestibulo-ocular reflex is studied for incremental and smooth tracking performance and is compared with the conventional step change based saccadic eye tracking. A computer, infrared light source and infrared light are detected by the modified head-mounted PlayStation-Eye camera used in the test equipment. Images captured by the camera are analyzed by the software subsystem. Detection of pupil, pupil movement direction determination, and cursor movement by corresponding direction and distance are the major parameters of analysis. Greater precision and accuracy is achieved with the smooth eye tracking system when compared to the conventional saccadic eye tracking models. However, slower cursor movements are achieved with smooth eye tracking due to its incremental nature. Controllability and predictability of movements are high with this system due to the closed-loop control. Future work is directed towards enhancing the speed of operation of the system.

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