JOURNAL OF SOFTWARE ENGINEERING & INTELLIGENT SYSTEMS
ISSN 2518-8739
30 April 2020, Volume 5, Issue 1, JSEIS, CAOMEI Copyright © 2016-2020
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GAZE DIRECTION IDENTIFICATION USING A 3D MODEL OF EYE

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Academic Editor: Adila Firdaus, Limkokwing, Malaysia.
Published: 30 April, 2020
Funding: Authors have no funds.
Article Type: Research Article

ABSTRACT

The idea of using eye movement tracking to facilitate navigation and control has provided new avenues of development in the field of computer vision technology. Nonetheless, the rapidity of eyeball movement requires more efficient methods of tracking them than are currently in use. In an extension to previous work, we have thus developed an effective method to track the multi directionality of an eyeball, using an extensive 3D-eyeball model, by means of utilising the corresponding features of the eye (its corners and pupil) to accurately measure the position of the eyeball without using specified calibration. Experimental results show that the approach achieves successful eyeball position measurement with lower error rates than have been obtained with other methods.

Keywords: gaze direction; 3D eyeball; image processing; gaze detection; iris image;

1. INTRODUCTION

Eye detection and movement tracking is an active field of research and has been used, amongst other things, to collect data for studies on human behaviour, perception and cognition. The significance of eye movements with regards to the perception of and attention to the visual world is well acknowledged since it is the means by which the information needed to identify the characteristics of the environment is gathered for processing in the human brain [1]. Eyes are a human's most sensitive yet powerful sensory organ that not only provide vision but now, due to advancements in eye tracking systems, facilitate a means of interaction with such devices as computers as well. This type of tracking system can be deployed for verification purpose, for behaviour analysis, for medical treatment and many others. For example, eye tracking technology is a way to implicitly measure people's attention to certain product packs, advertisements, billboards and many other forms of marketing strategies. Numerous methods have been proposed in this area of research, but researchers are trying to achieve yet better accuracy.

Eye tracking technology has also been deployed to help people with disabilities to interact and navigate their environment more easily. The technology works by transmitting signals, generated by an eye tracking system, to supportive equipment that acts appropriately in response to the received signal. For example, there are now battery driven wheelchairs whose movement is controlled through appropriate movement of the user's eyes [2]. In other endeavours, eye tracking has been used to diagnose abnormalities and disease of the eye. Moreover, eye tracking systems have been used in cognitive studies to help understand a human's behaviour and frame of mind [3]. Nonetheless, despite the significant achievements to date, eye tracking remains a difficult task, not least because of the speed with which humans can change their direction of gaze. Notwithstanding the difficulties, interest in eye tracking will continue to grow as domains such as virtual and augmented reality will develop further. Within such environments, being able to rapidly and accurately measure the gaze direction of users can significantly enhance their sense of emersion within them.

Despite the advancements in the technology, commercial eye trackers tend to be expensive and many require additional hardware such as glasses with connected cameras or customised headsets [4]. Our focus has been to develop an accurate method that can operate without using these additional hardware devices. To achieve this, we have used the webcam integrated within a laptop [5].

In previous work [6], we dealt with left, right, forward and upward gaze directions. In this paper we describe an efficient method that makes use of a 3D eye model to detect the direction of eye gaze. The method ameliorates the most common problem faced when considering downward gaze direction, which is the difficulty of detecting the eyeball when it is obscured by the eyelid.

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The rest of the paper is organized as follows: Section 2 explains some of the existing methods for eye detection and tracking; Section 3 details the methodology developed; Section 4 presents the results obtained; and, Section 5 articulates the conclusions reached.

2. EXISTING METHODS

Real-time eye tracking and gaze estimation is one of the most important topics in computer vision because of its beneficial implications for controlling devices. The techniques have the potential to revolutionise human computer interaction, including for those where traditional means of interface is not physically possible. One proposed algorithm for eye detection uses the geometrical information obtained from the iris of both eyes in turn to determine their location within an image. The iris is darker than its background (sclera), it is thus relatively straightforward to determine its edges and thus locate the pupil with respect to the radius of the iris. The algorithm provides good results, even when the eyes are only partially opened [7].

Each eye's uniqueness and simple architecture gives it potency in many biometric and security applications as they afford a means of identifying and tracking individuals. One method for locating eyes in real-time uses the Euclidean distance between the eye's edges, determined by using a combination of Sobel and Prewitt masks to identify the horizontal eye edges within the facial image. The Euclidean distance enables the verification of the measurements because the distance between each eye's centre and the mouth's centre is the same. The method described produced an accuracy of 93% for eye detection [8].

As mentioned earlier, one important application of eye tracking is to improve the user experience in virtual reality environments. In such systems, eye tracking is an important means of determining where a user's focus of attention is. This technology is playing an increasingly important role in the fields of business and marketing where automatically determining the focus of customers' attention can lead to better product placement strategies and thus potentially increased sales. For example, some advanced web-based applications constantly track the direction of a user's gaze as they look at a website. Data can be gathered that provides information about exactly how many users have seen an advertisement, noticed a brand, or consumed a key marketing message [9]. Other applications facilitate innovation, for example where a test group of potential customers are asked to wear eye tracking devices while shopping that can be used to determine what attracted their attention and for how long, results analysis can then inform produce placement and store layout.

Gaze-detection has also been used to help those with disabilities as, despite other impairments, many such users are still able to control their gaze. This can, for example, help them make use of gaze-based virtual keyboards through which all letters can be accessed directly through a single command. In addition to this, a USB mouth switch that is directly connected to the computer mouse can replace the mouse left-click button. Two consecutive steps are required for the selection of a command: the user directly focuses their gaze towards the desired command on the screen and then selects the command by means of the switch, operated by the mouth. Experiments performed to evaluate three possibilities - gaze detection with mouth switch, gaze detection with dwell time by considering the distance to the closest command, and the gaze detection within the surface of the command box– determined that the mouth switch resulted in the best performance in terms of typing speed [10].

Cost and hardware requirement are an issue in most portable and compact eyeball tracking systems. One method used to reduce cost uses infrared rays to detect the pupil of the eye using an energy-controlled curve fitting method that facilitates accurate eye tracking [11]. The method also uses an iterative eclipse fitting process for pupil detection where the gaze of the eye's field of view is estimated based on the pupil-tracking results and a 3D eye model. The results of experimentation produced an error rate of less than 0.5 degrees.

3. METHODOLOGY

We have developed a simple yet accurate method for tracking gaze direction. The method involves locating both the eyeball centre (pupil) and eye corner. A scalene triangle is created from the eye corner to the eyeball centre relative to a vertical line projected from the corner as shown in Figure 1. The angle between the two is calculated and, as the eyeball moves, the change of angle is indicative of that movement.

The method first acquires the input image in real-time before enhancing it and removing noise through pre-processing. The eyeball is then detected before the Viola-Jones algorithm is used to locate the eyes themselves. The location of each eye's pupil and corners are then used to calculate the angle of gaze. The overall flow of the methodology is shown in Figure 2.

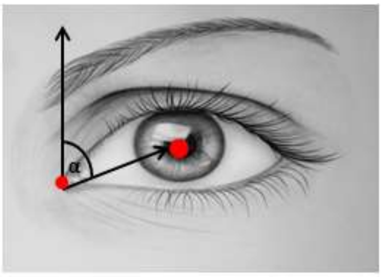


Figure. 1 Angle between pupil and eye corner standard dataset

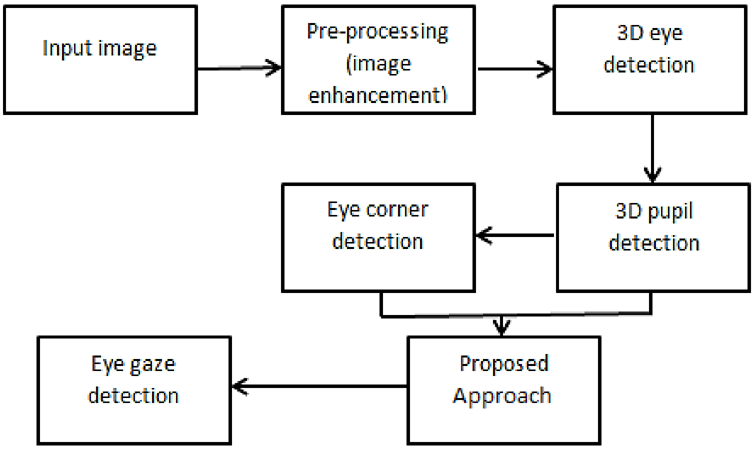


Figure. 2 Block diagram of methodology

3.1 Eye pupil detection

The central idea of the concept involves determining the 3D rotation of eyeball based upon the location of the eye's pupil, which is found using the Circular Hough Transform (CHT) [12], that enables the detection of circular objects even in noisy images. The CHT extracts three parameters that are necessary to draw a circle (that is, the X and Y coordinates of the circle's centre and its radius). The CHT algorithm works by detecting edges in a binary image and generating circles for every single pixel and updating the values of intersecting points; the pixel with the maximum value will be the centre of circle that represents the pupil, as illustrated in the image shown in Figure 3.

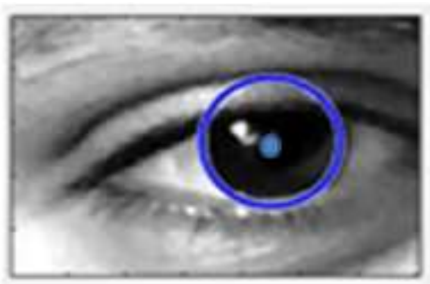


Figure. 3 The result of Circular Hough Transform (CHT)

3.2 Eye color detection

Eye corners are the points where both eyelids meet and, depending on illumination conditions, their detection can be challenging. One successful method of detection involves elliptical mask mapping followed by thresholding of the eye image [13]. The structural characteristics of an eye resemble an ellipse, where the two focal points are the eye corners. The method begins with a cropped grayscale eye image to which an elliptical mask is applied. The candidate eye corner positions are identified using the Harris and Stephens corner detector [13]. The actual corner positions are assumed to be the candidate eye corner positions with the furthest distance between them (see Figure 4).

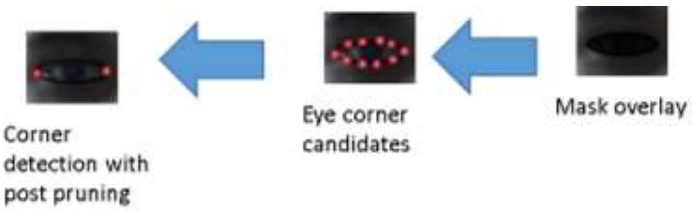


Figure. 4 Overall scheme for eye corner detection [13]

3.3 Proposed approach

Since the approach adopted resembles the shape of a right-angled triangle [13], Equation 1is used to calculate the acute angle which is indicative of eyeball movement and used identify point of gaze.

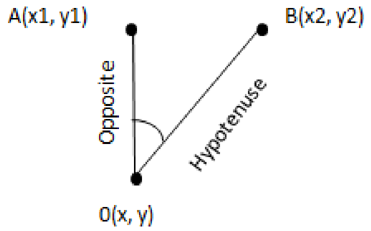


Figure. 5 The scenario of the direction view

Point O represents the left corner of eye, whose pixel value is known. Point B represents the centre of eyeball (pupil) with known value of XY coordinate. For point A, Y coordinate will be equal to Y coordinate of B (that is, y1=y2), similarly X coordinate of point A will be equal to x coordinate of O. x1=x. To find the acute angle α, the triangle equation is used:

$$Sin\ \alpha = \frac{Opp}{Hyp} \qquad eq(1)$$

$$\alpha = Sin^{-1}\frac{Opp}{Hyp} \qquad eq(2)$$

$$\alpha = Sin^{-1}\frac{Opp(x1 - x,\ \ y1 - y)}{Hyp(x2 - x,\ \ y2 - y)} \qquad eq(3)$$

3.4 Tracking strategy for gaze detection

The point of gaze will be fixed based on the value of angle calculated. For different gaze directions, the value of the angle changes accordingly. When using the left corner of the eye, as the eyeball moves toward the right side, the value of angle decreases and vice versa. Using the Equation 3, the angle can be determined that enables the direction the user is looking to be calculated.

3.5 3D eyeball construction

To facilitate analysis of the developed system, a 3D eyeball model has been constructed (see Figure 6) that shows a realistic 3D rotation of the eyeball as its movement is tracked.

Figure. 6 3D eyeball tracking viewing system

4. EXPERIMENTAL RESULTS AND FINDINGS

The output comprises of a 3D eyeball model that follows and displays the gaze direction in real-time. The results show that the developed method is, despite its simplicity, very effective at tracking direction of gaze. A sample of the output obtained for one user is shown in Figure 7.

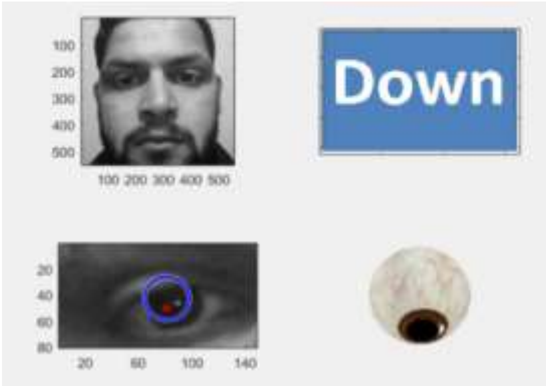
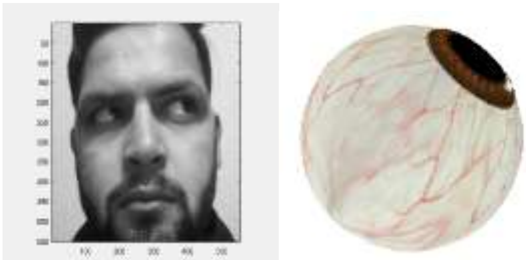


Figure. 7 The downward direction tracking of proposed system

User looking straight

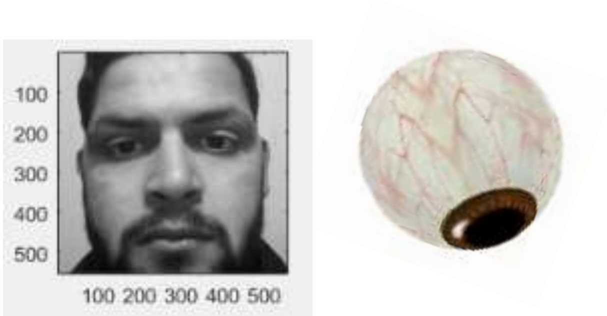
User looking towards right

User looking towards left



User looking towards upper right

User looking towards upper left



User looking towards slightly downward

Figure. 8 An example of the output obtained when detecting the gaze direction of an individual

The system has been tested on five groups of seven individual each with different skin colour, eye size, and where some wore contact lenses or glasses. Experimental results are analysed via graphical representation (see Figure 8) by setting error rate and response time as parameters. The error rate is measured by calculating the average of number of faces not detected a group and is shown in Figure 9.

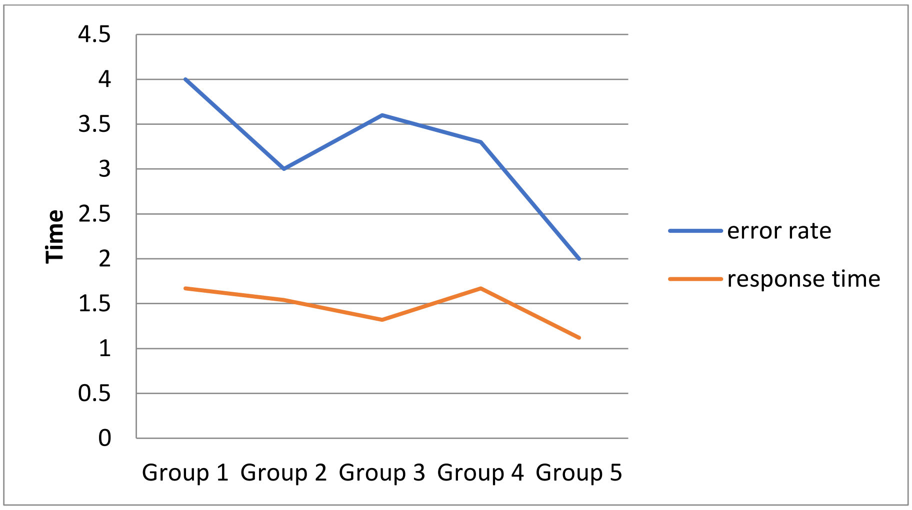


Figure. 9 Graphical representation of experimental results

5. CONCLUSION

The use of eye tracking within an 3D virtual/augmented reality system enables the user's gaze to be determined in a way that enables them to interact with their local environment. This paper articulates a method that provides an improvement to the techniques that are currently used to facilitate such tracking. Moreover, the method described is straightforward to setup and use.

ACKNOWLEDGEMENT

Authors are thankful to Army Public College of Management & Sciences, Rawalpindi, Pakistan and University of South Wales United Kingdom for supporting this research.

REFERENCES

1. Al-Rahayfeh, A. and M. Faezipour, *Eye tracking and head movement detection: A state-of-art survey.* IEEE journal of translational engineering in health and medicine, 2013. 1: p. 2100212-2100212.
2. Wanluk, N., et al. *Smart wheelchair based on eye tracking*. in *2016 9th Biomedical Engineering International Conference (BMEiCON)*. 2016: IEEE.
3. Harezlak, K. and P. Kasprowski, *Application of eye tracking in medicine: A survey, research issues and challenges.* Computerized Medical Imaging and Graphics, 2018. 65: p. 176-190.
4. Clay, V., P. König, and S.U. König, *Eye tracking in virtual reality.* 2019.
5. Kassner, M., W. Patera, and A. Bulling. *Pupil: an open source platform for pervasive eye tracking and mobile gaze-based interaction*. in *Proceedings of the 2014 ACM international joint conference on pervasive and ubiquitous computing: Adjunct publication*. 2014.
6. Khan, M.S., et al., *A new 3D eyeball tracking system to enhance the usability of page scrolling.* Optik, 2019. 185: p. 1270-1276.
7. D'Orazio, T., et al. *An algorithm for real time eye detection in face images*. in *Proceedings of the 17th International Conference on Pattern Recognition, 2004. ICPR 2004.* 2004: IEEE.
8. Azar, A.R. and F. Khalilzadeh. *Real time eye detection using edge detection and Euclidean distance*. in *2015 2nd International Conference on Knowledge-Based Engineering and Innovation (KBEI)*. 2015: IEEE.
9. Soundarajan, S. and H. Cecotti. *A gaze-based virtual keyboard using a mouth switch for command selection*. in *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. 2018: IEEE.
10. Li, X. and W.G. Wee. *An efficient method for eye tracking and eye-gazed FOV estimation*. in *2009 16th IEEE International Conference on Image Processing (ICIP)*. 2009: IEEE.
11. Nosrati, M. and R. Karimi. *Detection of circular shapes from impulse noisy images using median and laplacian filter and circular hough transform*. in *2011 8th International Conference on Electrical Engineering, Computing Science and Automatic Control*. 2011: IEEE.

12. Dasgupta, A., et al. *An improved algorithm for eye corner detection*. in *2016 International Conference on Signal Processing and Communications (SPCOM)*. 2016: IEEE.
13. Ochkov, V.F. and E.P. Bogomolova, *Teaching mathematics with mathematical software.* Journal of Humanistic Mathematics, 2015. 5(1): p. 265-285.