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Novel Method to Localize the Pupil in Eye Gaze Tracking Systems

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Abstract: In eye gaze tracking systems pupil localization is very significant task. Accurately localizing pupil within an eye image or in relative real time streaming video is still a challenge because the occlusion caused by eyelashes, eyelids and shadowing effects. In this paper we propose novel pupil positioning method to localize pupil in robust manner. This method is based on fusion of existing state-of-the-art eye localizing and pupil positioning methods. Proposed method gives improvement in accuracy and lowering the false detection.

Keywords: HCI human computer interaction, Gaze estimation, Eye Gaze Tracking, Pupil positioning, Gray projection, Hough Transform algorithm.

I. Introduction

The ability to detect the presence of visual attention from human users and/or determine the point of gaze (where one is looking at) by estimation of the eye gaze is known as eye gaze tracking [1]. It provides very significant information which is useful in many applications such as human computer interaction (HCI), cognitive psychology, medical research, communication systems for disabled, behavioral studies, virtual reality etc.

In order to track the eye gaze pupil positioning and estimation of pupil location plays an important role because once the exact pupil position and its coordinates get detected and computed, it becomes very easier to trace the eyeball movement and so forth to control the application as per change in direction of gaze. Unfortunately, there are still many unresolved problems preventing the use of eye-tracking systems in the actual applications such as computation complexity, occlusion by eyelashes and shadowing etc.

The problem with pupil identification resides in the structure of the organ itself [2]. Iris is usually partially occluded by eyelids and eyelashes when it is captured. Furthermore, the structure of iris and pupil is not definitely circular and concentric [2]. As pupil boundaries are presumed as circles, parts of pupil and eyelids will be improperly represented as localized iris region. These can lead to inaccuracy in recognition. Therefore, an effective positioning method is essential.

This paper presents robust pupil positioning method which is fusion of Hough transform, Gray Projection and Coarse Positioning method to accurately detect pupil boundary and coordinates of pupil center. The remainder of this paper is organized as follows. Section II discusses the related works. Theoretical methods are explained in Section III, proposed method explained in Section IV, followed by experimental results and conclusions in Section V and Section VI respectively.

II. Related Works

Recently eye gaze tracking has attracted the interest of many researchers and eye trackers have been commercially available for users. Eye gaze tracking becomes important research topic because it's wide usefulness in various applications. A comprehensive review of earlier works has been carried out by [3][4]. A good surveys of traditional eye gaze tracking techniques can be found in [5][6]. Some more recent reviews can be found in [7][8].

Early eye gaze trackers (EGT's) were developed for scientific exploration in controlled environments or laboratories. In early EGT's required physical contact with the user such as placing a dot directly onto the eyes called as intrusive methods [7], or attaching number of electrodes around the eyes and measuring the electric potential variance called as electro-oculography [9].

With advancement in research and technology of digital computers and video cameras, digital video based (optical) eye gaze tracking becomes an important and mainframe method. [7-14]. Optical methods do not requires any physical contact with an eye. Camera can be head mounted or remotely placed in front of user.

There are several advantages and limitations to existing video based methods. Dodge and Cline used the cornea reflection method to record the eye movement [9]. However, the accuracy is rather low because of the sensitivity to head movement. H.D Crane *et al* proposed another method called generation-V Eye tracker which was based on Purkinje image detection (Dual Purkinje image). This Eye tracker involves computational and implementation cost overhead [10].

One of the first commercial eye gaze tracking system developed by University of Virginia in late 80's called as ERICA. It was based on IR image processing. ERICA lacks in cost efficiency and was unaffordable for general public. Zhang *et al* developed a Tobii TX 300 eye movement tracker which is robust to interference caused by head movement [11]. Being capable of processing gazing data sampled up to 300Hz, this system satisfies some research requiring high sample frequency, such as glancing, correction glance, gaze, change in pupil size and blink. However, similar to Erica System, it is also very costly and unaffordable for users with less purchasing capacity.

III. Theoretical Methods

A. Circular Hough Transform Algorithm (CHT)

The Hough transform algorithm has good anti-jamming performance. Moreover, it also has high level of fault tolerance and robustness against discontinuities in the boundaries due to covering of other targets [12][13]. The circle is actually simpler to represent in parameter space, compared to the line, since the parameters of the circle can be directly transfer to the parameter space [14]. The equation of a circle is:

$$r^2 = (x - a)^2 + (y - b)^2 \quad (1)$$

As it can be seen the circle got three parameters, r, a and b. Where a and b are the center of the circle in the x and y direction respectively and where r is the radius. The parametric representation of the circle is:

$$x = a + r \cos(\theta) \quad y = b + r \sin(\theta) \quad (2)$$

It is obvious that three unknown parameters (a, b, r) are to be determined. In other words, if we know at least three points on the same arc, we can identify the parameters (a, b, r) by solving

$$\begin{cases} r^2 = (x_1 - a)^2 + (y_1 - b)^2 \\ r^2 = (x_2 - a)^2 + (y_2 - b)^2 \\ r^2 = (x_3 - a)^2 + (y_3 - b)^2 \end{cases} \quad (3)$$

Using (1,3), the Hough transform algorithm can then transform the image domain into parameter domain. Substituting the edge point set (x_n, y_n) into Eq.(3) successively and solving the equations, we can obtain the set of parameter (a_n, b_n) Based on which a best likely parameter set containing the center coordinates and the radius of the circle is estimated by a voting method. Then calculated center is called Hough centre (x_h, y_h) .

B. Gray Projection

The gray projection algorithm, bases on the principle of statistics which accumulates each pixel by row or column in gray scales. The process is described as follows [15]. Given a $M \times N$ gray image $I(i,j)$, which denotes the gray scale of the pixel with the coordinates (i,j) , the horizontal and vertical gray projection can be defined as

$$H(i) = \frac{\sum_{j=0}^{N-1} I(i,j)}{N} \quad (4) \quad V(j) = \frac{\sum_{i=0}^{M-1} I(i,j)}{M} \quad (5)$$

Histograms for both directions are generated by projecting the intensity of the image to the horizontal direction and the vertical direction. Then the center coordinate of the pupil boundary is estimated by the following equations (6,7) since the pixel intensity of the pupil is lowest across all iris images:

$$\bar{x}_g = \underset{i}{\operatorname{argmax}} (\sum_j I(i,j)) \quad (6) \quad \bar{y}_g = \underset{j}{\operatorname{argmax}} (\sum_i I(i,j)) \quad (7)$$

Where (x_g, y_g) are the estimated center coordinates of the pupil in the original image $I(i, j)$.

C. Coarse Positioning

The main aim of coarse positioning method is to compute a coarse range of the pupil using a slide window in the binary image formed during preprocessing [16]. Since the area of a pupil occupies the darkest part in the image region, the area which contains maximum number of 0 grayscale in the slide window is identified as that of

the pupil. At the same time, the center of the corresponding slide window is marked as the coarse central position of the pupil.

D. Filtering and Edge Detection using Canny method

The Gaussian smooth filter [17] with the Eq. (8) is used in the image filtering method. It has a good performance on reducing the random noise within the image and is helpful for the edge detection.

$$F_g(i, j) = e^{-\frac{(i^2 + j^2)}{2\sigma^2}} \quad (8)$$

The Canny edge-detection method [18-19] uses Gaussian one-step differentiation to calculate the gradients of an image by searching the partial max gradients of the image. The method detects a strong edge and a weak edge by the double-threshold method. The complete edge will be output when the strong edge connects to the weak one becoming the edge of the contour.

E. Thresholding and Image Binarization

Region of interest can be computed by selecting an eye image that contains the pupil and the iris. This region should include as much as pupil and iris region possible while minimally having boundary skin regions and eyelashes.

This process reduces the computational complexity and overhead of future image processing. Empirically two third of centre region of an eye image contain pupil and the iris. Then this image can be binarized according to thresholding method defined as (9),

$$P_n = \begin{cases} 0, & P_0 < P_{TH} \\ 255, & P_0 \geq P_{TH} \end{cases} \quad (9)$$

We assume that the threshold is P_{TH} , the value of the previous pixel is P_0 , the value of the processed pixel is P_n . If segmentation isn't enough for finding pupil area then exact boundary box of pupil area can be defined as (10).

$$bin(i, j) = \begin{cases} 255 & \text{if } j > f_v \text{ \& } j < b_v \\ & \text{for } l \leq j \leq n \\ 255 & \text{if } i > u_h \text{ \& } i < d_h \\ & \text{for } l \leq j \leq n \\ 0 & \text{if other} \end{cases} \quad (10)$$

Where $bin(i, j)$ is the binary image, b_v , f_v , d_h and u_h are right, left, down and up sides of the pupil boundary box respectively.

IV. Proposed Method

In this paper we propose fusion of three pupil positioning methods: Hough transform Algorithm, Gray projection Algorithm and Coarse Positioning method. Steps involved in implementation of proposed method are given as following and Shown in Figure.1 flow chart of proposed method.

1) Capture the image of an eye using camera. Initial eye image from the camera is converted to grayscale. Pupil part of the image is obviously different from rest of the grayscale image.

2) Using horizontal and vertical gray projection we computer the coordinates of pupil as (x_g, y_g) .

3) The system utilizes the circular Hough transform algorithm to detect the pupil center. The accuracy of pupil positioning is mostly decided by the edge of pupil. It is generally reckoned that the point of which the pixel has the large gray gradient is the edge point of the pupil. One of the edge detection operators is Canny operator that applies two thresholds to the gradient: a high threshold for low edge sensitivity and a low threshold for high edge sensitivity.

After detecting edges, it is time to use circular Hough transform to find the pupil exactly. To avoid the false or multiple circle detection problem use bounding box approach to limit the area of an image. Coordinates of pupil circle $hc_{(x_h, y_h)}$ detected and computed using Hough transform.

4) In Coarse positioning method [16] obtain centre of pupil (x_c, y_c) using adaptive thresholding and binarization.

5) For computation of localization of pupil, the distance between the coarse position centre (x_c, y_c) and gray projection method centre (x_g, y_g) is analyzed and corresponding pupil centre $cc_{(x_m, y_m)}$ is then calculated out by using following equation (11).

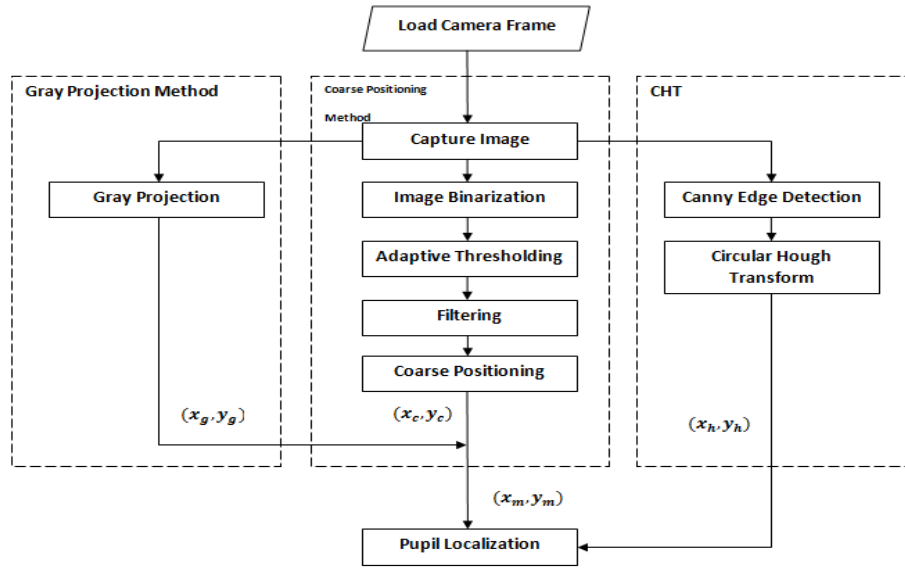
$$cc_{(x_m, y_m)} = \begin{cases} (x_c, y_c), & \max \geq |(x_c, y_c) - (x_g, y_g)| \geq \min \\ \frac{(x_c, y_c) + (x_g, y_g)}{2}, & \text{any other} \end{cases} \quad (11)$$

6) Using (x_m, y_m) and (x_h, y_h) , final position of pupil (x_f, y_f) is decided. Though we have used windowing to limiting implementation area of CHT, if the problems of multiple circles detection still persists for certain images, then choose a circle, whose center is nearest to approximate center of pupil that can be given as (12),

$$E_{dist}(hc, cc) = \sqrt{(x_{hc} - x_{cc})^2 + (y_{hc} - y_{cc})^2} \quad (12)$$

where $hc_{(x_h, y_h)}$ is coordinates of hough transform pupil center and $cc_{(x_m, y_m)}$ is coordinates of circle center. Finally, in pupil localization using E_{dist} , nearest circle is fitted to pupil center.

Figure 1 A flow chart of proposed method



V. Experimental Results And Analysis

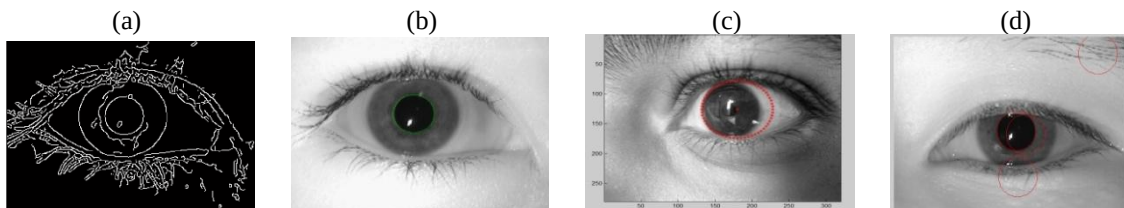
The implementation of the proposed algorithm focusing on pupil positioning is tested using open access iris image database provided by Malaysia Multimedia University (MMU). The version of database used is MMU1. Database consist of total 46 classes, each consisting of 5 images of the left eye and 5 images of right eye. There are total 459 images are available in MMU1.

We have also used Tag Fine-Pix 8MP camera to test real time performance of the proposed method. We developed the system and performed the experiment on a laptop with the following specification: Intel® Core™ i3 CPU @ 2.53 GHz and 4 GB RAM, windows 7 ultimate platform, in Matlab 7.10 student version environment. The accuracy of the experiment is verified through visual inspection. The details of experimental results are discussed in following sections.

A. Circular Hough Transform Results

The results of application of CHT are as shown in Figure.2 (a and b). CHT detects perfect circles. If the eye is get partially occluded then sometimes CHT fails and detects multiple pupil circles figure (c and d).

Figure 2: (a) Canny Edge detection. (b) Hough circle output. (c) & (d) Results of failed CHT.

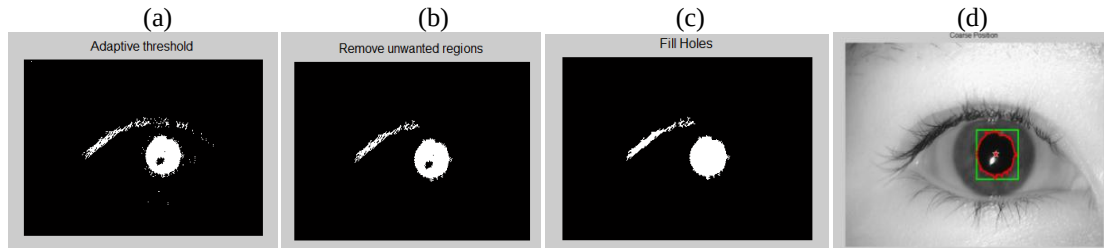


B. Coarse Positioning Results

In coarse positioning method eye image is preprocessed using preprocessing module. The size of which is 320*240 (pixels), of the binary image obtained from the preprocessing module. Ideally, the area where the

number of 0 grayscale in the scan window is the maximum will be the area of a pupil, if the size of the scan window is reasonable. Following figures 3 (a), (b), (c) and (d) shows preprocessing steps in coarse positioning method and final result.

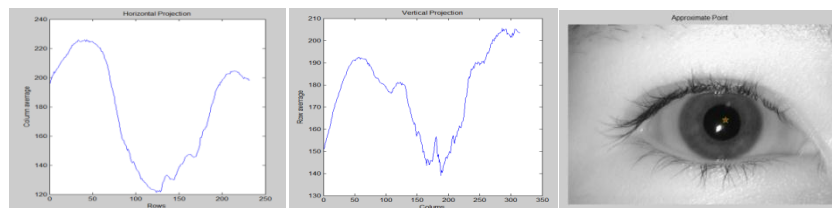
Figure 3: (a-c) Pre-processing steps in Coarse Positioning (d) Final result of coarse positioning method



C. Gray Projection Results

After binarization, the histograms for both directions are generated by projecting the intensity of the image to the horizontal direction and the vertical direction as in Figure.4 (a-b). Approximated pupil center is shown in figure (c).

Figure 4 (a-b) : horizontal and vertical projection graphs. (c) Approximated Pupil Center



D. Analysis of Robustness

The experiment on 459 MMU1 images and 120 Tag Fine-Pix images, resulted in successful detection in 514 eye images, excluding the initial 65 of failed due to eyelid occlusion, resulted in 88.77% of accuracy of pupil boundary and pupil circle center detection. We traced the inaccurate localization and categorized the reason of failure into two main causes: unsuccessful circular Hough transform, failed gray projection due to occlusion by eyelids or eyelashes. A summarization of the experiment results is presented in the following table I.

Although the pupil is perfectly localized via Coarse positioning and circular Hough transform, eyelids occlusion and the presence of eyelashes causes significant disturbance and contribute a considerable slip in the process of detecting the peak indicating pupil boundary.

Table 1: Summary of Experimental Results

Result Of	No Of Images	Correctly Localized images	Failed Localization images	Accuracy %
MMU1	459	417	42	90.84
Using Camera	120	97	23	80.83
total	579	514	65	88.77

VI. Conclusion

Pupil positioning is an essential process in eye gaze tracking system that directly contributes to the success and accuracy. The use of circular Hough transform (CHT) to pinpoint the location of pupil within an eye image is expected to be quite effective. However, this process is highly sensitive to occlusions and also dependent on image quality. Considering the experiment result, a more comprehensive pre-processing prior to the application of canny edge detector will more likely produce improved result. Overall, the outcome of using gray projection to detect pupil plane center is considerably quite satisfactory, but based on this experiment can be improved in future. In future, this technique is yet to be tested with different sets of database to ensure its robustness and universality. Furthermore, an improvement of pupil localization using fusion of robust positioning methods is a vital agenda to guarantee an efficient performance without sacrificing accuracy.

This paper proposes a novel idea of fusion of two or three best methods of fast and accurate pupil positioning which gives us better and robust results than existing methods. But however our next step of work is to implement these algorithms for various database images with different orientation of eye and occlusions. Center coordinates calculated by this method may require further approximations. However we have planned to approximate or ameliorate each algorithm individually so it will become easy to improve accuracy.

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