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Gaze Direction and Estimation Model Based on Iris Center Coordinates

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***Abstract*—** An appearance cum feature based iris center gaze detection model viz. Iris Center Based Gaze Estimation (ICGE) is proposed to detect the direction of gaze quadrants to overcome certain limitations like dependency on light sources, multiple glint formation, no formation of glint etc, observed in glint based gaze quadrant detection models. The model works on the adaptive thresholding technique for the detection of the iris center coordinates using more than two hundred images from an indigenous database of different subjects on a five quadrants map screen. The model works with the Circular Hough Transform (CHT) for localising circles in the eye images and then center coordinates on the iris edge for further detection of gaze quadrants. Gaze directions of five different positions of iris are estimated on a mapped screen within the eye region. The model generates almost ninety percent accurate results for correct iris and gaze quadrant detection. The distinguishing features of the low cost, non intrusive proposed model include non IR and affordable ubiquitous hardware designing, large subject-camera distance and screen dimensions, no glint dependency etc. The proposed model also shows significantly better results in the lower periphery corners of the quadrant map. The proposed model may be more suitable for interactive applications for healthy users who cannot use head and hands freely while doing other tasks or disabled users who have no movement in their hands and head etc.

***Keywords*—**Iris Center Based Gaze Estimation (ICGE) model, adaptive thresholding, iris center, gaze quadrant detection.

I. Introduction

Gaze estimation is generally done in relation to gaze direction of the user's eye position with specific eye movements by using segmentation or extraction techniques. These techniques are used for the extraction of local features like the eye outline, eye contours, edges of pupil, eye corners, center of the eye, iris or pupil or corneal reflections or glint etc [1-3]. Several image segmentation techniques, which partition the image into various parts based on different image features like pixel intensity value, colour, texture etc. have been used. These techniques can be categorized on the basis of the segmentation method being used for extracting RoI [4].

Most of the research work for the eye center detection methods can briefly be classified into two categories: pupil center and iris center detection. Pupil center detection along with glint detection is used mainly in intrusive systems. However, the use of infra red (IR) light makes the gaze detection limited to indoors. In addition, IR may be harmful to eyes due to ambient IR illumination. In case of pupil center detection based methods, the data quality of captured images may depend on the size of the pupil [5-7]. In contrast, iris center detection is more evident, cheap and widely used in non-intrusive systems. It often works under visible light. In addition, iris is circular, darker than sclera, constant in size, more stable and is not affected by glare or glint formation as in the case of pupil detection (Figure 1).

Iris segmentation or localization requires accurate detection of boundaries separating the iris from any other unwanted components or regions in the image. Iris recognition is independent of non-uniform illumination caused by the position of the light source [8].

As shown in Fig. 1, there may be multiple glints G_i within the sclera S_c region due to multiple sources of incident light on the pupil region. The relative position of the iris center (C_i) with center of eye (C_e) can be used for further gaze based processing [9].

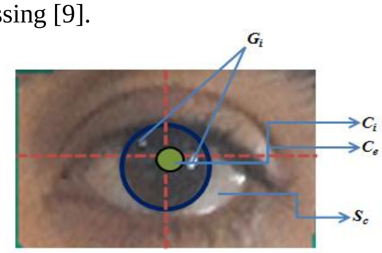


Figure 1. Coordinates of eye C_e, iris C_i & multiple glints G_i (Indigenous DB)

Iris based eye gaze identification and estimation systems find a lot of applications in various fields including personal identification and automated border crossing. For the segmentation of the iris, different image based segmentation methods based on template, appearance and features have been applied. These methods have been implemented using various techniques. These techniques include thresholding, ellipse fitting, edge detection, 2D Gabor wavelet filters, Circular Hough Transform (CHT), blob detection, eigenspace methods, adaptive thresholding etc [10-13].

All the above mentioned segmentation methods may be used to design the iris recognition and detection model using one or combination of the above techniques along with adaptive thresholding. The hough transform method is often used for binary valley or edge maps but depends on the threshold values leading to processing delays. CHT is used to detect the iris border precisely with both center and radius estimated simultaneously. In addition, this may also lead to high memory requirements. However, CHT fails to localize the RoI, if the correct estimation is not provided. CHT method may give good results when combined with some other segmentation methods [14-16].

In contrast to above mentioned methods, local adaptive thresholding technique selects an individual threshold to separate desirable foreground image objects from the background for each pixel in the image. The separation is based on the range of intensity values in its local neighbourhood. Adaptive thresholding is applied only to those generated images for which the global intensity histogram doesn't contain distinctive peaks. The adaptive thresholding system outperforms fixed thresholding because it adapts to local image properties [17-19]. It is further observed from the literature review that an efficient iris based system may not require IR light. In addition, the system should be simple, low cost, non intrusive utilizing affordable ubiquitous devices. The model should be able to detect the gaze of the subject at different positions on the screen placed in front.

In this research work, an appearance cum feature based shape model named Iris Center based Gaze Estimation (ICGE) has been proposed. The model is based on the detection of the center coordinates of segmented iris using adaptive thresholding technique without IR light for the estimation of the gaze direction based on the position of iris center coordinates. The image is binarised using an adaptive threshold technique along with the CHT to find out the circular shape of the iris along with estimated iris center. The eye images of different subjects are taken from indigenously created database. Various images have been processed for the analysis of results.

The ICGE model is an extension of already proposed Gaze Direction Estimation (GDE) model [9]. GDE model is a feature based shape model that primarily works on the detection of glints from the input eye images using two standard edge detectors canny and sobel. The limitations of the GDE model include multiple glint formation, absence of proper glint or no glint, dependency on light sources etc. In comparison, ICGE model is designed to estimate the gaze based on the position of the iris irrespective of glint formations. The experiments are performed in an indoor laboratory. Eyes with spectacles and squint eyes have not been considered in this research work. Target users for this system may include ordinary people with busy hands with still head and orthopedically impaired people who may have difficulty in moving their hands but can maintain steady head.

Rest of the paper is organized as follows. The literature review is presented in the section 2 *Related work*. The working methodology of the proposed ICGE model and its comparison with the earlier proposed GDE model is explained in the Sec. 3, *Experimental Analysis*. The results and discussion are described in the Sec. 4 *Results and Discussion*. The conclusion and further research directions are presented in the last section of the paper.

II. Related Work

Different methods are being used to estimate the direction and duration of eye gaze of a given subject. The significant part in any gaze based controlled system is the precise identification of direction, position and duration of the eye gaze. RoI can be glint, iris, iris center or any other related feature. Some of the significant algorithms and models for segmentation of RoI, iris localization and mapping presented by different researchers are discussed below.

The Gaze Direction Estimation (GDE) model proposed by Sharma *et al*. analysed the resultant images for estimating position of the glint coordinates as the RoI and subsequently the gaze direction in eye images dataset using the two standard edge detectors canny and sobel by capturing the facial images at a distance of 122 cm of the subjects from the camera. However, certain limitations of the *GDE* model like dependency on the orientation of the light sources, image resolution, multiple glint formation, absence of proper glint or no glint etc. leads to generation of wrong results in determining the exact glint boundaries in the eye images.The model shows 81% success rate in the detection of correct glint coordinates and correct gaze direction quadrants [9]. A comparative analysis for the glint detection has also been carried out by the same authors on different single eye images with various parameters of distance and orientation by using the edge detectors for eye gaze based systems using GDE model. The proposed model improves the interactivity time for enhancing the accuracy and performance by varying the number of processor affinities. The minimum execution time taken to find the glint coordinates and subsequently the gaze direction is estimated [20]. Sigut *et al*. have segmented the center of the iris without using IR light with iris center corneal reflection (ICCR) method with visible light instead of PCCR. Images with resolution of 752 × 582 pixels of only twenty five subjects at a maximum distance of only 70 cm feet have been used. However, the model is costly and time consuming [6]. Mingxin *et al*. proposes geometric relationship between the estimated rough iris center and the eye corners for only four states of iris within the eye region of twenty subjects placed at a distance of 60 cm from the camera. Although the proposed model generates 94% result but can only deal with the left and right states and not the down states of the iris. The performance of the model also decreases due to dependency on the ambient light conditions [19]. M. Zedah *et al.* proposes CHT with adaptive thresholding for iris segmentation from the images taken from different mobile devices. As reported, the researchers observe that the size of the iris in the image depends on the distance from camera. Colours of both skin and iris can degrade the performance of the iris segmentation algorithms. Additional process for removal of sclera is required. Further, the model could not properly estimate the upper and lower iris boundaries occluded by eyelids [17].

As it is evident from the literature review, different methods can be used for segmenting the boundary of iris for detecting gaze direction. The precision of the gaze detection is very important in the iris recognition methods. The limitations of the template matching, eigenspace like size and orientation of the face image and variation in illuminations as discussed above, requires further improvements. Requirement of specialized and expensive equipments adds an extra cost to the iris based models. The loss of iris circle configuration may lead to inaccurate detection and can and can be corrected by varying the range of expected radius for the correct detection of iris eye corner [10, 11]. Further as observed from the literature review, the use of IR light for gaze detection process may be hazardous to human eyes. Gaze detection model based on visible light may be preferred. In addition, the gaze detection at the down states especially bottom left and bottom right periphery appear to be difficult because of the factors like hidden iris edge and resulting in incomplete information of iris edge points [19].

III. Experimental Analysis

As mentioned above, an appearance cum feature based shape ICGE model has been proposed for the detection of the center coordinates of segmented iris using adaptive thresholding technique for the estimation of the gaze direction. The proposed ICGE model is low cost, non intrusive, simple and doesn't require IR light and edge detectors. Adaptive threshold technique has been used in ICGE to overcome the limitations of edge detectors and fixed thresholds. The model has been analysed for five different screen quadrants on the screen along with tuning parameters like pixel and radius range, window size etc. ICGE does not require initialization of search line radius and any template for the gaze detection process.

The design and methodology of the proposed research work of ICGE model has been discussed in detail below.

A. ICGE Model - Design and Development - A workflow for the detection of iris center coordinates has been shown in Figure 2.

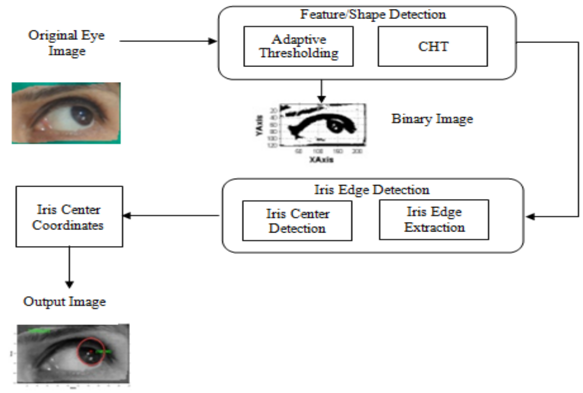


Figure 2. Work flow of iris center detection ICGE model.

The proposed iris localization method in the present research is adaptive thresholding [12, 21] along with CHT algorithm [17] which is used to extract the iris circle in the feature shape detection module. The single input eye image is converted into binary image using adaptive thresholding technique. The threshold value T at pixel location (x, y) in the image depends on the neighbouring pixel intensities. In adaptive thresholding, the local mean of every region within the selected window size (35x35) is computed by iterating over each pixel to generate local mean filtered image. The threshold value T(x, y) is normalised and computed using a parameter C_n ranging from 0.0143-0.0543 iteratively for every single pixel in the image. The threshold value obtained is applied to all the image area for the generation of a binary image. CHT algorithm is then applied to the binary image to find the boundary of iris in the image. Further, the extracted iris image is used for iris edge extraction and estimation of iris center coordinates in the iris edge detection module. The eye images are taken from indigenous *DB* consisting of eye images of different subjects. An experimental setup has been created using gaze estimation quadrant map *M* as shown in Figure 3.

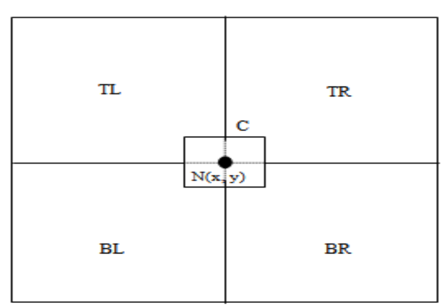


Figure 3. Gaze estimation quadrant map M (C – Center quadrant with N (x, y) for varying pixel range $\pm$ 10)

All the images have been captured using a digital camera of SONY NEX-5 ultra compact with resolution 4592x3056 pixels. The facial image of each subject is captured, cropped and normalized to a resolution of 220x120 pixels to select best of the two eyes. The eye image I_i for each region has been captured for each subject for the creation of comprehensive database *DB*. More than 220 images have been obtained from forty five different subjects. The subjects consist of both males and females (27:18) without spectacles within an age range of 20-40 years. The focal point of view rather than peripheral view is taken into consideration of the working of the model. The quadrant map *M*, placed at a distance of 122 cm (4 feet) from the subject has been divided into five specific regions namely TopLeft(TL), TopRight (TR), BottomLeft (BL), BottomRight (BR) and Center(C). Each subject has been instructed to gaze at five above regions of *M* in the sequence C->TL->TR->BR->BL respectively as shown in Figure 4.

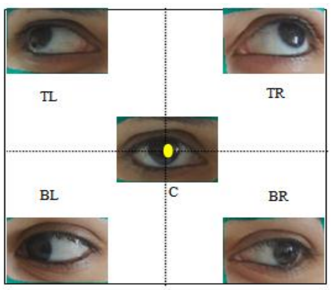


Figure 4. Eye images gazing at different quadrants.

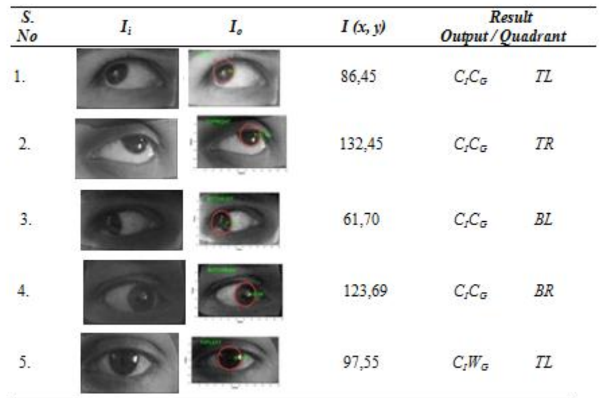
The central quadrant *C* with center *N(x, y)* has a pixel range of ±10. An input image I_i is taken from the *DB* for further processing. Superimposition of the extracted iris region over the input image I_i results in position detection of iris center coordinates *I (x, y)*.

Different cases of detection have been categorized as follows: C_IC_G, if both iris and gaze are detected correctly, C_IW_G, if iris is correctly detected but gaze is wrongly detected and W_IW_G, if both iris and subsequent gaze is wrongly detected. The ICGE model has been applied to each image I_i of *DB* for classifying the results in the above mentioned three categories.

The interface for ICGE model has been developed using MATLAB R2013a environment in a Dell Optiplex990 model with Windows7 professional 64-bit Operating system, Intel ® core i5-2500 CPU, 3.10 GHz and 2 GB RAM. The analysis of the results has been presented in the next section.

IV. Results And Discussion

As explained above, an appearance cum feature based ICGE model with adaptive thresholding has been proposed for gaze detection. In order to evaluate the performance of proposed ICGE model, a series of eye images of different subjects on the five region quadrant map *M* have been tested as explained in previous section. The results of five different subjects selected for five different map regions are presented in Figure 5. The second column I_i is the input image from the database *DB*. I_o represents the output image with segmented iris region and center coordinates I(x, y). I(x, y) is generated for each instance of image on the basis of position of iris within the eye. In case of I_1, since both x and y coordinates are below C(x,y), therefore, the generated region of gaze is correctly detected as TL and the output is C_IC_G. However, in case of I_5, even though the subject is gazing at the central region, ICGE generated output shows *TL* with the outcome as C_IW_G.



S. No	I_i	I_o	I (x, y)	Result Output / Quadrant	
1.			86,45	C_IC_G	TL
2.			132,45	C_IC_G	TR
3.			61,70	C_IC_G	BL
4.			123,69	C_IC_G	BR
5.			97,55	C_IW_G	TL

Figure 5. Resultant five gaze quadrants for selected subjects.

This may be attributed to the selected specific pixel range as mentioned above. A change in the region coordinates may affect the outcome of such cases. It has been observed that out of the 225 images, the ICGE model correctly identifies the iris and subsequently gaze quadrant (C_IC_G) for 202 images showing a success rate of approximately 90%. C_IW_G category (approx. 10%) is generated for the remaining images. Further, in all such cases of C_IW_G, the system correctly identifies the iris coordinates, but fails to detect the gaze quadrant of the subject correctly. In few cases, the output produced is W_IW_G (0.44%). This occurs due to incorrect detection of center coordinates leading to incorrect gaze quadrant detection. The reason for incorrect detection of iris coordinates may be improper iris formation or blurriness in image. Further, incorrect region mapping by the ICGE in spite of correct detection of iris coordinates may be attributed to the selected specific pixel range as mentioned above. A change in the region coordinates may affect the outcome of such cases. The quadrant wise detection of the correct gaze of all the images has been shown in Table 1.

Table 1 Quadrant wise results.

Quadrant (Q_i)	**Subjects** (45)	**CQD** (%)
TL	45	100
TR	42	93
BL	40	89
BR	38	85
C	43	96

The quadrant wise detection rate for all the forty five subjects has been pictorially represented in Figure 6. As evident from the graph the best gaze detection rate is at TL and C quadrant. The TR is also giving above 90% correct detection.

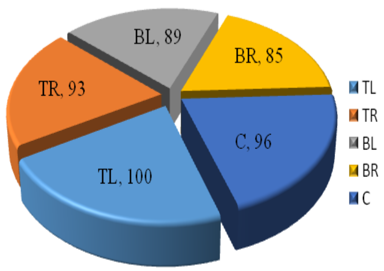


Figure 6. Quadrant wise detection rates for forty five subjects.

Although BL and BR quadrant is giving comparatively less but still significant detection rates (above 85%) at the lower periphery of the screen quadrant map. This is very significant as compared to other existing models in which gaze detection at down states was not significant and thus not considered.

V. Conclusion

In this research work, a design and analysis of appearance cum feature based shape model named Iris Centre based Gaze Estimation (ICGE) model has been proposed. The model is used for the estimation of the gaze direction based on the position of estimated iris centre coordinates using adaptive threshold technique with CHT. The proposed method is an improvement over the existing models used for iris recognition. ICGE model is experimentally evaluated using indigenous, non IR, simple, low cost and ubiquitous hardware based non intrusive database. The database comprises of 220 eye images taken from 45 different subjects at a distance of at least 122 cm (4 feet) from the camera on a five quadrants map with large screen size of 304 cm x 122 cm for detection of gaze direction. The proposed model generates better results without the use of edge detectors and static thresholding, specular reflections, template based methods etc. unlike used in other existing iris recognition methods. The result shows more than 85% correct gaze quadrant detection by the ICGE model for all the five quadrants of the map. The model detects the gaze correctly even in the lower periphery of BL and BR corners with better accuracy using certain selected tuning parameters for optimal performance. The instances of wrong gaze detection observed during the analysis may be attributed to factors like resultant noises, off-axis iris, incomplete iris circle, specific pixel range, iris on the move etc. The features that differentiates proposed ICGE model from other models include use of dynamic thresholding with CHT, ubiquitous hardware design, non IR, comparatively large subject camera distance and screen dimensions, single eye image processing, non glint dependency etc. Further, unlike many other existing models removal of sclera and glint is not required in ICGE model. This work may be further extended for online eye images with modified quadrant map for enhanced precision.

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