IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 5, Oct-Nov, 2013
ISSN: 2320 - 8791
www.ijreat.org

Eye Localization and Gaze Estimation in an Unrestrained Environment- A Survey

Sarmila.K.B[1] and Saranya.R[2]

[1]**Department of Computer Science & Engineering, Dr. N.G.P. Institute of Technology, Coimbatore.**

[2]**Department of Computer Science & Engineering, Dr. N.G.P. Institute of Technology, Coimbatore.**

Abstract

This paper reviews on various issues that influence eye detection and Gaze Estimation such as view point from which it is observed, illumination condition, occlusion condition like eyes with eye glasses and based on the appearance like size, shape, color and texture. This survey, focus on various difficulties in eye Localization and gaze Estimation and address on various algorithms analyzing the eye models from few training images under an unrestrained environment and organize the discussion towards efficient eye Localization and gaze Estimation. This survey paper concludes with several directions for future research.

Index terms— *Character Recognition, Eye Localization, Gaze Estimation, and Survey.*

I. INTRODUCTION

Eye Detection which is a prominent feature and Eye movement that is gaze estimation to be concerned in a wide variety of applications such as face detection that has a wide range of application in many areas like video surveillance, security, and entertainment. To these applications detecting eyes and their movements are the essential and difficult parts. Eye Localization and tracking researches mainly concentrate on two places, they are eye localization and gaze estimation [38]. There are three prospects of eye Localization. They are detecting the presence of eye on the image; next is to explain the location of eyes in the image and lastly to track the identified eyes in each frame of a video, including time factors and replicated data between two adjacent frames.

Though, eye localization and gaze estimation is important in above mentioned applications, they face many barriers which makes it much difficult due to eye's variability under an unrestrained environment. Specifically some of the factors that form this barrier are Illumination Condition, Expressions which involves the size, shape and appearance of eyes to vary, Occlusion conditions which forms an obstacle for eye detection, and Image quality.

LFW (Labeled Face in Wild) [6] database contains the training images used to represent various issues above mentioned. The conditions in various images denoted by above mentioned database affects the effective eye localization. Cheolkon Jung, Tian Sun, Licheng Jiao explains about eye detection under various lighting changes, which is a barrier affecting effective eye localization. Similar works are observed in these listed papers [1, 36, 43, 46, 48] illustrated by many other authors, which compels the requirement of robust eye detection in a real life scenario under an unrestrained environment.

Over last decades there are many methods used to illustrate various techniques for eye detection, Recently Fengyi Song, Xiaoyang Tan, Songcan Chen and Zhi-Hua Zhou [48] has illustrated a survey on efficient eye detection in an uncontrolled environment. Hansen and Ji [38] has given an survey on current progress in eye detection and tracking technique in an video based image, where art-of eye localization technique is used, which works good in an unrestrained environment. As mentioned eye localization and gaze estimation in real life scenario is a challenging task than in restrained environment and is far from being resolved.

The maximum contribution of this paper is based on the survey on the methods resolving these challenges, which is believed to be a useful complement to [48] and [38]. Some method of eye detection used in [48, 38] are illustrated in this paper. In addition, we arrange the discussion on eye detection and gaze estimation in unrestrained environment, towards the development of efficient eye detection for the purpose of real life scenario.

The paper is organized in following manner, that is, Section 2 contains Methodologies used for Recognition of Characteristics of an eye and Eye Localization which is been successfully applied in various papers. In Section 3, we focus on Gaze Estimation technique which is applied for identifying movements of eye, which leads to effective eye detection and followed by a performance evaluation on all successful techniques applied in Section 4. We conclude this survey with summary and

conclusion which promisingly provides several directions for future research on eye detection in Section 5.

II. CHARACTERISTICS OF AN EYE AND EYE LOCALIZATION

In this section we focus on various techniques used for eye localization by the process of recognition of characteristics of an eye process, these various techniques can be broadly classified into three classes, They are as follows: First is to measure the characteristics of eyes which is one of the facial component based on their distinct shape including iris and pupil contour, eyelids. Generally eye characteristics and eye localization can be done by detecting the features of the eyes and this method works well only with image which is of good quality, which is less

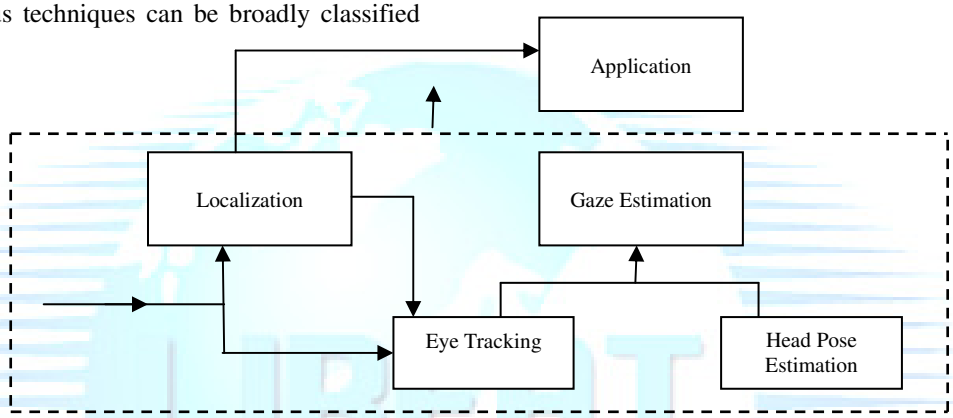

Fig. 1. Components of Video base Eye localization and Gaze Estimation [38]

probably possible in real life scenario. Second class, it deals with illustrating the appearance models, which is essential condition for eye localization and appearance models vary based on view point and illumination condition.

These eye models are identified here using the training data set with variable appearance of eyes. Third class is structural information which involves interior structural information of eyes that is geometric information about the shape of eyes with is complex in unrestrained environment, unless it works along with statistical eye model. Various algorithms and approaches used for eye detection under these three classes are discussed as follows

2.1 Character Recognition

The main objective of detecting the varying characteristics of eye is to satisfy the objective of itself that is eye is a special character of face which is to be detected. Many features of eye are already a distinct character which is ready for denoting eyes, like shape and color contrast that is white sclera and pupil of eyes. These are the features which are the best indicators of eyes. However in unrestrained environment these characters are less reliable which automatically affect the performance of eye localization.

The shape and intensity contrast are the main character of an eye which is described by Yali Li, Shengjin Wang and Xiaoqing Ding [57] using Deformable model. Oliver Zersorsky, Klaus J. Kirchberg and Robert W. Frischholz [44] also describes the above based on the circular shape of the pupil and also Ravi Kothari and Jason L. Mikhell [50] approached these features by using pupil centered out ward gradient field method. Context information of eyes is illustrated in [57] by detecting the eye corners and also given by [49] based on the facial region between the eyes.

2.2 Shape Characteristics

Identifying the model of eye is essential in case of eye detection, though it is a unique feature of eye it varies widely in various dimension and angles and also in researches on eye detection is still a challenging task due to the above mentioned issues like occlusion due to eye lids, viewing angles that is same object may have variation in its appearance at different viewpoints, degree of openness of eyes, etc. The open eye is well defined by its shape, which include iris, pupil contours, and eyelid. There are two components in eye model they are geometric model of eye and measuring of similarity between object and model.

Specifically, the deformable model illustrated by Yuille et al [57] gives a continuous mathematical formulation of shapes of eyes. Whereas Active Shape model (ASM) [21] represents shape of an eye in a discrete way, which is discussed in detail in Section 2.3. In [20] parameters of model are redesigned to

improve the flexibility and robustness of deformable model, and in [54] they tried to initialize the corners of eye first properly, though there are improvements there are still some disadvantages that they depend on image quality.

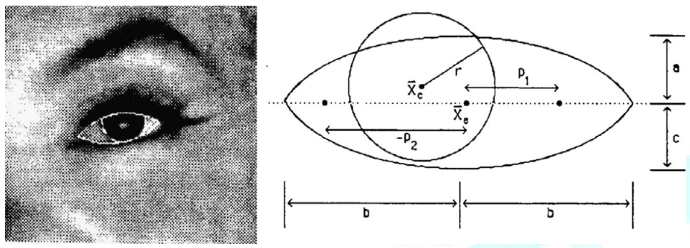

Fig. 2. Yuille et al's shape model of eyes [57, 48]

2.1.1. Intensity Based Character

In an open eye, intensity contrast between iris, pupil, sclera, and eyelids is very high which forms a distinct character of an eye. The methods used for measuring intensity distribution in an image which is essential feature for eye detection are done using Variance Projection Function (VPF) and Integral Projection Function (IPF) [13] and these both functions are used for General Projection Function (GPF) [58] for efficient eye detection, although they were useful in some real world applications it is influenced by bright spot lights reflected by iris. In another method Gradient patterns [50] are used instead of intensity patterns which are then served as eye template.

2.1.2. Recognizing the Context Character

When the shape and intensity features do not help for eye detection this context feature is efficient for eye localization, by using Bayesian framework based on the prior knowledge about the position of eye on the face, Shinjiro Kawato, Jun Ohya, Seika Cho, Soraku gun, Kyoto [50] proposed an eye tracking system through locating "between-eyes" region.

2.3 Appearance Model of an eye

The shape of an eye is an important character to be considered for eye localization in an image. *Image Template* is an appearance method where appearance of an eye is also another significant character to be considered. In this appearance based method it is used to directly track and identify the eye's presence using the photometric method based on chrominance distribution of the eye in an image and this appearance based method can be applied in spatial and in transformed domain. The transformed domain is used to overcome the effect of illumination variation by conserving the band that is less sensitive to illumination and removing the band that is sensitive to illumination. But this technique is applicable only for moderate illumination variation.

This appearance based model of eye is proposed in [27] by Mark Everingam, and Andrew Zisserman using Bayesian model. This model with larger appearance of eye is much efficient and false positive is less but eyes detection is efficient when including the eye brows into consideration on FERET [26] database. In [52] the authors used the method based on multi scale LBP character set for eye localization. In general LBP [9] is good at detecting the characters that is appearance and texture efficiently than in Gabor features [22] that encode the shape and texture of the eyes. In [17] the authors proposed to group different features of eyes and built an SVM classifier on it to distinguish objects. Static based descriptors are more advantages than feature based descriptor in handling images in unrestrained environment but is of high cost to for providing good performance with available training set.

Eye detection using discriminative methods are more efficient than that of generative method. In [27] Everingam and Zisserman made a comparison between various classifiers including generative and discriminative methods and resulted with Bayesian Classifiers including SVM classifier and Adaboost Classifier with proving good performance in eye localization . But in real life scenario discriminative method is not much efficient as they are sensitive to small localization errors and they provide good classification accuracy but not localization accuracy. There are many approaches to solve these problems. One of the approaches that explicitly inform the classifier about the images that is inaccurate that is the image look similar but that is not the object of interest. Appearance model is also given in [12] using Average of Synthetic Exact Filters (ASEF). In which each training image is assigned with a correlated image which is generated by a bright peak at the center of the eye that is the object of interest. This is achieved using correlation filter, which transforms input image into correlation image.

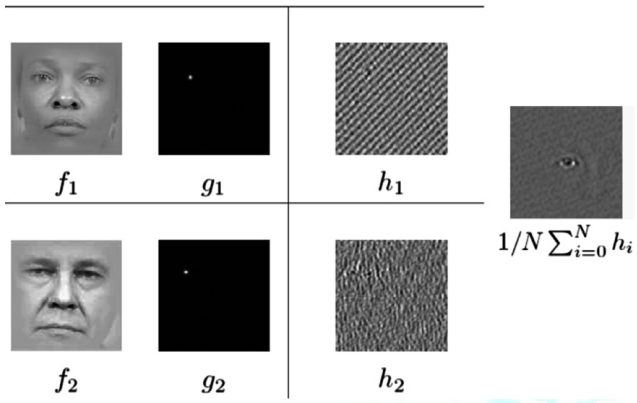

Fig. 3. Illustration of ASEF method: f_i denotes the image in training set and g_i is the output using desired filter respectively. A correlation filter h_i is produced by Fourier domain that exactly transforms f_i to g_i. The final correlation filter is taken with the average of many exact filters [12].

2.4 Structural details of human eye

The Spatial topological features define template of eye which consist of following components like eyelids, iris and pupil and these components has fixed structural relationship, whereas Appearance features are based on visual aspect of eyes. And in case of structural information it is less affected by unrestrained environmental condition than that of appearance features. So clearly there are two features that is appearance and structural features which are complementary to each other in identifying the eye template.

The structural information is proposed by David S. Bolme, Bruce A. Draper and J. Ross Beveridge [12] using Average of Synthetic Exact Filters (ASEF) which is used to train the images. And in [32] the authors gave Pictorial structural model, the objective of this model is to decompose the image into a set of parts and then use graph structure to model the topological relationship among them, which helps in localization of eye in an image which is the object of interest. In [30] Pedro F. Felzenszwalb and Daniel L. Huttenlocher illustrated an efficient method to measure the topological structure by changing the graph structure as a tree. In [29] the authors give still an efficient method with the principle for the task of objects detection and also be used in eye detection. To avoid measuring the multimodal distribution of eye in real life scenario, a discriminative method is proposed instead of generative method in [30] and these methods are tested on the LFW [6] data set which provides an unrestrained environmental condition images.

TABLE I. EYE DETECTION PERFORMANCE EVALUATED ON VARIOUS DATABASE

Databases	Issues	Methods
FERET [26]	Illumination condition, Expression, Pose.	General to Specific [17], Multi-scale LBP [52], Average os synthetic exact filters [12], Bayesian Method [27]
JAFFE [24]	Expression	General projection Function [58], Multi-views eye lacalization [31]
BioID [25]	Illumination condition, Background, Scale	General projection Function [58], Multi-scale LBP [52]
LFW [6]	Unrestrained Environment	Multi-views eye lacalization [31]

III. GAZE ESTIMATION

In [38] the authors provide various techniques involved in gaze estimation, where the main objective of these techniques is to identify the gaze that is to detect the eye where it is looking at. Authors describe that gaze modeling focus on relation between the image data and point of gaze direction. In [38] the authors also give a brief explanation on various eye models based on the comparison of all the method types under various conditions for the efficient identification of the positions of the eyes. They also give brief explanation to achieve this by using character recognition for gaze estimation using two approaches like model based and interpolation based, which is again classified into 2D interpolation based estimation and 3D model based estimation.

IV. PERFORMANCE EVALUATION

Evaluation of various eye detection techniques and make fair comparison of various models used to achieve this objective, ideally performance should be reported on the representative benchmark database and should follow a standard protocol. Algorithms are evaluated using various metrics as listed below. They are variations in databases, measure metrics, training samples, testing samples etc., which makes it impossible to directly compare eye detection.

Table 1 summarizes the performance evaluated on some of these databases. In the table we highlight the major issues contained in each database, the detection performance in terms of the percentage of images that have been successfully identified corresponding to certain detection error. Among them FERET [26] is the most popular database used for face recognition and eye detection. Face images in this database are taken in a controlled environment so can be applied for general eye detection application, but real life scenario contains many issues to be faced including unrestrained environmental conditions. Various methods works well under this controlled condition is illustrated in the table. The next dataset JAFFE [24] which contains facial images with various expression changes but with eyes to be wide open this is used for eye detection by using various geometric and illumination variation conditions illustrated by some of methods mentioned in the table. The BioID [25] database is the most challenging dataset for eye detection in unrestrained environment which includes varying illumination condition, background and size of face. This database provides an environment of still complicated uncontrolled conditions which becomes challenging for eye detection methods. Finally in the table, the database LFW [6] contains the face data of unrestrained environment which works for eye detection with methods as mentioned in the table.

V. SUMMARY AND CONCLUSION

In this paper, various efficient eye localization and gaze estimation methods are illustrated from numerous angles. Eyes are a component of face detecting it is involved in various real life applications, as mentioned above eye localization and gaze estimation is not an easy task as it is difficult in an unrestrained environment. Various techniques used towards the task of eye localization and gaze tracking under above mentioned properties have been successful in improving the task of eye localization and it remains significant potential for further developments.

Here we provide a survey of some researchers in this area. Mainly we have focused on practical issues affecting the efficiency of eye localization and gaze estimation in an unrestrained environment using various techniques used for achieving it and also made a review on various eye detection methods applied on various popular face databases. Here we have also considered gaze estimation technique in this paper which is another important property to be considered for eye localization in various applications involved in real life scenario. Though there are lots of methods used to achieve this objective still there is requirement for more efficient and accurate technique for eye localization and gaze estimation in an unrestrained environment. Some of the requirements which are forming a barrier for these tasks are as follows,

Eye localization based on various applications locating the position of eyes in an uneven lighting, occlusion, and all other mentioned issues are still problematic. There are various computer vision techniques, pattern matching and machine learning techniques which provides some good solutions for these problems. And also Neural networks is another efficient technique used as human brain can easily identify eye in an image in any unrestrained condition which is also applied for obtaining good result. Finally, databases used for eye detection are been specifically developed for face detection which cannot be used for gaze estimation which is an eye related task. Thus as the above specified difficulties does not mean that it cannot be achieved by the techniques used currently as shown above there are considerable efforts being done to achieve it. Since it is a wide practical application, we think that this area will find an increasing attention in various fields beyond the fields mentioned above in this paper based on eye detection and gaze estimation.

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