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Unsupervised Eye Center Localization Approaches for Real Time Eye Gaze Tracking Applications

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Abstract

This work deals with exploration of the latest and the most effective unsupervised approaches for automatic eye center localization, which may be suitable for the real time eye gaze tracking applications. These approaches were based upon direct mathematical formulations and principles without needing any complex trained models. The experiment was performed over standard face image dataset, which showed varying accuracy and processing times for automatic detection of pupil location in each face image. The outcome of this study suggested the significance and efficiency of each unsupervised approach for eye center localization under unconstraint environments. The results may be useful for the development of fast and accurate real time eye gaze tracking applications for interactive usage.

Keywords

Eye Center Localization, Eye Gaze Tracking, Unsupervised Approaches, Interactive

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1. Introduction

Human eye center localization is an important component of eye gaze tracking systems due to the reason that the better the pupil localization approach the better will be the gaze tracker accuracy as well as sensitivity. The task of detection of better approach for pupil localization may be done by studying all the conditions and challenges such as low resolution, illumination variations, and head pose, etc. Researchers worldwide are using two different approaches for eye center localization such as supervised approaches as well as unsupervised approach. The supervised approaches are developed using supervised machine learning algorithms which needs prior training and development of the trained models which are used for the testing. The unsupervised approaches are comparatively simpler to develop without any prior training model. These techniques use basic scientific principles and algorithms. Development of newer techniques for eye center localization using unsupervised approaches in recent years showed their utility in applications related to the accurate and fast eye center localization. The unsupervised techniques are further classified into techniques based upon appearance, shape and features. Recently combination of any two or more techniques are also tried which are known as hybrid techniques. The most commonly used unsupervised technique is based upon the vector field of image gradients. The gradient based approaches for developing system for eye center localization give high accuracies and is invariant to changes in scale, pose, illumination and rotation. Kothari and Mitchel [1] introduced this technique based upon flow field character that arises due to the strong contrast between iris and sclera region. They used the gradient vector to draw the line through the whole image and the intersection of all these lines will represent the estimated eye center. Timm and Barth [2] also used the aforesaid approach and by developing mathematical formulation for the vector field characteristics they described the relationships between the possible eye

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center and the orientations of all image gradients. The computation consist of dot products between the displacement vector of a center candidate and the image gradient. The position of the maximum gives the eye's center as it corresponds to the position where most image gradients intersect. The image gradient based approaches are also used by researchers along with some other techniques to improve upon the accuracy of detection of eye pupil which includes curvature features based upon Hough circularity, self-similarity characteristics, etc. Some researchers included curvelet features with the gradient distribution which is the gray intensity distribution in the frequency domain rather than the gray intensity distribution in the spatial domain as in case of simple gradient based approach [3]. Valenti and Gevers [4] introduced isophotes features to accurately locate eye centers in face images which is based upon radially symmetric brightness patterns. The term isophotes of an image are the curves connecting points of equal intensity which do not intersect each other [5]. The curvature is used to find the radius of the circle along with the orientation and direction. The orientation can be estimated from the gradient whereas its direction will always point towards the highest change in the luminance. Therefore, the gradient is multiplied with the inverse of isophote curvature getting direction of the center and ultimately, the center of the eye. However, to obtain the actual eye center voting based approach is used along with the curvedness feature due to the reason since the shape of the obtained isophotes may differ from the shape of the object and all the isophotes detected may not be meaningful or fit for voting. Convolving the image with a Gaussian kernel, can boost the voting of a center and increase the number of isophotes around the edges. A center voting mechanism is used to weight important votes to boost the center estimates. An unsupervised eye pupil localization is proposed using self-similarity space computation using normalized correlation coefficient between the intensity values of a local region and the intensity values of the same geometrically transformed local region [6]. At a given location the average normalized correlation coefficient which is computed over all orientations of the mirror line or different angles of rotation is known as radial similarity map or region self-similarity. The self-similarity score along with the estimation of the spatial distribution of circular shapes using circular Hough transform will give the joint space which was normalized in the range [0, 1] and then point-wise added. The maxima value will be the point selected as the pupil center. Further improvement of this technique was done by using different combination of unsupervised approaches wherein self-similarity along with differential geometry which is based upon isophotes features is used[7]. In all of the aforesaid approaches each input image is initially analysed by using the boosted cascade face detector proposed by Viola and Jones and the rough positions of the left and right eye regions are then estimated either using anthropometric relations or by Viola and Jones eye detector [8]. The current work deals with the basic analysis of currently used unsupervised techniques for eye pupil localization in a most practical way without using any pre-processing or post-processing steps. The time taken by each algorithm along with the accuracy for detection of eye center localization is useful for development of advanced techniques.

2. Methodology

A. Database Selection and Eye patch extraction

The development and analysis of the unsupervised algorithms were done in workstation computer, HP z620 having Windows 7 Professional operating system (64- bit), 32 GB RAM, etc. The software used for the programming was Matlab ver. 2013a. The human face database most used in the recent times in the literature is the BioID database which is found to be most popular for the detection of eye center localization. This database contains difficult images acquired as low resolution and varying illumination settings. The Viola-Jones technique which uses a rapid object detection method using Haar- like wavelet features based upon cascade classifier structure for face detection was used for the extraction of the eye patch information from the database. The extracted eye patch image contains very less information being low resolution images of the BioID database which makes the eye center localization more challenging task.

Fig. 1. Sample Image (http://www.bioid.com), Face Region Extraction and Eye Region Extraction.

Unsupervised Techniques For Eye Center Localization

The unsupervised techniques used for the eye center localization based upon certain physical parameters such as circularity, rate of change of intensity variations, etc. were explored. Authors developed these unsupervised techniques in Matlab 2013a software environment using basic information available from the literature without any optimizations. These algorithms were tested over same image database under similar conditions (Fig. 1).

B. Gradient Distributions based approach

In multi stage approach a face detector is applied first and rough eye location are extracted. This rough eye location is then used to derive precise estimation in next stage. This technique requires the eye patch image as input for the detection of the gradient features over it. The gray intensity distribution in the patch image is related to the specified eye center. In order to obtain the image gradients the computation of the partial derivatives was done in Matlab software by using the standard function as, [Gx, Gy] = gradient (image), where the image gradient were calculated in both x and y directions as Gx and Gy, respectively and the input image is filtered using Gaussian filter first. The magnitude of image gradients were calculated by applying thresholding operation based upon first order standard deviation. The next step is the calculation of the magnitudes of displacement vectors in both x and y directions. Finally, the magnitude of displacement vectors are multiplied to magnitudes of gradient vectors and the resultant matrix obtained when divided with image resolution showed the center of the eye at the maxima.

C. Isophotes features based approach

The definition of isophotes is the concentric curves connecting points of equal intensity. This property best utilizes the circular features present around the pupil of the eye, which is also known as limbus. Therefore, to represent the aforesaid features isophotes curvature estimation was successfully used for detection of accurate eye center localization. Similar to the gradient distribution technique magnitude of image gradients were calculated. In this technique the computation of the 1st and 2nd order partial derivatives were done using following standard Matlab functions,

[Gx, Gy] = gradient (image),

[Gxx,Gxy]=gradient (Gx) and,

[Gyx, Gyy]=gradient (Gy).

Based upon these gradient matrices, calculation of the displacement vectors was done using the technique followed by Valenti and Gevers, 2008.

Further, the curvature detection was applied which ensured that only curved features will be selected.

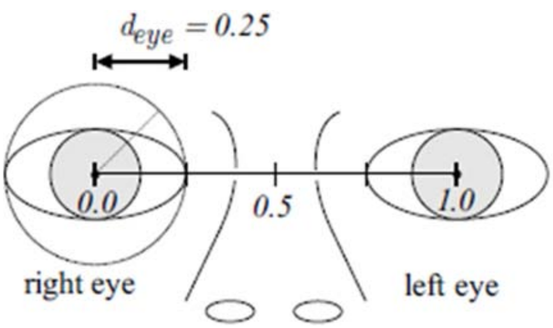

Fig. 2. Normalized error detection method (Jerosky et al. 2001).

D. Self-Similarity space computation approach

The human eye has such a geometrical shape which retains its peculiar characteristics even under rotations and variable illumination variations. So by following the self-similarity space computation approach (radial similarity map) an average normalized correlation coefficient may be computed over all orientations of the mirror line [9]. In this paper 8 different mirror line orientations were used in combination with 3 different radii. Also the computations also involved discarding of the outmost 5 pixels in each direction.

3. Eye Center Detection Accuracy

To evaluate the performance of the eye localization technique a well-known relative error measure based technique based upon Haurdorff distance is applied (Fig. 2). The interocular distances between the expected and detected eye positions gives relative error measure as following:

$$d_{eye} = \frac{\max\left(d_{Left\ eye}, d_{Right\ eye}\right)}{\left\|C_{Left\ eye} - C_{Right\ eye}\right\|}$$

where $d_{Left\ eye}$ and $d_{Right\ eye}$ are the maximum of the distances between the true eye centers $C_{Left\ eye}$ and $C_{Right\ eye}$ and the estimated eye centers. This distance is normalized by dividing it by the distance between the expected eye centers, making it independent of scale of the face in the image and image size which is referred as relative error [10]. If the measured value of relative error, $d\,eye \leq 0.25$ it corresponds to the distance between the eye center and the eye corners, whereas the relative error, $d\,eye \leq 0.10$ corresponds to the range of the iris, and the relative error, $d\,eye \leq 0.05$ corresponds the range of the pupil. Therefore, by using aforesaid method the performance evaluation is done.

4. Comparative Analysis and Conclusion

The comparisons (Table I) amongst explored unsupervised approaches showed that image gradient distributions based approach is far ahead in terms of accuracy for the detection of eye regions along with eye centers. This approach showed high accuracy of detection over the BioID face database [11], which is one of the most challenging face database with the detection percentage of eye, iris and pupil detection as 99.80%, 86.78% and 53.95%, respectively. The isophote features based technique showed the detection percentage of eye, iris and pupil detection as 99.80%, 67.24% and 51.18%, respectively which is lower than the image gradients approach. On the other hand, the processing time taken by the isophote features based technique is lower than the image gradients distributions based approach by a large margin i.e. time taken by the former one to process 1520 images of BioId database was 103.91 seconds wherein the latter one took just 10.28 seconds to complete the whole processing for the same number of images. Authors also tried some hybrid techniques based upon the combination of two or more unsupervised approaches as suggested in the literature. The hybrid approach made by combining image gradients distributions and isophotes features improved the detection percentage of pupil by a decent margin i.e. 59.73%. Further, the detection percentage of iris dropped to 79.73% whereas the detection percentage of eye remained unchanged along with the rise in processing time i.e. 115.40 seconds.

The results of the comparative analysis suggested that the combination of different unsupervised approaches for eye center localization along with supervised algorithms [12] for facial feature detection may also be explored to further enhance the performance of the eye center localization approaches for the development of accurate and real-time eye gaze tracking applications under unconstrained conditions.

5. Comparative Analysis and Conclusion

The authors are thankful to the image dataset providers for making available the large datasets along with its accurate ground truth information.

Table 1. Comparative analysis of accuracy of unsupervised techniques for eye center localization for BioID database along with processing times.

Unsupervised Approach	Eye (E=0.25)	Iris (E=0.10)	Pupil (E=0.05)	Processing Time (seconds)
Gradient distributions	99.80	86.78	53.95	103.91
Isophote features	95.20	67.24	51.18	10.28
Self- similarity	98.55	13.49	9.14	20.31
Isophotes + Self-similarity	99.47	53.28	35.33	31.78
Gradient + Self-similarity	99.47	58.55	35.92	112.89
Gradient + Isophotes	99.80	79.73	59.73	115.40
Gradient + isophotes + Self-similarity	99.60	63.75	42.43	122.36

E= Normalised error

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