A NOVEL PUPIL LOCALIZATION METHOD BASED ON GABOREYE MODEL AND RADIAL SYMMETRY OPERATOR

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ABSTRACT

The eyes are the most important facial landmarks on human face. The accuracy of face normalization, which is critical to the performance of the following face analysis steps, depends on the locations of the two eyes, as well as their relatively constant interocular distance. In this paper, we propose a novel GaborEye model for eye localization. Based on the special gray distribution in the eye-and-brow region, proper Gabor kernel is adaptively chosen to convolute with the face image to highlight the eye-and-brow region, which can be exploited to segment the two pupil regions efficiently. After getting the region of the pupil, a fast radial symmetry operator is used to locate the center of the pupil. Extensive experiments show that the method can accurately locate the pupils, and it is robust to the variations of face poses, expressions, accessories and illuminations.

1. INTRODUCTION

Face recognition has a variety of potential applications in public security, law enforcement and commerce, such as mug-shot database matching, identity authentication for credit card or driver license, access control, and video surveillance. In addition, there are many emerging fields that can benefit from face recognition, such as human-computer interfaces and e-services, including e-home, and tele-shopping. Related research activities have significantly increased over the past few years [1].

A practical face recognition system should include at least the following three steps: face detection, facial feature localization/extraction, and classification. Many researchers study the recognition problem based on the assumption that the positions of the main facial feature points, commonly the two eyes, are manually labeled. The FERET96 test shows that the performance of partially automatic algorithms (pupils are manually labeled) is obviously better than that of fully automatic algorithms (pupils are not labeled) [2]. Therefore, getting accurate location of eyes is an important step in a face recognition system.

There are some existing algorithms to extract main facial landmarks including: template matching [3], integral projection [3], Snakes [4], deformable template [5], Hough transform [6], elastic bunch graph matching [7], region growing search [8], Active Shape Models (ASMs), and Active Appearance Models (AAMs) [9]. Among these methods, deformation template models the eye as several parametric geometric curves: two parabolas modeling the eyelid, and one circle modeling the iris. And then the parameters of these curves are optimized to match the eye image. However, such an optimization process is deemed to be very slow. In addition, it is impossible to describe all kinds of eyes as the parameterized geometric curves. ASMs and AAMs are both based on statistical model of the shape and/or shape-free texture information. Though ASMs and AAMs have the ability to localize all the pre-defined facial landmarks, their accuracy and efficiency can be greatly improved if other methods can provide accurate initial eye positions as strong constraints for active searching.

In addition, most of the above-mentioned methods for eye localization are sensitive to the variations due to varying face poses, illuminations, expressions and accessories. Therefore, it is still necessary to design robust eye localization algorithms, which are robust to various imaging conditions. Different from the existing eye localization methods, which are mostly based on spatial features, this paper tries to localize the eyes using their special features in the frequency domain by proposing a novel GaborEye-based method for eye localization, which makes full use of the special gray distribution in the eye-and-brow region, and self-adaptively chooses proper Gabor kernel to convolute with the face image in order to highlight the eye-and-brow region of interest. In the magnitude domain of the convolution, two highlighted regions, named GaborEye, will appear in the eye-and-brow regions. Utilizing the salient GaborEye feature, we can efficiently segment the eye-and-brow region. Then Gabor kernel with smaller scale is further used to convolute with this region again to tune the segmentation of the pupil region. The center of the pupil is finally localized accurately by radial symmetry operation in the pupil region. Our extensive experiments on FERET and YALE database show that the proposed method can accurately localize the pupil and it is robust against the variations of illuminations, poses, and expressions. Figure 1 shows the flowchart of the proposed pupil localization method, in which the face detection takes the method [10].

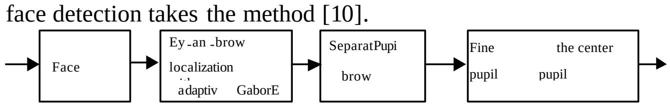


Fig.1. Flowchart of the proposed pupil localization method based on GaborEye model and radial symmetry operator

The remaining part of this paper is organized as follows: In Section 2, we introduce the motivation to propose the GaborEye and its definition; Section 3 describes the GaborEye-based eye segmentation and radial symmetry–based pupil localization method in detail. Experiments are conducted in Section 4, followed by some discussion, conclusion and future work in Section 5.

2. GABOREYE

The two eyes are the most salient organs on a human face. In a face image, eyes also have especial features -- two gray valleys due to the pupils, and rich edge segments in the eye-and-brow region because of the abrupt intensity change. So, the eye-and-brow region, as a piece of 2D signal, has specific frequency characteristics, which would be dramatically different from those of other regions in the face image. Therefore, in order to segment the eye-and-brow region, it is a natural idea to select a proper bank of band-pass filters to enhance the signal of the eye-and-brow region while suppress that of other face regions. In addition, the signal of the eye-and-brow region contains more changes in the horizontal orientation than the vertical orientation, that is, orientation is also its salient characteristics compared with other regions in the face. Considering the frequency and orientation characteristics of the eye-and-brow region, Gabor filters would be a natural choice, because it has been shown that it can capture salient visual properties such as spatial localization, orientation selectivity, and spatial frequency characteristics. The commonly used Gabor kernel is as following [11]:

$$\psi_{u,v}(z) = \frac{\| k_{u,v} \|^2}{\sigma^2} e^{(-\|k_{u,v}\|^2 \|z\|^2 / 2\sigma^2)} \left[e^{i\vec{k}_{u,v} z} - e^{-\sigma^2/2} \right] \quad (1)$$

where $k_{u,v} = k_v e^{i\phi_u}$, $k_v = \frac{k_{\max}}{f^v}$ gives the frequency, f is a constant spatial factor, $\phi_u = \frac{u\pi}{8}, \phi_u \in [0,\pi)$ gives the orientation, and $z=(x,y)^T$; $e^{i\vec{k}_{u,v} z}$ is the oscillatory wave function, whose real part and imaginary part are cosine function and sinusoid function respectively.

It has been shown that the Gabor kernel, a band-passing filter with a Gaussian window, is notably different from other band-passing filters with rectangle window [12]. By defining $U = \frac{k_v \cos\phi_u}{2\pi}$, and $V = \frac{k_v \sin\phi_u}{2\pi}$, in frequency domain, the envelop curve of the Gabor kernel is a Gaussian function whose center is located at *(U,V)*, and the corresponding center frequency changes with the window moving. Therefore, k_v totally determines the position of the Gabor Kernel in frequency domain, if ϕ_u, which controls the orientation of Gabor kernel, is constant. In other words, the *u* parameter in Equation.1 controls the orientation of the filter, while the *v* parameter determines the frequency center (scale) of the filter. And from $k_v = \frac{k_{\max}}{f^v}$, we can see that larger *v* means smaller *U*, *V*, that is, when *v* becomes larger, the frequency center of Gabor kernel will closer to the original point (see Figure 2 for reference.).

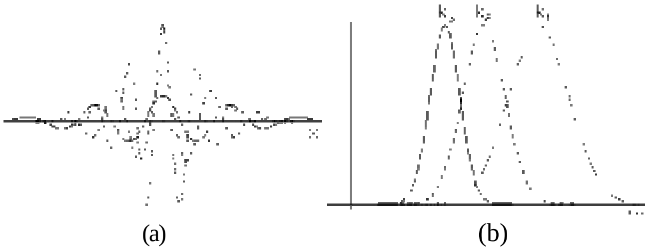

(a) (b)

Fig. 2. Representation of 1D Gabor kernel in spatial domain (a) and frequency domain (b)

In order to verify the capability of the Gabor filters to the eye-and-brow region, experiments are conducted. In our experiments, five scales $v \in \{0,...,4\}$ and five orientations $u \in \{0,1,2,6,7\}$ are chosen in the Gabor wavelet family. Figure 3 shows the real part of these Gabor kernels with the following parameters: $\sigma = 2\pi$, $k_{\max} = \pi/2$, and $f = \sqrt{2}$. In Figure 3 the variation in frequency (scale) and orientation of the kernels can be observed clearly.

When a face image passes these filters, the components with specific length and orientation are enhanced while the other parts are suppressed. Figure 4 and 5 show two examples, where two salient highlight regions corresponding to the eye-and-brow region in the original face image are its most dramatic characteristics, which indicates that some proper Gabor kernels do have excellent eye-and-brow region selectivity. So, one can draw the conclusion that convoluting face image with proper Gabor kernel can extract the distinct frequency features of eyes' region for segmentation purpose. We name the magnitude representation of the eye-and-brow region as ***GaborEye***. When the frequency and orientation of the Gabor kernel match those of the eye region, the eye's region can be significantly enhanced. Note that, since the high frequency change may also occur in the brow region, the center of highlight region may not always fit the center of the eye, but locating between the eye and the brow.

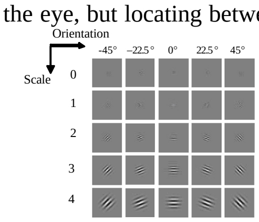


Fig. 3. The real part of the Gabor kernels

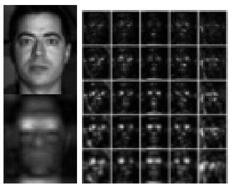


Fig. 4. The eye-and-brow selectivity of some Gabor kernel. Top-left: the original face image. Right: the magnitude domain after the Gabor transform. Bottom-left: the original image mixed with the magnitude domain transformed by the horizontal-orientation and fifth-scale kernel

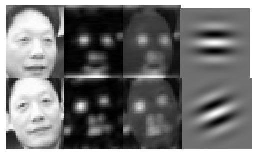

(a) (b) (c) (d)

Fig. 5. The magnitude of the representation of image transformed by Gabor Kernel, the faces in different poses. (a) Input face images.(b)The magnitude of the representation. (c) b mixed with a. (d) The Gabor Kernel used.

Obviously, it is important to choose the proper Gabor kernel. Fortunately, through analyzing the property of the detected face image, we can choose the proper Gabor kernel. Generally, a face detection module will provide rough size of the face, which can be used for scale selection. We use $s = \alpha h$ to select the scale of Gabor kernel, where *s* is the scale we used, *h* is the height of the detected face, and α is a constant coefficient. Figure.6 shows the result convoluted with the proper Gabor kernel selected by our strategy.

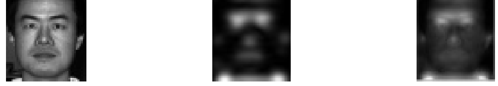

(a) (b) (c)

Fig. 6. Self-adaptive Gabor transform. (a) the original image (b) the magnitude domain of the Gabor transform: the eye-and-brow region are highlighted selectively. (c) *b* superposes on *a*

3. ROBUST GABOREYE-BASED PUPIL LOCALIZATION METHOD

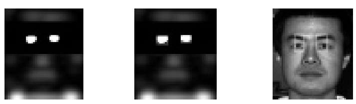
We use a coarse to fine strategy to segment the pupil region. In coarse segmentation step, we use a Gabor kernel with large scale, which enhances the comparatively low frequency region, to get the eye-and-brow region. Then, we take a Gabor kernel with smaller scale to extract the comparatively high frequency regions around the pupils. Compared with the one step approach, this strategy can prevent the false alarm when a smaller scale is applied.

3.1 Segmentation of the Eye-and-Brow Region

Based on the GaborEye, we use the following steps to segment the eye-and-brow region:

1. Morphology preprocesses: dilation. In order to cover the eye-and-brow region, we take Morphology operator—dilation to expand the GaborEye's region.
2. Integral project in GaborEye's region. Analyzing the prior structure knowledge of human face, we assume that eyes locate in the rectangle area whose top is H/4 from the top of image and bottom is 2H/3 from it (H is the height of image), within the rectangle integral projection is done in vertical direction, then the projection curve is got. Figure 7 shows these operations.
3. Analyze the projection curve; separate the left eye's region from the right eye's region. Two points of maximum value is found, then the point with minimum G_{min} between the two points is got, which is used to separate two regions, which are labeled as E_l, E_r.
4. Search the max gray value in E_l, E_r, label the two max values as GL_{max}, GR_{max}. Use T_l, T_r to threshold image in E_l, E_r, where T_l= a* GL_{max}, T_r=a* GR_{max}, a is the empirical factor which is 0.85. The typical image after threshold operation is in Figure 8 (a).
5. Segment the eye-and-brow region. Search maximum connected field in E_l, E_r, whose outward rectangles are labeled as R_l,R_r Figure 8(b) shows this result, H_l, H_r are the height of these two rectangles. As above has referred, the centers of these rectangle are not the center of eyes, they are located between eyebrow and up eyelid. Our experiments also prove that R_l and R_r can not entirely cover the two eyes' regions especially when the eyebrow is dark. To ensure the segmented eye-and-brow region containing the eye, we take this following strategy: we expand R_l by adding its bottom the length of H_l, R_r by adding its bottom the length of H_r (H_l is the height of R_l, and H_r is the height of R_r), then choose the maximum bottom of R_l and R_r as their bottom, as Figure 8(c) shows. we do not expand R_l and R_r in horizontal direction because the centers of eyes are close to the center of GaborEye in horizontal direction.

Fig.7. Vertical integral projection for separate the two eye region



(a) (b) (c)

Fig. 8. Locate the eyes' regions. (a) Binarize in two locations. (b) Outward rectangle. (c) The segmented eye-and-brow regions

3.2 Segmentation of the Pupil Region

A Gabor transform with smaller scale is applied to the areas R_l and R_r selected in the first step to separate the eyes from the brows and get the regions of pupil.

The parameters of Gabor kernel used to convolute with pixels in R_l and R_r are as follows: four scale, $v \in \{0,...,3\}$, orientation is 0°, u=0 always. $s = 2p$, $k_{max} = 1.5p$, the larger k_{max} is used because there is more high frequency information in the region which is between up-eyelid and down-eyelid. The scale of Gabor kernel is chosen by equation (5). Figure 9 is an example convoluting with selected region, We can get two integral projection curves in X and Y directions. Max_X is the maximum value of integral projection curve in X direction, the corresponding position is POS_X; Max_Y is the maximum value of integral projection curve in Y direction, the corresponding position is POS_Y. We use T_x (T_x= 0.3*Max_X) as threshold to search the integral projection curve from the two ends to the middle to determine the edge of pupil's region, while projection value is larger than T_x, the corresponding position is considered as an edge of region of pupil. The same operation is done in integral projection curve in Y direction with threshold T_y

$$S_2 = \begin{cases} 0 & d_y \le 15 \\ 1 & 15 < d_y \le 35 \\ 2 & 35 < d_y \le 50 \\ 3 & 50 < d_y \end{cases} \tag{5}$$

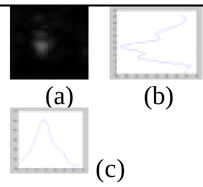


Fig.9. Integral projection curves in X and Y direction after Gabor transform in R_l and R_r(a) the transform result in R_l and R_r with Gabor kernel with smaller scale (b) Integral projection curve in X direction (C) Integral projection curve in Y direction.

(T_y=0.3*Max_Y) . R_{sl} and R_{sr} are the re-segmented rectangles. Figure 10 shows the result, the large rectangle is the first segment result, and the small one is the re-segment result.

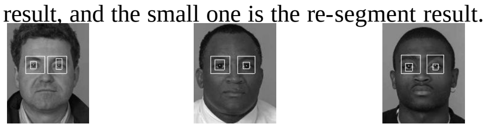


Fig.10. Segmentation of the Pupil Region (Small rectangle)

3.3 Accurate Localization of the Center of Pupils

Using the gray valleys around the two pupils to locate the position of eye is the simplest method, but this method does not work well in poor illumination environment, or melanoderm. Considering that radial symmetry is a basic property of pupils, we propose to apply the radial symmetry detection to locating the centers of pupils. The outline is as Figure 11.

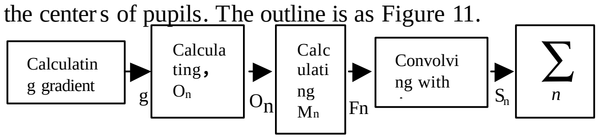


Fig.11. Diagram shows the steps involved in computing the transform.

Gradient is calculated with 3x3 Sobel operator in R_{sl} and R_{sr}, then each point with the gradient g. From each point p, a corresponding positively-affected pixel p_{+ve} and negatively-affected pixel p_{-ve} are gotten by

$$p_{+ve} = p + round\left(\frac{g(p)}{\|g(p)\|}n\right) \quad \text{and} \quad p_{-ve} = p - round\left(\frac{g(p)}{\|g(p)\|}n\right),$$

where g(p) is gradient vector, round means rounding each vector element to the nearest integer, and *n* is radius. For each radius *n*, an orientation projection image O_n and a magnitude projection image M_n are formed. The orientation and magnitude projection images are initially zero, O_n and M_n are constructed from following

$$O_n = (p_{+ve}(p)) + 1 \qquad O_n = (p_{-ve}(p)) - 1$$

$$M_n(p_{+ve}(p)) = M_n(p_{+ve}(p)) + \|g(p)\| \qquad M_n(p_{-ve}(p)) = M_n(p_{-ve}(p)) + \|g(p)\|$$

F_n is calculated as:

$$F_n(p) = \frac{M_n(p)}{k_n}\left(\frac{\tilde{O}_n(p)}{k_n}\right)^{a} \text{ where } \tilde{O}_n(p) = \begin{cases} O_n(p) & \text{if } O_n(p) < k_n \\ k_n & \text{otherwise} \end{cases}$$

then S can be got as:

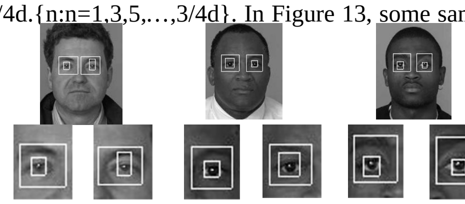
$$S = \frac{1}{|N|}\sum_{n\in N} S_n \text{, where } S_n = F_n * A_n \text{; } a = 2, \quad k_n = \begin{cases} 8 & \text{if } n = 1 \\ 9.9 & \text{otherwise} \end{cases}$$

A_n is a Gaussian window with size $n \times n$. The standard deviation of A_n is 0.5*n*. The detail about how to select parameter is in [13]. The whole transform steps are shown in Figure 12.

(a) original image (b) F5 (c)O5 (d) M_5 (e)S_5 (f) e superposes on a

Fig.12. the transformed samples

In Figure 12-(f), the blackest point in S_5 around eye's region is the center of pupil. So we can use the radial symmetry detecting operator in R_{sl} and R_{sr} to locate the center of pupil, we think that the blackest point of S in R_{sl} or R_{sr} is the center of pupil. In our syetem, we get the resegment region first then just use the radial symmetry detecting operation in this region. d is the maximum edge of R_{sl} or R_{sr}, n are all the odd integers from 1 to 3/4d.{n:n=1,3,5,…,3/4d}. In Figure 13, some samples are given:



(a)Re-segment result

(b)locate the center of the pupil

Fig.13. locate the center of pupil (the white point in R_{sl} or R_{sr} is the located point)

From the Samples in Figure 12, we can see that the center of pupil can be located accurately.

4、EXPERIMENT AND ANALYSIS

4.1 Face Database and Evaluation Measurement

In order to test the performance of this approach, we do experiments on FERET face base. We choose ba, bg, bk pose subbase, one image per person in these face base. The faces in ba, bk are frontal but under different illumination conditions. The faces in bg rotate 22.5° left. In our experiment, the size of face image is 138×168, the window size of Gabor kernel is 64×64, we take a equate to 0.016 in $s = ah$, and the following evaluation measurements are taken:

Coarse segment precision: If the eye is included in the rectangle R_l or R_r, the segmentation result is right. The left eye segmentation is right means that left eye is in R_l, The right eye Segmentation is right means that right eye is in R_r. Fine segment precison: After re-segmentation operation, if both pupils are in R_{sl} and R_{sr}, the re-segmentation is right.

4.2 Experiment Result and Analysis

Experiments are done on FERET face base, and the results are in table 1 and 2,

Table 1 Segmentation with scale equate to 3

face database	FERET ba	FERET bg (22.5° left)	FERET bk
Total images	200	200	200
Coarse segmentation precise ration in R_l	99.5%	95%	98.5%
Coarse segmentation precise ration in R_r	98.5%	100%	99.5%
Coarse segmentation precise ration (both R_l and R_s)	97%	95%	97%
Fine segmentation precise ration (R_{sl} and R_{sr})	96.5%	95%	96%
Correct locate the center of pupil	95%	91%	94%

Table 2 Segmentation with scale equate to 2

Total images	FERET ba	FERET bg(22.5° left)	FERET bk
Total images	200	200	200
Coarse segmentation precise ration in R_r	99%	98%	99%
Coarse segmentation precise ration (both R_l and R_s)	99%	100%	99%
Coarse segmentation precise ration (both R_l and R_s)	98.5%	98%	99%
Fine segmentation precise ration (R_{sl} and R_{sr})	98%	96%	96%
Correct locate the center of pupil	95.5%	91.5%	92%

Fine segmentation with the same scale, there is almost no difference between convolution with scale equal to 3 and convolution with scale equal to 2, so this conclusion can be drawn that our method is not sensitive to the size of image. This method is not sensitive to the illumination, the same experiment is done on YALE face base, and the result is also satisfied.

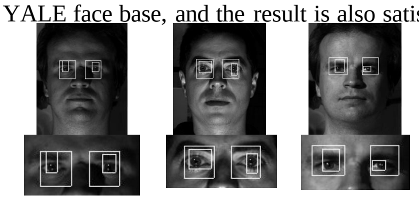


Fig.14. Example in Yale face base

5. CONCLUSIONS

In order to resolve the problem of locating feature points on face image taken under various imaging conditions, we present a novel eye localization method by proposing the GaborEye model in this paper. Based on the special gray distribution in the eye-and-brow region, a proper Gabor kernel is adaptively chosen to convolute with the image to highlight it, we define the region as GaborEye, which can be exploited to segment the two pupil regions efficiently. Based on the radial symmetry of pupil, we use radial symmetry detecting operation to locate the center of pupil. Experiments on FERET and YALE show that the performance of this method is robust against the variations of face poses, expressions, accessories and illuminations. To sum up, the main contributions of this paper are as following:

1. Find that some Gabor kernel has outstanding eye-and-brow selectivity, which can be exploited to highlight the attentive regions of interest for further segmentation.
2. Based on the segment result from GaborEye model, radial symmetry detecting operation is taken to locate the center of pupil. Experiments done on FERET and YALE face base show that the performance of this method is excellent.

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