A Fast and Robust Iris Localization Method
Based on Texture Segmentation

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ABSTRACT

With the development of the current networked society, personal identification based on biometrics has received more and more attention. Iris recognition has a satisfying performance due to its high reliability and non-invasion. In an iris recognition system, preprocessing, especially iris localization plays a very important role. The speed and performance of an iris recognition system is crucial and it is limited by the results of iris localization to a great extent. Iris localization includes finding the iris boundaries (inner and outer) and the eyelids (lower and upper). In this paper, we propose an iris localization algorithm based on texture segmentation. First, we use the information of low frequency of wavelet transform of the iris image for pupil segmentation and localize the iris with a differential integral operator. Then the upper eyelid edge is detected after eyelash is segmented. Finally, the lower eyelid is localized using parabolic curve fitting based on gray value segmentation. Extensive experimental results show that the algorithm has satisfying performance and good robustness.

Keywords: Iris recognition, biometrics, texture segmentation, iris localization, eyelid detection.

1. INTRODUCTION

To meet the increasing security requirement of the current networked society, personal identification is becoming more and more important. Traditional methods for personal identification include the token-based methods that use specific things such as ID cards or keys for authentication and the knowledge-based methods that use something you know such as password for identification. However, these methods are usually not reliable. For example, token may be lost and knowledge may be forgotten. Therefore, a new method for personal identification named biometrics has been attracting more and more attention. As a promising way of authentication, biometrics aims to recognize a person using the physiological and (or) behavioral characteristics such as fingerprints, face, gait, voice, and so on [1].

The human iris is the annular part between pupil and sclera, and has distinct characteristics such as freckles, coronas, stripes, furrows, crypts, and so on. It is an inner organ visible outside; hence, iris images can be captured without physical touch. Compared with other biometric features, personal authentication based on iris recognition can obtain high accuracy due to the rich texture of iris patterns. Some sample images of iris are shown in Fig.1. Each eye has its own iris pattern that is stable throughout ones life. So we can use iris patterns to identify individuals and iris recognition has many potential applications such as access control, network security, etc.

With the increasing interests in iris recognition, more and more researchers devote their attention into this field [2-7,13-24]. Daugman [2,3] built a recognition system in 1993 and the identification accuracy is up to about 100%. Wildes [4,5] designed a device to capture iris images at a distance, and super-resolution method was used to obtain clear images. Recently, some new algorithms are reported at the AVBPA. Bae et al. attempted to use the independent component analysis (ICA) to extract iris feature, but the detailed results of classification were not given in their paper. Kumar et al. tried an iris verification method based on correlation filters. Park et al. extracted the normalized directional energy as the iris feature and the equal error rate (ERR) is only 3.8%.

Our earlier attempts to iris recognition are based on texture analysis or shape description. In [22], the comparison had been done between existing methods and the conclusions showed that our method based on texture analysis was

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just worse than Daugman's method. In [23], we extracted the local sharp variation points of each row of normalized image as the key points of the iris patterns. Although the method has promising performance better than [23], the intra-class distribution can be further improved.

Although so great progress has been achieved, some problems cannot be ignored. In real systems, the conditions vary and we must improve the robustness of the systems. Moreover, we must improve the speed because we can capture many frames per seconds; otherwise the users cannot tolerate the long time. As we know, iris localization costs nearly more than half of the total time [Method in 23] and iris localization is very important for the subsequent processing such as iris normalization, feature extraction and matching. Therefore, the iris localization is crucial for the performance, i.e. accuracy and speed, of the iris recognition system.

Iris localization is generally introduced briefly. In [8], Wildes details his iris localization method. However, we must balance the localization accuracy and speed.

The remainder of the paper is organized as follows. Section 2 introduces the related work. The algorithm for iris localization is described in detail in section 3. Section 4 gives the experimental results of the method on the CASIA iris database. Section 5 concludes the paper.

2. RELATED WORK

As we know, preprocessing is very important in an iris recognition system and researchers pay more attention to it. In an iris recognition system, localization has great influence on subsequent feature extraction and matching. Iris localization methods are based on the object detection methods [9-11]. Generally, iris localization can be done by combining edge detector and curve fitting. Because iris is the annular part between pupil and sclera, the boundaries of the iris are modeled as two non-concentric circles and the eyelids are modeled as two parabolic curves.

Daugman [3] used an integral differential operator to localize iris:

$$\max_{x,y,r} \left| G_{\sigma}(r) * \frac{\partial}{\partial r} \oint_{(x,y,r)} \frac{I(x,y)}{2\pi r} ds \right| \tag{1}$$

where $G_{\sigma}(r) = \frac{1}{\sqrt{2\pi}} e^{-\frac{r^2}{2}}$ is a smoothing operator and $\oint_{(x,y,r)} \frac{I(x,y)}{2\pi r} ds$ is integration along a circle centered at (x,

y) with radius r. The method tries to search the position of the circle in a 3D space. It is accurate because it searches the global maximum, however, it will be time-consuming without any tricks, which are not introduced in his work. When detecting the eyelids, he just changed the integral path from a circle to a parabolic curve. The search is done in a 4D space.

Wildes [4] used a two-step method to localize iris: edge detection followed by Hough Transform. He first use the directional edge detector to detect the edge points; then he use curve fitting to localize the iris and eyelids with a parabolic curve. The method is accurate, however, the method need filter much noise with prior knowledge such as the position of the pupil.

Another Wildes' method is to optimize the consistent measure [8]:

$$\sum_{q=1}^{n} \left((n-1) \|g_{q,r}\| - \left(\sum_{f=q+1}^{n} \|g_{q,r} - g_{f,r}\| \right) - g_{q,r}/8 \right) \tag{2}$$

where $g_{q,r}$ stands for the gradient at (q,r) in the normalized image. From our experimental results, the method costs much time because it searches all the candidates and iterates the search process.

However, papers on eyelid localization are few. Daugman and Wildes introduced their algorithms to localize eyelids briefly. Daugman used a method similar to Eq. (1) and only changed the integral curve to an arcuate arc. Wildes still used a two-step method to localize eyelids and only gave some constrains to obtain the true edge points. However, no details are given on the algorithms and their performance.

Our early method combines two steps: edge detector and modified Hough transform. We adopt the Canny operator because it can detect thin edge and obtain connected edge.

3. IRIS LOCALIZATION BASED ON TEXTURE SEGMENTATION

We have mentioned above that preprocessing, especially iris localization is very important for an iris recognition system. We want to find the visible part of iris to obtain the feature vector, so iris localization includes not only locating the inner and outer circular boundary of iris, but also detecting the eyelids. However, eyelid detection is relatively difficult due to the low SNR (signal-noise ratio) in upper eyelid area and we will discuss this below. We select an easy-to-difficult scheme for iris localization: first pupil segmentation, then boundary localization and last eyelid detection. The scheme is selected because pupil edge is most distinct in our iris images and it is relatively easy to be localized. Local texture is important for iris localization and it is it is useful to save computational time. Thus, pupil detection can provide useful information for boundary localization and eyelid detection.

1.1 Iris outer and inner boundary localization

Because pupil is a black region with low frequency, we decompose the original image with Haar wavelet. We select Haar wavelet because it has zero-phase and minor displacement when it is used to localize pupil. Fig.2 (b, c) are the quantized decomposition results. From this we can easily localize pupil in a coarse-to-fine strategy, i.e., we compute the position of the iris in Fig.2 (c) and project the result to Fig.2 (b) and then to Fig.2 (a). The last result is shown in Fig.2 (d). This strategy can filter much noise such as eyelash. When computing the parameters of the circles, we use a modified Hough Transform to improve the speed. We select randomly three edge points in the edge map and computer the centroid and radius according to the equation:

$$(x_i - a)^2 + (y_i - b)^2 = r^2 \tag{3}$$

We will see from the experimental results that the method can reduce computational cost.

The outer boundary of an iris is localized with an integral differential operator. The differential operator is defined as

$$f'(i) = f(i+1) + f(i+2) - f(i-1) - f(i-2) \tag{4}$$

so it can improve the contrast of the outer boundary of an iris. If the pupil position is (x_c, y_c, r), the searching space of outer boundary is limited to $(x_c - x_1, y_c, r + r_1) \sim (x_c + x_1, y_c, r + r_2)$.

1.2 Upper eyelid localization

We can find from Fig.2 (a) that the edge of the upper eyelid is contaminated by eyelashes, hence the upper eyelid localization is difficult because of the low SNR. So the traditional methods that combine edge detection with Hough transform are not very efficient without some limits and an integral differential operator incurs high computational cost because it must search in a 3D parameter space. Considering the above two points, iris localization based on texture segmentation is adopted because we want to use not only gray information but also texture information. The method proposed in this paper uses the frequency property to segment eyelash. It avoids many false points because it adopts local texture property. The algorithm can be described as follows.

1) Segment eyelash region from the image to search the raw position of the eyelid. To segment the eyelash, we compute the energy of high spectrum at each region. If the high frequency is high enough, it can be seen as eyelash area.
2) Use the information of the pupil position to segment the upper eyelash.
3) Fit the eyelash with a parabolic arc $y = ax^2 + bx + c$.

If we obtain the points in eyelash area as follows:

$$(x_1 \ y_1) \quad (x_2 \ y_2) \quad \ldots\ldots (x_N \ y_N),$$

the parameter of the arc is:

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = (A^{\mathrm{T}} A)^{-1} A^{\mathrm{T}} Y \tag{5}$$

where
$$A = \begin{bmatrix} x_1^2 & x_1 & 1 \\ ... & ... & ... \\ x_N^2 & x_N & 1 \end{bmatrix} \text{ and } Y = \begin{bmatrix} y_1 \\ y_2 \\ ... \\ y_N \end{bmatrix}.$$

4)   Search in the neighborhood field of the parabolic arc denoted by (a, b, c) to get the final result.

Let $curve(c) = ax^2 + bx + c - y = 0$ be a cluster of parabolic arc with variable parameter c and

$$c_0 = \arg \max_{curve(c)} \left| \frac{\partial}{\partial c} \int_{curve(c)} I(x, y) ds \right|$$ then c_0 is the true position of the upper eyelid.

5)   The accurate parameter of the parabolic arc is (a, b, c_0).

1.3 Lower eyelid detection

We segment the lower eyelid using the histogram of the original image. The threshold is defined by computing the mean and variance of the gray value of the pixels in the iris. We select the upper points of the lower eyelid under the pupil to search the edge of the lower eyelid according the following steps.
1)   Segment the lower eyelid area;
2)   Compute the edge points of the lower eyelid;
3)   Fit the lower eyelid with the points obtained in step 2);
4)   Search the final result in the neighborhood field.
Step 3) and 4) are similar to step 4) and 5) in upper eyelid detection algorithm, respectively.

4. EXPERIMENTAL RESULTS

Because there are no common iris databases for comparison, the CASIA Iris Database is adopted [12]. It includes 108 classes and each class has 7 iris images captured in two sessions. The time interval is about one month. So there are totally 756 iris images with a resolution of 320*280 pixels. In these images, some irises are occluded by eyelids and some lower eyelids are not full, i.e., out of the image window. Some examples are shown in Fig.1. The experiments are performed in Matlab (version 6.1) on a PC with P4 2.4GHz processor and 256M DRAM.

4.1 Iris outer and inner boundary localization

From Fig.2 (b) and (c), we can see that much eyelash is filtered in low frequency domain and pupil is segmented in the low quantified frequency. In table 1, the accuracy is the results observed by eyes for we have not developed a method to evaluate the localization results.

Table 1 The localization results of outer and inner boundary

Accuracy	Mean time	Min. time	Max. time
99.34%	0.2426s	0.1870s	0.3290s

4.2 Upper eyelid localization

The result of eyelash area segmentation is shown in Fig.3 (a) and the localization result of upper eyelid is shown in Fig.3 (d). Also, the accuracy in Table 2 and Table 3 is the results observed by eyes.

Table 2 The results of upper eyelid localization

Accuracy	Mean time	Min. time	Max. time
97.35%	0.1827s	0.1090s	0.2810s

4.3 Lower eyelid detection

Segmentation result of lower eyelid area is shown in Fig.3 (c) and the localization result of lower eyelid is shown in Fig.3 (d).

Table 3 The results of lower eyelid detection

Accuracy	Mean time	Min. time	Max. time
93.39%	0.7700s	0.1710s	1.7030s

4.4 Discussions

From accuracy in Tables 2 and 3, we can see some false localization results that mean several-pixel displacement from the true position of eyelids. Because there are some tricks unknown in Daugman and Wildes' method, we do not compare with them, but compare the localization results of inner and outer iris boundary and the results are listed in Table 4.

Table 4 Comparison with other algorithms

Method	Accuracy	Mean time	Min. time	Max. time
Daugman	98.6%	6.56s	6.23s	6.99s
Wildes 1[5]	99.9%	8.28s	6.34s	12.54s
Wildes 2[8]	99.5%	1.98s	1.05s	2.36s
Proposed	99.54%	0.2426s	0.1870s	0.3290s

We can see that the accuracy is only lower than that of Wildes' two-step method. However, the method proposed in this paper is much faster.

The theoretical analyses of the high speed and robustness of the proposed method are as follows.
1) The efficient easy-to-difficult localization scheme is adopted. The localization method makes full use of the local information to reduce the effect of noise.
2) Pupil detection uses circle fitting, which is the solution of the parameter equations. The method is not the same as Hough transform and can reduce computational cost greatly.
3) In outer boundary localization, a high order differential operator is adopted to improve the iris image contrast. In addition, the search space reduces from 3D to 2D and we only search a small domain in the 2D space, therefore, the algorithm is fast and can avoid local maximum.
4) Upper eyelid detection is based on frequency characteristics of eyelashes and it is not affected by illumination. And the search space reduces from 3D to a small domain in 1D space, so the method is fast and robust.

In a word, the proposed method combines the edge and texture to localize the iris: (outer and inner) boundary and (upper and lower) eyelid.

5. CONCLUSIONS

Iris localization serves not only computing the position of the iris, but also detecting the eyelids to get the visible part of iris. This paper proposes an algorithm to localize iris based on texture segmentation. It localizes pupil with WT (wavelet transform) and iris boundary is localized with a differential integral operator. Edge of upper and lower eyelids is detected after eyelash and eyelid are segmented. We use the spectral information to ovoid the false edge points that always exist in edge-detection based method. The experimental results show the promising performance and robustness of the method. The method is fast and it is useful real time iris recognition system. In the near future, we will do experiments to see that the localization of eyelids is helpful to improve the accuracy of iris recognition.

ACKNOWLEDGEMENTS

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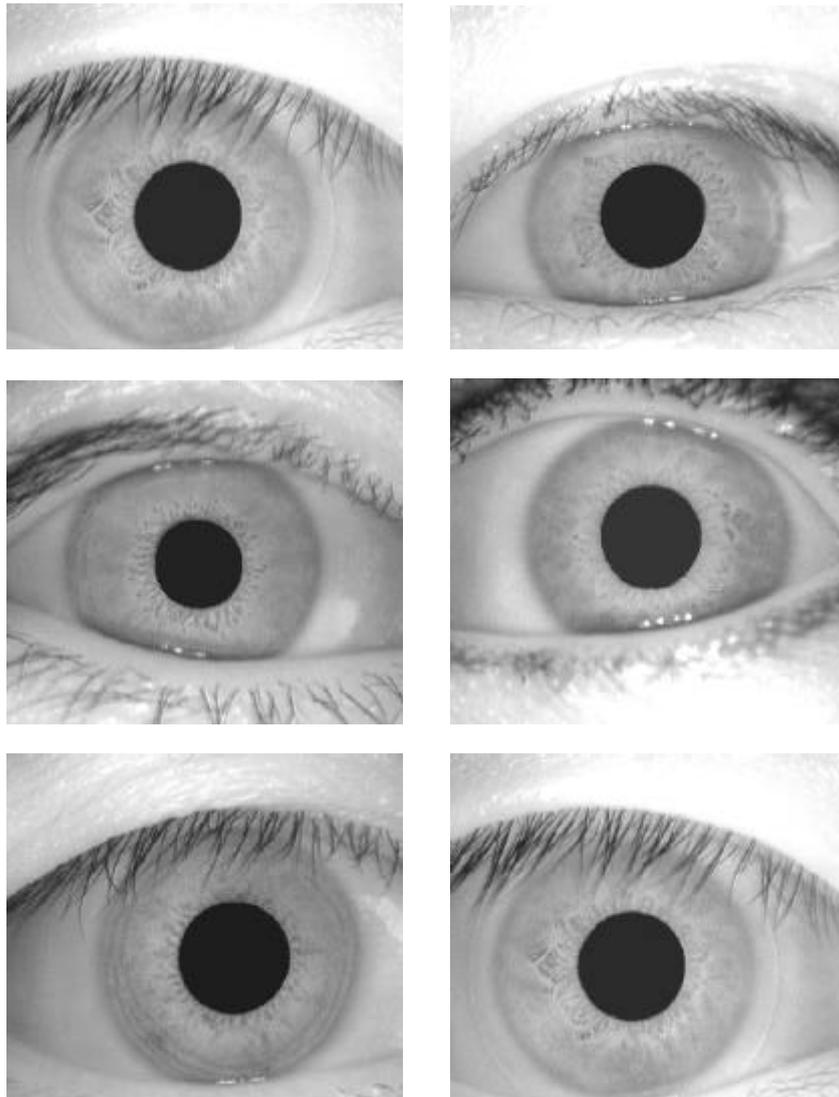
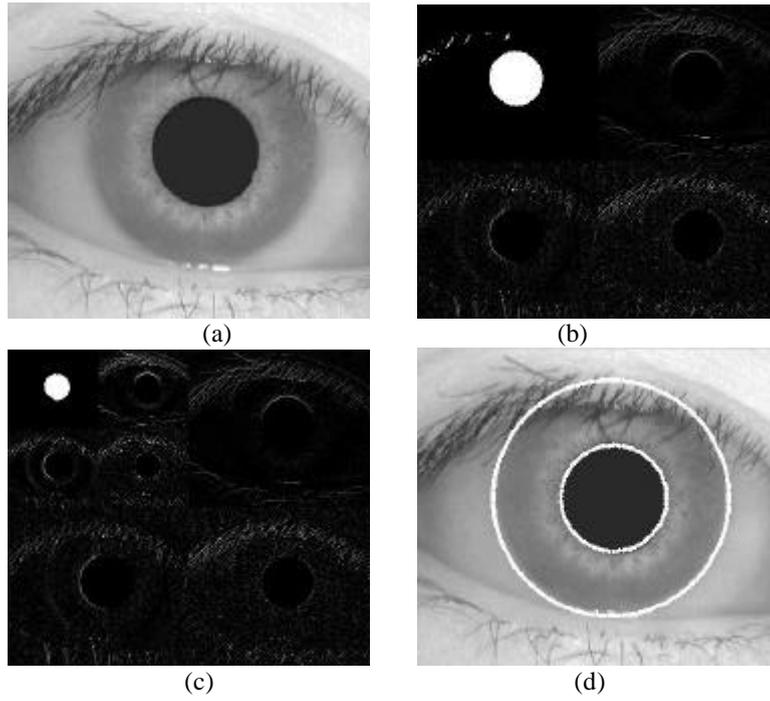Figure 1. Some examples of the iris images

Figure2 Localization results (a) original image (b) wavelet decomposition at level 1
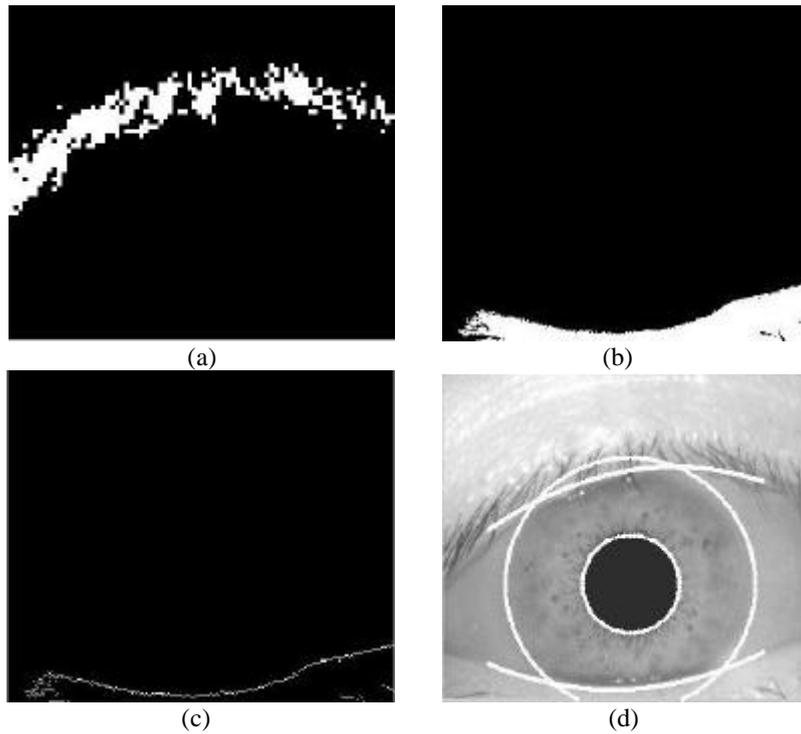(c) wavelet decomposition at level 2 (d) outer and inner circular boundary

Figure 3 Eyelid localization result (a) eyelash segmentation result
(b) lower eyelid segmentation result (c) edge of lower eyelid (d) eyelid localization result