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An Improved Daugman Method for Iris Recognition

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Abstract: An improved Daugman iris recognition algorithm is provided in this paper, which embodies in two aspects: ① Improvement for iris localization and ② The improvement for both iris encoding and matching algorithms. In Step 1, the localization and shape of the pupil are roughly determined in iris image, which is used as prior knowledge to quickly locate the inner and outer boundary of iris from rough to fine scale. Eyelids, eyelashes areas and the spot in the pupil are automatically detected and removed to improve the localization accuracy. In Step 2, the possible noise from residual eyelashes is further filtered by selecting a "pure" iris area as a reference and making a validation judgment pixel-wise. Furthermore, the validation flag for each pixel is introduced into the iris encoding and matching computation, as a result, the rejection rate of iris recognition is reduced. Compared with Daugman algorithm, iris recognition test on collected human eye images shows that our proposed algorithm has an obvious improvement both on boosting the speed and reducing the rejection rate.

Key words: iris recognition; iris localization; iris encoding

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0 Introduction

In the modern information and network society, identity authentication is closely related to individuals in the daily life, such as in the fields of aviation, finance, network, electronic commerce and national security. Because the traditional identity authentication methods rely on some factors such as external identification documents, user names, and passwords, which are forgettable or/and easy to counterfeite. Therefore, biometric identity with advantages such as universality, uniqueness, stability, non-invasiveness becomes a trend of research and development [1], of which iris recognition can supply better security, anti-deceptive function and higher accuracy than fingerprints, palm prints and face approach [2]. Therefore, it is considered as the most promising biometric methods in academia and business [3,4].

The idea to use the iris identification was first proposed by ophthalmology expert Frank Burch in 1936. Daugman [5] of Cambridge invented the world's first human eye iris recognition machines and proposed a theoretical framework for iris recognition in 1993. The iris recognition framework is divided into four parts [6, 7]: iris localization, iris normalization, iris feature extraction and matching. As for iris localization, KalKa *et al* [8] assumed that the iris boundary is an ellipse and is located by curve fitting via the least square method, but this method cannot extract the boundary points of eyelid and eyelash efficiently. In 2007, Daugman[9] proposed that the active contour method is more suitable than the fixed shape model in describing the inner and outside iris boundaries. However, this method is easily interfered by noise and occlusion, which leads to inaccurate localization due to convergence to local minima. As for iris feature extraction, Sun *et al* [10] obtained local gradient direction by applying Gaussian filter in a gradient field, then encoded the iris according to the gradient direction angle range. Monro *et al* [11] performed DCT transform on the normalized iris image and obtained the binary code by detecting the zero crossings of the adjacent coefficients. Rydgren *et al* [12] used wavelet transform for iris feature extraction. Sun *et al* [13] proposed that the fusion of several characteristics is more helpful to improve the accuracy of iris recognition, so he put forward the concept of a cascade classifier and set up a multi-layer classifier to classify the iris; the obtained iris recognition results are better than that uses single feature only. For iris feature matching, in Yuan's opinion[14], the feature coding method of fixed length is vulnerable, so the variance of two iris images' gray scale different surfaces can be used as the basis to measure the "similarity". Although this method eliminates the feature extraction time, its recognition rate is lower than that of the recognition algorithm of Dauman. Yuan's method cannot detect interference degree on the iris texture eyelid, eyelash, position and size of the available pure iris region. Hence, iris feature template contains the instability features caused by noise. Yuan *et al* [15] improved the previous work in 2009. He divided regional image which is not easy to be interfered into 4 sub-regions and then dynamically chose the features in the most similar sub-regions as matching basis. As a result, this improved method needs little calculation and overcomes the influence of the noise in the feature extraction. However, the extracted feature in local weak gradient image region is not accurate with this method, which is a problem needs to be solved in the process of extracting features in the spatial domain.

Iris localization is the most difficult and important step in iris recognition because of the interference with eyelid, eyelash, reflection and rotation of head. It determines the effectiveness of iris feature extraction and the real-time performance of iris recognition system[16]. So far, iris recognition algorithm developed by Daugman is the most mature one among all the iris recognition algorithms. This algorithm presents very high iris localization precision, but it needs to search over the entire image. In other words, it involves in massive calculation and cannot eliminate eyelash noise effectively. In order to improve recognition efficiency and safety further, we propose an improved Daugman's iris recognition algorithm based on physiological characteristics of human eye.

The rest of the paper is organized as follows. Section 1 determines the localization and shape of pupil roughly, then the inner and outer boundary of iris is searched from rough to fine scale. A method of eliminating the effect caused by eyelid and eyelash is also presented. In Section 2, the iris feature is encoded and matched by introducing the validity flag based on the validity judgment of iris pixel. The experiments are addressed in Section 3, where the running speed and the rejection rate are revealed. Section 4 is the summary of this paper.

1 Quick Localization of Iris from Rough to Fine Scale

1.1 Iris Inner Boundary (Pupil) Localization

Eye image has obvious gray change, i.e., the gray value in the pupil region is smaller than that in neighboring region. According to physiological characteristics of human eyes, we locate iris inner boundary quickly and accurately from rough to fine scale by the following steps.

1.1.1 Pupil rough localization

Pupil rough localization judgment can be divided into three steps, which mainly uses the gray value of image. ① Binaryzation: The pixels in the pupil region take small gray value and demonstrate minor difference from each other, so a clear peak in the histogram of the iris image is formed, which is a minimal global peak. According to this characteristic, a gray level threshold value is searched and found automatically in the histogram. The pupil is treated as shown in Fig. 1(a)-(c), wherein the gray threshold value is positioned in the valley on the right of the pupil peak. The pupil pixels are marked with white color. ② Morphological processing: As shown in Fig. 1(c), there is a lot of noise in the resulted binary image. Since the pupil can be considered as a circle, the noise can be eliminated by a morphological opening operator. The structural element of the opening operator is a circle whose radius has 2-3 pixels. Because morphological opening operator can eliminate protrusion, the noise, caused by eyelashes and dark folds, which can be removed from the binary image. The result is shown in Fig. 1(d). ③ Circle parameters calculation: According to Fig. 1(d), we can sum up the pixels number of the pupil. The sum S can be simply regarded as the pupil circular area. On the other hand, $S=\pi \times r^2$, so we can calculate the pupil radius r_T approximately. Further, we calculate the approximate geometric center (x_T , y_T) by calculating the mean value of all pupil pixels coordinates. Figure 1(e) shows the rough pupil localization. However, the light spot in the pupil makes a rough approximate (the pupil boundary is smaller and is shifted upwards), more accurate pupil positioning algorithm is needed.

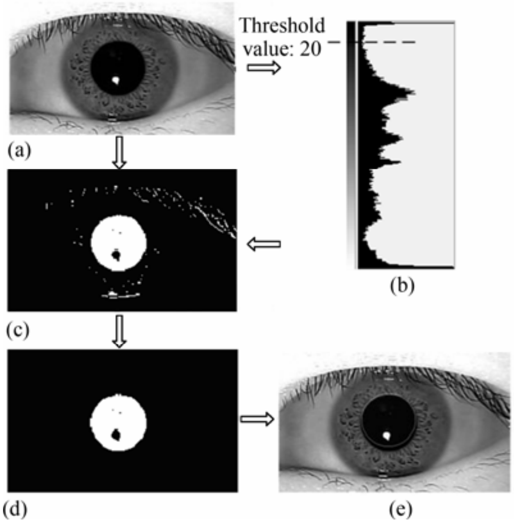

Fig. 1 Pupil rough localization

(a) Image of human eye; (b) Histogram of the iris image (binary image); (c) Resulted binary image of pupil; (d) Morphological processing; (e) Pupil image of circle parameters calculation

1.1.2 Pupil precise localization

The pupil and sclera edge is circular, so we can use the iris localization formula given by Daugman for pupil precise localization [9]. The maximum value is searched according to Formula (1) by taking (x_T , y_T) and r_T as the initial searching condition.

$$\max_{(r,x_0,y_0)}\left|\frac{\partial}{\partial r}\oint_{(r,x_0,y_0)}\frac{I(x,y)}{2\pi r}\mathrm{d}s\right| \quad (1)$$

The center of the circle radius can be limited within a small region, that is

$$(x_T-N)<x_0<(x_T+N)$$
$$(y_T-N)<y_0<(y_T+N)$$
$$r_0\in[r_T,K_0r_T]$$

where, r_0 and (x_0, y_0) are the precise radius and center, respectively; $N = 10; K_0 = 1.3$. In order to avoid the light spot in the pupil, we assign the mean gray value of the whole to the spot pixels.

1.2 Localization of the Outer Edge of the Iris (Sclera)

Usually, the outer edge of the iris and pupil are not concentric, but the distance between the center of the pupil and sclera is small. We also locate the sclera edge quickly by applying a rough-to-fine strategy.

1.2.1 Sclera rough localization

Firstly, we assume that the sclera and pupil are concentric circles, so we can locate the sclera edge by determining its circle radius *r*. The pupil has the center $O_0(x_0, y_0)$, and radius r_0 , Formula (2) is used to locate the outer edge of sclera roughly but quickly.

$$\max_{(r)}\left|\oint_{(r,x_0,y_0)}\frac{I(x,y)}{2\pi r}\mathrm{d}s-\oint_{(r_1,x_0,y_0)}\frac{I(x,y)}{2\pi(r+\Delta r)}\mathrm{d}s\right| \quad (2)$$

$$r=k_0\times r_0,\ k_0\in[1.2,2.1],\ \Delta r\in[5,10]$$

Obviously, Formula (2) is an approximation to Formula (1), by ignoring searching of the center and using a larger radius step Δr. Since sclera is covered by the upper and lower eyelids, the calculation does not need to integrate on the entire arc. As shown in Fig. 2, the integral calculation and differential calculation are carried out in two symmetrical fan-shaped areas on the left and right sides about 90 degree corner ($-45°<\theta<45°$, $135°<\theta<225°$). If the sclera radius is calculated as r_L and r_R , respectively from the left and right canthi during the sclera rough localization processing, the rough radius of sclera is $r_T=\frac{1}{2}(r_L+r_R)$. At the same time, we adjust the rough center of sclera $O_T(x_T, y_T)$ to $x_T=x_0+\frac{1}{2}(r_R-r_L)$ and $y_T=y_0+\frac{1}{2}(r_R-r_L)$.

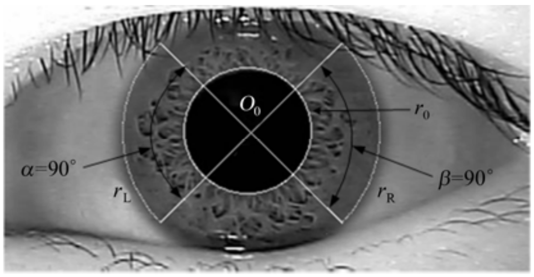

Fig. 2 Search area for quick localization of sclera boundary

1.2.2 Sclera precise localization

Formula (1) is used again to determine sclera precise localization by applying the radius and center, which have been obtained by sclera rough localization, as the initial condition. The center $O_1(x_1, y_1)$ and radius r_1 can be limited within a small region (Δv).

$$\begin{cases}(x_0-\Delta v)<x_1<(x_0+\Delta v)\\(y_0-\Delta v)<y_1<(y_0+\Delta v)\\(r_T-\Delta r)<r_1<(r_T+\Delta r)\end{cases} \quad (3)$$

In the process of iris localization, the interference of eyelids and eyelashes on iris must be eliminated as far as possible. The Daugman’s iris localization algorithm can remove eyelids coverage area, but leaves a lot of eyelash in the image. In theory, the iris has complex structure and supplies various biological characteristics, even only 65% of the iris is sufficient for iris recognition [7]. Besides, most of the iris features can be observed near the inner edge of the iris. So, we can abandon the outer iris region that is likely to be covered by the eyelids and eyelashes. From this point of view, only the black iris region is dealt with in this paper, which is divided into four parts as shown in Fig. 3.

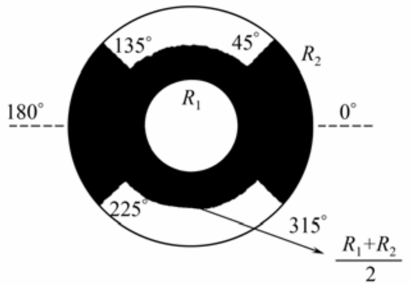

Fig. 3 Selected iris area after the removal of eyelids and eyelash regions

Where, R_1, R_2 are the radius of the pupil and sclera, respectively. Situation (4) are symmetrical 90 degree fan-shaped area of canthi without eyelids and eyelash interference. Situation (5) are inner area near the inner edge of iris. The boundary of the inner area is defined by the center of sclera, radius of pupil and sclera.

$$\begin{cases} 135° < \theta < 225° \\ R_1 < r < R_2 \end{cases}, \begin{cases} -45° < \theta < 45° \\ R_1 < r < R_2 \end{cases} \tag{4}$$

$$\begin{cases} 225° < \theta < 315° \\ R_1 < r < \frac{1}{2}(R_1 + R_2) \end{cases}, \begin{cases} 45° < \theta < 135° \\ R_1 < r < \frac{1}{2}(R_1 + R_2) \end{cases} \tag{5}$$

2 Iris Feature Encoding and Matching with Valid Flag Bits

2.1 Judgment of Iris Feature Encoding and Matching Process

Although the eyelids and eyelashes are removed, there remains a small amount of noise in iris image. The noise will influence the precision of the iris feature encoding and matching. If we assume the gray value of iris image as a random variable with normal distribution: $X \sim N(u,\sigma^2)$, the validity of pixels can be judged according to Eq.(6):

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(\frac{(x-\mu)^2}{2\sigma^2}\right) \tag{6}$$

$$\text{If } H > x > L \ \ \text{valid}(x) = 1 \ \ \text{else valid}(x) = 0$$

Where, x is the gray value of pixels. If $\text{valid}(x) = 0$, the pixel is a noise pixel to be dropped; $H = u + 3\sigma$; $L = u - 3\sigma$.

We use the iris area in Fig. 4 as the so-called "pure iris" since these regions are seldom covered by eyelids and eyelashes. In Fig.4, $\alpha_1 = \alpha_3 = 2\alpha_2 = 2\alpha_4 = 45°$. The gray value of pixels in pure iris is used to estimate the Gaussian function parameters u, σ.

Further, the result in these steps is introduced to the following iris feture encoding and matching process.

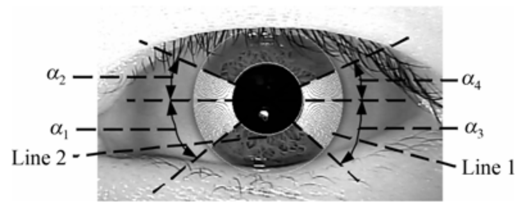

Fig. 4 Selected pure iris region

Line 1 is the edge of sclera; Line 2 is the edge of pupil; $\alpha_1, \alpha_3, \alpha_2, \alpha_4$ are all measured against the horizontal direction

2.2 Iris Feature Encoding

We use the Gabor wavelet filter to get the feature binary coding, just as Daugman did. But we supply an additional pixel validity flag hs. Let h{Re, Lm} be Gabor convolution result, Sign() be the symbol function, we use Sign() function to judge Re and Lm to get the coding results hr and hl of each pixel. The improved process gets the Gabor encoding with validity flag, which is shown in Fig. 5.

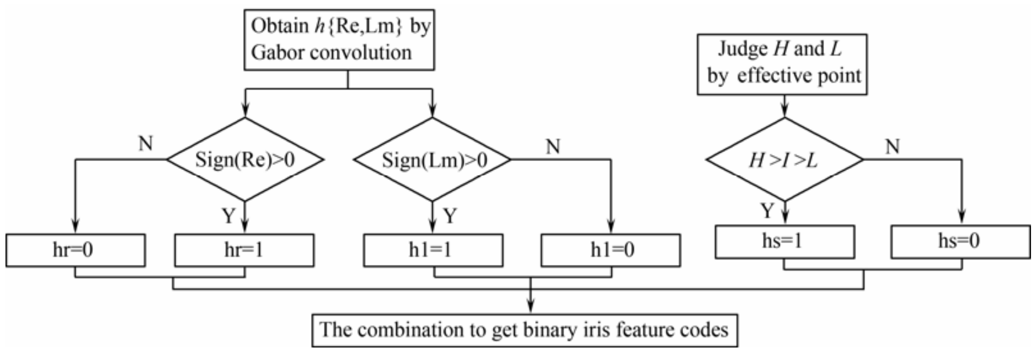

Fig. 5 Iris feature Gabor encoding with validity flag

2.3 Iris Feature Matching

The iris matching calculation uses an improved Hamming distance, which is shown in Eq. (7):

$$\mathrm{HD} = \frac{\left\|(\mathrm{code}A \otimes \mathrm{code}B) \cap \mathrm{valid}A \cap \mathrm{valid}B\right\|}{\left\|\mathrm{valid}A \cap \mathrm{valid}B\right\|} \tag{7}$$

Where, code$A$ and code$B$ are the feature code, valid$A$ and valid$B$ are the valid flag bit, $\| \ \|$ calculates the length of code. The improved method only calculates Hamming distance between valid iris pixels, so it can reduce the influence of noise and improve the accuracy of iris recognition.

3 Test and Analysis

The improved iris recognition algorithm is implemented with Microsoft Visual C++6.0 on a laptop computer(CPU rate is 1.9 GHz and the memory is 128 MB). About 500 people's left and right iris images are acquired. For every eye, 50 iris images are acquired in different time. All the images each consists of 768 pixel$\times$576 pixel. The part of the iris image is shown in Fig. 6.

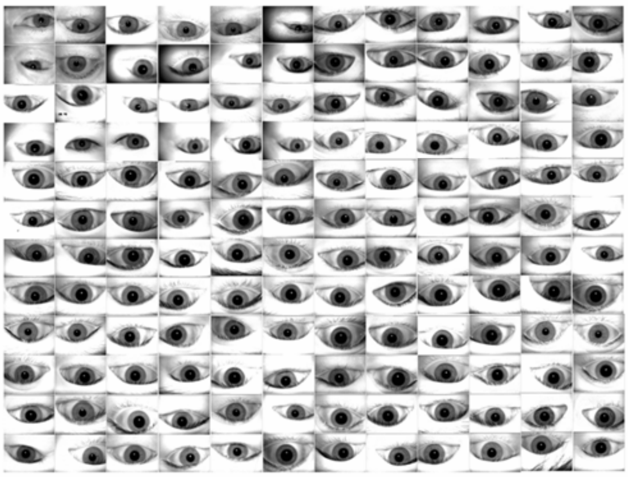

Fig. 6 Part iris images for algorithm test

The different iris images of 500 persons are used to test the identification error rate, meanwhile, 50 different iris images of the same eye are used to test the identification rejection rate. Table 1 compares our improved algorithm with the original algorithm in different stages of iris recognition. From Table 1, we can see that our proposed rough-to-fine scale iris localization algorithm can quickly realize iris accurate localization. Although some stages take more time, the overall computational efficiency is obviously improved by (195+9+100−82−9 −110)/(195+100+9)≈34%. In addition, Figs. 7 and 8 show that our improved algorithm can locate iris area more effectively by removing eyelash noise, which is helpful for subsequent iris feature encoding and matching.

Table 1 Comparison of traditional iris recognition algorithms with proposed one

ms

Steps	Average time	
	Our algorithm	Daugman's algorithm
Iris localization	82	195
Normalization	9	9
Feature extraction	110	100
HD calculation	0.08	0.07

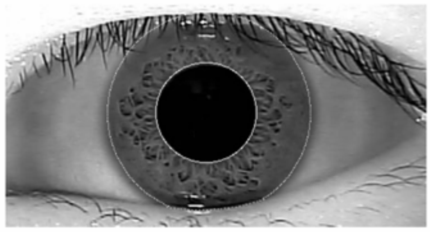

Fig. 7 Daugman's iris localization

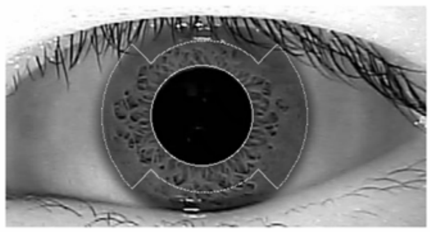

Fig. 8 Improved iris localization

As for the recognition, if the threshold of Hamming distance (HD) is set to 0.23, in $C_{50}^2 = 1\ 225$ iris matching tests between different people, the rejection rate is 2/1 225 (i.e. there is 2 rejection), the rejection rate is lower than that of the Daugman's method which is 1/100[9]. In $C_{500}^2 = 124\ 750$ iris matching tests between same people's iris, the error rate is 0. The improved algorithm can be reliably applied to personal identification. Figures 9 and 10 show the distribution of the Hamming distance HD in this paper.

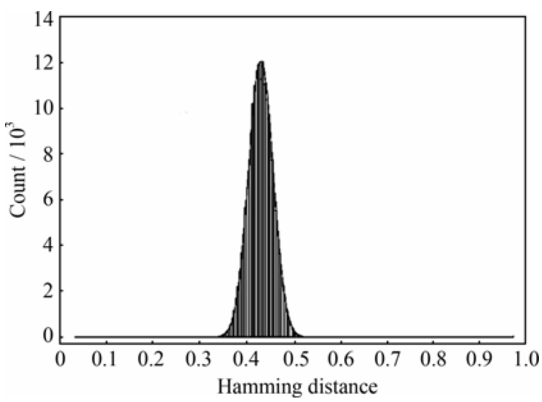

Fig. 9 HD distribution for iris error rate test

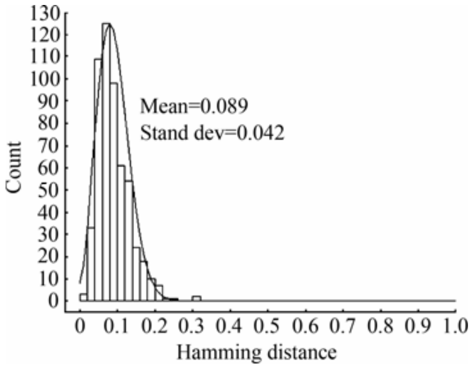

Fig. 10 HD distribution for iris rejection rate test

4 Summary

The identity authentication has a wide application prospect. Iris recognition, among kinds of emerging biometric technologies, has lowest error rate. We improve Daugman's iris recognition algorithm in several aspects. Firstly, the inner and outer edge of iris is located by rough-to-fine steps, which accelerates iris localization processing. Secondly, the iris feature matching is improved by integrating validity flag bits, which enhances the capability of anti-noise interference. Our test based on small iris samples shows that the improved algorithm has good identification performance. In the future, more iris image samples will be acquired for more complete system testing.

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