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Phase Correlation Based Iris Image Registration Model

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Abstract Iris recognition is one of the most reliable personal identification methods. In iris recognition systems, image registration is an important component. Accurately registering iris images leads to higher recognition rate for an iris recognition system. This paper proposes a phase correlation based method for iris image registration with sub-pixel accuracy. Compared with existing methods, it is insensitive to image intensity and can compensate to a certain extent the non-linear iris deformation caused by pupil movement. Experimental results show that the proposed algorithm has an encouraging performance.

Keywords phase correlation, image registration, iris recognition, biometrics

1 Introduction

As an emerging biometric, iris recognition aims to identify persons using the iris characteristics of human eyes. The human iris, an annular part between the pupil (generally appearing black in an iris image) and the white sclera as shown in Fig.1(a), has an extraordinary structure and provides many interlacing minute characteristics such as freckles, coronas, stripes, furrows, crypts and so on. These visible characteristics, generally called the texture of the iris, are unique to each subject[1−3]. Compared with other biometrics (such as face, fingerprints, voice, gait, palm-prints, hand geometry, etc.), iris is more stable and reliable for identification[4−6]. Furthermore, since the iris is an overt body, iris based personal identification systems can be non-invasive to their users[7−11], which is greatly important for practical applications. All these desirable properties (i.e., uniqueness, stability and non-invasiveness) make the iris suitable for highly reliable personal identification.

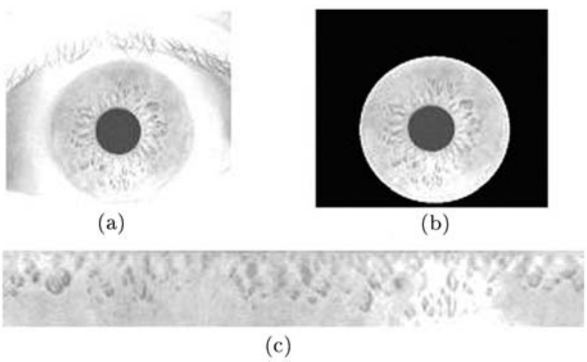

Fig.1. Preprocessing (a) Original iris image. (b) Localized image. (c) Normalized image.

As shown in Fig.2, an iris recognition algorithm generally includes four main steps, namely preprocessing, registration, feature extraction and matching. In real applications, there are significant differences between the reference iris image and the input iris image taken at different times. This is mainly caused by changes of the pupil and external environment. If two iris images from the same eye are not registered and directly used for feature extraction and matching, false rejection may occur. In this case, establishing a precise correspondence between an input iris image and a reference iris image provides preference for accurate recognition. Therefore, registration is an important step in iris recognition.

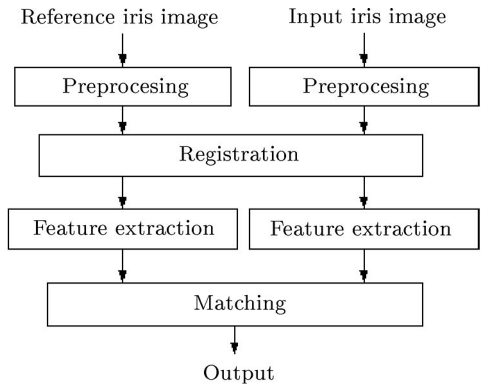

Fig.2. Diagram of iris recognition.

Iris image registration is greatly complicated because various movements may cause variations of iris images. Firstly, noninvasive image acquisition requires users to adjust their position continuously in order to capture iris images of high quality. Secondly, the eye and eyelids can move randomly. Their movements cause not only apparent shifts of iris but also rotation of iris around

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the center of the pupil. Finally, changes of illumination may affect the size of the pupil and thus cause non-linear deformation of iris.

In practical applications, capturing iris images generally needs careful cooperation of users, such as keeping the eyes in a fixed position. In such cases, the movements between iris images are relatively simple and can be well modeled by an affine motion model. Shift, scale and rotation respectively correspond to the iris motion in the plane parallel to the camera, the iris motion along the camera's optical axis and the iris rotation along the angular direction. Here, an implicit assumption for registration is that there are less intensity differences between two iris images to be registered. In addition, the non-linear deformation of the iris is ignored since the changes of illumination and the size of pupil are not significant.

Although iris image registration is greatly desirable, efforts on iris image registration are still limited. Daugman[1−3] did not perform real iris image registration in his system. To improve recognition accuracy, he solved this problem at the level of features. However, the non-linear iris deformation caused by the pupil movement was compensated using a linear model in his method. If we carry out image registration based on a nonlinear model, the deformed iris would be recovered better. Wildes *et al.*[7,8] adopted the affine motion model to represent the motion between iris images. His registration method is very time-consuming and impossible to be implemented in the practical systems. Our previous method[9−11] supposed that there are only global shifts in horizontal direction between two preprocessed iris images to be registered. It uses a simplified affine motion model for iris image registration and thus ignores the non-linear iris deformation. More details of our approach are introduced in the next section.

In general, the intensity of iris images changes greatly due to variations of external environment, and the linear model does not always approximate the non-linear changes of the iris texture. This implies that the existing methods for iris image registration do not always work well. In this paper, we present a new iris image registration method based on phase correlation. The novelty of this paper includes the following.

1) A new attempt is made to register images for iris recognition by searching the local movements between two iris images. The estimation of local movements can compensate to a certain extent the non-linear iris deformation caused by pupil movement. Experimental results show that the local movement model can better represent the movements between two iris images than the global movement model used in our previous method. This can improve the performance of iris recognition systems.

2) Phase, a very important feature for iris recognition, is defined as the benchmark for iris image registration in this paper. Compared with the existing methods, the proposed method is insensitive to the change of image intensity, and thus able to improve the robustness of iris recognition systems. Particularly, this is more obvious when the iris images are captured in the condition when users are not completely cooperative for image acquisition.

3) Sub-pixel motion estimation is used in the proposed method. Experimental results show that this can greatly improve the accuracy of iris image registration (hence the performance of iris recognition methods).

The remainder of this paper is organized as follows. Section 2 briefly describes our previous method. A detailed description of phase correlation based iris image registration algorithm is presented in Section 3. Section 4 reports experiments and results. Conclusions are given in Section 5.

2 Our Previous Method

As mentioned earlier, so far, there are few efforts on iris image registration. Our work[9−13] on iris recognition includes iris registration, iris image enhancement, feature extraction and matching. To describe the proposed method clearly, we firstly introduce our previous method for iris image registration in this section.

For the convenience of registration, iris images should firstly be preprocessed in our iris recognition system (as shown in Fig.2). Here, we briefly describe image preprocessing to explain our previous method more clearly. An iris image (shown in Fig.1(a)) contains not only the region of iris but also eyelid, pupil, etc. In addition, the intensity of an iris image is not uniformly distributed because of illumination variations. To reduce the influence of these factors and facilitate the subsequent processing, the original iris images should be preprocessed first. The preprocessing includes two steps, namely localization and normalization.

We can approximately regard the inner and outer boundaries of an iris as circles. Iris localization includes simple filtering, edge detection and Hough transform for circle detection. Fig.1(b) shows one example of iris localization.

In addition, the size of the iris in an image is not always the same as that of the iris in other images because of many factors such as different subjects and illumination. To achieve accurate recognition results, compensating these changes is necessary. We thus counter clockwise map the iris ring to a rectangular block with a fixed size. The example of iris normalization is shown in Fig.1(c). More details of preprocessing can be found in [10].

Our previous registration approach ignores the non-linear iris deformation and supposes that there are only global shifts in the horizontal direction between two preprocessed iris images to be registered. The purpose of registration is to find the shift offset. In experiments, Tan *et al.* searched the global shift between two images by minimizing the distance defined in the following equation[10]:

$$D = \sum_{m,n} (|I_1(m,n) - I_2(m+T,n)|)^2 \tag{1}$$

where $I_1(m,n)$ and $I_2(m,n)$ respectively represent the reference iris image and the input iris image, T is the shift offset between two images and is set in a range of $[-16, 16]$.

3 Phase Correlation Based Method

As discussed above, our previous method can represent only the global movements between iris images using a simplified affine motion model. Thus, it only compensates linear iris deformation and registers iris images with pixel accuracy. In reality, it is obviously not suited for iris recognition systems with high recognition rate. In this section, we propose an iris image registration method based on phase correlation. Similar to our previous method, preprocessed iris images are registered. However, it measures the local movement between the two iris images from their phases with subpixel accuracy[14−20]. This operation results in that the proposed method has not only higher registration accuracy but also lower computational complexity.

3.1 Principle of Phase Correlation

Firstly, we briefly introduce the principle of phase correlation. Suppose that there is a shift (d_1, d_2) between two images s_k and s_{k+1}:

$$s_k(n_1, n_2) = s_{k+1}(n_1 + d_1, n_2 + d_2). \tag{2}$$

The shift in the spatial-domain is thus reflected as a phase change in the frequency domain. We can obtain the complex-valued cross-power spectrum expression

$$C_{k,k+1}(f_1, f_2) = S_{k+1}(f_1, f_2) S_k^*(f_1, f_2) \tag{3}$$

where $*$ denotes the complex conjugate. To reduce the influence of luminance variation, the right side of (3) is normalized as follows:

$$\phi(C_{k,k+1}(f_1, f_2)) = \frac{S_{k+1}(f_1, f_2) S_k^*(f_1, f_2)}{|S_{k+1}(f_1, f_2) S_k^*(f_1, f_2)|}. \tag{4}$$

From (2) and (4), we can obtain the following equation:

$$c_{k,k+1}(n_1, n_2) = \delta(n_1 - d_1, n_2 - d_2) \tag{5}$$

where δ denotes the pulse function. The above equations indicate that if we can find the location of the pulse in the cross-correlation map of two images, we could obtain the spatial displacement between them. One example of the cross-correlation map is shown in Fig.3.

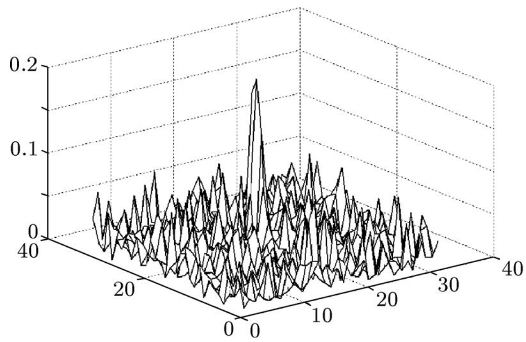

Fig.3. Phase correlation map.

3.2 Iris Image Registration

Based on the above phase correlation method, we can estimate the local motion between the input and the reference iris images. The reference and the input iris images are respectively divided into a number of 16×16 blocks. For each pair of blocks, phase correlation is calculated to estimate the local motion between them. These local motion vectors may be different in terms of direction and magnitude, whereas there are only global shifts estimated by our previous method. As we know, iris deformation is non-linear because of pupil movement. Thus, local motion vectors with possible direction and magnitude can better represent the movement between iris images than the global shifts. The experimental results introduced in Section 4 prove this view.

In experiments, we expand each 16×16 block to a 32×32 block to precisely estimate the phase correlation value. If we perform the phase correlation only for 16×16 blocks, their correlation value might be very low under some extreme conditions. For example, there are only small overlapping areas between a pair of 16×16 blocks, as shown in Fig.4(a). Once the block size is extended to 32×32, the overlapping area increases and more accurate correlation value can be estimated. A two-dimensional modified cosine window is applied to each 32×32 block so as to give more weight to the center region of 16×16.

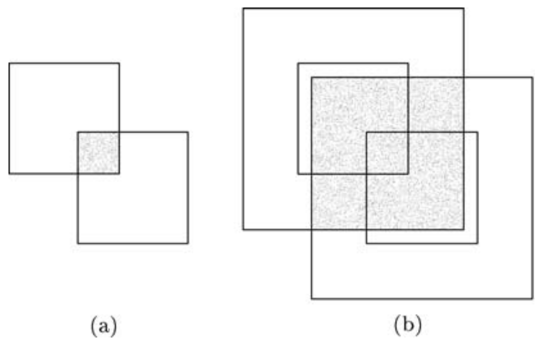

Fig.4. Correlation of regions with different sizes. (a) 16×16. (b) 32×32.

In practical iris recognition systems, it is unlikely to have very large rotation angles between iris images. We thus suppose that the maximum displacement is ± 16 pixels between the pre-processed iris images, which approximately corresponds to a rotation of $\pm 11.25°$ between the original iris images.

Although the phase correlation peak provides us some possible displacement between the blocks with the size of 32×32, it may not correspond to the real displacement between the blocks with the size of 16×16. The highest peak in the correlation map usually indicates the best match between the blocks with the size of 32×32, while not necessarily the best match for the 16×16 blocks. In this case, we may want to select several candidates instead of just one highest peak, and then decide which peak best represents the displacement vector for the 16×16 blocks. Once the candidates are selected, we examine them one by one. We choose the candidate that can result in the highest value of image correlation as the final result. Unlike the previous method, which searches for the motion vectors between iris images in the whole image, the proposed method performs image correlation after the displacement vectors are found. Therefore, this incurs less computational cost.

When the motion vector with pixel accuracy is obtained, we can further estimate the possible half-pixel offset from the correlation map by cubic spline interpolation. The procedure for 1-D case is shown in Fig.5. In the correlation map, "$*$" represents the integer offset, such as -1, 0, 1. The correlation map is firstly interpolated at half-pixel offsets. Samples represented by "o" are interpolated from their neighboring samples with integer offsets. We firstly check two interpolated correlation samples adjacent to the obtained integer motion vector (as -0.5 and 0.5 shown in Fig.5). If one of the interpolated correlation values exceeds the previously obtained highest integer value, the motion vector is updated to the new non-integer value. As shown in Fig.5, the offset obtained previously should be zero. However, the correlation value at 0.5 is even higher than the correlation value at zero in the interpolated correlation map. Thus, the final result of displacement is updated to the non-integer value 0.5.

4 Experimental Results

Unlike fingerprint and face, there is no reasonably sized iris database in public domain. Therefore, two iris image databases are constructed to evaluate the performance of the proposed algorithm. Moreover, we compare the proposed algorithm with our previous method for iris image registration and present detailed discussions on the overall experimental results. Since image registration is only one of the important parts of an iris recognition method, the proposed method is evaluated by analyzing the identification and verification performance changes of our previous recognition algorithm[10] with different registration methods.

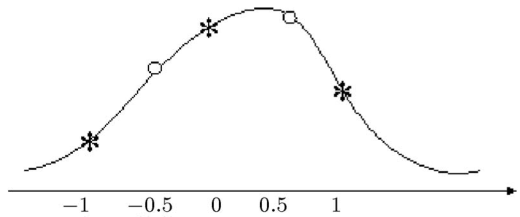

Fig.5. Interpolation of correlation map.

4.1 Experiment I

This group of experiments wae conducted with a large number of iris images in the NLPR database. The NLPR iris image database contains 134-class iris images. The total number of iris images is 1,088. They are from 109 different volunteers and captured by a digital optical sensor as shown in Fig.6. This iris database includes two parts. One is our previous database[9] that contains 500 images from 25 people. Each individual provides 20 images (10 for each eye). These images were captured in two different stages. In the first stage, 5 images of each eye were acquired. Four weeks later, 5 more images of each eye were obtained. The other part contains 588 images from 84 people. Each individual provides 7 images of the left eye. These images were also captured in two stages, similar to the acquisition of images of the first part. Capturing images on different dates provides a challenge to our method. Six samples from our iris database are shown in Fig.7.

Fig.6. Homemade iris sensor.

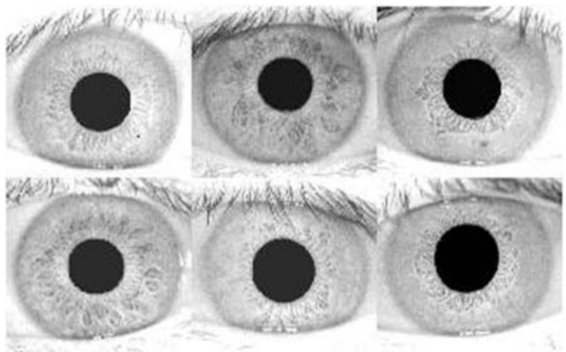

Fig.7. Iris samples from NLPR iris database.

For each iris class, we randomly chose three iris images captured in the first stage as the reference, and other iris images taken in the second stage served as test samples.

We respectively evaluated our previous method and the proposed method with the NLPR database. Two registration methods were tested on the MALAB platform using a Pentium 4 PC of 1GHz. Because the proposed method performs image registration using phase correlation and FFT can be used to accelerate this process, the running time of the proposed method is less than that of our previous method (refer to Table 1 for the comparison of running time).

Table 1. Comparison of the Computational Complexity

Method	Tan[10]	Proposed
Time (s)	0.32	0.26

Fig.8 shows an example of iris image registration based on phase correlation, where plot (Fig.8(c)) shows the motion vectors between these two iris images to be registered. From this figure, we can see that the local motion vectors are not always the same in terms of magnitude and direction. This is apparently different from the registration result by the previous method, which is only a global motion vector in the horizontal direction. The experimental results confirm that the local movement model used in the proposed method can better represent the movement between iris images than the global movement model used in our previous method.

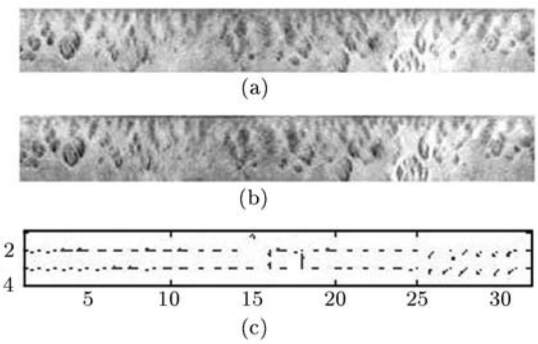

Fig.8. Example of registration. (a) Reference image. (b) Input image. (c) Motion vectors.

Table 2 tabulates the identification results and Fig.9 shows the verification results. As shown in Table 2, the identification result of the proposed method is the same as that of Tan's method[10]. However, in verification tests, the false non-matching rate (FNMR) and false match rate (FMR) of the proposed method are lower than those of our previous method. Different from our previous method[10] that registers iris images with pixel accuracy, the proposed method registers iris images with sub-pixel accuracy. This implies that the proposed method has higher registration accuracy.

Table 2. Comparison of Identification Results

Method	Tan[10]	Proposed
Correct recognition rate	99.85%	99.85%

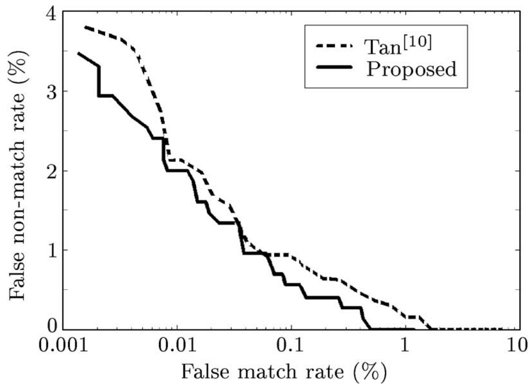

Fig.9. Verification results.

4.2 Experiment II

In order to further evaluate the robustness of the proposed method when users are not cooperative for iris image capturing, we constructed another iris image database. This database contains 460 iris images from 46 different eyes (hence 46 classes). They are from 23 different volunteers and were captured by a hand-held iris sensor designed by PATTEK corporation (the hand-held iris sensor is shown in Fig.10). The capturing course includes two sessions and the time interval is 3 months. In the first stage, each subject provided 5 clear images for each eye in the mode of cooperation. Four weeks later, five blurred images of each eye were taken in the mode of non-cooperation. Capturing iris images in different modes (the cooperation mode and non-cooperation mode) results in significant differences between iris images, and thus provides a challenge to the proposed method. For each iris class, we randomly chose three clear images captured in the first stage as the reference, and the blurred images captured in the second stage served as test samples. Fig.11 shows some samples from the new iris database. Images in the first

Fig.10. Hand-held iris sensor.

row were captured in the first stage, and the images in the second row were captured in the second stage.

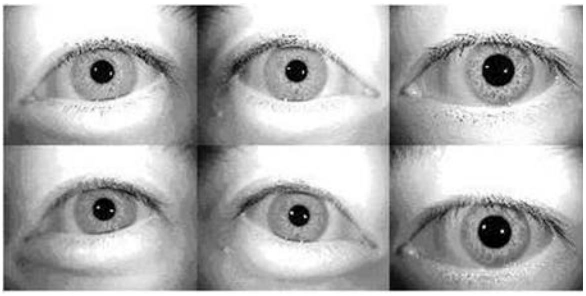

Fig.11. Iris samples from the new iris database.

We respectively evaluated our previous method and the proposed method using these iris images. Two iris images to be registered are shown in Figs.12(a) and 12(b). Fig.12(c) shows the motion vectors between these two images. Compared with the registration result by our previous method (there is only a global motion vector in the horizontal direction), the registration result by the proposed method better represents the non-linear iris deformation caused by pupil movement.

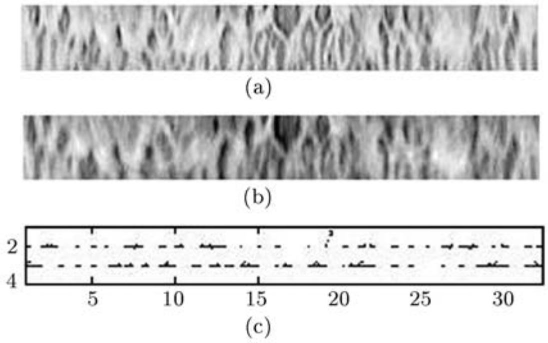

Fig.12. Example of registration. (a) Clear iris image. (b) Blurred iris image. (c) Motion vectors.

Table 3 tabulates the identification results and the verification results shown in Fig.13. From Table 3, we can see the identification result of the proposed method is much better than that of Tan's method[10]. In verification tests, the false rejection rate and false acceptance rate of the new method are apparently lower than those of our previous method. The reason is that the proposed method is based on phase correlation and insensitive to the change of intensity. For those iris images with different degrees of blur, the difference between their phases is relatively smaller than that of their intensity. With the increasing degree of blur, the advantage of the proposed method is more obvious. This means that the proposed method has better performance than Tan's method[10] when iris images are taken with the non-cooperative users at a distance. In reality, this is important for iris recognition systems.

Table 3. Comparison of Identification Results

Method	Tan[10]	Proposed
Correct recognition rate	94.78%	96.52%

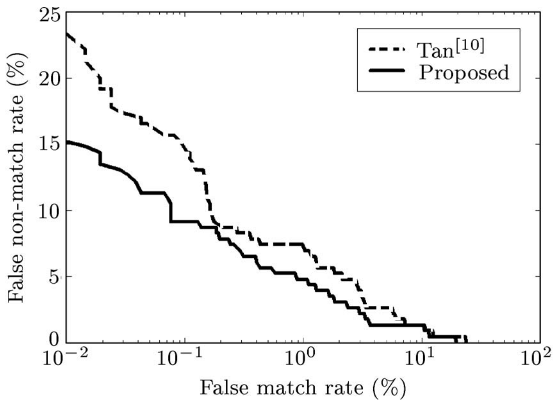

Fig.13. Verification results.

5 Conclusions

In this paper, a new iris image registration method with sub-pixel accuracy is proposed to improve the performance of iris recognition systems. It measures the local movement between the two iris images by phase correlation. Experimental results show that the proposed method has higher registration accuracy as well as lower computational complexity. Compared with previous methods, it not only can approximately compensate the non-linear deformation of iris, but also is robust in the condition where iris images are taken with the non-cooperative users at a distance.

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