Retinal Biometrics Based on Iterative Closest Point Algorithm

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Abstract— **The pattern of blood vessels in the eye is unique to each person because it rarely changes over time. Therefore, it is well known that retinal blood vessels are useful for biometrics. This paper describes a biometrics method using the Jaccard similarity coefficient (JSC) based on blood vessel regions in retinal image pairs. The retinal image pairs were rough matched by the center of their optic discs. Moreover, the image pairs were aligned using the Iterative Closest Point algorithm based on detailed blood vessel skeletons. For registration, perspective transform was applied to the retinal images. Finally, the pairs were classified as either correct or incorrect using the JSC of the blood vessel region in the image pairs. The proposed method was applied to temporal retinal images, which were obtained in 2009 (695 images) and 2013 (87 images). The 87 images acquired in 2013 were all from persons already examined in 2009. The accuracy of the proposed method reached 100%.**

I. INTRODUCTION

The prevalence of personal information leakage has heightened the importance of strong security measures. In authentication by identification and password, a more secure system can be realized by choosing a tricky password. However, this can be a burden to the user. Therefore, biometrics is attracting the most attention. Various biometric methods to authenticate the fingerprint, finger (or palm) vein, voice, iris, etc. have been developed for improved security [1-3]. The features of biometric methods are summarized in Tab. 1. Fingerprint authentication is the most popular method because of its low cost and high accuracy. However, it carries the risk of forgery by using artificial fingerprints. Face authentication has similar risks despite its popularity. Voice authentication is vulnerable to noise and the accuracy is low. The accuracy of finger vein authentication is good and the cost is low. Moreover, the file size is small. The accuracy of iris authentication is high although the file size is a bit large. Therefore, more iris and finger vein authentication systems are expected in the near future.

On the other hand, retina authentication has been developed because of its high accuracy [4-11]. The blood vessels of the retina are unique to each individual [12]. Moreover, the pattern of retinal blood vessels remains stable except in cases of illness. Although current retinal cameras are bigger compared to the machines used for other authentication methods, a smartphone phone-based retinal camera device is also being developed [13-15]. Therefore, a retinal image can be obtained easily in the near future.

Previous research on biometrics methods using retinal images have been reported. Bevilacqua et al. and Sasidharan have reported methods using the bifurcation and crossover points of blood vessels [4-5]. Qamber et al. proposed a method that used vessel endings and bifurcations as feature points and formed a feature vector based on relative angles and distances [6]. These methods [4-6] require high performances for the bifurcation and crossover points detection. By using the Mahalanobis distance, feature vectors were classified into correct and incorrect pairs. Köse et al. proposed an alternative personal identification method based on vessel segmentation and similarity measurements along with the tolerations [7]. Lajevardi presented an automatic retina verification framework based on the biometric graph -matching algorithm [8]. They used a support vector machine classifier to classify retinal images into correct and incorrect pairs. Gharami et al. proposed a method using singular value decomposition and a seven-state hidden Markov model for feature extraction and identification, respectively [9]. However, machine learning techniques, a hidden Markov model etc. need many images for their trainings. Tabatabaee et al. reported a method using Fourier-Mellin transform and a fuzzy C-means clustering algorithm [10]. However, they used only 37 images. We previously reported a biometrics method using template matching and the cross-correlation coefficient of the blood vessel regions [11]. When we evaluated a large database, which included 580 images with 88 pairs from the same person, the false acceptance rate (FAR) and false rejection rate (FRR) were 2.0×10^{-5} and 1.3×10^{-4}, respectively. However, our previous method erroneously matched some image pairs with reflexed vessels. Assuming that a pattern of blood vessels will not change in the short term, we hypothesized that the form of blood vessels is effective in registration. Therefore, this paper presents a robust biometrics method based on registration using the Jaccard similarity coefficient (JSC) of blood vessel regions.

* Research supported by Telecommunications Advancement Foundation, and a grant for the Grant-in-Aid for Scientific Research on Innovative Areas (Number 26108005) from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

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TABLE I. QUALITATIVE COMPARISON OF MAJOR BIOMETRIC METHODS [1–3]

Method	Security			Practicality				
	Antiforgery	False rejection rate	False acceptance rate	Speed	Enrollment	Convenience	Cost	File size
Fingerprint	–	0.10%	1.0%	•	–	•	+	+
Iris	•	0.99%	0.94%	•	•	–	•	–
Face	•	10%	1.0%	•	•	+	–	–
Voice	•	5.0-10%	2.0-5.0%	•	•	+	•	•
Finger vein	+	7.5%	0%	+	•	•	•	•

–: Poor, •: Average, +: Good

II. METHODS

In this study, we used temporal retinal images of the right eye, which were obtained in 2009 (695 images) and 2013 (87 images), to test our method. The 87 images acquired in 2013 were all from persons already examined in 2009, providing 87 image pairs from the same persons. The retinal images were captured using a retinal camera (TopconTRC-NW200). The image size was 2048 × 1536 pixels. This study has been approved by the research ethics committee of the University of Shiga Prefecture.

Fig. 1 summarizes our proposed method. In preprocessing, the blood vessels and their skeletons were first detected. The optic disc was then detected. After that, the two images were rough aligned by a parallel shift based on the centroid of the optic disc. The two images were registered by identifying the skeletons of the blood vessels in the two images as feature points. Finally, we classified these into correct and incorrect pairs using the JSC.

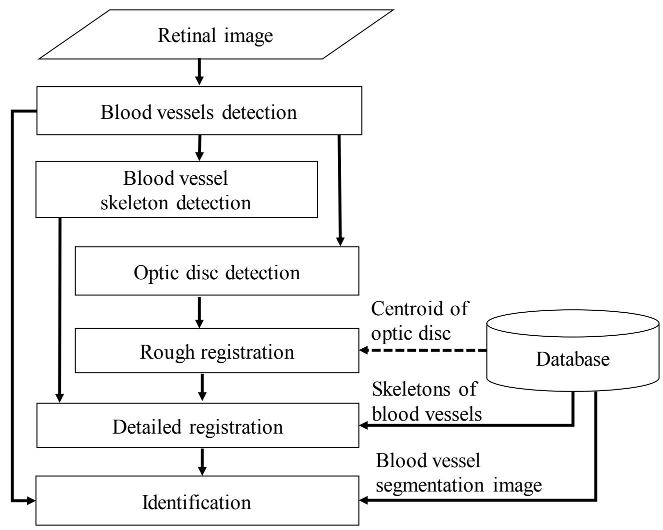


Figure 1. Flow of proposed method

A. Detection of Blood Vessels and Skeletonization

The green channel of the image was used to extract blood vessels because it gave the highest contrast between the vessel and background. Firstly, black top-hat transformation [16] was applied to the green channel of the image in order to emphasize the blood vessels. A black top-hat transform is defined as the difference between the results of morphological "closing" and the original image. By calculating the difference between the "closing" image and the original green channel of image, the blood vessel regions were enhanced.

Secondly, we converted to the binary image using the P-tile method. Thirdly, we rejected small regions as noise. Finally, the blood vessel regions were skeletonize using the Nagendraprasad–Wang–Gupta algorithm [17], which kept the central pixels and repetitively removed the pixels on the edge.

B. Detection of Optic Disc

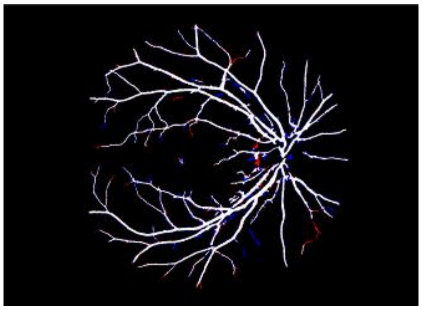
The presence of blood vessels that run along the outline of the optic disc made the accurate extraction of the outline difficult. Thus, to reduce the effect of blood vessels, the method proposed by Nakagawa et al. was applied to create a "blood vessel-erased" image [16]. The optic disc region tends to be brighter compared to the retina. Thus, the approximate region of the optic disc was extracted by using the P-tile thresholding method on gray-scale image. The change in intensity (brightness) was usually high at the outline of the optic disc; thus, we applied a canny edge detector [18] to enhance the edge. We determined the outline using the spline interpolation method based on the locations of the outline suggested by edge detection [19]. Finally, the centroid of the optic disc was determined for rough image registration.

C. Registrations

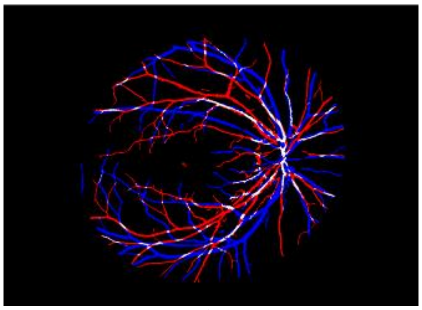
The registration process consists of two steps: rough registration and detailed registration. To accelerate the speed of registration, the two images were rough aligned by parallel shift based on the centroid of the optic disc. In order to align the two images with a high degree of accuracy, the Iterative Closest Point (ICP) algorithm [20] was applied to the blood vessel skeleton images. The ICP algorithm is a method used to find the transformation between two point clouds by minimizing the difference between the corresponding entities. Blood vessel skeletons were used as point clouds and the k-nearest neighbors algorithm was used to find the closest point. Where, affine transformation and perspective transformation were used for the rigid body transformation by the ICP. In order to suppress an increase in processing time, the iteration number of ICP was limited to 30 by our preliminary examination.

D. Identification

Correct and incorrect pairs were classified using the JSC. The JSC of blood vessel regions in the images is defined as



(a)



(b)

Figure 2. Examples of superposition images. White pixels show overlapping areas. Blue pixels indicate the blood vessel regions in 2009. Red pixels indicate the blood vessel regions in 2013. (a) Correct pair (JSC = 0.72). (b) Incorect pair (JSC = 0.11).

$$\mathrm{JSC} = \frac{\sum_{i}\sum_{j} A(i,j) \wedge B(i,j)}{\sum_{i}\sum_{j} A(i,j) \vee B(i,j)} \qquad (1)$$

where $A(i,j)$ and $B(i,j)$ refer to the first and the second image of the pair, and they are the binarized values (where blood vessel is 1, and background is 0) at position in the image. When the two images are incorrect pairs, JSC tends to show low values.

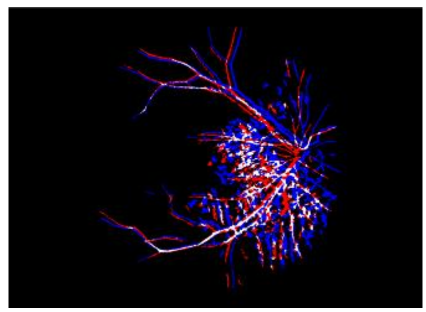
III. Results and Discussion

The proposed method was evaluated using 60465 combinations of temporal images pairs. Fig. 2 (a) shows a superposition image of a correct pair, and almost all blood vessel regions matched. Although the JSCs of correct pairs tended to be high, the JSC of a correct pair with abnormalities might be low. A case in Fig. 3 shows retinochoroidal atrophy, thus the JSC was 0.18. On the other hand, the blood vessel regions in the incorrect pair did not match as shown in Fig. 2 (b). The proposed method easily detected blood vessels using black top-hat transformation. We proposed a blood vessel detection method based on higher order local autocorrelation [21], whose accuracy was higher than that of black top-hat transformation. However, black top-hat transformation was faster and its performance was sufficient for this study.

Fig. 4 shows the normed frequency of JSCs. Some JSCs of correct pairs were low because perspective transformation was only applied for registration. By using non-rigid registration, the JSCs of correct pairs will be high. However, the JSCs of incorrect pairs were low in this study. Fig. 5 shows the relationship between the FAR/FRR and threshold values of

(a)

(b)



(c)

Figure 3. An example of correct pair with low JSC (JSC = 0.18). Retinochoroidal atrophy is shown in these pairs. (a) The retinal image obtained in 2009. (b) The retinal image obtained in 2013. (c) Superposition image.

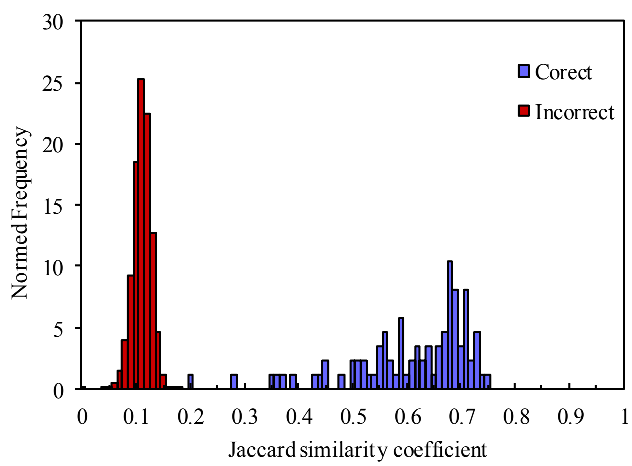


Figure 4. The histogram of Jaccard similarity coefficient

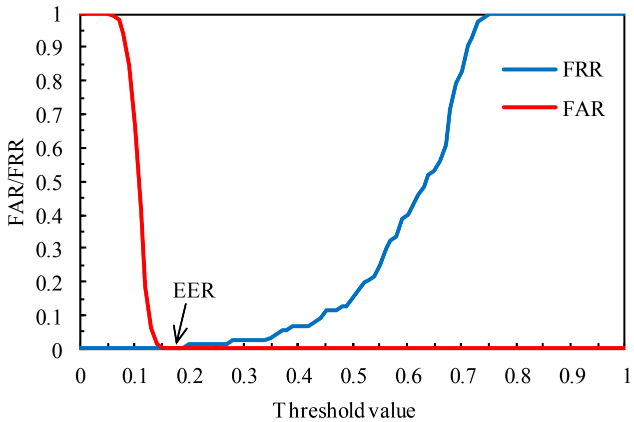


Figure 5. Threshold value for FAR/FRR

JSCs. Note that if the score distributions overlap, the FAR and FRR intersect at a certain point. The FAR and FRR values at this point, which are the same, is defined as the Equal Error Rate (EER). Fig. 5 shows that the EER was 0%. An EER = 0% means that the accuracy was 100%. In these tests, all correct pairs (87 pairs) and all incorrect pairs (60378 pairs) were identified correctly. The FRR and FAR of the proposed method were higher than those of the other biometric methods, although 60465 pairs were only tested. The proposed method will require further testing with a greater number of images, including abnormalities. We plan to apply the proposed method as preprocessing in temporal change analysis of time series images.

IV. Conclusion

This paper described a novel biometrics method based on registration using blood vessel skeletons in retinal images. Tests showed that the proposed method using the JSC of blood vessel regions had an accuracy of 100%. The proposed method will require further testing with a greater number of images, including abnormalities. The proposed method will be useful for biometrics.

Acknowledgment

This research was supported by grants from the Telecommunications Advancement Foundation and JSPS KAKENHI, with grant numbers 16K01415 and 26108005, respectively.

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