International Journal of Computer Applications (0975 – 8887)
Volume 33– No.9, November 2011

Personal Authentication through Retinal Blood Vessels Intersection Points Matching

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ABSTRACT
This paper presents a method of personal authentication process using digital retinal image matching. The process composed of four modules: reference point's detection, blood vessel segmentation and derivation of corresponding binary image skeleton of one pixel width, feature points extraction and finally matching similarities among these feature points of different images. The Fovea center and the Optic disc are used as reference points for compensating the unwanted rotational and translational effects. The maximum principal curvature of the Hessian matrix of the intensity image is used along with some image filtering to segment the blood vessel structure. Then the skeleton of the binary image and corresponding blood vessel intersection points are extracted using two proposed algorithms. Finally the matching process is done by proximity analysis of the intersection points of different retinal images. The whole process is then tested on several retinal images of different persons and the tested images were classified correctly.

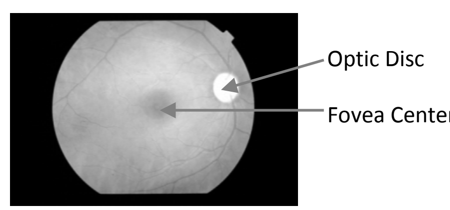
Keywords
Biometric personal authentication, fovea center detection, optic disc detection, Retina blood vessel skeleton generation, Blood vessel intersection point detection, blood vessel segmentation

1. INTRODUCTION
Reliable automatic personal authentication has long been an enticing goal in organizations as well as in civilian applications. To this purpose traditional authentication systems were based on one's knowledge such as pins or passwords, or one's possession of something such as cards or keys etc. But these systems are not totally reliable as they fail to distinguish between actual person and someone who steal or hack or somehow manage the things from that person. To solve this problem biometric based authentication systems are widely being used. Biometric systems depend on physical or behavioral characteristics of individuals those usually do not change throughout their life.

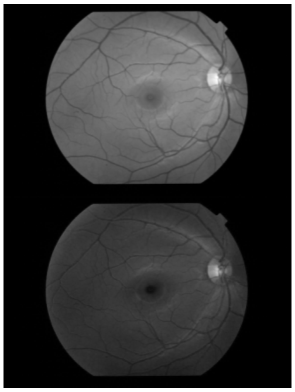
Several biometric authentication technologies are being used today. Some of them are: fingerprint, hand geometry, hand vein, iris, retinal pattern, signature, voice-print, face and facial thermogram etc [1]. Fingerprint recognition [2, 3] is the oldest and most popular. Iris [4] and retina pattern recognition [5-9] is relatively new approach compared to other biometric features. Among these retina pattern is stable and reliable for identification. This makes the retina pattern a prominent solution to the security in the near future [10]. Besides retina vessel pattern is unique and has been proved as valid biometric trait for personal authentication systems [8, 9]. In spite of these retina pattern was not used widely for biometric authentication due to technological limitations of attaining good quality pictures of retina and its high cost. But now new technologies give low cost picture acquisition of retina [5]. This paper proposes an efficient retina pattern recognition approach towards human authentication.

In the very first step of our method we require image acquisition. Retina image acquisition requires special arrangements of medical devices. This task is accomplished using a medical device Fundus Camera [7]. Images captured with this setup are of very high resolution, 1504 × 1000. Pictures of right eye were used for the analysis.

The paper is organized as follows. Section 2 describes effective preprocessing steps for retina images and reference point's detection. Section 3 describes blood vessel segmentation approach. Section 4 describes the extraction of one pixel width blood vessel structure and blood vessel intersection points. Section 5 describes template generation and matching process. Section 6 shows some experimental results. Finally section 7 provides some discussions and conclusions along with some future works.



(i)



(ii) (iii)

Fig 1: (i) Red layer, (ii) Green layer and (iii) Blue layer of a retinal image

2. REFERENCE POINTS DETECTION

In a digital retinal image the brightest and the darkest regions are optic disc and fovea center respectively (Fig 1). And for these characteristics they are easily identifiable using some image processing. The optic disc and fovea center are most prominent in the blue and green layer of the intensity image of retina respectively (Fig 1). And the blood vessels can be easily identified in the green layer of the retinal images [7].

2.1 Fovea Center Detection

A fixed region in the center of the blue layer image of retina is used to detect fovea center. We took the center of the image of size (X_{max} - X_{min}) × (Y_{max} - Y_{min}) using equation (1) [7].

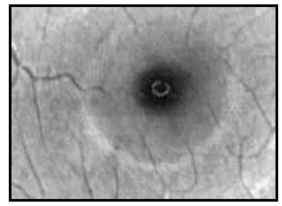
$$X_{\max} = W/2 + 0.1*W \quad X_{\min} = W/2 - 0.1*W$$
$$Y_{\max} = H/2 + 0.1*H \quad Y_{\min} = H/2 - 0.1*H \tag{1}$$

Then a Gaussian convolution in equation (2) [11] is applied to this sub image.

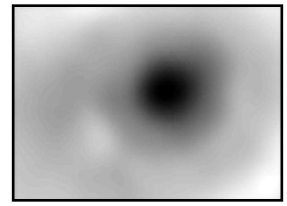
$$I(x, y; x) = I(x, y) \otimes G(x, y; s) \tag{2}$$

Where G is: $G(x, y; s) = \frac{1}{2\pi s^2} e^{-\frac{x^2+y^2}{2s^2}}$ and

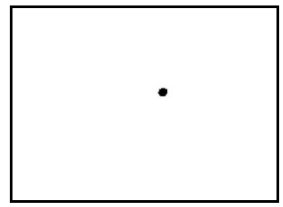
s is a scale factor. The scale factor and the required kernel size [11] are chosen 11 and 39 × 39 respectively. Then the convolution operation is applied to the central image of retina as of Fig 2(i) and the processed image of Fig 2(ii) is found. Finally the location of the fovea center is found as of the binary image of Fig 2(iii) by thresholding the image of Fig 2(ii).



(i)



(ii)



(iii)

Fig 2: (i) Center region (ii) Convoluted image (iii) Threshold Image of blue layer of Retina

2.2 Optic Disc Detection

Optic disc is brightest and most prominent in the red layer in the image. As the right eye images are used for analysis, the optic disc always resides right side of the fovea center. This makes easier for optic disc detection. An approach described in [7] for detecting optic disc almost deviation less is used to this purpose.

2.3 Rotating and Separating a Circular Region

After detecting the reference points: fovea center's coordinates (f_x,f_y) and optic disc's coordinates (O_x,O_y), a fixed portion of the image is taken for further processing. To make a uniform pattern for all the retina images, fovea center is taken as new center of the image. As the retina image scan is to be performed in different time, the person may not align exactly as to his previous scan. So some translational and rotational displacement can occur in the scanned retina images. To remove these translational and rotational displacements, the optic disc is then placed in the same horizon as of the fovea center by rotating the image into required no of degrees, so that the line from fovea center to optic disc align parallel to the x-axis. The distance between fovea center and optic disc does not vary in large magnitude, so a radius of 424 pixels is taken from this new center and all regions beyond this radius are excluded from the pattern. Then a k-mean filter [11] of size 5x5 is used to remove any unwanted noise from the image. At this stage an image of Fig 3 is found.

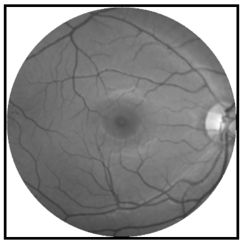


Fig 3: Pattern found after preprocessing

3. Blood vessel Segmentation

Retinal blood vessel segmentation is a challenge due to wide variation in the vessels width. Hence appropriate features should be selected to identify blood vessels of different widths, lengths and orientations. The gradient magnitude and the principle curvature are two features based on the first and the second directional derivatives of the intensity image, give information about the vessel topology and ensure robust detection of blood vessels in different widths, lengths and orientations. Since blood vessels appear as ridge-like structures in the digital retinal images, we look for the pixels where the intensity image has a local maximum in the direction for which the gradient of the image undergoes the largest change i.e. largest concavity. The second directional derivative information is derived from the Hessian of the intensity image I(x, y) [12, 13].

$$H = \begin{pmatrix} \partial_{xx} I & \partial_{xy} I \\ \partial_{yx} I & \partial_{yy} I \end{pmatrix} \quad (3)$$

The maximum Eigenvalue (λ_+) corresponds to the maximum principal curvature of the Hessian tensor is referred as *maximum principal curvature*. Thus, a pixel belongs to a vessel region will be weighted as a vessel pixel if $\lambda_+ >> 1$, we calculate the largest Eigenvalue (λ_+) as follows:

$$\lambda_+ = \frac{\partial_{xx} I + \partial_{yy} I + \alpha}{2} \quad (4)$$

Where $\alpha = \sqrt{(\partial_{xx} I - \partial_{yy} I)^2 + 4\partial_{xy}^2 I}$

After applying the principle curvature feature we got largest Eigen value (λ_+) for each pixel of the intensity image. The largest Eigen value of each pixel is used as image intensity value. That is:

$$I(x, y) = \lambda_+(x, y) \quad (5)$$

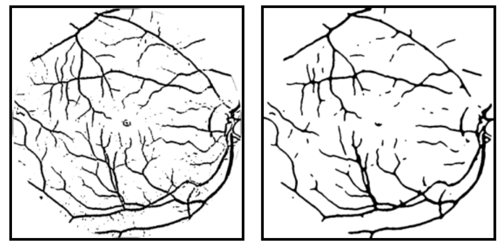
Then the binary image is obtained by thresholding the image on the average of the maximum Eigen value (μ) as follows:

$$I(x, y) = \begin{cases} 0 & if \quad \lambda_+ \geq \mu \\ 1 & if \quad \lambda_+ < \mu \end{cases} \quad (6)$$

Where

$$\mu = \frac{\sum \lambda_+(x, y)}{\text{total no of pixels}}$$

At this stage we found the resulted image of Fig 4(i) and then a median filter of size 5×5 is applied to reduce the unwanted noise and the image of Fig 4 (ii) is obtained.



(i) (ii)

Fig. 4: (i) Segmented binary image after application of principle curvature feature and (ii) 5×5 median filter

4. FEATURE EXTRACTION AND MATCHING

At this stage we need to find the blood vessel structure as one pixel width to extract vessels intersection points correctly.

(x-1, y-1)	**(x-1, y)**	**(x-1, y+1)**
(x, y-1)	**(x, y)**	**(x, y+1)**
(x+1, y-1)	**(x+1, y)**	**(x+1, y+1)**

Fig 5: a pixel and its eight neighboring pixels

4.1 One Pixel Width Vessel Extraction

For making the blood vessels into one pixel width we first identified the boundary pixels, whose removal do not break the connectivity of the vessel structure. Then a thinning algorithm is applied to get one pixel width blood vessels. The process works as follows: we took each pixel and observed its eight neighbors as in fig 5 and applied the following IsBoundaryPixel(I, x, y) algorithm of Fig 6, if the pixel is a boundary pixel we change the pixel's color to background. In this way we check all the pixels using ThintoOnePixel(I) algorithm of Fig 7.

```
IsBoundaryPixel(I, x, y)
   LC = 0; RC = 0; UC = 0; DC = 0;
   for i = x-1 to x+1
      LC = LC + I(i,y-1)
      RC = RC + I(i,y+1)
   for j = y-1 to y+1
      UC = UC + I(x-1,j)
      DC = DC + I(x+1,j)
   isBoundary = true
   if I(x-1,y-1) = 0 and I(x-1,y)+I(x,y-1) = 2 and RC+DC < 6
      isBoundary = false
   else if I(x-1,y+1) = 0 and I(x-1,y)+I(x,y+1) = 2 and LC+DC < 6
      isBoundary = false
   else if I(x+1,y-1) = 0 and I(x,y-1)+I(x+1,y) = 2 and UC+RC < 6
      isBoundary = false
   else if I(x+1,y+1) = 0 and I(x+1,y)+I(x,y+1) = 2 and LC+UC < 6
      isBoundary = false
   else if I(x,y-1)+I(x,y+1) = 2 and UC+DC < 6)
      isBoundary = false
   else if I(x-1,y)+I(x+1,y) = 2 and LC+RC < 6)
      isBoundary = false
   return isBoundary
```

Fig 6: Algorithm for determining whether a pixel at position (x, y) is a boundary pixel

```
ThintoOnePixel(I)
   update = true
   while update = true
      update = false
      for each vessel pixel I(x, y)
         if IsBoundaryPixel(I, x, y)
            remove I(x, y) from vessel pixels
            I(x, y) = 1
            update = true
```

Fig 7: Algorithm for making a binary image I to one pixel width

We applied the algorithm of Fig 7 to the image obtained at Fig 4(ii) and found the resultant image of Fig 8.

Fig 8: One pixel width skeleton image

4.2 Blood Vessels Intersection Points Detection

To classify a retina pattern appropriately, we need to find features that can provide large inter-class and small intra-class variation. At this perspective, we choose blood vessel intersection point coordinates as a feature to classify images, since blood vessel structure is different in retina images for different persons; hence the coordinates are different too. Now to identify intersection points from the binary one pixel width image of retina, obtained from above steps, we counted for each vessel pixels number of adjacent pixels along eight neighbors having gray level value 0. We then identified the vessel pixels those have three or more adjacent as intersection points. Then for each of these intersection points we tracked all the branches starting from these points and took only the points those have three or more branches having length greater than 15 pixels. Finally we divided the whole image into regions of size 7 × 7 and removed all intersection points but one from each region that has least x coordinate and least y coordinate in case of a tie. At this stage we obtained retina image of Fig 9 with intersection points.

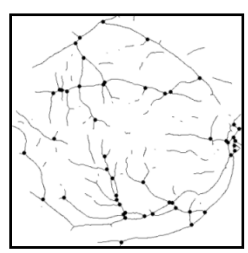


Fig. 9: Binary image of one pixel width retina image along with intersection points marked

```
MatchTemplates (T1, T2)
   totalmatched = 0
   for each sub region Si in T1 and corresponding sub region Sj in T2
        matched = 0
        for each intersection point Pk1 in Si
           Find an intersection point Pk2, which has minimum distance
           Dmin with Pk1, from Sj and it's 8 adjacent sub regions
           if Dmin ≤ Dth and mark[Pk2] = false
                matched = matched + 1
                mark[Pk2] = true
        totalmatched = totalmatched + matched
   return totalmatched
```

Fig 10: Algorithm for finding number of matching points between two templates

4.3 Template Generation and Matching

The blood vessel intersection points found in previous steps were collectively treated as a template for a person and stored for further matching with other templates. The algorithm of Fig 10 is then used to calculate the number of matching points between two templates. We divided the whole image template into 8 × 8 sub regions and the value of D_{th} was used 11. Finally the degree of matching between two templates T_1 and T_2 is calculated as follows:

$$DegreeMatch = \frac{Max(MatchTemplates(T_1, T_2), MatchTemplates(T_2, T_1))}{Total\ points\ in\ T_1 and\ T_2} \times 100$$

5. EXPERIMENTAL RESULTS

The proposed method is applied to a dataset [7] containing 18 retina images of 6 different persons each having 3 samples. The sample1 of each person was used for training the system and other two sample2 and sample3 were used for testing purpose. Table 1 shows the result of the comparison of sample1 with sample2 and sample3 of these 6 different persons. The matching percentage of intersection points is more than 80% in the cases of comparing two images of the same person, while this percentage is less than 25% in the cases of comparing two images of different persons.

Table 1: Comparison of sample1 with sample2 and sample3 of 6 different persons

Person No	Sample No	Sample1 of					
		Person 1	**Person 2**	**Person 3**	**Person 4**	**Person 5**	**Person 6**
P1	**Sample2**	81.72%	12.90%	11.11%	11.24%	16.16%	13.86%
	Sample3	82.47%	13.33%	10.75%	17.20%	08.42%	13.08%
P2	**Sample2**	08.70%	84.78%	11.24%	06.82%	10.20%	18.00%
	Sample3	18.75%	80.90%	10.87%	04.35%	8.51%	16.98%
P3	**Sample2**	15.38%	08.79%	95.45%	13.79%	12.37%	20.20%
	Sample3	14.74%	06.82%	90.11%	15.38%	10.75%	13.33%
P4	**Sample2**	10.99%	15.38%	13.64%	82.76%	10.31%	10.10%
	Sample3	08.42%	11.36%	13.19%	90.11%	08.60%	17.14%
P5	**Sample2**	12.37%	08.25%	10.64%	08.60%	87.38%	07.62%
	Sample3	11.88%	10.64%	10.31%	10.31%	84.85%	09.01%
P6	**Sample2**	14.68%	09.17%	20.75%	13.33%	08.70%	85.47%
	Sample3	14.16%	13.21%	23.85%	11.01%	09.01%	82.93%

6. CONCLUSION

We have presented an approach for authenticating a person through his own unique retina pattern. Although the number of retina images was used to justify the proposed method were not very high, the results found were very interesting and indicative of the robustness of the method.

The space and time complexity is reasonable, since we found that each retina images contains no more than 100 of intersection points.

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