Pattern Matching Algorithm using Polar Spectrum in Retina Recognition for Human Identification System

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Abstract: In biometric applications, an image may be represented by several feature points which can be used for recognition and identification. Since the retina is considered as one of the most reliable and impossible to forge biometric; we are presenting an innovative approach towards the human identification system using the retina. The proposed system is composed of three modules including the blood vessel extraction module, the feature point extraction module and the pattern matching module. Our contribution is to propose a faster and efficient matching algorithm which is translation, rotation and scaling invariant, using a polar spectrum of the feature points found in retinal images for identification.

Key words: Biometrics; image processing; pattern recognition; polar spectrum; retina recognition.

INTRODUCTION

As we are entering in the new wave of technology, security concerns have started gaining prominence in organizations. It is very essential to provide security parameter in order to safeguard what is intended to be restricted. Among several methods to improve security; biometric system is considered as the most authentic and difficult to forge. A biometric system uses the characteristics of a person for identification. These characteristics, related to person's behavioral and physical traits, are stored in a database and later on used for identification purposes if the same person intends to use the system.

There are several biometric features both behavioral and physical that can be used in security like finger prints, iris, face, retina, signature, gait etc. To qualify for a biometric trait; following conditions must be fulfilled (Anil *et al*., 2004):

- Universality: every person should have this trait.
- Distinctiveness: no two persons have the same features in the trait.
- Permanence: the information in the trait should be stable for a very long time.
- Collectability: quantitatively it can be measured.

After considering the above criteria for a biometric characteristic, retina earns a favor being the most reliable, stable and secure biometric feature and hence can be utilized in highly secured area like weapons facilities, chemical plants, biological laboratories etc.

Figure 1 shows a cross sectional view of the eye. The retina is a 40 mm thin layer of cells at the back of the eyeball that converts the received light to electrical nervous signals and sends it to the brain (Hamid *et al*., 2006).

Since retina is at the back wall of the eye and optic nerve is in the center of retina. All major blood vessels emits from the center of optic nerve. Hence, it is not exposed to the external environment and possesses great stability and security against forging.

There are several approaches used in the past to identify human based on retinal identification. In (Hamid *et al*., 2006), the position of optic disc is determined by applying HAAR Wavelet in three levels of retinal image, then for feature extraction, Fourier-Mellin transform and Complex Moment Magnitudes (CMM) are used to compensate the transformation problems. For recognition, they used Fuzzy C-mean Clustering. This approach is complex and computational cost is high, especially in a large database. In (Hadi *et al*., 2008), the polar image is calculate from ROI and then after the analysis, feature vector is constructed. This approach is rotation invariant but not very efficient since conversion from ROI to polar image and then feature vector construction increases the computational burden. Also, the algorithm is sensitive towards the change in blood vessel diameter, which may occur due to certain diseases. There are several other methods which additionally require the position of fovea to be determined. In this paper, we are presenting novel approach towards retina identification using polar

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spectrum. In our proposed system, there is no need to determine the position of fovea and also, the experiments shows that our matching algorithm is much faster and efficient.
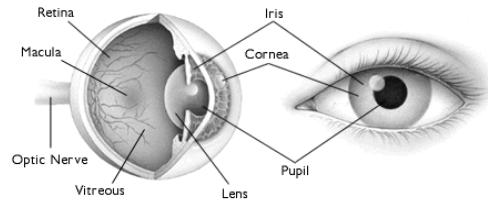

Fig. 1: Eye Anatomy.

The proposed system generates features points which are translation, scaling and rotation invariant, and calculates the polar spectrum using the center of optic disc (OD) as the origin and the line between OD and closest feature point as positive x-axis.

Our contribution in this paper is as follows:
1. The propose pattern matching algorithm for retina is faster and efficient.
2. Proposed algorithm is translation, scaling and rotation invariant.
3. Algorithm requires OD location to be determined, but, the position of fovea is not required at all.

The rest of the paper is detailed as follows. The next section describes the retinal technology overview which is then followed by detection of anatomical structure of retina, the feature detection process. Next elaborates the polar spectrum followed by matching algorithm and finally results are explained with conclusion.

Retina as Biometric Information:

The biometric information in the retina lies within its blood vessels pattern. Simon and Goldstein (Adam *et al.*, 2000) discovered in 1935, that, the pattern of blood vessels in retina is unique in every eye. Moreover, in 1950s, Dr. Paul Tower discovered that, even in identical twins, this pattern of retinal blood vessels is unique (Hadi *et al.*, 2008). Figure 2 describes this pattern of blood vessels.
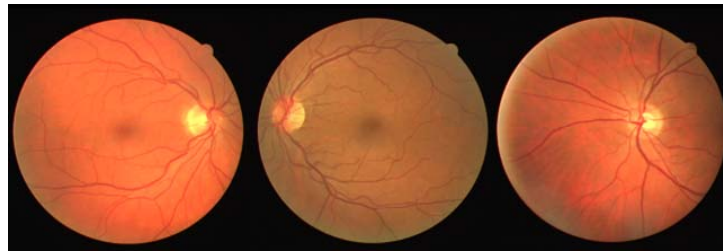

Fig. 2: Pattern of blood vessels in retina.

Since location of the retina is so internal in the eye; retina may provide higher level of security due to its indigenous robustness against imposture (Mehran *et al*, 2009). Furthermore, the pattern of blood vessels remains stable in individuals over lifetime period. So, places requiring very high security or physical access like intelligence, military facilities, laboratories etc. Retinal imaging is a form of identification which can be used in both animals and humans.

Retinal scanners are similar in operation like iris scanners but require the user to be very close to a special camera. This camera takes an image of the patterns created by tiny blood vessels illuminated by a low intensity laser in the back of the eye - the retina. A retinal scan is performed by casting an undetectable ray of low-energy infrared light into a person's eye as they look through the scanner's eyepiece. This beam of light outlines a circular path on the retina. Because retinal blood vessels are more sensitive to light than the rest of the eye, the amount of reflection fluctuates. The infrared light is reflected back to the retinal scanning device for processing in order to capture the blood vessels pattern of the retina.

Detection of Anatomical Structure of Retina:

The normal features of a retina are optic disc, macula and the blood vessels. In our proposed algorithm, optic disc (OD) center and the closest feature point are used to create the reference line called as positive X-axis. This reference line would compensate the rotational and translational transformations of retinal images. Hence, it is very necessary to detect the correct position of the optic disc.

Optic Disc Detection:

For our proposed system; the location of the optic disc is very essential. As in figure 2, OD is the brighter region in the retina as compared to other regions. There are several methods to detect the optic disc in retina. The optic disc was located by the largest region that consists of pixels with the highest levels (Zheng *et al.*, 1997). The area with the highest intensity variation of adjacent pixels was identified as optic disc (Chanjira *et al.*, 1999). These approaches are suitable for image of healthy retina where OD segmentation is easy to obtain but may give false results in the presence of outsized areas of bright lesions creating similar effect as an OD in the image. In our system, we have implemented the process described as in (Siddalingaswamy and Prabhu, 2007). For segmentation of brightest regions in the image; optimal thresholding is used that approximates the image histogram which is based on weighted sum of two or more probability densities with normal distribution. Image histogram is scanned from high intensity to lower intensities. This process stops whenever it finds the intensity hl_k having a minimum of one thousand pixels of same intensity as hl_k. The initial threshold is calculated as:

$$T_n = \frac{hl_k + hl_{\max}}{2} \tag{1}$$

Where, hl_{max} is the maximum intensity level. In the next iteration; the updated threshold is set as the closest gray level corresponding to the minimum probability between the maximum of two the normal distribution as follows,

$$T_{n+1} = \frac{M_b + M_o}{2} \tag{2}$$

Where, M_b and M_o representing the mean background pixels and the mean foreground pixels respectively, and are defined as follows:

$$M_b = \frac{\sum_{i=k}^{n} np i^{hl} i}{\sum_{i=k}^{n} {}^{hl} i} \tag{3}$$

and,

$$M_o = \frac{\sum_{i=n+1}^{mx} np_i hl_i}{\sum_{i=n+1}^{mx} hl_i} \tag{4}$$

Where np_i is the pixel count having i^{th} intensity and hl_i represents the ith intensity level. After every iteration, T_{n+1} is updated as current threshold value and these iterations are stopped when either T_{n+1} equals T_n or their difference is less than the value set by the user. It produces strong gray level variance between the object and the background.

After thresholding, the image results in the regions(s) of white pixels having black background. For finding the optic disc; the region with maximum number of pixels in it can be considered as optic disc. Furthermore, the center of optic disc is computed by having minimum and maximum spatial coordinates of the optic disc pixels. The diameter of the optic disc can be of 100 pixels. If the region is greater than this diameter, the process is again repeated by decrementing the threshold by 1. The process is repeated until the proper size of the OD is obtained. Figure 3 is explaining the process of optic disc segmentation and detection.
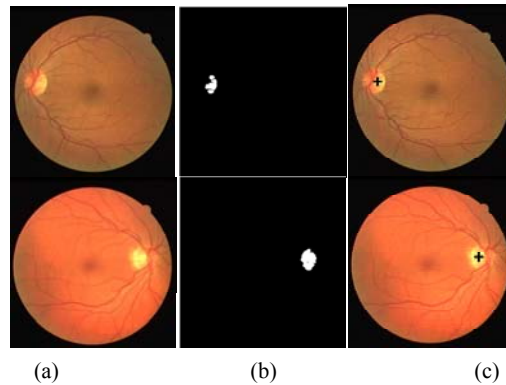

| (a) | (b) | (c) |

Fig. 3: Column (a) Retinal images (b) optic disc segmentation and (c) optic disc detection.

Retina Vascular Network Detection:

In retina, for biometric identification, the pattern of blood vessels in retina is very essential. Primarily, it is the blood vessel pattern that is the foundation for retinal biometrics. The blood vessels in retina carry certain characteristics which can be used as the feature points for identification. Since this pattern of blood vessels in retina hardly change in one's lifetime; the feature points extracted from these vessels are likely to provide the same information that can be used for verification.

There are three main steps for pattern extraction of blood vessels in retina:
1. Segmentation of blood vessels in the retina.
2. Thinning of extracted blood vessels.
3. Detection of bifurcation points of blood vessels.

In retina, the pathological change in blood vessel appearance may provide the information about certain diseases like retinopathy, diabetics, hypertension etc. Furthermore, the segmentation and extraction of these vessels are the most important representations which can be used in retinal biometric system due to the three following reasons: 1) it maps the whole retina 2) the representation is very stable throughout the life span except in some severe diseases and 3) it provides sufficient information about the feature points (Thitiporn and Guoliang, 2003) i.e. bifurcation points in our case. Literature shows there are many approaches to describe this pattern of blood vessels in retina (Joes *et al.*, 2004; Kenneth *et al.*, 2007; Benson and Hong, 2008; Kexin *et al.*, 2010; Zhang and Karray, 2010). In our proposed system, we are using (Thitiporn and Guoliang, 2003). This method consist of four steps: 1) Compute Matched Filter Response 2) Implement entropy based thresholding 3) Length filtering and 4) Bifurcation point detection. Since blood vessels in retina have low reflectance; a two-dimensional matched filter kernel is designed to convolve with the original image in order to enhance the blood vessels. This matched filter kernel can be expressed mathematically as:

$$f(x, y) = -\exp\left(\frac{-x^2}{2\sigma^2}\right), \qquad for\,|y| \le \frac{L}{2} \tag{5}$$

Where, L is the length of the segment for which the vessel is assumed to have a fixed orientation and aligned along the y-axis. Because a vessel may be oriented at any angles, the kernel needs to be rotated for all possible angles (Thitiporn and Guoliang, 2003).

In the next step, an efficient entropy-based thresholding algorithm, is used because image pixel intensities are not independent of each other. Specifically, a local entropy thresholding technique is implemented, described in (Nikhil *et al.*, 1989) which can preserve the structural details of an image.

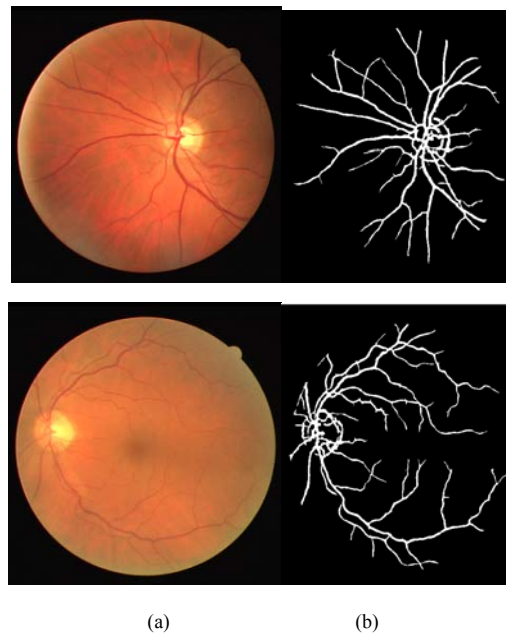The results are shown in figure 4 for various retinal images.

(a)   (b)

Fig. 4: Column (a) retinal images and column (b) vascular tree obtained by entropy based thresholding and length filtering.

Bifurcation-Point Detection:

For our proposed system, the bifurcation points are the most important features present in the vascular tree of the retina which is obtained using the process described above. In order to get the bifurcation points, first we apply the morphological thinning operation so that every vessel in the vascular tree gets one pixel wide as shown in figure 5.

After performing the morphological thinning operation, a 3x3 filter is applied in order to get the bifurcation points. The filter is convoluted on the image so that if any point containing 3 neighborhood pixels, it is considered as the bifurcation point. Figure 6 describe this process by showing the skeleton of vascular tree of retina and the detected bifurcation points.

Template Generation And Matching:
Polar Spectrum Calculation:

After getting the bifurcation points which, in our case, can be considered as the feature points, the polar spectrum is calculated in the following manner. First, a line is drawn between the center of the optic disc and the center of macula. This line is considered as the positive x-axis and will be used as a reference axis for all the bifurcation points. Furthermore, the center of optic disc is considered as the origin so that the angle and the distance 'ρ' can be calculated. All feature points are recalculated considering the optic disc as the origin. The values for angle 'θ' w.r.t positive x axis and the distance 'ρ' can be calculated as:

$$\theta = \tan^{-1}\left(\frac{y}{x}\right) \tag{6}$$

$$P = \sqrt{x^2 + y^2} \tag{7}$$

Where, x and y are the coordinates of the feature points. Figure 7 shows the detected feature points and their polar plot. After the generation of polar spectrum, the information is stored in database. Each feature point FP in the template can be stored as:

$$FP = [PID, PN, \theta, \rho] \tag{8}$$

Where, PID is person's identification number which is unique for every person and PN is the print number. A person with same PID may have multiple prints of the retina. Once all the FPs are collected for a template, the FPs are sorted in ascending order w.r.t. the 'θ' so that the matching process would be easier.
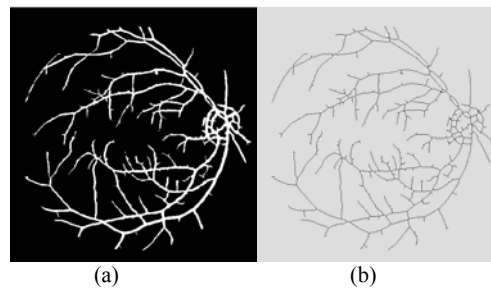

| (a) | (b) |

Fig. 5: (a) Vascular tree (b) Skeleton of vascular tree.

| (a) | (b) |

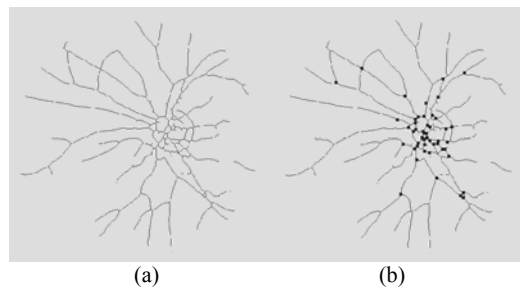**Fig. 6:** (a) Skeleton of vascular pattern (b) bifurcation point detection.

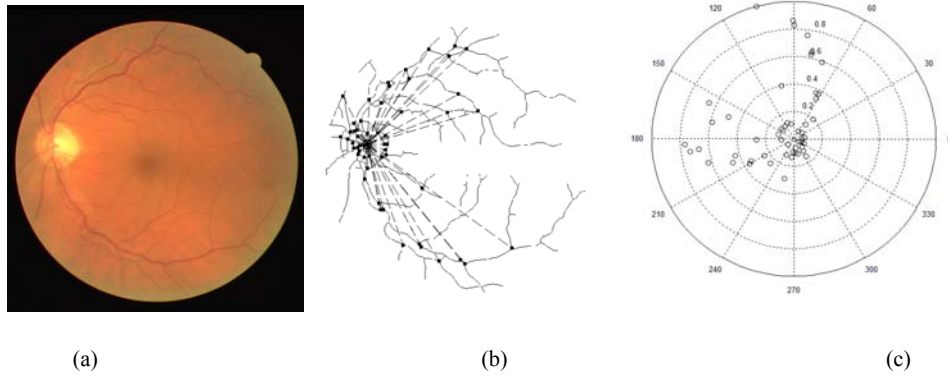(a)   (b)   (c)

Fig. 7: (a) Retina Image (b) Polar spectrum calculation (c) Polar spectrum plot.

Feature Matching and Verification:

The important point in polar matching is the establishment of reference axis along which all the feature points are aligned. Since, normally all the features in the retina including optic disc, macula and the blood vessels pattern are stable in any individual and we are using the line between the optic disc and the macula as the reference axis line with optic disc as the origin. So there is no need to perform further alignment to individual points. The matching process contains two steps. In first step the total number of feature points is counted and matched with the template. If the difference of points are within the defined threshold then second step begins and in this step the angle 'θ' and the distance 'ρ' are matched.

If 'C' is the template generated for the retina being scanned and 'I' is the template stored within the database then:

$$c = [(PID_1, ID_1, \theta_1, \rho_1)...(PID_m, ID_m, \theta_m, \rho_m)]$$
$$I = [(PID_1, ID_1, \theta_1, \rho_1)...(PID_n, ID_n, \theta_n, \rho_n)]$$

Where, m and n are the total number of feature points found in template currently generated for identification and template stored in the database respectively. Therefore, in the first step we will determine if:

$$|m - n| \leq T_1 \tag{9}$$

Where, T_1 is the threshold value for feature point difference. After equation (11) is satisfied, next step starts to match the feature points' angle and the distance according to the following method.

$$|\theta_C - \theta_1| \leq T_2 \tag{10}$$

$$|\rho_C - \rho_1| \leq T_2 \tag{11}$$

Where T_2 and T_3 are the threshold for angle and the distance. The idea of storing the feature points in sorted order w.r.t. the angle is if the first angle of the input template matched with the second or higher row in the stored template, then, the next match will always be in the next coming rows of the stored template and there is no need to search each feature point from the start. Hence, it will save cost of searching also. If all the features satisfied the conditions described in equation (10) and (11), it results in the verification of the person holding that PID.

RESULTS AND DISCUSSION

We have tested our proposed system on 2.26 GHz Corei5, using MATLAB 6.5 with DIP toolbox on windows 7 operating system. The feature extraction (first time only) from the retinal image took approximately 4.0 seconds and subsequently, comparison with each template took a maximum of around 0.020 second (worst case scenario). For our experiments, we use dataset of around 100 retinal images with multiple registrations. Along with these, public databases of DRIVE (Joes *et al*., 2004) and STARE (Adam *et al*., 2000) are also used.

We kept 75% as the matching threshold i.e. minimum 75% feature points in input retinal image should match with the template stored in the database. We took two samples of retina for registration and used the third randomly taken for matching. Table I and II shows the results of our experiments with multiple registrations.

Table 1: Accuracy Of Matching Algorithm.

Trial input	Accuracy with matching template1 (%)	Accuracy with matching template2 (%)	Average accuracy of matching template (%)	Average matching with other templates in the database (%)
trial1	83	91	87	05
trial2	89	87	88	10
trial3	85	88	87	07
trial4	90	89	90	11
trial5	93	89	91	16
trial6	85	93	89	08

Table 2: Mean And Standard Deviation Of Matching Algorithm.

Mean percentage of matching templates	89.33%
Std. Dev. Of the matching templates	2.88%

Conclusion:

This paper presents the novel and simple approach for person identification through retina using polar spectrum. Our proposed algorithm is favorable because of the following merits:

1. The matching and verification is rotation, translation and scaling invariant.
2. Feature extraction is faster since the location of macula or fovea is not requires.
3. Simple implementation.
4. It's processing and comparison time is very short for larger dataset due to the fact that if, whenever, the algorithm found 25% mismatch (or whatever be the minimum threshold is set) of the input template with the stored one; it immediately jumps on the next template. Hence, for searching in larger set of templates, this algorithm is handy.

Also, it is noted the accuracy can be improved if we increase the number of registrations per person. We suggest that to achieve more that 95% of accuracy, we should have 3 registrations per person. Further improvement can be made in the area of OD detection. It is essential to estimate the accurate position of the center of OD. There are cases when there are brighter regions as OD found in the retina because of certain diseases resulting in the wrong detection of OD center. Also greater work can be done in the field of artificial intelligence to train the feature points of different templates, the system would be self learning in this case after every enrollment and matching.

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