

EFFECTUAL HUMAN AUTHENTICATION FOR CRITICAL SECURITY APPLICATIONS USING RETINAL IMAGES

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Abstract

A robust method of human authentication based on the retinal blood vessel pattern is presented in this paper. This method entails a segmentation process to identify retinal blood vessel pattern, template generation consisting of the bifurcation points in the retina and matching of the intersection points in the template patterns. The number of matched blood vessel intersection points between the two patterns compared is used as a measure of similarity. As Liveness detection is a highly desirable anti-spoofing measure in biometric authentication, it is ensured while acquiring retinal images in real-time. The validity of our approach is verified with experimental results obtained from 603 comparisons made using 303 retinal images from three different publicly available databases, namely DRIVE, VARIA and STARE. We found that the proposed retinal recognition method gives 100%, 96.3% and 91.1% recognition rates respectively for the above databases. To the best of our knowledge, this is the first work that uses a large number of retinal images from different retinal databases for the authentication purpose.

Keywords:

Authentication, Blood vessels, Bifurcation Points, Feature Extraction, Retinal Recognition

1. INTRODUCTION

Trustworthy recognition of users of any specific location (office, research lab, etc.) has been an important and attractive goal of scientific research. Out of many authentication technologies, Biometric authentication gets the leading role, since it cannot be borrowed, stolen or forgotten and also forging is practically impossible. So it is used as the most secure and convenient authentication tool. Biometric authentication is a process that validates the identity of a user, who wishes to sign into a system, by measuring the unique physical or behavioral characteristics of that user. Biometric samples include fingerprints, face, ear, palm print, retina, voiceprints, typing patterns, etc.

Retinal recognition is relatively a new approach, compared to other biometric features. It is one of the most accurate, stable and reliable approaches of the available biometric technologies [1]. Since retinal patterns have highly distinctive traits, the features extracted from retina identify effectively persons, even among genetically identical twins. The interior location of retina is not exposed to threats as present in other biometrics. Since the feature vector size is very small, it aids in quicker verification and identification processing. These characteristics make retinal recognition, a prominent solution to security in the near future.

Retina is the light-sensitive layer of tissue that lines the inside of the eye and sends visual messages through the optic nerve to the brain. These vessels have a unique pattern that allows the generation of up to 400 unique data points for comparison. The primary application of retinal recognition is in

providing physical security and access to entry into highly secured locations like military installations, nuclear facilities and research laboratories. Eyes affected by diseases such as hard glaucoma, cataracts provide less accurate results. Image acquisition involves more cooperation of the subject, entails contact with the eyepiece and this makes less public acceptance.

2. RELATED WORKS

Research based on retinal authentication is very much limited, related to the retinal vascular patterns. First retina based identification system, named as Eyedentification 7.5 was introduced by EyeDentify Company in 1976 [1]. Ortega et al [2] used a fuzzy circular hough transform to localize the optical disk in the retina image. Curvature evaluation [3] is used to detect vessel-like patterns in a noisy environment. In order to improve the segmentation results, morphological open operations [4] are also applied for post processing of resulting binary images. Retinal vessel detection methods are broadly classified into two categories, edge-based and kernel-based. Edge-based methods attempt to identify vessel edges with edge detector, such as directional matched differentiator template [5], Sobel operator [6] and morphological detector [7]. Kernel-based methods work by convolving images with a filter kernel defined by the model of vessel cross-sectional profile. Blurred half-elliptical profile [8], Gaussian shaped profile [6], [9] and simple rectangular profile have been proposed for modeling profile cross-sections. Another method constructs optimal matched filters with the shape of a Gaussian profile [6]. The matched-filtering repeats at various orientations and the maximum response is retained and threshold to produce a vessel pattern. Gaussian shaped profiles have been examined in scale-space and in the wavelet domain to automate extraction of the vascular tree. Marino et al. [10], [11] introduced an authentication system based on retina. The complete arterial-venous tree structure was used as the feature pattern for individuals. [12] Extracts the fingerprint features using a minutiae-centered region encoding method and then performs anonymous enrollment and verification. Based on the idea of fingerprint minutiae [13], a set of landmarks (bifurcations and crossovers of retinal vessel tree) were extracted and used as feature points. The database included only 6 individuals with 2 images for each of them. The drawback of the system was the necessity of storing and handling a whole image as the biometric pattern. [15] Describes a retinal verification method characterized by adding semantic information to the biometric pattern. It reduces the computational load in the matching process as only points classified equally can be matched. In [16], [17] a pattern was defined using the optic disc as reference structure and using multi-scale analysis to compute a feature vector around it. The dataset used consists of 60 images that were rotated 5 times each.

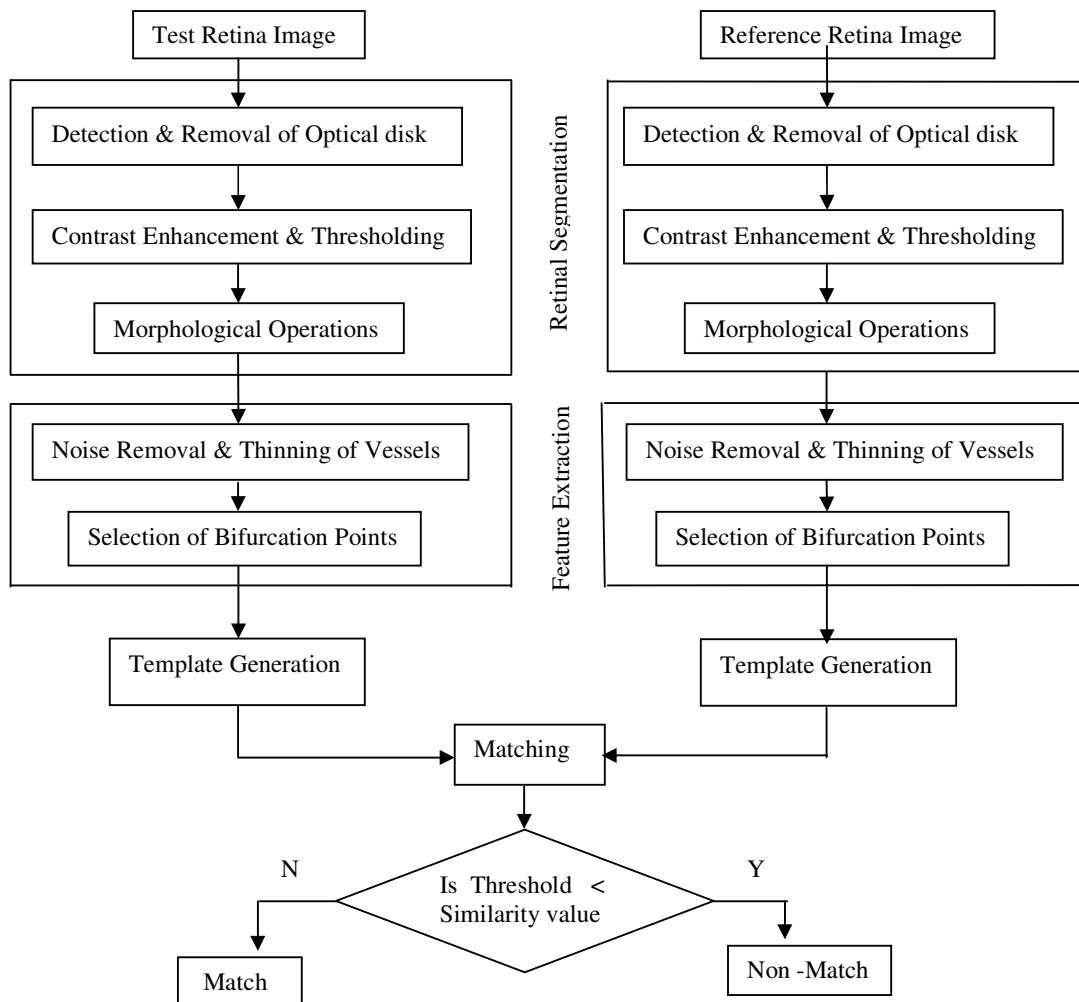


Fig.1. Block diagram of Proposed Retinal Authentication process

3. RETINAL AUTHENTICATION SYSTEM

Retinal recognition technology captures and analyzes the patterns of blood vessels on the thin nerves that are on the back of the eyeball. The system processes light entering through the pupil. Also the liveness of input retinal images is ensured while acquiring in real-time, since the retinal pattern is visible only when the person is alive. It disappears when a person is no more. So spoofing is impossible in retinal recognition. A robust representation of retina recognition must be invariant to changes in size, position and orientation of the vessel patterns. The proposed person authentication scheme contains four basic processes: segmentation, feature extraction, template generation and template matching as shown in Fig. 1.

3.1 RETINAL VESSEL TREE EXTRACTION

Segmentation process identifies the blood vessel pattern of the retina by using the oscillating components of scanning retinal images. The input image is projected onto a closed convex set [4] consisting of functions with zero mean. Then the signs of the

projection are regarded as the output of the segmentation system. The method uses nonlinear orthogonal projection to capture the features of vessel network and a local adaptive threshold algorithm for vessel detection. This algorithm minimizes the vessel variation problem involved in image decomposition [20], [21]. The original retinal image and segmented vessel tree are shown in Fig. 2(a) and Fig. 2(b).

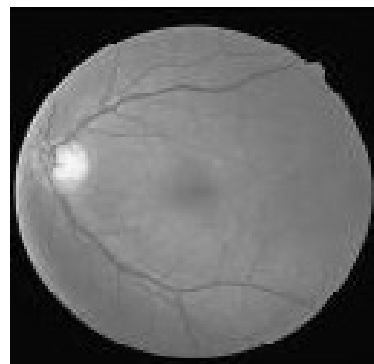


Fig.2(a). Retinal Image

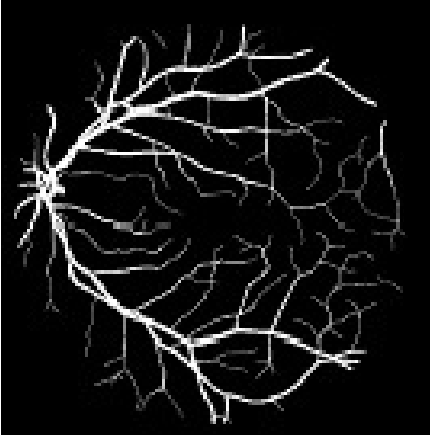


Fig.2 (b). Retinal Vascular Tree

The vessel detection algorithm performs the following steps:

1. Compute the orthogonal projection using the fixed-point algorithm [4].
2. Apply threshold to the projection of step-1 to get the output binary image.
3. Apply morphological open operator to the binary image to remove blob-like structures and shorter linear structures.

3.2 FEATURE POINTS EXTRACTION

The features present in the retinal vessel tree are the bifurcations and crossovers, which are unique for every individual. The algorithm used here extracts these feature points called as retinal minutiae. As a preprocessing step, before extracting the features, thinning is performed and noise present in the scanned retinal image is filtered out.

3.2.1 Thinning and Noise Removal

The blood vessels are thinned into one pixel width to find the bifurcation points accurately from the retinal images. First the boundary pixels of blood vessels are determined. A pixel is said to be a boundary pixel [26], if the pixel value is 0 and at least one of its four neighbors at horizontal and vertical pixel is 1. Then remove the boundary pixels that do not break the vessel connectivity. The resultant thinned image is shown in Fig.3. Then Median filtering is used to decrease the false feature point detection rate by removing noisy pixels and bridging the gap between vessel lines.

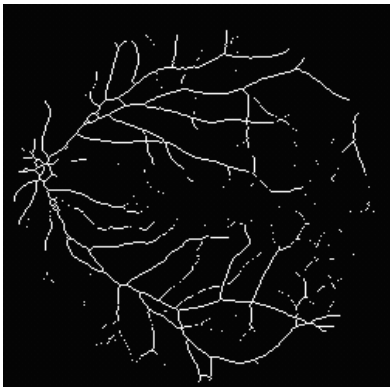


Fig.3. Thinned Retinal Image

3.2.2 Finding Bifurcation Points

Due to eye movement during the image acquisition stage, patterns may suffer from deformations like translational, rotational displacements and non-linear distortion of blood vessels. To deal with these distortions of retinal patterns, first a minutiae-centered region is constructed to avoid the translation error. Then polar coordinate conversion with respect to the corresponding core minutia is applied to handle the rotation distortion. Finally, tessellation quantification is performed to work with non-linear distortion by removing noise present in retina image.

Each minutia in the retinal image is represented as a 3-tuple $T(a,b,\theta)$, where a and b represents the location and θ represents the orientation attributes of the feature points. A circular region P of same radius, around each minutia is constructed. The center minutia is named as the core minutia and the others named as neighbor minutiae. Then each neighbor minutia with respect to the corresponding core minutia will be transformed into the polar co-ordinate system. They are represented as a new 3-tuple $T(\alpha, \beta, \gamma)$, where α and β indicate the radial distance and radial angle and γ represents the orientation of the neighbor minutia with respect to the core minutia and $\beta, \gamma \in [0 \text{ to } 360 \text{ degree}]$. An illustration is given in Fig. 4.

Tessellation quantification is carried out on each of the neighbor minutiae by tessellating the region of interest that is centered at the core minutia. The 3-tuple $T(\alpha, \beta, \gamma)$ in the polar coordinate system will be quantified into a rougher 3-tuple $T(rd, ra, o)$ given by

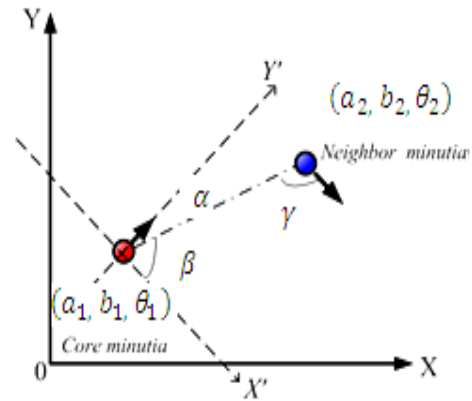


Fig.4. Illustration of the feature extraction algorithm

$$rd = [\alpha / drd], \quad ra = [\beta / dra] \quad \text{and} \quad o = [\gamma / do] \quad (1)$$

where 'drd' is the bandwidth of the region tessellation, 'dra' is the distortion tolerable difference of radial angle and 'do' is the distortion tolerable difference of the orientation of the neighbor minutia with respect to the core minutia.

The i^{th} neighbor minutia in a region P is represented as $T_i = (rd_i, ra_i, o_i)$. Suppose that there are 'm' neighbor minutiae in the region P , then P can be represented as a set of m-tuples as

$$MC = \langle T_1, T_2, \dots, T_m \rangle \quad (2)$$

where the set MC is called retinal minucode. If there are N minutiae in the entire retinal image, then the resultant retinal feature template is given by a set of minucodes as

$$Temp = \{MC_1, MC_2, \dots, MC_N\} \quad (3)$$

The algorithm for feature extraction is given below and the obtained bifurcation points are shown in Fig.5.

1. Construct minutiae-centered region and represent each retinal minutia as a 3-tuple $T(a,b,\theta)$ to avoid the translation error.
2. Transform step-1 into polar co-ordinate system to remove the rotation distortion and represent it as $T(\alpha, \beta, \gamma)$.
3. Apply tessellation quantification to step-2 to remove the non-linear distortion and get a rougher $T(rd,ra,o)$.
4. Perform steps 1 to 3 for all minutiae in retinal image and obtain the final feature template.

3.3. TEMPLATE CREATION

The blood vessel skeleton is removed from the input retinal image, by applying binary threshold after the process of extracting the bifurcation points. These bifurcation points are collectively stored in a template along with its coordinates. The generated template is shown in Fig.6.

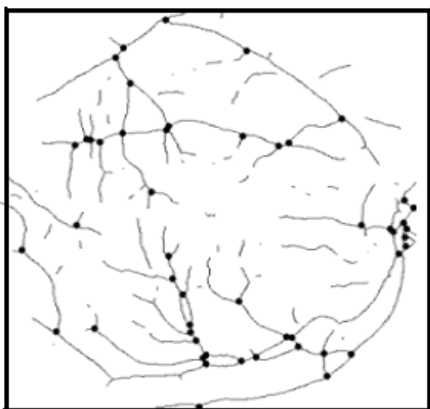


Fig.5. Extraction of Bifurcation Points

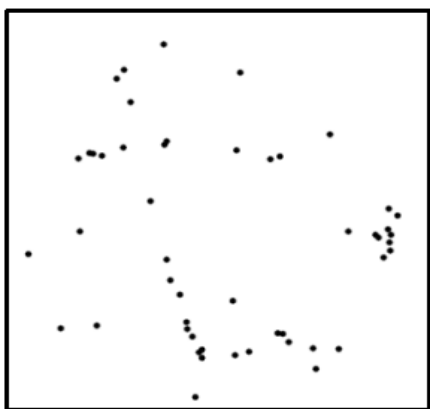


Fig.6. Feature Template

3.4 TEMPLATE MATCHING

This process describes a methodology for verification of individuals based on retinal patterns. Since patterns may undergo translational or rotational displacements, it is necessary to align the images to be matched. The reference point detection method [18] is used to identify the blood vessel intersection points properly. The patterns compared could have a different number

of points for the same individual, which is due to different conditions of illumination and orientation of the image in the acquisition process. Scaling is nearly constant for all images due to eye proximity to the camera. In addition, rotations are very slight as the eye orientation when facing the camera is very similar. Then matching of the intersection points is carried out. The number of matched blood vessel intersection points between the two patterns is used to quantify the degree of matching. This system generates a safe confidence band in the similarity measure space between scores for patterns of the same individual and between different individuals. The template-matching algorithm is given below:

Each retinal template is subdivided into 8×8 sized sub regions.

1. Let the two templates to be matched as TP1 and TP2 and sub regions as SR1 and SR2.
2. Initialize the total number of matched points in a template 'TMP' to be 0.
3. For each sub region SR1 in TP1 and SR2 in TP2, perform:
 - (i) Initialize the total number of matched points in a sub region 'MP' as 0.
 - (ii) For each intersection point IP1 in SR1, perform:
 - Find the IP2 in SR2 and the 8 neighbor sub regions of SR2, which has minimum distance, D_{min} with IP1.
 - If $D_{min} \leq D_{thres}$, distance threshold and IP2 is not already matched, then $MP = MP + 1$.
 - Mark IP2 as matched.
 - (iii) Find $TMP = TMP + MP$.
4. Intersection point matching percentage is

$$P = (2 * TMP / (TIP1 + TIP2)) * 100 \quad (4)$$

where TIP1 is the total number of intersection points in TP1 and TIP2 is the total number of intersection points in TP2.

5. Similarity of matching is given by

$$S = \max \{ \text{Template Matching (TP1, TP2)}, \text{Template Matching (TP2, TP1)} \} \quad (5)$$

The distance threshold, D_{thres} represents the maximum offset by which, the same intersection point on different templates can be displaced. It is used in order to consider the quality loss and discontinuities arrived during the vessel extraction process that leads to dislocation of feature points by some pixels.

4. EXPERIMENTAL RESULTS AND DISCUSSION

Images from three publicly available databases namely DRIVE [9], VARIA [25] and STARE [26] databases are used for the evaluation of the proposed method. DRIVE database contains only 40 normal retinal images. In order to have intra class variations, two synthetic images were generated for each image in the database by applying rotation to the images and used this along with the existing database. VARIA database consists of 463 normal images and STARE database contains a mixture of 397 normal and affected retinal images of which 60 images were taken for comparison. The retinal images from these databases were tested for similarity, by comparing the

images of different persons that generate inter user values and of the same person which give intra user values. Graphs are plotted for the obtained similarity values of compared images and are shown in Fig.7, 8 and 9.

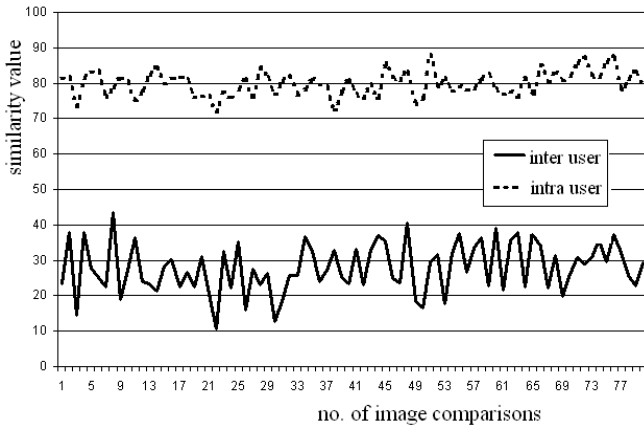


Fig.7. Inter and Intra Class Variations for DRIVE Images

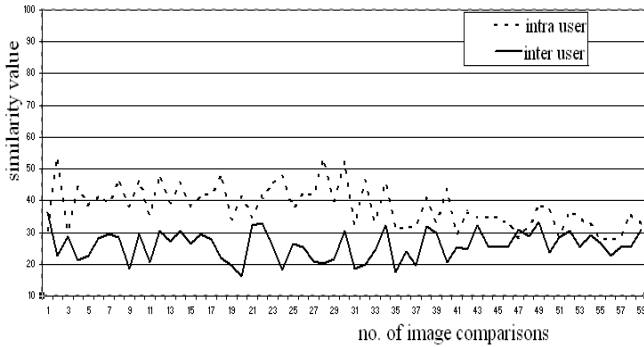


Fig.8. Inter and Intra Class Variations for STARE Images

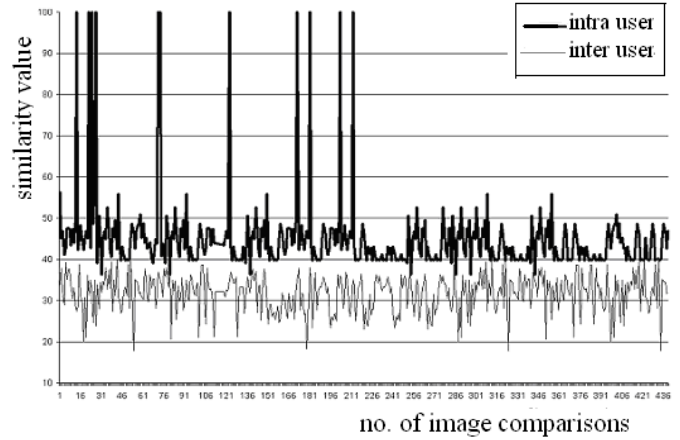


Fig.9. Inter and Intra Class Variations for VARIA Images

The performance measures used in our analysis are Genuine Acceptance Rate (GAR), False Acceptance Rate (FAR), False Rejection Rate (FRR) and Equal Error Rate (EER). The rate of accepting genuine user is called GAR and the rate of accepting imposter is called FAR. The rate of rejecting genuine user as an imposter is called FRR.

To find GAR, the extracted features of each person are compared with other image samples of the same person. In all the comparisons, if the similarity score is greater than the fixed threshold, then the person is accepted as a genuine user and if he is rejected, then it implies that a genuine person is not accepted i.e. falsely rejected. This gives FRR. To get FAR, the features of each person are compared with other persons' features in the database. In any of the comparison, if the match score is more than the fixed threshold, then it implies that an imposter is accepted. All such comparisons are made on the database to compute GAR, FRR and FAR at fixed thresholds. The experiment is repeated by changing threshold to different values. Table.1 shows the set of values obtained for the above measures at different thresholds for the three databases.

Table.1 Representation of GAR, FRR and FAR values at different thresholds

DRIVE Database				VARIA database				STARE Database			
Threshold	GAR (in %)	FRR (in %)	FAR (in %)	Threshold	GAR (in %)	FRR (in %)	FAR (in %)	Threshold	GAR (in %)	FRR (in %)	FAR (in %)
20	100	0	87.5	20	100	0	100	20	100	0	87.5
25	100	0	62.5	25	100	0	98.9	25	96.6	3.33	62.5
30	100	0	38.8	30	100	0	72.1	30	83.3	16.7	38.8
35	100	0	26	35	100	0	23.5	35	58.3	41.7	26
40	100	0	4	40	82	17.9	0	40	36.6	63.3	4
45	100	0	0	45	39.5	60.4	0	45	20	80	0
50	100	0	0	50	6.69	93.3	0	50	5	95	0
70	100	0	0	60	4.31	95.6	0	55	0	100	0
75	95	5	0	65	2.37	97.6	0	60	0	100	0
80	51	48.7	0	70	2.37	97.6	0	70	0	100	0
85	7.5	92.5	0	80	2.37	97.6	0	80	0	100	0
90	0	100	0	90	2.37	97.6	0	90	0	100	0

ROC curve shows the accuracy and performance of our biometric system. We have generated the ROC curves by varying the threshold on the classification image. An optimal threshold is then selected, which maximizes the accuracy. The ROC curve showing the relationship between GAR and FAR is shown in Fig.10 for the 3 different databases. Equal Error Rate is the location on a ROC curve where FAR and FRR are equal. The EER is found from the ROC curve drawn between FAR and FRR as shown in Fig.11 for the 3 different databases.

Our algorithm produced 100% recognition rate and 0% EER for DRIVE images with well-separated interclass distance between genuine users and imposters as shown in Fig.7. This is due to the good quality of input retinal images. For the VARIA database, the proposed retinal authentication method gave 96.3% recognition rate and 0.015% EER. Since most of the images taken from the STARE database were diseased ones, the method produced 91.1% recognition rate and an EER of 0.14%. We also observed that the distance of separation between the two classes is lesser in VARIA and STARE databases compared to DRIVE, as shown in the Fig.8 and Fig.9. On Pentium 4 machine with 3.06GHz CPU, 1.97GB RAM and using MATLAB version 7.2, and the computational time taken for retinal image recognition is given in Table 2.

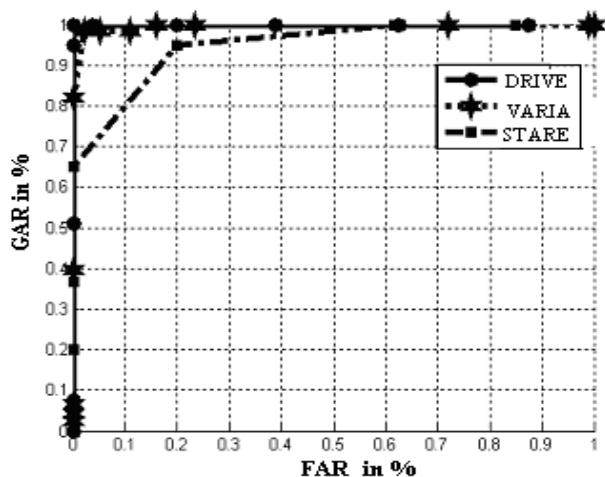


Fig.10. ROC drawn between FAR and GAR

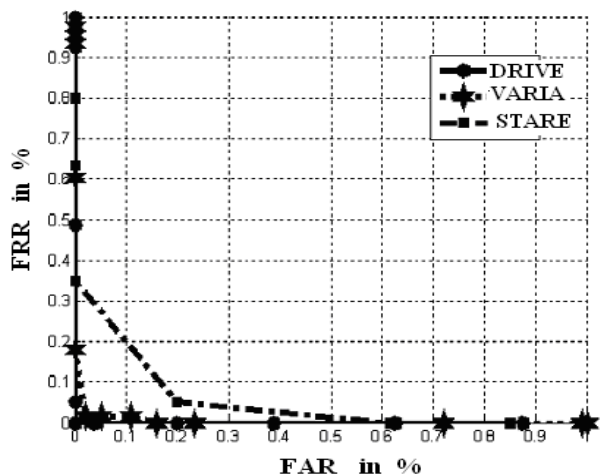


Fig.11. ROC drawn between FAR and FRR

Table.2. Performance analysis of our approach for different databases

Database used	No. of images taken	No. of comparisons made	Recognition rate (in %)	EER (in %)	Time taken (seconds)
DRIVE	40	80	100	0	28.966
VARIA	233	463	96.3	0.015	31.168
STARE	30	60	91.1	0.14	23.208

5. CONCLUSION

We have developed an automated method for human authentication by retinal pattern matching. This method involves blood vessel segmentation, generation of feature template consisting of the bifurcation points and then matching of these points. The number of matched points quantifies the degree of matching. We have made a performance analysis by using the publicly available databases namely DRIVE, VARIA and STARE. We found that there is a large inter-class distance for the images in the DRIVE database than for the STARE and VARIA databases. This maintains higher recognition rate even for larger dataset containing noisy images. The method is quite insensitive to translational and rotational displacement of retinal images. In addition, the retinal template contains only the intersection points and not the entire vessel structure, so the storage requirement is less. The proposed retinal authentication method gives 100%, 96.3% and 91.1% recognition rates for the DRIVE, VARIA and STARE datasets respectively. As a future work, we wish to provide retinal template security in addition to authentication.

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