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Multimodal Biometric Authentication Combining Finger Vein and Finger Print

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Abstarct:- Bio-Metric is a process of identifying a person using physiological and behavioural features. Physiological features are Iris recognition, DNA matching, hand vein identification, finger print identification and behavioural features are voice recognition, signature, password, keystroke etc. Since Unimodal systems are having drawbacks, in this paper we are focusing into Multimodal biometric systems. Multimodal biometric systems have been widely used to achieve high recognition accuracy. Among various multimodality options, fingerprint and finger vein has gained much attention to combine accuracy, universality and cost efficiency of the solution. In this paper a new approach is employed to improve the authentication. The system simultaneously acquires the finger vein and low resolution fingerprint images and combines these two evidences using a two new score level combination strategy i.e., holistic and nonlinear fusion.

Keywords:- Accuracy, Holistic, Multimodal, Unimodal, Universality.

I. INTRODUCTION

As technology advances, information and intellectual properties are wanted by many unauthorized personnel. As a result, many organizations have being searching ways for more secure authentication methods for user access. Furthermore, security has always been an important concern to many people. From Immigration and Naturalization Service (INS) to banks, industrial, military systems, and personal are typical fields where security is highly valued. It is soon realized by many, that traditional security and identification are not sufficient enough; people need to find a new authentic system in the face of new technological reality.

Conventional security and identification systems are either knowledge based – like a social security number or a password, or token based – such as keys, ID cards [9]. The conventional systems can be easily breached by others, ID cards and passwords can be lost, stolen or can be duplicated. In other words, it is not unique and not necessary represent the rightful user. Therefore, biometric systems are developing intensively and many researches are going on.

Biometric authentication is an automated method of recognizing a person. Biometric authentication can be classified into unimodal and multimodal biometric systems [2]. Unimodal systems that use single biometric trait for recognition purposes; and suffers a several practical problems like non-universality, noisy sensor data, intra-class variation, restricted degree of freedom, unacceptable error rate, failure-to-enroll and spoof attacks. So, the performance of single biometric system needs to be improved. The techniques of multimodal biometric system can offer a feasible method to solve the problems coming from unimodal biometric system. Multimodal biometric system makes use of different biometric traits simultaneously to authenticate a person's identity. Robustness and high security of authentication can be achieved by using the multimodal biometric systems.

1.1 Common human biometric characteristics

The common human biometric characteristics are physiological and behavioural [9], the common human biometric characteristics are showed in below figure 1.

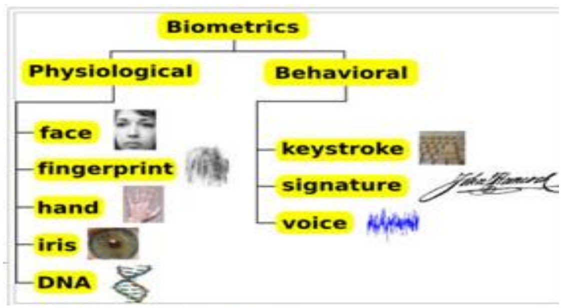


Fig 1. Common human biometric characteristics.

1.2 The different Biometric parameters are explained in this section

Biometric authentication system should meet the basic biometric parameters. [2] [3] [7] The different important biometric parameters are explained in this section.

1. Universality: each person should have the characteristic
2. Uniqueness: is how well the biometric separates individuals from another
3. Permanence: measures how well a biometric resists aging and other variance over time
4. Collectability: ease of acquisition for measurement
5. Performance: achievable recognition accuracy, resources required, operating environment
6. Acceptability: degree of approval of a technology.

1.3 Selection of best combination of biometric traits

Many biometric traits are available for authentication but there is a need to choose the best combination of traits hence comparison of different biometric traits with the biometric parameters are to be done in order to choose the best suitable technology [2] which gives the high authentication rate, a comparison of popular biometrics is shown in below table 1.

Table 1. Comparison of parameters for different biometric technologies

Bio-Metrics	**Universality**	**Uniqueness**	**Permanence**	**Collectability**	**Performance**	**Acceptability**
Face	High	Low	Medium	High	Low	High
Finger Print	Medium	High	High	Medium	High	Medium
Hand	Medium	Medium	Medium	High	Medium	Medium
Iris	High	High	High	Low	Low	Low
Signature	Low	Low	Low	High	Low	High
Voice	Medium	Low	Low	Medium	Low	High
Vein	High	Medium	Medium	Medium	High	Medium

By referring the above table, one can conclude that the combination of fingerprint and finger vein traits will leads to best performance of the recognition system. Finger print is an important biometric trait for personal identification. The metric used for performance of identification techniques are directly scanned finger prints or inked impression of finger prints. Finger prints is a protected internal organ whose random texture is stable throughout life, it can serve as a kind of living password that one need not remember but one always carries along. Finger vein recognition is one of many forms of biometrics used to identify individuals and verify their identity. Blood vessel patterns are unique to each individual, as are other biometric data such as fingerprints or the patterns of the iris. Unlike some biometric systems, blood vessel patterns are almost impossible to counterfeit because they are located beneath the skin's surface [1]. The anatomy of human fingers is quite complicated and largely responsible for the individuality of fingerprints and finger veins. The high individuality of fingerprints has been attributed to the random imperfections in the friction ridges and valleys which are commonly referred to as minutiae fingerprint features. The conventional fingerprint features, which illustrate macro finger details such as ridge flow and pattern type, can be extracted from the low resolution fingerprint images. The utility of such features, which can be more conveniently captured from the low resolution (webcam) images, multimodal biometric system deserves attention for its possible usage in personal identification for civilian or forensic applications.

II. DESIGN OF THE PROPOSED SYSTEM

In this paper an alternate novel method of finger vein and finger texture recognition system has been implemented. The proposed system has taken more advantages than the existing system in terms of security purpose, since the vein pattern is not visible to human vision without any special device and it will not produce any trace in any object. Hence got more benefits than the normal finger vein pattern system.

2.1 Proposed method

A new approach for personal identification that utilizes simultaneously acquired finger-vein and finger surface (texture) images are presented. Our experimental results illustrate significantly improved performance over previously proposed approaches. The finger-vein identification approach utilizes peg-free and more user-friendly unconstrained imaging by normalization, rotational alignment, and segmentation to effectively minimize resulting intraclass variations.

2.2 Block diagram

The block diagram of the proposed system is shown in figure 2. The finger presented for the identification of subjects are simultaneously exposed to webcam and infrared camera. The finger vein and finger texture images are simultaneously acquired using the switching device/hardware that can switch the infrared illumination at a fast pace. The near infrared illumination incident on the finger dorsal surface is absorbed by the branches of arteries, veins and haemoglobin in the blood. The acquired finger vein and finger texture images are firstly subjected to pre-processing steps which automatically extract the region of interest (ROI) images while minimizing the translational and rotational variations. The enhanced and normalized ROI images are employed to extract features and then generate matching scores like conventional biometrics system. The combined matching scores are employed to authenticate the user.

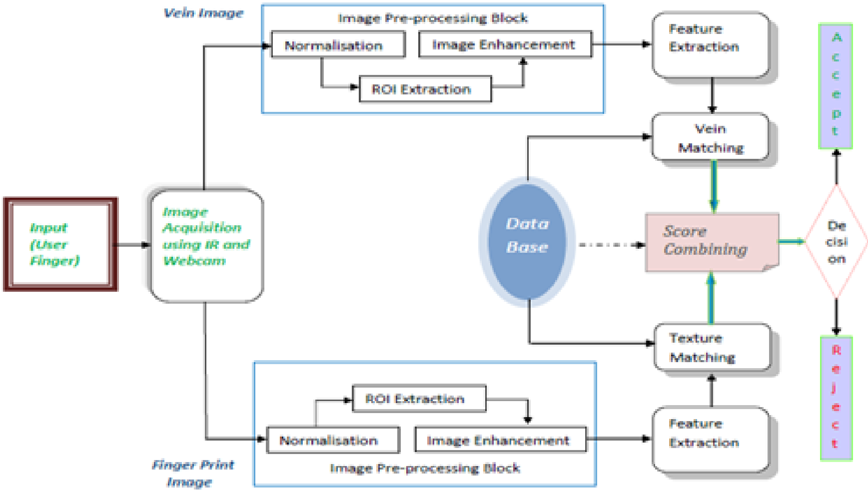


Fig 2. Block diagram for multimodal biometric authentication combining finger print and finger vein.

III. WORKING

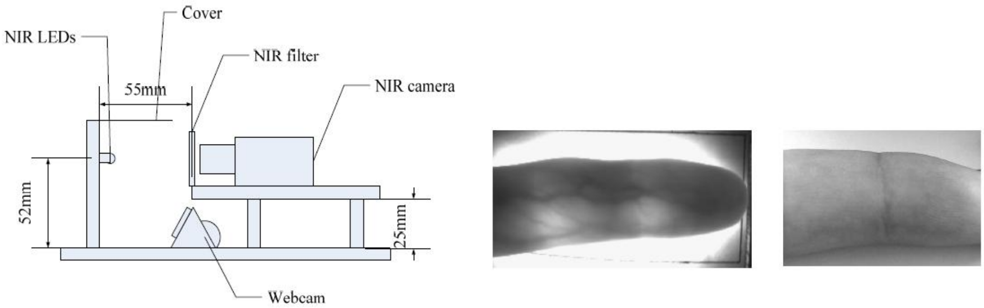
The working consists of two phases, i.e. enrollment phase and verification phases [2].

3.1 Enrollment phase

Enrollment phase covers the section of image acquisition, pre-processing and extraction of the image features, the extracted features will be given to the verification phase. Below sections explains the working of enrollment phase.

3.1.1 Image acquisition

The fingers presented for the identification of subjects are simultaneously exposed to webcam and infrared camera device [1] [7] as illustrated in figure 3. The dorsal side of finger is exposed to the near infrared frontal surface illuminators, using light emitting diodes whose illumination peaks at 850 nm wavelength, while the frontal surface entirely remains in the contactless position with both of the imaging cameras. Although our imaging system is unconstrained, i.e., it does not use any pegs or finger docking frame, it may not be designated as completely touch less. This is because the user often partially or fully touches the finger dorsal surface with the white diffusion background which holds the infrared illuminators beneath. The captured finger vein and finger print images are processed separately.



(a) **(b)**

Fig 3.(a) Unconstrained finger identification using near infrared camera and webcam imaging; (b) simultaneously acquired image samples from the imaging device.

3.1.2 Image pre-processing

i. Finger vein pre-processing

The captured finger vein images are noisy with rotational and translational variations. To remove these variations, it is subjected to pre-processing steps, which includes: Binarization, ROI extractor, image enhancement.

➢ **Image binarization**

The captured vein image will be resized to standard range i.e. [120* 180] pixels by applying image expansion or compression method according to the captured image size. In order to reduce the computational complexity, the resized RGB (coloured) image will be converted to gray scale image. Each of the acquired (gray scale) finger vein images is firstly subjected to binarization, using a fixed threshold value as 230, to coarsely localize the finger shape in the images [1]. Some portions of the background still appear as connected to the bright finger regions, predominantly due to uneven illumination. The isolated and loosely connected regions in the binarized images are eliminated in two steps: firstly, the Sobel edge detector is applied to entire image and the resulting edge map is subtracted from the binarized image.

➢ **ROI extractor**

In the finger images, there are many unwanted regions (that cannot be taken for analysis) has been removed by choosing the interested area in that image. The useful area is said to be "Region of Interest". Subsequently, the isolated blobs (if any) in the resulting images are eliminated from the area thresholding, i.e., eliminating number of connected white pixels being less than a threshold [1] [3]. The resulting binary mask is used to segment region of interest from the original finger vein image. Figure 4 shows the key steps applied for pre-processing and figure 5 shows the image samples from pre-processing steps that automatically ensures reliable segmentation of region of interest. The orientation of the image is determined to remove the low quality images that present in finger vein image.

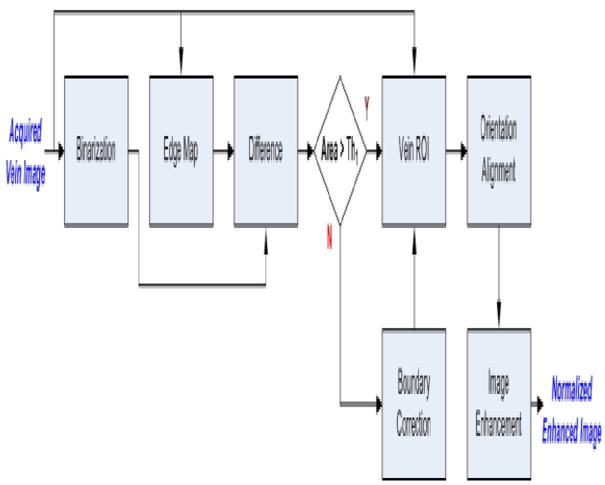


Fig 4. Pre-processing block diagram.

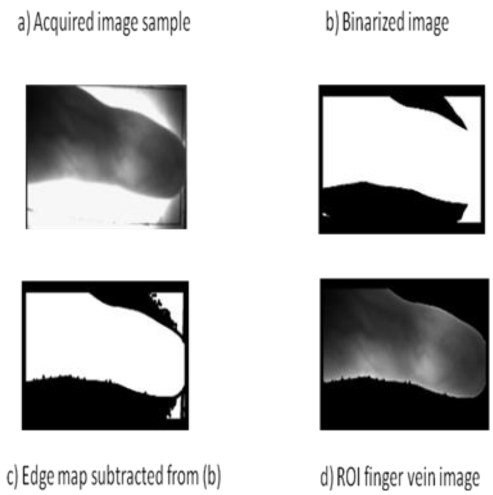


Fig 5. Extraction of ROI from veimages.

➢ **Finger vein image enhancement**

Image enhancement operation improves the quality of the image and it can be used to improve the image contrast and brightness characteristics, reduce its noise content, and/or sharpen its details [6] [7]. Image enhancement techniques may be grouped as either subjective enhancement or objective enhancement. Subjective enhancement technique may be repeatedly applied in various forms until the observer feels that the image yields the details necessary for particular application. Objective image enhancement corrects an image for known degradations. Here distortions are known and enhancement is not applied arbitrarily. This enhancement is not repeatedly applied but applied once based on the measurements taken from the system. Image enhancement falls into two broad categories: Spatial domain technique and Frequency domain technique. Spatial domain refers to the image plane itself, where approaches in this category are based on direct manipulation of pixels in an image. Also, spatial domain refers to the aggregate of pixels composing an image. They operate directly on these pixels. Frequency domain processing techniques are based on modifying the Fourier transform of an image.

The finger vein details in the acquired images, especially the thin ones, are not very clear. This can be attributed to the uneven illumination and imperfect placement of finger during the imaging. Therefore the vein images with low contrast and uneven illumination are subjected to nonlinear image enhancement. The acquired images are firstly divide into overlapping 30*30 pixels sub blocks and average gray level in each of the blocks is computed. This average gray level is then used to construct average background image using bicubic interpolation. The segmented finger vein images also include automatically filled background area that does not have any useful details and thus direct partitioning of image into sub blocks results in the biased estimation of background illumination. Therefore, the average gray level of each sub blocks is computed as follows:

$$IB = \{ [(\sum V(x,y) \in B \; B(x,y)) / \| M \|], \; \|M\| > 0\} \text{ and}$$
$$\{ 0, \text{ otherwise}\}$$
$$M = \{ (V(x,y) \in B, B(x,y)) \neq Ibg \} \quad \ldots\ldots \quad (1)$$

where B is the image sub block, M is the sub set of B that contains all the foreground pixels, i.e. those pixels whose values are not equal to the filled/fixed background pixel value, Ibg represents the background pixel intensity values while || || represents the cardinality operator that yields number of elements inside. The resulting image is then subjected to the local histogram equalization to obtain the final enhanced vein image.

ii. Finger print pre-processing

The acquired finger texture images from the webcam (640 × 480 pixels) are firstly automatically reduced to 580 × 380 pixels gray level images since the cropped part does not provide any useful finger details. This reduced size gray level image is employed for the pre - processing as shown in below figure.

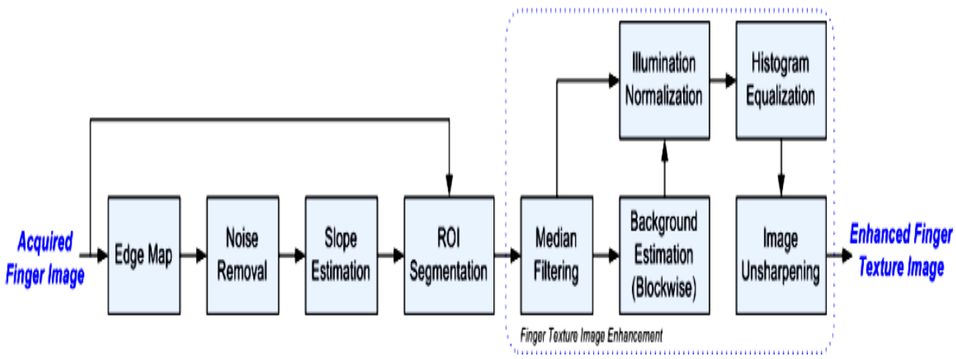


Fig 6. Block diagram illustrating key steps employed for the pre-processing of acquired finger-print images.

➢ **Localization and normalization**

In texture pre-processing, the captured image from web camera is given to edge map block, where Sobel edge detector is used to obtain the edge map and localize the finger boundaries [1] [2]. This edge map is isolated with noise and it can be removed from the area threshold, i.e., if the number of consecutive connected pixels is less than the threshold value, resulting images are shown in figure 7. The slope of the resulting upper finger boundary is then estimated. This slope is used to automatically localize a fixed rectangular area, which begins at a distance of 20 pixels from the upper finger boundary and is aligned along its estimated slope. We extract a fixed 400* 160 pixel area, at a distance of 85 and 50 pixels, respectively, from the lower and right boundaries, from this rectangular region. This 400*160 pixel image is then used as the finger texture image for the identification.

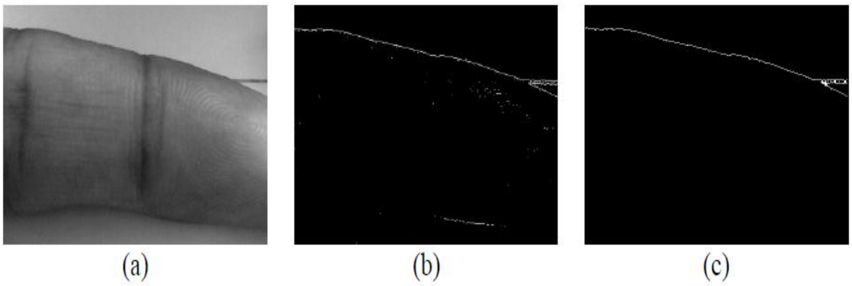


Fig 7 Localisation of finger texture regions; a) The original captured image, b) edge map image, and c) image after area of thresholding.

➢ **ROI segmentation**

In general, only a Region of Interest (ROI) is useful to be recognized for each fingerprint image. The image area without effective ridges and furrows is first discarded since it only holds background information. Then the boundary of the remaining effective area is sketched out since the minutia in the boundary region is confusing with that spurious minutia that is generated when the ridges are out of the sensor. To extract the ROI, a two-step method is used. The first step is block direction estimation and direction variety check, while the second is intrigued from some Morphological methods.

i. Block direction estimation

The direction for each block of the fingerprint image with W x W in size (W is 16 pixels by default) is estimated. The algorithm steps are [10]:

1. The gradient values along x-direction (gx) and y-direction (gy) for each pixel of the block is calculated. Two Sobel filters are used to fulfil the task.
2. For each block, following formula is used to get the Least Square approximation of the block direction for all the pixels in each block.

$$tg2\beta = 2 \sum\sum (g_x * g_y) / \sum\sum (g_x^2 - g_y^2)$$

3. The formula is easy to understand by regarding gradient values along x-direction and y-direction as cosine value and sine value. So the tangent value of the block direction is estimated nearly the same as the way illustrated by the following formula.

$$tg2\theta = 2\sin\theta \cos\theta / (\cos^2\theta - \sin^2\theta)$$

4. After the estimation of each block direction, those blocks without significant information on ridges and furrows are discarded based on the following formulas:

$$E = \{2 \sum\sum (g_x * g_y) + \sum\sum (g_x^2 - g_y^2)\} / W * W * \sum\sum (g_x^2 + g_y^2)$$

5. For each block, if its certainty level E is below a threshold, then the block is regarded as a background block.

ii. ROI extraction by morphological operations

Two Morphological operations called 'OPEN' and 'CLOSE' are adopted. The 'OPEN' operation can expand images and remove peaks introduced by background noise . The 'CLOSE' operation can shrink images and eliminate small cavities. The bound is the subtraction of the closed area from the opened area. Then the algorithm throws away those leftmost, rightmost, uppermost and bottommost blocks out of the bound so as to get the tightly bounded region just containing the bound and inner area.

➢ **Finger print image enhancement**

The finger texture is firstly subjected to median filtering to eliminate the impulsive noise often present in the webcam acquired image. The resulting images have low contrast and uneven illumination. Therefore we firstly obtain the background illumination image from the average of pixels in 10 × 10 pixel image subblocks and bicubic interpolation. The resulting image is subtracted from the median-filtered finger texture image and then subjected to histogram equalization. The image enhancement scheme improves the amount of contrast and the effect of uneven illumination [1] [7] [8]. However, they are not adequate to extract finger texture details.

Therefore the resulting image is subjected to unsharpening, i.e., subtracting a Gaussian ($\sigma = 5$, $\mu = 16$) filtered image from the original image and then adding resulting image to the original image . It can be observed from the sample result in figure 8 that unsharpening has been quite successful in further improving the image contrast and texture details.

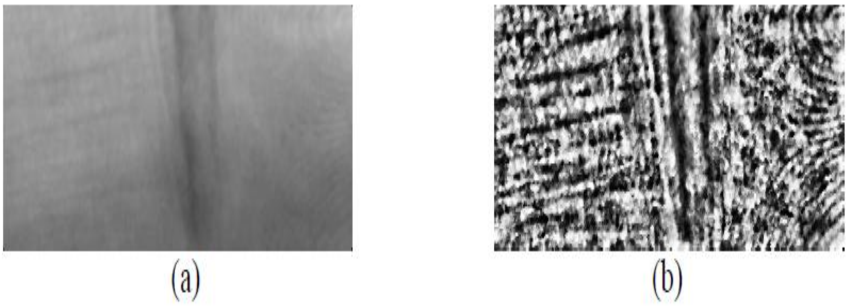


Fig 8. (a) Median filtered finger texture image, and b) the enhanced finger texture image using unsharpening.

3.1.3 Feature extraction

Many features will be extracted from each print. The co-ordinates of each minutia and the type of the minutiae can be determined. The number of total minutiae is also recorded. A fingerprint can have up to 80 minutiae. It is generally accepted as the same Print if 8 to 17 points match. Some translation of the fingerprint will be acceptable, however rotation must be minimized since no techniques have been implemented which specifically counteracts rotation.

- **Finger vein feature extraction**

In this paper a new approach is employed for the finger vein feature extraction using Gabor filters. In addition to that, we also investigate a new feature extraction approach using matched filters, as the matched filters have been successfully utilized for the enhancement of retinal features. Following are the list of approaches employed in this project for feature extraction.

i. Gabor filters for feature extraction

The spatial modulation frequency ωm is a one direction and we use the Gabor filters to detect width and length. The coordinate transformation is used to obtain self-similar even Gabor filters for different orientations. The angle rotates the Gabor filter for the desired orientation. The power spectrum sampling of each of the finger vein images using a set of self-similar even Gabor filters is performed [1] [3]. The filters are obtained by the rotation of even Gabor filter in Ω intervals. The computational complexity of this method is only a linear factor Ω times the complexity of convolution. The noise of the image will be suppressed.

ii. Morphological operations and feature encoding

The venous patterns in the combined output image are subjected to morphological operations to further enhance the clarity of vein patterns. The morphological operations are of low computational complexity and compare a vein image with another known object. The shape and size of this structuring element is chosen from the prior knowledge for the purpose of object detection and noise elimination [5] [7]. The thin veins patterns are enhanced after top-hat operation, unnoticeable part from the original extracted image are also enhanced. The method accentuates on the structural information of the vein, since all the extracted veins/lines are of nearly the same width after applying the top-hat transformation, encode the phase information. The feature map will be generated and employed to generate the matching scores.

iii. Matched filters

A matched filter is to explore a group of 1-D Gaussian functions to match finger vein of cross section profiles [5]. The Gaussian functions are rotated in different orientations and only the maximum response is utilized.

➢ **Fingerprint feature extraction**

The Localized Radon Transform (LRT) and Gabor Filter based Orientations Encoding technique are used for fingerprint feature extraction. The extraction of localized fingerprint texture orientation offer results for the identification of finger knuckles and palm prints.

i. Localized radon transform

The Radon Transform is used in detecting and locating lines in the image by integrating the intensity of the image in all orientations. The LRT [1] [3] is efficient in extracting line and curve segments in the local area. The curved lines can be estimated by small piecewise line segments and it integrates the intensity value in a local region, but instead of integrating all pixel values inside the local region, only the pixels that fall into confined line width area is integrated, and the orientation gives the maximum integration value and it is selected as the dominant direction.

ii. Gabor filter based orientations encoding

This approach uses a set of Gabor filters to comparatively ascertain the fingerprint texture orientation. The orientation of filter which generates the maximum response is encoded using direction index. This approach is also referred to as Comp Code approach.

3.2 Verification phase

Verification phase covers the section of comparison and decision making [3] [4]. In this phase accessor and stored images are compared and decision is done based on score level combination, whether accessor is authenticated or not.

3.2.1 Finger vein and texture matching

The fingerprint and vein features extracted are encoded as orientations (or index of directions) [6] [8]. The Hamming distance is utilized for generating matching scores between the two features vectors/map. Vein matching, also called vascular technology, is a technique of biometric identification through the analysis of the patterns of blood vessels visible from the surface of the skin. Though used by the Federal Bureau of Investigation and the Central Intelligence Agency [4], this method of identification is still in development and has not yet been universally adopted by crime labs as it is not considered as reliable as more established techniques, such as fingerprinting. The general block diagram for matching is given below

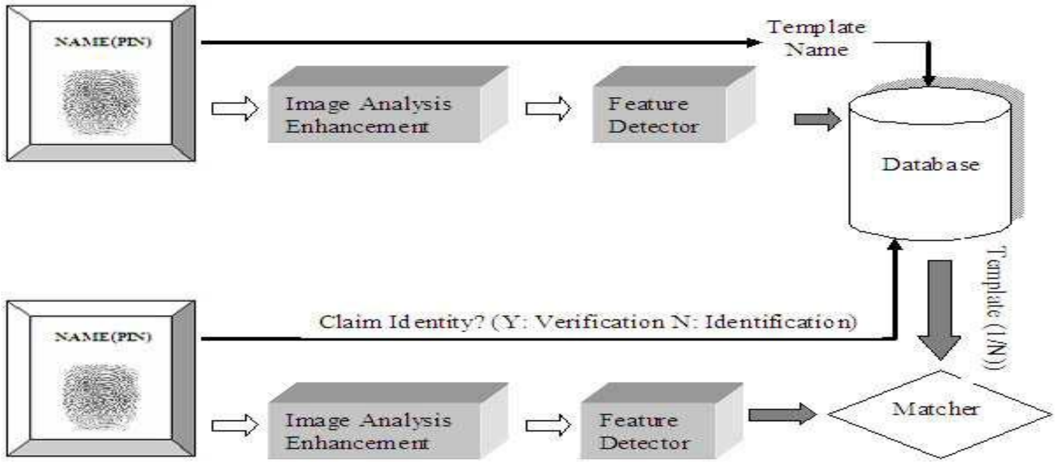


Fig 9. Block diagram for matching

In that, the matcher block predicts that the vein and texture image is matched with the database [11]. The database contains the features of all vein and texture images. For matching, two steps has been done (a) Extracting features and (b) Matching features.

➢ **Vein matching**

The features extracted from finger vein images are already stored in a database [11]. The features of the input image are matched with all the extracted veins in the database to check whether the input image is matched with any one of the extracted veins.

1. If the input image is matched with any one of the extracted veins, the message box will be opened and display "vein matched" [10] [11].
2. If the input image is not matched with any one of the extracted veins, the message box will be opened and display "vein not matched" [10] [11].

   Similar way texture matching also done.

3.2.2 Score combination

The main motto in this method is to effectively integrate the observations from the simultaneously acquired fingerprint and finger vein images. The combination strategy developed should be robust and achieve better performance [6]. The multiple observations can be combined at feature, score, and at decision level. In this paper, the score level combination employed and it is expected to achieve better results than decision level combination, as the decision level strategy often suffers from the loss of information. Next, the score level combination allows each of the observation to operate which is not possible in feature level combinations. [1] [7] Score level combination has therefore emerged as the most popular level of combination and several strategies have been explored in the literature. The two new score level combination approaches are employed first time for authentication, i.e., holistic fusion and nonlinear fusion.

➢ **Holistic fusion**

This approach is developed and investigated to utilize the prior knowledge in the dynamic combination of matching scores [1] [4]. Let s_v , s_t and $\hat{s}$ represent the matching score from finger vein, finger texture and combined score respectively, and this holistic rule of score combination is illustrated as following:

$$\hat{s} = \{(s_v * \eta) + (s_t * (1 - \eta))\} + \frac{\{(s_v * \eta) + (s_t * (1 - \eta))\}}{(2 - s_v)} \quad ..... \quad (2)$$

The above equation can also be written as,

$$\hat{s} = \{(s_v * \eta) + ((s_t * (1 - \eta))\} * (1 + \frac{1}{2 - s_v}) \quad ..... \quad (3)$$

By using this equation, the final combined score have similar trend as the score from vein matching, i.e. when the score from finger vein matching is high the fused score will also become high and vice versa. The factor η is selected to reflect the reliability of each modality or matching score. We choose the matching score from finger vein as the controlling factor since the performance of finger vein matching is more stable as compared to that of the texture.

➢ **Nonlinear fusion**

The nonlinear score combination attempts to dynamically adjust the combined score according to the degrees of consistency between the two matching scores [1] [4], and is illustrated by using following equation

$$\hat{s} = \left(\frac{c + s_t}{c + s_v}\right)^{\Upsilon} * (c + s_v)^2 \quad ..... \quad (4)$$

where c is a positive constant and by conventionally fixed to 1, Υ is selected in the range of [1,2]. As the equation suggests, when the two matching scores are consistent the final combined score is primarily contributed by the vein matching score. On the contrary, while these two are inconsistent the final score is contributed by the modulated joint probability (product) of two scores. This combination scheme, intending to involve information both from vein and texture as well as consider potential variation between their matching scores. Firstly, in most circumstances it is expected that the two scores are more or less consistent, and since the finger vein matching is more stable we incline to treat this score as the combined score.

The information will not be ignored from the texture matching score when they are consistent, however, since the first item of the equation will become greater than one when the texture matching score is a little larger and thus the final score will be even larger and vice versa. In other words, when the two scores are consistent we use the score from texture to fine tune the final matching score. Secondly, based on our prior knowledge, it is likely that the two matching scores will be inconsistent (with large difference) if one of the finger texture or vein imaging is not proper, and thus the final score is mainly determined by the one that have higher similarity score. A positive constant c is to ensure that the system is still able to make correct decisions when one of the observation/modal fails (e.g. no vein is extracted from the finger vein image/ modal).

IV. FLOW CHART

Flow chart of the proposed algorithm is shown in below figure.

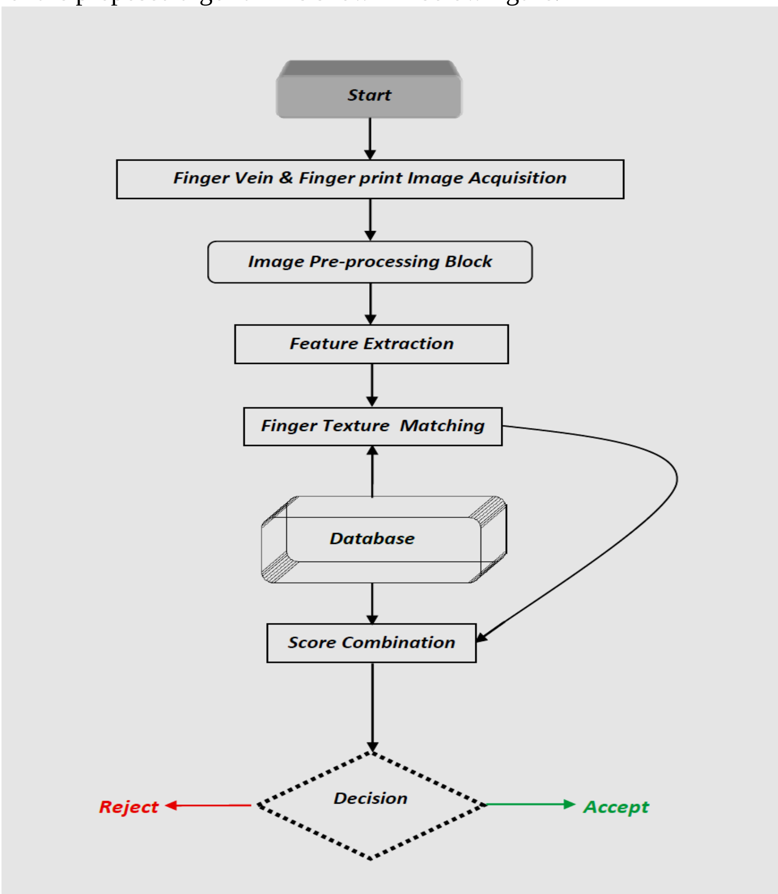


Fig 10. Flow Chart

V. RESULT

Mat lab output screen shots of the proposed scheme are shown in below figures.

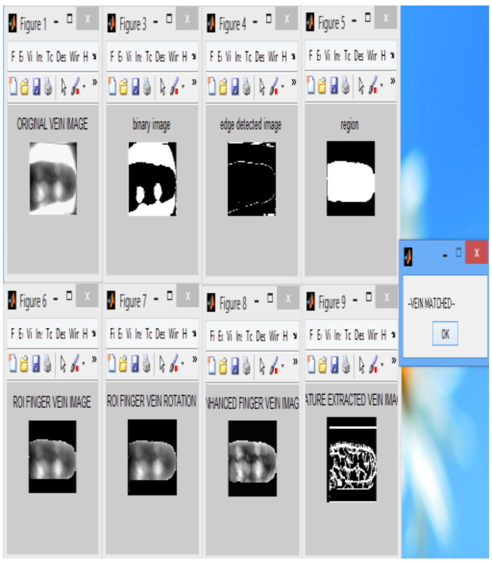


Fig 11. Vein matched output

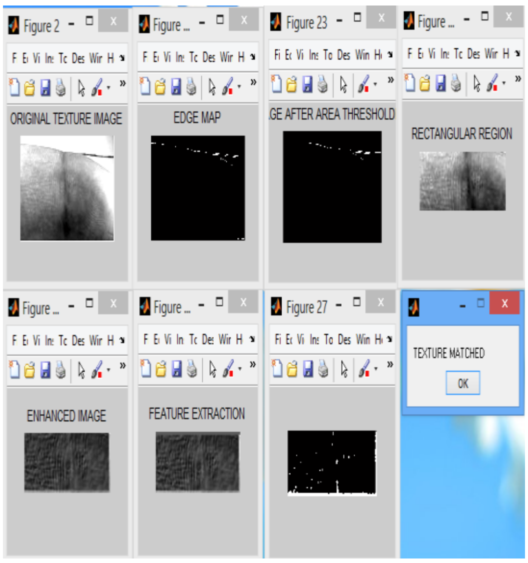


Fig 12. Texture matched output

Below figure shows the command window of Mat lab, where the Holistic fusion matching score is 98.78% and Nonlinear fusion method score is 98.27. By using both the fusion techniques, we can achieve high authentication rate hence system will be more secure and reduces the attacks.

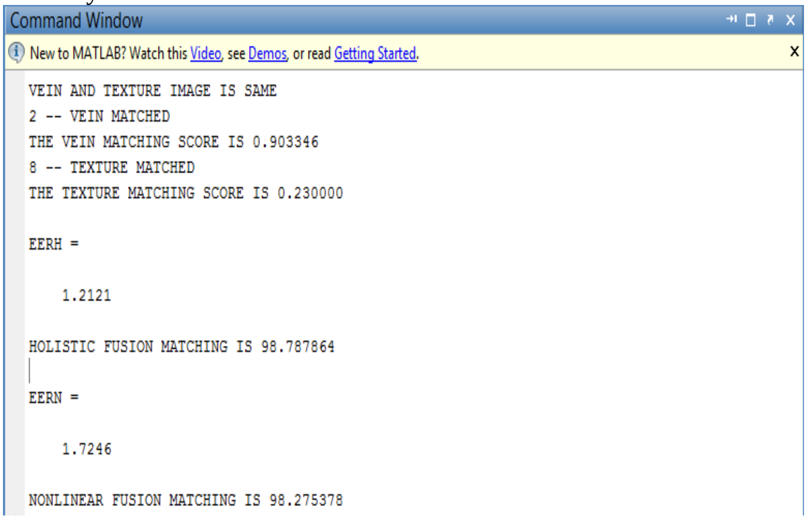


Fig 13. Score combination result

VI. ADVANTAGES

- Increase security – provide a convenient and low-cost additional tier of security.
- Reduce fraud by employing hard-to-forget technologies and materials. For e.g. minimize the opportunity for ID fraud, buddy punching.
- Eliminate problems caused by lost IDs or forgotten passwords by using physiological attributes. For e.g. prevent unauthorized use of lost, stolen or borrowed ID cards.
- Reduce password administration costs.
- Replace hard-to-remember passwords which may be shared or observed.
- Integrate a wide range of biometric solutions and technologies, customer applications and databases into a robust and scalable control solution for facility and network access.
- Make it possible, automatically, to know WHO did WHAT, WHERE, and, WHEN.
- Offer significant cost savings or increasing ROI in areas such as Loss Prevention or Time and attendance.

VII. APPLICATIONS

Multimodal biometric authentication combining finger print and finger vein recognition technology has some fundamental advantages over fingerprint systems. Vein patterns in finger are biometric characteristics that are not left behind unintentionally in everyday activities. IBG expects it to play a larger role and comprise more than 10% of the biometric market. Nearly all major multimodal authentications are manufactured in Japan and Korea, and the application of these manufactures are used in Asia. In Japan and some other countries, such products spread particularly in the financial sector.

1. Financial services (e.g., ATMs).
2. Immigration and border control (e.g., points of entry, pre cleared frequent travellers, passport and visa issuance, and asylum cases).
3. Social services (e.g., fraud prevention in entitlement programs).
4. Health care (e.g., security measure for privacy of medical records).
5. Physical access control (e.g., institutional, government, and residential).
6. Time and attendance (e.g., replacement of time punch card).
7. Computer security (e.g., personal computer access, network access, Internet use, e-commerce, e-mail, encryption).
8. Telecommunications (e.g., mobile phones, call centre technology, phone cards, televised shopping).
9. Law enforcement (e.g., criminal investigation, national ID, driver's license, correctional institutions/prisons, home confinement, smart gun).

VIII. CONCLUSIONS AND FUTURE WORK

In this paper, a complete and fully automated finger image matching framework is developed by simultaneously utilizing the finger surface and finger subsurface features, i.e., from finger texture and finger vein images. A new algorithm is proposed for the finger vein identification which can more reliably extract the finger vein shape features and achieve much higher accuracy than previously proposed finger vein identification approaches. The finger vein matching scheme works more effectively in a more realistic scenarios and leads to more accurate performance.

Two new score level combination approaches nonlinear and Holistic, for effectively combining simultaneously generated finger vein and finger texture matching scores. The nonlinear approach consistently performed better than other promising approaches, i.e., average, product, weighted sum and likelihood ratio approaches are considered in this work.

Further improvement in the performance from the proposed approaches using feature discretization and image quality measurements is expected, and is suggested for the further work on the large scale finger image databases.

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