A Simple and Efficient Roadmap to Process Fingerprint Images in Frequency Domain

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ABSTRACT

In the field of computer vision, image enhancement is one of the most important and critical stage, which eventually or indirectly decides the final results in the boolean form, as far as image recognition or comparison is concern, fingerprint recognition system is also the part of computer vision and considered as one of the most matured and accepted biometric system, which implies the matching of fingerprint impression with template data. The normal issue which arise in the making such systems is the noise in input fingerprint image which actually depends upon the devices i.e. used to capture fingerprint image. In this paper we demonstrate the techniques for fingerprint image enhancement in frequency domain, after getting back in spatial (time) domain, we exact the ROI from the output image of frequency domain using least square approximation method and finally we extract minutiae from fingerprint image using cross number (CN) [5] and compare with template data in post-processing stage. The demonstration has been made under the MATLAB's background and the experiments conducted on FVC 2002 fingerprint dataset of University of Bologna [1]

General Terms

Fingerprint Recognition, Data Extraction, Security, Minutiae Extraction, Cross Number

Keywords

Minutiae extraction, Fingerprint recognition, Minutiae matching, False Minutiae, Least square estimation, Fourier transformation

1. INTRODUCTION

Biometrics is the most generally utilized enclave which makes a difference in distinguishing an individual by means of his behavioural and physiological properties. *Behavioural* biometric characteristics are refers to the pattern of the behaviour of a person in activities they perform, either consciously or unconsciously, it includes walking style, hand geometric, speech, typing, blinking pattern, game strategy [11][12] and many more, but there exist a common problem, they are change according to the person's age, on the other hand, *Physiological* characteristics refers to the shape of the body like fingerprints, palm-print, face, DNA, iris, and retina these features do not change throughout the lifetime of individual person.

Factually, fingerprints have been integrated and allied with criminology from a long time, particularly crime scene investigation or forensic evidence, So, it generally gets more privilege then other physiological characteristics as far as feasibility, reliability, accuracy and acceptability is concern, because in other physiological characteristics there are some bottle necks which are actually difficult to avoid, like two persons can have the same face and retina or iris recognition systems are actually expensive.

A fingerprint is composed of many ridges and valley present on the surface of human finger [5], however fingerprint are distinguished by their ridges rather than valley, earlier is was considered that "ridges and valleys in the fingerprint have a similar width and are equally spaced" [5], so both can be consider for recognition process, but it was not true for various finger impressions taken from different sensors as shown in Fig 1.

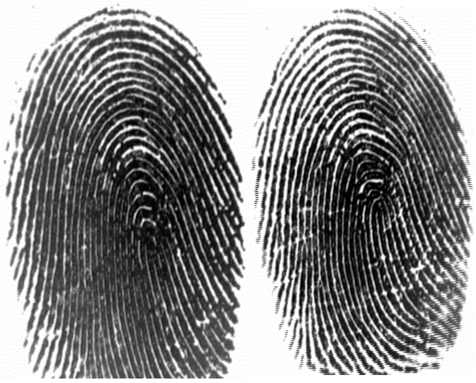

Fig 1: Two different impressions of same finger with ridge's width > valley's (Courtesy: FVC 2002 DB1[1])

Since ridges are more prominent in every fingerprint image, that's way, the rate of information loss is always on positive side and also that's the reason, that mostly FRS (Fingerprint Recognition System), recognize fingerprints via ridges instead of valley.

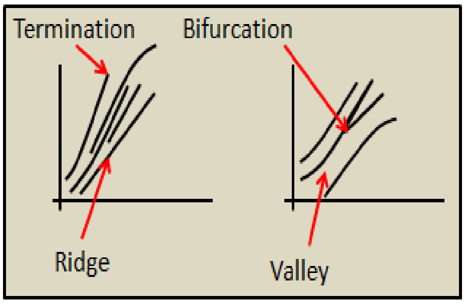

Fig 2: Fingerprint General Pattern

Ridges contains some abnormal points called *Minutiae* which are actually used to identify the actual person because there pattern vary from person to person, no two persons can have same the set of minutiae points, even they are twins, Normally there are two types of minutiae, *ridge endings* (immediate ending of a ridge) and *ridge bifurcations* (point on the ridge from which two branches derive) which are use in the identification process, these constitute pattern are shown in Fig 2.

This paper illustrate and describe each and every stage of image processing which are actually use in fingerprint recognition process, but our main focus is on pre-processing stage because the better the results of pre-processing, the better the impact on mid and post-processing stages, Fig 3 describes the complete flow our FRS system and Fig 4 describes its three stage approach.

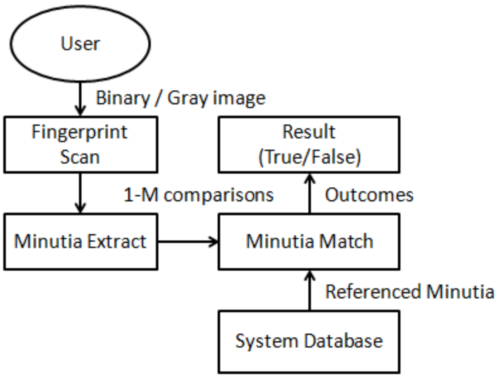

Fig 3: Fingerprint Recognition System

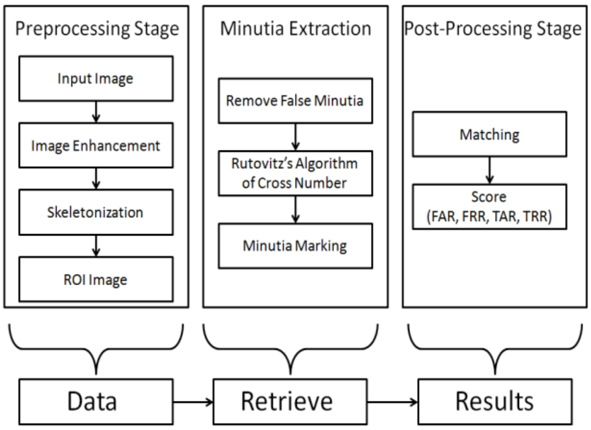

Fig 4: Three-stage approach for fingerprint recognition

2. PRE-PROCESSING STAGE

Pre-processing stage in image processing is one of the most critical stage because the final results of post processing stage are entirely depends on this stage and the reason is quite obvious, because the image that user want to recognize may contains noise or the medium from which it taken, may not gave appropriate or standard quality image. In fingerprint recognition the most important step is accurately extricating finer points from the query finger impression, that which doesn't matters from which channel it was taken or how much noise variation are present, system must process each on every image and show results accurately. In order to make standardized image, some enhancement techniques are applied, so that the system shall provide best possible results in latter stages. Fig 5 show the complete flow that will used to parse input fingerprint image in order to make it standardized image.

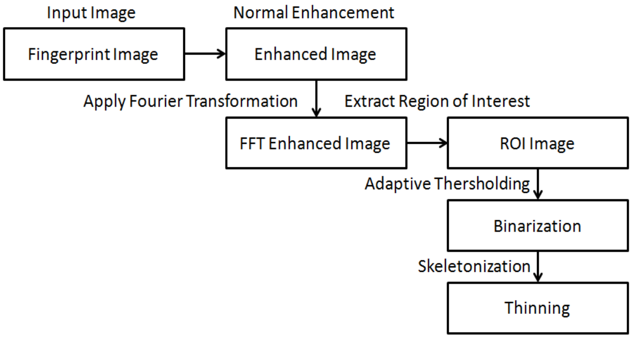

Fig 5: Pre-processing Stage of Fingerprint Recognition.

2.1 Fingerprint Image Enhancement

Since the input image may receive from different medium i.e. touch pad, sensors e.t.c. which are sometimes not guaranteed as far as image quality is concern, so image enhancement is necessity, in order to make it clear for further operations. Enhancement techniques are basically for providing increment in the contrast between ridges and valley which is quite useful for keeping a higher accuracy to fingerprint recognition.

Following are the two techniques/method are adopted in our fingerprint recognition system

1. Histogram Equalization
2. Fast Fourier Transform (FFT)

2.1.1 Histogram Equalization

There are several techniques to enhance fingerprint image in pre-processing stage but only Histogram Equalization provides much better results than other as shown in Fig: , the obvious reason behind this is the strategy typically builds the overall divergence of pictures, particularly when the usable information of the picture is depict by close divergence values. Through this modification, the intensities can be better appropriated on the histogram which permits the territories of lower neighbourhood divergence to increase a higher divergence.

This performs by adequately spread out the most incessant intensity values as shown in Fig 7, however from Fig 6, It is clear to judge that there is no any significant change in original image and image processing via "Local Histogram Equalization" or "Contrast stretching"

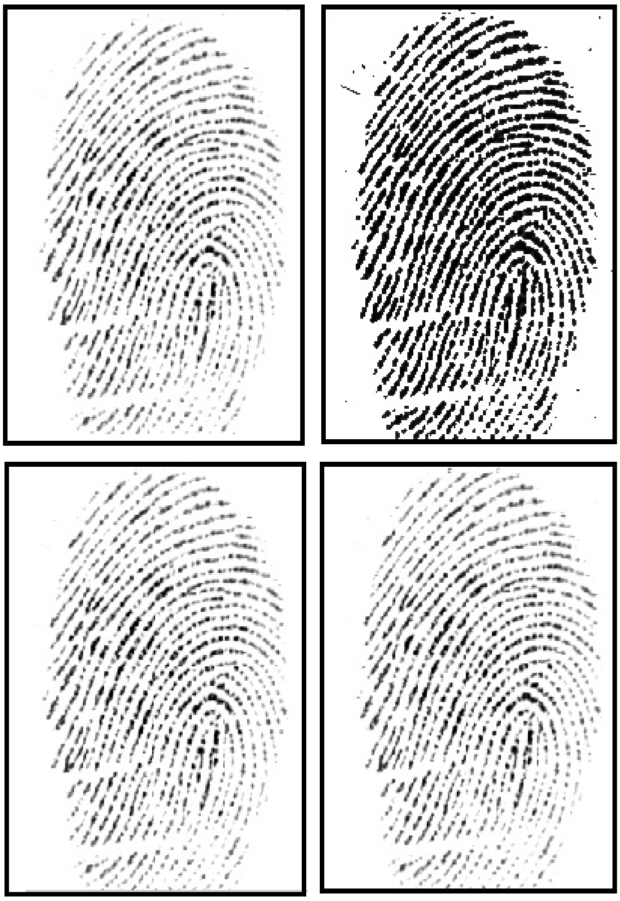

Fig 6: Image Enhancement (a) Original Image. (b) Result of histogram equalization. (c) Result of local histogram equalization. (d) Result of contrast stretching.

Whereas, enhancement via histogram equalization will provide approximate full span histogram.

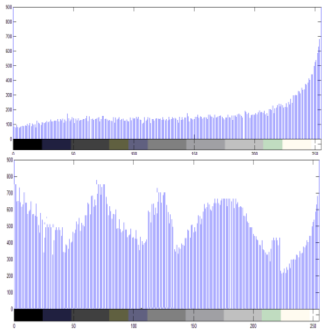

Fig 7: Histogram of input fingerprint image. b): After applying histogram equalization technique on input image.

2.1.2 *FFT Enhancement*

In this step picture is partitioned into little transforming obstructs (32 by 32 pixels) and perform the Fourier change as indicated by:

$$F(u,v) = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y) * \exp\left\{-j2\pi * \langle\frac{ux}{M} + \frac{vy}{N}\rangle\right\}$$

For $u = 0,1,2...31$ and $v = 0,1,2...31$

Where,

$F(u,v)$: is the image getting from frequency domain,

$f(x,y)$: is the image in time domain

$H(x,y)$: is enhancement mask.

$$H(x,y) = \text{abs}\left(F(x,y)\right)^{K}$$

"k in formula is an experimentally determined constant, which is $k = 0.45$ [2]. While having a higher k improves the appearance of the ridges, filling up small holes in ridges, but having too much increment in k can result in false joining of ridges, thus a termination might become a bifurcation" [2].

From our elementary knowledge, in time domain the convolution of two functions is the product of two functions in frequency domain

$$G(x,y) = H(x,y) * F(u,v)$$

Where "G" is the enhanced version of "F" in frequency domain, In order to get your image back in "Time domain",

$$f(x,y) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} F(u,v) * \exp\left\{j2\pi * \left(\frac{ux}{M} + \frac{vy}{N}\right)\right\}$$

For, $x = 0,1,2,\ldots,31$ and $y = 0,1,2,\ldots,31$

But the image that comes from above equation after processing i.e. "FFTEnhanceImg $= f(x,y)$" contains exponential terms in pixels, so there must be, some sort of threshold level in order to avoid them:

- Find the Max(G)
- If Max(G)=0, then replace Max(G)=1;
- FFTEnhanceImg = FFTEnhanceImg / Max(G)

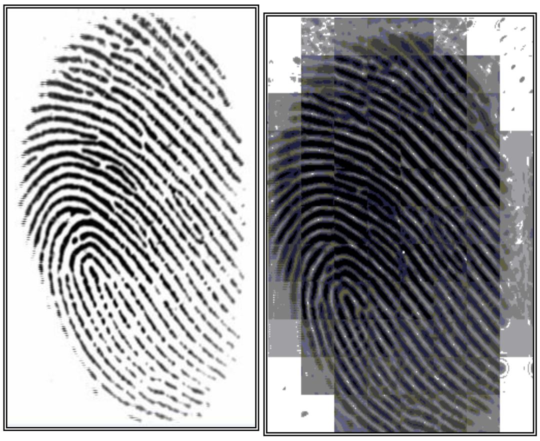

Fig 8: After applying FFT Enhancement technique.

The inflate picture after FFT has upgrades to interface and hitch some erroneously broken focuses on edges and evacuate some spurious associations between edges as appeared Fig 9a.

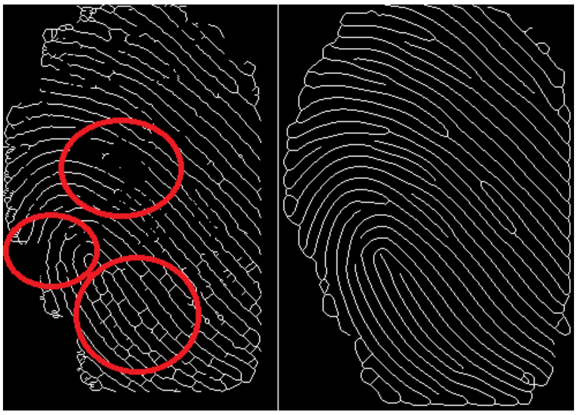

Fig 9: Skeleton Images. (a) Before FFT enhancement. (b) After using "FFT" enhancement.

2.2 Fingerprint Image Binarization

In order to segment ridges and valley from the input fingerprint image, normally 8-bit gray image transform to a 1-bit (binary) image, which consists of matrix with values 0(black) and 1(white) that represents valley and ridges respectively.

Algorithm 1: Fingerprint image binarization

```
FPImageBinarize(Input Image)
{
-   Apply binarization on 16x16 window block in image i.e.
    "Block"
-   ThresholdValue=0.5* mean(Block)
-   If(Block(i, j)<ThresholdValue),
        o   Block(i, j)=0
-   Otherwise
        o   Block(I,j)=1
}
```

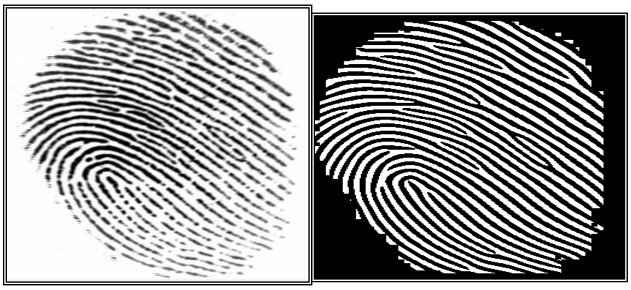

Figure 10a): Input image b): After adaptive binarization.

2.3 Fingerprint Image Segmentation

Image Segmentation in fingerprint recognition, refers to Region of Interest (ROI) that need to be extract before correct minutia extraction because in order to extracting minutia from fingerprint image, image shall contain only useful/effective ridges and furrows (valley), otherwise system will considered the extra part of image and mark it as genuine/true minutia as shown in Fig 12.

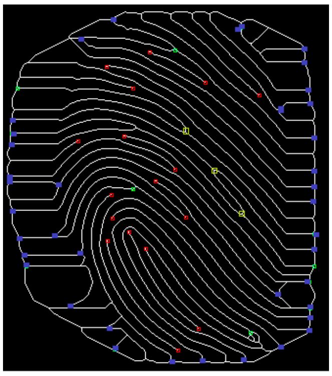

Fig 11: Before extraction of ROI (Blue: false Minutiae, Green: Bifurcation, Red: Ridge Ending).

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.

2.3.1 Block Direction Estimation

Estimate the block direction for each block of the fingerprint image with WxW in size (W is 16 pixels by default). The algorithm is:

- Find the gradient with respect to x-direction (g_x) and y-direction (g_y) for each pixel of the slab (Sobal Filter).
- For each block, use following formula to get the Least Square approximation (standard approach to the approximate solution of over determined systems) of the block direction.

$$tan2\theta = \frac{2\sum_{i=1}^{W}\sum_{i=1}^{W}(gx*gy)}{\sum_{i=1}^{W}\sum_{i=1}^{W}(gx^2-gy^2)}$$ for all the pixels in each block.

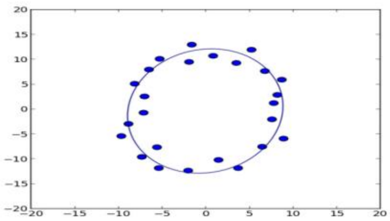

Fig 12: Conic fitting a set of points using least-approximation [13].

The equation is easy to interpret with gradient values gx and gy as cosine value and sine value respectively. So the tangent value of the block direction is estimated nearly the same as the way illustrated by the following formula.

$$Tan2\theta = \frac{Sin2\theta}{Cos2\theta}$$

After completed the estimation of each one slab, those slab without meaning full information on edges and grooves are rejected with respect to the reluctance based on following equation:

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

For each block, "if its certainty level E is below a threshold, then the block is regarded as a background block" [14], as result (route/orientation map) shown in Fig 13.

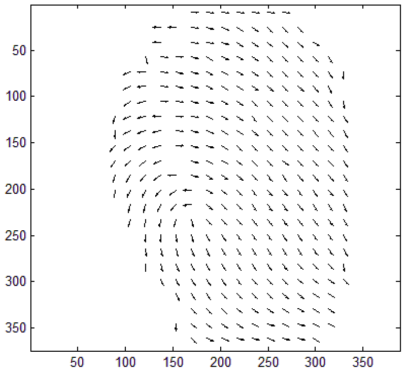

Fig 13: Ridge Direction.

3. MINUTIAE EXTRACTION AND VALIDATION

A critical step in a fingerprint recognition system (FRS) is reliably extracting minutiae from the input fingerprint images, the approach or the method that is used to extracting minutiae from image is the skeleton/tinning-based method which generally consists of the following main steps:

(1) Use an adaptive thresholding algorithm on fingerprint enhanced ROI image as describe in Pre-processing stage (section 2) to compute the binary image from the input gray scale fingerprint image;

(2) Use MATLAB morphological operator "bmorph" in order to get skeleton/tinned version of fingerprint image.

(3) Use MATLAB morphological operator "bmorph" in order to remove false minutia from skeleton version of fingerprint image as discussed in Section 3.2.

(4) "Use Rutovitz Crossing Number" [5] [5] algorithm to extract minutiae from the skeleton of fingerprint image as discussed in Section 3.3.

3.1 Fingerprint Ridge Thinning

Ridge Thinning is used to eliminate the redundant pixels of ridges till the ridges are just one pixel wide. [3]Uses an iterative, parallel thinning algorithm. In each scan of the full fingerprint image, the algorithm marks down redundant pixels in each small image window (3x3). And finally removes all those marked pixels after several scans. In my testing, such an iterative, parallel thinning algorithm has bad efficiency although it can get an ideal thinned ridge map after enough scans. [4] Uses a one-in all method to extract thinned ridges from gray-level fingerprint images directly. Their method traces along the ridges having maximum gray intensity value. However, binarization is implicitly enforced since only pixels with maximum gray intensity value are remained. Also in my testing, the advancement of each trace step still has large computation complexity although it does not require the movement of pixel by pixel as in other thinning algorithms. Thus the third method is bid out which uses the built-in Morphological thinning function in MATLAB i.e. Thinn_Image = bwmorph(Input_Image, 'thin')

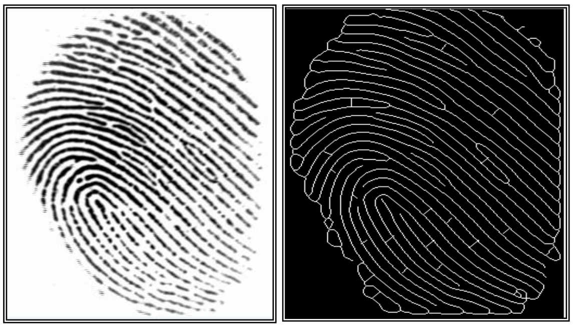

Fig 14: Tinned version of fingerprint image.

3.2 Removal of false Minutia

By the observation of the skeleton image, it can be seen that the misconnections and the isolated regions (hole, dot, and island) in the binary images as shown in Fig 15.

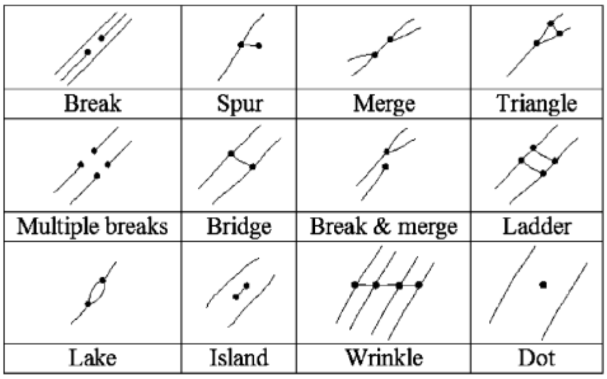

Fig 15: Example of false Minutiae in fingerprint image [5]

These false minutias will significantly affect the accuracy of matching if they are simply regarded as genuine minutia. So some mechanisms of removing false minutia are essential to keep the fingerprint verification system effective.

In order to get rid of, from these false minutia's, we use, MATLAB morphological operators i.e. "Spur", "H-break", "Triangle", where as the rest of false minutiae are not handle in our system e.t.c.

3.3 Minutia Marking

The concept of Crossing Number (CN) is widely used for extracting the minutiae. Crossing number for a pixel "P" is:

P4	*P3*	*P2*
P5	*P*	*P1*
P6	*P7*	*P8*

$$CN = \frac{1}{2}\sum_{i=1}^{8} |P_i - P_{i+1}|$$

Where Pi is the binary pixel value in the neighbourhood of P with Pi = (0 or 1) and P1=P9 [5].

The skeleton image of fingerprint is scanned and all the minutiae are detected using the properties of CN, as illustrated in Fig 17 and Table 1 [5]

Table 1: Cross Number (CN) properties.

CN	Property
0	Isolated Point
1	Ending Point
2	Connective Point
3	Bifurcation
4	Crossing Point

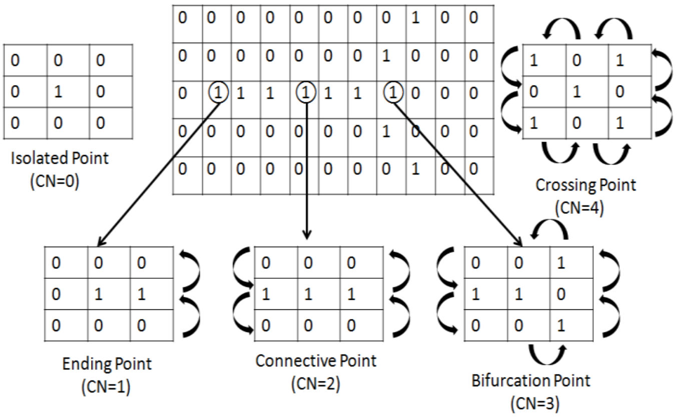

Fig 16: Demonstration of CN properties [5].

After taking CN for each pixel in thinned image:

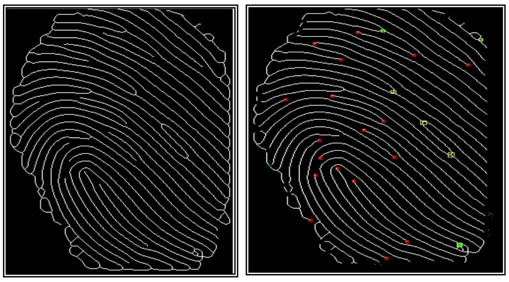

Fig 17: Minutiae extraction from fingerprint image (Green: Bifurcation, Red: Ridge Ending).

4. POST PROCESSING:

Fingerprint image exhibits a quasi periodic pattern of ridges (darker regions) and valleys (lighter regions). The local topological structures of this pattern together with their spatial relationships determine the uniqueness of a fingerprint. There are more than 100 different types of local ridge structures that have been identified [8]. Nevertheless, most of the automatic fingerprint identification / verification systems adopt the model used by the Federal Bureau of Investigation [8]. The model relies on representing only the two most prominent structures: ridge ending and ridge bifurcation, which are collectively called minutiae.

4.1 Minutia Matching:

In this step the fingerprint data is compared with the template data of the system. The extracted minutiae data is stored as a matrix with total number of rows equal to total number of minutiae points, here the template data refers to the data which is stored in database file, this file updates at the time of account creation or at the time of training, database schema stores following attributes:

Column 1: Index of each minutiae point (PK)

Column 2: Location of each minutiae point

Column 3: Orientation Angles of minutiae point

Column 4: Type of minutiae point (1- Ridge Ending, 2- Bifurcation)

During the matching process each query minutiae point is compared with the template data.

4.1.1 Orientation Angle:

In fingerprint recognition the results of matching are not based on minutiae location, because every time fingerprint sensor gives new or different impressions of even same person(as shown in Fig 19), so it's obvious that minutiae's location is different in every new image, however the concept of "Orientations Angles" had overcome this problem.

Algorithm 2: Minutiae angle finder

```
-   Function (Image FPImg , Minutiae M , Radius r)
-       Point    C     =   M.Location(x,y)
        //Center of circle of minutiae M1
-     Angle    θ     =     0
        //Starting angle in degree  range(0-to-360)
-
        //Draw arc until white pixel occurs at location C(x,y)
-       For(i=0; i<=360 && C(x,y) !=1; i++)
-      {
        //Parametric Equation of circle at abscissa
              ▪   C.x=C.x+ Radius * Cos (θ);
        //Parametric Equation of circle at ordinate
              ▪   C.y=C.y+ Radius * Sin (θ);
              ▪   θ++;
-      }
-   Return θ;
```

Algorithm 2 returns angle θ at minutiae m with radius r which depends upon the quality of thinned version of image, if the pre-processing and midlevel-processing (Minutiae extraction) steps are followed correctly as mention in section 2 and 3 respectively then radius $r = 2$ is fine because higher the radius is lower the angle is, which means the difference in angles between two minutiae of different person is almost zero.

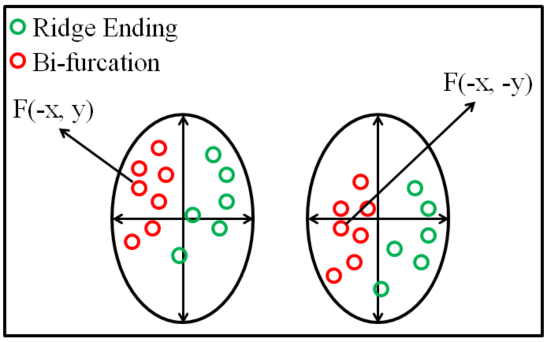

Fig 18: Visual representation of two different impressions of same person.

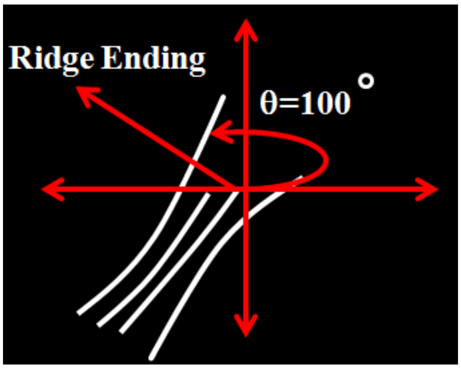

Fig 19: Orientation angle of minutiae "Ridge ending".

Finally, eliminate those minutiae that are too close to each other and all the minutiae within a certain distance threshold T from the image border. After post-processing, a large percentage of the spurious minutiae are eliminated

5. SCORING:

The comparison score S between two fingerprints is the ratio of the total number matched pair m over the total number of template minutia (M),

$$S = {}^{m}/_{M}, \quad where\ m \leq M$$

However the final boolean result depends upon following two factor

- FAR: Accepted rate of un-matched minutiae,
- FRR: Reject rate of un-matched minutiae.

$$Result = \begin{cases} FAR > 1 - S, & Match \\ Otherwise, & Unmatched \end{cases}$$

Lemma:

If the total number of un-matched minutiae$(1 - S) \geq FRR$, then the system shall return "un-match" and match otherwise as far as result is concern.

The purpose of setting, scoring criteria on the false side i.e. FAR and FRR, rather than on true side, is because of the time complexity $O(N)$ for $1{:}N$ comparison and $O(N\text{^}2)$ for $N{:}N$ comparison, so rather than checking each every image from "True" side then best time saving approach is to check from false side i.e. if the total number of un-matched minutiae are greater than FRR, than there is no need to compare further minutiae between query and template image, it's obvious that images are not from same finger.

6. CONCLUSIONS

After exploring the characteristics of fingerprints, we try to present a systematic and fully organized, mechanism which efficiently process and enhance fingerprint images in frequency domain as described in Pre-processing stage, also in the same stage we discuss an algorithm which smartly extract the ROI(Region of Interest) from the fingerprint image using "Least square approximation method" [13] after which the output of pre-processing stage will became the input of mid-processing stage i.e. "Minutiae extraction", were we describe the method to remove false minutiae from fingerprint image and extract true minutiae, (using Rutovitz cross number algorithm [5]) and finally in Post-processing stage the extracted minutiae are compared with template date. Experimental results are performed on publically available database FVC 2002 [1] and the illustration and implementation is made under the MATLAB framework.

7. FUTURE WORK

Biometric and cryptographic frameworks can be united and form a mechanism for crypto key, in future there must be an mechanism which can encrypt and decrypt any type data (text, images, audio, e.t.c) using fingerprints, it can be possible by using Juels and Sudan, fuzzy vault's scheme [10], in the combinations of genuine points and fake points are union and form fuzzy vaults, where the genuine points are form via fingerprint minutiae and fake points are the points which are other the genuine points formed via random generators.

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