TOUCHLESS FINGERPRINT RECOGNITION SYSTEM

M.TECH RnD REPORT

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Abstract

Touchless Fingerprint recognition system is an implementation of fingerprint verification and identification system on mobile phones that utilizes mobile phone Camera to acquire finger images. Once the finger images are captured, they are pre-processed using standard pre-processing algorithm to obtain a fingerprint skeleton. This is used to extract true minutiae eliminating all the false minutiae. The minutiae extraction algorithm works on mobile phones and the template is sent over the air to server during enrolment phase to be stored in the database. During identification, a test template is extracted out and is sent over the air via socket connection to the application on server that does matching with the stored templates. The highest match score is identified and the result is returned back to mobile phone. The usage of mobile phones for fingerprint recognition makes it quite convenient and feasible for everyone. Also touchless systems have a lot of advantage over touch based ones and hence, they become a more popular choice in fingerprint recognition.

1. Introduction:

Biometric identification systems have become one of the crucial identity recognition systems today. It has played an important role to safeguard security in numerous areas such as banking transactions, aadhar identification, high security wireless access, biometric attendance, authorized personnel identification for entry to restricted areas.

Traditional identification system made the use of id cards or passwords, however they might be stolen, lost or forgotten impending a threat to security system. The recognition systems which employ those traits inherent to humans can probably decrement fraudulent cases. Biometric systems has the advantage of user convenience as opposed to cards, codes keys etc.

Biometric identification systems employing fingerprints is widely used. The fingerprint of an individual is unique and doesn't alter over lifetime. A pattern of ridges and valleys form a fingerprint. Ridges are continuous curved lines whereas a valley is the region between two adjacent ridges. The fingerprint analysis performed for matching with other fingerprints requires several features to be extracted. The analysis of fingerprint patterns is carried out for matching. These pattern include:

1) **Loop:** The ridges entering from one end of the finger forming a curve and leaving the same end forms a loop.
2) **Arch:** The ridges entering one end of the finger, rising at the centre forming an arch and leaving at the other end forms an arch.
3) **Whorl:** The ridges which forming circularly around the central point of the finger forms a whorl.

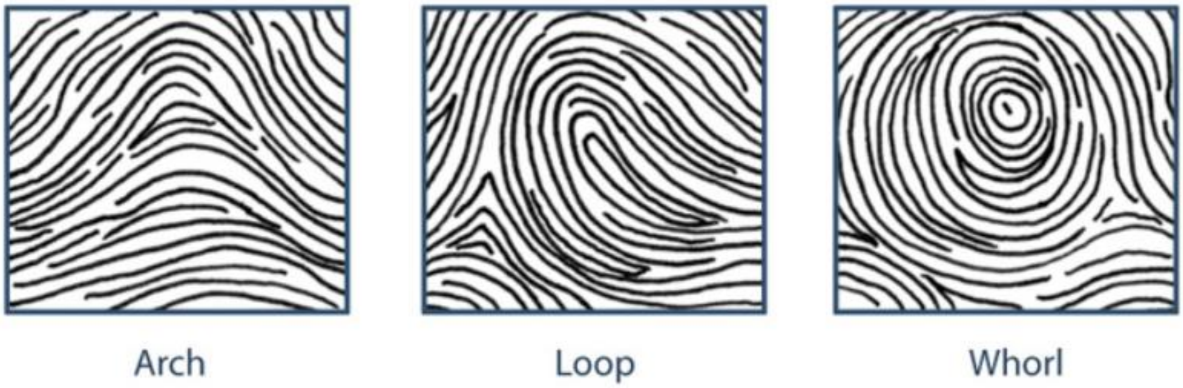
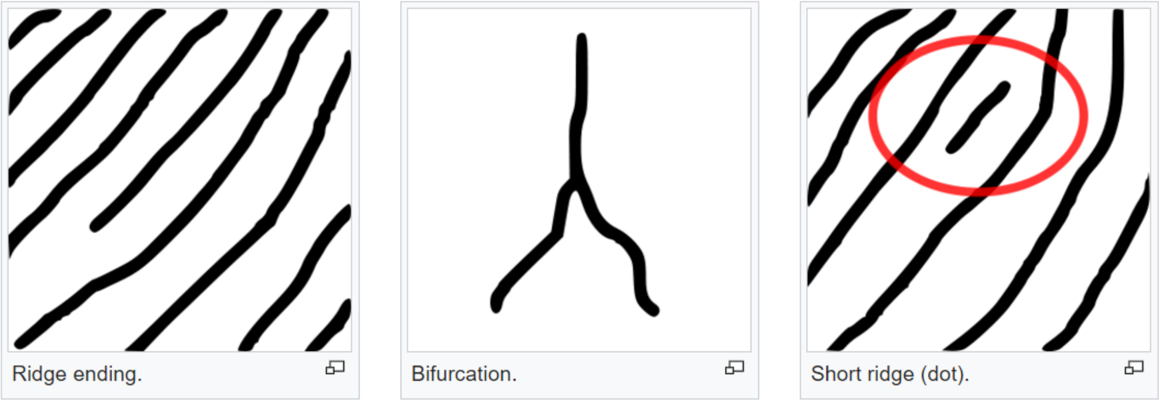


Figure 1: Fingerprint pattern – Arch, Loop, Whorl

These are general patterns observed in the fingerprints which can be used to make initial comparisons. To perform matching analysis of a fingerprint with other, a more detailed investigation incorporating minutia or ridge characteristics is employed. The major minutia features are ridge ending, bifurcation and short ridge (or dot). The termination point of a ridge marks ridge ending. Splitting of a ridge in to two ridges marks ridge bifuraction. Short ridges are significantly shorter than the average ridge length.



Ridge ending.

Bifurcation.

Short ridge (dot).

Figure 2: Minutia points – Ridge ending, Bifurcation and short ridge

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The fingerprint image obtained during the image acquisition process may be blurred, noisy, distorted or may not be well defined. Hence fingerprint image pre-processing forms a crucial step before minutia extraction and matching.

2. Fingerprint Image Pre-processing:

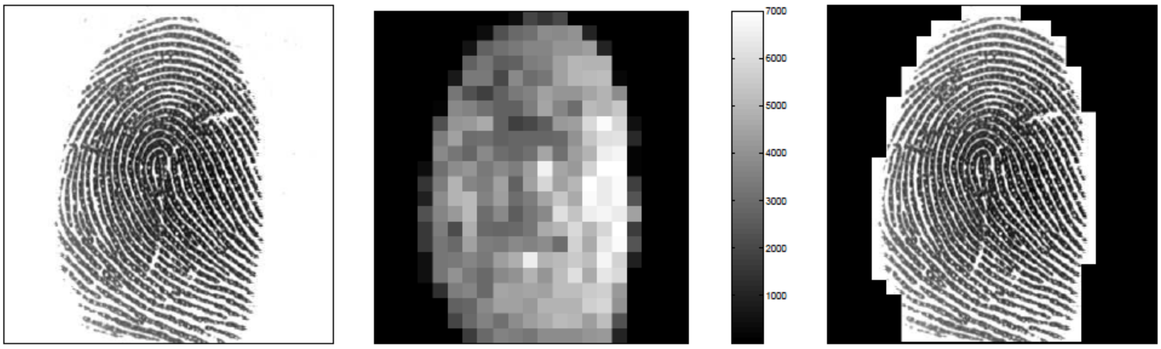
The first step in image enhancement is to segment out the finger image from the acquired image. This is image segmentation. Once the fingerprint image is segmented, the process of normalisation is carried out. This helps in normalizing the mean and variance of the image to a pre-specified value. There are certain imperfections that arise out due to non-uniform ink intensity, non-uniform pressure contact on the fingerprint device or camera image capture under poor illumination or lighting conditions that affects the grey-level intensity values along ridges and valleys which calls the need for normalisation of the image. Once the image is normalised, then an orientation image which exhibit the matrix of directional vectors is evaluated. These vectors represent the ridge orientation in each direction. These orientations get distorted in the presence of noise and other such factors and hence Gaussain smoothing is carried out on this oriented image to eliminate such effects. The next step is to compute the frequency of ridges in the image. This is called the estimation of ridge frequency image. Once the ridge frequency is calculated, the directional ridges are enhanced and other elements are supressed using frequency-selective and orientation-selective Gabor filters. This enhances the contrast level between the foreground ridges and background and supresses' spurious noise levels. Minutia extraction algorithms work on binary image and hence the filtered gray scale image is converted to binary image and the process is called Binarisation. The binary image has only two values: one for ridges and zero for non-ridges or valleys. The final step is thinning which is a morphological operation, carried out to make ridges, one pixel thin. This final pre-processed image is now ready for minutia extraction.

The following is a detailed description about image preprocessing:

1) **Fingerprint Image Segmentation:** The process of isolating fingerprint image consisting of ridges and valleys in the foreground from the descriptive or non-descriptive background is called segmentation. The background regions are outside the fingerprint boundary which carry no fingerprint information and hence needs to be segmented out. If background information is allowed, the minutia extraction algorithm will produce false minutia and hence the matching will suffer. In touchless acquisition, when the camera flash light falls on the finger image, the foreground finger image brightens up whereas the background darkens. Thus foreground image represents high grey-scale covariance than background and covariance thresholding can be used for segmentation. The image is divided in to blocks and each block is processed through grey-scale variance. If it is above global threshold, then it is considered to be a foreground fingerprint image else background image. If the block size is W*W, then, the grey-level variance is defined as:

$$V(k) = \frac{1}{W^2} \sum_{i=0}^{W-1} \sum_{j=0}^{W-1} (I(i,j) - M(k))^2$$

where $I(i, j)$ is the grey-level value at pixel, $M(k)$ is the mean grey-level value for the block k and $V(k)$ is the variance for block k.



(a) Original image (b) Variance image (c) Segmented image

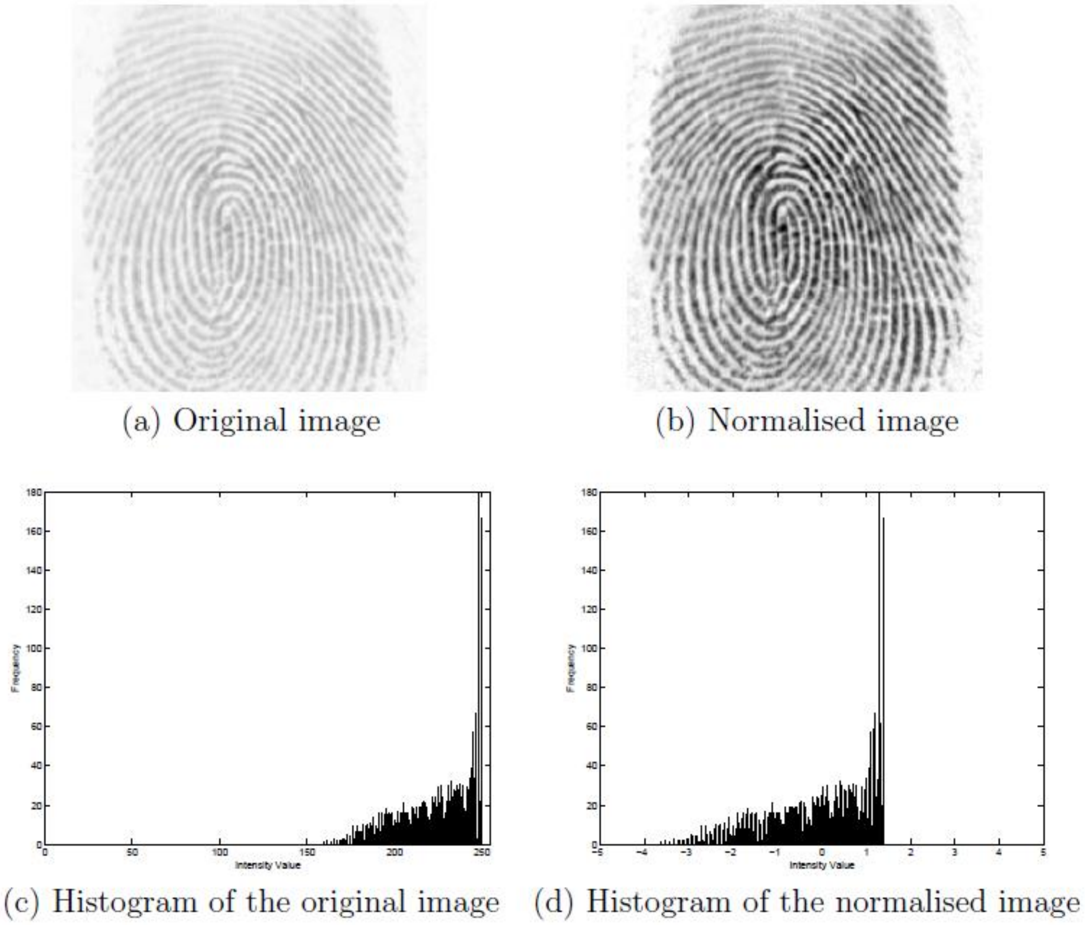
Figure 3: Segmented Image from Original Image

Here, the variance threshold is kept at 100 and size of the block is 16*16.

2) **Grey-level value Normalisation:** To convert the mean and variance of the acquired image to pre-specified values, the process of normalisation is applied. If *N(i,j)* is the normalised grey-level value at pixel *(i,j)*, then,

$$N(i,j) = \begin{cases} M_0 + \sqrt{\frac{V_0(I(i,j)-M)^2}{V}} & \text{if } I(i,j) > M, \\ M_0 - \sqrt{\frac{V_0(I(i,j)-M)^2}{V}} & \text{otherwise,} \end{cases}$$

where M and V are calculated mean and variance of image *I(i,j)* and M_0 and V_0 are pre-specified mean and variance values respectively. Normalisation standardizes grey-level intensity values to facilitate subsequent pre-processing stage and does not alter the pattern of local ridge structure.



(a) Original image

(b) Normalised image

(c) Histogram of the original image

(d) Histogram of the normalised image

Figure 4: Normalised Image from the segmented Image with histogram levels

3) **Estimation of a ridge pixel orientation:** This step helps in estimating the local orientation of a pixel in a ridge. Following are the steps to determine orientation:

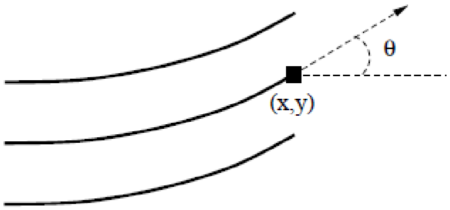


Figure 5: Ridge pixel orientation

1. A block of size W*W is centred at pixel (i,j).
2. A horizontal and vertical Sobel operator is applied to the block to estimate gradient magnitudes in x and y direction.

$$\partial_x(i,j) \text{ and } \partial_y(i,j).$$

3. Local orientation is then determined as follows:

$$V_x(i,j) = \sum_{u=i-\frac{W}{2}}^{i+\frac{W}{2}} \sum_{v=j-\frac{W}{2}}^{j+\frac{W}{2}} 2\partial_x(u,v)\partial_y(u,v),$$

$$V_y(i,j) = \sum_{u=i-\frac{W}{2}}^{i+\frac{W}{2}} \sum_{v=j-\frac{W}{2}}^{j+\frac{W}{2}} \partial_x^2(u,v)\partial_y^2(u,v),$$

$$\theta(i,j) = \frac{1}{2} tan^{-1} \frac{V_y(i,j)}{V_x(i,j)},$$

where $\theta(i, j)$ is the local orientation at the block at pixel (i, j).

4. Now, this orientation image is now converted to continuous vector field as:

$$\Phi_x(i,j) = cos(2\theta(i,j)),$$

$$\Phi_y(i,j) = sin(2\theta(i,j)),$$

and the Gaussain smoothing is applied on this:

$$\Phi'_x(i,j) = \sum_{u=-\frac{w_\Phi}{2}}^{\frac{w_\Phi}{2}} \sum_{v=-\frac{w_\Phi}{2}}^{\frac{w_\Phi}{2}} G(u,v)\Phi_x(i-uw, j-vw),$$

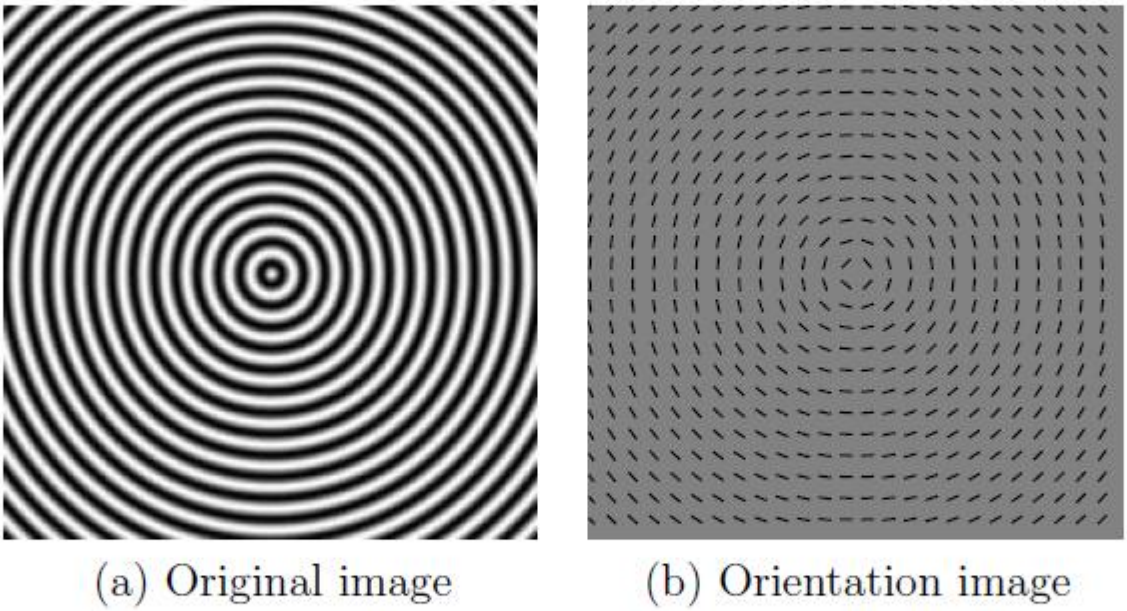
$$\Phi'_y(i,j) = \sum_{u=-\frac{w_\Phi}{2}}^{\frac{w_\Phi}{2}} \sum_{v=-\frac{w_\Phi}{2}}^{\frac{w_\Phi}{2}} G(u,v)\Phi_y(i-uw, j-vw),$$

Where G is a Gaussian low-pass filter of size $w_\Phi * w_\Phi$.

5. The orientation of the smoothed image O(i,j) is given by:

$$O(i,j) = \frac{1}{2} tan^{-1} \frac{\Phi'_y(i,j)}{\Phi'_x(i,j)}$$

The following is the orientation image for the given synthetic image:



(a) Original image

(b) Orientation image

Figure 6: (a) Shows 200*200 synthetic image of wavelength 8 and (b) shows Orientation image of the synthetic image with 0.0003 radians of mean square error between them.

4) **Estimation of Ridge Frequency:** Gabor filter requires orientation image along with the ridge frequency image for its construction. Ridge frequency image is representative of local ridges in an image. Here we divide the image in blocks of size W*W and then project each of the grey-level pixel values in the block along a direction orthogonal to the local ridge orientation. Thus a sinusoidal shape wave is obtained because of such projection where the minima points correspond to ridges in the fingerprint as shown below:

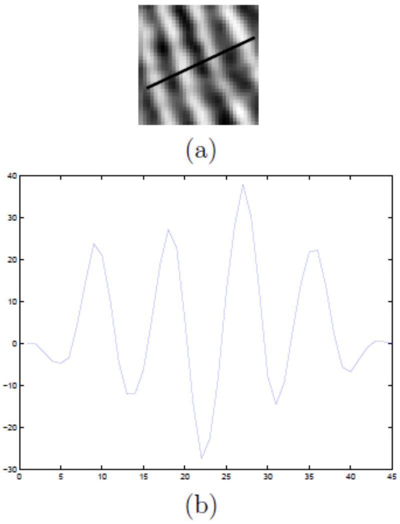


Figure 7: (a) shows Projection of local intensity values from a 32*32 block along an orthogonal direction to local ridge orientation. (b) shows Sinusoidal shape waveform projection where local minima correspond to ridges

An additional step of Gaussian smoothing the projected waveform in ridge frequency image estimation can be performed prior to calculating ridge spacing. This reduces any noise disturbances caused while projection. The ridge spacing *S(i,j)* can be calculated by couting the number of pixels between two consecutive minima points. Thus ridge frequency *F(i,j)* is given by :

$$F(i,j) = \frac{1}{S(i,j)}.$$

Whenever valid minutia points are encountered or there is no local minima points on projection, a valid frequency estimation cannot be obtained. To solve such issues, we need to interpolate the out of range frequency values using neighbouring blocks having well-defined frequency values.

5) **Gabor Filtering:** Orientation image and Ridge Frequency Image together helps in constructing an even symmetric Gabor Filter. A 2D Gabor filter is tuned to a particular orientation and frequency consisting of a sinusoidal plane wave modulated by Gaussian envelope. Such a filter gives maximal response when tuned to local ridge frequency structure. It enhances the ridges and supresses non-ridge structure improving the local contrast. When a cosine wave is modulated by a Gaussian, it gives an even symmetric Gabor filter which is a real part of Gabor function. In spatial domain, it is represented as follows:

$$G(x,y;\theta,f) = \exp\left\{-\frac{1}{2}\left[\frac{x_\theta^2}{\sigma_x^2} + \frac{y_\theta^2}{\sigma_y^2}\right]\right\}\cos(2\pi f x_\theta),$$

$$x_\theta = x\cos\theta + y\sin\theta,$$

$$y_\theta = -x\sin\theta + y\cos\theta,$$

Note that θ is the orientation of Gabor filter, f is the cosine wave frequency, σ_x and σ_y are the standard deviation of Gaussian filter in x and y direction whereas x_θ and y_θ are the x and y axis of the filter coordinate frame.

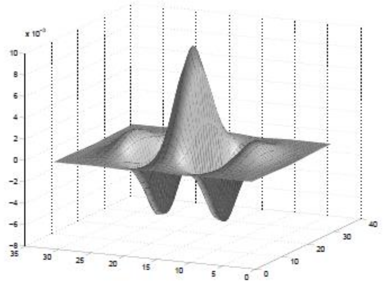


Figure 8: An even symmetric Gabor filter

This filter is spatially convolved with the fingerprint image. The convolution now requires the computed orientation image value *O(i,j)* along with the frequency image *F(i,j)* that forms the parameters to the Gabor filter. Such a Gabor filter convolved with the fingerprint image now produces an enhanced version *E(i,j).*

$$E(i,j) = \sum_{u=-\frac{w_x}{2}}^{\frac{w_x}{2}} \sum_{v=-\frac{w_y}{2}}^{\frac{w_y}{2}} G(u,v;O(i,j),F(i,j))N(i-u,j-v),$$

note that *N* here is the normalized image and w_x and w_y are the width and height of the Gabor filter mask respectively.

The filter bandwidth refers to the range of frequency the filter allows which in turn is decided by the standard deviation values of the filter. Here, since the bandwidth is tuned to match the local ridge frequency, the standard deviation values are related to ridge frequency. So if the standard deviation values are kept fixed irrespective of ridge frequency, it will lead to non-uniform image enhancement and other artefacts. Thus it is necessary to also tune standard deviation values depending upon the ridge frequency as follows:

$$\sigma_x = k_x F(i,j),$$

$$\sigma_y = k_y F(i,j),$$

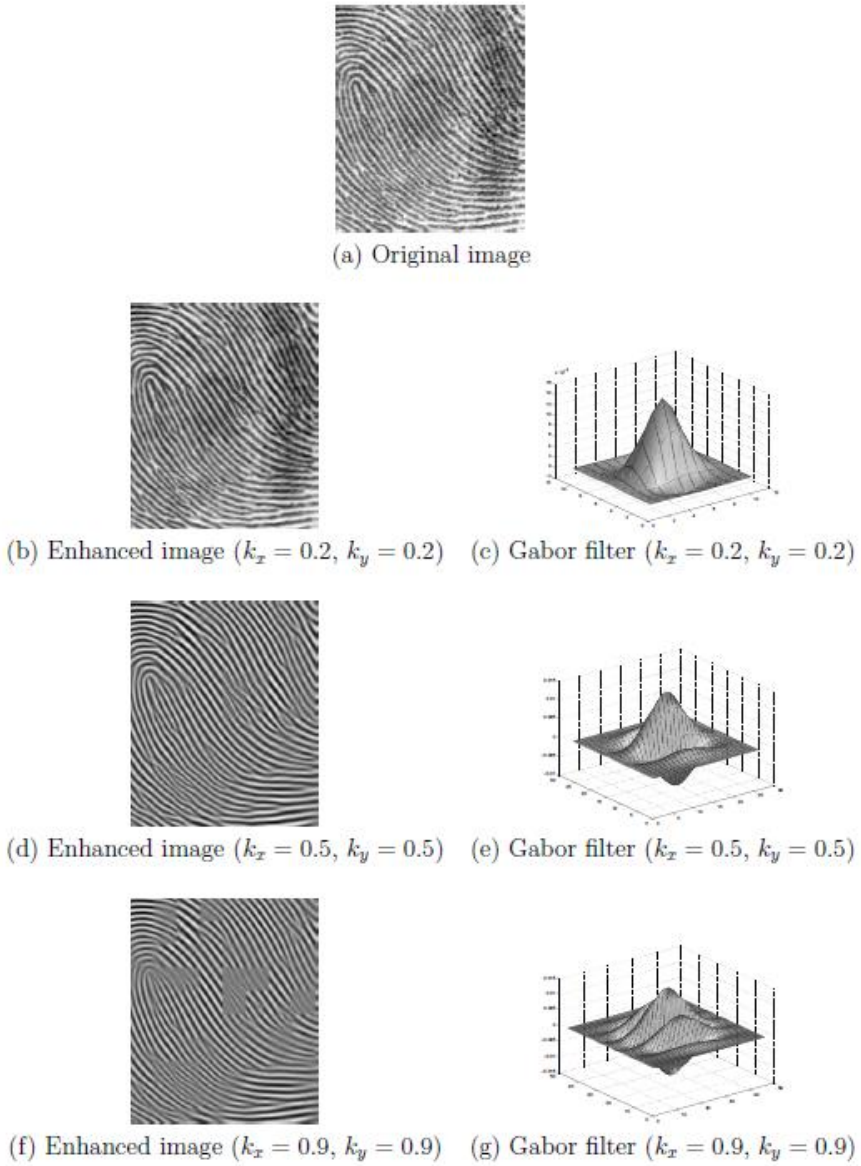
where k_x and k_y are constants for σ_x and σ_y respectively.

Also, fixed size Gabor filters are not optimal in the sense that it does not accommodate different sized Gabor waveforms of different bandwidths. Hence to vary the Gabor filter size according to the bandwidth of the Gabor function, the filter size must be proportional to the standard deviation of the Gabor filter which in turn depends upon ridge frequency, Hence the size of the filter varies with ridge frequency which in turn achieves optimal enhancement.

$$w_x = k * \sigma_x ,$$

$$w_y = k * \sigma_y ,$$

where k value depends upon the maximum amount of information that needs to be captured from the Gabor waveform. Generally, it is set to 6.



(a) Original image

(b) Enhanced image ($k_x = 0.2$, $k_y = 0.2$) (c) Gabor filter ($k_x = 0.2$, $k_y = 0.2$)

(d) Enhanced image ($k_x = 0.5$, $k_y = 0.5$) (e) Gabor filter ($k_x = 0.5$, $k_y = 0.5$)

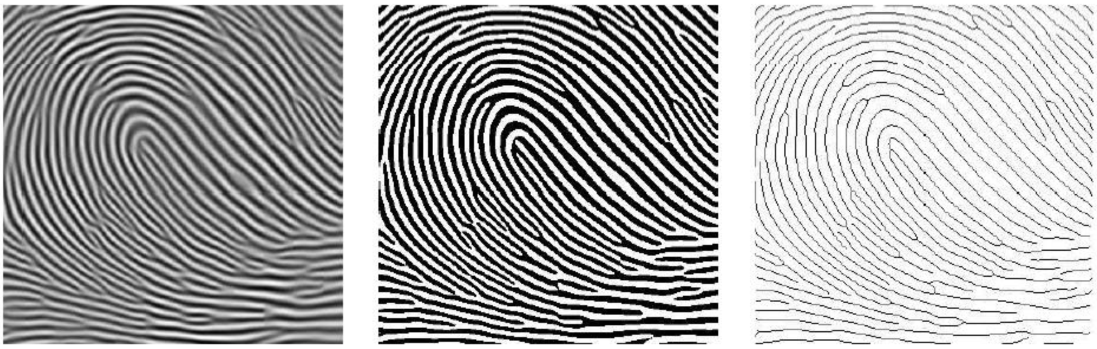
(f) Enhanced image ($k_x = 0.9$, $k_y = 0.9$) (g) Gabor filter ($k_x = 0.9$, $k_y = 0.9$)

Figure 9: Gabor filter enhanced fingerprint images with different kx and ky values

Here, σ_x determines the amount of contrast enhancement between subsequent ridges and valleys whereas σ_y determines ridge smoothening extent along local orientation. If the values of k_x and k_y is large, then it introduces unwanted artefacts and blurs the ridge structures. This is because larger values will over-smoothen the image. If the values are very small, then the filter is ineffective in removing noise. Thus it involves trade-off in the selection of standard deviation values.

6) **Binarisation and Thinning:** To extract minutia from the fingerprint image requires it to be in the binary format wherein the black pixels correspond to the foreground ridge structures whereas white pixels corresponds to the background non-ridge structures or valleys. Thus Binaristation converts grey-scale image to binary image which further improves the contrast between the ridges and valleys thereby facilitating extraction of minutia points. Gabor filters are zero mean filters which mean that the binarisation can be easily performed by introducing a global threshold of zero. If the grey-level value of the

enhanced image is greater than the global threshold, then the pixel value is set to a binary value of 1 else 0. Once the image is binarised, a morphological operation of selecting only one pixel thin lines out of thick ridges is performed. This is called Thinning. The algorithm detects which neighbourhood pixels are eligible to be deleted and works iteratively till no more pixels can further be deleted. This algorithm preserves the connectivity of ridge structures without introducing any line breakages or false contours. This is the skeleton image which is used in extracting out minutia points like ridge endings and bifurcations.



(a) Enhanced image (b) Binary image (c) Thinned image

Figure 10: Binarized and Thinned images of the enhanced image

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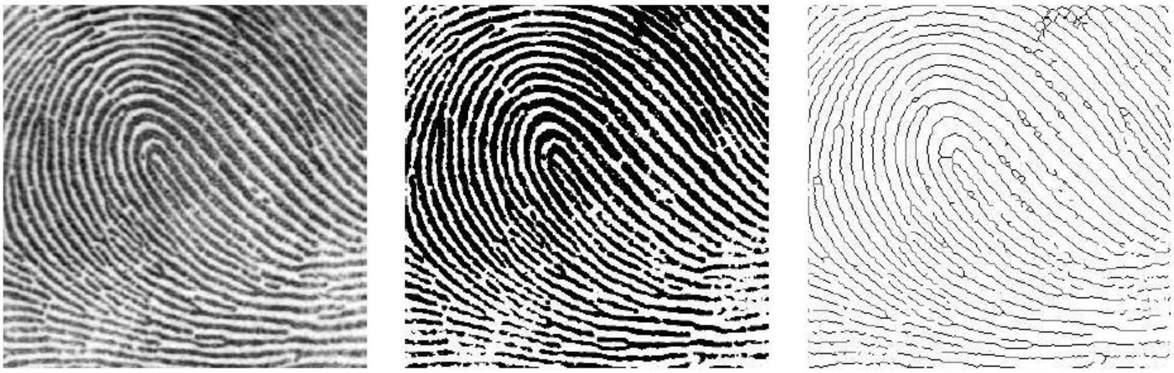
The enhancement process is important before binarizing and thinning the fingerprint image. This becomes clear from the following result:

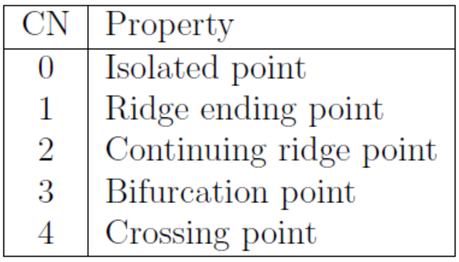


(a) Original image (b) Binary image (c) Thinned image

Directly binarizing and thinning the original fingerprint image introduces line breakages and increases the probability of extracting false minutiae. It also introduces significant amount of noise and unwanted elements.

3. Extraction of Minutiae and Removal of False Minutiae:

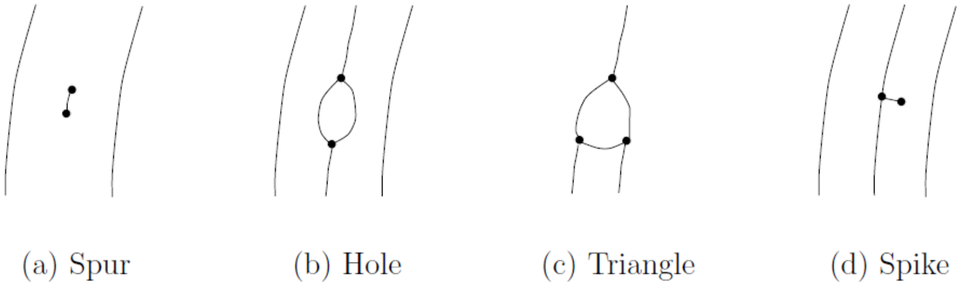
The concept of Cross Numbering (CN) is used to extract out Minutiae. The skeleton image is scanned with the help of 3*3 window over its ridges. Then, the CN value is calculated which is half the mod of sum of the differences between pairs of adjacent pixels in 8-neighbourhood. Ridge pixel can be classified as isolated point, ridge-ending point, continuing ridge point, bifurcation point and crossing point according to the CN as follows:



CN	Property
0	Isolated point
1	Ridge ending point
2	Continuing ridge point
3	Bifurcation point
4	Crossing point

Table. Ridge pixel property corresponding to CN value

False minutia introduced due to noise and thinning process needs to be detected and eliminated by image post-processing. Hence, Image post-processing stage is important in order to validate minutiae. Following figure illustrates different cases of extracting false minutiae from a thinned image:



(a) Spur (b) Hole (c) Triangle (d) Spike

Figure 11: False Minutia extraction due to spur, hole, triangle or spike in a thinned image

Spur generates false ridge endings whereas hole and triangle generates false bifuractions and the spike structure generates a false bifuraction and ridge ending point. These false minutia can be eliminated by applying a set of heuristic rules. For example, to remove a spike structure, a bifurcation point connected to ridge ending point below a certain distance are considered as false minutia and are eliminated. Such kind of heuristic rules can be applied on other types of false minutiae. Also, a boundary effect treatment is also applied to eliminate those minutiae points which are near to fingerprint boundary below a certain threshold distance.

False minutia can be eliminated by a single algorithm as well rather than considering a set of heuristic rules. This algorithm tests the validity of each minutia by scanning the skeleton image and examining the local neighbourhood around such minutia. Thus, based on the configuration of the ridge pixels connected to the minutia points, false minutiae can be eliminated.

4. Minutia extraction algorithm:

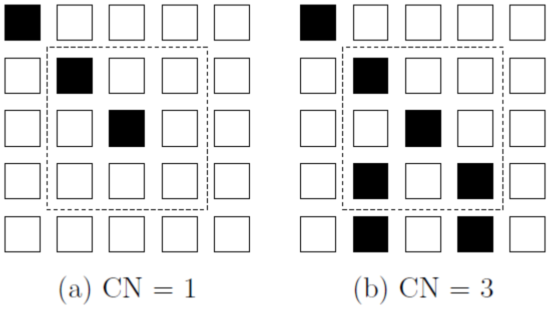
The Cross Numbering method extracts minutiae i.e. ridge endings and bifurcation points from the skeleton image obtained from thinning process by examining the local neighbourhood of every ridge pixel by a 3*3 window. The Cross Numbering value for a ridge pixel *P* is estimated as follows:

$$CN = 0.5\sum_{i=1}^{8}|P_i - P_{i+1}|, \qquad P_9 = P_1$$

Where P_i is a pixel neighbouring to pixel *P*. The 8 pixels neighbouring to pixel *P* is scanned as follows:

P_4	P_3	P_2
P_5	P	P_1
P_6	P_7	P_8

Figure 12: 3*3 window with P as ridge pixel and others as neighbouring pixels



(a) CN = 1

(b) CN = 3

Figure 13: Ridge Ending (a) and Bifucation (b) examples with Crossing Number

The above figure shows two examples: Ridge Ending and Bifurcation. The dotted square denoted a 3*3 mask as shown above. The centre pixel *P* is a ridge pixel and the mask around it is used to compute CN value using the equation of CN as described above. Those with black squares are labelled as 1 and the ones with white are labelled as 0. Once the CN of a ridge pixel is computed, it can be classified according to the property of its CN value as tabulated above. If CN =1, it marks the ridge pixel as a ridge ending point. If CN=3, it’s a bifurcation point. Now, once the minutiae are extracted, the following information is stored in the form of fingerprint template for matching purpose:

1. X and Y coordinates of the minutia point in the fingerprint image
2. Orientation in degrees of the associated ridge structure
3. Classification of minutiae (ridge ending or bifurcation)

5. Fingerprint Matching:

There are two stages for matching minutia of the test fingerprint from the template ones:

1. Registration aligns both the fingerprints. Some algorithms use translation, scaling and rotation for performing image registration task which is called a rigid transformation. Another transformation called a non-rigid transformation may also be applied for registration. It is also called as elastic transformation.

2. Once the registration is completed, the matching score is calculated by counting the corresponding minutia pairs that are present in both the fingerprints. If there exist a minutia from the test set which is located within the bounding region or tolerance zone from the template set, then the two minutia correspond. The matching score is computed based on the number of minutiae matched divided by the total number of minutia.

Following factors complicate minutia matching:

1. Test or template set may suffer from missed, false or displaced minutia which may be caused due to poor minutia extraction.
2. Both the set may be translated, scaled or rotated w.r.t. each other.
3. Both sets may originate from different part of the same fingerprint which means it has a very small overlapping region.
4. Non-linear elastic deformations may occur due to improper capture or acquisition of fingerprints.

Elastic Minutiae Matching Algorithm:

This algorithm employs non-linear transformation model in two stages.

1. Local matching: It estimates the minutia which could possibly form a matching pair based on local similarity measures.
2. Global matching: It makes the use of possible correspondences to determine a global non-rigid transformation that is used to register two fingerprints.

Once registration is completed, counting of corresponding minutia using bounding boxes. These boxes can be chosen strictly as the distance between corresponding pair of minutia after elastic registration is small.

Local Matching: The minutia in the template image or test image can be described by location (x,y) and orientation (θ). The matching algorithm does not distinguish between the minutiae types as they may be interchanged by noise or other factors like differences in pressure during acquisition on the scanner. Every minutia has the corresponding minutia neighbourhoods. It consist of minutia itself along with two nearest neighbouring minutia. If the reference minutia is labelled m_0, then its closest neighbours with decreasing distance is labelled as m_1, m_2, m_3,…, m_{n-1}. Three neighbourhood sets $\{m_0, m_1, m_2\}$, $\{m_0, m_1, m_3\}$ and $\{m_0, m_2, m_3\}$ are selected for each minutia. This makes matching more robust to missing and false minutiae. Then, it compares each minutia neighbourhood in the test fingerprint with the template fingerprint. The two structures are aligned using least square algorithm that determines the optimal rotation, scaling and translation. Then, the sum of squared distance between the corresponding minutiae, orientation difference and the scaling determines the similarity between two minutia neighbourhoods. If the structures match, then the pair of minutia neighbourhoods and the transformations (t,s,r) consisting of translation t = (t_x,t_y), scaling (s) and rotation (r) is stored. Once each minutia neighbourhood in test fingerprint is compared with each of the minutia neighbourhood in the template fingerprint, a list of corresponding minutia neighbourhood pairs is obtained. All of the minutia neighbourhood pairs might not give an indication of true correspondences but is the first step to the degree of similarity between the two fingerprints.

Global Matching: This stage requires the design of global transformation model that optimally registers two fingerprints. The list of minutia neighbourhood pairs that exhibit local similarities are utilized to determine the global transformation. This transformation selects the largest number of matching minutia pairs from the entire minutia sets. Initially, the largest group of pair of minutia neighbourhood that share approximately the same registration parameters are selected. This can be achieved by analysing, for each matching pair, the number of pairs for which the registration parameters differ less than a certain threshold. Then the transformation (t,r,s) needs to be calculated in least square sense that optimally registers the selected minutiae in the test set to the corresponding minutiae in the template set. Here the problem comes only for elastically deformed fingerprints which won't be well registered due to non-existence of an accurate rigid registration. This needs to be compensated in the counting stage. Elastic registration model like the TPS (Thin plate spline) model needs to be considered in order to compensate for elastic distortion. This TPS model needs to be fitted in a number of iterations. Firstly, an initial model is fitted to the minutia in the minutia neighbourhood pairs that were found in the local matching stage. Then, the corresponding minutia in both the sets which differs in location and orientation less than a pre-determined threshold, are estimated and a new model is fitted to those corresponding minutiae. This gets repeated again and again, each time with a decreasing threshold r_0 until the model converges to its final state. This iterative process improves the quality of the non-linear registration significantly leading to an increased match score. The matching score is finally computed as follows:

$$S = \frac{n_{\mathrm{match}}^2}{n_1 \cdot n_2}$$

where n_{match} = no. of matching minutiae, n1 = number of minutiae in the test fingerprint and n2 = number of minutiae in the template fingerprint. This equation gives optimal results of false acceptance and false rejection for fingerprints with lesser minutiae. The match and non-match decision is then taken depending upon a pre-determined threshold.

6. Android App Implementation:

The Touchless Fingerprint application developed using Android platform is a Criminal Identification System App which can be used by Police Authority to identify criminals/suspects on the field. The application provides three facilities to capture fingerprints using Mobile phone Camera (touchless) or Fingerprint Scanner (Touch based) or phone gallery (acquired/saved fingerprints). Pre-processing and Template Extraction of finger images is performed in the mobile phones and these templates are sent over-the-air, in the encoded format, to the server. The server stores the training set of fingerprint templates in to its own local Database during the enrolment phase. During the identification phase, the server acquires the test fingerprint template and performs matching operation of it with the stored templates in the database. The matching score is calculated by the server. If the matching score goes above a predefined threshold, then the closest match is identified. The person's name corresponding to the closest match fingerprint template having the maximum matching score is returned by the server to the mobile phone. This helps the police authority to identify the criminals/suspects on the field using only a mobile phone.

The Touchless fingerprint application is developed for mobile phones operating on Android Platform using Android Studio 2.3.1. The application is tested on Lenovo Vibe K5 plus having following features:

Processor	***Octa-core Qualcomm Snapdragon 616***
Speed	***1.5 GHz***
RAM	***3 GB***
Android Version	***5.1.1***
Code name	***Lollipop***
API Level	***21***

The minimum requirement of the application to be compatible with the android handset is as follows:

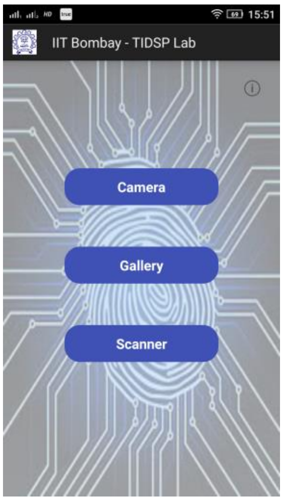
Source Compatibility Java Version	***1.8***
Target Compatibility Java Version	***1.8***
Min SDK Version	***21***
Min API Level	***21***

The android application was developed in the following environment:

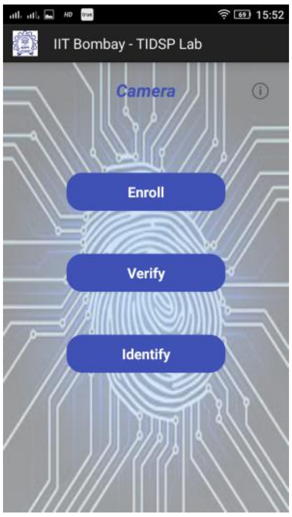
Android Studio Version	***2.3.1***
Java Version	*1.8 (Jack Enabled)*
Compiled SDK Version	***24***
Build Tools Version	***25.0.0***
Target SDK Version	***24***
Build Gradle Version	***2.3.1***

7. Touchless Fingerprint App Description:

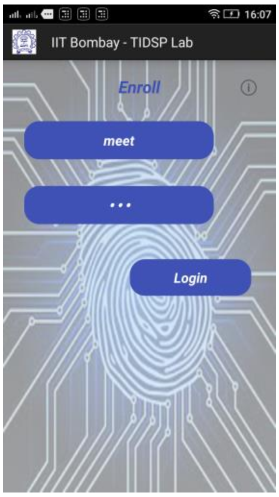
The first activity provides three options for the user:

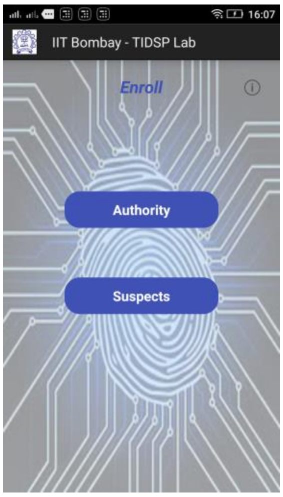


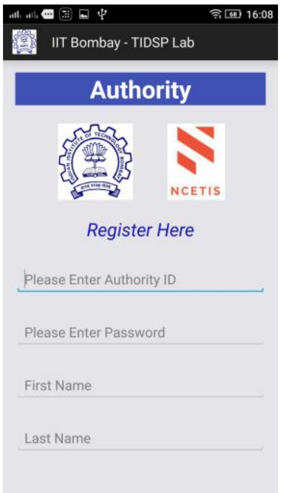
1) **Camera:** The camera further provides three options:

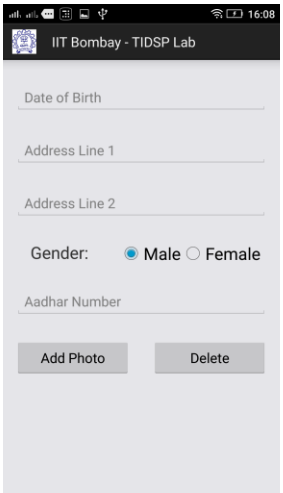


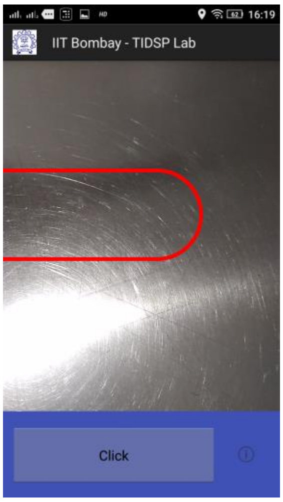
i) **Enrol:** In the enrolment option, first the authority police is asked to enter its login id and password. This ensures that the enrolment can be done only by police authority or with the consent of police authority. Once the login is successful, there are two options for enrolment of authority and suspects. By clicking on either of the options, a form is displayed. The police authority is asked to enter new login id and password for a new police authority entry along with other personal details like first name, last name, address, date of birth, gender, aadhar-id, photo, camera fingerprint, scanner fingerprint whereas suspects have a unique suspect id along with such personal details. The information of the police authority is stored in the separate table, enrollment_authorization, of the fingerprint database whereas the information about the suspects is stored in the other table, suspects_enrollment, in the same database. Thus, this option enrols the fingerprints along with other personal information in the database.

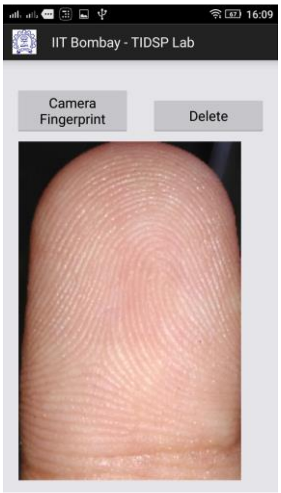


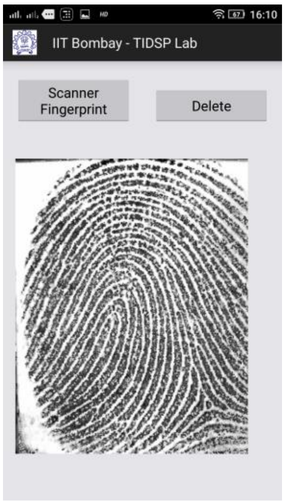


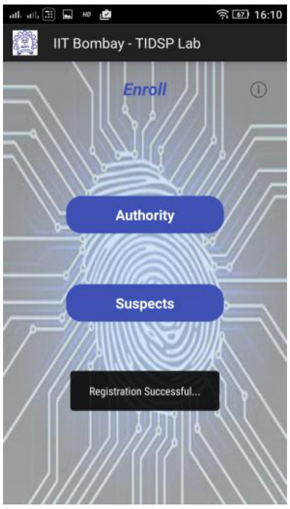






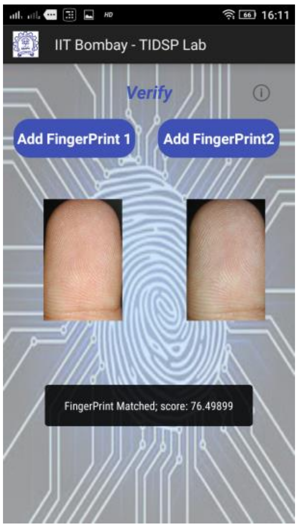






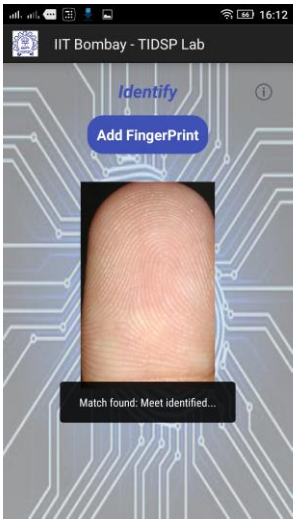
Registration Successful...

ii) Verify: This option is used to verify two fingerprints. Once the add fingerprint is clicked, the user is asked to give the finger image through mobile camera. The mobile phone extracts out fingerprint template out of the image and performs matching operation with the other fingerprint template obtained from the second option of add fingerprint. If the matching score is above the predefined threshold, then the "Fingerprint Matched" message is displayed else "Fingerprints Not Matched".



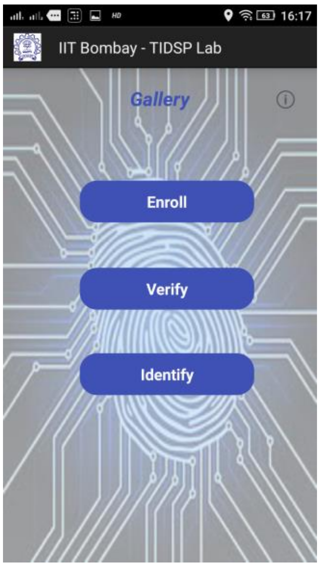
FingerPrint Matched; score: 76.49899

iii) Identify: This option acquires the finger image from the mobile camera, extracts out the fingerprint template and sends it to server via a socket port. After sending the fingerprint template, it waits for the response from the server displaying whether the person is identified or not.

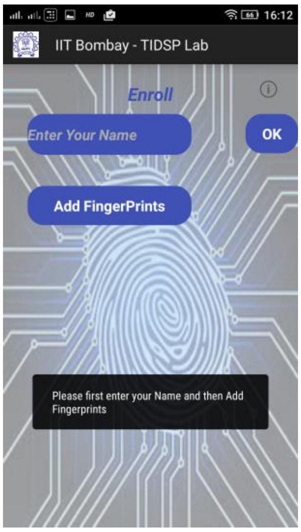


Match found: Meet identified...

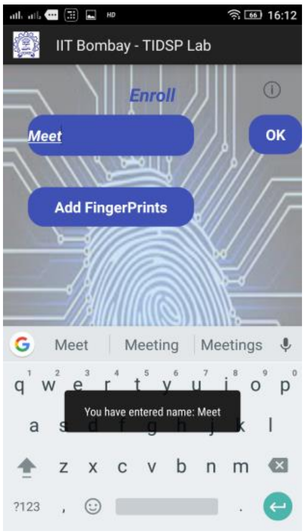
2) **Gallery:** Currently, the gallery option is used to save fingerprint image in the database local to application. This is the SQLite database used to store the incoming data. The gallery further provides three options:



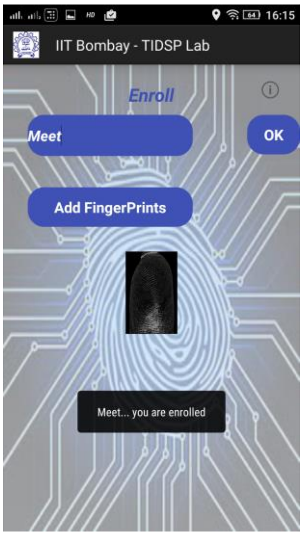
i) **Enrol:** This option is used to enrol user in the app's local SQLite database. The user has to enter his name and then provide stored fingerprint images from gallery.



Please first enter your Name and then Add Fingerprints

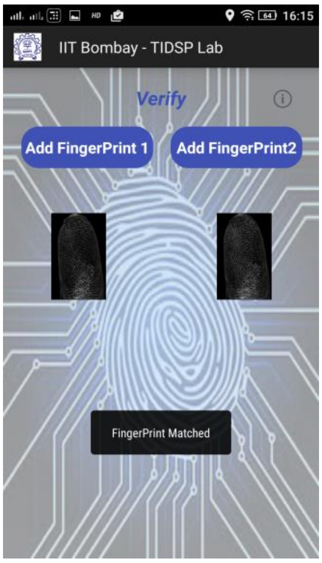


You have entered name: Meet



Meet... you are enrolled

ii) Verify: This option is used to verify two fingerprints images provided from the gallery. If the matching score of two fingerprint images is more than the predefined threshold, then the "Fingerprint Matched" message is displayed else "Fingerprints Not Matched".



16:15

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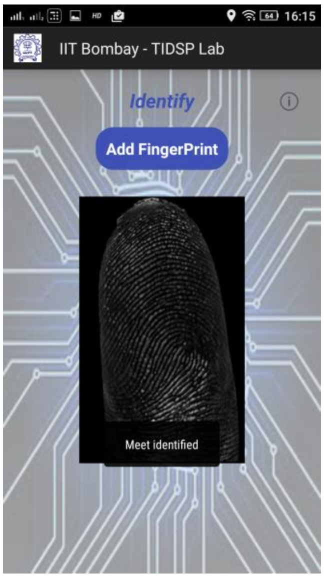
Verify

FingerPrint Matched

iii) Identify: This option is used to identify a test fingerprint image from the local SQLite database. If the match is found, then the name of the person corresponding to that fingerprint is displayed else no match is found.



16:15

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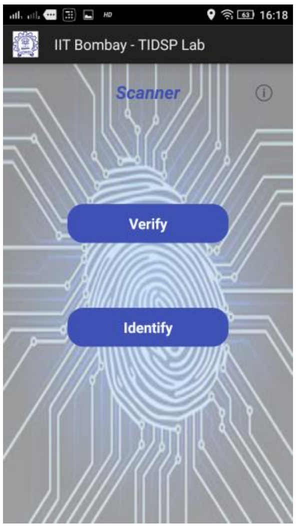
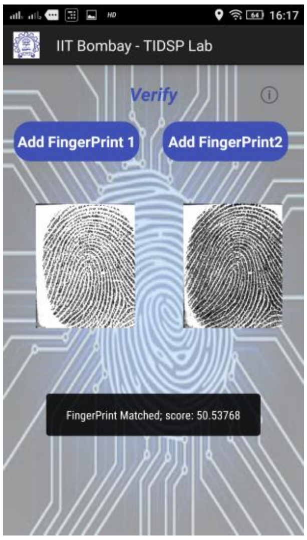
Identify

Meet identified

3) **Scanner:** The enrolment using fingerprint scanner is done in the enrolment phase of the camera option. The fingerprint scanner device is attached to the mobile phone via a USB-OTG cable. The scanner provides two options:

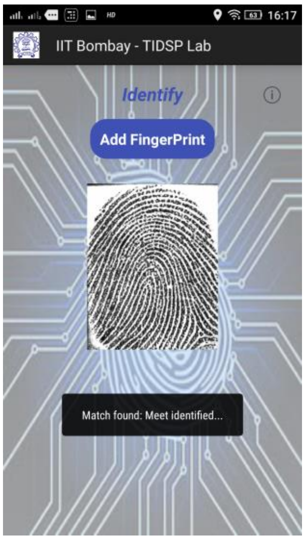


i) **Verify:** Once the device is connected, the user is asked to place the finger on the scanner device. The fingerprint is captured and its template is extracted and the matching operation is performed. If the matching score is above the predefined threshold, then the “Fingerprint Matched” message is displayed else “Fingerprints Not Matched”.



FingerPrint Matched; score: 50.53768

ii) **Identify:** In this option, once the fingerprint is captured from the scanner device, its template is extracted and is sent to server. The server performs matching with other templates from the database and returns the best match result which is displayed on the phone.



Match found: Meet identified...

Note: In the identification stage, fingerprint template can be extracted from either the finger image from mobile camera or the fingerprint image from scanner device. In any case, the matching operation of such a template is performed with other templates in the database which may belong to mobile camera based finger image or scanner device based fingerprint image or both.

8. Web Server and Database:

XAMPP is an open source, cross platform package and it stands for cross platform (X), Apache (A), MySQL (M), PHP (P) and Perl (P). XAMPP server is being used to deal with server side communication and to deal with Databases. Every web application requires to store data in to the database. MySQL queries are used to query the database. PHP (Hypertext pre-processor) is a server side scripting language which is used on the server side to communicate with the app and the database. PHP scripts are stored on the server and holds MySQL queries. These scripts are used to connect to the database by providing the database name, username, password and server name to MySQL query.

Once the database is connected to server, the tasks of logging in or registering the details is performed in other PHP script. The script to be run and other user credentials are sent from the mobile phone via http server connection to the server. When the XAMPP control panel modules like Apache and MySQL is started, the server receives this data sent from mobile phone. The mentioned PHP script is run on that server. For eg: if the script is formregister.php , as in this case, it first receives those credentials from the server, runs the SQL query by opening the database connection and stores the content in to the database. This way, the registration and logging data is sent from mobile phone to the server and the server performs the required action on the database. The response string can also be sent back to mobile phones from server using this PHP script as described next.

PhpMyAdmin is an open-source package available within Xampp to work with MySQL and MariaDB with the use of web browser. Here the database handling is done by phpMyAdmin. It provides the following:

1) MySQL and MariaDB database management
2) Imports data form SQL and CSV
3) Facilitates SQL query execution on tables and databases to perform manual operations on them.
4) It helps in administering multiple servers.
5) It also provides a better web interface.
6) Data can be exported in various formats like PDF, XML, SQL, CSV, Word, Excel, LaTeX etc.
7) Helps in searching entities in the database locally as well as globally.

9. Mobile-Server Communication: HTTP URL Connection:

All the user information and login credentials are stored in the form of Strings. The fingerprint template extracted from the image is in the form of Java object. These objects are converted to JSON (JavaScript Object Notation) strings using GSON. GSON(Google Gson) is an open source Java library to serialize and deserialize Java Objects to and from JSON. Finally, the data to be sent is available in the String format. Thus, the mobile phone collects the data from the form or login credentials from the activity and posts it to the server via HTTP URL Connection. It sends the buffered data on the output stream by opening the URL connection in an encoded "UTF-8" format. The URL string contains the ip-address of the network to which the data needs to be posted followed by the PHP script name. (For eg: http://10.107.79.150/formregister.php). The mobile phone can also receive the data from PHP script via input stream to know about the connection or whether the registration is successful.

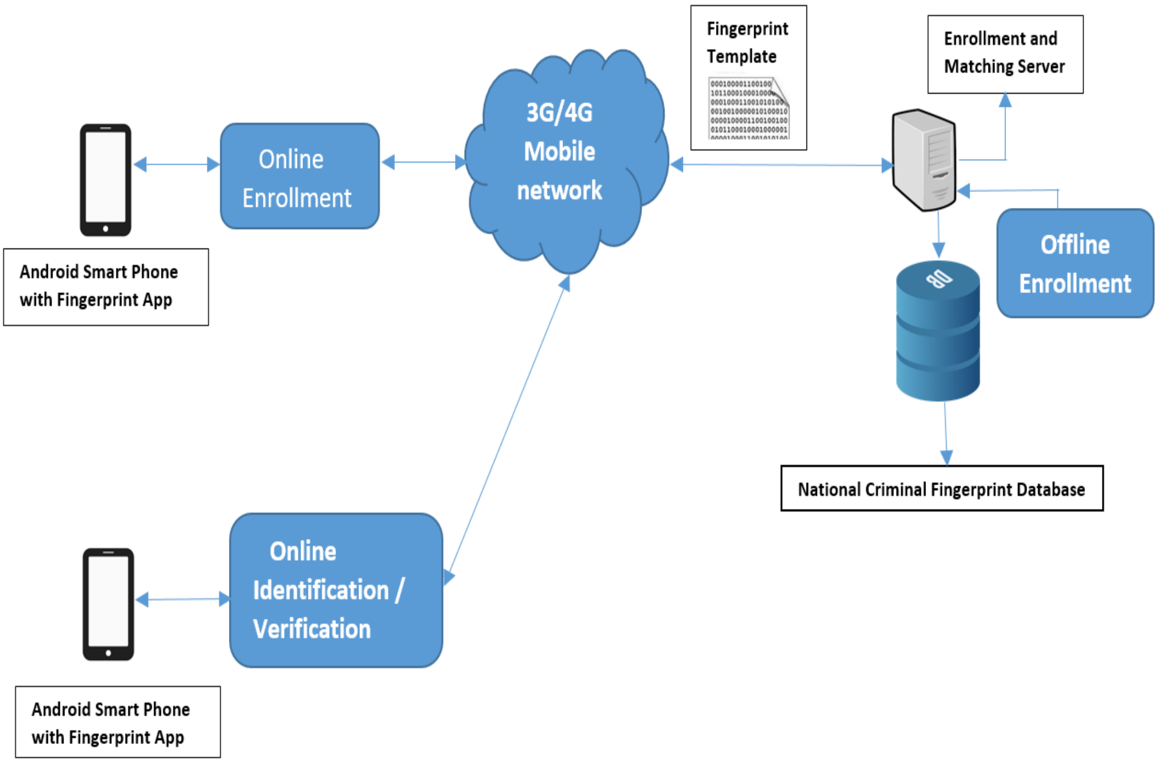

Fingerprint Template
Enrollment and Matching Server
3G/4G Mobile network
Online Enrollment
Android Smart Phone with Fingerprint App
Offline Enrollment
National Criminal Fingerprint Database
Online Identification / Verification
Android Smart Phone with Fingerprint App

Figure 14 : Touchless Fingerprint Identification System

10. Java Socket Communication:

In the identification phase, the fingerprint template that needs to be sent from the mobile phone to server is done via socket communication. The server ip-address and port address is set in the socket and the data is sent from the mobile phone through this socket to the server. On the server side, this data is accepted by the Eclipse IDE which runs a java socket program to accept the data. The java socket program is always in the listening mode in order to accept the data anytime from the mobile phone and its connection is never closed. Once the application receives the fingerprint template in JSON string format, it deserializes the string back to JSON object or Java object. Then, the SQL database connection is invoked from the eclipse and the stored templates are retrieved one by one. Each of the retrieved template is in the JSON string format which needs to be deserialized to java object using GSON. Once the retrieved template is converted back to java object, it is passed on to the matching algorithm which returns the matching scores of the test template with that of the retrieved templates from the database. The person name corresponding to the highest match score above the pre-determined threshold is sent back to the mobile phone through the existing socket connection and is displayed.

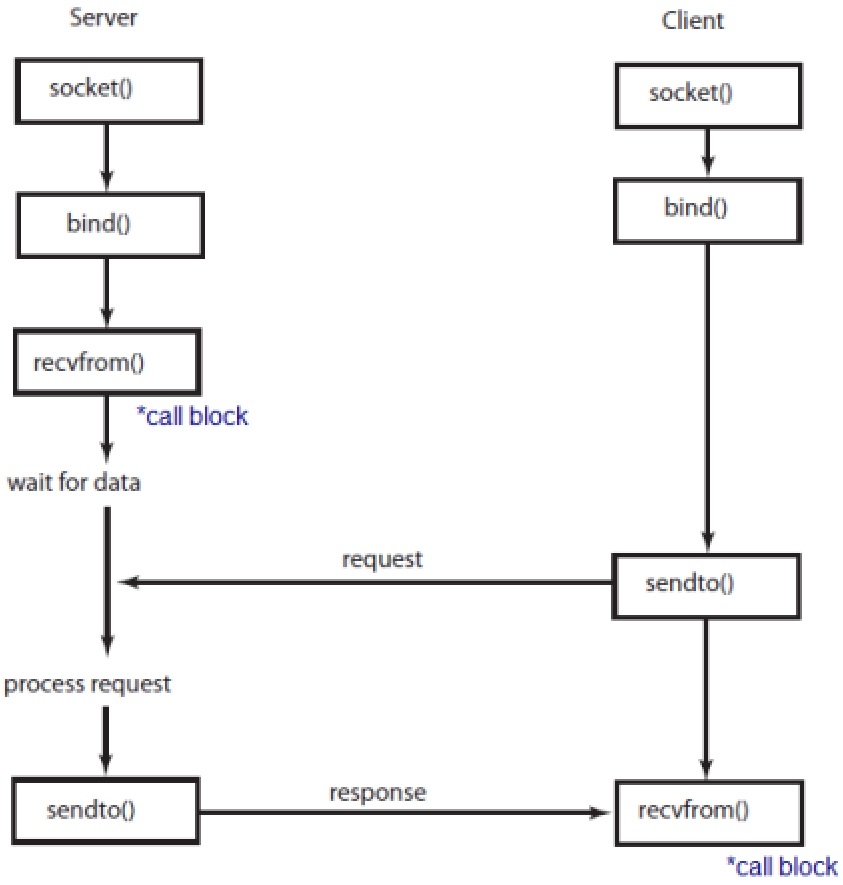


Figure 15 : Java Socket Communication

11. SourceAFIS Libraries:

SourceAFIS is an opensource project initiated by Robert VanZan which provides an SDK for fingerprint recognition and matching. The library is implemented in C#, .NET and Java. The SourceAFIS Java SDK involves various packages like extraction, filters, minutiae, model, matching, templates etc. which can be used for minutiae extraction and matching.

12. Conclusion and Future Work

Using mobile – webserver communication in a secured manner, it has become convenient to acquire fingerprints just from a smartphone without any dedicated and costlier fingerprint scanner, extract out minutiae from the pre-processed fingerprint image and perform matching. When it comes to acquiring fingerprints from devices like mobile phones which is possessed, nowadays, by almost everyone, it becomes a more popular choice because of convenience and feasibility. Also, mobile phone cameras provide a greater depth of resolution in 3D which fingerprint scanners fail to provide. This gives more information about the fingerprint which in turn improves the accuracy of matching decreasing FAR and FRR rates. Also the problem of deformation due to differences in pressure while acquiring fingerprints form scanner is eliminated. Since the quality of fingerprints acquired from mobile phone cameras is resolution dependent, at first sight it seems to be a drawback, but the rising technology trends that provide best resolution cameras in cheaper phones makes resolution dependency, less of a problem. A minimum of 8 MP front camera resolution can acquire best images which can be conveniently pre-processed. Once pre-processing is done, true minutiae can be extracted easily eliminating the false minutiae occurrences. Thus, the touchless mobile phone fingerprint acquisition have become an emerging trend in the field of fingerprint biometrics that will soon replace the traditional fingerprint scanners, safeguarding the security in a more convenient way.

The future work is as follows:

1) Improving the touchless acquisition process without asking user to tap on the screen. This can be achieved by detecting finger inside the bounding box and triggering autofocus. Once the finger image is under focus, the image can be automatically captured. Thus the only obligation for the user that remains is to adjust the finger in the bounding box.

2) An alternate approach to fingerprint pre-processing using Monogenic wavelets needs to be tested against the traditional method described in this report. Monogenic wavelet based pre-processing provides a more accurate way of enhancing finger images that further improves matching accuracy.

3) Incorporating multimodal biometrics in this app. Palmprint along with fingerprint acquisition will further improve identification accuracy and security. Palmprint also involves ROI extraction, pre-processing, feature extraction and matching. Feature extraction in palmprint can be done using convolutional scattering networks.

4) A different approach to minutia extraction and matching of fingerprints acquired from mobile phone camera is required. More specifically, a machine learning approach to fingerprint matching can be done to improve the accuracy of matching score.

5) A study on finger knuckles, its uniqueness and building an identification system to be incorporated in the multimodal biometric app is also a part of future work.

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