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An Automated System for Fingerprint Classification using Singular Points for Biometric Security

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***Abstract*— Automated fingerprint identification system (AFIS) is very popular now days for biometric security because of the uniqueness of individual's fingerprint. The need for fingerprint classification arises due to very large fingerprint databases resulting in long response time which is unsuitable for real time applications. Hence in order to reduce number of comparisons fingerprint classification is necessary. It also plays a key role in identifying fingerprints. In this paper we have proposed a new classification technique based on the detection of singular points (core and delta points) consisting of four stages. In the first stage, preprocessing of input fingerprint image is done followed by fine orientation field estimation in second stage. In the third stage, singular points are located using modified Poincare index technique and hence in the fourth stage, classification is done on the basis of these singular points. The proposed technique was tested on NIST 4 database and the results show a significant improvement in classification of different types of fingerprints.**

Keywords-Biometrics; Fingerprints Classification; Singular Points; Core and Delta Points; Orientation Field; Modified Poincare Index Technique

I. INTRODUCTION

The Fingerprint is the most popular biometric technology and it is a reliable method for personal identification because everybody holds distinctive pattern of fingerprints, even identical twins have different fingerprints [1]. The use of fingerprints for criminal verification, access control, credit card and passport authentication is becoming very popular [2].

Fingerprints are the unique patterns of the ridges and valleys present on the surface of fingertip. These ridges and furrows mostly run in parallel direction sometimes they bifurcate and sometimes terminate. The part or area fingerprint with different patterns of curvature, termination and bifurcation etc is called singular region. The singular points are either delta point or core point depending upon its position and type [3].

A core point is a point at which the orientation in the small area surrounding this point represents a semi circular shape and delta point is a point where a small area around the point forms three sectors with hyperbolic tendency as shown in figure 1[4]. These core and delta points are used for fingerprint classification.

Fingerprint classification is the division of fingerprint images into different classes. The different classes of fingerprints are shown in Figure 2. Classification reduces the time for fingerprint matching.

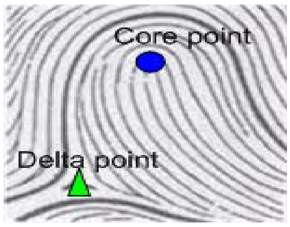


Figure 1. Core and delta points

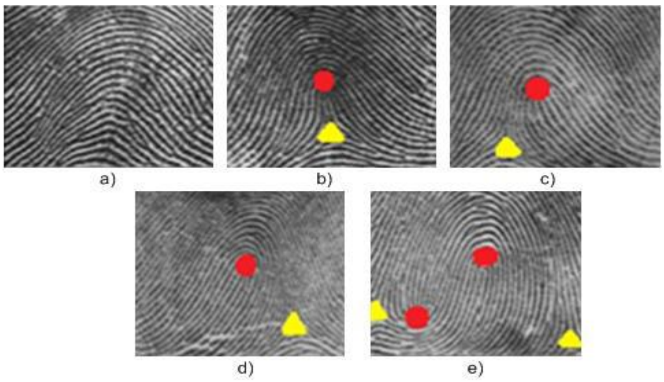


Figure 2. Five classes of fingerprints; a) Arch, b) Tented arch, c)Right loop, d)Left loop, e)Whorl

Many approaches for fingerprint classification have been proposed till now. Monowar and Dhruba proposed an effective method for fingerprint classification by making use of data mining approach. They presented partition clustering technique for the classification of fingerprint images [5]. Chaur-Chin Chen and Yaw-Yi Wang implemented an AFIS by using classification of fingerprints (using number of singular points) and minutiae pattern matching [6]. Liu Wei proposed a finger print classification method based on the singular points. The proposed fingerprint classification method relies on the positioning of singular points, so they should be located accurately. Singular points are detected by using Direction of curvature (DC) technique and Geometry of Region (GR) technique [7]. GonzaloVallarino et al. proposed

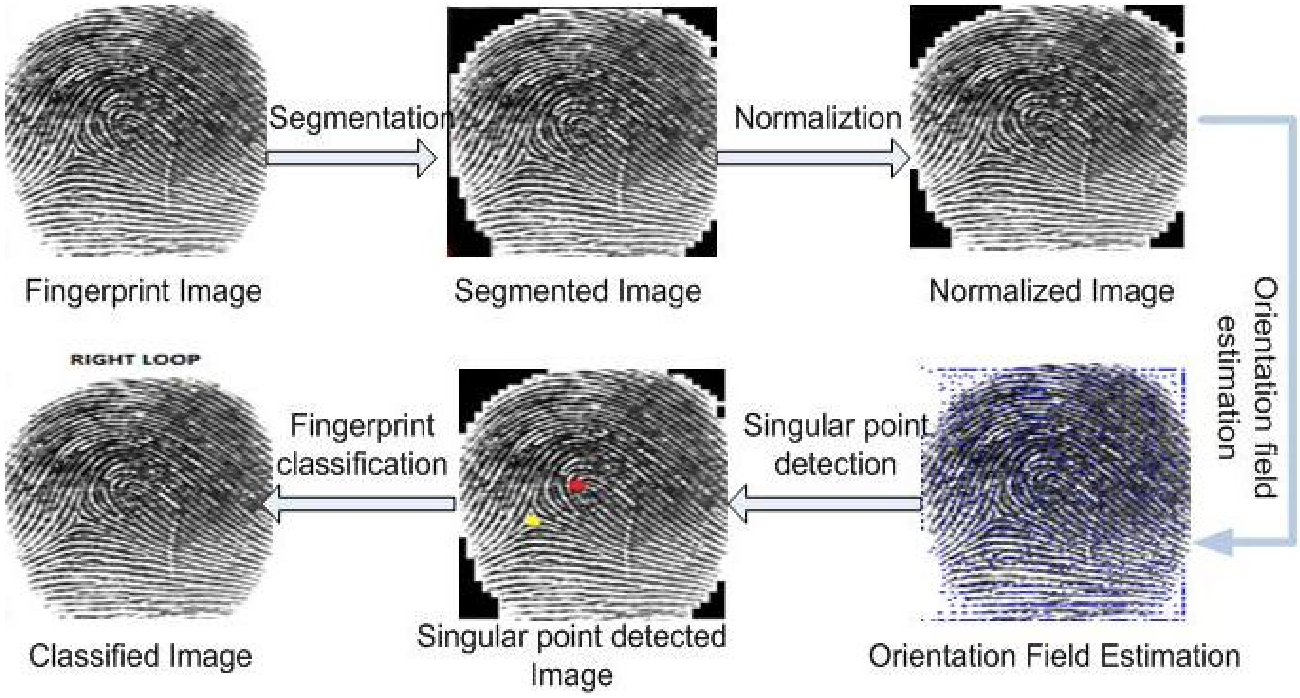


Figure 3: Processing steps of automated fingerprint classification system

a classification algorithm which makes use of the Karu and Jain method and they matched its performance with a manual method used at the Direccion Nacional de Identificacion Civil (DNIC) [8]. Mohammad Rahmati, Ali Jannatpour proposed a new way of finding singular points from the directional image. This method of fingerprint classification uses both the structural method and Fourier transform concurrently [9].

The earlier techniques were not efficient because most of them were unable to make proper utilization of the useful information present in the ridge patterns and they were depended only on the orientation field information. This paper makes the use of singular points for classification because exactly located singular points play a vital role in fingerprint classification. The techniques of fingerprint classification used in the past were able to detect only one core point, which is inefficient for the classification of a fingerprint [10]. The major characteristic of proposed technique is that it detects all core points and also the delta points that exist in the fingerprint image.

The proposed algorithm consists of three stages of processing: First stage is fingerprint image enhancement and Second stage is singular point detection. Our enhancement part increases the quality of image so that singular points are correctly allocated. Singular point detection is done by using Poincare index technique with some modifications. Last stage is the proper classification of fingerprints.

This paper is divided into four sections. In the second section the major steps of fingerprint classification and the techniques used in these steps are presented. The third section discusses the experimental results followed by the conclusion in the fourth section.

II. PROPOSED TECHNIQUE

Automatic fingerprint identification is very useful especially for large databases. In the absence of a fingerprint classification scheme, a lot of time is consumed in matching a specific fingerprint with all fingerprints saved in the database; this makes fingerprint identification process slow.

Fingerprint classification divides the fingerprints into pre-specified categories. Therefore it is needed that during fingerprint matching a specific fingerprint should be matched to the fingerprints of the same category present in the database [9]. This speeds up the fingerprint identification process. The Figure 3 shows the important processing steps involved in fingerprint classification system.

A. Preprocessing

The Preprocessing of fingerprint image involves segmentation (the process of separating background from the foreground image) and normalization (the process of standardizing the variation in gray-level values of an image) for enhancing the fingerprint image, for removal of noise and other irrelevant information [11]. The main steps in image pre-processing are following:

I. Segmentation

Segmentation is performed in order to separate fingerprint region from the background [12]. A modified Gradient based technique is used for segmentation of fingerprints. The brief form of steps performed during segmentation is given below [13]:

a) Take input fingerprint image I (i, j) and divide it into separate blocks.

b) Histogram equalization method is used for enhancing the contrast of fingerprint image.

c) A median filter of size 3x3 is used for noise reduction.

d) Gradients x and y are computed at the center of each block.

e) Now calculate mean values for x and y components of the gradient using equation no. (1) and (2) respectively.

$$M_x = \frac{1}{k^2}\sum_{i=-k/2}^{k/2}\sum_{j=-k/2}^{k/2}\partial_x(i,j) \quad \ldots (1)$$

$$M_y = \frac{1}{k^2}\sum_{i=-k/2}^{k/2}\sum_{j=-k/2}^{k/2}\partial_y(i,j) \quad \ldots (2)$$

f) Now calculate standard deviation of x and y components using equation no. (3) and (4) respectively.

$$std_x = \sqrt{\frac{1}{k^2}\sum_{i=-k/2}^{k/2}\sum_{j=-k/2}^{k/2}(\partial_x(i,j) - M_x(I))^2} \quad \ldots (3)$$

$$std_y = \sqrt{\frac{1}{k^2}\sum_{i=-k/2}^{k/2}\sum_{j=-k/2}^{k/2}(\partial_y(i,j) - M_y(I))^2} \quad \ldots (4)$$

g) Calculate gradient deviation using equation no. (5).

$$grddev = std_x + std_y \quad \ldots (5)$$

h) The value of threshold is selected after testing. The block of fingerprint image is taken as a foreground if gradient deviation is greater than the threshold value; otherwise it is taken as background [13].

II. Normalization

The Normalization is the process of changing the range of gray-level values. It is also called contrast stretching. [14]. The steps involved in normalization process are:

a) At pixel (i, j) gray-level value is denoted by I(i,j). Equation no. (6) is used to calculate the normalized value 'N'.

$$N(i,j) = \begin{cases} M_0 + \sqrt{\frac{V_0 (I(i,j) - M)^2}{V}} & if\ I(i,j) > M \\ M_0 + \sqrt{\frac{V_0 (I(i,j) - M)^2}{V}} & otherwise \end{cases} \quad \ldots (6)$$

In this equation M_0 is desired mean and V_0 is the variance.

b) The mean '*M*' and variance '*V*' of the fingerprint image are calculated using equation no. (7) and (8) respectively.

$$M(I) = \frac{1}{LN}\sum_{i=0}^{L-1}\sum_{j=0}^{N-1} I(i,j) \quad \ldots (7)$$

$$V(I) = \frac{1}{LN}\sum_{i=0}^{L-1}\sum_{j=0}^{N-1}(I(i,j) - M(I))^2 \quad \ldots (8)$$

In above equations *I (i, j)* is used to represent the pixel intensity at the *ith* row and the *jth* column [13].

B. Orientation Field Estimation

The Orientation field estimation plays a vital role in fingerprint identification systems. The orientation field image presents the inherent property of fingerprints and it gives the coordinates of valleys and ridges in local neighborhood [15].

Orientation field estimation is used for the detection of core points and for fingerprint matching process. Let θ denote the orientation field of a fingerprint image [4].

The basic steps of the estimation of smooth orientation field using *least mean square algorithm* are given below:

a) Take an input fingerprint image I and divide it into separate blocks.

b) Now compute the gradient $\partial_x(i,j)$ and $\partial_y(i,j)$ at the center of every block.

c) Now compute the local orientation using equation no. (9) And (10) [16].

$$V_x(i,j) = \sum_{u=i-w/2}^{i+w/2}\sum_{v=j-w/2}^{j+w/2} 2\partial_x(u,v)\partial_y(u,v), \quad \ldots (9)$$

$$V_y(i,j) = \sum_{u=i-w/2}^{i+w/2}\sum_{v=j-w/2}^{j+w/2} \partial_x^2(u,v)\partial_y^2(u,v), \quad \ldots (10)$$

Then, calculate θ using equation 11.

$$\theta(i,j) = \frac{1}{2}\tan^{-1}\left(\frac{V_y(i,j)}{V_x(i,j)}\right) \quad \ldots (11)$$

In this equation θ (i,j) represents least square estimate of local ridge orientation at a certain block.

d) Noise causes the discontinuity in ridges and valleys which is softened by applying a low pass filter. Orientation field image is needs conversion into continuous vector field for apply a low pass filter. The components of a continuous vector filed are defined by equation no. (12) And (13) [16].

$$\Phi_x(i,j) = \cos(2\theta(i,j)), \quad \ldots (12)$$

$$\Phi_y(i,j) = \sin(2\theta(i,j)), \quad \ldots (13)$$

e) Now apply a two dimensional low pass filter G on this continuous vector field using equation 14 and 15. The size of specified filter is wΦx wΦ.

$$\Phi'_x(i,j) = \sum_{u=-w_\Phi/2}^{w_\Phi/2}\sum_{v=-w_\Phi/2}^{w_\Phi/2} G(u,v)\cdot\Phi_x(i-uw, j-vw), \quad \ldots (14)$$

$$\Phi'_y(i,j) = \sum_{u=-w_\Phi/2}^{w_\Phi/2}\sum_{v=-w_\Phi/2}^{w_\Phi/2} G(u,v)\cdot\Phi_y(i-uw, j-vw), \quad \ldots (15)$$

f) Smooth orientation field can be computed by using equation no. (16) [16].

$$\theta'(i,j) = \frac{1}{2}\tan^{-1}\left(\frac{\Phi'_y(i,j)}{\Phi'_x(i,j)}\right) \quad \ldots (16)$$

C. *Singular Points Detection*

Singular points include core points and delta points. Accurate allocation of these points is necessary for fingerprint classification. A modified Poincare index technique is used for the detection of singular points [17]. The main steps involved in singular points detection are described below:

I. *Computation of Poincare index for the oriented image*

The Poincare index of each pixel of oriented image is calculated using Poincare index technique. Where oriented image is the image obtained after orientation field estimation. The most commonly used technique for the detection of core and deltas points is the Poincare index technique [18].Poincare index technique can be summarized as [4]:

a) The ROI (region of interest) is located on the basis of background certainty.
b) A new image (A) is taken in order to present the core points.
c) Compute Poincare index at each pixel of the oriented image , PC (i,j),where

$$PC(i,j) = \frac{1}{2\pi}\sum_{k=0}^{N_p-1}\Delta(k) \qquad \text{… (17)}$$

$$\Delta(k) = \begin{cases} \delta(k) & if\ \delta(k) < \pi/2 \\ \pi + \delta(k) & if\ \delta(k) \leq -\pi/2 \\ \pi - \delta(k) & otherwise \end{cases} \qquad \text{… (18)}$$

Now,

$$\delta(k) = \varepsilon(x_{(k+1)\bmod N_p}, y_{(k+1)\bmod N_p}) - \varepsilon(x_k, y_k) \qquad \text{.. (19)}$$

In the above equation Np denotes particular number of points.

d) For a core point the Poincare index should be in range (0.45 and 0.55). If it is true, then the related pixel A(i,j) is labeled as 1 otherwise it is labeled as 2. A block is called a delta block if its Poincare index is (-0.5).
e) Find all the linked components in image A with the pixel values equal to 1. The largest area among them will have the core point.
f) After this, calculate the centroid of that area. This centroid will give the core point location.

II. *Optimal Detection of singular points*

a) Take a new image (A) for indicating the singular points.
b) At each pixel in the Poincare image, assign the corresponding pixel in image (A) a value equal to '1' If (0.45 <Poincare Index<= 0.55) and a value equal to '2' If (-0.55 <Poincare Index<= -0.45).
c) Find out all the linked components in image (A) having the pixel values equal to 1. Compute the area of each of these linked components. Suppose LC denote the biggest area among these components, then
   - If (LC < 7),
     Core point does not exist.
   - If (LC > 7 && LC < 20),
     Compute the central point of that component having biggest area LC. This central point is the position of the core point.
   - If (LC > 20),
     Compute the central points of the two linked components having the biggest areas. These central points give us the location of the two core points.
d) Find out the entire linked components in A having the pixel values equal to 2. Compute the area of each of those linked components. Suppose LD denote the biggest area among those components, then
   - If (LD = = 0),
     Delta point does not exist,
   - If (LD > 0 && LD < 7),
     Compute the central point of that component having biggest area LD. This central point is the position of optimal delta point.
   - If (LD > 7),
     i) Compute the central point of the component having the biggest area LD. This central point gives the location of first delta point.
     ii) Calculate the central point of the component having biggest area less than or equal to '7'. This central point is the location of the second delta point [4].

D. *Fingerprint Classification*

Fingerprint classification is the division of fingerprints into different classes. The division of fingerprints is done on the basis of number of core and delta points. There are mainly five classes of fingerprints which are; (1).Arch, (2).Tented arch, (3).Left loop, (4).Right loop and (5).Whorl.

The classification criteria used in proposed technique is as follows:

- If number of core points is two, i.e. Nc=2 and two delta points are present, i.e. Nd=2, then the class of fingerprint is 'Whorl'.
- If no core points are present, i.e. Nc=0 and no delta points are present, i.e. Nd=0,, then the class of fingerprint is 'Arch'.
- If there is one core point, i.e. Nc=1and one delta point, i.e. Nd=1, then classify the fingerprint image

using the core and delta assessment algorithm given below.

- If all of the above conditions are not satisfied then reject the fingerprint.

The core and delta assessment algorithm is used to classify a one-core and one-delta fingerprint into one of the following categories: (i) Left loop, (ii) Right loop, and (iii) Tented arch. The steps of this algorithm are:

- Estimate the symmetric axis which crosses the core in its local neighborhood.
- Compute the angle (α) between the symmetric axis and the line segment which matches the core point to delta point.
- Compute the average angle difference (β) between the local ridge orientation on the line segment which matches the core point to the delta point and the orientation of the line segment.
- Count the number of ridges (γ) that cross the line segment which matches the core point to the delta point.
- If ($\alpha < 10^{o}$) or ($\beta < 15^{o}$) and ($\gamma = 0$), then classify the input as a tented arch.
- If delta point is located to the right side of the axis then classify the input fingerprint to left loop class.
- If the delta point is located to the left side of the axis then classify the input fingerprint to right loop class.

III. EXPERIMENTAL RESULTS

The proposed classification technique is tested on NIST 4 database [19] for checking the performance of our system. This database consists of 2000 8-bit gray scale image pairs. Each image is of 512x512 pixels and classified using 5 classes as described in figure 2. The database is evenly distributed over each of the five classes with 400 fingerprint pairs from each class. Table I shows the accuracy of developed system. Accuracy is the ratio of correctly classified fingerprint images. Proposed method achieved an accuracy of 96.55% for five classes as it has correctly classified 3862 out of 4000 test fingerprint images. Table II shows the average processing time for each step of fingerprint classification. The experiments were carried out on an hp dv-6 workstation with core i-5 (2.24 GHz) and with 4GB RAM. MATLAB 7.8 (R2009a) revised version in windows (64-bits) platform was used for the performance evaluation. Table III shows the confusion matrix for 800 images in the database. Each row in the table sums up to 800. A large number of misclassification errors come between arch and tented arch classes.

TABLE I. FINGERPRINT CLASSIFICATION RESULTS

Parameter	Value
Average Accuracy	0.9655
Accurate fingerprint classification	96.55%
Inaccurate fingerprint classification	3.45%

TABLE II. AVERAGE PROCESSING TIME

Steps	Time (ms)
Segmentation	135 ms
Normalization	10 ms
Orientation Field Estimation	125 ms
Singular Points Detection	100 ms
Classification	5 ms

TABLE III. CONFUSION MATRIX

True Class	Assigned Class				
	Right loop	Left loop	Arch	Tented Arch	Whorl
Right loop	789	8	1	1	1
Left Loop	10	785	1	3	1
Arch	1	1	750	50	1
Tented Arch	1	2	49	747	1
Whorl	3	2	1	3	791

The proposed classification technique is capable of classifying the fingerprints at a good success rate. The results of correct classification are shown in Figure 4 and Figure 6. Only 5% fingerprints were misclassified or wrongly classified (shown in Figure 5). This is mostly due to the non-presence of the core or delta points or due to the poor quality of fingerprint.

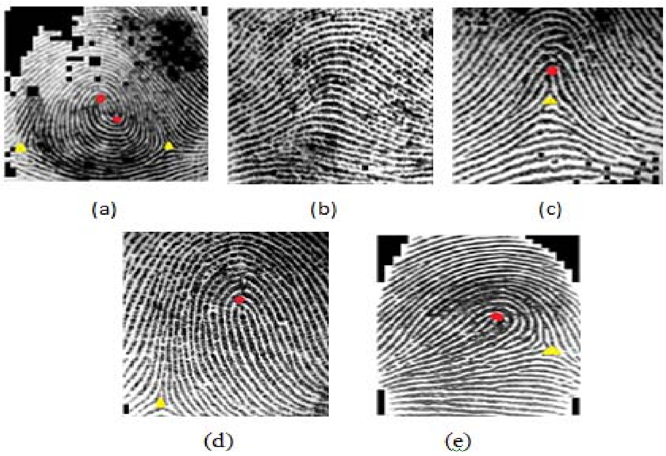


Figure 4. Correctly Classified Images (a) Whorl, (b) Arch (c) Tented Arch, (d) Right loop, and (e) Left loop.

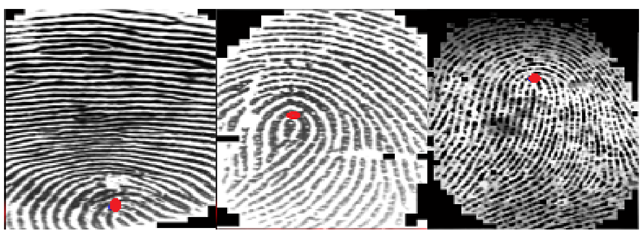
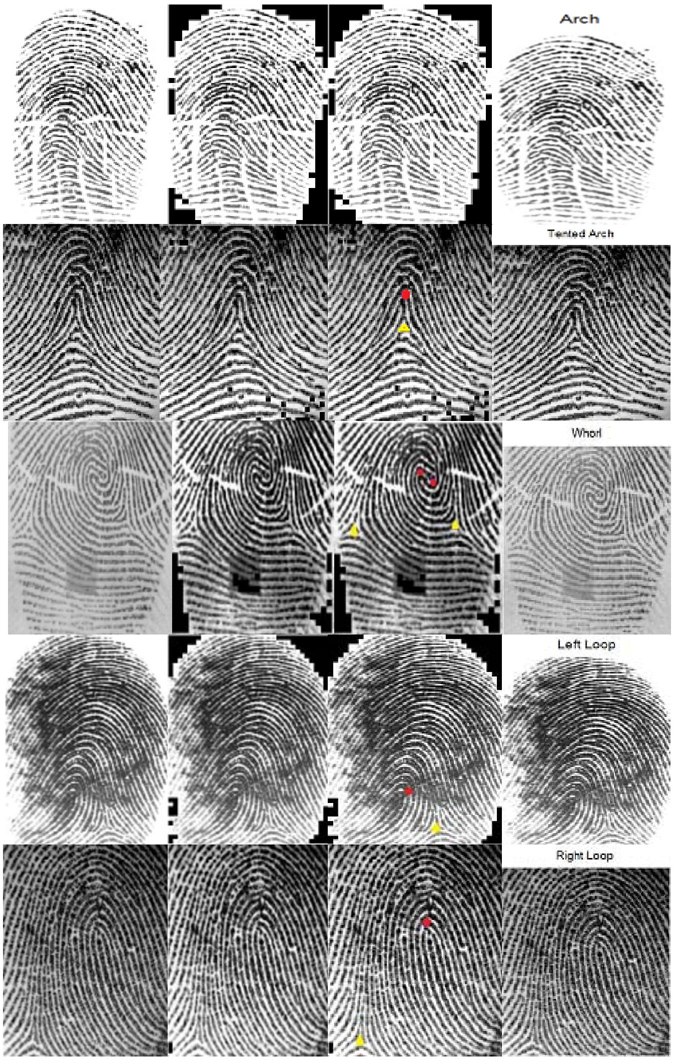


Figure 5. Wrongly Classified Images (only one core point, no delta or second core point detected).



(a) (b) (c) (d)

Figure 6. Correctly Classified Images. Column (a): Original images, Column (b): preprocessed images, Column (c): Images with singular points, Column (d): Final classified images.

IV. CONCLUSION

The fingerprint classification technique presented in this paper is largely dependent on the singular points i.e. core and delta points. Image segmentation technique is used for extracting the ROI from the input image and then for the accurate location of singular points, a modified Poincare index technique is used. The proposed technique used for the singular points detection is very useful because the previous techniques were able to detect only a single core point, whereas this technique can detect all core points and delta points present in the fingerprint image and gives very good results. About 95% of fingerprints are successfully classified using proposed technique. The proposed classification system is simple but an effective system that classifies fingerprints on the basis of singular points present in them. It is an automated system so it is less labor demanding. Results of system are quite encouraging. This system will be helpful in the field of biometrics and it is used in fingerprint identification systems.

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