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Procedia Computer Science 2 (2010) 133–142

Procedia Computer Science

www.elsevier.com/locate/procedia

ICEBT 2010

An efficient Algorithm for fingerprint preprocessing and feature extraction

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Abstract

In practice, the placement of finger on the scanner for authentication is not done with the utmost care as when placed during the enrollment and this result in rejections of genuine users. Moreover, user behaviour and envionmental conditions decrease the geniune acceptance rate (GAR) for authentication of fingerprints. To overcome these limitations, an efficient preprocessing algorithm is proposed to achieve good vertical orientation and high ridge curvature area around the core point for fingerprint authentication and analysis. The algorithm is implemented in two stages. The process of obtaining the vertical oriented fingerprint image is carried out in the first step. This is followed by core point detection of a fingerprint. Core point detection is efficiently identified for any type of fingerprints. The developed algorithm is tested using a line based feature extraction algorithm with a large internal database and samples of fingerprint vericication competition (FVC). Only for the poor quality images, broken ridges are identified which results in a difference in minutiae points. With the proposed algorithm 94% of the tested images were oriented vertically and its genuiness is verified by comparing the minutiae details of the oriented and unoriented image of the same subject.**

Keywords: Vertical orientation, high ridge curvature area, Core detection. Feature extraction

1. Introduction

A fingerprint is the pattern of ridges and furrows on the surface of a fingertip. At a fine level or local level, the characteristic of ridges and valley are known as minutiae. In reality, the fingerprints are not exactly vertically oriented and it may be ±45º away from the assumed vertical orientation [1]. In this paper, the finger print image rotation is carried out well before image enhancement for the process of extraction of high curvature area around the core point. Also, a good orientation model can provide a comprehensive description of the subject that enables discovery of the embedded features.

Minutiae around the core point play an important role as it is useful in many applications particularly in fingerprint classification and fingerprint analysis. User behaviour and environmental considerations such as angle and placement of the finger on the scanner, dirt or residue on the sensor, injury or residue on the finger are also necessary for fingerprint matching and analysis. Enrolment of quality fingerprints may be achieved when collection of multiple samples from a same subject is possible. There are applications where decision should be made with a single available template. The existing method does not reliably handle poor quality fingerprints when the orientation field is very noisy and can be misled by poor structural cues due to the presence of finger cracks. Around the core point rich minutiae information's exist than other region, which is necessary for the fingerprint verification/identification [2].

Initially, the enrolled fingerprint image is oriented vertically using rotation algorithm. The orientation of the image is estimated as the angle between the x axis and the major axis of the ellipse. A reasonably good quality images with an angular displacement of 1to ±90 degrees are oriented vertically. In the proposed algorithm, the candidate core pixel is selected by considering all the pixel locations where the sum of all the difference values in the window is around 360, where we use a tolerance of ±3. Then all the candidate pixels present close to each other are bridged together and only the centroid of the region is considered. After vertical orientation and core detection, the region of interest with core point and high curvature pattern is cropped by selecting n pixels around the core point. The selection of n pixels depends on the application and necessity. The proposed processes are verified with the line based feature extraction developed by the authors [8].

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doi:10.1016/j.procs.2010.11.017

This paper is organized as follows. Section 2 addresses the literature review. The steps involved in the proposed algorithm are described in Section 3. Section 4 contains the experimental results using line based feature extraction algorithm followed by the summary in section 5.

2. Literature Review

In reality, fingerprints enrolled in the database are not exactly vertically oriented and may be displaced angularly away from the vertical orientation. A.K. Jain et al. [9] showed that the image rotation is partially handled by a cyclic rotation of the feature values in the FingerCode in the matching stage; in future implementations, the image rotation will be correctly handled by automatically determining the fingerprint orientation from the image data. The orientation field is reliably estimated using the methods based on neural networks [10], gradient based approach [3, 11] and filter based approaches [12]. The filter based approaches are not as accurate as gradient based because of limited number of filters [13]. Hong et al [14] proposed a decomposition method to estimate the orientation field from a set of filtered images obtained by applying a bank of Gabor filters on the input fingerprint images. Although this algorithm can obtain a reliable orientation estimate even for corrupted images, it is computationally expensive which makes it unsuitable for an on-line verification system [3]. The proposed algorithm detects the angular displacement accurately and rotates the image vertically without disturbing the quality of the image.

It is dificult to detect fingerprint core exactly when the nonlinearity of the boundary curve become higher. Linear approximation is applied to generate approximated straight line of the segment boundary curves. Direction of curvature technique (DC) has been used in coarse core point detection whilst geometry of region (GR) technique is used in the fine finding of the core point [15]. Nevertheless this algorithm fails in locating the core point of the fingerprint with arc structure. The general relational graph proposed [1] has only the adjacent relationship between directional segments. The extended relational graph has additionally the boundary information between segments and the direction of each segment [16].

Core detection is carried out as a second stage. The majority of existing algorithms are based on the calculation of Poincare index (PI) [5] using the computed directional field of the fingerprint. The drawback of the methods based on PI is a tendency to return false positive detections of singular points, in particular in fingerprints of degraded quality [5-7]. The extended relational graph has (additionally) the boundary information between segments and the direction of each segment. In the proposed approach, the orientation is calculated from the thinned image and then the difference angle to pick the candidate pixels for core point. By further processing (logically and morphologically), the right candidate pixel (core point) is identified and all the false pixels which have been considered as candidate pixel are eliminated. The pre-processed fingerprint after vertical orientation and core detection is applied to the line based fingerprint feature extraction algorithm [8].

3. Proposed Algorithm

The block diagram shown in fig 1 demonstrates the two stage processing (shown within the dotted box). For fingerprint image enhancement an efficient Gabor Filters based method is adopted [3]. Also, thinning is performed for the binary image [4]. To refine the ridges three stages of Morphological filtering is performed. The process of image orientation, enhancement, core detection and process of finding region of interest are as given below.

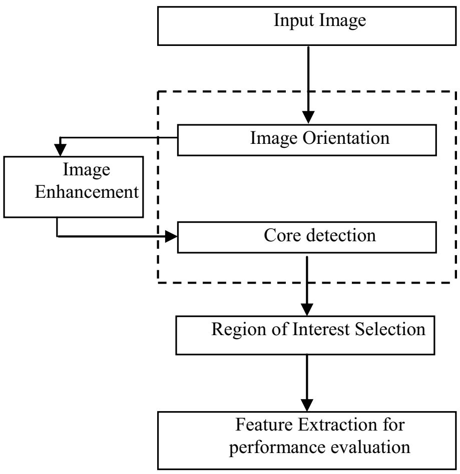


Fig.1. Image orientation and Core detection process flow chart

3.1. Image Orientation

An input image is read from graphics file. Bilinear interpolation is adopted to resize the image into a standard or assuming constant size. Let I(x, y) denote a two dimensional grey-scale image, Fig 2 explains the steps involved in the fingerprint rotation process

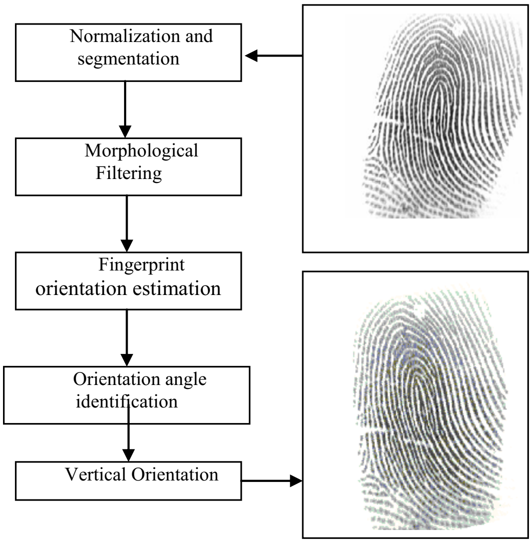


Fig.2. Fingerprint rotation process

(i) Normalization and Segmentation: This process identifies the ridge region of the input image. The given input image is segmented into blocks of size n x n and the standard deviation (STD) in each region is evaluated. If the standard deviation is above the threshold it is marked as part of the fingerprint. The image is normalized to have zeroed mean, unit standard deviation prior to performing this process so that the threshold specified is relative to a unit standard deviation. MASK image I_{M1} is obtained using equation (1), (2) and (3)

$$I(x,y) = I(x,y) - mean(I) \quad (1)$$

$$I(x,y) = I(x,y)/STD(I) \quad (2)$$

$$I_1(x,y) = RM + I(X,Y) \times SQRT(RV) \quad (3)$$

Where, RM is the required mean and RV is the required variance.

(ii) Morphological Filtering: Morphological filtering is based mainly on some mathematical morphology transformations [17, 18]. Here we perform morphological closing on the normalized and segmented gray scale image IM1 (equation 3) to obtain the closed image, I_{M2}. The structuring element (SE) must be a single structuring element object, as opposed to an array of objects. The morphological close operation is a dilation followed by erosion, using the same structuring element for both operations. This fills the image regions and holes.

Dilation of a MASK image $I_{M1}(x, y)$ by a structuring element SE (m, n) is denoted by $I_{M2}(x, y)$

$$I_{M2}(x, y) = D(I_{M1}, SE)(x, y) = \max\{I_{M1}(x - m, y - n) + SE(m, n)\} \quad (4)$$

Erosion of $I_{M2}(x, y)$ by a structuring element SE (m, n) is denoted by $I_{M3}(x, y)$

$$I_{M3}(x, y) = E(I_{M2}, SE)(x, y) = \min\{I_{M2}(x + m, y + n) - SE(m, n)\} \quad (5)$$

(iii) Fingerprint Orientation Estimation: Taking the MASK image as input, the orientation or the angle between the x-axis and the major axis of the ellipse bounding the MASK IM3 image that has the same second-moments as the region is calculated. Normalized second central moments of a pixel with unit length for the region 1/12 is calculated.

$$G_{XX} = \sum \frac{x^2}{N} + (1/12) \tag{6}$$

$$G_{YY} = \sum \frac{y^2}{N} + (1/12) \tag{7}$$

$$G_{XY} = \sum \frac{xy}{N} + (1/12) \tag{8}$$

If $G_{YY} = G_X$

$$\text{Num} = G_{YY} - G_{XX} + \sqrt{(G_{YY} - G_{XX})^2 + 4 \times G^2{}_{XY}} \tag{9}$$

$\text{Den} = 2 \times G_{XY}$

Else

$$\text{Num} = 2 \times G_{XY} \tag{10}$$

$$\text{Den} = G_{XX} - G_{YY} + \sqrt{(G_{XX} - G_{YY})^2 + 4 \times G^2{}_{XY}} \tag{11}$$

End

If $\text{Num} == 0 \;\&\; \text{Den} == 0$

Orientation =0

Else

$$\text{Orientation} = \frac{180}{\Pi} \times \tan^{-1} \text{Num/Den} \tag{12}$$

End.

(iv) Orientation Angle Identification: If orientation obtained in equation (12) is less than zero, the orientation angle is negative and if the orientation is greater than zero, the orientation angle is positive. This is done to ensure whether the rotation should be in clockwise (negative) or counter clockwise (positive).

If Orientation < 0

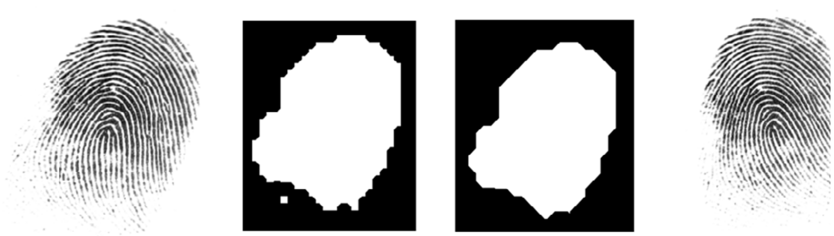
$$A = -(90 + \text{Orientation}) \tag{13}$$

Else

$$A = (90 - \text{Orientation}) \tag{14}$$

End

(v) Vertical Orientation: Calculated angle of rotation is used to rotate the whole image. Nearest neighbour interpolation is used to set the values of pixels in the rotated image. Obtain the mask for the rotated image by slightly shrinking the mask using morphological erosion with a SE 'disk' of radius 3. Finally by converting the values of the region outside the mask to maximum value (255), the final rotated image is obtained. Fig 3 shows the results of the rotation process.

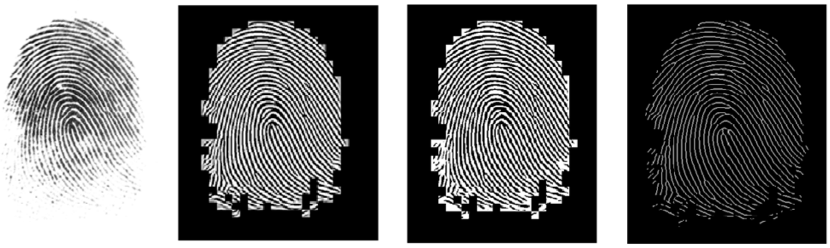


(a) (b) (c) (d)

Fig.3. Results after rotation :(a) Input image, (b) mask image before filtering (c) mask after morphological filtering (d) Image after rotation process.

3.2. Enhancement

Gabor Filters based technique is used for the enhancement of the image [14]. Enhancement process involves normalization, segmentation of ridge region, removal of small objects morphologically and estimation of the local orientation of ridges in a fingerprint. Thinning is performed for the obtained binary image [4]. Enhancement of fingerprint is illustrated in fig. 4



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

Fig. 4. Results after Enhancement (a) Image after Rotation, (b) Enhanced Grayscale Image (c) Enhanced Binary Image (d) Image after thinning

To refine the ridges three stages of filtering is performed using morphological filtering

- Connect the disjoint pixels, so that all the 0-valued pixels are converted to 1 where it has two nonzero neighbours without connection.
- Remove the isolated pixels i.e. if the centre pixel is 1 and all the neighbours are 0's then the centre pixel is considered to be isolated and converted to 0.
- Remove H-connected pixels i.e. if the centre pixel is 1 and it is connected to its neighbours as H, it is converted to 0.

3.3. Core Detection

The proposed core detection algorithm is as follows. Fig. 5 shows the results of core detection.

(i) The thinned image obtained after filtering is transformed to complement greyscale image by replacing 0's to 255 and 1's to 0's.

(ii) The local orientation of ridges in a fingerprint is estimated and the region mask is applied. Since the orientation is calculated in radians it is converted to degrees.

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

Fig. 5. Results after Core Detection (a) Thinned image with candidate core pixels marked in red, (b) result after bridging the closer points and minimizing (c) result after applying conditions 1 and 2 (d) Final core detected image

(iii) For every 3x3 window the difference between the angles is obtained and the following conversion is made. Let D (k) is the difference angle for kth element in the window k = {1, 2, 3 …8}.

If D (k) <= -pi/2

$$D(k) = D(k) + pi; \tag{15}$$

Else if abs *(D (k)) < pi/2*

$$D(k) = D(k); \tag{16}$$

Else

$$D(k) = pi - D(k); \tag{17}$$

End

Obtain the sum of all difference values in the window.

(iv) The candidate core pixel is selected by considering all pixel locations where the sum of all the difference values in the window is around 360, where we use a tolerance of ±3. Now all the candidate pixels present close to each other are bridged together and only the centroid of the region is considered.

(v) Considering the thinned image around each candidate core pixel, a 3x3 window is taken and the pixels at each side of the window is taken as n1,n2,n3 and n4. The false core pixels are eliminated based on the following two conditions.

1. If $(n_1 \,\&\, n_3) > 0 \,\&\, (n_2 \,\&\, n_4) == 0$ (18)
2. If $(n_2 \,\&\, n_4) > 0 \,\&\, (n_1 \,\&\, n_3) == 0$ (19)

(vi) As a final step, if still more than one pixel is marked, the candidate pixel which is closest to the centre of the fingerprint mask is considered to be the identified core point.

3.4. Region of Interest

On completion of detection of core point, region of interest is cropped from the image. For cropping of the region of interest, 'n' pixels around the core point are selected. Number of pixels around the core point 'n' is chosen to be 100 -200 such that an adequate area around the core is considered.

(a) (b)

Fig.6. Results after Core Detection (a) Input to the algorithm, (b) Output of our method

3.5. Feature Extraction

The line based feature extraction algorithm [8] is used to find the features in the identified region of interest image. The line based feature extraction is briefed as follows. By using connected component analysis and the ridge tracing approach, all connected line segments with respect to all the pixels are determined. The minutiae extraction process is accomplished by block processing. In order to validate the minutiae, post processing is performed on the minutiae extracted image. Two features are identified as shown in fig. 7. Bifurcation is shown as red colour and termination revealed by yellow colour.

(a) (b)

Fig. 7. Feature extraction process. (a) Input image (b) feature extracted image. Bifurcation is represented by red color; termination is represented by yellow color.

4. Data Set

Fingerprint images of FVC2004 DB1_A database [19] and internal database were used to evaluate the proposed preprocessing algorithm. The internal database fingerprint images were collected using fingkey Hamster II scanner manufactured by Nitgen biometric solution, Korea [20]. The size of the FVC images is of 8 bit gray level with a size of 640 X 480 and the internal database is of 8 bit gray level with a size of 260 x 300 and resolution of 500 dpi. FVC2004 DB1_A database contains 800 images categorized from 1 to 100 and in each category there are 8 samples of same finger. The images are numbered from 1_1 to 100_8. The internal database fingerprints are collected from various peoples irrespective of gender and age. When these fingerprints were captured without any restrictions on the position, pressure on the scanner and orientations were imposed. All 10 fingers of each person were scanned. To test the proposed algorithm three images of a person is scanned, one with vertically oriented and other two with different orientation. Altogether, the internal database contains 2500 fingerprints of 250 people and 750 samples (250x3) of index fingers. The line based feature extraction algorithm developed by the author [8] is used to analyze the results obtained from the application of the proposed algorithms.

The fingerprint images in the database vary in quality. The developed algorithm has been simulated, debugged and tested on a PC with an Intel(R) Celeron(R) CPU 540 @ 1.86 GHz, 1.99 GB of RAM and using the MAT LAB 7.1 image processing tool. For the verification process of the proposed algorithm, 750 samples of index fingerprint and some randomly selected samples of FVC2004 DB1_A database are used.

5. Experimental Results

The angle of rotation is positive if the image is oriented vertically in counter clockwise direction and negative if the image is rotated clockwise direction. Fig.8 depicts samples of FVC2004 data base and internal database. In addition, its rotated image along with its core point is shown.

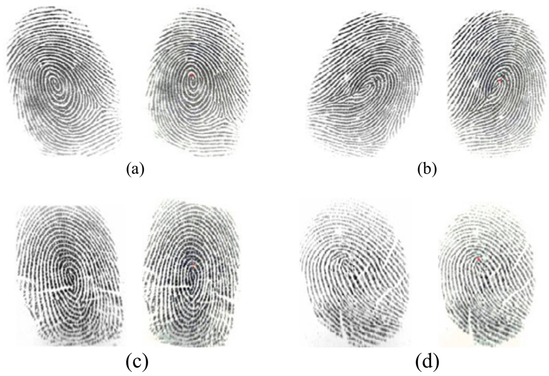


Fig. 8 (a) FVC2004_DB1_7_6 input image and its rotated image and core point. The angle of rotation is -10.3171 degrees. (b) FVC2004_DB1_8_6 input image and its rotated image and core point. The angle of rotation is+8.7009 degrees. (c) Internal DB_233_9 input image and its rotated image and core point. The angle of rotation is-11.2726 degrees (d) Internal DB_143_10 input image and its rotated image and core point. The angle of rotation is-5.0534 degrees

The core detection is tested with all 8 types [21] of the fingerprint classification. By manual verification, it is found that the core detection algorithm provided satisfactory results. The region of interest with core point and high curvature pattern is cropped by selecting ‘n’ pixels around the core point. In the proposed algorithm ‘n’ is chosen as 200. However ‘n’ may be chosen between 100 and 200 to select the region of interest based on the requirement and the application.

By doing the rotation process, the change in the number of bifurcation and termination in the rotated image is carried out using line based algorithm [8]. The proposed algorithm is tested as follows. Five samples of FVC2004 DB1_A and five samples of internal database are selected randomly. Feature extraction is performed in the input image and the number of bifurcation (B) and termination (T) noted. The details are noted after the feature extraction is performed in the rotated image. On comparing the features between the input image and the rotated image the accuracy of the proposed algorithm is calculated. The results are provided in the table. I.

Table 1. Results of feature extraction

FVC2004 DB1_A				
	Minutiae Details			
Sample Name	**Input image**		**Rotated image**	
	B	**T**	**B**	**T**
7_6	25	10	24	11
8_5	14	19	15	18
10_6	27	15	25	14
26_5	26	15	25	16
27_6	20	10	18	9
Internal Database				
116_4	26	7	25	6
143_10	14	18	14	17
214_8	12	5	11	4
224_9	14	4	15	5
233_9	18	9	20	9

In the first column, the sample names of FVC2004 DB1_A and internal database are listed. The details of the feature extracted are given in the second column for the input image and the details of the feature extraction of the rotated image are shown in the third column.

The percentage difference between the minutiae extraction obtained from the input image and the processed image is calculated as follows. Let the number of features of cropped input image is x1 and the number of features of rotated cropped image is x2. The percentage difference (x) in the minutiae extraction is calculated as follows.

If $x_1 > x_2$,

$$x = \frac{|x_1 - x_2|}{x_1} \times 100 \tag{20}$$

This value indicate that the rotated image has x percentage less minutiae than the given input image. It is indicated in the table 2 as negative

If $x_1 < x_2$.

$$x = \frac{|x_1 - x_2|}{x_2} \times 100 \tag{21}$$

This value indicate that the rotated image has x percentage more minutiae than the given input image. It is indicated in the table 2 as positive. In Table II, the percentage difference x is tabulated and the line chart of the table II is shown in fig. 9.

Table 2. Percentage difference (x) of cropped input image and rotated image

FVC2004 DB1_A		
Sample Name	Bifurcation	Termination
7_6	-4	9.1
8_5	6.6	-5.3
10_6	-8	-6.6
26_5	-3.8	6.3
27_6	-10.	-10
Internal Database		
116_4	-3.8	-14.3
143_10	0	-5.5
214_8	-8.3	-20
224_9	6.6	20
233_9	10	0

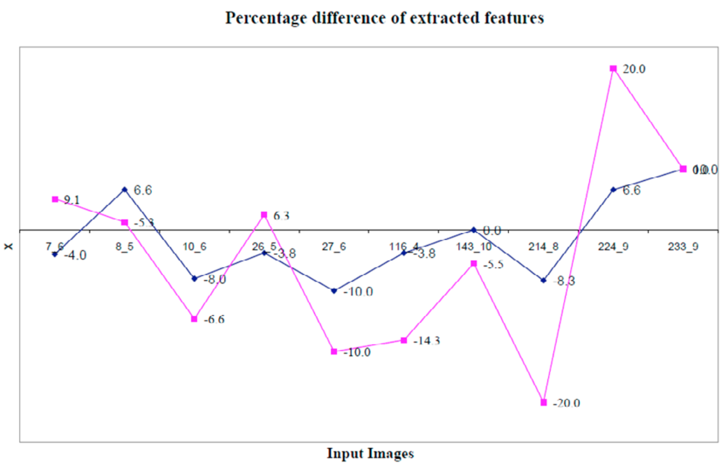


Fig. 9. Line chart

The average percentage difference of bifurcation between the cropped input image and the rotated and cropped image is 6.11. Similarly, the average percentage difference of termination between the cropped input image and the rotated and cropped image is 9.71. Average time consumed for the various process of the algorithm is listed in the table 3. The average time for complete process is found less than 5.5 sec and for better illustration the in fig. 10 bar chart is shown.

Table 3. Time taken for various processes in our method

S. No	Process	Time(s)
1	Rotation	1.3021
2	Enhancement	2.2769
3.	Morphological Filtering	0.1164
4.	Core Detection	1.7978
5.	Alignment	0.0429
	Total	5.5361

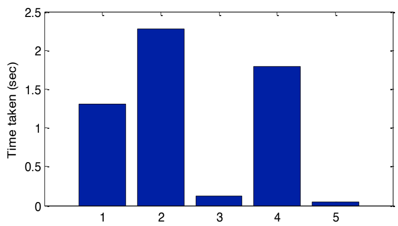


Fig. 10. Bar chart illustrating the time consumption of the processes mentioned in table III.

The proposed algorithm is tested with 640 samples of FVC data base and 250 samples of internal database. The result shows the accuracy level is 94 percentages in rotation and 92 percentages in core detection. Moreover, the algorithm provides more accurate, time advantage and cost effective solution in fingerprint authentication and analysis. Also, the algorithm produced wide difference in the count of minutiae points for the actual image and rotated image due to the impact of poor quality of the images. In addition, the delta point is identified as core point due to poor quality.

An image is considered as poor quality when the image is partially scanned and with oily or greasy. Also, scanned image with variation in pressure also considered as poor quality. Fig 11 shows some of the poor quality images.

Fig. 11. Poor quality images randomly selected from the FVC2004_DB1 database

6. Conclusion

To improve the performance of the matching algorithms and fingerprint analysis, an efficient algorithm has been proposed. The step by step procedure for the vertical orientation is carried out with necessary illustration is provided. For the performance evaluation, line (ridge) based algorithm using connected component analysis. The minutiae extraction performed for the input image and the processed image are compared. 640 samples of FVC2004 DB1_A database and 250 samples of internal database are used to test the proposed algorithm. The performance evaluation shows that the minutiae extracted from the processed image are closely matching (94%) with its original input image. The core detection is achieved in the entire fingerprint and 92 percent of the core detection is found correct. The quality, classification, various pressure and placement of the fingerprint on the scanner has impacted the accuracy of the core point. The proposed algorithm has a limitation in vertical orientation process; the quality of the image is disturbed as the ridges after processing are not as smooth as the original. This requires further enhancement. Also, the proposed algorithm identifies the delta as core point for few images of loop type. Research is also in progress to eliminate the limitation of the algorithm to reduce computation time, cost and to provide good accuracy.

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