Fingerprint Recognition Using a Hybrid of Minutiae- and Image-Based Matching Techniques

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***Abstract*— Biometrics recognition has been one of the standout research areas in the past decades as the demand for security systems increases. Fingerprint recognition remains as a popular choice for the ease of acquiring such data and it is universally accepted as a feature that is unique to all individuals. One of the limitations of existing fingerprint recognition techniques is that the systems tend to fall short when the available fingerprint is of low quality. This work describes a hybrid method that improves the performance of fingerprint recognition technique by using a combination of minutiae-based and image-based techniques, extracting features from both techniques to compensate the limitations of each of them. Results show that the proposed hybrid method is capable of achieving better recognition rate. Further analyses indicate that the percentage of similarity score and the Euclidean distance computation are both improved.**

Keywords - fingerprint recognition, biometric recognition system, feature extraction

I. INTRODUCTION

Fingerprint is one of the biometrics features that are unique to each human. Fingerprints are rich with details, consisting of many ridges and furrows [1]. Many modern security systems utilize this uniqueness for identity recognition and verification purposes. Both systems work on the same fundamentals, but in different matching modes: fingerprint identification or recognition is one-to-many matching process, while fingerprint verification or authentication is a one-to-one matching process.

Most existing fingerprint recognition systems have no difficulty in matching high quality fingerprint images. However, many falls short when the fingerprint images are low in quality. There are three main categories of techniques used, namely the minutiae-based (feature-based) matching, the pattern-based (or image-based) matching, and correlation-based matching. There have been other techniques introduced for fingerprint matching outside of the core three techniques, including the principal component analysis technique, which utilizes statistics theory for computation operation, and the use of neural network.

The image-based technique is capable of producing acceptable matching rate to a certain degree when low quality images are used. This proposed work incorporates relevant algorithms from the image-based technique into the well-established minutiae-based technique to improve the recognition rate when fingerprint images provided are of low quality, compensating the limitations of each of the methods.

Minutiae-based technique is the backbone of many fingerprint recognition studies [2], where it utilizes the rich local features of a fingerprint, namely termination points and bifurcation. It is widely used as it is computationally inexpensive. This technique locates the maximum number of minutiae pairings between the template and an input set of minutiae extracted from the input image for matching purpose.

The image-based technique is generally used to match fingerprints based on global features, without the need to extract any reliable minutiae-features [3]. This technique utilizes the ridge shape, texture information and local orientation for fingerprint verification. Image matching is done by computing the similarity between the template image and the input image. One of the main drawbacks of this technique is the lack of robustness when tracking variations of scale and orientation [4].

This paper consists of five sections: Section II provides a short review of previous related work, while Section III details the hybrid technique. Results and analysis of the proposed method is given in Section IV and a conclusion is provided in Section V.

II. RELATED WORK

Numerous works have been done in terms of using a hybrid of different fingerprint recognition methods to improve the conventional methods. This section details a selection of such work. One of the more successful attempts is as described in [5], whereby a fingerprint matching technique using a combination of minutiae and texture features was detailed. This work tackles the issue of insufficient minutiae points due to the small contact area of solid-state fingerprint sensors. The addition of textural (regional) information helps to provide more details necessary for better recognition rate. The method described was shown to be capable of producing substantial improvement in the overall matching performance.

Another hybrid between the minutiae and correlation-based techniques is described in [6]. In this method, the postprocess phase of the minutiae-based technique was improved by a combination of both algorithms, which resulted in an improvement from the original technique. The ridge detection algorithm was modified to use the center point of the fingerprint, instead of the conventional reference point. The authors concluded that the hybrid technique improved on both techniques.

Another such hybrid system using minutiae and ridge flow information is detailed in [7]. The system takes the entire image into account while constructing the ridge feature map. The translation and rotation parameters are deduced from minutiae-matching, such that the template image for ridge feature map extraction can be created. The hybrid setup was shown to perform better than the minutiae-based fingerprint matching system.

An enhanced image-based algorithm using tessellated invariant moment features was found in [8]. The enhanced algorithm reduced multi-spectral noise by enhancing the image such that a reference point can be obtained more accurately. The image is then aligned according to the position and orientation of the reference point computed. The authors then obtain a set of fixed-length moment feature, invariant to affine transformation from tessellated cells located within the region of interest. The authors show that the proposed method is capable of improving the existing image-based algorithm.

III. Hybrid Fingerprint Matching System

As previously mentioned, both the minutiae-based and image-based techniques have their strengths and weaknesses. The proposed hybrid method is composed of appropriate algorithms from both of the techniques, taking the minutiae-based technique as the backbone for this system.

Fig. 1 shows the flowchart for the hybrid algorithm. The system, as it is with the conventional system, consists of the image pre-processing, feature extraction, image post-processing stage, and finally the fingerprint matching process. New features, as well as features adopted from the image-based technique are given.

A. Image Pre-Processing

In this stage, the fingerprint obtained is enhanced such that it achieves a state where it is suitable for fingerprint matching. As shown in Fig. 1, the process begins with histogram equalization. This process reduces unwanted noise and increases the contrast of the image effectively for fingerprint images with low contrast. An example of the result is as shown in Fig. 2(b).

The following process is to detect the core of the fingerprint. This algorithm is part of the image-based matching technique, which is now embedded into the minutiae-based technique. The core detection algorithm finds and detects the reference point in a fingerprint image. To determine the region of interest (ROI), a minimum threshold value is fixed for the variance. The input image is divided into non-overlapping blocks and only blocks with a variance smaller than this threshold are classified as background. Blocks with concentrated ridges are considered as core point. The core point is represented by (x, y) co-ordinate. The core point is marked with an 'O' as shown in Fig. 2(c). This reference point is used in the cropping process, as well as in minutiae alignment process.

The next step in this algorithm is a newly introduced step, which is image rotation adjustment. This step is necessary in order for the images to satisfy the upright requirement for the matching process, which some of the images in available databases ([9],[10]) may not be. The rotation is done automatically using a built-in feature in MATLAB. After the rotation process, the image is cropped to remove the outer parts of the image, framing the essential ROI, as shown in Fig. 2(d). The ROI is determined using the core point as determined earlier, and a 190 x 190 pixels square window around the core point is cropped using the rotated image.

Gabor filtering is applied to the cropped image to remove any residual noise. This step is adopted from the image-based matching technique and introduced to the minutiae-based technique. On top of removing residual noise, this step is also essential to help restore lost minutiae points, ridge and valley features in poor quality fingerprint images. Filtering is applied to each block using the local orientation angle and frequency using the following equations [11]:

$$h(x, y, \phi, f) = \exp(-1/2[(x_\phi^2/(\delta_x^2)+(y_\phi^2/\delta_y^2)])\cos(2\pi f x_\phi) \quad (1)$$

$$x_\phi = x \cos \phi + y \sin \phi \quad (2)$$

$$y_\phi = -x \cos \phi + y \sin \phi \quad (3)$$

where ϕ is the orientation of the Gabor filter, f is the frequency of a sinusoidal plane wave, and d_x and d_y are the sigma of Gabor envelope which are set to constant values respectively. Eight orientations are applied to the image, which are 0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135° and 157.5° filters. The resulting eight filtered images, which are all in gray-scale, are combined through extracting the highest value of each pixel in the image. An example of the filtered image is as shown in Fig. 2(e). This resulting gray-scale image is then transformed into a binary form (Fig. 2(f)), and the image is then divided into 16 x 16 pixels blocks.

The next procedure marks the beginning of the image segmentation process. This begins with ridge flow estimation before the ROI extraction is carried out. Ridge flow estimation is determined by first applying Sobel filtering to compute the value of gradient along the x-direction (g_x) and y-direction (g_y) for each 16 x 16 pixels block. This process requires up to two layer of Sobel filtering. Next, the least square approximation of the block direction is computed using (4) and blocks without significant information on ridges and furrows are discarded through applying (5) [12].

$$\tan 2\beta = (2\Sigma\Sigma(g_x * g_y))/(\Sigma\Sigma(g_x^2 - g_y^2)) \quad (4)$$

$$E=(2\Sigma\Sigma(g_x * g_y) + \Sigma\Sigma(g_x^2 - g_y^2))/(W*W*\Sigma\Sigma(g_x^2 + g_y^2)) \quad (5)$$

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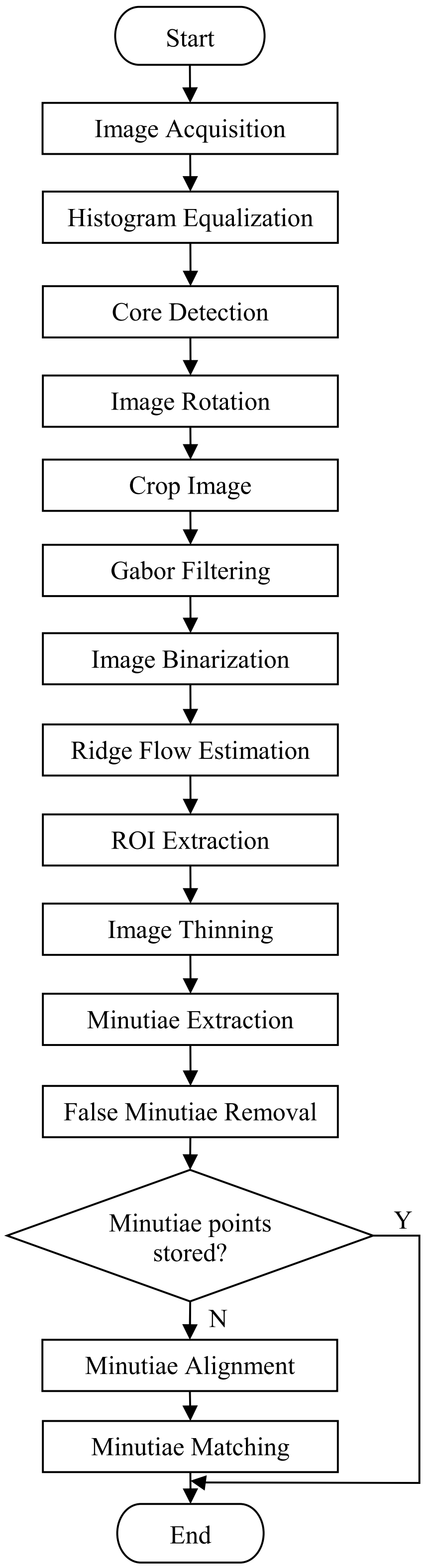

Figure 1. Flowchart of the Hybrid Fingerprint Recognition System.

Any blocks that are with the value of *E* below the set threshold value is categorized as a background block. The background blocks are separated from the foreground blocks. Fig. 2(g) shows an example of the direction map with the green lines representing the ridge flow of the fingerprint.

The ROI is extracted by discarding the image area without effective ridges and furrows. The remaining effective area into two areas, namely the white area used to determine bound, and the gray area represents the inner area. Only the bound and inner areas are essential for minutiae extraction. Two morphological operations, known as 'open' and 'close' are used to extract the ROI. The 'open' operation expands the image and removes any peaks introduced by background noise, while the 'close' operation shrinks the image and eliminate any small cavities [12].

The morphological filter is also applied for image thinning purpose, resulting in sharpening of ridge pixels into one pixel wide. The erosion operation of the morphological filter is used to smooth the lighter region, allowing thick lines to become thin, as shown in Fig. 2(h). The filter is then applied to remove H-break and spike of the thinned ridges to reduce the introduction of false minutiae. This process eliminates any isolated points and H connected pixels that occurred in the thinned lines. Fig. 2(i) shows the effect of applying H-break and spike removal.

B. Minutiae Extraction

Two types of minutiae features are extracted, which are ridge endings and bifurcations. The minutiae are marked using a 3 x 3 pixels window to extract ridge ending and bifurcation. The central pixel is classified as ridge branch (bifurcation) if the central pixel and three other pixels around it are '1'. If the central pixel and only one other of its neighbouring pixel have the value of '1', the central pixel is classified as ridge ending. The pixels are marked as branches if the uppermost pixel and the rightmost pixel have the value of '1' [12]. The different types of pixels are marked in different colours, as shown in Fig. 2(j). The red crosses represent the ridge termination or endpoints, while the yellow crosses represent bifurcation.

C. Image Post-Processing

In this stage, any false minutiae are removed, which may be created due to noise as a result of the image thinning process. The types of spurious minutiae that are removed includes 1) a spike piercing into a valley, 2) a spike falsely connecting two ridges, 3) two nearby bifurcations located in the same ridge, 4) two ridge broken points with similar orientation and a short distance, 5) one part of the broken ridge is too short such that a termination is generated, 6) a third ridge is found in the middle of two parts of a broken ridge, and 7) only one short ridge is found in the threshold window [13]. An example of the result is as shown in Fig. 2(k), with different features highlighted in different colours. Similarly, the ridge termination or endpoints are represented by red crosses, bifurcations are marked in yellow crosses and the green lines represent the direction of terminations and bifurcations.

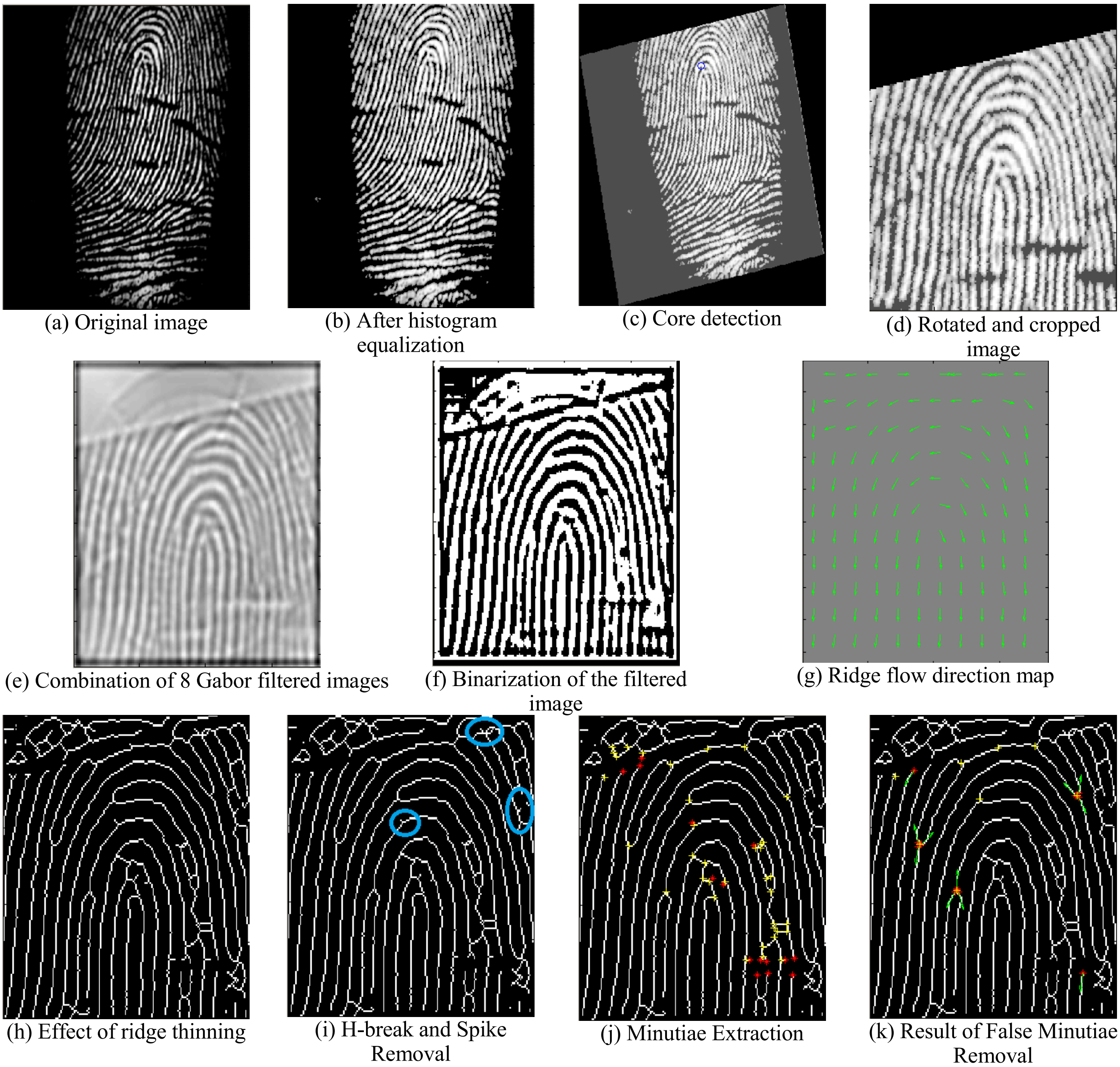

Figure 2. An Example of the Different Stages of the Pre-Processing, Minutiae Extraction and Post-Processing of a Fingerprint Image.

D. *Minutiae Alignment*

Prior to the matching process, minutiae alignment is executed to improve the robustness of image rotation between the processed image and those available in the database for more accurate fingerprint matching. In order to match an input image to those in the database, the core points of both fingerprint images are chosen as reference point to align and rotate the minutiae position until a match of a major minutiae point is achieved. Using the coordinate system calculation, when the similarity is larger than a set threshold, a new set of coordinates of the minutiae points is recalculated with the reference point used as the origin and the *x*-axis is set to coincide with the direction of the reference point.

E. *Minutiae Matching*

After aligning the minutiae points, the minutiae points are matched for either identification (one-to-many matching) or verification (one-to-one matching). Two matching scores are used, namely the percentage of similarity matching score and by computing the Euclidean distance.

Using the percentage of similarity score, the pair-by-pair minutiae similarity comparison is done between the input image and those in the database. The percentage of similarity is determined by taking the highest matching percentage

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score between the input image and all the images in the database.

Along with this score computation, the Euclidean distance between all minutiae features of those in the input image and those in the database is also computed. This method computes the shortest distance between fingerprint features from images in the database with those in the input image. The shortest distance computed is determined as the fingerprint match.

IV. RESULTS AND ANALYSIS

The hybrid system is tested using 200 images stored across four databases extracted from the Fingerprint Verification Competition (FVC) 2002 database (for DB1-3) [9] and the CrossMatch_Sample_DB (for DB4) [10], which contains fingerprint images of various qualities, including ideal, high and poor quality. Table I shows a summary of the database used for this work.

TABLE I. SUMMARY OF FVC IMAGES USED FOR TESTING.

Total FVC images used	200
Total individuals selected	40
Number of ideal quality images	40
Number of low quality images	80
Number of high quality images	80
Dimension of images	296x560 pixels (DB1) 388x374 pixels (DB2) 300x300 pixels (DB3) 504x480 pixels (DB4)
Image acquisition method	Optical sensor (DB1) Optical sensor (DB2) Capacitive sensor (DB3) Optical sensor (DB4)
Colour format of images	Gray-scale

Fingerprint images of 40 individuals were used for this test. Each set of images representing the individuals consists of fingerprint images of different qualities. The ideal images are used as the template for matching purpose

A. Testing using Low Quality Fingerprint Images

One of the aims of developing this hybrid method is to tackle the issue of fingerprint matching for low quality images. The experiment was conducted on 80 low or poor quality images. Each image was treated to the same process as described in Section III prior to the matching process. Experiments were conducted for verification (one-to-one) and recognition (one-to-many) separately on the same database.

A summary of the percentage of fingerprint matching for each of the four databases used are as shown in Table II. Results indicated that the proposed hybrid method made correct matches of all the fingerprints to the correct individuals. In comparison, the minutiae-based technique achieved an average of 5% matching accuracy for the four sets of databases used. The image-based technique, as expected, performed better in comparison to the minutiae-based technique for low quality images, whereby it achieved an average of 92.5% success rate.

TABLE II. PERCENTAGE OF MATCHED FINGERPRINT FOR EACH DATABASE FOR LOW QUALITY IMAGES

Method	DB1	DB2	DB3	DB4
Minutiae-based	0%	5%	15%	0%
Image-based	90%	95%	90%	95%
Hybrid method	100%	100%	100%	100%

A comparison was made for results obtained using the percentage of similarity score for the minutiae-based and the proposed hybrid techniques. Only the minutiae-based technique was used as it performs a one-to-one verification and returning a matched percentage score value. Results indicated that improvement of the matching score was obtained for 98.75% of the 80 images used. The average percentage of improvement is 40%, with a standard deviation of 20%.

Testing was also done using the Euclidean distance calculation methods comparing the performance of the image-based technique and the proposed hybrid system. As image-based technique is largely used for one-to-many matching, for this analysis, mismatches are excluded from this analysis. Results indicated that there are improvements in Euclidean distance computation for 82.5% of the 74 correctly matched fingerprint images. An average improvement of 46.35 was achieved, with a standard deviation of 110.85.

B. Testing using High Quality Fingerprint Images

Experiments were also conducted using high quality fingerprint images. Similarly, 80 images were used and all images were treated to the same process as described in Section III.

In terms of the recognition rate, the proposed hybrid method is able to correctly match all 80 images to the correct individuals. The minutiae-based technique was able to achieve an average of 90% accuracy, while the image-based technique achieved an average of 93.75% accuracy. A summary of the results are as shown in Table III.

TABLE III. PERCENTAGE OF MATCHED FINGERPRINT FOR EACH DATABASE FOR HIGH QUALITY IMAGES

Method	DB1	DB2	DB3	DB4
Minutiae-based	90%	100%	90%	80%
Image-based	90%	100%	90%	95%
Hybrid method	100%	100%	100%	100%

Results and analysis was done the scores obtained for both the percentage of similarity and Euclidean distance. Similarly, the comparison for percentage of similarity was done for the minutiae-based technique and the proposed hybrid system. An improvement was observed for 95% of the 80 images used for this comparative study. The average percentage of improvement is 20.2%, with a standard deviation of 16.43%. This improvement is lower than that achieved when using the low quality images. This result is unsurprising as the conventional system has a good record of performing well when high quality images are used.

The Euclidean distances were computed for the image-based technique and the proposed hybrid technique. As there are images which are mismatched to the correct individual, these results are excluded for this analysis. Out of the 75 images that were correctly matched, an improvement for Euclidean distance was observable for 68.75% of the images. An average improvement of 75.55 was achieved, with a standard deviation of 241. 9.

C. Analysis of Recognition Accuracy Rate

Analysis were done to investigate the accuracy of the hybrid system for fingerprint matching with various size of database used. Using the same databases as described in Table I, databases consisting of a selection of 10, 20, 30 and 40 fingerprint sets were used. Fingerprint matching results were done using the image-based and hybrid system. A summary of the results are given in Table IV.

TABLE IV. PERCENTAGE OF MATCHING ACCURACY FOR IMAGE-BASED AND HYBRID SYSTEM USING DIFFERENT DATABASE SIZES

Database Size	Image-based		Hybrid system	
	Rejected fingerprints	Accuracy %	Rejected fingerprints	Accuracy %
10	4	60%	0	100%
20	11	45%	5	75%
30	20	33.3%	12	60%
40	33	17.5%	17	57.5%

From the results shown in Table IV, it can be seen that the hybrid system improves on the overall accuracy in matching, with lower number of fingerprints being rejected, compared to the conventional image-based technique. This highlights the advantage of the hybrid system.

V. CONCLUSION

This paper describes a hybrid method to improve on two conventional fingerprint matching techniques, namely the minutiae-based and image-based techniques by taking specific features from the image-based technique, and integrate it into the minutiae-based technique such that the accuracy of fingerprint matching with low quality fingerprint images can be improved.

Results indicate that there improvement when using the proposed hybrid method. The improvement is prominent especially when using low quality fingerprint images for fingerprint matching. The average overall percentage of similarity and Euclidean distance are improved.

Testing using both high and low quality fingerprint images also indicates that the proposed hybrid method is able to achieve 100% correct recognition, while the conventional minutiae-based and image-based fell short on both sets of images, with the minutiae-based technique providing the worst performance for matching low quality images. This indicates that the performance of the proposed method is overall superior to both of the original techniques.

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