Adaptive and Faster Approach to Fingerprint Minutiae Extraction and Validation

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Abstract

Fingerprint is a very vital index in the field of security. Series of Automatic Fingerprint Identification Systems (AFIS) have been developed for human identification. These systems compare each of the features of a template fingerprint image with each of the features in the feature sets in the reference database to determine whether the template and each of the reference images are from the same source. Comparison is done on the basis of preset parameters such as feature type, location, orientation and so on. Getting the features used for the construction of a reference database from the images involve the implementation of a sound fingerprint feature detection, validation and extraction algorithm. In this paper, the process of detecting and extracting true and false feature points in a fingerprint image is discussed. Attention is also given to the elimination of the false feature points through the process of validation. Some of the existing fingerprint feature extraction and validation algorithms were firstly modified and the resulting algorithms were implemented. The implementation was carried out in an environment characterized by Window Vista Home Basic as platform and Matrix Laboratory (MatLab) as frontend engine. Fingerprints images of different qualities obtained from the manual (ink and paper) and electronic (fingerprint scanner) methods were used to test the adequacy of the resulting algorithms. The results obtained show that with the modified algorithm, valid and true minutiae points were extracted from the images with greater speed and accuracy.

Keyword: AFIS, Pattern Recognition, Pattern Matching, Fingerprint, Post Processing, Minutiae Extraction.

1. INTRODUCTION

Fingerprint is an essential index in the enforcement of security and maintenance of a reliable identification of any individual. Fingerprint is currently being used as variables of security during voting, operation of bank accounts among others. It is equally used for controlling access to highly secured places like offices, equipment rooms, control centers and so on. The following reasons had been adduced for the wide use and acceptability of fingerprint for the enforcement of security [1-4]:

a. Fingerprints have a wide variation since no two people have identical prints.
b. Unlike in other biometrics, fingerprints exhibit high degree of consistency and they do not change in relative appearance.
c. Fingerprint is left each time the finger contacts a surface.

Other reasons for the much larger market of personal authentication using fingerprints are:

a. Availability of small and inexpensive fingerprint capture devices
b. Availability of fast computing hardware
c. High recognition rate devices that meet the needs of many applications
d. The explosive growth of network and Internet transactions
e. The heightened awareness of the need for ease-of-use as an essential component of reliable security.

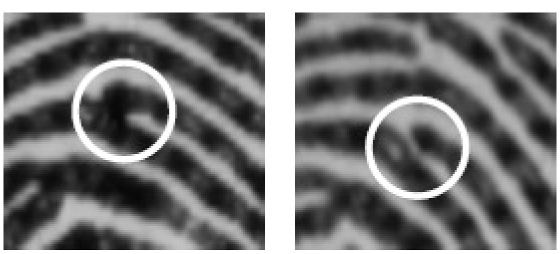
2.0 FINGERPRINT FEATURES

The main ingredients of any fingerprint that are useful during pattern recognition and matching tasks are the features it possesses. The features are defined by type, position, orientation and so on and they exhibit uniqueness from fingerprint to fingerprint. Fingerprint features are classified into two categories; namely local and global features [5]. The local features are the tiny, unique characteristics of fingerprint ridges that are used for identification. They are found in the local area only and are invariant with respect to global transformation [6]. Two or more impressions of same finger may have identical features but still differ because they have minutia points that are different [7]. In Figure 1, ridge patterns (a) and (b) are two different impressions of the same finger (person). The same minutia point is read as bifurcation in (a) while it appears as a ridge ending in (b).

Global features are characterized by the attributes that capture the global spatial relationships of a fingerprint. The following are the common fingerprint global features [7-9]:

2.1 Basic Ridge Patterns:

The ridge patterns are the patterns formed from the dark areas of the finger tip epidermis produced when a finger is pressed against a smooth surface. The valleys are the bright areas. Ridges and valleys run in parallel as shown in Figure 2.



(a) Minutiae as a bifurcation point (b) Minutiae as an end point

FIGURE 1: The same minutiae extracted from two different impressions.

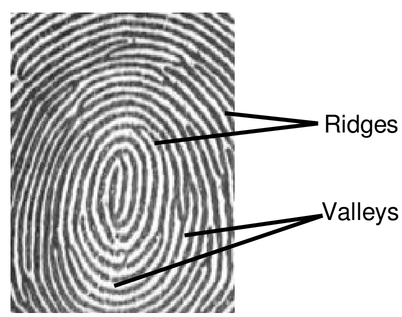


FIGURE 2: Ridges and valleys on a fingerprint image

The ridges form pattern of left loop, right loop, whorl, arch and tented arch as shown in Figure 3. In the loop pattern, the ridges enter from either side, re-curve and pass out or tend to pass out the same side they entered. In the right loop pattern, the ridges enter from the right side while the ridges enter from the left side in the left loop. In a whorl pattern, the ridges are usually circular while in the arch pattern, the ridges enter from one side, make a rise in the center and exit generally on the opposite side.

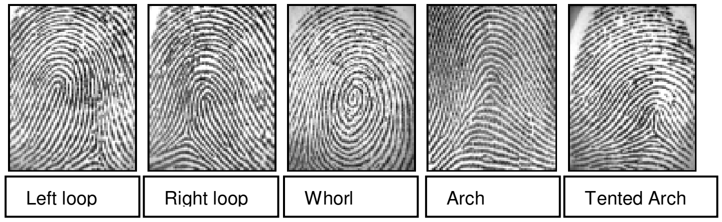


FIGURE 3: Basic types of fingerprint pattern

2.2 Pattern Area

The pattern area is the part of the fingerprint where the global features are found. Fingerprints can be read and classified based on the information in this area. The following are the information available in the pattern area of a fingerprint [2-4]:

a. Type Lines and Ridge Count: Type Lines are the two innermost ridges that start parallel, diverge, and surround or tend to surround the pattern area. When there is a definite break in a type line, the ridge immediately outside that line is considered to be its continuation. The Ridge Count is most commonly the number of ridges between the Delta and the Core. To establish the ridge count, an imaginary line is drawn from the Delta to the Core and each ridge that touches this line is counted. The ridge count between the core and delta shown in Figure 4 is the number of ridges crossed by the imaginary lines drawn across the ridges.

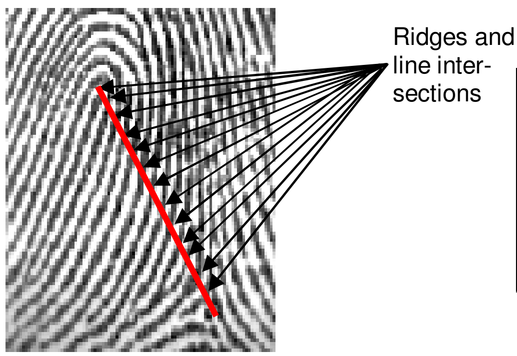


FIGURE 4: The ridge count between Delta and Core

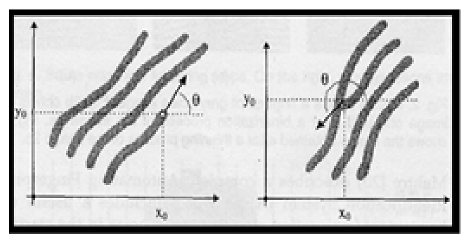


FIGURE 5: Minutia point orientation

b. Position: The position of the minutia point refers to its x, y location, either in an absolute sense or relative to fixed points like the Delta and Core points.

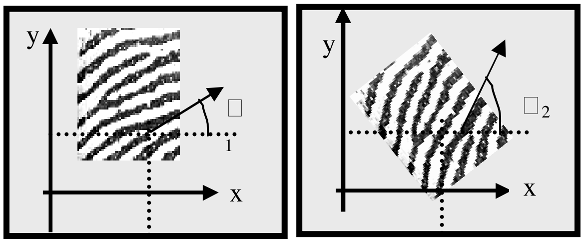
c. Type: Different types of minutiae are found in the fingerprint pattern area. They include termination, bifurcation, lake, independent ridge, point or island, spur, cross over and so on.

d. Spatial Frequency: Spatial frequency refers to how far apart the ridges are in the neighborhood of the minutia point. It is measured by the average distance apart of the ridges.

e. Orientation: The minutia orientation is defined by its direction. The orientations of the ridge ending and bifurcation of Figure 5 are marked as □ and β respectively.

f. Curvature: The curvature refers to the rate of change of ridge orientation. The curvature, c of one of the two ridge endings of Figure 6 is obtained from the absolute difference between $\square_2$ of Figure 6(b) and $\square_1$ of Figure 6(a). It is the displacement angle resulting from the change in orientation of the ridge pattern.

g. Core and Delta Areas: The core area is located at the approximate center of the finger impression as shown in Figure 7 and it is used as a reference point for reading and classifying the print. The Delta area is the region in the ridge pattern where there is triangulation or a dividing of the ridges as shown in Figure 7. It is also the point of the first bifurcation, abrupt ridge ending, meeting point of two ridges, dot, fragmentary ridge, or any point upon a ridge at or nearest to the center of divergence of two type lines, located at or directly in front of their point of divergence. It is a definite fixed point used to facilitate ridge counting and tracing.



(a) (b)

FIGURE 6: Change in ridge orientation

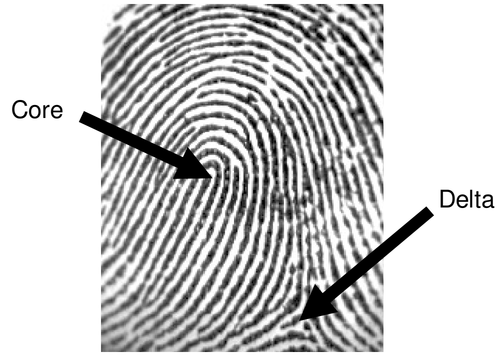


FIGURE 7: The Delta and Core structure of fingerprint

3. DETECTION AND EXTRACTION OF FINGERPRINT FEATURES

The sequence of activities connected to the detection and extraction of features from any fingerprint is illustrated in Figure 8.

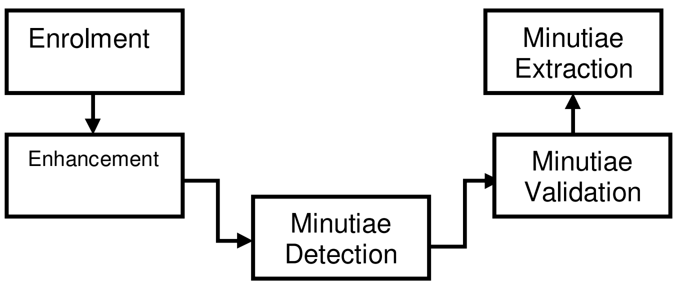


FIGURE 8: Sequence of activities connected to fingerprint feature extraction

Manual or electronic method could be adopted for the enrolment of fingerprint images [5]. In [10-11], several image enhancement algorithms were discussed and implemented. Features were also detected, validated and extracted from the thinned images obtained as the final results of the enhancement stage. A Crossing Number (CN) method for feature detection and extraction from the thinned image had been implemented in [12-13]. In the CN method, the extraction of the features is done through the scanning of the 3 x 3 neighborhood of each ridge pixel in the thinned image. The CN value is then calculated from half the sum of the differences between pairs of adjacent pixels in the eight-neighborhood as shown in Equation 1.

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

Using the CN properties shown in Table 1, the ridge pixel is classified as a ridge ending, bifurcation or non-minutiae point. For example, a ridge pixel with a CN of one corresponds to a ridge ending, a CN of 2 corresponds to a continuing ridge point and a CN of three corresponds to a bifurcation.

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

TABLE 1: Properties of the Crossing Number.

Similar to the Crossing number approach was the method proposed in [14-15]. These authors devised a method that uses a 3 x 3 window to examine the local neighborhood of each ridge pixel in a skeleton image. A pixel is classified as a ridge ending if it has only one neighboring ridge pixel in the window, and classified as a bifurcation if it has three neighboring ridge pixels. False minutiae may be introduced into the image due to factors such as noisy images, and image artifacts created by the thinning process [12]. Hence, after the detection of minutiae, it is important that a post-processing method is employed to validate them. Some examples of false minutiae structures are illustrated in Figure 9. The false structure include the spur, hole, triangle and spike structures [16]. From inspection, it is revealed that the spur structure generates false ridge endings, while both the hole and triangle structures generate false bifurcations. The spike structure on its own generates a false bifurcation and a false ridge ending point.

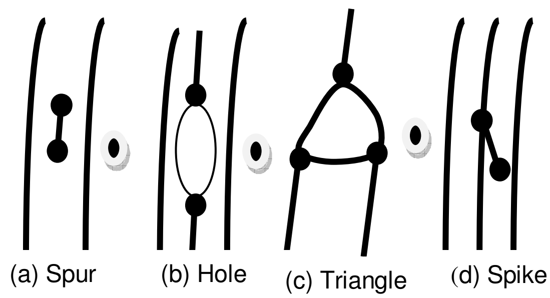


FIGURE 9: Examples of typical false minutiae structures.

A novel approach to the validation of minutiae is the post-processing algorithm proposed in [17]. This algorithm operates on the skeleton image. However, rather than employing a different set of heuristics each time to eliminate a specific type of false minutiae, this approach incorporates the validation of different types of minutiae into a single algorithm. It tests the validity of each minutia point by scanning the skeleton image and examining its local neighborhood. The algorithm is able to cancel out false minutiae based on the configuration of the ridge pixels connected to the minutiae point. In this research, the Crossing Number (CN) method for a pixel P is slightly modified with a view to speed up its operation. The modified version is presented as follows:

$$CN = \sum_{j=0}^{7} | P_{j+2} - P_{j+1} |, \qquad P_9 = P_1 \tag{2}$$

The eight neighbouring pixels of P are scanned in clockwise direction as follows:

P_2	P_3	P_4
P_1	P	P_5
P_8	P_7	P_6

With this modification, a ridge pixel with CN count of 2 corresponds to ridge ending and CN count of 6 corresponds to bifurcation as illustrated in Figure 10.

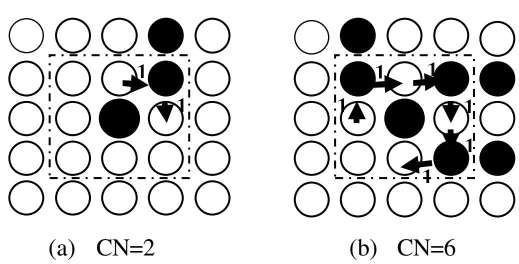


FIGURE 10: CN values for ridge ending and bifurcation point

Towards the validation of the minutiae points, a minutiae validation algorithm proposed in [17] was also modified before its implementation. The modified algorithm tests the validity of each minutiae point by scanning the skeleton image and examining the local neighborhood around the point. The first step in the modified algorithm is the creation of an image M of size W x W centered on the candidate minutia point in the skeleton image. The central pixel of M is labeled with a value of -1. The rest of the pixels in M are initialized to values of zero, as shown in Figure 11(a) and Figure 11(d).

The subsequent steps of the algorithm depend on whether the candidate minutiae point is a ridge ending or a bifurcation.

i. For a candidate bifurcation point:
   - Examine its 3 x 3 neighborhood in a clockwise direction. For the three pixels that are connected with the bifurcation point, label them with the value of 1. An example of this initial labeling process is shown in Figure 11(b).
   - Label with 1 the three ridge pixels that are connected to these three connected pixels. Example of this labeling process is shown in Figure 11(c).
   - Count in a clockwise direction, the number of transitions from 0 to 1 (T_{01}) along the border of image M. If T_{01} = 3, then extract the candidate minutiae point as a true bifurcation.

ii. For a candidate ridge ending point:
   - Label with a value of 1 all the pixels contained in M, which are in the 3 x 3 neighborhood of the ridge ending point (Figure 11(e)).
   - Count in a clockwise direction, the number of 0 to 1 transitions (T_{01}) along the border of image M. If T_{01} = 1, then extract the candidate minutiae point as a true ridge ending.

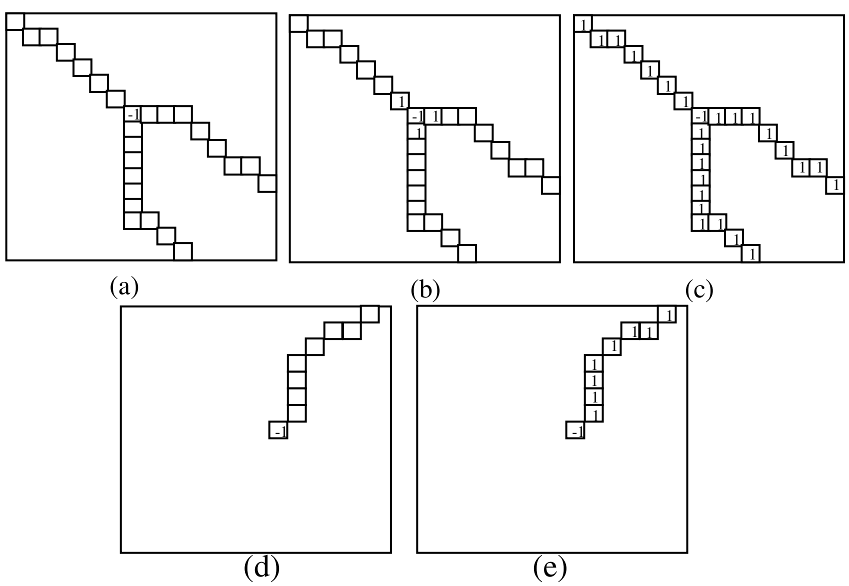


FIGURE 11: Example of validating a candidate bifurcation point T_{01}=3 and ridge ending point. T_{01} = 1.

4. EXPERIMENTAL RESULTS

The fingerprint minutiae extraction experiment was carried out in an environment characterized by Window Vista Home Basic Operating System as platform and Matlab (Matrix Laboratory) as frontend engine on a Pentium IV Personal computer with 1.87GB processor and 1024MB RAM.The essence of the experimental stage is to ascertain that the modified CN and the post-processing algorithms perform well and better in accuracy and speed over their original versions in the detection and extraction of features from fingerprint images. Shown in Figures 12(a) and 12(b) are the results of using the modified CN method to extract minutiae from a medium quality fingerprint image obtained using a manual fingerprinting method. Figures 12 (c) and 12(d) show the results for the fingerprint image obtained from the electronic method. From the experimental plots of the extracted minutiae points on the thin images shown in Figure 12(a) and 12(c), it is deduced that both the true and false ridge pixels corresponding to a CN value of two and six have been detected from the images. Ridge endings are denoted by six pointed stars (hexagrams), and bifurcations are denoted by diamonds. The experimental plot presented in Figure 12(b) and 12(d) depict the extracted false and true minutiae points superimposed on the original image.

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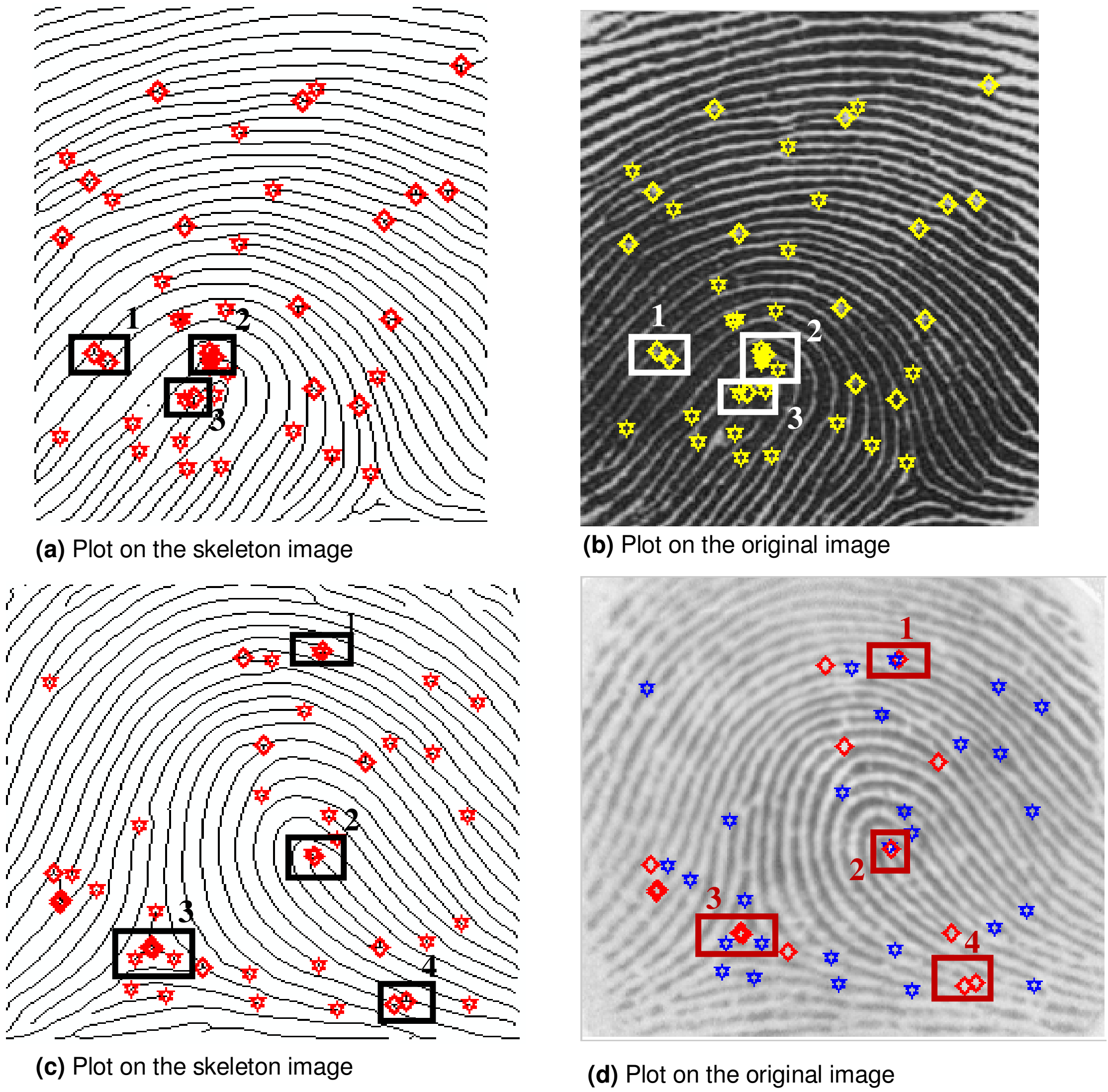
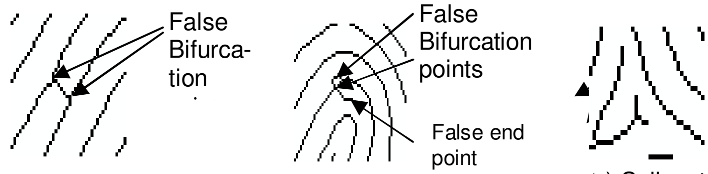


FIGURE 12: Results of performing minutiae extraction on a fingerprint image obtained by manual and electronic methods.

Visual inspection of the plots on the images indicates that the majority of the marked minutiae points from the thin images correspond to valid minutiae points in the original images. In all the plots, false minutiae point sets are covered by large boxes with appropriate labels.

Enlarged views of the false minutiae points shown in Figures 12 (a) and 12(b) are presented in Figure 13. Figure 13(a) depicts a false minutia point called a cross-over structure, which corresponds to the box labeled 1 and Figure 13(b) depicts a false minutiae point comprising of both the hole and the spike structures, which correspond to the box labeled 2. It can be seen that the cross-over structure shown in Figure 13(a) generates two false bifurcation points while the hole and spike structures shown in Figure 13(b) generate two false bifurcation points and a false end point. Similarly, the spike structure shown in Figure 13(c) generates two false endpoints. However, in the original image shown in Figure 12(b), these minutiae points do not exist.



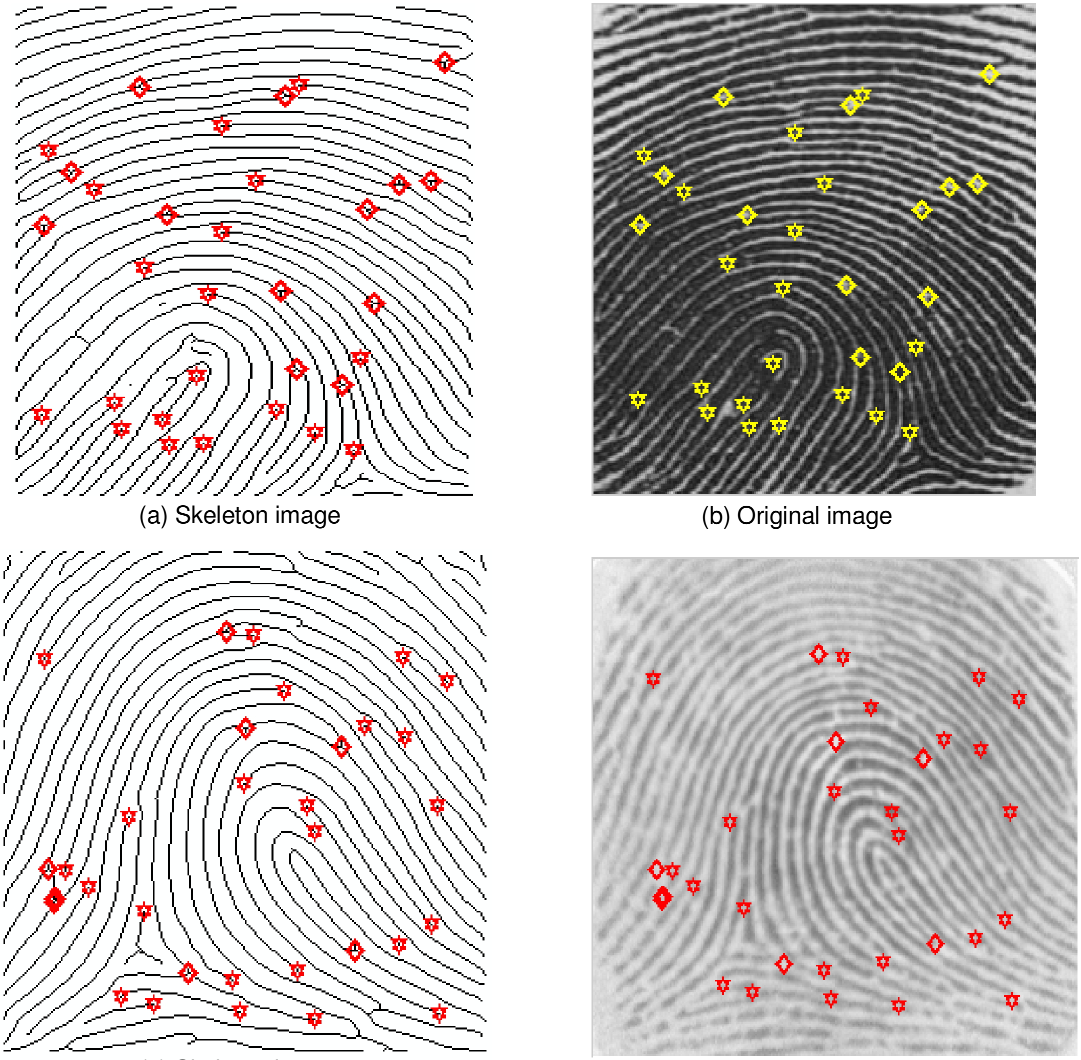
(a) Cross over (b) Hole plus spike structures (c) Spike structure

FIGURE 13: Enlarged view of the false minutiae from Figure 12(a).

The modified post-processing algorithm was implemented to eliminate the false minutiae that were extracted using the modified CN method. The experimental plots of the result of the post-processing experiment on the images shown in Figure 12 are presented in Figure 14. It is revealed in Figure 14(a) and 14(c) that all the false minutiae points on the skeleton images have been eliminated at the post-processing stage. The results shown in Figure 14 were obtained with image window of size 25 x 25 centered on the candidate minutia point. When window size is smaller than this value, the algorithm could not eliminate some false minutiae points. Shown in Figure 15(a) and Figure 15(b) are the false minutiae points not eliminated due to small window size of 21. This is due to fact that the entire local neighborhood around the candidate minutiae points could not be captured. This forced the number of 0 to 1 transition to 3 for bifurcation as illustrated in Figure 11(c). The number of 0 to 1 transition is also forced to 1 for the ridge ending as illustrated in Figure 11(e). Similarly with a higher window size, the algorithm eliminated some valid minutiae points. Shown in Figure 15(c) is the valid minutia point that is eliminated due to oversize window of 27. This is explaining the fact that the window extended beyond the local neighbourhood of the candidate minutia point and hence the number of 0 to 1 transition round the border is forced to 0.

In the original algorithm implemented in [12-13], scanning around the candidate minutia point was done in counter-clockwise direction to obtain the CN value. However, in the current study, the CN value was obtained by scanning the pixels around the candidate point in clockwise direction. In the two cases, both true and false minutiae were accurately extracted from the images. It is therefore established that during minutia extraction, emphasis is placed on the CN value rather than the direction of scanning. An implementation of the original CN algorithm over one hundred and seventeen (117) different fingerprint images obtained from FVC2004 fingerprint database DB3 set A took a mean time of 1.93 seconds to extract an average of forty two (42) true and false minutiae points from images. This task takes a mean time of 1.79 seconds with the modified CN algorithm under the same operational environment. This implies that the modified CN algorithm operates 7.25% faster than its original version with this set of images. This is attributed to lesser calculation involved in the modified version.

A window of size 23 x 23 around the candidate minutia point was reported to be most effective in eliminating the false minutiae by the original post-processing algorithm proposed in [17] and implemented in [12]. However, in the modified post-processing algorithm implemented in this research, a window size of 25 x 25 proved to be most effective. The higher window size led to increased reliability as the modified algorithm placed premium on elimination of false minutiae even at the expense of some valid minutiae points.



(a) Skeleton image (b) Original image

(c) Skeleton image (d) Original image

FIGURE 14: Results of minutiae post-processing experiment

5. CONCLUSION

This paper presents the results of the verification and modification of the minutiae detection and extraction method proposed and implemented in some concluded research works. The CN method proposed and implemented in [12-13] had been modified by varying the order and reducing the level of computation. The post-processing algorithm proposed in [17] was modified by labeling all the three connecting ridges to the candidate bifurcation point with 1 thereby raising the 0 to 1 transition to 3. The modified algorithms were implemented with images obtained from the manual (ink and paper) method as well as the electronic (fingerprint scanner) method. In the manner of the original algorithm, the modified CN algorithm extracted both the false and true minutiae points from the fingerprint images. However, greater speed and accuracy is recorded with the modified algorithms. Results also show that with suitable window size, the modified post-processing algorithm extracted all the true minutiae points from the images and ignored all the false minutiae points.

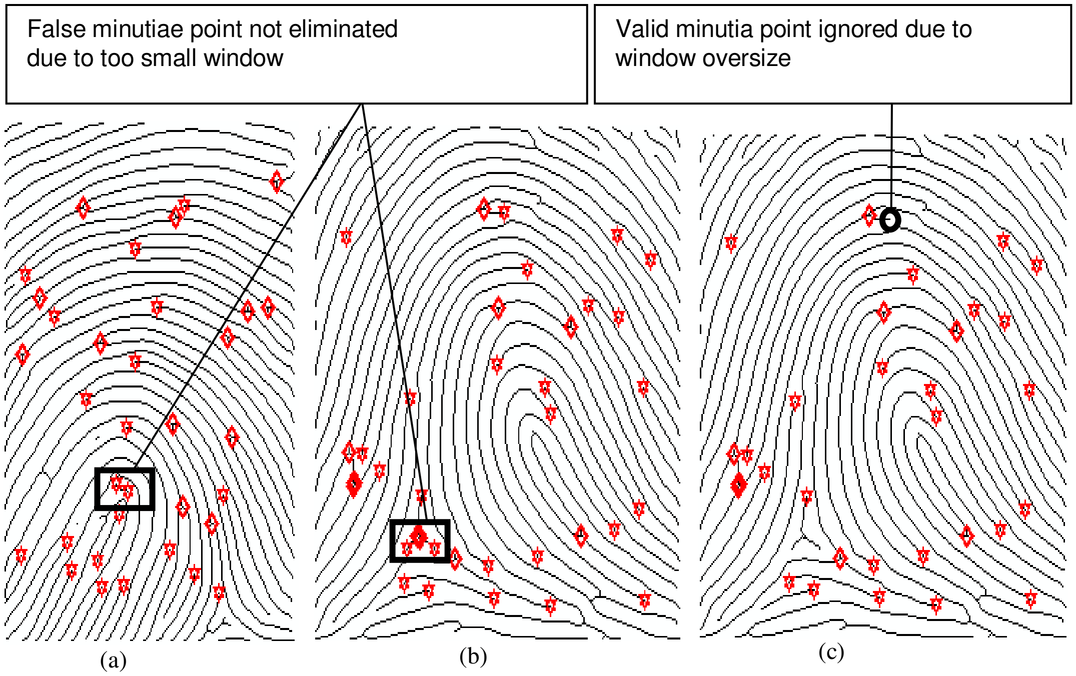


FIGURE 15: Experimental plots for too small and too large neighbourhood

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