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Development of an Improved Multi-filtering Matching Model for Fingerprint Recognition

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Abstract:** Over the years research done in the area of fingerprint recognition in which the hybrid matching algorithm is one of the most common techniques, though the hybrid algorithm performed well but still faced with the challenge of false minutiae. This study formulated, simulated, and evaluated a multi-filtering fingerprint matching model to develop a multi-filtering matching model for fingerprint recognition. The method employed a multi-filtering model that was formulated using image pre-processing; minutiae feature extraction, post-processing, and cancellation of false minutiae algorithms in the processed images. The model was simulated using Matlab and fingerprint images from the Fingerprint Verification Competition (FVC) 2002 database. The performance of the model was evaluated using the False Acceptance Rate (FAR), False Rejection Rate (FRR), and Error Equal Rate (EER). The results showed that the false minutiae cancellation algorithm considerably reduced the false minutiae points in the thinned images which resulted in the reduction of false acceptance when two different images were tested, and also reduction in false rejection rate when two same images were tested. The match score was below the threshold value of 50 for false acceptance rate and above the threshold value of 50 for the false rejection rate. The error equal rate EER value of 0.076 was recorded. The study concluded that there was a significant reduction in the false minutiae points present in the thinned images and that a high accuracy of fingerprint matching was achieved when the datasets include poor quality fingerprint images.

***Keywords:** Fingerprints Verification Competition (FVC), Multi-filtering Matching Model, Minutiae Feature Extraction and False Minutiae.*

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1. INTRODUCTION

Biometric identification is used to confirm a person's identity by measuring specific human traits digitally and comparing those measures with those that have been recorded in a database for that same person (Lawan, 2010). The accuracy, speed, and resource requirements for a functional biometric system should be met. It also needs to be safe for users, accepted by the target population, and sufficiently resistant to different fraud schemes and systemic attacks (Jain et al., 2004). In a practical biometric system, issues regarding performance should be considered. This refers to the attainable recognition accuracy and speed, the resources required to achieve the desired recognition accuracy and speed, as well as the operational and environmental factors that affect the accuracy and speed; Acceptability, specifies the extent to which people are willing to accept the use of a particular biometric identifier (characteristic) in their daily lives; circumvention reveals how easily the system can be tricked using dishonest techniques. According to Delac and Grgic, 2004, various methods employed for biometric authentication include infrared thermogram (capturing the heat radiated in the body with an infrared camera), gait (the peculiar way one walks), keystroke (the way one types on a keyboard), odor, ear, hand geometry (dimension of fingers and the position of joints, form, and size of palm), fingerprint (pattern of ridges valleys located on the tip of each finger), face, retina, iris, palmprint, voice, deoxyribonucleic acid (DNA), and signature. Biometric identification methods fall into two groups. They are both behavioural and physiological traits. Physiological traits are linked to a person's physical makeup, whereas behavioural traits are linked to how they behave (Bhosale and Sawant, 2012). Any physiological or behavioural trait of a human being may be employed as a biometric feature as long as it complies with the principles of universality, distinctiveness, permanence, and collectability, according to Jain et al., 2004. The fingerprint, which is the imprint of patterns made by friction ridges of the skin of the fingers and thumbs (Willis and Myers 2002), and an important component in cyber-related crime investigation (Akomolafe et al., 2018), is the main subject of this work. Over the years, researchers have worked in the area of fingerprint recognition and the hybrid matching algorithm is one of the most common techniques, although the hybrid algorithm performed well but, it is faced with the challenge of false minutiae. This paper however focuses on improving an existing fingerprint matching model such that it becomes better suitable for fingerprint recognition based on an end-to-end filtering approach using image preprocessing, feature extraction, false minutiae cancellation (using morphological operation: opening and closing process, erosion and dilation to filter false minutiae introduced at the feature extraction stage by the thinning process) and minutiae-based matching process.

Related Work

Ross et al., (2001) produced a hybrid matching algorithm. The algorithm was considered and applied in Oyekan and Opoola (2021) and Oyekan and Aderibola (2020). They combined minutiae information available in a fingerprint with the underlying texture information in local regions to perform matching. This method performed well when compared with the minutiae-based approach which does not utilize texture information. Chen et al., (2013) developed a novel categorized

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minutiae matching algorithm for fingerprint and palmprint identification systems. The technique was used in the breakdown of matching stages into several phases and rejecting untrue fingerprints or palmprints on different phases. This method saves searching time when compared with the traditional method. Youssif et al., (2007) developed a hybrid automatic fingerprint recognition system using minutiae and correlation-based techniques. Lim and Chin, 2013 developed a hybrid matching technique to improve the performance of fingerprint recognition via the fusion of minutiae-based and image-based techniques and extracting features from both techniques. This method performs better than individual algorithms individually but the issue of false minutiae was not addressed. Fingerprint recognition using minutia matching was presented in the work of Bhargava et al., 2012. The study presents different types of fingerprints and, the implementation of a minutiae-based approach to fingerprint identification and verification. It also discussed a minutiae-based matching technique using Ridge-end and bifurcation points. In this research, the minutiae-based fingerprint matching technique is studied in detail and implemented in Matlab. The research shows analyzer can recognize the fingerprint image by minutiae point calculation as well as location evaluation of minutiae points. The algorithm employed did not include any post-processing of the fingerprint images, which involves the removal of false minutiae in the thinned image. As a result, the work achieved a poor recognition rate with reduced effectiveness. Rawat 2009, worked on a hierarchical matcher in a fingerprint system. In this work, the matching of level 2 features (minutiae) with level 3 features (pores and ridge contour) is used. The hierarchical matcher does not consider image post-processing and image alignment before matching. This makes fingerprint comparison difficult. Also, in the cause of image preprocessing, the false minutiae points introduced as a result of thinning can make the performance of the hierarchical matcher to be low. Though this work achieved its aim, however, its algorithm did not include any stage for false minutiae removal. Bana and Kuar 2011, worked on Fingerprint recognition using image segmentation. The implementation was made to better understand how Fingerprint Recognition is utilized as a biometric to identify individuals. It covers every step, from extracting the smallest details from fingerprints to matching those tiny details to provide a match score. In the processing's intermediary stages, a number of conventional approaches are employed, however the results were disappointing. The algorithm utilized is not very robust and is susceptible to effects like scaling and elastic deformations because of its relatively low verification rate when compared to other types of biometrics. The preprocessing of the poor quality fingerprint photos, which also contributes to the low verification rate, presents a significant difficulty in the task of fingerprint recognition.

2. METHODOLOGY

In order to find the match correlation between the questioned and the known fingerprints, fingerprint recognition involves comparing a query fingerprint against a referred (known) fingerprint. A match between two human fingerprints can be verified automatically using fingerprint recognition or fingerprint authentication. According to Bana and Kaur (2011), it has two sub-domains: fingerprint identification and verification. High-quality fingerprint images are easily matched by the majority of fingerprint recognition systems now in use. When the fingerprint

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images are of poor quality, many fail (Lim and Chin, 2013). The fundamentals of a well-defined representation of a fingerprint and matching remain the same in all fingerprint recognition challenges, whether verification (one-to-one matching) or identification (one-to-many matching) (Bana and Kaur, 2011). The following; fingerprint acquisition, fingerprint image preprocessing, feature extraction, fingerprint image post-processing, minutiae alignment, and minutiae matching, are the main processes in this procedure and automated fingerprint identification.

The model was developed utilizing an end-to-end filtering strategy that included image preprocessing, feature extraction, post-processing algorithms, and morphological filtering techniques to remove erroneous minutiae. In order to verify the model's data input, fingerprint images from an existing database were used to simulate the model in Matlab software. The false acceptance rate (FAR), false rejection rate (FRR), and error equal rate (EER) were used to assess the performance of the suggested model.

The Proposed Model

Having discovered that existing models of fingerprint recognition are still being faced with the challenge of false minutiae points within the sample fingerprint images which are introduced during the thinning process, the need for improvement becomes more pronounced because this challenge leads to an increase in the probability of higher false rejection and acceptance rate during matching process. The proposed multi-filtering matching model for fingerprint recognition is a combination of various stages which involves the acquisition, preprocessing, minutiae feature extraction, post-processing, false minutiae cancellation, minutiae alignment, and minutiae matching. The false minutiae cancellation introduced in the proposed model was the enhancement work carried out on the existing model. The false minutiae cancellation was achieved using morphological filtering operations. Fig 1 below describes the proposed model while Fig 2 depicts the flowchart of the proposed multi-filtering matching model. This model was simulated, using Matlab and fingerprint images from the FVC2002 DB 1 database.

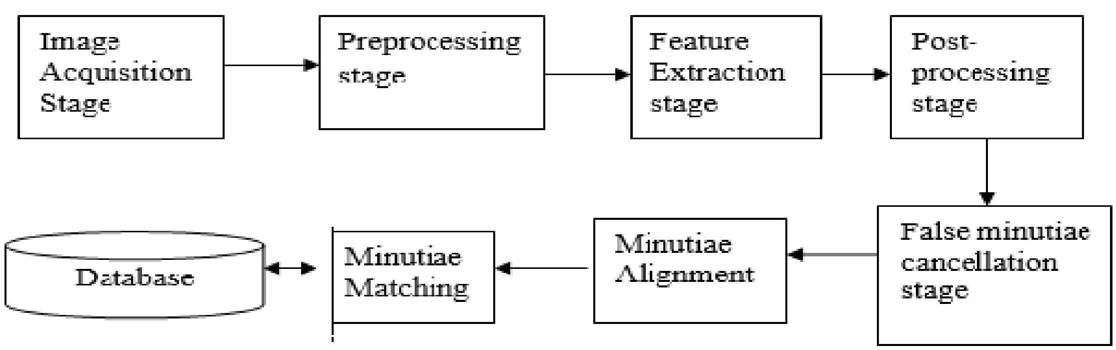

Fig. 1: Proposed Multi-filtering Model for Fingerprint Recognition

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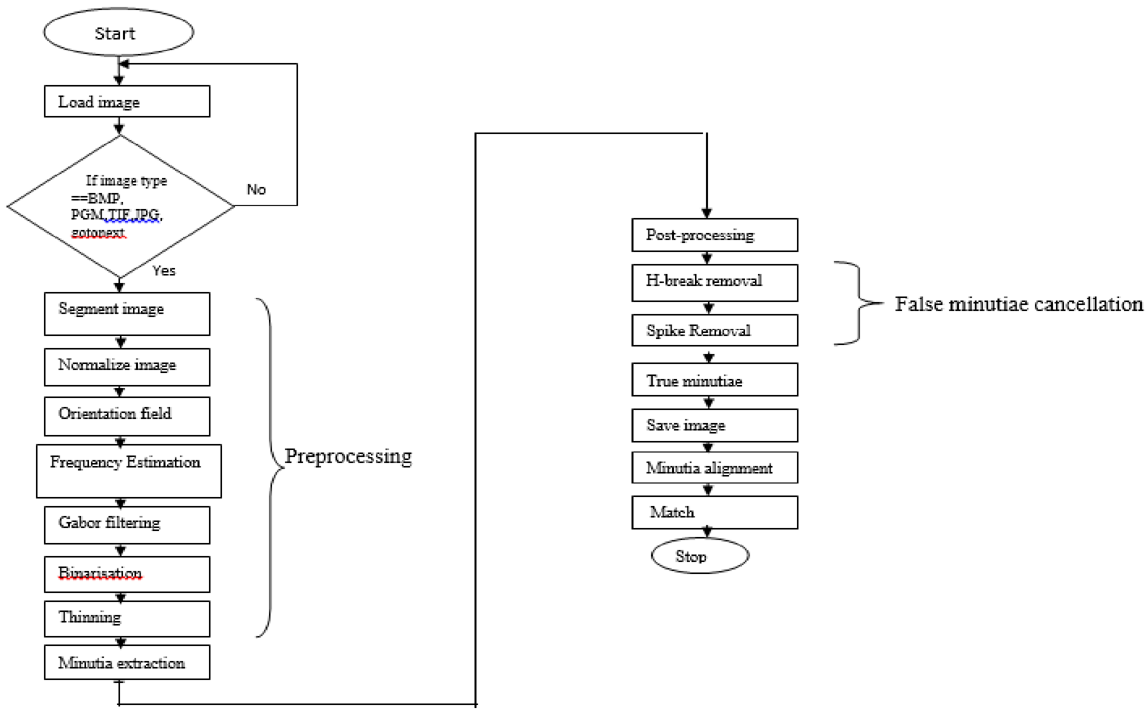

Fig 2: Flowchart for the Proposed Model

The input was the gray-scale fingerprint image, while the output was the matching score of the verified images.

a. Image Acquisition

For this research, the database used for testing was obtained from the available fingerprints provided by the Fingerprint Verification Competition 2002 (FVC2002). Fig 3 below also shows the sample images from the four sub-databases; DB1, DB2, DB3, and DB 4 which made up the whole FVC2002 database. The image type is TIFF image and the file format is (.tif). The size of each database used in the FVC2002 test, however, is established as 100 fingers, 8 impressions per finger (800 impressions). The relevant specification of image acquisition is the quality of the image either a good quality image or poor quality image. Good-quality images often yield good results

b. Image Pre-Processing

To remove background noise, effects of device noise, and gray level background which are caused by differences in finger density, the following preprocessing steps were used: segmentation, and normalization. To further enhance the fingerprint image, we made use of the orientation field, and frequency orientation estimation techniques which were carried out and also, edge detection and Gabor filtering were used, and binarisation was used to alter the grayscale of the fingerprint image to white and black. The processed image was finally enhanced using the thinning process.

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c. Minutiae Feature Extraction

The crossing number (CN) approach is used to extract the minute points from the improved image. This method analyses the local neighbourhood of each ridge pixel using a 3x3 window to extract the ridge ends and bifurcations from the skeleton image.

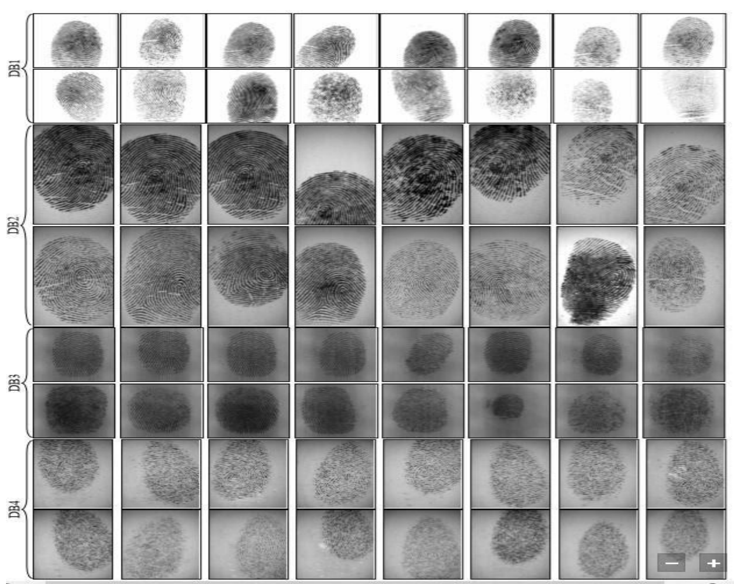

Fig 3: Sample images in the FVC2002 database (Source: Maio et al. (2002)

d. Fingerprint Post-Processing

The post-processing was done using the inter-ridge distance D. This represents the averaging of two adjacent distances. This equation was implemented to remove false minutiae in the form of spikes, bridges, holes, breaks, and short endings. To effectively cancel out the remains of the result of post-processing, the H-break and spike removal step was introduced.

False Minutiae Cancellation Using Morphological Operations

Implementation was carried out in Matlab using mathematical morphological operations on the thinned image. The thinned image was cleaned using the following three Matlab morphological functions below to remove H-breaks, isolated points, and spikes present in the image.
bwmorh(binaryImage, 'hbreak')bwmorh(binaryImage, 'clean')bwmorh(binaryImage, 'spur') bwmorh(binaryImage, 'hbreak') removed H-connected pixels, bwmorh(binaryImage, 'clean' removed secluded pixels i.e specific pixel 1s that are bounded by 0s while bwmorh(binaryImage, 'spur') removed spur pixel.

H-break and Spike Removal Process

Spikes piercing into valleys and incorrectly connecting two ridges are represented as H-connected pixels. Open and close operations, a morphological process known as erosion, were used to remove the H-connected pixels. The 'open' operation was used to enlarge the image and remove any background noise-induced peaks, while the 'close' operation was used to reduce the image and get rid of any minor cavities. The morphological filter was also used to sharpen ridge pixels into one-pixel widths in order to thin the image. The lighter area was smoothed using the morphological filter's erosion operation, which made it possible for thick lines to thin out. In order to eliminate the false minutiae contained in the image, the filter is then used to remove H-breaks and spikes of the thinned ridges. This process eliminated isolated points and H-connected pixels that occurred in the thinned lines of the images.

Performance Evaluation Metrics

This section describes the simulation and approach used to evaluate the performance of the proposed model. The approach includes the false rejection rate, false acceptance rate, and the error equal rate.

a. False Rejection Rate (FRR)

False rejection rate measures the fraction of genuine fingerprints that were rejected over the total number of tested cases as expressed in equation (1) below.

$$\mathrm{FRR} = \frac{\text{Number of genuine fingerprints rejected}}{\text{Total number of tests}} \qquad (1)$$

To calculate FRR, each image was matched against different impressions from the same finger. The matching process was carried out two times to determine the match correlation between the two images.

b. False Acceptance Rate (FAR)

The FAR is the fraction of imposter or false fingerprint match out of total number of tested cases and is expressed in equation (2) below:

$$\mathrm{FAR} = \frac{\text{Number of impostor fingerprints accepted}}{\text{Total number of imposition images used}} \qquad (2)$$

To calculate FAR, the first sample from each finger was matched against the first sample of the remaining fingerprint images in the database. This was done nine different times to determine their match correlation.

c. Error Equal Rate (EER)

The error equal rate is the point of interception at which the FAR curve equals the FRR. The lower the error equal rate the better the system.

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3. RESULTS AND DISCUSSION

The simulation results obtained is presented here. the false acceptance rate (FAR) and false rejection rate (FRR), receiver operating characteristics curve (ROC), and error equal rate (EER) which are the parameters used for performance evaluation in this work. In the preprocessing stage, the fingerprint image obtained was enhanced such that it achieved a state where it was suitable for fingerprint feature extraction. Fig 4(a-h) shows the Matlab interface of the fingerprint image before the image preprocessing stages were carried out on it. The segmentation stage was the first preprocessing stage employed after the image was loaded into Matlab. The best result was obtained for image segmentation with a variance threshold of 100. The segmentation of images with a variance threshold of 100 produced the best results. According to the fingerprint picture on b, this threshold value produced the best segmentation results for discriminating between the foreground and background regions.

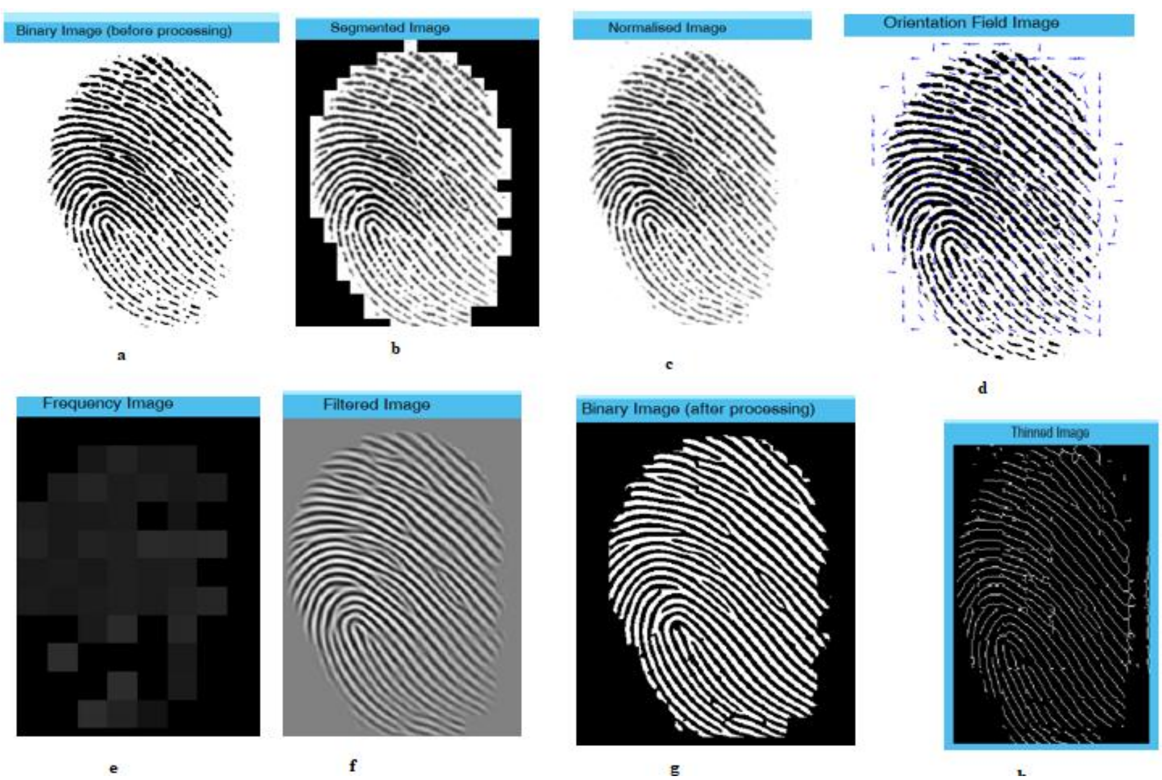

Fig 4(a-h): A screenshot of the preprocessing and post-processing of a fingerprint image

The normalization phase came next. As demonstrated in Fig. 4c, the required mean of zero and variance of one from Thai, (2003) and Hong et al., (2006) were applied to normalize the ridges in the images. The ridges and valleys are positioned well and appropriately because, during normalization, all places were uniformly adjusted along the horizontal axis.

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According to Fig. 4d, the orientation fields for the fingerprint images were discovered around their unique points. In contrast to the typical ridge flow pattern, the orientation of the ridges varied dramatically at the single spots, where the orientation field was discontinuous. This finding showed that there is no difference between the actual orientation of the fingerprint ridge and the predicted orientation of the vectors. According to the direction of the ridge structures in the fingerprint images, the orientation vectors created by the algorithm flow smoothly and consistently with one another. The ridge frequency estimate for the fingerprint image result, as shown in Fig. 4e, revealed by visual inspection that the intensities of frequency vary for blocks or sections within the same image. Some blocks or regions exhibited high contrast while others exhibited low contrast this was because fingerprints exhibit variation in their average ridge frequency characteristics and contrast levels.

The noise in the images shown in Fig. 4f might be eliminated by the Gabor filtering technique. Using the parameter values of kx = 0.5 and ky = 0.5, the outcome was produced. These results demonstrated that the contrast between the ridges and valleys for each image was just right—not too high, nor too low. The calibre of the image that was used also had an impact on this. Fig. 4g shows the outcome of the experiment with binarizing the image. A visual examination of the outcome revealed that the binarization method distinguished the valleys (white pixels) and ridges (black pixels) with absolute precision. In order to achieve this outcome, each pixel in the filtered image has its grey-level value evaluated. If the value is higher than the threshold value of 0.8, the pixel value is set to a binary value of one; if not, it is put to zero. In Fig.4h, the image thinning experiment's results are displayed.

The Matlab bwmorph operation using the 'thin' option was used to generate the thinned images. These results showed that the ridge thickness in each of the images has been reduced to its skeletonized form (one pixel wide). It is also shown that the connectivity of the ridge structures was preserved. When thinning was done to these binary images, the result in Fig. 4h. showed that the correct extraction of minutiae was not possible due to the large number of unauthentic features produced. The result of the minutiae extraction with spurious minutiae points is shown in Fig. 5a. The visual inspection of the result showed that there are lots of false minutiae in the extracted features. Some of the false minutiae are identified using a pointed arrow. When the minutiae cancellation algorithm was applied, the true minutiae were obtained as shown in Fig. 5b. Fig. 5b showed that the minutiae cancellation algorithm employed considerably reduced the false minutiae in the image leaving only true minutiae.

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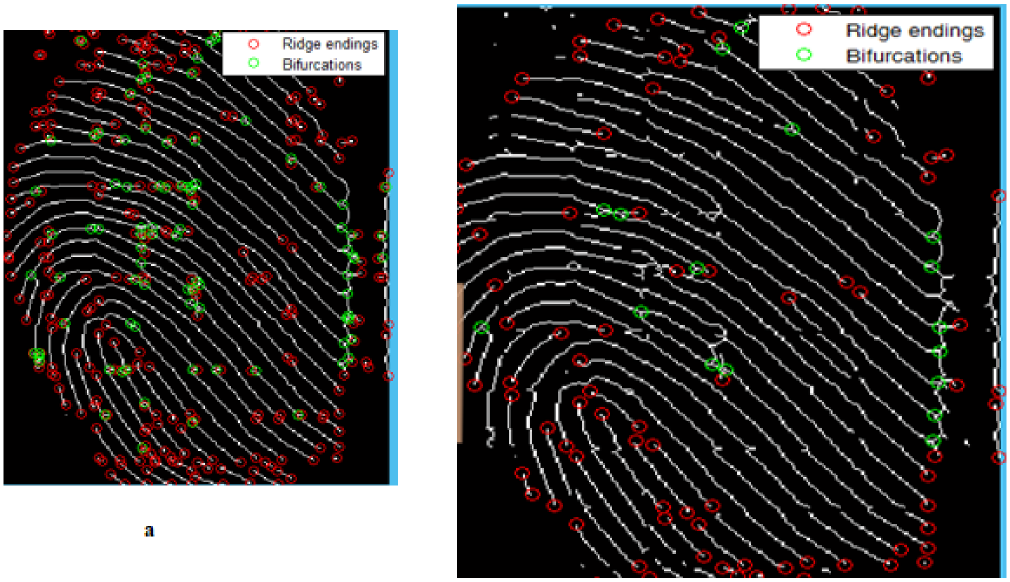

a

b

Fig 5 (a - b): Fingerprint Image with False Minutiae Points and Fingerprint Image Showing True Minutiae Feature

The fingerprint image preprocessing, feature extraction, and false minutiae cancellation were carried out on all the images used for the test, and minutiae alignment and matching were then carried out. During matching, the first impression of each image was matched with the first impression of another image to determine the false acceptance rate while on the other hand, the first impression of each image was matched with the other impression of the same image to determine the false rejection rate. 110 match tests were carried out to determine their match score. The result of the match test. From Table 1 below, image 101_1 was matched with image 102_1 which gave a match score of 43.1%. The expected output is 0 which implies rejected and the system rejected it. But for images 101_1 and 103_1, the expected output is 0 but the system accepted with a match score of 62.4%. A match test was carried out for other images and Table 1 shows the result. The result of the matching led to the evaluation of the performance of the model. This was done using the value of the FAR and FRR to determine the result of the FAR and FRR at different thresholds. The table 1 below shows the match score from the test carried out.

Table 1: Match Score between Two Images

S/N	Image1	Image2	Match %	Binary output	Expected
1	101_1	102_1	43.10	0	0
2	101_1	103_1	62.40	1	0
3	101_1	104_1	45.60	0	0

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4	101_1	105_1	39.25	0	0
5	101_1	106_1	49.55	0	0
6	101_1	107_1	47.60	0	0
7	101_1	108_1	24.10	0	0
8	101_1	109_1	56.40	1	0
9	101_1	110_1	24.10	0	0
10	102_1	101_1	43.45	0	0
11	102_1	103_1	47.74	0	0
12	102_1	104_1	35.74	0	0
13	102_1	105_1	26.10	0	0
14	102_1	106_1	32.73	0	0
15	102_1	107_1	66.43	1	0
16	102_1	108_1	10.56	0	0
17	102_1	109_1	47.63	0	0
18	102_1	110_1	44.30	0	0
19	103_1	101_1	82.40	1	0
20	103_1	102_1	47.74	0	0
21	103_1	104_1	83.40	1	0
22	103_1	105_1	32.14	0	0
23	103_1	106_1	36.50	0	0
24	103_1	107_1	39.05	0	0
25	103_1	108_1	36.40	0	0
26	103_1	109_1	100.00	0	0
27	103_1	110_1	44.74	0	0
28	104_1	101_1	45.60	0	0
29	104_1	102_1	35.74	0	0
30	104_1	103_1	83.10	0	0
31	104_1	105_1	51.20	0	0
32	104_1	106_1	34.43	0	0
33	104_1	107_1	32.81	0	0
34	104_1	108_1	44.55	0	0
35	104_1	109_1	28.45	0	0
36	104_1	110_1	48.71	0	0
37	105_1	101_1	39.25	0	0

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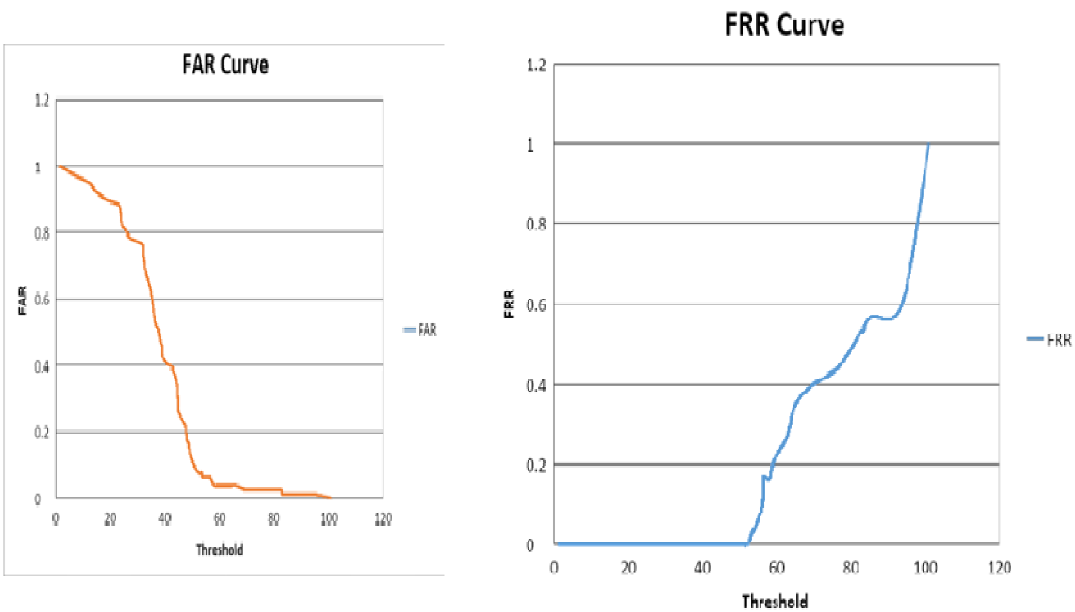

a

b

Fig. 6 (a and b): False Acceptance Rate and False Rejection Rate

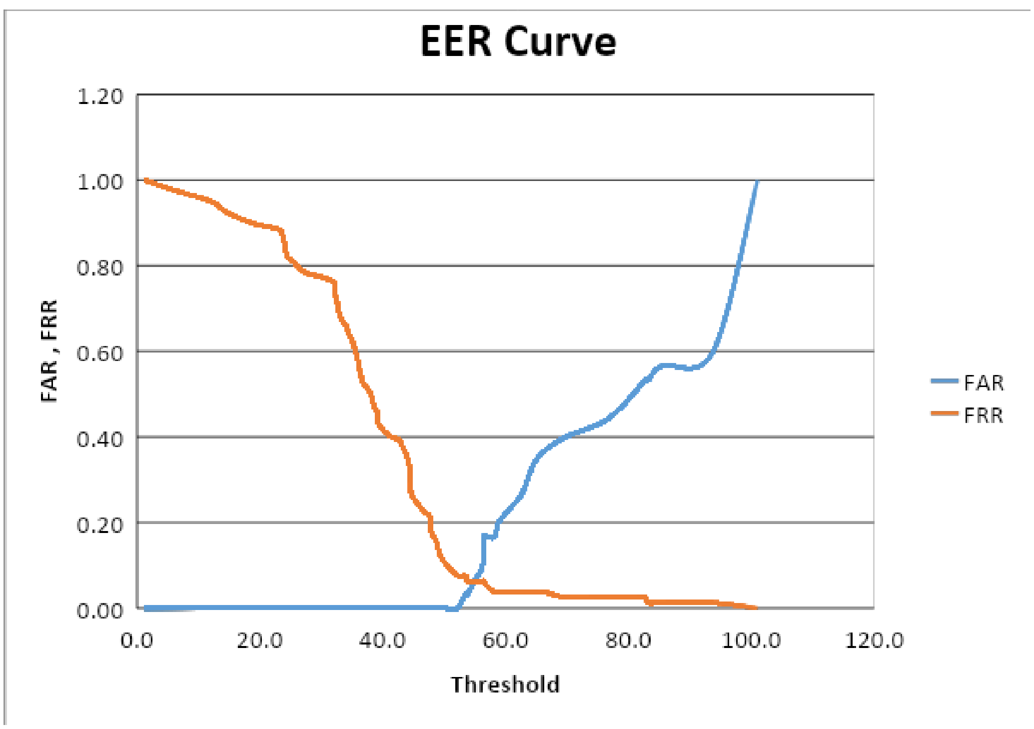

Fig 7: Error Equal Rate Curve

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4. CONCLUSION

This study has been able to address the problems of false minutiae in thinned images used for matching in fingerprint recognition which often lead to errors in the matching process via the use of morphological filtering processes. Images from an existing database of fingerprint images were used for the study, image preprocessing, minutiae feature extraction, post-processing, and matching stages were carried out to generate match scores for performance evaluation. Various regular techniques were used in the stages of preprocessing. The post-processing method greatly improves the quality of thinned images and eliminates several irrelevant minutiae which is justified by the experimental results. The false minutiae removal technique used successfully reduced the false minutiae structures like spurs, bridges, ladders, ridge breaks, short ridges, and holes. The FAR, FRR, and EER were used in measuring the model performance. According to the evaluation scheme the lower the EER, the better the system. This work performed better by achieving a lower EER value. Therefore, the study has achieved its goal of reducing false minutiae present in captured fingerprint images. Fingerprint post-processing increases the performance of the automatic fingerprint identification System by eliminating the false minutiae and validating the remaining minutiae. Only valid minutiae are helpful in fingerprint recognition. From this study, it is believed that the observed reduction in the false minutiae point present in the thinned images was made possible through the combination of the H-break and spike removal algorithms used. Therefore, the multi-filtering model gave an improved performance and it can be effective in fingerprint recognition especially when the datasets include poor-quality fingerprint images, and good accuracy is needed.

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