A Mathematical Modeling Method for Fingerprint Ridge Segmentation and Normalization

Iwasokun Gabriel Babatunde
Department of Computer Science
Federal University of Technology, Akure, Nigeria

Akinyokun Oluwole Charles
Department of Computer Science
Federal University of Technology, Akure, Nigeria

Olabode Olatunbosun
Department of Computer Science
Federal University of Technology, Akure, Nigeria

***Abstract*—Series of Automatic Fingerprint Identification Systems (AFIS) exist for human identification. One of the indices for evaluating the contributions of these systems is the degree to which they enforce security through proper identification and verification of individuals. This degree is generally determined by the quality of the fingerprint images and the efficiency of the algorithm. Ridge normalization and segmentation are parts of the important and successive stages of a raw fingerprint image enhancement. In this paper, existing mathematical models for fingerprint ridge normalization and segmentation were modified for increased speed and accuracy. The implementation was carried out in an environment characterized by Window Vista Home Basic operating system as platform and Matrix Laboratory (MatLab) as frontend engine. Real fingerprints obtained from the FVC2004 fingerprint database DB3 set A, B, C and D were used to test the adequacy of the resulting models. A comparison of the results from the modified models with the results from the original models shows that the modified models performed well.**

***Keyword:** AFIS, Pattern recognition, pattern matching, fingerprint, minutiae, image enhancement.*

I. INTRODUCTION

Fingerprint has continued to be one of the essential variables used for enforcing security and maintaining a reliable identification of any individual. Fingerprints are currently being used to maintain transparency and security during voting, examination, operation of bank accounts among others. They are also used for controlling access to highly secured places like offices, equipment rooms, control centers and so on. The result of the survey conducted by the International Biometric Group (IBG) in 2004 on comparative analysis of fingerprint with other biometrics is presented in Fig. 1. The result shows that a substantial margin exists between the uses of fingerprint for identification over other biometrics such as face, hand, iris, voice, signature and middleware [1].

Fingerprint is widely used for different purposes for the following reasons [1]-[4]:

a. There is a wide variation in fingerprints since no two people have identical prints.
b. Fingerprint is highly consistent since multiple fingerprints of same person may change in scale but not in relative appearance, which is not the case in other biometrics.
c. Every time the finger touches a surface, a fingerprint is left behind.
d. There is a good number of small and inexpensive fingerprint capture devices
e. Existence of affordable fast computing hardware
f. Availability of high recognition rate and speed devices that meet the needs of many applications
g. The explosive growth of network and Internet transactions
h. The heightened awareness of the need for ease-of-use as an essential component of reliable security.

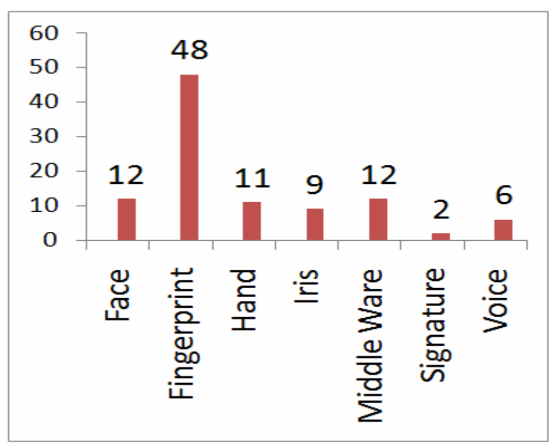

Figure 1: Comparative survey of fingerprint with other biometrics

The main ingredients of any fingerprint used for proper identification and enforcement of security are the features it possesses. The features exhibit uniqueness defined by type, position and orientation from fingerprint to fingerprint and they are classified into global and local features [5]-[8]. Global features are those characteristics of the fingerprint that could be seen with the naked eye. They are the features that are characterized by the attributes that capture the global spatial relationships of a fingerprint. Global features include ridge pattern, type, orientation, spatial frequency, curvature, position and count. Others are type lines, core and delta areas. The Local Features include ridge ending, bifurcation, lake, continuing ridge and isolated points. They form the tiny, unique characteristics of fingerprint ridges that are used for positive identification. Local features contain the information that is in a local area only and invariant with respect to global transformation.

Reliable and sound verification of fingerprints in any AFIS is always preceded with a proper detection and extraction of its features. A fingerprint image is firstly enhanced before the features contained in it could be detected or extracted. A well enhanced image will provide a clear separation between the valid and spurious features. Spurious features are those false minutiae points that are created due to noise or artifacts and they are not actually part of the fingerprint [8]. This paper presents modified mathematical modeling approaches to fingerprint ridge segmentation and normalization which are essential parts of the enhancement process.

II. FINGERPRINT IMAGE SEGMENTATION

There are two regions that describe any fingerprint image; namely the foreground region and the background region. The foreground regions are the regions containing the ridges and valleys. As shown in Fig. 2, the ridges are the raised and dark regions of a fingerprint image. The low and white regions between the ridges are the valleys. The foreground regions are also known as the Region of Interest (RoI) since they contain the unique features that define the image. The background regions are mostly the outside regions where the noises introduced into the image during enrolment are mostly found.

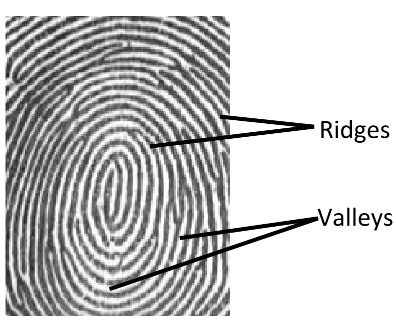

Figure 2: Ridges and valleys on a fingerprint image

The foreground and the background regions of the image shown in Fig. 3 are marked by the arrows. The essence of segmentation is to reduce the burden associated with image enhancement by ensuring that focus is only on the foreground regions while the background regions are ignored [8].

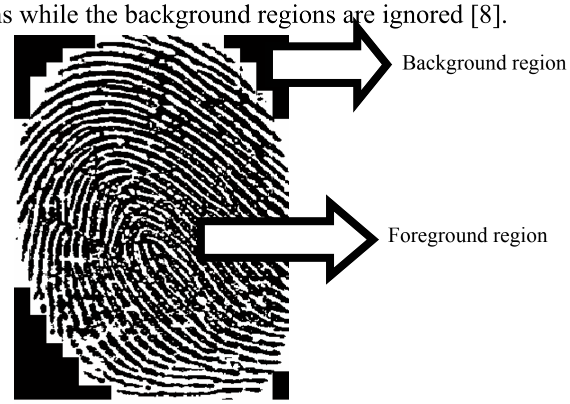

Figure 3: A fingerprint image and its foreground and background regions

The background regions possess very low grey-level variance values while the foreground regions possess very high grey-level variance values [9-10]. A modified version of the approach presented in [10] is used in this research for obtaining the grey-level variance values. The modified approach firstly divides the image into blocks of size S x S and then the variance, $\sigma^2(b)$ for each of the pixels in block b is obtained from:

$$\sigma^2(\mathbf{b}) = k \sum_{a=0}^{S-1} \sum_{b=0}^{S-1} ([L(a+1, b+1) - N(b))]^2 \qquad (1)$$

$$N(b) = k \sum_{i=0}^{S-1} \sum_{j=0}^{S-1} P(i+1, j+1) \qquad (2)$$

$$k = \frac{1}{S^2} \qquad (3)$$

L(u+1, v+1) and P(i+1, j+1) are the grey-level value for pixel (u+1, v+1) and (i+1, j+1) respectively in block b.

III. FINGERPRINT IMAGE RIDGE NORMALIZATION

The purpose of normalization of the ridge structure of the segmented image is to standardize the level of variations in the image grey-level values. By normalization, the grey-level values are adjusted to certain range that is good enough for improved image contrast and brightness. The first of the tasks of image normalization implemented in [9]-[10] and adopted for this research is the division of the segmented image into blocks of size S x S. The grey-level value for each pixel is then compared with the average grey-level value for the host block. For a pixel L(u,v) belonging to a block of average grey-level value of μ and variance V, the result of comparison produced a normalized grey-level value φ(u,v) defined by the formula:

$$(u,v) = \begin{cases} \mu_0 + \sqrt{\dfrac{V_0(\mathbf{L}(\mathbf{u},\mathbf{v}) - \mu)^2}{V}} & if\ \mathbf{L}(\mathbf{u},\mathbf{v}) > \mu \\ \mu_0 - \sqrt{\dfrac{V_0(\mathbf{L}(\mathbf{u},\mathbf{v}) - \mu)^2}{V}} & otherwise \end{cases} \quad (4)$$

where μ_0 and V_0 are the assumed mean and variance respectively.

IV. EXPERIMENTAL RESULTS

The models presented in this research were implemented by using MATLAB Version 7.6 on the Windows Vista Home Basic operating system. The experiments were performed on a Pentium 4 – 1.87 GHz processor with 1024MB of RAM. The purpose of the experiments was to analyze the performance of the modified algorithm under different conditions of images as well as provides basis for comparing the results from the research with results from related works.

The best results were obtained for image segmentation with variance threshold of 100. The results obtained with this threshold show high level of similarity to results obtained with the original algorithm presented in [9-10]. The results of the segmentation experiments using threshold value of 100 for the fingerprint images presented in Fig. 4(a), 4(e), 4(i) and 4(m) are presented in Fig. 4(b), 4(f), 4(j) and 4(n) respectively. These results represent the best segmentation in terms of differentiating between the foreground and the background. The results of segmentation experiments using lower threshold value of 95 are presented in Fig. 4 (c), 4(g), 4(k) and 4(o) while the results of segmentation using higher threshold value of 105 are presented in Fig. 4 (d), 4(h), 4(l) and 4(p). These results show inappropriate segmentation due to inaccurate variance thresholds. Visual inspection of the results of segmentation with lower threshold of 95 shows that there are substantial part of the background that had been segmented to the foreground. Similarly, it is revealed that under higher threshold of 105, some foreground regions were segmented to the background.

For the purpose of ascertaining that the modified algorithm performed faster than its original version, two sets of experiments were performed on images contained in FVC2004 fingerprint database DB3 set A, B, C and D. The first set of segmentation experiment implemented the original algorithm while the second set of experiment implemented the modified version. The two sets of experiments were performed under same conditions of coding and environments. It is showed in Table 1 that the modified version of the algorithm performed with greater speed having recorded lesser average completion time (completion time per image) for all the image sets.

TABLE I: Computational time for the original and modified algorithms

Set	Size	Original Algorithm Average Completion time in Second	Modified Algorithm Average Completion time in Second	% Increase
A	258	0.92	0.77	16.30
B	247	0.91	0.74	18.48
C	326	0.87	0.69	19.57
D	195	0.93	0.79	15.22

The different average completion time is attributed to non-uniformity in the sizes and pattern of the images across the four sets. While the original algorithm emphasized computation for all the pixels, the modified algorithm emphasized computation for the center pixel in each block, thereby reducing the computation time.

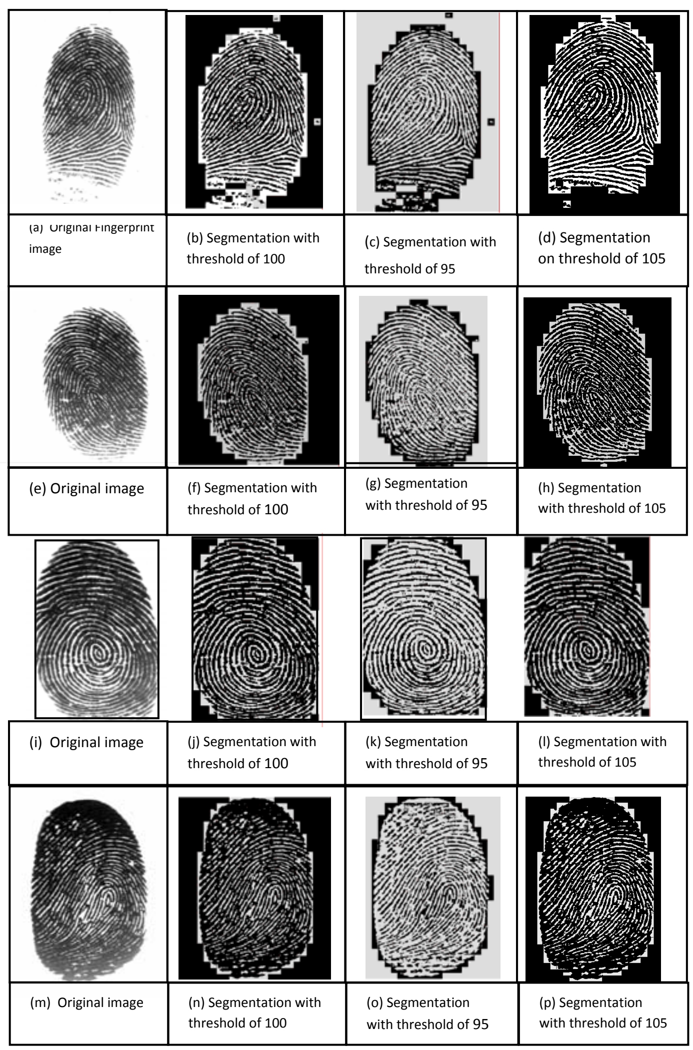

Figure 4: Results of segmentation with different threshold

The result of the normalization experiment on the segmented fingerprint images shown in Fig. 4(b), 4(f), 4(j) and 4(n) is presented in Fig. 5(a), 5(b), 5(c) and 5(d) respectively. The desire mean of zero and variance of one were used to normalize the ridges in the segmented images. The results obtained with these desired values show high level of similarity to results obtained with the original algorithm presented in [9-10]. During normalization, all positions are evenly shifted along the horizontal axis, which makes the structure of the ridges and valleys to become well and suitably positioned. The histogram plots of the original images shown in Fig. 4(a), 4(e), 4(i) and 4(m) are shown in Fig. 5(e), 5(f), 5(g) and 5(h) respectively while the histogram plots of the normalised images shown in Fig. 5(a), 5(b), 5(c) and 5(d) are shown in Fig. 5(i), 5(j), 5(k) and 5(l) respectively. The histogram plots of the original images show that all the intensity values of the ridges show irregular frequency values and also fall within the right hand side of the 0–255 scale, with no pixels in the left hand side. This leads to images with a very low contrast. The histogram plots of the normalized images show that the range of intensity values for the ridges has been adjusted between 0-1 scale such that there is a more evenly and balanced distribution between the dark and light pixels and that the ridge frequencies fall within close values. The normalized image histogram plots also show that the normalization process does distribute evenly the shape of the original image. The positions of the values are evenly shifted along the *x*-axis, which means the structure of the ridges and valleys are now well and suitably positioned. This shifted and improved positioning lead to images with a very high contrast shown in Fig. 5(a), 5(b), 5(c) and 5(d).

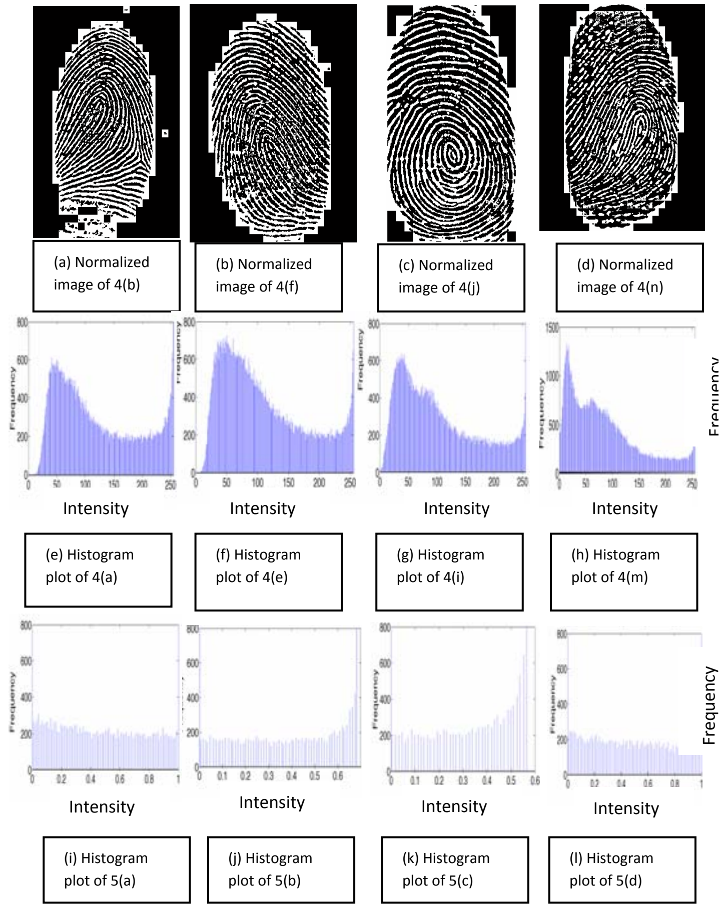

Figure 5: Histogram plots of original and normalised images

V. CONCLUSION

This paper discusses the results of the verification and modification of the fingerprint ridge segmentation and normalization algorithms presented in [9-10]. Some stages of the segmentation algorithm were slightly modified for improved performance. The results of the experiments revealed that the modified algorithms performed well.

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