Quality-Based Fingerprint Segmentation

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Abstract. The need for segmentation of low quality fingerprints in forensics, high security and civilian applications is constantly increasing. Most segmentation algorithms proposed in the literature normally deal with separation of the background from the foreground. However, low quality foreground regions must also be removed to lower errors in feature extraction, matching and decision modules. In this research work, a quality based fingerprint segmentation algorithm is proposed. The proposed algorithm is block-wise, it utilizes the auto-correlation matrix of gradients and its eigenvalue to compute the score quality measure of each block. The score quality measures both local contrast and orientation in each block. The threshold is computed by taking the mean for all the scores assigned to each block. It was evaluated on FVC 2002 and NIST High Resolution 27A databases. Its performance compared to other algorithms was evaluated by independent fingerprint quality measure algorithm. The results from both FVC and NIST databases show that the proposed algorithm results are promising.

Keywords: Eigenvalues, Auto-correlation, Local Contrast, Local Orientation, Gradients.

1 Introduction

The term segmentation refers to the process of parsing biometric signal of interest from the entire acquired raw signal [12]. There are three types of fingerprint images that researchers normally focus on in this process, namely, rolled, plain and latent, see figure 1. Rolled fingerprints are obtained by rolling a finger from one side to the other ("nail to nail"). Flat fingerprints are impressions in which a finger(s) is pressed down on a flat surface without rolling. Lastly, latent fingerprint images are those that are left behind when people intentionally or unintentionally touch the object's surface.

The quality of rolled, latent and flat fingerprints is directly affected by ageing, skin diseases and environmental and skin conditions, thus only a small portion of them is useful for recognition. The biometrics assurance group reported that

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(a) (b) (c)

Fig. 1. Three types of fingerprints images (a) Rolled, (b) Plain and (c) Latent [20]

it is often hard to obtain good-quality fingerprints from people over the age of 75 due to the lack of clarity of ridges on the pads of the fingers [5]. Skin diseases such as psoriais, atopic eczema, verruca vulgaris and pulpitis sicca was reported in [9] as major skin diseases that affect the quality fingerprint's micro and macro structures. Some possible solutions to these problems are:

1. The use of multi-instance biometrics.
2. The use of multi-modal biometrics.
3. The use of intelligent scanning devices capable of discriminating low-quality regions from high quality regions.
4. The use of signal/image processing subsystem capable of segmenting low-quality regions instead of discarding the probe presented.

However, due to higher cost of implementation, some of the above solutions are not feasible. In this research paper, a quality based segmentation algorithm utilizing auto-correlation of gradient's vectors and its eigenvalue to measure both ridges direction and contrast strength is proposed. The rest of this work is divided into five sections, In section 2 the background theory is presented, in section 3 literature survey for previous work is presented. Section 4 lays down the methodology of the proposed algorithm, in this section an algorithm flawchart and low-level pseudocode are also provided. Section 5 shows simulations results, and lastly section 6 concludes this research work.

2 Background Theory

At the conceptual level, fingerprint segmentation algorithms can be categorized into two categories, namely, supervised and unsupervised. These categories are independent of the type of fingerprint aforementioned in section 1. At the lower level; these algorithms can be further categorized into three categories [16], specifically, pixel-based, block-based and graph-based, see figure 2. Supervised segmentation algorithms first extract features of interest like coherence, mean,

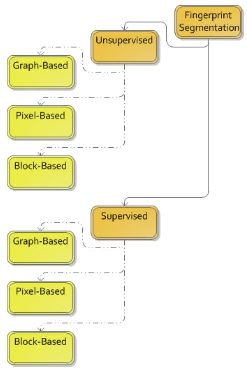

Fig. 2. Hierarchical View of Fingerprints Segmentation

variance or standard deviation and Gabor response [19] from a raw image, then a supervised machine learning algorithm, such as a simple linear classifier [7], Hidden Markov Model (HMM) [13], Neural Network [17] is used for classification. Unsupervised segmentation algorithms first divide the fingerprint image into blocks of equal and non-overlapping sizes, then features such as local histogram of ridge orientation [21], [15], variance or standard deviation, gradient magnitude and Gabor features [2] are extracted. In addition to supervised and unsupervised segmentation algorithms, some are semi-supervised/unsupervised [11]. Supervised segmentation algorithms first extract features of interest like coherence, mean, variance or standard deviation and Gabor response [19] from a raw image, then a supervised machine learning algorithm, such as a simple linear classifier [7], Hidden Markov Model (HMM) [13], Neural Network [17] is used for classification. Unsupervised segmentation algorithms first divide the fingerprint image into blocks of equal and non-overlapping sizes, then features such as local histogram of ridge orientation [21], [15], variance or standard deviation, gradient magnitude and Gabor features [2] are extracted. In addition to supervised and unsupervised segmentation algorithms, some are semi-supervised/unsupervised [11].

3 Literature Survey

Most segmentation algorithms proposed in the literature either considers the ridges direction/gradient strength leaving out the contrast or vise versa. In addition, they do not remove low quality foreground regions from high-quality foreground regions. In [3] an algorithm that uses three features, namely, coherence, mean and variance was proposed. An optimal linear classifier is trained for the classification of pixels belonging to foreground and background, while morphological operations are applied for post-processing. Authors in [8] proposed a hybrid algorithm based on block-wise classifier to separate the foreground from the background and pixel-wise classifier to deal with pixels accurately was proposed. Authors in [22] presented a novel algorithm that, firstly, uses the method of gradient projection, secondly adopt gradient coherence and finally carry out morphological operation to get the exact foreground region. A combination of the variance, mean and ridge orientation features was used for pre-processing, and median filter was also employed for post-processing [11]. Authors in [1] presented a modified gradient based method to extract the region of interest. Their method computes the local gradient values for fingerprint images, which detect sharp changes in the gray level value of background. A two steps segmentation algorithm was presented in [18] to exclude the remaining ridge region from the background. The non-ridge regions and unrecoverable low quality ridge regions are removed as background in the first step, and then the foreground produced by the first step is further analyzed to remove the remaining ridge region.

4 Methodology

4.1 Proposed Approach

The algorithm proposed herein is unsupervised, block-wise and pixel-wise in each block. The flowchart and the steps of the proposed algorithm are explained and depicted in the figure 3.

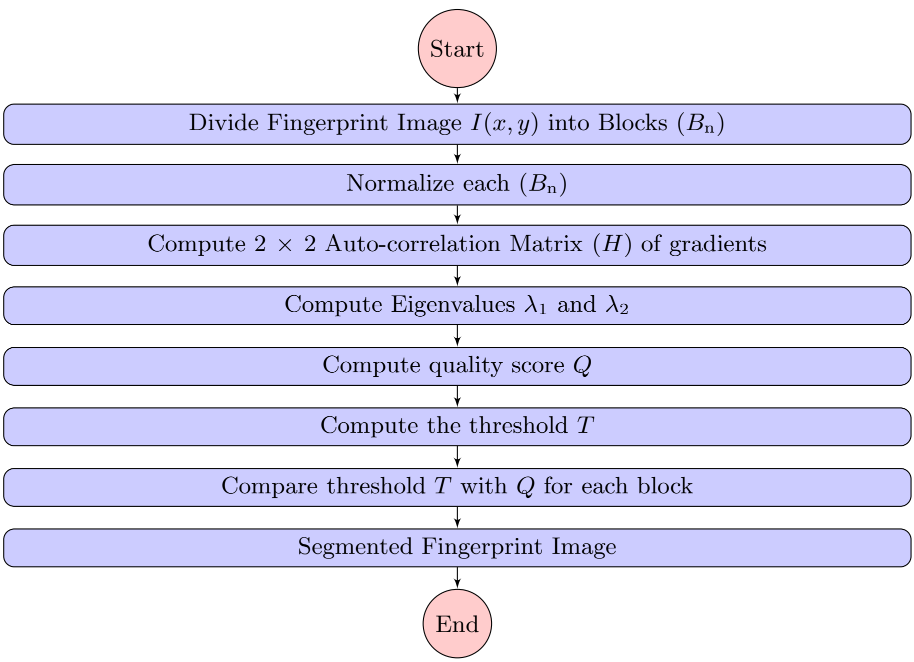

Fig. 3. Proposed Methodology

1. An image is first divided into equal and non-overlapping blocks of size (16×16).
2. Normalize each block with equation 1 [14].

$$B(i,j) = \begin{cases} M_0 + \sqrt{\dfrac{V_0\left(I\left(i,j\right)-M\right)^2}{VAR}} & \text{if } B\left(i,j\right) > M \\ M_0 - \sqrt{\dfrac{V_0\left(I\left(i,j\right)-M\right)^2}{VAR}} & \text{otherwise} \end{cases} \quad (1)$$

   Where M and VAR are the estimated mean and variance of M_0,V_0 respectively and M_0 and V_0 are the desired mean and variance values, respectively.
3. Compute the derivatives of each block for all pixels by convolving B_{n} with a 3×3 prewitt mask to find horizontal G_{x} and vertical G_{y} derivatives of equation 2, as shown in equations 3 and 4 below respectively.

$$\partial B_{\mathrm{n}} = \left(\frac{\partial B_{\mathrm{n}}}{\partial x}, \frac{\partial B_{\mathrm{n}}}{\partial y}\right) \quad (2)$$

$$G_{\mathrm{x}} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \otimes B_{\mathrm{n}} \quad (3)$$

$$G_{\mathrm{y}} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}^{\mathrm{T}} \otimes B_{\mathrm{n}} \quad (4)$$

4. Compute a 2×2 auto-covariance matrix of gradients H as shown in equation 5 below [4]. This procedure is use to measure the strength of gradients.

$$H = \begin{bmatrix} G_{\mathrm{x}}^2 & G_{\mathrm{x}} G_{\mathrm{y}} \\ G_{\mathrm{y}} G_{\mathrm{x}} & G_{\mathrm{y}}^2 \end{bmatrix} \quad (5)$$

5. To avoid the explicit eigenvalue decomposition of H, compute trace $Trace$ and determinant Det of the matrix H as shown in equations 6 and 7 below respectively.

$$Trace\left(H\right) = \sum_{(\mathrm{x,y}) \in \mathrm{B_n}} \left(G_{\mathrm{x}}^2 + G_{\mathrm{y}}^2\right) \quad (6)$$

$$Det\left(H\right) = \left(\sum_{(\mathrm{x,y}) \in \mathrm{B_n}} G_{\mathrm{x}}^2\right) \left(\sum_{(\mathrm{x,y}) \in \mathrm{B_n}} G_{\mathrm{y}}^2\right) - \left(\sum_{(\mathrm{x,y}) \in \mathrm{B_n}} G_x G_{\mathrm{y}}\right) \quad (7)$$

6. Compute two eigenvalues of the matrix H as shown in equations 8 and 9 below.

$$\lambda_1 = \frac{1}{2}\left(Trace\left(H\right) + \sqrt{Trace^2\left(H\right) - 4Det\left(H\right)}\right) \quad (8)$$

$$\lambda_2 = \frac{1}{2}\left(Trace\left(H\right) - \sqrt{Trace^2\left(H\right) - 4Det\left(H\right)}\right) \quad (9)$$

7. Compute the quality measure Q of each block using equation 10 below.

$$Q = \log_{10} \frac{|\lambda_2|}{|\lambda_1|} \times \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2} \tag{10}$$

The first term in equation 10 represents the contrast of the block, while the second term measures the strength of the local orientation. When contrast is very low or high but uniform in each sub-image $\log_{10} \frac{|\lambda_2|}{|\lambda_1|}$ becomes negative.

8. Lastly, Compute the threshold T to discard low quality foreground and background regions by computing the mean of eigenvalues using 11 below.

The pseudocode of the proposed methodology is presented in algorithm 1.

$$\overline{T} = \frac{1}{N} \sum_{\mathrm{i}=1}^{\mathrm{N}} Q_{\mathrm{i}} \tag{11}$$

Algorithm 1: Proposed Algorithm

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Algorithm: Quality Based Fingerprint Segmentation
input  : Fingerprint Image (I(x, y) )
output: Segmented Fingerprint
—Compute Segmentation–
for Bn.row=1 to Bn .max(row) do
    for Bn.column=1 to Bn .max (column) do
        1. Normalise with equation 1;
        2. Compute Gx and Gy with 3 and 4, respectively ;
        3. Compute λ1 and λ2 using equations 6 and 7 respectively;
        4. Compute Q using equations 10;
        5. Save Q in matrix;
    end
end
Compute threshold T value using equation 11;
for Q.row=1 to Q .max(row) do
    for Q.column=1 to Q .max (column) do
        if Q(i,j) > T then
            Block belong to the foreground;
            Bn = Bn;
            else if Q(i,j) < T then
                Block Belongs to the background;
                Bn = zeros;
            end
        end
    end
end
```

4.2 Post-processing

Although the algorithm proposed in this work segmented fingerprints image almost accurately it still needs some post-processing to filter noisy blocks. Morphological operations such as bwareaopen (4-connected neighborhood) and imcomplement, filtering techniques such as median filter (28-by-28 neighborhood) and convex hull were employed to clean up after segmentation.

5 Results and Performance Evaluation

The performance of the proposed algorithm was compared to two segmentation algorithms, namely, simple mean-variance [23] and directional mean-variance [24]. The results from each of these algorithms were evaluated using fingerprint quality measure proposed in [25]. FVC 2002 DB1 and NIST Special Database 27A were used. FVC 2002 DB1 database contains 800 fingerprint images. The size of each image in the database is 374×388, and the resolution is 500dpi. NIST special database 27A contains 1000ppi resolution images. The size of each image in the database is 1331×1171. The implementation was done using $Matlab^{®}$. The performance and experimental results of the proposed method are shown in figure 4, 5 and table 1.

The y-axis labelled as scores on the graphs show the quality score of the image after segmentation while x-axis correspond to the actual fingerprint segmented i.e. 1 correspond to image 1 and so 2.

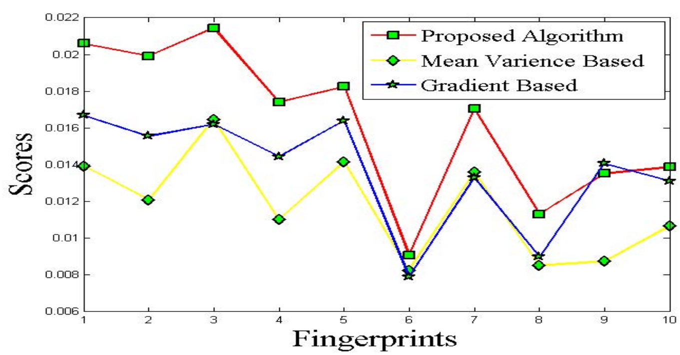


Fig. 4. Performance Evaluation Using Fingerprint Verification Competition (FVC) Database 2002

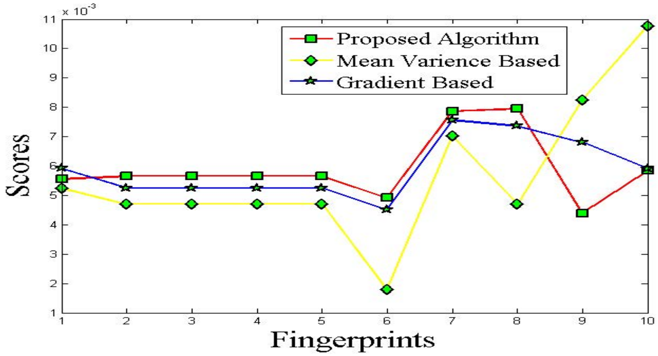
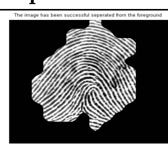
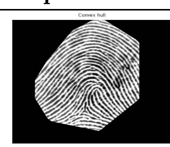
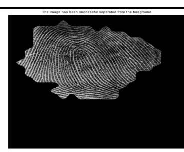


Fig. 5. Performance Evaluation Using NIST High Resolution Special Database 27A

Table 1. Experimental Results for FVC2002 and NIST High Resolution Special Database 27A

Original Image	Pre-processed Image	Post-processed Image
		
		

6 Conclusion

In this paper, a novel algorithm for segmentation of low quality and high resolution fingerprint has been proposed. The steps involved in the segmentation process have been outlined and well documented. Results show that this algorithm can be use with 1000ppi and 500ppi fingerprints of low quality. Experiments conducted show that the algorithm proposed can accurately remove low quality regions in the fingerprint foreground leaving the foreground with high quality. Hence, reducing errors in feature extraction, matching and decision modules.

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