Segmentation of Low Quality Fingerprint Images
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ABSTRACT
A fingerprint image is a pattern which consists of two regions, foreground and background. The foreground contains all important information needed in the automatic fingerprint recognition systems. However, the background is a noisy region that contributes to the extraction of false minutiae in the system. To avoid the extraction of false minutiae, there are many steps which should be followed such as preprocessing and enhancement. One of these steps is fingerprint segmentation. The aim for fingerprint segmentation is to separate the foreground from the background. Due to the nature and the poor quality of fingerprint image, the segmentation becomes an important and challenging task.

This paper presents a new algorithm to segment fingerprint images. The algorithm uses four features, the global mean, the local mean, variance and coherence of the image to achieve the fingerprint segmentation. Based on these features, a rule based system is built to segment the image.

The proposed algorithm is implemented in three stages; preprocessing, segmentation, and post-processing. Gaussian filter and histogram equalization are applied in the pre-processing stage. Segmentation is applied using the local features. Finally, fill the gaps algorithm and a modified version of Otsu thresholding are invoked in the post-processing stage.

In order to evaluate the performance of this method, experiments are performed on FVC2000 DB1. Segmentation of 100 images is performed and compared with manual examinations of human experts. It shows that the proposed algorithm achieves a correct segmentation of 82% of images under test.

General Terms

Keywords
Fingerprint Recognition System, Fingerprint, Otsu, Split and Merge, Histogram Equalization, mean, variance and coherence.

1. INTRODUCTION
Fingerprint is fully created at about seven months of fetus development. It is unique and unchangeable during individual’s life excepting the situation of accidents in the finger such as cuts or injuries. A captured fingerprint image usually consists of two components; the foreground and the background. The foreground is the area of scanner surface which is in contact with a finger surface. It includes the necessary information needed for fingerprint recognition, while the background is the noisy area which is located at the borders of the image. Fingerprint segmentation is the process by which the foreground is separated from the image background. The result of fingerprint segmentation is a fingerprint image in which the foreground is segmented to be a challenging task.

Fingerprint segmentation is achieved on the pixel level. While in the pixel–wise approach, the fingerprint image is divided into blocks and each block is classified into foreground or background based on features calculated for the block. While in the pixel–wise method, segmentation is achieved on the pixel level.

In this paper, a new algorithm for the segmentation of fingerprint images is presented. Segmentation is achieved by using a number of rules related to global mean, local mean, local variance and coherence. It includes pre-processing and post-processing stages to enhance segmentation.

The rest of the paper is organized as follows. Automatic fingerprint recognition system is described in section 2. Segmentation methods and enhancement techniques are given in section 3 and 4. The features for fingerprint segmentation are shown in section 5. In section 6 the proposed algorithm is illustrated. The experimental results based on the proposed method are displayed in section 7 and in section 8, the conclusion is presented.

2. Automatic Fingerprint Recognition System
Fingerprint recognition system is the oldest recognition system. In the early twentieth century, fingerprint recognition becomes accepted as a personal identification system in forensic. Afterwards, different fingerprint recognition techniques, like latent fingerprint acquisition, fingerprint classification, and fingerprint matching were developed. At present, automatic fingerprint recognition is in progress day after day not just in forensic applications, but even in civilian applications.

Fingerprint recognition systems consist of the following parts (figure 1):
- Sensing or Image acquisition
  - Pre-processing
  - Feature or minutiae extraction
  - Matching

Figure 1. Fingerprint Recognition System

2.1.1 Sensing or Image Acquisition
The acquisition of a fingerprint images was accomplished by using off-line sensing or live-scan. Off-line sensing is defined as ink-technique. An individual place his finger in black ink then his finger is pressed in a paper card. However, live-scan scanners become presently more frequent, because of its simplicity in...
usage. There is no need for ink. The digital image is directly 
acquired by pressing against the surface of the scanner.

2.1.2 Pre-processing

To simplify the task of minutiae extraction and make it more 
easy and reliable, some preprocessing techniques are applied to the 
raw input image. Enhancement and segmentation of the fingerprint are the 
most commonly methods performed in the preprocessing step.

The principal aim of enhancement is to improve the clarity of 
ridge in the recoverable area in the image and to assign the 
unrecoverable ridges as a noisy area. Recoverable region is 
considered when ridges and valleys are corrupted by a small 
amount of dirt, ceases, or other kind of noise. Unrecoverable 
region are the regions which are impossible to recover them from 
a very corrupted and noisy image [14].

However the primary purpose of segmentation is to avoid 
extraction of feature in the background that is in reality considered 
as a noisy area [8]. Segmentation indicates the separation of 
fingerprint area or foreground from the image background. Due to 
the streaked nature of the fingerprint area, a simple thinning 
technique is not sufficient. In addition to the presence of noise in a 
fingerprint image, fingerprint segmentation requires more robust 
and strong techniques [1].

2.1.3 Feature extraction

After preprocessing step, the segmented and enhanced fingerprint 
is further processed to identify the main and distinctive 
minutiae. Most of the minutiae extraction methods necessitate the 
fingerprint gray-scale image to be transformed into a binary 
image. The acquired binary image is forwarded to a thinning stage 
to reduce the thickness of the ridge to one pixel ridge. Afterwards, 
the minutiae are simply detected by a simple image scan.

Due to the characteristic of the pixel that corresponds to minutiae, 
the simple scan image is one of many methods developed for 
minutiae detection. It depends on calculating crossing number of a 
pixel. The crossing number is the half sum of the differences 
between pairs of adjacent pixels in the 8-neighborhood of p. Since 
the minutiae pixel can be bifurcation, crossover, termination, and 
so on. Therefore, the crossing number for minutiae must be 
different from 2 [9].

To avoid the problems related to fingerprint binarization and 
thinning, many methods have been proposed. Direct gray-scale 
minutiae extraction is one of these methods. The basic idea of this 
algorithm is to track the ridge lines in the gray-scale image by 
going according to the local orientation of the ridge. When a ridge 
line terminates or intersects another line, the algorithm detects this 
location as a minutiae point [9].

2.1.4 Matching

Algorithms that extract important and efficient minutiae, will 
 improve the performance of the fingerprint matching techniques. 
The features extracted of the input image are compared to one or 
more template that was previously stored in the system database. 
Therefore the system returns either a degree of similarity in case 
of identification or a binary decision in case of verification.

Minutiae-based and correlation-based matching techniques are the 
most common techniques in fingerprint matching. In Minutiae- 
based techniques, first systems extract the minutiae in both images 
then the decision is based on the correspondence of the two sets of 
minutiae locations. However in correlation-based techniques 
compare two fingerprints based on their gray level intensities.

First it selects relevant templates in the primary fingerprint then it 
uses template matching to locate them in the secondary image and 
compare positions of both fingerprints [4]. In correlation-based 
techniques, the propagation of errors in minutiae extraction step is 
avoided. It doesn’t require any preprocessing steps. Nonetheless, minutiae-based technique is the most widely used 
technique in fingerprint matching.

3. SEGMENTATION METHODS

Generally, Image segmentation methods are classified into two 
categories, discontinuity and similarity of intensity value. In the 
 discontinuity-based categories, segmentation can be defined as 
edge-based segmentation that subdivides an image based on 
 abrupt changes in the intensity. In the similarity-based categories, 
the segmentation is related to partitioning an image into regions 
according to their similarity. The similarity is a measure that is 
defined in advance depending on the fundamental problem in the 
image. This measure can be a specific intensity level, mean value, 
variance value, and so on. Point, line and edge detection are 
examples of discontinuity methods. Also, threshold, Otsu,
splitting and merging and region growing are examples of 
similarity-based methods. The combination between different 
methods can give an improvement in segmentation performance.

3.1 Threshold method

The main idea in threshold methods is to select a threshold T that 
can separate objects from the background. This threshold can be 
specified according to the intensity histogram. Histogram of an 
image displays the gray-level values versus the number of pixels at 
that value. Any pixel with gray level \( f(x, y) > T \) is assigned as 
a foreground; otherwise the pixel is assigned as background see 
formula 3.1.

\[
\begin{align*}
G(x, y) &= \begin{cases} 
255 & \text{if } f(x, y) > T \\
0 & \text{if } f(x, y) \leq T
\end{cases} 
\end{align*}
\]

For fingerprint images, the histogram shows the contrast of the 
image and the distribution of the gray level. As shown below in 
figure.2 the image is a bright image and no obvious gray level 
point can be as thresholding point. Because of the nature of 
fingerprint images, this algorithm cannot apply a simple 
thresholding technique.

![Figure 2. Histogram for bright fingerprint](Image 368x609 to 438x682)

3.2 Optimum Global Thresholding, Otsu’s method

The basic idea of Otsu’s method is that an optimum threshold 
maximizes the separation between classes with respect to intensity 
value. According to maximizing the between-class variance, this 
method is optimum. Otsu’s algorithm can be presented as the 
follows [12]:

- Compute the normalized histogram of the input image by 
  using equation (3.2)
  \[ p_i = \frac{n_i}{MN} \]  
  (3.2)

  Where \( n_i \) is the number of pixels with intensity \( i \), \( MN \) is total 
  number of pixel

- Set through possible threshold as shown in equation (3.3)
  \[ T(k) = k \]  
  (3.3)

  Where \( L \) is the maximum intensity level in the image and is 
  between 0 and \( L-1 \)

- Compute the cumulative sum by using equation (3.4) 
  \[ P(k) = \sum_{i=0}^{k} p_i \]  
  (3.4)

- Compute the cumulative means by using equation (3.5) 
  \[ m(k) = \sum_{i=0}^{k} (i P_i) \]  
  (3.5)

- Compute the global intensity mean by applying equation 
  (3.6) 
  \[ m_g = \frac{\sum_{i=0}^{L} i P_i}{M} \]  
  (3.6)

- Compute the between class variance by using equation 
  (3.7) 
  \[ \sigma^2 = \frac{(P(0)\mu_0 - P(L)\mu_1)^2}{P(0)\mu_0 + P(L)\mu_1} \]  
  (3.7)

  Compute the Global variance by using equation (3.8) 
  \[ \sigma^2 = \sum_{i=0}^{L} (m_i - m_g)^2 P_i \]  
  (3.8)

- Obtain the Otsu threshold as in equation (3.9)
In 2D the Gaussian distribution has the form of (4.1).
\[ G(x,y) = \frac{1}{2\pi \sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \] (4.1)

The goal of Gaussian Filter is to use this distribution as a point spread function which can be performed by convolution mask. The meaning of convolution is the process of moving the mask from the upper-left corner to the lower-right corner and replacing the value of the center pixel in the image by the value of \( g(x,y) \). \( G(x,y) \) is calculated by the sum of products of the filter coefficients and the corresponding image pixels in the area spanned by the filter mask. Normally, the filter mask is a two dimensional array in which the values of the mask coefficients affect the nature of the image [5]. Therefore Gaussian filters smoothes the image by using the following mask based on discrete approximation to the Gaussian function (Figure 7).

![Gaussian mask](image.png)

Figure 7: Gaussian mask

Figure 8 shows the result of using Gaussian filter with \( \sigma = 5 \). This filter blurs the fingerprint image by reducing some noises in the background.
4.2 Histogram Equalization

The usage of Gaussian Filter in fingerprint images help efficiently to enhance the image in case of the presence of noise such that image acquisition noise. However, this filter cannot enhance an image which is affected by contrast problem. Therefore Histogram Equalization is a good solution for this problem. Histogram Equalization is the most common technique for improving the appearance of a poor image. It is the technique to get the histogram for the destination image as flat as possible. Histogram Equalization defines a mapping of gray level $p$ into gray level $q$ such that the distribution of gray level $q$ is uniform. This mapping stretches the contrast of gray level near the maxima in the histogram [6]. The probability density function of a pixel intensity level $r_k$ is yield by formula (4.2).

$$p_i(r_k) = \frac{n_i}{k} \tag{4.2}$$

Where $r_k$ is between 0 and 1, $k=0, 1, \ldots, 255$, $n_i$ is the number of pixels at intensity level $r_k$ and $n$ is the total number of pixels.

The new intensity value $s_j$ for level $k$ is derived by formula (4.3).

$$s_j = \sum_{k=0}^{255} n_k \cdot p_i(r_k) \tag{4.3}$$

By applying histogram equalization in a fingerprint image, the contrast is increased in most of fingerprint pixel. The first image in figure 9 shows the original image with its corresponding histogram and the equalized image with its corresponding histogram. As expected, the histogram of the original image (a) is concentrated on the light side of the intensity scale. The result of histogram equalization show important improvement in the contrast. In the equalized histogram (d), the intensity values cover the entire gray scale. Therefore, the significant contrast differences between the original histogram and the equalized one, illustrate the power of histogram equalization as a principal contrast enhancement tool.

Coherence feature indicates the strength of the local window gradients centered on the processed point along the same dominant orientation.

Local mean, local variance and local coherence [7] are calculated as the following formulas (5.1) and (5.2).

$$\text{Variance} = \frac{1}{w^2} \sum_{i,j} (I - \text{mean})^2 \tag{5.1}$$

$$\text{mean} = \frac{1}{w^2} \sum_{i,j} I$$

Where $I$ is the intensity and $w$ is the window size centered on the processed pixels.

$$\text{coh} = \sqrt{(G_{xx} - g_{xx})^2 + 4(G_{yy}^2) (G_{xy} + g_{xy})} \tag{5.2}$$

Where $G_{xx}$ and $G_{yy}$ are corresponding horizontal and vertical gradient components which are given by Sobel operators.

4.3 The usage of Gaussian Filter in fingerprint images helps efficiently to enhance the image in the presence of noise such that image acquisition noise. However, this filter cannot enhance an image which is affected by contrast problem. Therefore Histogram Equalization is a good solution for this problem. Histogram Equalization is the most common technique for improving the appearance of a poor image.

Figure 8. (a) Original image 1_4, (b) Noise reduction with Gaussian Filter

Figure 9. (a) Original image, (c) histogram of the original image, (b) equalized image, (d) histogram of the equalized image

5. FEATURES FOR FINGERPRINT SEGMENTATION

Fingerprint features must reflect both the gray level of fingerprint and the direction of ridge lines. However, the complicated construction of fingerprint pattern and the imbalance in the contrast, require local feature instead of the global feature. Local Mean and variance are the features for gray-level based methods while coherence is the feature for direction based method. The combination for these features in one algorithm show efficiently the distribution of the pixels for ridges and valleys in the image.
6. THE PROPOSED METHOD

The detailed steps of the fingerprint segmentation algorithm are depicted in figure 15. In this paper, fingerprint segmentation is achieved by three stages:

6.1 Pre-processing
Fingerprint images with low contrast, false traces ridges or noisy complex background cannot be segmented correctly. Therefore, it is required to enhance the image. Techniques used in this paper are Gaussian Filter, and Histogram Equalization. Gaussian Filter is used to smooth the image and hence background areas. This step together with split and merge technique, which is applied in the next stage, will collect pixels with similar gray levels into big areas. Histogram Equalization is invoked in this stage too. When the global mean of the image under consideration is higher than a certain threshold, which mean a bright image, histogram equalization is used to enhance the image by reducing the brightness of the image.

6.2 Segmentation
In this stage, split and merge technique is applied to collect similar background areas after the smoothing process. In order to separate the foreground from the background, the image is divided into a number of non-overlapping sub-images of size 10x10 pixels and the local mean, local variance, and local coherence are computed for each sub-image. The global mean together with the three aforementioned parameters are used to build a rule based system to segment the foreground and the background of the image under consideration. The result of this rule based system is to decide whether a certain block is a foreground or a background. When a certain block is decided to be a background, a set of white pixels are placed in this block, otherwise the image pixels are kept.

The segmentation is achieved by dividing the active space shown in figure 4, which is specified by minimum and maximum values of local mean, variance and coherence, into a number of subspaces. Then the global mean is invoked to build a simple hierarchy of if then rules to decide whether a certain block belongs to a background or a foreground region.

6.3 Post-processing
The segmented fingerprint image may contain isolated background blocks which are surrounded by foreground blocks. Obviously, these background blocks are foreground in the original image. A simple post-processing technique is proposed to eliminate the presence of these isolated blocks. It is as follows, see figure 16:

For all blocks in the image, if a background block (i,j) is found
- Check the N_4 neighbor blocks which are located at (i, j-1), (i, j+1), (i-1, j) and (i+1, j) for the presence of foreground.
- If two or more of these neighbors are foregrounds, change all of the pixel in the block (i,j) back to their original value before any segmentation.

After filling the foreground with the missing blocks, a modified version of Otsu thresholding [11] method is applied. The modified algorithm works locally in the blocks of the image to find the corresponding optimal threshold for each block and segments the image into white background and black foreground.

6.4 Modified Otsu’ method
Noise and non uniform illumination in the foreground and background play a principal role in the performance of original Otsu’s algorithm. Also, the algorithm goes through the entire image to find an optimal threshold to further use in segmentation. In this paper, a new version of Otsu method is developed. The developed algorithm seeks locally in small regions of the image and find corresponding optimal threshold for every region.

The main idea of this method is to extract the foreground from the background by applying the global Otsu’s method and to preserve ridges lines in the foreground by using Otsu’s in image partitioning (figure 4).

7. EXPERIMENTAL RESULTS
The proposed algorithm is tested on 100 fingerprint images which are selected randomly and without repetition from FVC2000 database DB1. These images are collected by using two small-size and low-cost optical sensors.
To evaluate the efficiency of this algorithm, human expert examines the results of the segmentation algorithm from these random images. Figure 17 shows a number of successful segmentation achieved by this algorithm.

In order to evaluate this method quantitatively, a four-level segmentation scheme is suggested. The number of correctly segmented blocks in the image is measure on which this scheme is based. This scheme is defined as follows:

- Good, when more than 90% of the background blocks are segmented correctly.
- Almost Good, when 75% - 89% of the background blocks are segmented correctly.
- Almost Bad, when 60% - 74% of the background blocks are segmented correctly.
- Bad, when less than 60% of the background blocks are segmented correctly.

The results of classification into four categories are shown in figure 18.

<table>
<thead>
<tr>
<th>Result</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>66%</td>
</tr>
<tr>
<td>Almost Good</td>
<td>16%</td>
</tr>
<tr>
<td>Almost Bad</td>
<td>4%</td>
</tr>
<tr>
<td>Bad</td>
<td>14%</td>
</tr>
</tbody>
</table>

8. CONCLUSIONS

This paper presents a new algorithm for the segmentation of fingerprint images. The proposed algorithm is implemented in three stages; pre-processing, segmentation, and post-processing. Segmentation is achieved by using a number of rules related to global mean, local mean, local variance and coherence.

Experiments of testing this algorithm show that it is able to segment 82% of images used for testing. Further analysis to these results can reveal to a set of modifications of this algorithm to be implemented in the future. These modifications can be either the use of Support Vector Machine (SVM) classifier or Fuzzification techniques to replace the rule based system, which can lead to better segmentation results. The scheme was applied on the tested images extracted from FVC2000 DB-1. More intensive tests can be done in other FVC2000 databases.

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