Segmentation Procedure for Fingerprint Area Detection in Image Based on Enhanced Gabor Filtering

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Abstract

This paper describes a detailed description of segmentation procedure for fingerprint area detection in a digital fingerprint image. Purpose of this procedure is to extract very precisely the fingerprint area and to separate it from the image background. The precise fingerprint area detection is important not only for vendors of minutiae extraction algorithms but also for semantic conformance testing for finger minutiae data in the newly created international standard.

Our segmentation procedure was evaluated for real-world scenario, so the used fingerprints were scanned from real dactyloscopic fingerprint cards. These fingerprints were taken from Ground Truth Database of fingerprints (used subset of GTD originally belongs to NIST SD14 and SD29 databases). Our procedure had to deal with specific problems and properties of these images such as handwritten or printed characters, drawings or specific noise in the background or spread over the fingerprint itself. Our approach was compared with three other methods and yields significantly better results than the best of the benchmarked methods.

1. Introduction

In 2005 the ISO standard 19794-2 [7] was released. This standard defines data interchange format for finger minutiae data. The main objective of this standard was to ensure an interoperability of fingerprint templates among different vendors. Various tests showed that the interoperability is not as good as it was expected. MINEX report by NIST [6] tried to find reasons of these problems. It found that some algorithms from some vendors tend to place minutiae inaccurately. Placements of their minutiae create some kind of grid (compared with irregular placement of manually set minutiae). This situation can cause both interoperability and security problems. Therefore a new group of standards of conformance testing is under preparation.

Nowadays, semantic conformance testing for finger minutiae data is developed [8] for the purpose of validating the compliance of a minutia extractor with the ISO/IEC interchange standard 19794-2 [7]. In [2,3] a new methodology for conformance testing was presented. This methodology proposed three conformance rates, which describe to which extend a finger minutiae record is indeed a faithful representation of the physiological characteristic captured in the input image. One of the main objectives is the assessment whether an algorithm under test did or did not find false minutiae at the border of the fingerprint area or in the image background.

For the purposes of semantic conformance testing a special database (GTD – *Ground Truth Database* [3]) of fingerprints was prepared. This database consists of fingerprint images selected from the NIST special databases SD 14 and SD 29. Fingerprint images were thoroughly selected so, that the resultant GTD have a balanced ratio of pattern types, position codes (instance type) etc. However the majority of fingerprints in SD 14 and SD 29 databases are scanned from dactyloscopic fingerprint cards. These images have their specific properties and thus it is not possible to use standard algorithms for their processing. An example of such a fingerprint can be found in Figure 1. Typical problems of fingerprint area extraction for these images are handwritten or printed characters, drawings, and the printed border of a cell of the fingerprint card or the dirt (noise) in the background. All these problems can occur in the image background or can interfere in the fingerprint area (e.g. right cell border of dactyloscopic fingerprint card in Figure 1.), which represents a challenge for every algorithm.

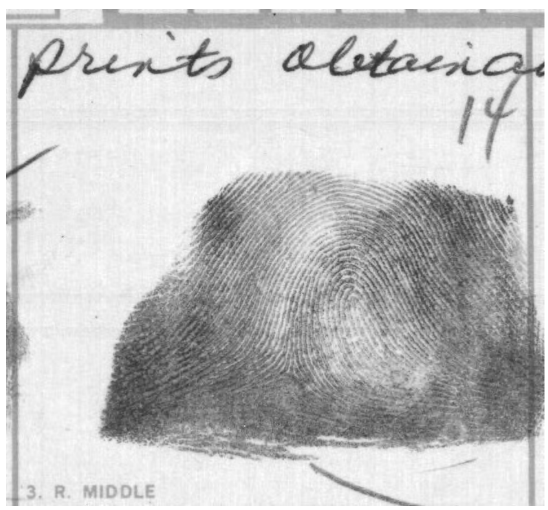

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Figure 1. Example of a fingerprint image from the Ground Truth Database (GTD).

2. Existing methods

The detection of the fingerprint area is a relevant preprocessing step in many fingerprint analysis pipelines. However none of the pipelines requires a high precision as it is required for a conformance testing suite. In this section we provide a survey of published concepts for fingerprint are detection and investigate their exactness. None of the surveyed methods was appropriate for our purpose, nevertheless they inspired our approach and all of them provide a baseline for benchmarking, as reported in Section 4.

2.1. NIST algorithms

The National Institute of Standards and Technology (NIST) provides implemented algorithms that can be used for fingerprint segmentation. For example, the NBIS (NIST Biometric Image Software) package contains the Segmentor routine [9], which deals with fingerprint segmentation for fingerprint classification purposes. By using special thresholding based on global and local pixel intensity minimums and maximums, massive erosion and edge detection, the Segmentor routine computes the most suitable fixed-size rectangle in input fingerprint and declares it as a segmentation result.

Second example of segmentation method using by NIST algorithm is segmentation based on NFIQ (NIST Fingerprint Image Quality). NFIQ is fingerprint image quality factor developed and used by NIST. Using quality image map and minutiae quality statistics it computes the feature vector, which is used as input for neural network classifier. The classifier's output is fingerprint image quality value. NFIQ values are integers from 1 to 5 where 1 means the highest quality and 5 means the worst quality.

In NFIQ segmentation process, the input fingerprint image quality map is computed using NFIQ algorithm. Then the result image is created by special thresholding, where areas with quality equal or better than the specific threshold are considered as fingerprint area whereas other areas are marked as background.

2.2. Ratha algorithm

An interesting approach was chosen by Ratha et. al.[4]. They proposed a method that exploits the fingerprint orientations field. The orientation field is used to compute the optimal dominant ridge direction in each 16×16 block. Then they compute the variance of gray level in a direction perpendicular to the local orientation field. Foreground areas containing fingerprint will have very high variance whereas the variance of background areas will be low.

2.3. Basic Gabor filter based algorithm

Allonso-Fernandez et al. [1] introduced a new application of Gabor filters for fingerprint segmentation, originally used for fingerprint quality measures [5]. Using several different orientated Gabor filters responses the so-called magnitude Gabor features are computed. Then it is possible to segment the fingerprint using thresholding, where the standard deviation of the magnitude Gabor features represents the threshold for each block. Allonso-Fernandez et al. also proposed some enhancements, for example, half block overlapping, ridge frequency computation etc., which can help with foreground/background decision problems. This basic Gabor filter method provides quite good results on "well-posed" fingerprints but still has many disadvantages and fails in "ill-posed" cases. The segmented area is very jagged, and the method has problems with any kind of otherwise oriented patterns like edge lines in dactyloscopic fingerprint cards, descriptions, hand drawings, white scars inside fingerprint area etc.

3. Proposed segmentation pipeline

For the processing of the NIST special databases and the similar purposes, a more complex method is needed, as none of the methods described in Section 2 was able to produce sufficiently good results and distinguish reliably the fingerprint area from the drawing and noise in the background. Therefore, we further developed the method of Allonso-Fernandez

Gabor Filter-Based segmentation and propose a fingerprint area segmentation pipeline, which consists of eight phases (see Figure 2). Proposed pipeline begins with preprocessing of the input fingerprint image and continues with the segmentation followed by an erosion of image. Next three steps deal with a removal of detected artifacts, holes and insignificant areas. Final two phases consist of manual correction of possible inaccuracies and detection of the border of fingerprint area.

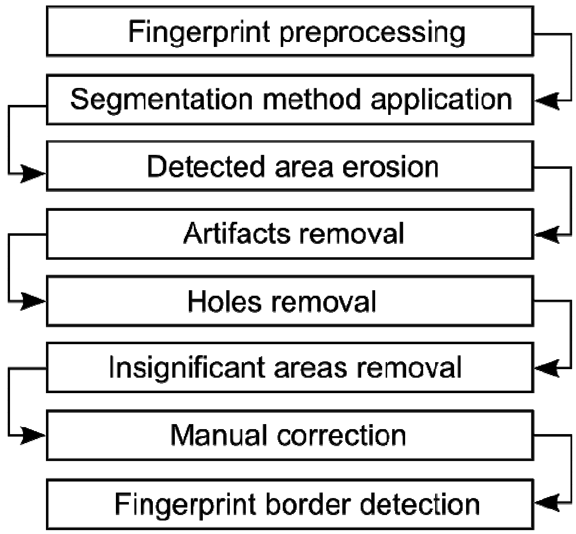

Figure 2. Proposed segmentation pipeline.

3.1. Fingerprint preprocessing

Before the usage of main segmentation method, the several fingerprint image preprocessing operations are used. Due to adjustment and clearing of input image it is possible to make the segmentation method faster and more accurate.

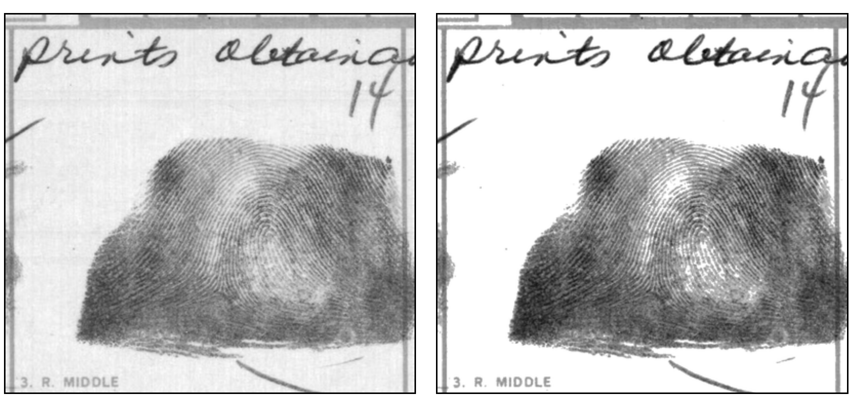

Figure 3. Fingerprint before and after preprocessing.

In our proposed processing pipeline, three preprocessing operations are used: grayscale conversion, contrast stretching and semithresholding. Grayscale conversion of eventual color input image accelerates the main processing. After that the contrast stretching operation deals with faded or too dark images. Finally, the semithresholding is used for noise elimination purposes. The example of the fingerprint before and after preprocessing can be found in Figure 3.

3.2. Enhanced Gabor filter based segmentation method and erosion of detected area

A major enhancement can be achieved, if the overlap of blocks is not fixed to half the block size, as originally suggested by Allonso-Fernandez [1]. In proposed algorithm it will be possible to set up the size of overlap in horizontal and vertical direction in pixels. With maximal set overlap in both directions (blocks of 6×6 pixels overleaping in 5 pixels), the segmented area will be smooth enough to precise interpolation of fingerprint ridge endings, while sufficiently big blocks have a good standard deviation of magnitude features value for foreground/background thresholding. In the basic method proposed by Allonzo-Fernandez one threshold for each block was computed in a way that all pixels in each block had the same value after thresholding. In our revised method the average value of standard deviations for every pixel is computed during the Gabor filtering process. The average value of standard deviations for one image pixel is computed as a sum of deviations (based on 8 Gabor features) for all blocks containing that pixel divided by the number of such blocks.

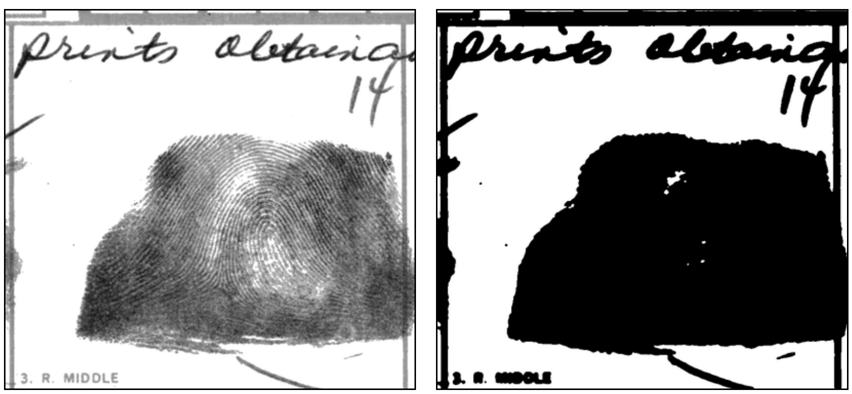

Figure 4. Preprocessed image before and after main segmentation.

As a result (see Figure 4), the segmented image is very smooth. Since the segmented area is slightly larger in size than it is appropriate for our purposes, the minimal omnidirectional morphological erosion (square 6×6 pixels) is used.

3.3. Removal of artifacts

After the main segmentation phase, it is necessary to tackle unwanted artifacts like lines in the dactyloscopic fingerprint cards, annotated descriptions, hand drawings etc. All these objects are likely to be marked as foreground by the Gabor filter. In most image processing applications a morphological operation called binary opening is used for background noise removal. An opening is defined as binary erosion followed by a binary dilatation. We use the same structural element for both operations and intend to remove background noise. However such morphological opening may damage some fine details along the detected fingerprint area edge. Therefore, some more sophisticated variation of this method is needed. First, a temporary image is created by copying the input image (the status after the Gabor thresholding). This temporary image is eroded (by the use of square structure element 15×15 pixels) such as all unwanted entities are eliminated. After that, the temporary image is dilated, but with a structural element that is slightly larger in size (17×17 pixels), than the one used for erosion. Now we have two intermediate binary images: the temporal image without artifacts containing the main fingerprint area slightly enlarged with respect to the input image and the original input image. By using a logical conjunction operation we get the resulting thresholded image without lines, drawings and other artifacts (only holes and insignificant areas remain – see Figure 5).

Figure 5. Segmented image before and after artifacts removal.

3.4. Removal of holes and insignificant areas

After removing unwanted artifacts, the pipeline has to address a further challenge in the third phase. After main segmentation and artifacts removal, the segmented image may contain more than just one separated foreground areas and each foreground area may contain one or more holes (inside "background" areas) caused by scars, noise etc. Therefore, we propose as third phase an algorithm for eliminating of the holes and insignificant foreground areas.

We start with an algorithm removing holes. First we extend the binary image by one line/row (background padding) and thus adding to the input image one white (background) row on the top, bottom and left and right side. Thus the binary fingerprint is despite all artifacts in the two preceding processing phases bordered as background area. This is essential in a situation where foreground detecting phase may split the background area into several parts. Next we detect all background (white) areas using flood seed fill, where every new detected background area is filled with a gray (temporary) color and a starting point as well as a number of filled pixels for every area is stored. Next step is filling the biggest detected area with white color (color of background) and other detected areas with black color (color of fingerprint area). Finally, we remove columns and rows added in the first step.

Removing insignificant foreground objects is a similar task. We detect all black areas and their sizes and then we eliminate insignificant areas by white filling. Decision which areas are insignificant is controlled by a detection policy. Our detection policy keeps always the larges area and other areas are removed if their size is less than ten percent of the input image. After these two steps, we get in the final phase of the pipeline a segmented image without any artifacts (see Figure 6.).

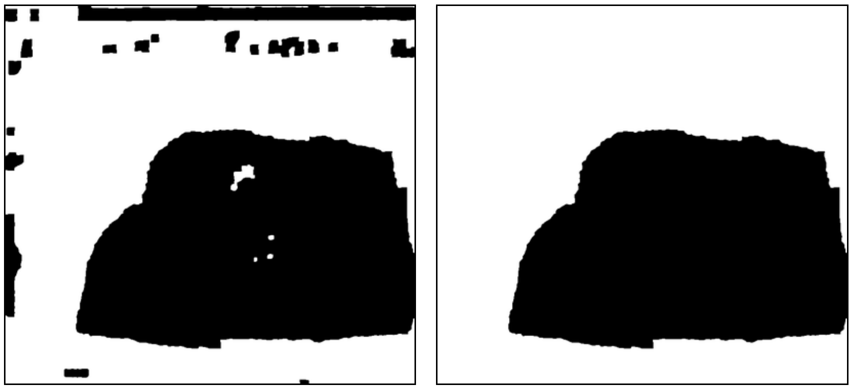

Figure 6. Arifacts-free image before and after removal of holes and insignificant areas.

3.5. Manual correction

For the purposes of manual correction of images processed by our automatic pipeline we developed an application with graphical user interface able to correct detected fingerprint area in easy and comfortable way (see Figure 7). The application displays original image and fingerprint area image in two separate layers. The lower layer is ineditable and contains the original fingerprint image. The upper layer is editable and contains fingerprint area image, which is displayed as transparent mask for lower layer where background areas are colored whereas fingerprint area are not. Our application enables to interactively change the transparency value and offers three possible background colors. The fingerprint area is manually editable using pen, eraser and fill tool in a way similar to common raster image editor. Supporting tools like zoom, tool shape and size makes the work with this application much easier. Our application can be used not only for correction of some existing fingerprint area image but also for creating a new one. It is possible to load only original fingerprint and draw the fingerprint area from the scratch. This is convenient for dactyloscopic experts that can define the ground truth for fingerprint images.

3.6. Fingerprint border detection

Last step in our processing pipeline is detection of fingerprint border and determination fingerprint border area with certain width. Before fingerprint border detection we extend the image by one white row at each side in same way like we did it in holes removal algorithm. Due to this operation it is possible to draw fingerprint border in places where fingerprint area reaches end of the image. Then we extract fingerprint border line using simple morphological operations. Next step is to enlarge detected border line up to demanded width. After that we draw determined border area into fingerprint area image.

Figure 7. Application for manual correction/creation of fingerprint area image.

4. Benchmarking results

For the purpose of developing a semantic conformance testing methodology, we needed a reliable fingerprint area segmentation that is applicable for each fingerprint in our database. Thus we cannot rely on any automatic area segmentation and have implemented a program for manual extraction of the fingerprint area for the sake of quality assurance implemented. We applied this parallel automated and manual processing to a set of 595 images in the Ground Truth Database (347 of them was originally from NIST SD 14 database and 248 was originally from NIST SD 29 database).

Table 1. Results of tests for selected part of database SD14.

Method/Algorithm	Mean (%)	Median (%)
Our segmentation pipeline	4,129	2,618
NFIQ best threshold (T = 2)	10,113	9,904
NFIQ default threshold (T = 3)	11,564	10,265
Gabor Filter-Based algorithm [1]	13,950	13,503

Gabor Filter-Based algorithm (enhancement proposed by Allonso-Fernandez) [1]	16,069	15,512

The results from manual extraction of the fingerprint area were compared with the automated approaches; NIST NFIQ quality map (the best threshold and default threshold are shown); basic Gabor filter based algorithm and its second version with enhancements proposed by Allonso-Fernandez in [1]. The results from manual extraction were considered as a baseline (100%). We report the difference between the baseline and the results of the benchmarked methods such that 0% indicates absolute overlap (consensus) between the manually extracted area and the automatically extracted area and 100% indicates absolute difference, i.e. inverted selection. The results of our benchmark are reported in Table 1 and 2. An example of processed images and the associated results are displayed in Figure 8.

Table 2. Results of tests for selected part of database SD 29.

Method/Algorithm	Mean (%)	Median (%)
Our segmentation pipeline	4,396	2,742
NFIQ best threshold (T = 1)	7,495	6,896
NFIQ default threshold (T = 3)	16,623	15,598
Gabor Filter-Based algorithm [1]	7,530	6,647
Gabor Filter-Based algorithm (enhancement proposed by Allonso-Fernandez) [1]	8,627	7,649

According to conducted benchmark, our segmentation pipeline was approximately two respectively three times better than the other methods. Our pipeline also produced in several cases the 100% correct area extraction, which was not achieved by other methods. Of course, a 100% correctness of area extraction is hard to justify, as the manual determined area may be different, if a second operator analyses the fingerprints. Unfortunately, manual extraction is very time consuming, but we plan to perform this test in the near future.

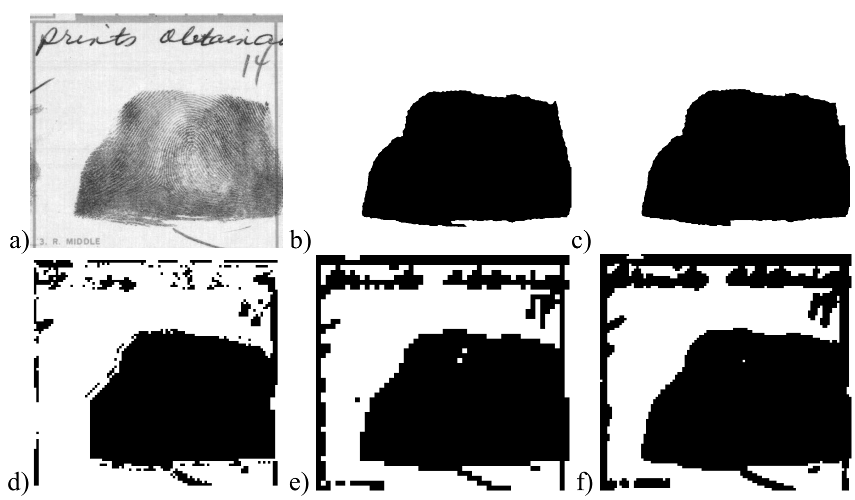

Figure 8. a) tested fingerprint; b) fingerprint area extracted manually; fingerprint area extracted c) by our algorithm; d) by NIST NFIQ quality map with threshold 2; e) by Gabor filter-based algorithm [1]; and f) by Gabor filter-based algorithm (with enhancement proposed by Allonso-Fernandez) [1].

On the other side, our pipeline did not achieve so good results for fingerprints with low quality – fingerprints containing the large area(s) created by dotted papillary lines. Example of a small area with dotted papillary lines can be seen in Figure 9.

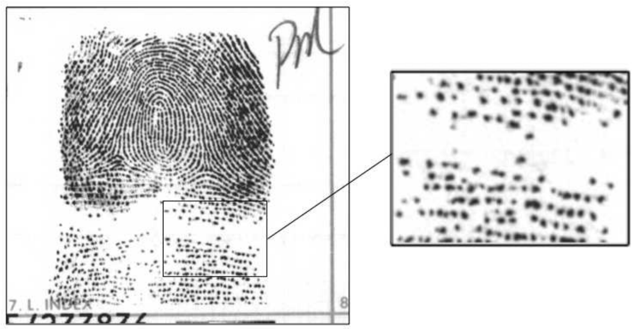

Figure 9. Example of low quality fingerprint with a detail on dotted papillary lines.

5. Conclusions

In this paper we have presented a detailed description of segmentation procedure for fingerprint area detection, which was developed to process fingerprints scanned from dactyloscopic fingerprint cards. Our pipeline was benchmarked with other methods and achieved significantly better results than the other methods. The proposed pipeline is able to deal with the most drawing and characters, borderlines found on dactyloscopic fingerprint cards. Further the pipeline can well handle dirt in the background or interfering fingerprint areas. Nevertheless a problem with fingerprints with low quality papillary lines (especially dotted papillary lines) still remains.

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