A Comprehensive Study on Image Enhancement and Minutiae Extraction Techniques

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Abstract

Fingerprint recognition stands as a widely embraced and effective means of person identification, leveraging the distinctive minutiae characteristics within fingerprints—points where a curve track concludes, intersects with other tracks, or diverges. Yet, attaining high-quality fingerprint images poses a continual challenge, as they are seldom pristine. Various factors, including skin and impression conditions, contribute to degradation and corruption of fingerprint images. Consequently, the implementation of image enhancement techniques becomes crucial before minutiae extraction, aiming to achieve a more dependable determination of minutiae locations. This paper delves into a comprehensive study, evaluating the efficacy of diverse fingerprint enhancement techniques.

Keywords — Fingerprint, Minutiae, Fingerprint enhancement, Binarization, Thinning, Minutiae Extraction, Fingerprint Recognition.

1. Introduction

The term "biometrics" originates from the Greek words "bios" (meaning life) and "metron" (meaning measurement), referring to measurements derived from the living human body [3]. Biometric identifiers represent a blend of both anatomical and behavioral characteristics, challenging their exclusive classification into either category. Take fingerprints, for example—being anatomical in nature, their usability is influenced by the person's behavior when interacting with the input device. Consequently, the input to the recognition engine comprises a combination of anatomical and behavioural traits. Fingerprints, the patterns formed on the epidermis of the fingertip, consist of series of ridges and valleys (furrows) on the fingertip's surface, with a core around which patterns like swirls, loops, or arches are curved to ensure each print is distinctive [3].

The fingerprint's composition involves ridges as single curved segments and valleys as the regions between two ridges, constituting the most evident structural characteristic with their interleaved pattern. Minutiae, discontinuities in the local ridge structure, serve as the most commonly used fingerprint features, aiding forensic experts in matching two fingerprints. Approximately 150 different minutiae types exist [7], with "ridge ending" and "ridge bifurcation" being the most frequently utilized, as all other types are combinations of these fundamental elements. A "ridge ending" marks the abrupt conclusion of a ridge, while a "ridge bifurcation" denotes the point where a ridge forks or diverges into branch ridges [3]. Figure 1 illustrates some common types of minutiae for reference.

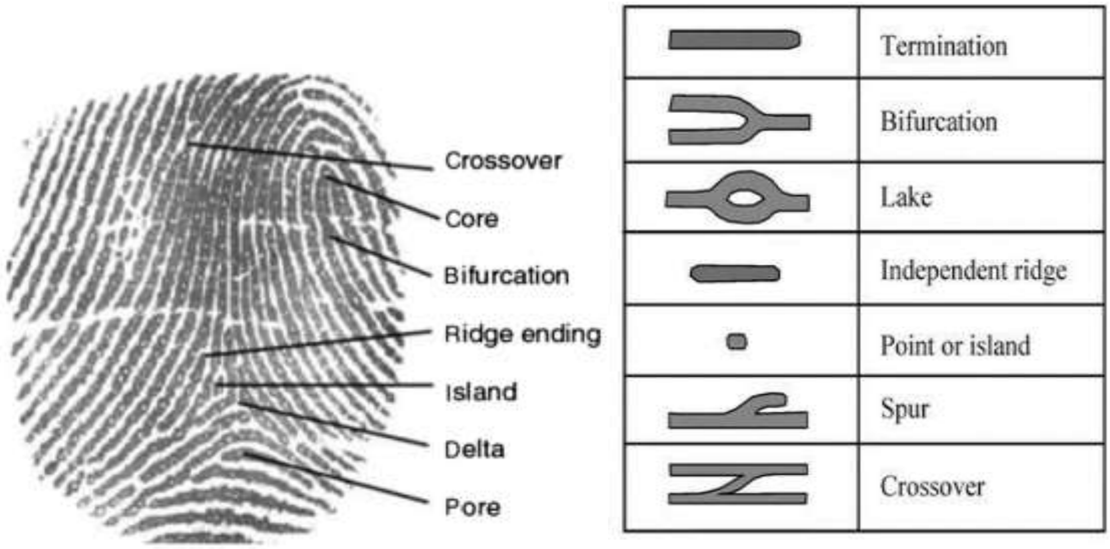

Figure 1: Fingerprint and Types of Minutiae

2. Related Work

Lili Liu and Tianjie Cao [1] introduced an efficient biometric verification system, leveraging Gabor filter-based enhancement and the CN concept for Minutiae Extraction. They developed a two-stage Identity Authentication system involving minutiae extraction and minutiae matching. They introduced an alignment-based elastic matching algorithm for minutiae matching. Manvjeet Kaur, Mukvinder Singh, and Parvinder S. Sindhu [9] proposed a Fingerprint Verification System utilizing a Minutiae Extraction Technique. Their approach integrated various methods for constructing both a minutia extractor and a minutia matcher, employing segmentation with morphological operations to enhance thinning, remove false minutiae, and mark minutiae. Histogram Equalization and FFT were used for fingerprint image enhancement, while the CN Concept aided in Minutiae Extraction.

F. A. Afsar, M. Arif, and M. Hussain [5] presented an Automatic Fingerprint Identification System based on minutiae extraction from thinned, binarized, and segmented fingerprint images. The system incorporated fingerprint classification for indexing during matching, significantly enhancing the overall matching algorithm's performance. Ishpreet Singh Virk and Raman Maini [11] employed histogram equalization for fingerprint image enhancement, coupled with segmentation using morphological operations and minutia marking based on triple branch counting. They introduced an alignment-based elastic matching algorithm for minutia matching, incorporating minutia unification through decomposition. This algorithm efficiently finds correspondences between minutiae without resorting to exhaustive search.

The literature has witnessed various proposals for fingerprint enhancement and matching algorithms. While many algorithms excel in matching high-quality fingerprints, the persistent challenge lies in effectively matching low-quality fingerprints.

3. Image Processing Methodology

The pre-processing of fingerprint images involves the subsequent steps:

i. Segmentation

ii. Enhancing Fingerprint Image

iii. Binarizing

i. Segmentation:

Segmentation is the process of distinguishing the foreground regions within an image from the background regions. In the context of fingerprint images, the foreground encompasses the distinct fingerprint area containing ridges and valleys—the region of primary interest. On the other hand, the background refers to areas outside the borders of the fingerprint, devoid of pertinent fingerprint information [8]. Applying minutiae extraction algorithms to the background can lead to the extraction of spurious and erroneous minutiae. Hence, segmentation is employed to eliminate these background regions, facilitating the accurate extraction of minutiae.

In a fingerprint image, background regions typically exhibit a very low grayscale variance value, while foreground regions possess a significantly higher variance. Consequently, a segmentation method based on variance thresholding proves effective. Initially, the image is divided into blocks, and the grayscale variance is computed for each block. If the variance falls below the global threshold, the block is designated as a background region; otherwise, it is identified as part of the foreground.

ii. Enhancing Fingerprint Image:

Fingerprint Enhancement involves enhancing image quality by eliminating noise through the application of a low-pass filter. The distinctive configuration of parallel ridges and furrows in a fingerprint image, characterized by well-defined frequency and orientation, offers valuable information for noise removal. The sinusoidal-shaped waves of ridges and furrows exhibit a gradual variation in local constant orientation. Employing a band-pass filter tuned to the corresponding frequency and orientation proves effective in eliminating unwanted noise while retaining the authentic ridge and furrow structures. The image undergoes filtration, with Gabor filters serving as suitable band-pass filters due to their frequency-selective and orientation-selective properties, ensuring optimal joint resolution in both spatial and frequency domains [4].

iii. Binarizing:

Most minutiae extraction algorithms are designed to operate on binary images, where only two levels of interest exist: black pixels representing ridges and white pixels representing valleys. Binarization is the transformation process that converts a grayscale image into a binary one. This conversion enhances the contrast between ridges and valleys in a fingerprint image, thereby facilitating minutiae extraction. Typically, a grayscale image is transformed into a binary image using a global threshold [4]. The binarization procedure involves evaluating the grey-level value of each pixel in the enhanced image. If the value surpasses the global threshold, the pixel is set to a binary value of one; otherwise, it is set to zero. Consequently, the outcome is a binary image with distinct levels of information—foreground ridges and background valleys.

4. Minutiae Extraction

The minutiae extraction process involves the following steps:

1. Thinning:

Thinning is a morphological operation that systematically erodes foreground pixels until they become one pixel wide [2]. A standard thinning algorithm is utilized, employing two sub-iterations. This algorithm is accessible in MATLAB through the 'thin' operation under the bw morph function [2]. In each sub-iteration, the neighbourhood of each pixel in the binary image is examined. Based on specific pixel-deletion criteria, it is determined whether a pixel can be deleted. These sub-iterations continue until no further pixels can be deleted. The application of the thinning algorithm to a fingerprint image preserves the connectivity of ridge structures while generating a skeletonized version of the binary image. This skeleton image is subsequently employed in the minutiae extraction process.

2. Minutiae Detection:

The Crossing Number (CN) concept stands out as the prevailing approach for minutiae extraction. This method capitalizes on the skeleton image, characterized by an eight-connected ridge flow pattern. Minutiae extraction is accomplished by systematically scanning the local neighbourhood of each ridge pixel using a 3×3 window. The computation of the CN value follows, defined as half the sum of differences between pairs of adjacent pixels in the eight-neighbourhood. Subsequently, the ridge pixel is classified based on the property of its CN value.

5. Conclusion

The effectiveness of fingerprint feature extraction and matching algorithms is significantly influenced by the quality of the input fingerprint image. Numerous enhancement techniques, such as Histogram Equalization and FFT, have demonstrated improvements in fingerprint image quality and recognition performance in various studies. Notably, Gabor filters, with their frequency-selective and orientation-selective properties, have proven particularly effective. Studies indicate that employing the Gabor filter method for fingerprint image enhancement yields superior results. In the minutiae extraction stage, the Rutovitz Crossing Number (CN) algorithm applied to skeleton images post-thinning can successfully detect all minutiae, encompassing both true and false minutiae.

6. References

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