Some experimental results for fingerprint image processing

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Abstract

Fingerprints offer a reliable and unique means of identification and hence are crucial in fields such as law enforcement and personal identification. However, fingerprint images are hardly of good quality. They may be corrupted and degraded with elements of noise owing to many issues including deviations in skin and impression circumstances. We test some commonly available fingerprint image processing codes and show some experimental results to see the progress and challenges of fingerprint image enhancement, segmentation and minutiae extraction.

Keywords

Fingerprint image segmentation, fingerprint image enhancement, fingerprint image recognition

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1 INTRODUCTION

Fingerprint recognition is a reliable biometric technology utilized for both forensic investigation and personal authentication. While it has been utilized for over a century, the technology is undergoing a rapid evolution, moving from manual, paper-based classification to advanced *automated fingerprint recognition systems* (AFRS). The traditional fingerprint image recognition by humans involves a process of manual comparison and analysis of the unique patterns found in fingerprints, which is labor intensive and time consuming and may cause mistakes easily. The use of computer system for automatic reading, classification and coding of fingerprints is in much progress. However, as stated in [12] by Jothi and Palanisamy and in [13] by Maltoni et al., fingerprint images are hardly of good quality. They may be corrupted and degraded with elements of noise owing to many issues including skin conditions and injuries, leading to high false rejection rates. Hence, AFRSs are still facing persistent challenges.

By [13], the current state of the art for most biometric modalities can be attributed to the use of deep neural networks along with large training sets. Fingerprint recognition has also been approached in terms of data-driven learning techniques. This has resulted in new effective methods for automated processing of latent fingerprints and learning robust fixed-length fingerprint representations. However, the top-down minutiae-based "geometric" matching is still the best performing approach for most use cases of fingerprint recognition. This shows that tiny ridge details are still competitive with the powerful representations learned by huge neural networks trained on big data. According to [17] by National Science and Technology Council, the most widely used fingerprint recognition technique is minutiae-based matching that relies on the minutiae points.

The minutiae-based fingerprint matching involves transforming a fingerprint image into a skeletal representation to identify unique ridge characteristics (minutiae) for comparison. The core steps include segmentation (isolating the fingerprint from the background), enhancement (improving image quality), binarization, thinning (skeletonization), feature extraction (identifying minutiae), post-processing, and alignment-based matching to calculate a similarity score. As shown in [20] by Socheat and Wang, after thinning fingerprint images during preprocessing, currently no single algorithm is perfect due to the potential for introducing noise and generating spurious minutiae. According to [16] by Newton, it is incredibly important for fingerprint matching algorithms to be accurate because fingerprints are used for many forms of identification including convicting criminals using forensic science (NIJ 2016). The Gabor Filter Enhancement Algorithm is the best algorithm to employ, as it is the most accurate in all regards. It is also the fingerprint image enhancement method in [7] by Choudhary et al., which was published recently. According to [19] by Shreya and Chatterjee, despite several AFRSs developed till now, the accuracy rate of latent fingerprint recognition still needs to be up to the mark. In [18], Shams et al. provided a method for fingerprint image enhancement using multiple filters. In [3], Bature et al. demonstrated a method for extracting minutiae points of fingerprint images. In this paper, we test some commonly available fingerprint image processing codes and show some experimental results to see the progress and challenges of fingerprint image enhancement, segmentation and minutiae extraction.

2 Some experimental results for fingerprint image segmentation, enhancement, binarization, and minutiae extraction

We have downloaded and tested some recently available computer programming codes. In this section, we show some experimental results for fingerprint image segmentation, enhancement, binarization, and minutiae extraction.

2.1 Some experimental results for fingerprint image segmentation

Fingerprint image segmentation aims to separate the fingerprint area (foreground) from the image background. It is important for

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fingerprint image recognition because it helps to improve performance by reducing noise, decreasing false minutiae detection, and limiting processing to the region of interest. The segmentation method in [18] by Shams et al. is based on the variances of the image blocks. Fig. 1 shows that this method may not be able to segment some fingerprint images well. In [4], Bishay uses the block range as a feature to achieve fingerprint segmentation. Then some morphological closing and opening operations are performed to extract the foreground from the image. However, as shown in Fig. 2, this method is sensitive to image noise and hence may not be able to segment some fingerprint images well either. The fingerprint image segmentation results shown in Fig. 24 in [11] are not very ideal either. The deficiencies of the previous methods for fingerprint image segmentation and enhancement can also be seen from the binarized image in Fig. 2 of [21] by Tan. Hence, improvements to the previous methods are still needed.

2.2 Some experimental results for fingerprint image enhancement and binarization

In [6], Chikkerur et al. introduced an approach for fingerprint enhancement based on short time Fourier transform (STFT) analysis. The Matlab code can be downloaded from [5] by Chen. However, as shown in Fig. 3, the binarized enhanced image may not be able to show the ridge structures in the original fingerprint image well and there are extra components (which are not fingerprint features) outside the image domain in the binarized image. Furthermore, in Fig. 4, some components representing fingerprint ridges contain holes, extra vertical line segments and extra connections near the fingerprint boundary which may cause false minutiae. The Python code in [8] by Utkarsh-Deshmukh uses oriented Gabor filter bank to enhance the fingerprint image. The orientation of the Gabor filters is decided by the orientation of ridges in the input image. As shown in Fig. 6, a component in the binarized enhanced image using this method may not be connected; and there are extra components outside the image domain in the top-right image. In [9, 10], Li et el. have used an improved fingerprint image enhancement method based on Gabor filter. After Fourier transforms, fingerprint images are enhanced by the directional filter in the frequency domain. The Matlab code is available in [14] by Manu. As shown in Figs. 5, 7 and 8, there are some side effects from the filtering near the boundary of the fingerprint domain and there are extra components in the binarized image. In [18], Shams et al. put forward a novel method of fingerprint image enhancement using a combination of diffusion-coherence filters and 2D log-Gabor filters. As shown in Fig. 9, the segmentation may not match the original image domain well and the binarized enhanced image may not be ideal.

2.3 Some experimental results for fingerprint image minutiae extraction

Minutia matching is the most popular approach to fingerprint identification and verification. To extract minutiae points of a fingerprint image, the image usually requires pre-processing to enhance quality, reduce noise, and isolate ridge structures. Key pre-processing steps include normalization, segmentation, ridge orientation estimation, enhancement, binarization, and thinning. According to [15], the codes in [2] for minutiae points extraction are based on the methods in [1]. As shown in Figs. 10 and 11, the results may not be ideal for some fingerprint images. In [2], there is an assumption that, for any fingerprint image, there exist two rows and two columns of the image pixels separating the fingerprint image's foreground from its background. We can let the minimal and maximal values of the image is 0 and 255 respectively and let 255 denote the image value at the background. To find such rows and columns, in [2], if the number of the pixels (in a row or column) with image values less than 200 is less than 8, then the whole row or column may be assumed to be in the background. However, when a fingerprint image is very noisy, such an assumption may not be suitable as shown in Figs. 10 and 11.

3 Conclusion

Our experimental results have shown that important progress has been made in the development of methods for fingerprint image segmentation, enhancement, binarization and thinning. Improvements to those methods are still needed. In the future, with the development of hardware and software, the accuracy rate of fingerprint image recognition may be significantly increased.

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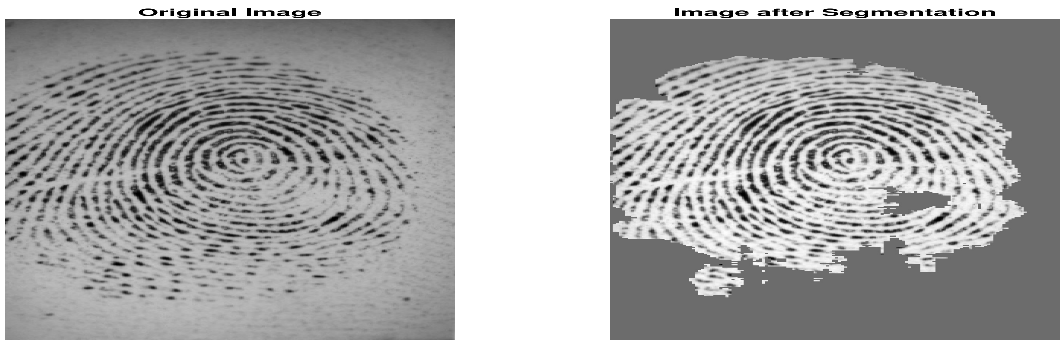

Figure 1: The left is the input image which is Fig. 101_8 of the DB2_B dataset in [18]; the right is the segmented image by [18].

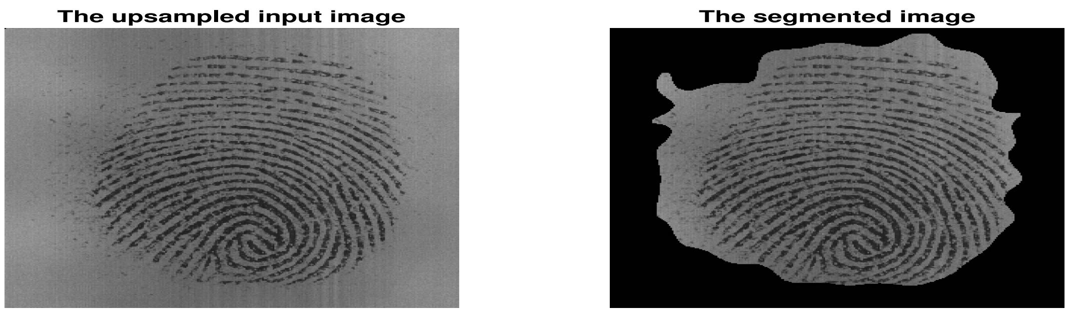

Figure 2: The left is the input image which is Fig. 107_3 of the DB3_B dataset in [18]; the right is the segmented image by [4].

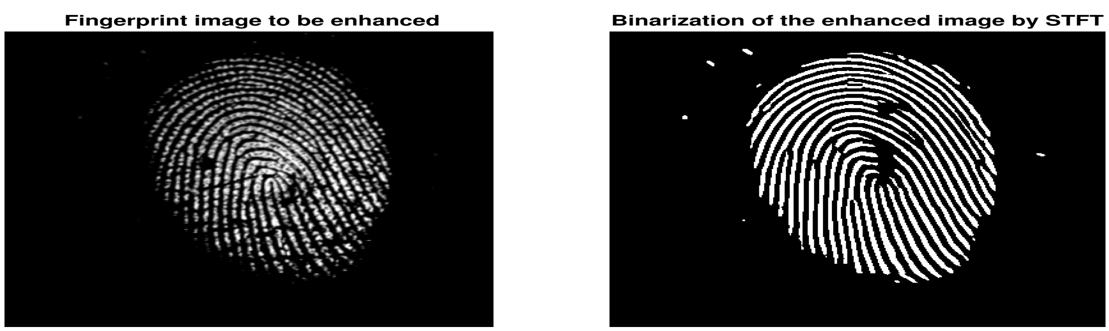

Figure 3: Fingerprint enhancement using STFT analysis. The left shows the original image which is Fig. 103_8 of the DB1_B dataset in [18]. The right shows the binarized enhanced image using STFT.

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Figure 4: Fingerprint enhancement using STFT analysis. The left shows the original image which is which is Image 1 in [8]. The right shows the binarized enhanced image using STFT.

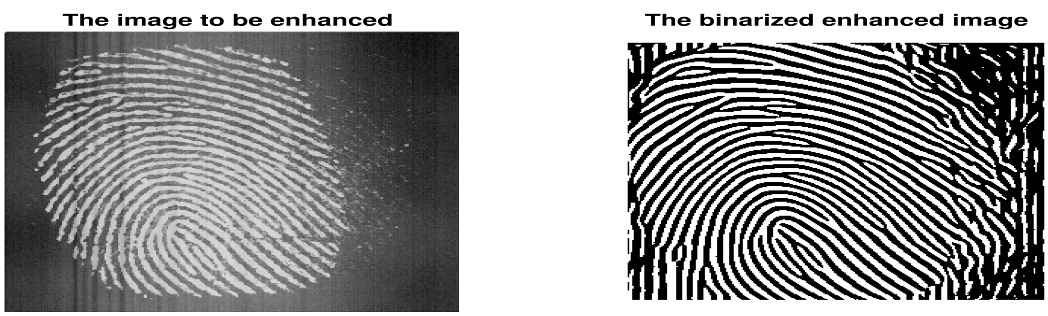

Figure 5: The left shows the original image which is Fig. 106_1 of the DB3_B dataset in [18]. The right shows the binarized enhanced image using the method in [14].

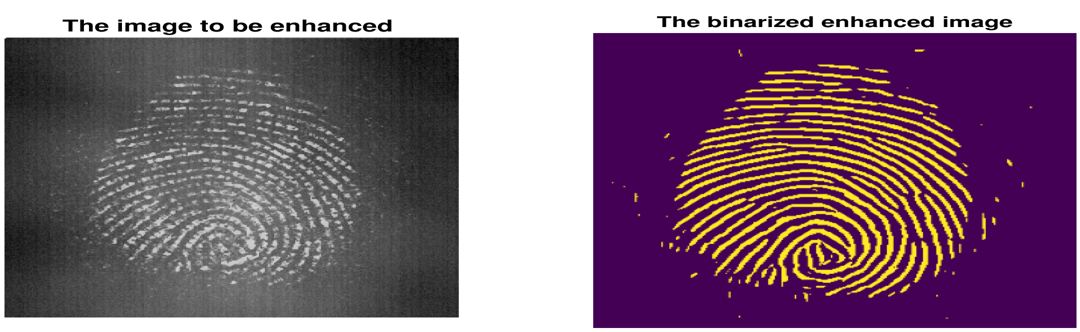

Figure 6: The left shows the original image which is Fig. 107_7 of the DB3_B dataset in [18]. The right shows the binarized enhanced image using the method in [8].

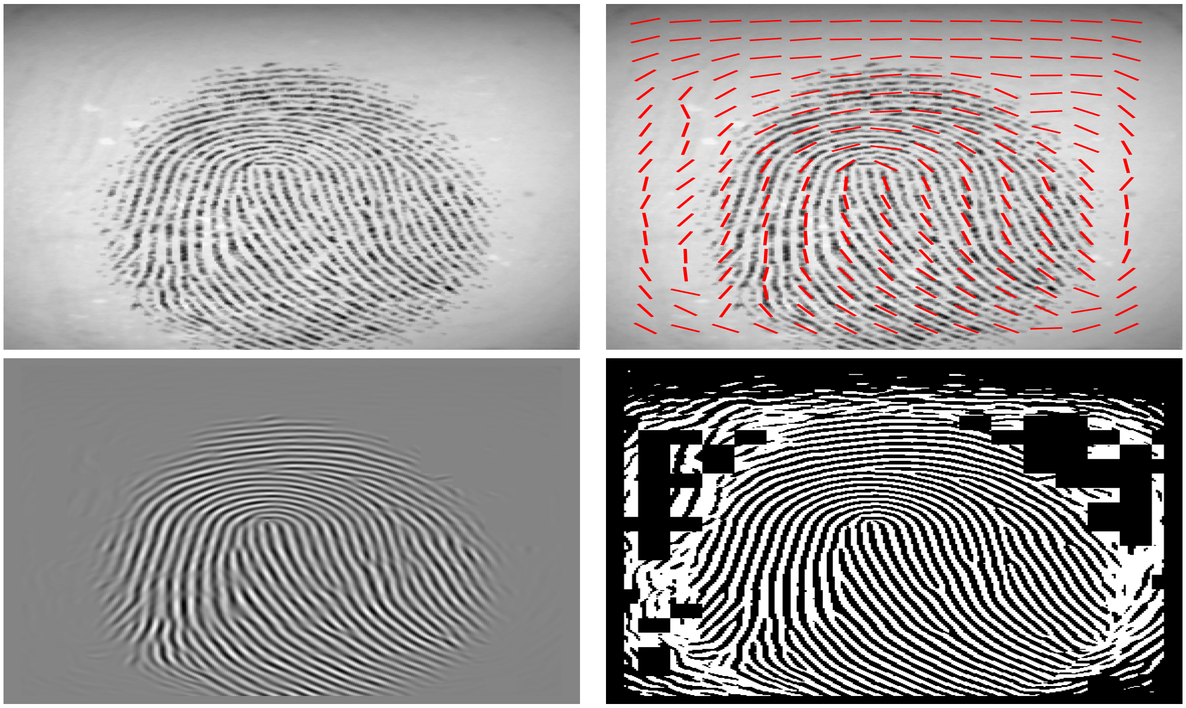

Figure 7: The top-left is the input image which is Fig. 103_1 of the DB4_B dataset in [18]; the top-right, bottom-left, and bottom-right are the image of ridge directions, filtered image, and binarized image using the method in [14].

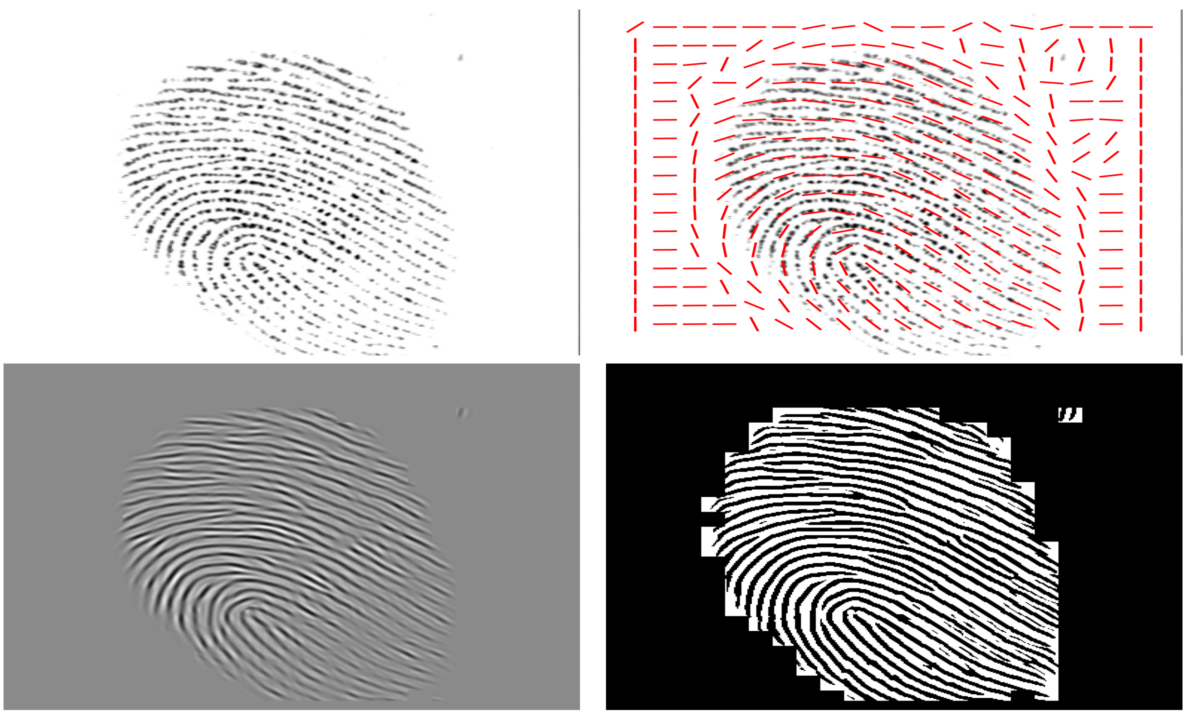

Figure 8: The top-left is the input image which is Fig. 101_4 of the DB4_B dataset in [18]; the top-right, bottom-left, and bottom-right are the image of ridge directions, filtered image, and binarized image using the method in [14].

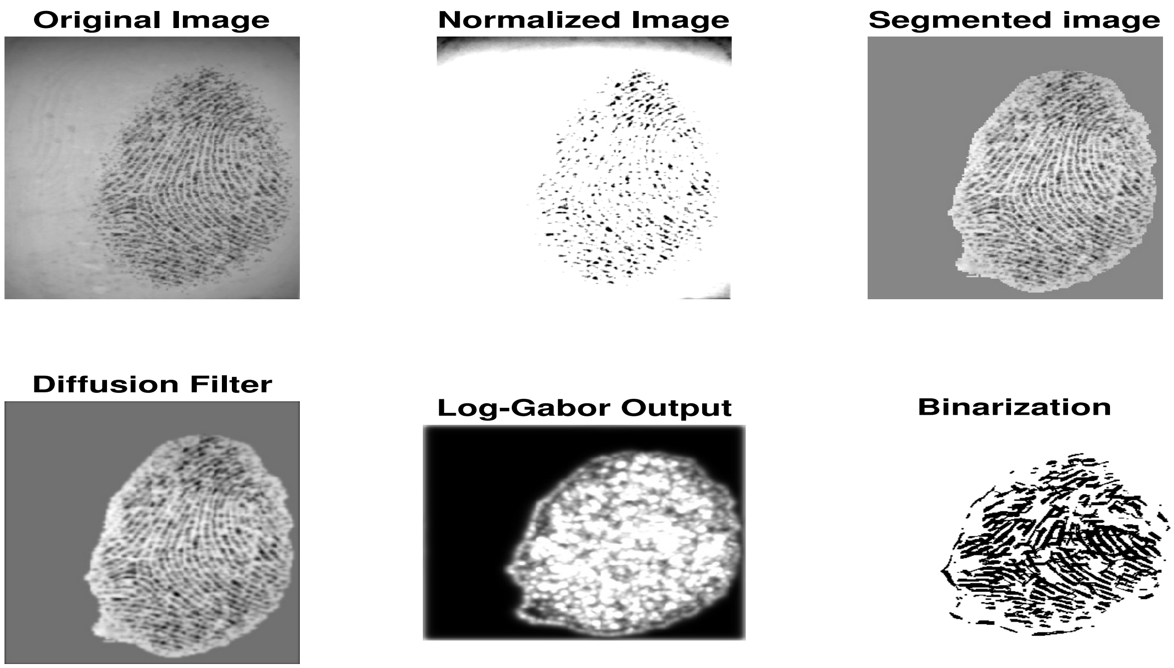

Figure 9: The top-left shows the original image which is Fig. 110_5 of the DB4_B dataset in [18]. The top-right shows the segmented image; the bottom-right shows the binarized enhanced image using the method in [18].

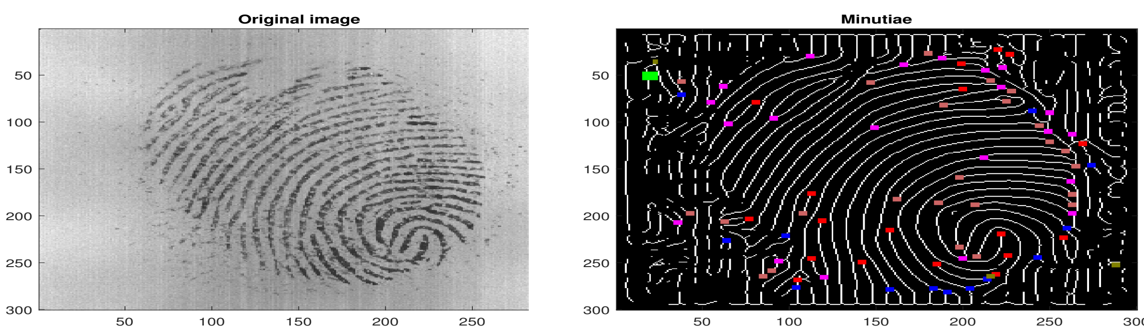

Figure 10: The left is the input image which is Fig. 104_4 of the DB3_B dataset in [18]; the right is the image showing the extracted minutiae points by [2].

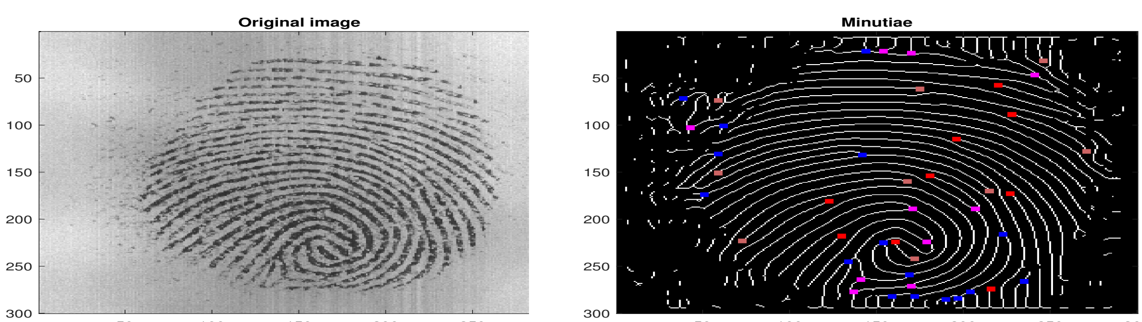

Figure 11: The left is the input image which is Fig. 107_3 of the DB3_B dataset in [18]; the right is the image showing the extracted minutiae by [2].