Latent Fingerprint Enhancement Based on Directional Total Variation Model with Lost Minutia Reconstruction

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Abstract: Image enhancement plays an important role in biometric systems, this paper presented automatic latent fingerprint segmentation and matching. While considerable progress has made in both rolled and plain fingerprint image enhancement, latent fingerprint enhancement is a challenging problem due to the poor image quality of latent fingerprint with unclear ridge structures and various overlapping patterns, along with the presence of structured noise. Prior to latent fingerprint segmentation and feature extraction, latent fingerprint image enhancement is important to suppress various types of noise and to clarify the ridge structure. This paper reviews the current techniques used for latent fingerprint enhancement and presents a hybrid model which combines the edge directional total variation model (EDTV) and quality image enhancement with lost minutia reconstruction. The NIST SD27 database is used to test the performance of the proposed techniques with RMSE and PSNR. The proposed technique is effectively clarify input latent fingerprint images and eliminate noise in good, bad and ugly latent fingerprint images. A statistically significant difference, which focused on the mean lengths of PSNR and RMSE for different categories of latent fingerprint, images (good, bad and ugly). The proposed technique performs well for the good latent fingerprint images compare to bad and ugly images. Enhancement respectively presents RMSE averages of 0.018373, 0.022287, and 0.023199 for the good, bad and ugly image SD27 image set, as opposed to 82.99068, 81.39749, and 81.07826 for PSNR. The proposed enhancement technique improved the matching accuracy of latent fingerprint images by about 30%.

Keywords: Image enhancement; Latent fingerprint; structured noise; ridge structure

Introduction

Fingerprints are one of the biometrics used for the identification of individuals and recognition of identities. According to Jiangyan et al., [1] fingerprints can be categorized into three different categories as presented in the figure 1.

The first type is rolled followed by plain and latent fingerprints, where each type of the fingerprint kinds collected through a diverse procedure. For instance, rolled can be attained by undulating the finger from one side to the other to capture all the ridge details. The plain fingerprints are obtained by pressing the fingertip onto a flat surface while latent fingerprints normally

elevated from object surfaces touched by somebody. Champed demonstrated [2] that latent fingerprint is finger skin impression left in the crime scene by accident and not directly visible to human eyes unless some physical or chemical techniques are used to process them.

Figure 1. Types of fingerprint (a) Rolled fingerprint (b) Plain fingerprint (c) Latent fingerprint.

The correctness of fingerprint matching is extremely dependent on the quality of the collected fingerprint images. This presents a challenge for the latent fingerprints since their image quality is low due to the existing of structures noise. As a result, minutiae and ridges are not clear and visible to the human eyes. As consequence, accuracy of the latent fingerprint segmentation and recognition is much lower than that in rolled and plain fingerprints. For example, in National Institute of Standards and Technology (NIST) evaluations, while the best performing automated fingerprint identification system (AFIS) achieved a rank-1 identification rate of 99.4 percent on a database of 10,000 plain fingerprints, the best performing latent could only achieve identification rate of 63.4 percent in searching 1,114 latent against database containing 100,000 prints as described by Kai Cao et al., [3].

Furthermore, Robinson and Edward [4] studied and showed that latent fingerprint image enhancement is generally necessary step in the forensic analysis workflow to increase the latent fingerprint image quality. Therefore, in this paper the researchers will mainly review the existing algorithms and techniques published in latent fingerprint enhancement and propose latent fingerprint enhancement hybrid model using edge directional total variation model and quality image enhancement with lost minutia reconstruction. The remaining of the paper is organized as follows, section two discusses the previous work of latent fingerprint enhancement while section three presents the methodology of the proposed technique and section four presents the results, discussions and performance evaluation while section five concludes the paper by highlighting the recommendations and future remarks.

Related Work

The previous works on fingerprint enhancement confirm many different approaches have been proposed to solve the problem of quality of fingerprint images. Earlier research has shown the application of Gabor filter in fingerprint enhancement [5]. In this technique, the local ridge orientation and frequency are calculated in every pixel. After that, a Gabor filter is tuned to the local orientation and frequency and applied on the image pixel to defeat the unwanted noise and recover the clarity of ridge structure. It may work well for high quality images. However, this method needs reliable estimation of local ridge orientation and frequency. This is difficult task for poor quality fingerprint. Moreover, several techniques have been proposed to solve the latent fingerprint enhancement research issues including methods based on spatial domain [6] [7] frequency domain [8] [9] [10] and neural network [11]. These mentioned algorithms

were applied for the rolled and plain fingerprints and little considerations have been given to latent fingerprint images. The above approaches may not be practical in this situation.

Previously excessive work has been dedicated to the study of plain and rolled fingerprint enhancement while there has been little systematic analysis of latent fingerprint image enhancement/pre-processing. It's relatively new area requiring research in order to put on firmer foundations [12]. Few models have been implemented for latent fingerprint enhancement to enable reliable estimation of orientation. In [13] the orientation field was obtained by fitting a polynomial model to the coarse orientation field. In addition to that, authors have further improved the technique by applying Gabor filter method that uses STFT method [14]. This obtains multiple orientation elements in each block. One of the limitations of this method it requires manual mark-up of singular points and the region of interest (ROI) for enhancement. Recently, Feng et al., [15] proposed a robust method to estimate orientation field using the prior knowledge of fingerprint ridge structure, which is represented by a dictionary of reference orientation patches and the compatibility constraint between neighbouring orientation patches. The fingerprint orientation field is calculated by a mixture of candidate's which minimizes an energy function using loopy belief propagation with robust orientation estimation; Gabor filtering was applied to achieve improvement for enhancement of latent fingerprints. However, the above methods set a fixed ridge frequency to tune Gabor filters for enhancement. In practical applications, it is not always constant in fingerprint image, which limits the enhancement performance of Gabor filtering. Total variation (TV) models, which aim at minimizing the total variation of an image, have been widely studied for image decomposition [16]. Zhang *et al.* [17] proposed an adaptive TV model to remove the structured noises for latent fingerprint segmentation. They further proposed an adaptive directional total variation (ADTV) model by integrating the local orientation and scale for fingerprint segmentation and enhancement [18]. These TV based methods decompose latent image into texture and cartoon components. The texture component mainly consists of the oscillatory fingerprint ridge patterns while the cartoon component contains the left unwanted contents for instance structured noises. Latent fingerprint segmentation and enhancement are performed on the texture component with the structured noises removed. However, it is not easy to reliably estimate the local parameters (i.e., ridge orientation and scale) of ADTV model for latent images of poor quality. In addition, the noise corrupted regions are

not restored and the extracted fingerprint pattern is usually very weak, which will limit the performance of latent fingerprint identification. A dictionary-based method was proposed to enable reliable estimation of ridge orientation and frequency fields and facilitate the automatic segmentation and enhancement of latent fingerprints [19]. The TV model was first applied to remove the piecewise-smooth and structured noises. Then, both coarse and fine ridge structure dictionaries were learnt from a set of high quality fingerprint patches and used to reconstruct the ridge structure of latent image. Finally, the orientation and frequency fields were estimated with the reconstructed patches and used for latent fingerprint enhancement by Gabor filtering. Although reliable estimation of ridge orientation and frequency can improve the performance of latent fingerprint enhancement, there are two inherent limitations in these methods. First, in the regions of high curvature, the assumption of a single dominant ridge orientation is not valid. As a result, the Gabor filters with fixed orientation will be likely to destroy the ridge structure and lead to spurious ridge artefacts. Second, although the Gabor filtering with correct orientation and frequency parameters can work well to enhance the ridge clarity, it fails to restore the ridge structure destroyed by heavy structured noises. Latent fingerprint enhancement algorithm, which effectively combines the TV model and the multi-scale patch, based sparse representation for removing noises and improving the clarity of ridge structure has been proposed [19]. Each latent image is decomposed into cartoon and texture components by the TV model and the multi-scale patch based sparse representation is iteratively applied on the texture component to reconstruct the high quality fingerprint image. The proposed algorithm not only can remove various structured noises but also can restore and enhance the corrupted fingerprint ridge structures.

The proposed algorithm can be further improved by making use of the global ridge structure through global optimization for the low quality latent fingerprints. The global structure has a certain degree of regularity, which can be used to guide fingerprint enhancement. The main challenging problem for latent fingerprint enhancement is to remove various types of image noises while reliably restoring the corrupted regions and enhancing the ridge clarity and details.

Image compression has proposed by SOFM of neural network to reduce lossy image file with high compression ratio [20, 21] the model used as vector quantization after pre-processing and image subsample, image compression classification used variety of transformation such as DCT, and DWT and vector quantization [22], the image identification and

authorization used variety technique such as digital signature, fingerprint, face detection and recognition [23], iris and retina detection and identification.

Proposed Technique Methodology

The following flowchart presents the steps used in the hybrid proposed latent fingerprint enhancement model.

Figure 2. Process of the proposed technique.

The main steps of the methodology illustrated in flowchart figure 2. which are:

Normalization: input latent fingerprint image is normalized to reduce the variations in gray level values along ridges and valleys. This is to facilitate the subsequent processing steps. The normalization process specifies mean and variance. Let, $I(i, j)$ denote the gray-level value at pixel (i, j) , M and VAR denote the estimated mean and variance of I respectively, and $G(i, j)$ denote the normalized gray-level value at pixel (i, j) .

Adaptive de-noise based on EDTV model: Edge direction total variation model (EDTV) is used to effectively remove the noise of latent fingerprint images. The model is adaptive to image edge direction and capable of handling images with several dominant directions.

Reliable Orientation Image Estimation: The orientation image is reliably estimated from normalized input fingerprint image after applying the adaptive de-noise.

i. **Local Frequency estimation:** the frequency is computed from normalized input

fingerprint and the reliable orientation estimation after applying the adaptive de-noise.

ii. Region Mask estimation: It's obtained by classifying each block of the image into recoverable and unrecoverable blocks.

iii. Gabor filters: To obtain an enhanced latent fingerprint image bank of Gabor filters is applied to the ridge and valleys pixels in the image.

To evaluate the performance of the proposed latent fingerprint enhancement Root mean square error (RMSE) and peak signal to noise ratio (PSNR) has been deployed.

Results and Discussion

This section presents results and discussions focused on enhancement of latent fingerprint images, it eliminates different structured noise that exist in the image based on edge adaptive directional total variation model with lost minutia reconstruction technique to enhance the quality of image. Table 4.1 presents the result of RMSE and PSNR of good, bad and ugly latent fingerprint images in SD27 Dataset. The average of RMSE for the total 85 good images in SD27 dataset is 0.018373 while the average of PSNR is 82.99068. In addition to that, the result of RMSE and PSNR of latent fingerprint bad images is slightly lower compare to good images. The average of RMSE for the total 85 bad images in SD27 dataset is 0.022287 while the average of PSNR is 81.39749. Furthermore, the ugly images score the lowest performance among the three. The average of RMSE for the total 85 ugly images in SD27 dataset is 0.023199 while the average of PSNR is 81.07826. The following table presents the average result of the experiment for three categories good, bad, and ugly in SD27 dataset.

Table 1. RMSE and PSNR Average of Image categories.

Image Category	RMSE Average	PSNR average
Good	0.018373	82.99068
Bad	0.022287	81.39749
Ugly	0.023199	81.07826

To measure the performance of the proposed method, the result after and before enhancement has been compared. The following graph presents the RMSE comparison of the different categories before and after enhancement.

The following graph presents the PSNR comparison of the different categories before and after enhancement.

Figures 3 and 4, the comparison before and after enhancement of latent fingerprint images have done.

The result shows that the proposed latent fingerprint enhancement technique improved the quality of the latent fingerprint images about 30%. Furthermore, two state of the art techniques has been compared with the proposed model. The followings figure 3 and figure 4 presents the RMSE and PSNR comparison of the three models.

Figure 3. RMSE Image categories comparison.

Figure 4. PSNR Image categories comparison.

Figure 5. RMSE comparison of the three models.

The figures 3,4,5 and 6 respectively, the proposed model outperforms for both TV and DTV models for all

the three different categories of latent fingerprint images.

Figure 6. PSNR comparison of the three models.

Conclusion

Latent fingerprint Image enhancement plays a significant role in automatic latent fingerprint identification systems. Even though significant development was made for both plain and rolled fingerprint enhancement, latent fingerprint enhancement still is a challenging problem. Poor quality images and existence of structured noise contribute to the challenges of latent fingerprint enhancement. The paper reviewed the current techniques used in latent fingerprint enhancement that leads to the identification of current issues and challenges in the searched area. Thus, it proposed hybrid model which is combination of edge directional total variation model and quality image enhancement with lost minutia reconstruction. The proposed techniques are tested using NIST SD27 data set. PSNR and RMSE is deployed to measure the performance of the hybrid technique. There is a statistically significant difference in the mean length of PSNR and RMSE for different categories of the latent fingerprint images (good, bad and ugly). It's observed that the proposed technique performs well for the good latent fingerprint images compare to bad and ugly images. The proposed technique can be further enhanced by taking into account the overlapped latent fingerprint images.

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