A Fingerprint Enhancement Algorithm using a Federated Filter

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ABSTRACT

In the application of the Automatic Fingerprint Identification System (AFIS), some fingerprint images are noisy and corrupted. In such situation, an effectively enhancement algorithm to improve the clarity of the ridge structure is necessary. The available enhancement algorithms are based on either the local orientation field filtering scheme in space domain or the Gabor filtering scheme in the frequency domain. The local orientation could not be correctly estimated for fingerprint images of poor quality, which greatly restricts the applicability of these filtering techniques. The Gabor filters could obtain the reliable orientation estimate even for corrupted images, but it is time consuming. It is unsuitable for an on-line fingerprint recognition system such as AFIS. In this paper, an enhancement algorithm using a space-frequency federated filtering scheme is proposed, which adapts the filtering methods to the input images according to a pre-defined quality factor. The quality factor is calculated on the orientation field filtered image. Only parts of the images of which quality factor do not meet the requirement are filtered by the Gabor filter. Experiments show that the proposed algorithm is computationally efficient, with the same level of the enhancement performance.

Keywords: AFIS image enhancement federated filter quality factor

1. INTRODUCTION

Accurate automatic personal identification is becoming more and more important to the operation of our increasingly electronically inter-connected information society. Automatic fingerprint verification system (AFIS) is wildly used in various fields of our society, such as finance, electronic commerce, access control, social security and so on\(^{[1,8]}\). In the practice of the AFIS, due to variations in customers’ ages and occupations, skin conditions, acquisition devices, impression conditions, etc., a significant percentage of acquired fingerprint images is of poor quality. In such situation, an effective enhancement algorithm to improve the clarity of the ridge structure is necessary. For the AFIS to be acceptable in practice, the response time needs to be within few seconds. Therefore the enhancement algorithm should meet the requirement of real time verification, besides the verification accuracy. The above performance index involves a trade-off.

A fingerprint image enhancement algorithm using a space-frequency federated filter suitable for the AFIS is proposed in this paper. The proposed scheme selects the filtering scheme adaptively based on the quality factor of the acquired image. The algorithm is a computationally efficient filtering scheme, with similar performance with the Gabor-filter enhancement algorithm\(^{[2]}\).

2. FINGERPRINT IMAGE ENHANCEMENT

The local ridge orientation is an intrinsic property of the fingerprint images. By viewing a fingerprint image as an oriented texture, a number of methods have been proposed to estimate the orientation field of fingerprint images\(^{[3]}\). The previous enhancement algorithm is either local orientation field filter-based or Gabor filter-based. The orientation field filtering techniques usually assume the local ridge orientation could be reliably estimated and be taken advantage to enhance the fingerprint image\(^{[4]}\). The ridge structures in poor-quality fingerprint images are not always well-defined and, hence, the orientation information could not be correctly detected, which greatly restricts the applicability of these techniques. The Gabor filter based technique could obtain a reliable orientation estimate even for corrupted images\(^{[5]}\). It is unsuitable for an on-line fingerprint recognition system such as AFIS because the algorithm is computationally expensive.
2.1 Fingerprint enhancement using local orientation filtering

The local orientation filtering technique taking advantage of the local ridge orientation which is the intrinsic property of the fingerprint images is wildly used in the fingerprint verification system. The precondition of the algorithm is the assumption that the local ridge orientation could be reliably estimated. In practice, this assumption is not valid for fingerprint images of poor quality. Fig. 1 and Fig. 2 show the orientation estimation of images of different quality. The algorithm applying Gabor filters on the fingerprints images could obtain a reliable orientation estimation even for corrupted images. However, it is computationally expensive and time consuming.

Fig.1 Orientation Image of the image of good quality   Fig. 2 Orientation Image of the image of poor quality

2.2 Fingerprint enhancement using Gabor filters

In the gray-level fingerprint image, the pixel value could be modeled as a sinusoidal-shaped wave along the direction perpendicular to the local ridge orientation (see Fig. 3). The local ridge frequency is another intrinsic property of a fingerprint image. The Gabor filter have both frequency-selective and orientation-selective properties and have optimal joint resolution in both spatial and frequency domains. Therefore the Gabor filter could remove the noise and preserve true parallel ridges structures taking the advantage of the local orientation and local frequency\(^2\).

\[
S[k] = \frac{1}{w} \sum_{u=0}^{w-1} N(u,v) \quad k = 0,1,\ldots,l-1
\]

\[
u = i + \left[\frac{w}{2} - n\right] \sin \theta(i,j) + \left[k - \frac{l}{2}\right] \cos \theta(i,j)
\]

\[
v = j + \left[n - \frac{w}{2}\right] \cos \theta(i,j) + \left[k - \frac{l}{2}\right] \sin \theta(i,j)
\]

\(\theta(i,j)\) is the local orientation and \(N(i,j)\) is the normalized image. The \(S[0],S[1],\ldots,S[l-1]\) form a discrete sinusoidal-shape wave, which has the same frequency as that of the rides and valleys in the frequency window (see Fig. 3(b)). Let \(T(i,j)\) be the number of pixels between two consecutive peaks.
Utilizing the information of orientation and frequency properties, the Gabor filter shows better performance in visual quality of local orientation than orientation field filtering scheme. However, the high computational complexity of Gabor filter could not meet the real-time requirement of the Automatic Fingerprint Identification System.

3. FEDERATED FILTERING USING QUALITY FACTOR

The purpose of the enhancement is to remove the noise in fingerprint images, clarify the parallel ridges and valleys, and preserve the true configuration of them. The final evaluation of results of image enhancement algorithms are usually obtained from human perception and subjective opinions and this method is obviously not suitable for the real-time application required by Automatic Fingerprint Identification System.

We note that the fitting curve (Fig.3(b)) from the $S[0], S[1], \ldots, S[l-1]$ obtained from formula (1) is usually not a standard sinusoidal-shape wave as we expect, which can be attributed to the false points caused by the noise brought in during the image acquisition process. So the curve usually cannot reflect the true local ridge frequency property if the noise disturbs original pixels greatly. The fitting curve can present good frequency property only when the fingerprint image has enough high quality, as illustrated in Fig.4 and Fig.5.

![Fig. 4 Frequency Image of good-quality image](image)

![Fig. 5 Frequency Image of poor-quality image](image)

Based on the above discussion, we take the characteristic parameters of the fitting curve as the quality factor to evaluate the quality of the fingerprint image. Using the quality factor as an indication of which filtering scheme to use for the image enhancement, our scheme achieves adaptability of selection of the two filtering schemes-the orientation field filtering and the Gabor filtering, and this guarantees good filtering performance while keeping the total computational complexity still quite low to meet the real-time requirement.

The frequency parameter and the amplitude parameter could determine the unique ideal sinusoidal-shape wave. The above fitting curve is similar to ideal sinusoidal shape wave. Therefore, we take the frequency parameter and the amplitude parameter as two important parameters for the quality factor. Considering the noise interference, the differences of the peaks and vales are also introduced into the calculation of the quality factor. We could obtain the statistic data $S[0], S[1], \ldots, S[l-1]$ form formula (1) and the fitting curve of them. Let the $DI(i,j), Df(i,j), DPd(i,j), DVd(i,j)$ be the variance of the amplitude, the period and the differences of the peaks and vales, so the local quality factor is defined as

$$Q(i, j) = \alpha DI(i,j) + \beta DT(i,j) + \gamma DP_d(i,j) + \eta DV_d(i,j)$$

(2)
where, $\alpha, \beta, \gamma, \eta$ are weight coefficients, and $0 < \gamma, \eta < \alpha, \beta < 1$. The local quality factor $Q(i,j)$ is the estimation of every block in the fingerprint image. Then the quality factor of the whole image is defined as

$$Q = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} Q(i,j)}{M \times N}$$  

(3)

Where $M \times N$ is the number of the blocks in the fingerprint image. The quality factor could be the indication of the quality of the fitting curve, so as to the quality of the image and the performance of the enhancement algorithm. The steps involved in federated filtering with the quality factor are as follows:

Step1. Enhance the acquired image with local orientation field filter.
Step2. Obtain the fitting curve of the results from formula (1) and calculate the quality factor of the image.
Step3. Make decision of filtering schemes by the quality factor: if the quality factor is below the predefined threshold $\tau$, the quality of the processed image could be accepted and the processed image could be output as the enhanced image; otherwise we consider the quality of the processed image not acceptable and go to Step4;
Step4. Perform the Gabor filter on the image which is not acceptable for Step3 and output the resulting image as the enhanced image.

4. Experimental Results

Experiments have been done using the proposed scheme on images with different qualities in the FVC database. The results show that the adaptability of quality evaluation and filtering scheme selection on fingerprint images can be achieved by the adoption of the quality factor, as shown in Fig.6 and Fig.7. Note that the Gabor filter scheme is only used in the case the quality factor cannot meet the requirement. This saves much of computational complexity and expedites the whole fingerprint identification process.

Fig.6 The estimated frequency properties of the fingerprint images after the orientation field filtering
(a) Orientation field filtering result of a high quality image (b) Estimated frequency property with $Q=0.515$
(c) Orientation field filtering result of a low quality image (d) Estimated frequency property with $Q=18.006$
5. CONCLUSION

Based on the analysis and comparison of the two different fingerprint image enhancement algorithms-orientation field filtering scheme and Gabor filtering scheme, we propose a quality factor to integrate the two schemes in practical applications. The quality factor endows the whole fingerprint identification algorithm with adaptability which selects different filtering schemes according to the image quality. The experimental results demonstrated the accuracy and efficiency of the proposed scheme and exhibited the scheme’s applicability for the Automatic Fingerprint Identification System. To further expedite the algorithm, we can adopt the Gabor filtering scheme only in some noise-highly-polluted local areas.

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7. REFERENCES


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