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A Review on Fingerprint Image Enhancement Techniques

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Abstract— A lot of fingerprint image enhancement algorithms have been done in the past. There are many techniques and approaches in enhancing the low quality fingerprint images. In this paper, a review of several approaches and techniques used in the past to solve low quality problem in fingerprint images are discussed. Results of those techniques are shown and discussed in this paper.

Index Terms—Enhancement, Filtering, Transform Methods, Inverse Filtering

1 Introduction

BIOMETRICS is a natural and reliable solution to identity determination problem by recognizing individuals derived from their physiological or behavioral characteristics that are inherent to the person [1]. Physiological and behavioral characteristics that commonly used for biometric recognition are face, fingerprint, iris, retina, DNA, signature, palm print, ear, voice, keystroke dynamics, hand-geometry and gait. Automated fingerprint identification system (AFIS) is a well known and accepted mostly by whole world. It is also became one of the importance in security field which by many researchers have interest to keep on doing research on it.

A fingerprint is the pattern of ridges and valleys that known as furrows in the fingerprint literature (A. Moenssens, 1971) on the surface of a fingertip. Generally, there are three main criteria about fingerprint:

1. **Unchangeable**: Configuration and information about fingerprint pattern is permanent and never change even while body's growth process.
2. **Unique**: The varieties of fingerprint ridges levels are higher. Hence, everybody have the unique fingerprint ridges even the identical twins have different fingerprint.
3. **Classification**: Classification of fingerprint pattern is limited. This will make the systematic classification of fingerprint pattern easy.

Fingerprint image obtained from the acquisition phase are not always well define and rarely of perfect quality. Several factors such as scars, moist in scanner and many more will affect the quality of the image. In this case, this could lead to a failure or false minutiae extraction. Hence, it is essential to occupy image enhancement techniques to decrease the noise and improve the definition of ridges against valleys.

In this paper, we are going to discussed several of fingerprint images enhancement techniques that have been used in the past in the Section 2. The result of these techniques is shown in the Table 1 and results of these techniques are also discussed in Section 3.

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2 Fingerprint Image Enhancement Techniques

2.1 Short Time Fourier Transform (STFT) Analysis

In [2, 3], STFT analysis has been introduced as a new technique for fingerprint enhancement. Fig.1 below shows the overview of the proposed technique.

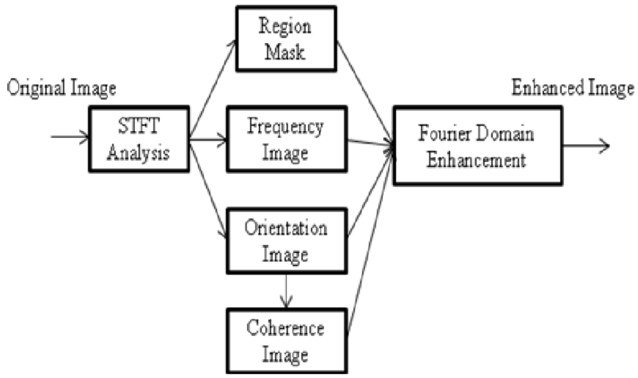

Fig. 1. Proposed technique in [2]

A new fingerprint image enhancement algorithm based on contextual filtering in the Fourier domain presented. Based on Fig. 1, input image is divided into overlapping windows during STFT analysis. They assumed that the image is stationary within this small window and can be modeled approximately as a surface wave. Probabilistic estimates of the ridge frequency and ridge orientation are obtained then.

A non-stationary one dimension signal x(t) it is assumed that it is approximately stationary in the span of a temporal window w(t) with finite support during the analyzing process. The STFT analysis also yields an energy map which is maybe used as to do the computation of the angular coherence. The use of this coherence image is to adapt the angular bandwidth. Then, to filter each window on the Fourier domain, the resulting contextual information was used.

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Algorithm:  FFTEnhance
Inputs   :  Image I(x,y)
Outputs  :  Enhanced Image I'(x,y), Ridge Orientation Image O(x,y),
            Ridge Frequency Image F(x,y), Energy Image E(x,y),
            Orientation Coherence Image C(x,y), Region Mask(x,y)
STAGE I: STFT Analysis
1. For each overlapping block B(x,y) in the image
      a. Remove DC content of B, B=B-avg(B)
      b. Multiply by spectral window W
      c. Obtain the FFT of the block, F = FFT(B)
      d. Perform root filtering on F
      e. Perform STFT Analysis. The analysis yields values of
         E(x,y),O(x,y),F(x,y)
   end for
2. Smoothen orientation map O(x,y) by vector averaging to yield O'(x,y)
3. Perform isotropic diffusion on frequency map F(x,y) to yield F'(x,y)
4. Compute coherence image C(x,y) using O'(x,y)
5. Compute region mask R(x,y) by thresholding E(x,y)

STAGE II: Enhancement
6. For each overlapping block B(x,y) in the image
      a. Compute angular filter FA centered around O(x,y) and with
         bandwidth inversely proportional to C(x,y)
      b. Compute radial filter FR centered around frequency F(x,y).
      c. Filter the block in the FFT domain, F= F*FR*FA
      d. Compute the enhanced block B'(x,y) = IFFT(F)
   end for
7. Reconstruct the enhanced image by composing enhanced blocks B'(x,y)
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Fig. 2. Outline of proposed enhancement algorithm in [2]

The algorithm for enhancement can be outlined as follow. The algorithm consists of two stages. The first stage consists of STFT analysis and the second stage performs the contextual filtering. The STFT stage yields the ridge orientation image, ridge frequency image and the block energy image which is then used to compute the region mask. This is similar to the approach that proposed in [4]. Therefore, the analysis phase simultaneously yields all the intrinsic images that are needed to perform full contextual filtering.

2.2 Pyramid-based Filtering

This technique is proposed in [5] where the research used common techniques for the enhancement and minutiae extraction stage. They used two types of symmetries to model and extract the local structure in a fingerprint image which is parabolic and linear symmetry. Both symmetries can be estimated by separable filtering of the orientation tensor.

In the enhancement process, a Laplacian-like image pyramid was used in order to decompose the original fingerprint image into sub-bands corresponding to different spatial scales. Contextual smoothing was performed on these pyramid levels where the corresponding filtering directions stem from the frequency-adapted structure tensor.

A pyramid decomposition requires resizing such as scaling or geometric transformation. Based on Fig. 3, in order to create Gaussian and Laplacian-like pyramids, they defined the reduce (I, k) and expand (I, k) operation. This will decrease and increase an image, I in size by the factor of k, respectively. During reduce, the image is initially low-pass filtered to prevent aliasing using Gaussian kernel [6].

a) Pyramid Decomposition PD	
Gaussian-like	Laplacian-like
$g_1 = reduce\,(fp, k_0)\,;$	$l_1 = g_1 - expand\,(g_2, k)\,;$
$g_2 = reduce\,(g_1, k)\,;$	$l_2 = g_2 - expand\,(g_3, k)\,;$
$g_3 = reduce\,(g_2, k)\,;$	$l_3 = g_3 - expand\,(g_4, k)\,;$
$g_4 = reduce\,(g_3, k)\,;$	

b) Reconstruction R
$fp = expand\,(\ldots, k_0)\,;$
$\Uparrow expand\,(\ldots, k) + l_1$
$\Uparrow expand\,(l_3, k) + l_2$

Fig. 3 Pyramid building process in [5]

Then, parabolic symmetry was added to the local fingerprint model which allows to accurately detecting the position and direction of a minutia simultaneously. Essentially, the parabolic symmetry was attenuated if the linear symmetry was high, whereas it was preserved in the opposite case. All these were implemented during the minutiae extraction process.

2.3 Curved Gabor Filters

In the field of the enhancement of various types of images and also extraction of Gabor features, Gabor filters played important role. Based on [7], the researchers introduced curved Gabor filters for the purpose of enhancing curved structures in noisy images. This technique locally adapted their shape to the direction of flow. It also enables the choice of filter parameters that increased the smoothing power without creating artifacts in the enhanced images. In many areas of image processing and pattern recognition, Gabor functions [8], in the form of Gabor filters [9] and Gabor wavelets [10] were applied for multitude of purposes.

In the [7], they applied curved Gabor filters to the curved ridge and valley structure of the poor quality fingerprint images. At the beginning, they combined two orientation field estimation methods to obtain more robust estimation for very noisy fingerprint images. Next, the curved regions were conducted by following the respective local orientation and then were used to estimate the local ridge frequency. At last, curved Gabor filters were defined based on curved regions and were applied for the enhancement of poor quality fingerprint images.

Unfortunately, there was a limitation which if the ridges were curved, the enlargement of the rectangular window does not improve the consistency of gray-profile. It is because the straight lines will cut neighboring ridges and valleys. Thus, to prevent this situation occur, they came out with curved regions which adapted their shape to the local orientation. Advantage of using curved Gabor filters is that they enable the choice of larger curved regions without creating spurious features. Only then, curved Gabor filters have much greater smoothing potential in comparison to the traditional Gabor filter.

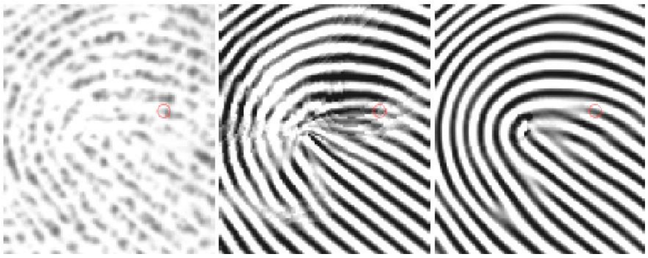

Fig. 4. (Left): Original image, (Middle): Traditional Gabor filter, (Right): Curved Gabor filter

2.4 Histogram Equalization, Fast Fourier Transform and Image Binarization

In the [11], an implementation of fingerprint recognition based matching has been done. Fig. 5 shows the detailed design description where two focused stages in the paper was designed. The two stages are minutiae extraction and minutiae matching. Minutiae extraction includes image enhancement, image segmentation and final extraction processes while minutiae matching include minutiae alignment and match processes.

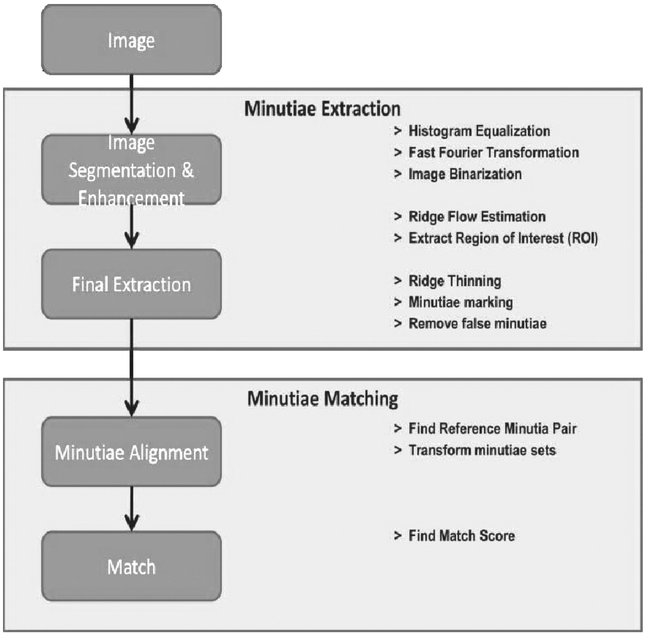

Fig. 5. Overall design in [11]

Histogram equalization used to improve the global contrast of an image by adjusting the intensity distribution on a histogram. This technique accomplished by effectively spreading out the most frequent intensity values. In the FFT implementation, image was divided into small processing blocks (32 x 32 pixels) and performs the FFT.

In order to enhance specific block by its dominant frequencies, thus they multiply the FFT of the block by its magnitude a set of times where the magnitude of the original FFT = abs (F (u, v)) = |F (u, v)|. The result of this technique is made the enhanced image has improvements as some falsely broken points on ridges get connected and some spurious connections between ridges get removed.

To extract the region of interest, they applied two steps: Block direction estimation and ROI extraction by Morphological methods. This ROI technique is also being used in [12]. Ridge thinning process was done by using Matlab's built in morphological thinning function. They marked the minutiae by using templates for each 3 x 3 pixel window. Next, they implemented false minutiae removal process to remove unwanted spurious minutiae that might be created in the early process. However, the remaining issue in this research is spurious minutiae occurred due to over inking are not totally eliminated and needed to be removed.

2.5 Oriented Diffusion Filtering and Curved Gabor Filters

This combination of novel method was proposed in [13] to enhance low quality fingerprint images. First, they estimated the local orientation of the fingerprint ridge and valley flow. Then, they performed oriented diffusion filtering followed by a locally adaptive contrast enhancement step. In the paper, they examined three types of nonlinear anistropic which are coherence-enhancing, incoherence-enhancing and edge-enhancing diffusion and they also examined linear anistropic diffusion.

They generated their diffusion tensor from a more reliable orientation field (OF) estimation (Fig. 6). In Fig. 6, we can see the structure tensor derived from the aggregated OF clearly outperforms the classical gradient based tensor in areas with a high noise level. To do this, they computed the OF by using a combination of the line sensor method from [14] and the gradients based method from [15, 16].

Fig. 6. (Left): Original image, (Middle): After coherence-enhancing diffusion filtering using the image gradients, (Right): After linear diffusion filtering with a-priori estimated OF

Locally adaptive contrast enhancement has been done to improve image quality by smoothing along the local orientation. Their contrast enhancement was based on the normalization formula in [4] which was proposed for global image normalization. However, this method may reduce overall image contrast and after the diffusion, there were also considerable differences in gray-level intensities along ridges and valleys. They also tuned the contrast enhancement to slowly change in steps from the foreground and background area. This may result less false minutiae detection and lower the EERs. Advantages of diffusion filtering are they do not require estimation of the ridge frequency (RF) and can be computed fast.

2.6 Discrete Fourier Transform (DFT) and Histogram Equalization

In [1], they proposed an algorithm for fingerprint image enhancement and feature extraction by using the combination of Discrete Fourier Transform (DFT) and histogram equalization to reconstructs the information of the fingerprint image. They claimed that DFT is an important image processing tool to decompose an image into its sine and cosine components. The basic is to split the image into frequency domain F (u, v) and multiplying this frequency domain with a constant such as [17]. Enhanced image produced after this operation; if we take the inverse Fourier to this altered frequency domain. Then, histogram equalization and binarization was applied. They implemented adaptive binarization method with threshold value in 0 to 1 range.

In thinning process, morphological operation such as erosion and dilation is implemented to decrease the width of ridges to one pixel while preserving the extent and connectivity of the original shape. They first applied erosion, then dilation. After thinned image obtained, minutiae extraction process was implemented by using a 3 x 3 window scanner for minutiae search. In this research, each ridge endings and ridge bifurcations were represented by a white dot pixel. They claimed by using DFT and histogram equalization, the quality of input image greatly increased and minutiae extraction result more accurate.

2.7 Coherence Diffusion Filter and Gabor Filter

In [18], they came out with a novel method of fingerprint image enhancement by combined spatial domain two dimensional Gabor filter and diffusion-coherence filter. Additionally, the technique of new blocks overlapping is used for eliminate the blocking artifact in the enhanced image. They mentioned in their research that by using diffusion method, it gives better results in the region of image with high curvature ridges which is in the core point surrounding region. However, it produced unsatisfactory results for cut and broken ridges. Same to the Gabor filter-based method, it may enhance the cut and broken ridges but gives distorted image results for high curvature region of the image surrounding the core point.

Thus, they combined both filters to get better results for their research. Algorithm used in their research is described as follows:

Step 1. *They determine core point of the image to be enhanced by using the Poincare index method. Fig. 7 shows the determined core point location.*

Fig. 7. Images from FVC 2002 databases with core point location is highlighted as green point

Step 2. *The ridge with high-curvature region R1 (Fig. 8) of dimensions 100 x 100 pixels surrounding the core point location that found in Step 1 is selected.*

Fig. 8. Selected region of *R1* from Fig. 7

Step 3. *Diffusion Coherence method is applied to the selected region R1 determined in Step 2. The proposed algorithm uses the coherence-enhancing anisotropic diffusion filter proposed by the Weickert in [19].*

Step 4. *2D Spatial-domain Gabor filtering method is applied to the remaining region R2 of the input image. They employed a novel overlapping blocks technique to remove the blocking artifacts by using method of Hong L. et al. [4].*

Step 5. *Finally, the image of regions R1 and R2 obtained in Step 3 and Step 4 was merged to get the final enhanced image.*

For the experimental results in this research, it is obvious that the images enhanced by the proposed method are better (see Fig. 9 (c) and (f)) than those enhanced by diffusion method (see Fig. 9 (b)) and Gabor filter method (see Fig. 9 (e)). The enhanced images by this proposed method have clear distinction between ridges and valleys. Fig. 9 shows the results in their experiment.

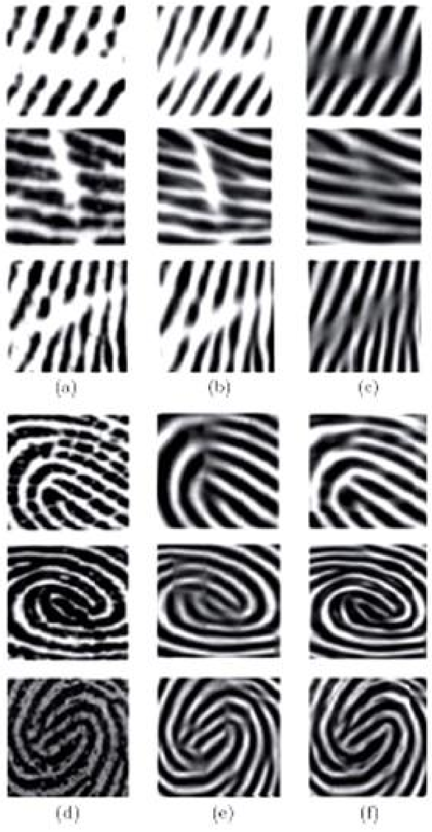

Fig. 9. Results of proposed method in the plane ridge valley region and core region: (a) and (d) Original image, (b) Enhancement by diffusion coherence method, (e) Enhancement by Gabor filter method, (c) and (f) Enhancement by proposed method.

3 RESULT

Table 1 shows the result of the accuracy of methods used for fingerprint images enhancement based on the EERs percentage from review papers above.

TABLE 1. RESULTS OF FINGERPRINT IMAGE ENHANCEMENT TECHNIQUES

Author	Techniques	Result/Accuracy
Bhowmik et al. [1]	DFT and Histogram Equalization	Quality of fingerprint image greatly increased and more accurate minutiae extraction
Chikkerur, Cartwright, Govindaraju [2]	Short Time Fourier Transform (STFT) Analysis	% of EER (FVC2004) DB1 = 19.1 DB2 = 11.9 DB3 = 7.6 DB4 = 10.9
Fronthaler, Kollreider, Bigun [5]	Pyramid-based filtering	% of EER (FVC2004) DB1 = 12.0 DB2 = 8.2 DB3 = 5.0 DB4 = 7.0
Gottschlich [7]	Curved Gabor filters	% of EER (FVC2004) DB1 = 9.7 DB2 = 6.3 DB3 = 5.1 DB4 = 6.5
Bana and Kaur [11]	Histogram Equalization, FFT and Image Binarization	FVC2004 FAR and FRR = 30 -35 % approximately
Gottschlich and Schonlieb [13]	Oriented Diffusion filtering and Curved Gabor filters	% of EER (FVC2004) DB1 = 9.0 DB2 = 5.0 DB3 = 4.2 DB4 = 5.4
Ali et al. [18]	Coherence Diffusion filter and Gabor filter	Enhanced images have clear distinction between ridges and valleys

EER = Equal Error Rate, FAR = False Acceptance Rate, FRR = False Rejection Rate

EER value indicates that the proportion of FAR is equal to the proportion of FRR. The lower the EER value, the higher the accuracy of the biometric system. Based on Table 1, the novel combination of oriented diffusion filtering and curved Gabor filter proposed by [13] has the lowest equal error rates among the other techniques and technique proposed in [2] achieved the highest equal error rates rather than the other. The performance of oriented diffusion filtering for enhancing low quality fingerprint images is quite impressive in comparison to existing methods such as enhancement based on the short time Fourier transform [2] and pyramid-based filtering [5]. Advantages of diffusion filtering are that they do not require estimation of the ridge frequency (RF) and they can be computed first. In addition, the performance of curved Gabor filters [7] heavily depends on the quality and reliability of the orientation fields (OF) and RF estimation. Combining oriented diffusion filtering with curved Gabor filters led to additional advancements and gives the lowest EERs.

4 CONCLUSION

The performance of a fingerprint feature extraction and matching algorithms are greatly depends on the quality of the input fingerprint image. Different fingerprint image enhancement approaches have shown to improve the quality of fingerprint images in different studies. It is observed that the combination of oriented diffusion filter and curved Gabor filter technique give better results in the fingerprint image enhancement.

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