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Enhancement of fingerprint using FFT×|FFT|^n filter

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Abstract

Fingerprint enhancement is an indispensable task in the Automatic Fingerprint Identification System. In this paper, a simple method for the enhancement of fingerprint images is presented, which is based on FFT. The FFT is found out after the fingerprint image is partitioned into blocks. It is then multiplied with |FFT|^n, where n is obtained by trial and error as 2.2. The best enhancement results were obtained for a block size of 4×4. In this approach, patching of pore holes in the ridges and joining discontinuous ridges were achieved. This method was compared with the different conventional enhancement techniques.

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Keywords: Fingerprint; Enhancement; FFT; Preprocessing; Postprocessing;

1. Introduction

Due to growing concerns of authentication and security in the world, biometric security systems are becoming increasingly popular. Fingerprints tend to be the most used biometric feature in most security and identification system. In any fingerprint identification system, enhancement of the fingerprint image prior to recognition is essential.

A fingerprint is an impression left by the friction ridges of a human finger. In a wider perspective, fingerprints are the traces of an impression from the friction ridges of any part of a human or other primate hand or foot[1]. Impressions of fingerprints are caused on a surface by the natural secretions of sweat from the eccrine glands that are present in friction ridge skin. These can also made by artificial means such as ink or other substances, transferred from the peaks of friction ridges on the skin to a relatively smooth surface such as a fingerprint card.

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An Automatic Fingerprint Identification System (AFIS) consists of fingerprint classification, fingerprint image enhancement and fingerprint matching[1,2]. An important requirement with most of the existing AFIS techniques is that they all require a reasonable standard of input image. In practice, a fingerprint may be corrupted by noise. This corruption can result in bad prints as well as bad images. Both bad prints and bad images reduce the efficiency of AFIS systems. Therefore fingerprint enhancement techniques are used to improve the performance.

Fingerprint enhancement is used to recover the topology structure of ridges and valleys from the noisy image. Many sophisticated fingerprint enhancement algorithms do exist in literature[1-7]. However, most of these techniques are suited for forensic applications, where processing time is quite relaxed. Other enhancement techniques are mostly based on predetermining the ridge orientation which requires complex and wieldy calculations[2,3,4,8]. Thus a technique which is not just easy to implement but requires comparatively lesser processing time and provides satisfactory output is sorely needed.

An effective and robust algorithm for fingerprint enhancement was proposed by Cheng Pu[4]. In this technique, contrast stretching approach was used to improve the clarity between foreground and background of the fingerprint image. Then the structure tensor property, advantages of Gabor and Diffusion filtering and a low pass filter were made use of in this paper. Dhanabal et al.[6] discussed the application of Gabor Filter technique to enhance the fingerprint image. This work produced change in Gabor filter design by increasing the quality of an output which helps in higher security applications. The main disadvantage of this method is that the computation time is high. Shalaby and Ahmad[8] introduced a novel low-complexity multilevel structural technique for fingerprint recognition. A fast multilevel matching algorithm based on the new fingerprint representation was also proposed. In a technique proposed by Chikkerur[3], a new fingerprint image enhancement algorithm based on STFT analysis and contextual/non-stationary filtering in the Fourier domain was developed. The performance of a fingerprint feature extraction and matching algorithm depends critically upon the quality of the input fingerprint image. In the method developed by Oliveira and Leite, to improve the quality of the fingerprint images, the specific problem of reconnecting broken ridges was addressed[2]. Complex operators like erosion and dilation are used here. In the technique proposed by Babatunde[5], enhancement of fingerprint is achieved by a complex algorithm. In He et al.[7], a fingerprint image enhancement method was developed based on orientation field and a minutiae matching algorithm was introduced. But the results showed that some fingerprint images of bad quality exist. Most of the existing methods are time consuming and uses complex process[3,4,2,8]. To overcome these disadvantages, a method proposed by Willis and Myers[1] that uses FFT is used in this paper.

The paper is organized as: section 2 discusses Fourier transform for fingerprint enhancement, section 3 deals with implementation of the algorithm; section 4 gives the results and discussions.

2. Fourier Transform for fingerprint enhancement

The use of FFT on a set of pixels from a small region of image allows reconnection of broken ridges following the same FFT orientation. Image is divided into overlapping blocks of size, powers of 2. Fourier Transform of a specific block was taken in order to get directional information of that block[1]. If Fourier transform of a block that contains two or three parallel ridges was taken, then dominant frequencies of that block corresponds to the ridges in that block. The Fourier Transform is computed using equation:

$$F(u,v) = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\, exp\left\{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)\right\}$$

$$\textit{for } u=0,1,2\ldots M\text{-}1 \textit{ and } v=0,1,2\ldots N\text{-}1. \tag{1}$$

The inverse of FFT is computed using the equation:

$$f(x,y) = \frac{1}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1} F(u,v)\, exp\left\{j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)\right\} \quad \textit{for } x=0,1,2\ldots M\text{-}1 \textit{ and } y=0,1,2\ldots N\text{-}1. \tag{2}$$

In order to enhance a specific block by its dominant frequencies, it is possible to multiply the FFT of the block by its magnitude a set number of times. This makes the parallel ridges to be finely separated and also make the ridges thick.

If the magnitude of the FFT were squared or cubed and then multiplied, an even better result would be obtained. But it was seen that minutia was obscured. Hence rather than multiplying whole factors of FFT magnitudes, a fraction or power of the magnitude can be used[1], i.e.

$$g(x, y) = F^{-1}\{F(u, v) \times |F(u, v)|^n\} \tag{3}$$

where *g(x,y)* is the enhanced block and *'n'* is a constant determined experimentally, which is between one and three.

3. Implementation

The implementation of the above fingerprint enhancement technique was done on the images obtained from VeriFinger database[9]. The database consists of fingerprint samples which were scanned with Digital Persona U.are.U 4000 scanner at 500 ppi. The fingerprint database consisted of a total of 1098 control fingerprint samples from a random crowd[9]. Out of this 930 samples are of .tif format and the rest 168 samples are of .bmp format[9, 10]. The samples chosen for implementing the different enhancement techniques were of .tif format. The different steps involved in implementing the fingerprint enhancement algorithm is given below

3.1. Algorithm

The image to be processed was taken from the fingerprint database[9]. Before finding FFT, the following preprocessing was done on the image:

- Initially this image was subjected to contrast enhancement as a part of pre-processing.
- Histogram equalization was done on the output obtained from the above step. This helps in further defining the finer details of the fingerprint image.
- Image was binarized to facilitate easier recognition of ridges and key features.

The preprocessed image was partitioned into overlapping small blocks. Usually, square blocks of size 2^k are taken, where k can be any whole number. The power of 2 are taken so that fast radix-2 FFT can be used and thus optimize the speed. The block size is selected through trial and error.

FFT of the block was computed using the equation (1). The magnitude of the FFT is taken and raised to some real valued 'n'. This is then multiplied by the original FFT. To find the new enhanced image in the frequency domain,

$$G(u, v) = F(u, v) \times |F(u, v)|^n \tag{4}$$

Experimentally it is found that values of n ranging from 1.4 to 2.3 yield the best output. The inverse Fourier transform is computed by the equation (2). Thus the overall process can be summarized using equation (3):

$$g(x, y) = F^{-1}\{F(u, v) \times |F(u, v)|^n\} \tag{5}$$

where *g(x,y)* is the enhanced block and *'n'* is an experimentally determined constant.

The following post processing were done in the spatial domain after the enhancement procedure:

- smoothening
- gradient
- background removal.

This process is repeated for all the image blocks. It was found that the ridges are indeed made solid and well separated as required.

4. Results and Discussion

4.1. Pre-Processing Techniques

A contrast stretching is first carried out so that the overall contrast of the image is enhanced. Contrast stretching tries to improve an image by stretching the range of intensity values it contains to make full use of possible range of values[11, 12]. Adaptive histogram equalization is subsequently used to improve the local contrast of the image[12]. In the adaptive method, several histograms, each corresponding to a distinct section of the image are computed, and are used to redistribute the lightness values of the image. It is therefore suitable for improving the local contrast of an image and bringing out more detail.

The obtained image is then binarized before giving as input to the $FFT \times |FFT|^n$ technique. A binary image facilitates easier recognition of ridges and key features. The results of pre-processing techniques are shown in Fig. 1.

(a) (b) (c) (d)

Fig. 1. Pre-processing Technique results (a) Original image (b) Image after contrast stretching (c) Output image obtained after adaptive histogram equalizing (d) Output image obtained after binarizing.

4.2. Determination of block size

The size of the overlapping blocks to which the image is divided is generally, square blocks of size 2^k, where k can be any whole number. Choosing an arbitrary value of n=1.4 and overlap=block size− 1, different square blocks of size 2×2, 4×4, 8×8, 16×16, 32×32 and 64×64 were taken and subjected to the technique. The results obtained are shown below in Fig. 2

From the results, it is observed that block sizes of 4×4 and 8×8 gave good output however as the block sizes increases most of the image details are lost. On close examination of the outputs, it is seen that for 8×8 block size, some of the minutiae in the output is lost. This is undesirable for recognition process. Also, the 4×4 block had higher correlation of 0.5698 and PSNR of 53.3345 than 8×8 block. Hence 4×4 is chosen as the standard block size for further processes.

(a) (b) (c) (d) (e)

Fig. 2. Determination of overlapping block size using trial and error method when =1.4 (a) Original fingerprint image (b) Output of $FFT\times|FFT|^n$ technique when block size=2×2 (c) when block size =4×4 (d) when block size = 8×8 (e) when block size =32×32.

Table 1. Various block sizes chosen for computing FFT×|FFT|^n method and corresponding correlation and PSNR values between original image and enhanced image.

Block size	Correlation	PSNR (*dB*)
2×2	0.5779	53.5141
4×4	0.5698	53.3345
8×8	0.5534	53.0989
16×16	0.5150	52.7293
32×32	0.4352	52.1502
64×64	0.2555	50.9715
128×128	0.3280	51.0415
256×256	0.6167	51.0556

4.3. Determination of n value

Different values of n are substituted in equation (3) and their output images were studied. The values of ‘n’ in the range of 1.4 to 2.3, yielded visually good outputs. Fig. 3. shows the outputs obtained for n=1.4, 1.7 and 2.2 for an overlap of 3 pixels when block size is 4×4.

The correlation and PSNR between the output and input images are shown in table 2.

Table 2. Various ‘n’ values chosen for computing FFT×|FFT|^n method and corresponding correlation and PSNR values between original image and enhanced image.

‘n’ value	Correlation	PSNR (*dB*)
1.4	0.5479	52.8796
1.5	0.5480	52.8804
1.6	0.5483	52.8812
1.7	0.5484	52.8823
1.8	0.5487	52.8835
1.9	0.5492	52.8848
2.1	0.5496	52.8874
2.2	0.5503	52.8882

Here when ‘n’ = 2.2 gave the highest correlation of 0.5503 and PSNR of 52.8882.

(a) (b) (c) (d)

Fig.3.Determination of n using trial and error method for a block size of 4×4 and n=2.2 (a) Original fingerprint image (b) Output of the technique when block size =4×4 and n=1.4 (c) when n=1.7 (d) when n=2.2.

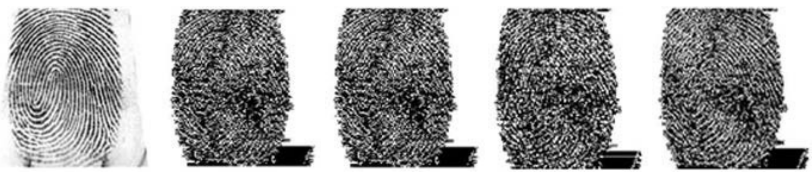
4.4. Determination of overlap

The block size is fixed at 4×4 and the value of 'n' is fixed at 2.2 in an effort to optimize the output. To validate the previously chosen overlap of blocksize-1overlap was determined experimentally. For a 4×4 block, different values of the overlap i.e. 0, 1, 2 and 3 pixels were considered. The results obtained are shown in Fig. 4.

The best result is obtained at 3 pixel overlap. For a block size =4×4 and n=2.2, the correlation and PSNR value for different overlap values are given in the following table 3.The preprocessed binary image is divided into block size 4×4, n=2.2, overlap=3, FFT was computed using equation (1) and IFFT was computed using equation (2).

Table 3. Various overlaps chosen for computing $FFT\times|FFT|^n$ method and corresponding correlation and PSNR values between original image and enhanced image.

Overlap (*pixels*)	Correlation	PSNR (*dB*)
0	0.5515	52.9415
1	0.5544	52.9730
2	0.5497	52.8988
3	0.5510	52.8905



(a) (b) (c) (d) (e)

Fig. 4. Overlap determination using trial and error method when block size =4×4 and n=2.2 (a) Original fingerprint image (b) Output of the technique for 0 pixel overlap (c) when 1 pixel overlap (d) when 2 pixel overlap (e) when 3 pixel overlap.

4.5. Post-Processing Techniques

The IFFT output was too sharp with many discontinuities in certain portions of ridges. An averaging filter was implemented so as to smoothen the output image obtained.

In order to thicken the ridges and enhance the edges of the output obtained, the gradient was taken.

(a) (b) (c)

Fig. 5. Post-processing results. (a) Output image obtained after the technique and average filtering using a 3×3 mask (b) Output image obtained after taking gradient (c) Output image obtained after changing background.

Finally, attempts were made to replace the black background of the image with a white background in order to make the image visually appealing. This is illustrated in Fig. 5. Instead of considering an entire image, when a 162×178 block was taken, enhancement obtained was more visible. In this case, a correlation of 0.6537 and a PSNR ratio of 54.2769 dB were obtained. This is shown in Fig. 6.

(a) (b)

Fig. 6. FFT×|FFT|^n technique inputs and outputs (a) a 162×178 block of the original fingerprint sample (b) output of the same block when subjected to the technique.

To understand how the enhancement process patches pore holes and improves the degraded portion of the image, a 50×20 block is considered. The results illustrates that the degraded parts of the original image was also enhanced by using this technique as shown in Fig. 7.

(a) (b)

Fig. 7. FFT×|FFT|^n technique results on degraded portion of original image of Sample 1 (a) a 50×20 block of the degraded portions of original fingerprint sample (b) output of the same block when subjected to the technique.

Conventional fingerprint enhancement techniques such as histogram equalization and Gabor filtering were performed on the fingerprint images. The results of these techniques are shown in Fig. 8.

(a) (b) (c)

Fig. 8. Results of conventional fingerprint enhancement techniques. (a) Original fingerprint image (b) Output image obtained after histogram equalization (c) Output image obtained after Gabor filtering.

The PSNR and correlation values of these results were found to be very less in comparison with the FFT based technique. It is visually evident from these results that FFT×|FFT|^n technique yields a better enhanced fingerprint image.

5. Conclusion

The fingerprint enhancement algorithm called FFT×|FFT|^n was developed and implemented in this paper. Many pre-processing and post-processing methods were introduced into this technique so as to increase the quality of output enhanced image. The best results were observed for an overlap of 3 pixels, a block size of 4×4 and n=2.2 It is evident from the result images that pore holes in the ridges were patched up. Moreover, discontinuities in the ridges were joined thus reducing the chances of false minutiae. This aids in feature extraction and further fingerprint recognition.

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