Fingerprint Image Enhancement using Wavelet over Gabor filters

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Abstract

Fingerprint identification is one of the most popular biometric technologies and is used in criminal investigations, commercial applications, and so on. The performance of a fingerprint image-matching algorithm depends heavily on the quality of the input fingerprint images. It is very important to acquire good quality images but in practice a significant percentage of acquired images is of poor quality due to some environmental factors or user’s body condition. Therefore, an image enhancement algorithm is necessary to increase the performance of the minutiae extraction algorithm. The traditional approach is based on Gabor filter, which is the most common approach used in the fingerprint image enhancement. The proposed approach deals with the wavelet denoising which enhances the fingerprint image by reducing noise and selecting threshold values by the computation of discrete wavelet transform, and thus comparing the performance of the traditional and proposed approach.

Keywords- fingerprint, enhancement, Gabor filter, Wavelet, Performance measure

1. Introduction

Image enhancement improves the quality (clarity) of images for human viewing. Removing blurring and noise, increasing contrast, and revealing details are examples of enhancement operations. An adaptive enhancement algorithm reveals these details. Adaptive algorithms adjust their operation based on the image information (pixels) being processed. In this case the mean intensity, contrast, and sharpness (amount of blur removal) could be adjusted based on the pixel-intensity statistics in various areas of the image.

Fingerprint is the first biometric system adopted by law enforcement agencies, and now is also the most widely used system. Although iris recognition has been deemed among the most stable of the biometric technologies available today, fingerprint recognition has been around the longest, and there are more commercial applications of it than iris recognition. For example, different types of fingerprint recognition devices can be found for network access and physical access entry configurations; it is the primary tool utilized for Automated Fingerprint Identification System (AFIS) databases; and it is also the biometric tool of choice for financial institutions. Most AFISs are based on minutiae matching. The major minutiae features used by AFISs, are endings and bifurcations, which represent terminations and intersections of fingerprint ridge line flows. Although the automatic fingerprint recognition and identification have wide and long practical application, there still exist a lot of challenging and established image processing and pattern recognition problems. Fingerprint image quality is of much importance to achieve high performance in AFIS. Enhancement of fingerprint images can be performed on either binary ridge images or direct gray images. Binarization before enhancement will generate more spurious minutiae structures and lose some valuable original fingerprint information; it also poses more difficulties for later enhancement procedure. Therefore, most enhancement algorithms are performed on gray images directly.

In order to ensure that the performance of an automatic fingerprint identification system will be robust with respect to the quality of input image, it is essential to incorporate a fingerprint enhancement algorithm [1] in the feature extraction module. The purpose is to reduce above distortion by using preprocessing algorithm and to approach input raw
Ones receive that the ideal fingerprint may be described by distorted circular grating and the properties of ideal fingerprint image will be the same as properties of distorted circular grating. Purpose of pre-processing is to decrease False Acceptance Probability and increase Authentic Acceptance Probability. The improved Gabor filtering \([2,7]\) can protect the ridge structure and avoid the spurious ridges effectively. In addition, a Fourier-Transformation based method \([4]\) is proposed to compute the orientation field more precisely and efficiently. A hybrid fingerprint enhancement algorithm is based on morphological enhancement \([3]\) in the additive wavelet transform domain and Wave Atom denoising. The adaptive filtering \([5]\) step enhances the edges of the fingerprints. Background Subtraction is the primary step carried out in order to subtract the background from the input fingerprint image. From the filtered images \([6]\), the orientation field is estimated and a quality mask which distinguishes the recoverable and unrecoverable corrupted regions is found. The image is enhanced in the recoverable regions.

The fingerprint image enhancement algorithm \([8]\) applies image processing to only pixels whose locations are the inside of center lines of ridges. So ridges can be enhanced and also ridges aren’t eliminated as when the smoothing filter is applied. This algorithm enhances valleys by replacing original image with eroded image only in areas where valleys are thin and disconnected. So valleys aren’t eliminated as when the smoothing filter is applied. On the analysis of the survey, the thirst of the enhancement procedure still exists. The noisy fingerprint images are not suited to extract the feature very well; hence it becomes first and foremost task in an fingerprint identification process.

This paper introduces fingerprint image enhancement process, which is done using both Gabor filter method and wavelet denoising method. The enhanced image produced as a result of the two enhancement procedure is compared using Peak Signal-to-Noise and Mean Square Error. This paper deals with the fingerprint images affected by two types of noises namely Gaussian noise and Salt & Pepper noise, which is briefly discussed in Section II. The enhancement procedure for these noises is carried out with the Gabor filter and Wavelet that is elaborated in Section III. The overall process of the fingerprint enhancement process is depicted in Fig. 1

The skeleton view of the fingerprint image enhancement process in Fig. 1 is discussed as the fingerprint image is injected with the noises say, Gaussian and Salt & Pepper noise; these noisy images are then filtered using Gabor filter procedure and wavelet denoising procedure to enhance the fingerprint image. The enhanced image is thus analysed and compared using performance measures namely PSNR and MSE.

![Figure 1. Fingerprint Image Enhancement Process](image-url)

2. Noise

Image noise is random (not present in the object imaged) variation of brightness or color information in images, and is usually an aspect of electronic noise. It can be produced by the sensor and circuitry of a scanner or digital camera. Image noise can also originate in film grain and in the unavoidable shot noise of an ideal photon detector. Image noise is an undesirable by-product of image capture that adds spurious and extraneous information. Image Noise is generally of the following types:

1) Amplifier noise (Gaussian noise)
2) Salt-and-pepper noise
3) Quantization noise (uniform noise)
4) Shot noise
5) Film grain

2.1 Amplifier noise

The standard model of amplifier noise is additive, Gaussian, independent at each pixel and independent of the signal intensity, caused primarily by Johnson–Nyquist noise (thermal noise), including that which comes from the reset noise of capacitors. In color cameras where more amplification is used in the blue color channel than in the green or red channel, there can be more noise in the blue channel. Amplifier noise is a major part of the "read noise" of an image sensor, that is, of the constant noise level in dark areas of the image. Gaussian noise provides a good model of noise in many imaging systems. Its probability density function (pdf) is:

\[
\text{PDF} = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(n-n_0)^2}{2\sigma^2}}
\]
where, \( P_n(n) \) is the probability density function
\( n \) is the zero mean Gaussian noise distribution
\( \sigma \) is its standard deviation

The Gaussian distribution has an important property: to estimate the mean of a stationary Gaussian random variable, one can't do any better than the linear average. This makes Gaussian noise a worst-case scenario for nonlinear image restoration filters, in the sense that the improvement over linear filters is least for Gaussian noise. To improve on linear filtering results, nonlinear filters can exploit only the non-Gaussianity of the signal distribution.

Figure 2. Gaussian distribution with mean 0 and standard deviation 1

Figure 3. Probability density function for the Salt & Pepper noise model

The salt & pepper noise is generally caused by malfunctioning of camera’s sensor cells, by memory cell failure or by synchronization errors in the image digitizing or transmission. Fig. 3 illustrates the probability density function for the salt & pepper noise model and there are only 2 possible values, a and b, and the probability of each is typically less than 0.2 – with numbers greater than this the noise will swamp out the image.

3. Fingerprint Image Enhancement Procedure

The fingerprint image enhancement process is carried out as described further using Gabor filter and Wavelet denoising method. Gabor filter enhancement procedure is thus computing the orientation of the ridges in the fingerprint image and thus by applying the symmetric property of the filter, enhancement is done in one quadrant so that the result can be easily applied to the other quadrants. The input fingerprint image is added with noise and thus the noisy image is then denoised by applying soft thresholding and keeping the coefficients approximation to one. Thus, fingerprint image is enhanced using the wavelet denoising. Gaussian noise is initially injected to the fingerprint image and the enhancement procedures are carried out to enhance the image. The procedure is repeated with Salt & Pepper noise too. The performance is analysed using the parameters Peak Signal-to-Noise Ratio (PSNR) and Mean Square Error (MSE) values of the denoised images.

3.1 Gabor Filter Enhancement Procedure

The Gabor filter enhancement is done in the following procedure. Gabor filter enhancement procedure is thus computing the orientation of the ridges in the fingerprint image and thus by applying the symmetric property of the filter, enhancement is done in one quadrant so that the result can be easily applied to the other quadrants.
Fig. 4 illustrates Gabor Filter Enhancement. The following are the steps involved in this procedure. First, the fingerprint image is injected to the noise, and then the orientations of the ridges are estimated and finally the image is enhanced using Gabor filter by choosing the appropriate parameters. The noise thus injected is both Gaussian and Salt & Pepper noise. The entire process is first done with Gaussian noise and then with the Salt & Pepper noise and the performance measures are analyzed.

Figure 4. Gabor Filter Enhancement

The fingerprint enhancement algorithm using Gabor filter for enhancing the images injected with the noise is as follows:

1. Input the fingerprint image and assume it to be ‘X’.
2. Add Gaussian noise say ‘A’ to the input image and the resultant noisy image be ‘S’
3. To enhance the image ‘S’
   3.1 Estimate the ridge orientation of the image ‘S’ by processing the pixel coordinates say (x,y) using sines and cosines of the gabor filter parameter theta θ
   3.2 Filter the orientational image using symmetric property of the Gabor filter.
4. Compute the MSE and PSNR values for the noisy and denoised image.
5. The same process is repeated for the other noise say Salt & Pepper noise.
6. The procedure is done with the set of fingerprint images and the performance measure values for those images are computed.

3.2 Wavelet filter Enhancement Procedure

Wavelet based enhancement is done in the following procedure. The input fingerprint image is added with noise and thus the noisy image is then denoised by applying soft thresholding and keeping the coefficients approximation to 1. Thus, fingerprint image is enhanced using the Daubechies wavelets (db2). The noise thus injected is both Gaussian and Salt & Pepper noise. The entire process is first done with Gaussian noise and then with the Salt & Pepper noise. And the performance parameters namely (PSNR) and (MSE) values are computed for both noisy and enhanced images.

Figure 5. Wavelet based Enhancement

The fingerprint enhancement algorithm using Wavelet filter for enhancing the images injected with the noise is as follows:

1. Input the fingerprint image and pre-process the input image and assume it to be ‘X’.
2. Add Gaussian noise say ‘A’ to the input image and the resultant noisy image be ‘S’
3. To enhance the image ‘S’
   3.1 Apply the soft threshold and set the coefficients approximation to 1.
   3.2 Using those values denoise the fingerprint image using the wavelet function.
4. Compute the MSE and PSNR values for the noisy and denoised image.
5. The same process is repeated for the other noise say Salt & Pepper noise.
6. The procedure is done with the set of fingerprint images and the performance measure values for those images are computed.

4. Results and Discussion

For the fingerprint image authentication, fingerprints acquired must be of good quality. Practically that doesn’t be the fact. There arises a need to enhance the fingerprint image. The implementation of the enhancement of fingerprint image is carried out with Gabor based and wavelet based enhancement procedure. The noises that are injected in the fingerprint image are Gaussian and Salt & Pepper noise.

Initially, the fingerprint image injected with any of the noise say, Gaussian noise is enhanced using Gabor filter enhancement procedure. This procedure is carried out by computing the orientation of the ridges in the fingerprint image and there by filtering the orientational image. Thus a fingerprint image is denoised with Gabor filter. The same procedure is repeated with the fingerprint image injected with the Salt & Pepper noise. In the same manner, the enhancement must be carried out with the wavelet based enhancement. Here, the work is done by applying the soft thresholding to the coefficients and approximating the coefficients to one. There by, the fingerprint image is denoised using Daubechies wavelets db2. The outcome (results) of both the enhancement procedures with that of Gaussian as well as Salt & Pepper noise are
compared using PSNR and MSE values of the denoised (enhanced) image.

**Table 1 Performance Measure Table**

<table>
<thead>
<tr>
<th>Image ID</th>
<th>Gaussian Noise</th>
<th>Salt &amp; Pepper Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wavelet Filter</td>
<td>Gabor Filter</td>
</tr>
<tr>
<td>PSNR</td>
<td>MSE</td>
<td>PSNR</td>
</tr>
<tr>
<td>Φ</td>
<td>72.4827</td>
<td>0.0037</td>
</tr>
<tr>
<td>Ψ</td>
<td>72.2303</td>
<td>0.0049</td>
</tr>
<tr>
<td>ζ</td>
<td>79.8206</td>
<td>0.0026</td>
</tr>
<tr>
<td>η</td>
<td>68.3445</td>
<td>0.0151</td>
</tr>
<tr>
<td>θ</td>
<td>66.267</td>
<td>0.0258</td>
</tr>
<tr>
<td>φ</td>
<td>66.6581</td>
<td>0.0168</td>
</tr>
<tr>
<td>ħ</td>
<td>69.3991</td>
<td>0.0076</td>
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<tr>
<td>ι</td>
<td>66.2201</td>
<td>0.0098</td>
</tr>
<tr>
<td>κ</td>
<td>66.9781</td>
<td>0.0108</td>
</tr>
</tbody>
</table>

The performance of Wavelet and Gabor filters are analyzed using PSNR and MSE values of the denoised (enhanced) image and these values are tabulated in Table 1. From the Table, it is evident that the wavelet enhancement procedure works well than that of the Gabor enhancement procedure. It is observed that the Wavelet enhancement procedure suits well to the Salt & Pepper noisy images than that of the Gaussian noisy images.

Figure 6. Original Image with Id f1, Psnr=∞ and Mse =0

Figure 7. Wavelet Denoised Image f1 with Psnr=72.4827 and Mse = 0.0037

Figure 8. Gabor filter based denoised image f1 with Psnr = 69.8707 and Mse = 0.0067

The image enhancement procedures are done with the set of 50 fingerprint images. The results for the set of sample images given in Table 1 are presented in the graph below,

Figure 9. MSE Value Graph for salt and pepper noise

Figure 10. MSE Value Graph for Gaussian noise

Figure 11. PSNR Value Graph for salt and pepper noise
The performance measure values obtained are plotted in the graph shown in Fig. 9, 10,11 and 12. The MSE and PSNR values determine the efficiency of the denoising procedures. It is evident from the graph that PSNR values for wavelet filter is higher than that of the gabor filter. Added to that, MSE values for wavelet filter is lesser than that of the gabor filter. Thus the results clearly explain that the Wavelet Enhancement procedure is well suited for Salt & Pepper noisy images than that of the Gaussian noisy images. The Gabor filter enhancement procedure works well with Gaussian noisy images.

5. Conclusion and Future Work

It is concluded that the fingerprint images are enhanced to a higher quality by denoising the images using Wavelet based enhancement procedure. The PSNR and MSE values computed for those enhanced images reveals that the enhancement is done efficiently over the noisy images. It is evident from the results that the wavelet based enhancement is superior to that of the traditional approach. The traditional approach enhances the images, but the noise still persists and quality is not much improvised. This doesn’t mean that the proposed approach removes the entire noise in the fingerprint image, but to the greater extent.

The future work relies on the feature extraction process and identifying the fingerprint image in an efficient way. The thought emerged is that the enhanced image is thus used in fingerprint recognition system that is, used for identification. The identification in the fingerprint recognition system compares an input fingerprint with the prints of all enrolled users in the database. The recognition system needs to extract the features from the image using an efficient feature detection algorithm, which is able to extract the features from the fingerprint images very clearly and legibly, and thus the fingerprint image is used in the identification process.

6. References