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An Efficient Multistage Fingerprint Enhancement Technique using Filters and SVD-DWT

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***Abstract*—- Biometrics technology, which uses physical or behavioral characteristics to identify users, has attained increased attention. Among various biometric indicators, fingerprints are most widely used due to their uniqueness and reliability. The task of fingerprint enhancement scheme is to counteract the quality impairments and to reconstruct the actual fingerprint pattern as true to the original as possible. It is observed that a single stage enhancement is not sufficient to improve the ridge structures of a fingerprint image. In this paper, multiple stages of fingerprint enhancement techniques are employed for efficient fingerprint quality. The original image is first filtered using a spatial ridge compensation filter namely gabor filter to remedy the ridge areas and enhance the contrast of the local ridges. The first stage filtered image is then enhanced using an anisotropic diffusion filter. To obtain an even further reliable and high quality image, a third stage enhancement using Single Value Decomposition- Discrete Wavelet Transform (SVD-DWT) is used. The performance is measured using mean square error (MSE), peak signal to noise ratio (PSNR) and structural similarity index (SSIM). It is proved that our methodology provides better result in improving the image quality and better enhancement.**

Keywords— Biometrics, enhancement, gabor filter, anisotropic diffusion filter, SVD-DWT

I. INTRODUCTION

Biometrics is defined as the physiological and/or behavioral attributes of an individual, used to provide safety and security from fraudulent acts. Among all biometric traits, fingerprints have one of the highest levels of reliability and have been extensively used by forensic experts in criminal investigations. A fingerprint refers to the flow of ridge patterns and anomalies in the tip of a finger. The ridge flow exhibits anomalies in local regions of the fingertip and it is the position and orientation of these anomalies that are used to represent and match fingerprints. Minutiae characteristics are local discontinuities in the fingerprint pattern and represent the two most prominent local ridge characteristics: terminations and bifurcations. A ridge termination is defined as the point where a ridge ends abruptly, while ridge bifurcation is defined as the point where a ridge forks or diverges into branch ridges. Fingerprint images are frequently of low quality, because of the contexts of the image acquisition process. In general noise from input devices can be easily eliminated using simple filters though the inadequacy of crumple structures from each individual are not typically well defined, and it is very hard to enhance the contexts of these images[1]. The distinction of a fingerprint image may be poor or significantly different because of various factors, such as wetness and dryness, pressure strength, smears, and so on, which lead to different types of degradation in fingerprint images. Fingerprint enhancement is the process of improving the quality of image by increasing contrast, sharpness, brightness etc. In order to eliminate noise, a process called preprocessing is done. Preprocessing include various techniques like binarization, thinning, normalization.

Most of the previous works are based either on spatial domain filters or frequency domain filters. In a spatial domain technique, an input fingerprint image is convolved with a spatial filter mask. The size of the filter mask determines the computational complexity of the filtering process. Some of the spatial domain methods are based on the use of contextual filters, log gabor filters, compensation filters, image- scale- based filters etc.

In the spatial domain, the most popular method is based on the use of gabor filter. The filtering kernel is both frequency selective and orientation selective, which makes it to give maximal responses to ridges at a specific orientation and frequency in the fingerprint image.

In [2], the fingerprint enhancement based on contextual filter was proposed. The filter increased the ridge contrast in a direction perpendicular to ridges, while it performed smoothing in the direction of ridges. It includes mainly four steps: i) user- specification of appropriate image features ii) determination of local ridge orientation throughout the image iii) smoothing of this orientation image iv) pixel-by-pixel image enhancement by application of oriented, matched filter masks.

An oriented non linear diffusion driven by ridge curvatures and singular points was proposed in [3]. First, the singular points were determined iteratively from Poincare index. Second, the orientation field is regularized using a singularity driven non linear diffusion process. Finally, an oriented diffusion process driven by curvature and singular points is applied to enhance the fingerprint image. The performance of this method is good, but the iterative procedure to determine the singular points increases the computational complexity.

In a frequency domain technique, the input image is convolved with a frequency domain filter. Convolution operation is equivalent to multiplication operation in spatial domain.

The bandpass filter proposed in [4] has two filters: radial filter and angular filter. The input image is first divided into several blocks. For each block, the ridge orientation and frequency are approximated. At the center of ridge orientation and frequency, radial and angular filters are obtained. These filters filter the block images to obtain the block enhanced image. Finally, the enhanced image is obtained by combining all the block enhanced images.

The proposed bandpass filter in [5] in the DCT domain consists of ridge frequency and orientation filters. This method requires accurate contextual information (local ridge orientation, frequency, angular bandwidth). One of the drawbacks of this method is blocking artifacts around singular regions.The method proposed in [6] uses both spatial domain and frequency domain filtering to enhance the low quality fingerprint image. The spatial domain filter is computed from local ridge orientation of the input fingerprint image. It is then followed by a frequency domain filter that consists of a raised cosine filter and exponential bandpass radial filter. Although this method enhances the image, execution time is increased due to the iteration applied at the spatial domain filtering.

A single stage enhancement either in spatial domain or frequency domain is not sufficient to eliminate the noises and enhance the low quality fingerprint image. Hence, a three stage enhancement that uses filters in both spatial domain and frequency domain is proposed. The proposed scheme makes use of a i) directional gabor filter that compensates ridges in the spatial field ii) anisotropic diffusion filter removes noise without blurring edges iii) single value decomposition-discrete wavelet transform (SVD-DWT) protects the edge information from degradation.

II. PROPOSED METHOD

The existing enhancement algorithms are not always satisfactory in enhancing low quality fingerprint images. To overcome the demerits of these methods, a new and effective scheme for enhancement of fingerprint images are proposed in this paper.

a) Spatial ridge compensation filter

This filter estimates local orientation and uses it to compensate for the defects. The scheme [7] consists of three steps: i) local normalization ii) local orientation estimation iii) local ridge compensation filter.

Local normalization reduces the local variations and standardize the intensity distributions to correctly estimate the local orientation.

Normalized image is defined as:

$$\text{norimg}(i,j) = M_0 + \text{coeff} * (\text{img}(i,j) - M) \quad (1)$$

$$\text{coeff} = V_0 / V \quad (2)$$

Here, img(i,j) is the gray level value of the fingerprint image. norimg (i,j) is the normalizing value in (i,j), coeff is the amplificatory multiple, M is the mean of the subimage, V is the variance of the subimage, M0 and V0 are the desired mean and variance.

Local orientation estimation determines the dominant directions of the ridges in a fingerprint image. The original image is subdivided into non overlapping blocks of size W x W. The block orientation values are calculated using vertical and horizontal gradients by applying a simple gradient operator. The gradient operator is chosen according to the computational requirement. The most used gradient operator is sobel operator. It is less susceptible to noise.

Local ridge compensation filter compensates for ridge artifacts in the image. It is accomplished by using a rotated rectangular window to match the local orientation.

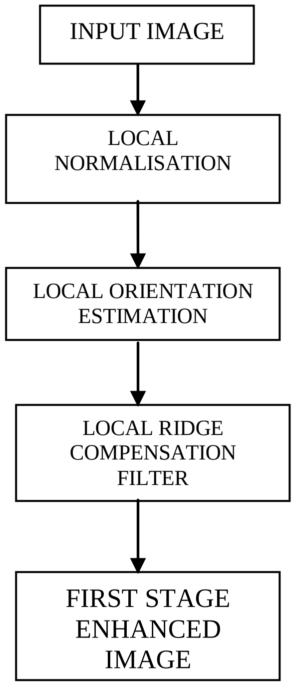


Fig 1. Block diagram of first stage enhancement scheme

The spatial filter increases the ridge contrast in a direction perpendicular to the ridges, but it may blur the image as well. So a second stage enhancement scheme using an anisotropic diffusion filter is used to enhance the image.

b) Anisotropic diffusion filter

Anisotropic diffusion, also called Perona–Malik diffusion, is a technique aiming at reducing image noise without removing significant parts of the image content, typically edges, lines or other details that are important for the interpretation of the image. Anisotropic diffusion [8] can be used to remove noise from digital images without blurring edges. With a constant diffusion coefficient, the anisotropic diffusion equations reduce to the heat equation which is equivalent to Gaussian blurring. This is ideal for removing noise but also indiscriminately blurs edges too. The anisotropic diffusion filter is applied to the first stage enhanced image using the following equation

$$\begin{cases} \dfrac{\partial u}{\partial t} = div(D(\tau_\rho(\nabla u_\sigma), O_{FC})\nabla u) & on\ \Omega \times (0,\infty) \\ u(x,y,0) = I(x,y) & on\ \Omega \\ \langle D(\tau_\rho(\nabla u_\sigma), O_{FC})\nabla u, n \rangle = 0 & on\ \partial\Omega \times (0,\infty) \end{cases}$$

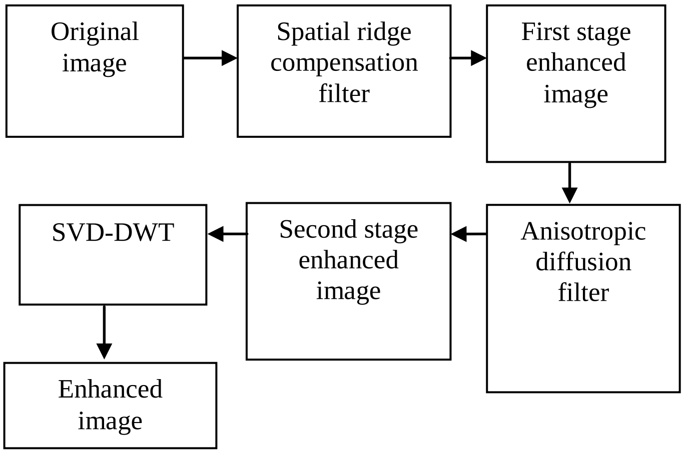


Fig 2. Block diagram of the proposed method

c) Singular value decomposition – discrete wavelet transform (SVD – DWT)

This method is based on SVD of an LL subband image obtained from DWT. DWT is used to separate a low contrast fingerprint image into different frequency subbands, where the LL subband contains the illumination information. The singular value matrix obtained by SVD [10] contains the illumination information. Therefore, changing the singular values will directly affect the illumination of the image; hence, the other information in the image will not be changed. The second important aspect of this work is the application of DWT. The illumination information is embedded in the LL subband. The edges are concentrated in the other subbands (i.e., LH, HL, and HH). Hence, separating the high-frequency subbands and applying the illumination enhancement in the LL subband only will protect the edge information from possible degradation. The final image is reconstructed by using DWT. The method uses the ratio of the largest singular value of the generated normalized matrix, with mean zero and variance of one, over a normalized image which can be calculated the formula

$$\xi = \frac{\max\_\Sigma N(\mu=0,\mathrm{var}=1)}{max(\sum A)}$$

III. EXPERIMENTAL RESULTS

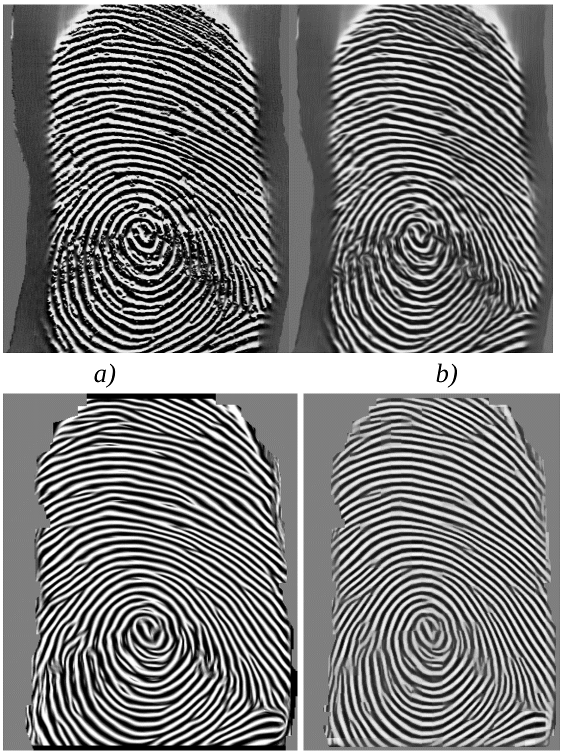
The proposed algorithm is tested to various type of input images and experiments shows that it works well for all type of images without any complexity. The database that is used in this experiment is the FVC2004 database set_a [11], which contains four distinct subdatabases with four different scanners.

For first stage enhancement, we used desired mean M_0=128 and desired variance V_0 =128 * 128. Local normalization is better compared to global normalization as it enhances the contrast between the ridges and valleys in the low contrast image.

The result with the image from FVC2004 (DB1A) database is shown in Figure 3. The original input image consists of broken ridges as well as creases as shown in Figure 3(a). By means of the first stage enhancement, the broken ridges are joined as shown in Figure 3(b). However, the breaks created by creases still remain as well as a degradation of the contrast in the first-stage enhanced image is noticed. The proposed second-stage filtering can connect small gaps created by creases along with a significant improvement in the contrast, as seen from the image in Figure 3(c). In Figure 3(d), the second-stage enhanced image is further filtered using the third stage to connect big gaps created by creases, yielding a significant improvement in the quality.

fig 3. a) Input image(DB1A) b) first stage enhanced image
c) second stage enhanced d)third stage enhanced image
image

The image from FVC2004 (DB3A), as shown in Figure 4 (a), consists of broken ridges and noise near singular regions. By using the first-stage enhancement, the broken ridges are joined as seen in the image of Fig 4 (b). The enhanced image has visible noise present around the singular region. After the second-stage filtering, the noise around the singular region is removed, as seen from the image of Fig 4 (c). From Figure 4 (d), it can be seen that the final enhanced image has a much better visual quality than the original one shown in Fig 4(a).



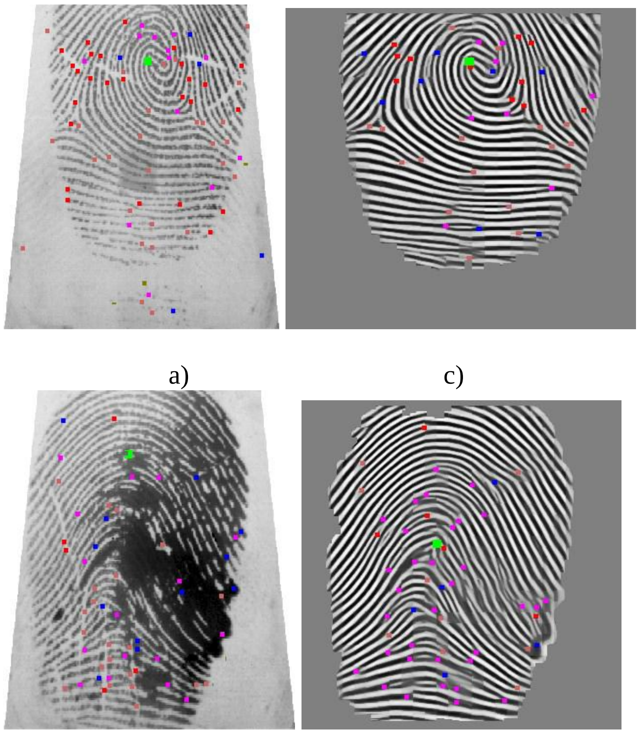
a) b) c) d)

fig.3. a) input image(DB3A) b) first stage enhanced image c) second stage enhanced image d) third stage enhanced image

The effectiveness of fingerprint enhancement using the proposed method can be examined using minutiae extraction. Minutiae are ridge endings or ridge bifurcations. A minutiae extraction algorithm is applied to the original and enhanced images in order to show the effectiveness of the proposed enhancement scheme. Accurate extraction of minutiae depends on the quality of input fingerprint image. Minutiae extraction method consists of binarization and thinning. First, the gray-scale fingerprint image is transformed into a binary intensity of black (0) or white (1). In second step, the binarized image undergoes a thinning operation which reduces the thickness of all ridges to a single pixel. The image obtained after the thinning operation, namely, the skeleton image contains the locations and orientations of the minutiae similar to that in the input fingerprint image. Next, the thinned binary image is analyzed in order to extract and store minutiae information. The Rutovitz crossing number is used to obtain the minutiae information within a 3×3 window centered at each pixel p as

$$cn(p) = \frac{1}{2}\sum_{i=1}^{8}\left|val(p_{(i \bmod 8)}) - val(p_{i-1})\right|$$

where *cn(p)* is the crossing number of a pixel *p* and $val(p) \in \{0,1\}$ is the binary image pixel value. The crossing number is used to identify minutiae pixel location. A ridge ending has *cn*=1, bifurcation has *n*=3, core point has *cn*=5 and delta point has *cn*>5 within the thinned image.

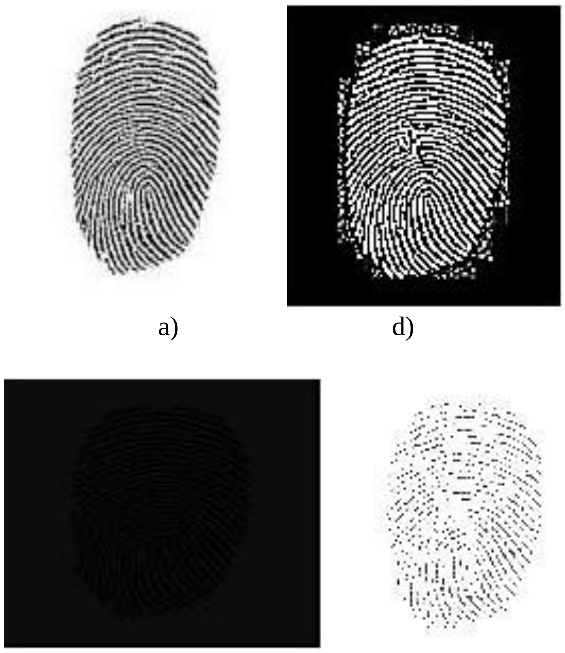


a) c) b) d)

fig. 4. a), b) minutiae from input images c) ,d) minutiae from enhanced image

IV. PERFORMANCE MEASUREMENT

The proposed method is compared with several other conventional filters like histogram equalization, median filter, high pass filter, high boost filter, high boost Gaussian filter.



a) d) b) e)

c) *f)*

fig 5.a) input image b) median filter c)high pass filter d) high boost filter e) high boost Gaussian filter f) proposed filter

The above figure shows the input image and corresponding images obtained using median filter, high pass filter, high boost filter, high boost Gaussian filter and proposed method.

The performance was evaluated using the structural similarity index measurement (SSIM) and Peak Signal Noise Ratio (PSNR) in order to evaluate the quality of the image. PSNR is defined as the ratio between the maximum possible power of a signal and corrupting noise. Structural similarity index is used to measure the similarity between two images. It is considered as one of the most effective and consistent parameter. Table 1 shows PSNR and SSIM values of various filters and it is found that the proposed method shows better value.

Table 1. PSNR and SSIM values of various filters

FILTER	PSNR	SSIM
MEDIAN FILTER	23.4583	0.7458
HIGH PASS FILTER	19.8305	0.4287
HIGH BOOST FILTER	41.8762	0.5198
HIGH BOOST GAUSSIAN FILTER	41.8630	0.5237
PROPOSED METHOD	31.9248	0.9597

V.CONCLUSION

Fingerprint enhancement is the most commonly used operation to improve the feature extraction and matching performances in a fingerprint recognition system. In this paper, an effective multi-stage enhancement scheme for the fingerprint images has been proposed. Fingerprint images are of low quality and so, a single stage enhancement is not sufficient to meet the context of a high performance verification system. The performance of the proposed method is measured using structural similarity index measurement (SSIM) and Peak Signal Noise Ratio (PSNR). Experimental results show that the proposed method is better compared to other filters.

Although the performance of proposed method is better compared to the existing techniques, this method can be extended to include more features in order to further improve the quality of fingerprint image.

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