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Fingerprint Image Enhancement with Second Derivative Gaussian Filter and Directional Wavelet Transform

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Abstract— **In this paper, we propose a technique for enhancing the quality of fingerprint images. Directional wavelet transform and second derivative of a Gaussian filter are applied. The original fingerprint image is decomposed into approximation and detail sub-images. To each sub-dimension a directional filter: second derivative of Gaussian filter is applied for tuning up the image features. The enhanced image is measured for its improvement by testing the success of core point identification where Poincare technique is used. The commonly-well-known database FVC-2004 is used in this study. The obtained results offer clean visualization as well as the increase the success of true core point detection.**

Keywords-Fingerprint enhancement; Wavelet transform; the second derivative of Gaussian filter; Biometric.

I. INTRODUCTION

Among all the biometrics, fingerprint-based identification is one of the most popular and reliable biometric techniques. This is because it holds many desirable features such as universality, permanence, collectability, and distinctiveness. Personal identification based on fingerprint matching is now popular in wide range of applications. Most automatic fingerprint identification systems are based in minutiae matching [1, 2, 3].

A fingerprint is the pattern of ridges and valleys on the surface of a fingerprint. Minutiae are local discontinuities in the fingerprint pattern. The most important ones are ridge ending and ridge bifurcation. Spurious ridge structure may change the individuality of input fingerprints. Ridges and valleys in a local neighborhood form a sinusoidal-shaped plane wave, which has a well-defined frequency and orientation. The core point has played important roles in many fingerprints identify techniques. The success of the identification (or matching) process is very much relied on the image quality. In many cases, fingerprints are with numerous discontinuous ridges (dry, wet, damped, scars and smudges). The main difficulty for feature extraction is that fingerprint quality is often too low, thus noise and contrast deficiency can produce false minutiae or hide valid ones. Even high quality images can also yield false minutiae, for example, when the person has cuts or scars in his/her fingers.

There appear many algorithms and techniques proposed and applied to fingerprint image enhancement: using Fourier transform [4, 5], Gabor filters [2, 6], Wavelet transform [7, 8, 9, 10,11], and minutiae filtering, applied to binary [12] or gray-scale images [13]. The main of an enhancement algorithm is to improve the clarity of ridge structures of fingerprint images in recoverable regions and to remove the unrecoverable regions.

In the fingerprint image, the pattern is related to the ridge direction. In principle, the enhancement can help visualizing the ridges. It is reasonable to use any type of directional filter in either single or multi-resolution analysis. In this work, a directional wavelet transform is applied to decompose the image into its orientation representation. Directional filtering is applied to each direction before image reconstruction. This is shown in Fig. 1 below. Unlike many filters reported in the literature, we have applied the second derivative of Gaussian filter in the DL state.

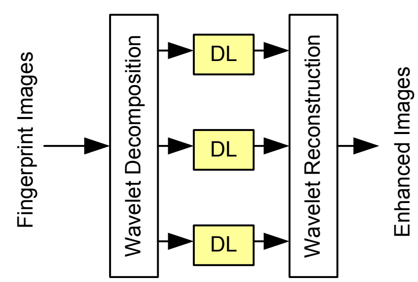

Figure 1: Fingerprint enhancement by mean of wavelet transform and directional filtering

The second derivative of Gaussian filter is the straightforward extension of the Gaussian (and also first derivative) filter. It can be applied independently in each dimension. The second derivative filter also holds the features that it depends very much on the orientation and ridge frequency. By nature, the local orientation changes quite rapidly in the core point area (sometimes also delta point), we almost cannot make it accurate. So, the result of enhancement in the ridge in such an area is fairly poor. There have been many methods attempt to solve this problem [14].

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The rest of this paper is organized as follows. In section II, the directional wavelet transform is again given in brief. Several steps in enhancement procedure in cluing transform and filtering are given in section III. In section IV, to evaluate the quality of enhanced image, we count the success in core point detection. A Poincare technique is reviewed. In section V, we demonstrate the obtained results indicating the performance of applying the directional wavelet transform second derivative filtering, and finally we concluded the paper in section VI.

II. DIRECTIONAL WAVELET TRANSFORM

Wavelet transform is suited for the analysis of transient and time varying signals. In two dimensions, a scaling function $\varphi(x,y)$, and three directional wavelets $\psi^H(x,y), \psi^V(x,y)$ and $\psi^D(x,y)$ are necessary. Each scaling function or wavelet is the product of the one dimensional scaling function φ and corresponding wavelet ψ. The four two-dimensional products produce the scaling function (1) and separable directional sensitive wavelets (2), (3) and (4).

$$\varphi(x,y)=\varphi(x)\varphi(y) \quad (1); \qquad \psi^H(x,y)=\psi(x)\varphi(y) \quad (2)$$

$$\psi^V(x,y)=\varphi(x)\psi(y) \quad (3); \qquad \psi^D(x,y)=\psi(x)\psi(y) \quad (4)$$

These wavelets measure the gray level variations for images along three directions, where $\psi^H(x,y)$ measures variations along columns (horizontal), $\psi^V(x,y)$ responds to variations along rows (vertical) and $\psi^D(x,y)$ corresponds to variations along diagonals.

In a two dimensional discrete wavelet transform, the scaled and translated basis functions are defined by:

$$\varphi_{j,m,n}(x,y)=2^{j/2}\varphi(2^j x-m,2^j y-n), \qquad (5)$$

$$\psi^i_{j,m,n}(x,y)=2^{j/2}\psi^i(2^j x-m,2^j y-n), \quad i=\{H,V,D\}, \quad (6)$$

where index i identifies the directional wavelets according to equation (2), (3) and (4). The discrete wavelet transform of function $f(x,y)$ of size $M\times N$ is formulated as:

$$W_\varphi(j_0,m,n)=\frac{1}{\sqrt{MN}}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}f(x,y)\varphi_{j_0,m,n}(x,y) \qquad (7)$$

$$W^i_\psi(j,m,n)=\frac{1}{\sqrt{MN}}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}f(x,y)\psi^i_{j,m,n}(x,y) \quad ;i=\{H,V,D\} \; (8)$$

where $i=\{H,V,D\}$, j_0 is the starting scale, the $W_\varphi(j_0,m,n)$ coefficients define the approximation of $f(x,y)$, at scale j_0. The $W_\psi(j,m,n)$ coefficients represent the horizontal, vertical and diagonal details for scales $j\geq j_0$. Here $j_0=0$ and select $M+N=2^J$ so that $j=0,1,2,..,J-1$ and $m,\ n=0,1,2,..,(2^J-1)$. Then $f(x,y)$ is obtained via the inverse discrete wavelet transform.

$$f(x,y)=\frac{1}{\sqrt{MN}}\sum_m\sum_n W_\varphi(j_0,m,n)\varphi_{j_0,m,n}(x,y)$$
$$+\frac{1}{\sqrt{MN}}\sum_{i=H,V,D}\sum_{j=j_0}^{\infty}\sum_m\sum_n W^i_\psi(j,m,n)\psi^i_{j,m,n}(x,y), \qquad (9)$$

Now the wavelets are defined by both the scaling function $\varphi(x,y)$ (Father Wavelet) and wavelet functions $\Psi(x,y)$ (mother wavelet) in the discrete time domain. The wavelet function acts as a bandpass filter whose bandwidth is reduced to half after each scaling. At the level 1, rows of $f(x,y)$ are lowpass and highpass filtered and downsampled. Then columns of the row filtered images are lowpass and highpass filtered and downsampled similarly. The two dimensional discrete wavelet transform filters the scaling approximation coefficients to construct the scale approximation and detail coefficients. The output of each level always includes: approximation, horizontal detail, vertical detail and diagonal detail. As a result, each of them is a quarter of the size of its original image. Four quarter size output sub-images $(W_\varphi, W^H_\psi, W^V_\psi, W^D_\psi)$ are the inner products of $f(x,y)$ and the 2D scaling and wavelet functions, followed by downsampling by a factor of two [7].

III. WAVELET-BASED FINGERPRINT ENHANCEMENT

One of the most widely cited fingerprint enhancement using wavelet transform and Gabor filtering. This method uses wavelet transform for demising and increases the contrast between the ridge and background (valley) by using a map function to the wavelet coefficient set, and thereafter, the Gabor filter method can further enhance the ridge using the orientation and frequency information [7, 8, 9, 10,11]. In contrast, we alternatively used the modified second derivative Gaussian filter at this state.

In our method, the Daubechies wavelet (db4) is used to decompose the fingerprint image before directional filtering. The second derivative of Gaussian filter is applied directly to each sub-image. We reconstruct the fingerprint image by using the enhanced approximation image and detail images produced in decomposition. The detail process of the enhancement are as follows.

A. Normalization

The processing of fingerprint normalization can reduce the variance in gray-level values along ridges and valleys by means of adjust the gray-level values to the predefined constant mean and variance. And normalization can remove the influences of sensor noise and gray-level deformation.

B. Ridge Frequency

In a gray scale image, repeated ridges and valley appearance of fingerprint patterns can be viewed as a sinusoidal shape with some particular frequency. We can approximate ridge frequency of the fingerprint image by dividing it into blocks (for instance, 5×5 pixels). For any local neighborhood which does not have singularities (core or delta), the gray-levels of the pixels form a sinusoidal shape along the direction orthogonal to the ridge orientation. An oriented window (oriented in the direction orthogonal to the local ridge orientation) is used to approximate this sinusoid. The inverse of the average distance between the numbers of peaks encountered is the local frequency of that block. In our case, the ridge frequency of 0.10-0.12 was measured. The obtained frequency is used in the directional filtering step.

C. *Wavelet Decomposition*

Different base function convolution with the image can have different effect in the resolution. In this paper, we select Daubechies to implement the decomposition for its sufficient information in sub-image approximation. Theoretically, we can decompose the image into sub-images at any level. However, too low resolution is not suitable because an excessive down sampling of the signal can vanish the orientation characteristic of the ridge structure. Generally, only one or two decomposition levels are selected [9, 10]. We used only one decomposition level in this experiment. The obtained decomposed images are shown below. The upper right sub-image shows horizontal component. The lower left sub-image shows vertical component while the lower right sub-image shows the diagonal component respectively.

Figure 2: Wavelet transforms decomposition one level.

D. *Orientation Field Estimation*

Since directional filtering is a direction-sensitive filter. We have to estimate the local orientation before applying the filter. Before such an attempt we apply 2D Low Pass Weiner filter (block of 5×5) to the image as a purpose of noise reduction with some effect of directional filtering.

Let $\phi(i,j)$ be defined as the *orientation field* of a finger print image. $\phi(i,j)$ represents the local ridge at pixel (i,j). In general local ridge is specified for a block rather than for every pixel. Thus, an image is divided in to a set of non-overlapping blocks, size of $w\times w$. Each bock holds a single orientation. A procedure proposed for orientation estimation is summarized below [2].

Divide the input image into consecutive (non-overlapping) blocks size of $w\times w$. We used $w=16$.

Compute the x and y magnitude of the gradients $\partial_x(u,v)$ and $\partial_y(u,v)$, at each pixel (i,j).

The local orientation of each block centered at pixel (i,j) can be estimated by:

$$\phi(i,j)=\tfrac{1}{2}\tan^{-1}\left(\frac{V_y(i,j)}{V_x(i,j)}\right) \tag{11}$$

Where, $\phi(i,j)$ is the least square estimate of the local ridge orientation of the block centered at pixel (i,j) and

$$V_x(i,j)=\sum_{u=i-w/2}^{i+w/2}\sum_{v=j-w/2}^{j+w/2} 2\partial_x(u,v)\partial_y(u,v), \tag{12}$$

$$V_y(i,j)=\sum_{u=i-w/2}^{i+w/2}\sum_{v=j-w/2}^{j+w/2} 2\partial_x^2(u,v)\partial_y^2(u,v), \tag{13}$$

E. *The Second Derivative of Gaussian Filter*

In normal fingerprint image, the sinusoidal-shaped waves of ridges and valleys vary slowly in a local constant orientation. Therefore, a band-pass filter that is tuned to the corresponding frequency and orientation can efficiently remove the undesired noise while preserving the true ridge and valley structures [14].

The 2-D Gaussian filter is mostly adopted as an image preprocessing step for image smoothing and denoising. The second derivative of Gaussian filter given in equation (15) is the straightforward extension of the Gaussian first derivative filter. This can be applied independently to each dimension.

$$sdg(x,y:\phi)=\frac{(x_\phi^2-\sigma_\phi^2)(y_\phi^2-\sigma_\phi^2)}{2\pi\sigma_\phi^{10}}\exp\left(-\frac{x_\phi^2+y_\phi^2}{\sigma_\phi^2}\right) \tag{15}$$

$$x_\phi = x\cos\phi + y\sin\phi \tag{16}$$

$$y_\phi = -x\sin\phi + y\cos\phi \tag{17}$$

This second derivative can enhance the ridge and suppress the valley for certain degree. To enhance the effectiveness of the filter we can modify equation (15) slightly by co-operating the cosine function (or plan wave) as follow:

$$sdg(x,y:\phi,f)=\frac{(x_\phi^2-\sigma_\phi^2)(y_\phi^2-\sigma_\phi^2)}{2\pi\sigma_\phi^{10}}\exp\left(-\frac{x_\phi^2+y_\phi^2}{\sigma_\phi^2}\right)\cos(2\pi f x_\phi) \tag{18}$$

Where, ϕ is the orientation of the second derivative filter, f is the frequency of a sinusoidal plane wave, σ_ϕ ($\sigma_\phi = 4$) is the standard deviations of the Gaussian envelope. x_ϕ and y_ϕ define the x and y axes of the filter coordinate frame.

F. Wavelet Reconstruction

After modifying the approximation sub-image with the second derivative of Gaussian filter, we can reconstruct the final fingerprint image.

IV. CORE POINT DETECTION TECHNIQUES

The performance of the enhancement method detailed in the previous section is evaluated by an accuracy of core point detection. Among several core point detection method, the Poincare one is fairly simple and suitable for both core point and delta point identifying. Upon the availability of estimated orientation field $\phi(i,j)$ given in the previous section, for the pixel in the sub block centered at (i,j) we can compute Poincare index, $PC(i,j)$, for particular number of point N_p [15, 16].

$$PC(i,j) = \frac{1}{2\pi}\sum_{k=0}^{Np}\Delta(k) \tag{19}$$

$$\Delta(k) = \begin{cases} \delta(k) & if\,|\delta(k)| < \pi/2 \\ \pi + \delta(k) & if\,|\delta(k)| < -\pi/2 \\ 0 & otherwise \end{cases} \tag{20}$$

$$\delta(k) = \xi(x_{(k+1)_{\mathrm{mod}\,Np}}, y_{(k+1)_{\mathrm{mod}\,Np}}) - \xi(x_k, y_k), \tag{21}$$

The number of points used in the experiment is 8. The core point should yield the Poincare index 0.5. If the Poincare index is less than –0.5 then such a block is the delta block, and the center of the block with the value of one is considered as a core point.

V. EXPERIMENT RESULTS

We used the downloaded DB1_A of FVC-2004 as database in our study. There are 800 fingerprint images captured with optical sensor, “V300” by CrossMatch. An image size is of 640×480 pixels with 500 dpi resolutions. With eyes observation, we found that 746 images hold core point. The rest do not. We fed these 746 images into the Poincare procedure for core point detection. Images with wrong core point detection are selected and fed them to the enhancement process where directional wavelet transform and second derivative of Gaussian filter are imposed before core point detection.

In our results of experiment are shown in shown in Fig. 3(a) the fingerprint enhance images seem to look better that the non-enhanced. However, with or without can yield the right core point detection. This is because the original images are fairly of good quality, and shown in Fig. 3(b) first row are original fingerprint images is very poor quality. It can be seen clearly that there are broken ridge gaps in some regions. Second row concept of our method corresponding to directional wavelet transforms. We observe that our proposed second row is improving the quality of fingerprint image obviously. Our proposed algorithm offers better results in enhancing the weak edges of ridge with suppressing the noise and healing the interrupted ridges.

The directional wavelet transform that involve the second derivative of Gaussian filter enhancement can be result in alias core points reducing as shown in Fig. 3(b). Further investigation to those 746 images, 185 images hold 2 core points (dual core) and 561 images hold single core point (many of them in this group hold left-loop and right-loop patterns). With this observation, we performed the experiment separately. The result of those with 2 cores is shown in Fig. 4(a). Moreover, the result of those with single core is shown in Fig. 4(b). We classified the obtained results into: *i)* 2-core detected correctly (no alias at all); *ii)* 2-core detected but together with some aliases, *iii)* only one core can be detected and some aliases present; *iv)* no core detected but only with aliases; *v)* no point detect at all (fail case).

From the obtained results shown in Fig. 4(a) and Fig. 4(b), we can conclude that the correct detection of the core point could be improved when directional wavelet transform that involves the second derivative of Gaussian filter enhancement is applied. With such an attempt, alias point detection could be dramatically reduced. The filter has removed noise, the ridge and valley patterns are enhanced greatly.

VI. CONCLUSION

In this paper, we propose fingerprint enhancement with directional wavelet transform that involves the second derivative of a Gaussian filter. The experiment results indicate that noise in the image could be reduced significantly. As a result, the ridge (and valley) and core point detection of fingerprint could be improved. With less computational complexity the wavelet transform can be omitted and applying only the second derivative of a Gaussian filtering. The images could also be improved but not as good as that involves the directional wavelet transform.

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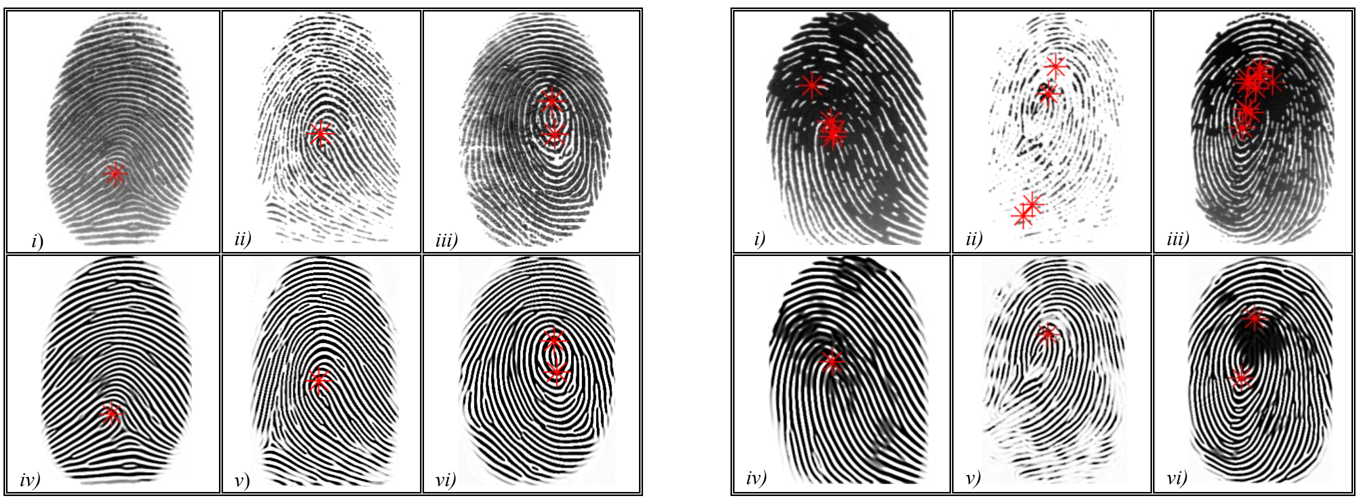
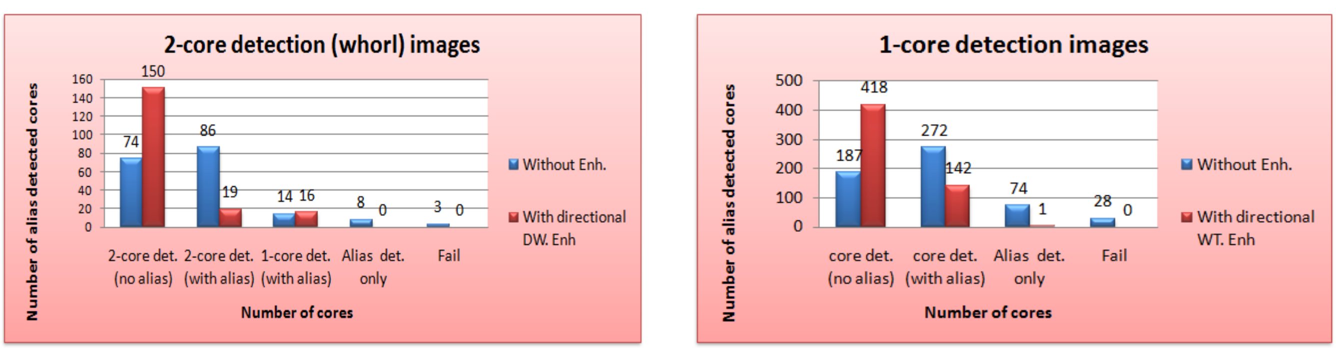


(a) (b)

Figure 3: Core point location results of some fingerprint images: first row of (a) and (b) are original images, second row are images after enhancement. Set (a) are images with fairly high quality whilst set (b) are poor quality images.



(a) (185 images hold double core points)

(b) (561 images hold single core points)

Figure 4: (a) Result of 2-core point fingerprint pattern images and (b) result of 1-core point fingerprint pattern images