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FINGER PRINT IMAGE ENHANCEMENT BASED ON ENERGY MINIMISATION PRINCIPLE

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ABSTRACT

Finger print Image Enhancement method using filter is discussed in this paper. For this purpose a system design using filters is proposed. Finger Print Images have ridge directions and ridge frequencies due to several peaks and valleys available on the surface of human finger. Both the features of the images are required to be enhanced, so two distinct filters in Fourier domain, one for enhancing ridge frequencies and other for ridge directions, have to be designed. In literature review it was found that there were some of the Finger Print Image Enhancement research work, which had been done so far, was based on ridge direction but if the image enhancement done based on ridge frequency along with ridge direction, image would be very quite clear. Selecting such image features i.e. Frequencies and directions which minimize energy function based on energy minimization principle, a very good enhanced image can be produced. This energy function for selecting above image features is defined by intensities of the images obtained by the designed filters and smoothness of image feature is measured also in proposed method. Image features obtained by the above filters which minimize energy function too, can be utilized for many applications. Net outcome of this designing is that it reduces two -third matching error rate compared with other methods.

Keywords: Finger print, Minisation Principle, Filter, Minutia, Fourier Domain.

1. INTRODUCTION

Fingerprint is a graphical pattern of ridges and valleys on the surface of human finger. It has uniqueness and permanence characteristics because of that it can be among the most reliable human characteristics that can be used in serval ways for personal identification. Due to well understood biological and biometric formation properties, it has been used for personal identification, identification of criminals by various forensic departments around the worlds since centuries. Most automatic systems for fingerprint comparison are based on minutiae matching. Minutiae characteristics are local discontinuities in the fingerprint pattern which represent terminations and bifurcations. A ridge termination is defined as the point where ridges end abruptly. A ridge bifurcation is defined as the point where a ridge forks or diverges into branch ridge. These two most prominent characteristics ridge termination and ridge bifurcation, define minutiae of fingerprint image. A good quality fingerprint image contains about 40 to 100 minutiae.

Fingerprint pattern contain narrow ridges separated by narrow valleys and these ridges flow almost parallel to each other. As defined above minutiae, it is the most important features in fingerprint matching. But the dirty images may have many pseudo-minutiae. For example finger print images may be worsened due to various kinds of noise causing cracks, scratches and bridges in the ridges as well as ink blurs. Due to this, it may make many pseudo-minutiae on fingerprint images and may cause matching error. So any effective image enhancement method for finger print matching must eliminate these pseudo-minutiae. For this reason we have to obtain correct ridge frequencies and ridge directions of finger print image and design a method to eliminate the pseudo-minutiae.

Most of the research work which has been done so for is based on ridge directions only and not much attention has been given to the frequency of fingerprint ridges. Ridge frequency feature is important in finger print filter design, because fingerprint ridges have various widths which correspond to ridge frequencies. Purpose of this research work is to provide filters which consider both ridge frequencies and ridge directions as well offer a method for enhancing fingerprint images which is suited to such filters. This image enhancement method is applied to fingerprint matching and many other forensic science applications. In experiments with rolled print images, it is found that the matching error rate is reduced by about two-thirds compared with other methods like Asai's Method.

In this paper Section 2 describes the filter system designing. Section 3 explains image enhancement methodology using the filters. Section 4 explains implementation process. Section 5 describes filtered output as net outcome of proposed method and section 6 at the end conclusion.

2. DESIGNING FILITER SYSTEM FOR FINGERPRINT IMAGES

2.1 Fingerprint Images in Fourier Domain

Fingerprint images have narrow ridges separated by narrow valleys and these ridges flow parallel to each other very nearly. The 2-D Fourier Spectrum of a small area of images shows two high peaks including DC component, which indicate significance of parallel ridges. These peaks are symmetrical to the DC components. As shown in Figure 1(c) which is 2-D Fourier power spectra of the finger print image Figure 1(a) has twin peaks. The location of the peaks in the Fourier domain provides two characteristic features of fingerprint images-the frequency and the direction of ridges flows in the area.

First features i.e frequency of ridges is shown by the distance between the peaks and the direction of the ridges is shown by the direction of the line connecting the peaks. For low quality images such as shown in Figure 1 (b) and Figure 1 (c), the peaks are not distinct. Since image in Figure 1 (b) is blurred so peaks in Fourier power spectra Figure 1 (e) is blurred also. In similar way alphabetical letter appears in images of Figure 1 (c) and as a consequences other peaks appear in Figure 1 (f) too.

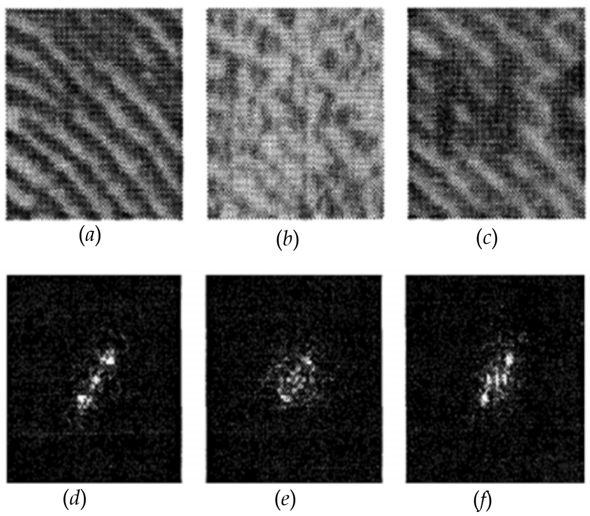

Figure 1: Fingerprint Images (*a*), (*b*) and (*c*) are Actual Images and (*d*), (*e*) and (*f*) are Fourier Power Spectra of (*a*), (*b*) and (*c*) Respectively

With the above features of fingerprint images in Fourier power spectra, it has become necessary to differentiate between fingerprint signal component and noise component and to filter the images to produce a greater contrast between the signal components and the noise components, once enhancing ridges of the fingerprint images.

2.2 Filter Design in Fourier Domain

The above cited characteristics of fingerprint image are used while designing filter in Fourier domain and characterized by ridge frequencies ρi, ridge directions $ø_j$ and several other parameters. Filter should satisfy following criteria:

1. Filters should be characterized by the ridge frequency and ridge direction as it is inherent features of fingerprint image that it has various ridge frequencies and ridge directions in each area.
2. Filters should transmit the peak spectra corresponding to ridges and attenuate the other noise spectra. This will increase the contrast between the ridges and valleys in spatial domain and reduce the noise components.
3. The band pass of a filter determines the ridge-to-valley contrast and the degree of difference between the original and filtered images. In image enhancement, a narrow band pass filter is usually effective in producing a higher ridge-to-valley contrast, if right filter selected. Wrong filter selection may produce error prone ridge connections. A band pass parameter which can be easily determined by experiment is desired.
4. The DC and low frequency component should be eliminated, since they are not relevant to ridge features such as frequencies and directions, and thus interfere with features extraction.

Based on above features required to meet out the need, following filter $H(\rho, ø)$ is designed:

$$H(u, v) = H(\mathrm{r}, ø) = H_{\mathrm{radial}}(\rho).\ H_{\mathrm{direction}}(ø) \qquad (1)$$

Here $(\rho, ø)$ shows the polar coordinates in the Fourier domain and $(u, v) = (\rho\cos ø, \rho\sin ø)$ shows the orthogonal co-ordinates. Filter $H(\rho, ø)$ is separable into ρ and $ø$ components. The ρ component $H_{\mathrm{radial}}(\rho)$ is the frequency filter corresponding to a ridge frequency and the $ø$ component $H_{\mathrm{direction}}(ø)$ is a directional filter corresponding to a ridge direction.

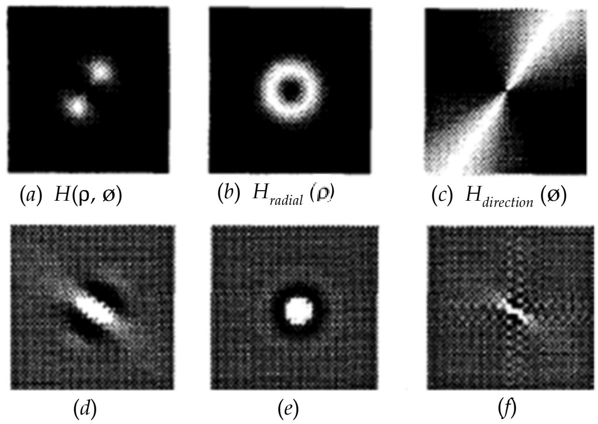

Figure 2. Fourier Output Spectra (*a*) Filter, (*b*) Ridge Filter and (*c*) Directional Filters and (*d*), (*e*) and (*f*) are Inverse Fourier Transform of Filters (*a*), (*b*) and (*c*) Respectively

Filters output in Fourier domain and Inverse Fourier transform filters output are shown in Figure 2. The designed filter is matched to ridge patterns which have the same ridge direction and ridge width as shown in Figure 2 (d), (e), (f).

Filters operations is performed under the following equations:

$$g'(x, y) = F^{-1}\,[H(u, v).\ F\,\{g(x, y)\}] \quad (2)$$

where $g(x, y)$ is an original image in the spatial domain and $g'(x, y)$ is an image filtered by filter $H(u, v)$. $F\{g(x, y)\}$ and $F^{-1}\,[H(u, v).\ F\{g(x, y)\}]$ show Forward and Inverse 2-D Fourier Transform respectively.

3. ENHANCEMENT METHODLOGY

Fingerprint filter design and fingerprint image enhancement method is based on the intrinsic characteristics of fingerprint patterns in the Fourier domain rather than spatial domain. Since Signal components of fingerprints ridges are localized in the Fourier domain. So to enhance the localized signal components and attenuate the other noise component, fingerprint filters is designed in Fourier domain one to enhance ridge direction and other for ridge direction enhancement.

Fingerprint image enhance method using the above filter is based on the energy minimization principal. An energy function for extracting local image features i.e. frequencies and directions is defined using image obtained with the above filters and assuming spatial smoothness in fingerprints. Using image features which minimizes the energy function, an enhanced image is produced from the filtered images. Methodology of fingerprint enhancement of interest is shown in Figure 3.

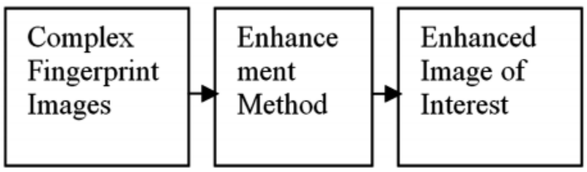

Figure 3: Enhancement Methodology

3.1 Energy Function Used In Filter Selection and Design

Energy function $E\{\rho(x, y), \varnothing(x, y)\}$ for filter selection is defined by image intensities and measures of the departure from smoothness of ridge features are as follows:

$$E\{\rho(x, y), \varnothing(\mathrm{x}, \mathrm{y})\} = -\sum_{\forall(x,y)} \rho\{x, y \mid \rho(x, y), \varnothing(\mathrm{x}, \mathrm{y})\} + \alpha_\rho$$

$$\sum_{\forall(x,y)} \sum_{(x'\,y') \in C_\rho(x,y)} D_\rho\{\rho(x, y), \rho(x', y')\} +$$

$$\alpha_\varnothing \sum_{\forall(x,y)} \sum_{(x'\,y') \in C_\varnothing(x,y)} D_\varnothing\{\varnothing(\mathrm{x}, \mathrm{y}), \varnothing(\mathrm{x}', \mathrm{y}')\} \quad (3)$$

Here $\{\rho(x, y), \varnothing(x, y)\}$ represents the parameters $(\rho_i, \varnothing_j)$ of the filter which is selected in each point (x, y). $C\rho(x, y)$ and $C\varnothing(x, y)$ are neighbours of (x, y). First term in equation (3) represents filtered image intensities, second term is measure of the departure from smoothness of frequencies and third term is measure of directions. $D\rho\{\rho(x, y), \rho(x', y')$ and $D_\varnothing\{\varnothing(x, y), \varnothing(x', y')\}$ are penalty function for the difference between each feature in neighbours given by the equations:

$$D\rho\{\rho(x, y), \rho(x', y')\} = \|\, \rho(x, y) - \rho(x', y') \,\|^2 \quad (4)$$

$$D_\varnothing\{\varnothing(x, y), \varnothing(x', y')\} = \|\, \exp[i^2\{\varnothing(x, y) - \varnothing(x', y')\}] \,\|^2 \quad (5)$$

Above energy function is minimised by the Greedy Algorithm. Values $\{\rho(x, y), \varnothing(x, y)\}$ in each point (x, y) are selected to minimise the energy while values in the other points are fixed.

4. IMPLMENTATION PROCESS

Fingerprint images may have ridges with various directions and frequencies. So it is must to select correct filters which match ridge feature at each point. With this right filter it is possible to enhance fingerprint ridges and direction effectively.

While selecting filters parameters $(\rho_i, \varnothing_j)$, effect of noise must be considered. Due to this effect of noise, filters parameters which give the most enhanced image in each area, may not respond sharply and do not always accurately represent the ridge features. This makes spatial smoothing of the image features necessary. We have explained a smoothing method for ridge direction and ridge frequency which is based on the energy minimization principle. In this method, a ridge direction in a local area has direction reliability of the direction, which is scalar. Image intensities in each local area are used as reliabilities for all directions and frequencies and features detection and smoothing processes are combined to one process.

Spatial smoothness is put into consideration to define the energy function for filter selection at each point. Such selected filters which minimize the energy function represent local ridge features and produce enhanced images.

4.1 PROCESS

As shown in Figure 4 implementation process are given below:

1. Selected Filters $\{H(\rho, \varnothing \mid \rho_i, \varnothing_j)\}$ with various centre frequencies and centre directions prepared as per diagram.
2. Input Original Image is filtered by selected and prepared filters. Prepared filter produces multi-filtered images with the various filters.
3. Local Image intensities of filtered images are calculated.
4. Filters minimizes the energy function by selected filters at each local region of the image.

5. An enhanced image is produced from the multi filtered images by using selected filters.

Frequency and Direction features in each region are expressed by filter parameters (ρ_i, $ø_j$) selected in that region as shown in Fig. 4.

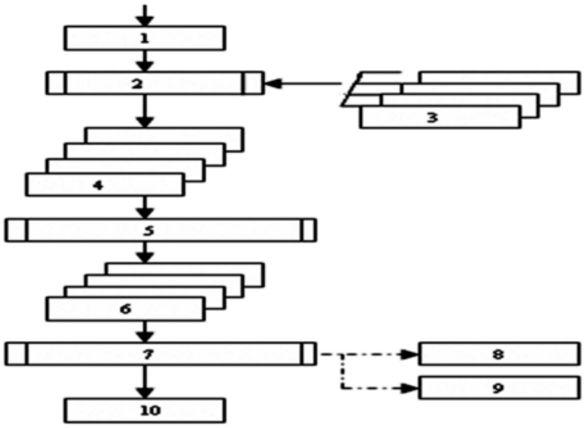

Figure 4: Image Enhancement Block Details

1. Input Image
2. Filtering
3. Filter
4. Filtered Image
5. Image Intensity Calculation.
6. Intensity Image
7. Filter Selection
8. Frequency Feature
9. Direction Feature
10. Enhanced Image

4.2 Implementing Filter Design

Due to limitation in processing time and some extent computer primary memory, number of filter bank required is limited. But it is needed that filter bank $\{H(\rho, ø \mid \rho_i, ø_j)\}$ should cover entire region of the Fourier domain where signals of Fingerprint are expected to appear. Second need for above design is that each filter should be normalized in order to make sense when comparing each filter output. So while implementing the above design first need is obtained by using large number of filters. As per second need is concerned i.e. normalization is taken into consideration by using band pass filter designed as $H_{\text{radial}}(\rho)$:

$$H_{radial}(\rho \mid \rho_i, \rho_{\min}, \rho_{\max}, \sigma_p, c) = \begin{cases} 1/z\, f(\rho \mid \rho_i \sigma_p, c), & \rho_{\min} < |\rho| < \rho_{\max} \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

where $$f(\rho \mid \rho_i, \sigma_p, c) = 1/(p+c)\exp^{\{-(\rho-\rho_i)^2/2\sigma_p^2\}} \quad (7)$$

and $$Z = \int f(\rho \mid \rho_i, \sigma_p, c)\, d_\rho \quad (8)$$

Here ρ_i and ρ_p are the centre frequency and bandwidth parameter of the filter. $\rho_{\min}$ is a parameter for low cut off frequency which suppresses the effects of low frequency unevenness such as ink blotches. $\rho_{\max}$ is a parameter for high cut off frequency which suppresses the effect of high frequency noise such as sweat gland holes and scratches in the ridges. Z is a normalisation factor for the filter output and $1/(p + c)$ is factor which suppresses relatively high frequency components. C is constant.

For the $H_{\text{direction}}(ø)$ filter is designed as follows:

$$H_{\text{direction}}(ø \mid ø_i, ø_j) = \exp\left[-\min(ø - øj + n\pi)^2/2\,\sigma_ø^2\right] \quad (9)$$

where $ø_j$ is the direction of the band pass filter and $\sigma_ø$ is the direction bandwidth parameter.

4.3 Filtering Operaton and Image Intensity

With the above designed and prepared filter original image is filtered using each filter in the filter bank $\{H(\rho, ø \mid \rho_i, ø_j)\}$. The following local image intensities are used as a measure of the filter output. The local image intensities $p(x, y \mid \rho_i, ø_j)$ of the image $g'(x, y \mid \rho_i, ø_j)$ filtered by $\{H(\rho, ø \mid \rho_i, ø_j)\}$ are calculated as follows:

$$p(x, y \mid \rho_i, ø_j) = 1/S \sum_{b=-h_y}^{h_y} \sum_{a=-h_x}^{h_x} g'\{(x+a), (y+b) \mid (\rho_i, ø_j)\}^2 \quad (10)$$

$$S = (2h_x + 1)(2h_y + 1) \quad (11)$$

5. FILTERD OUTPUT IMAGE

Figure 6 below is filtered and enhanced image of original input image of Figure 5. A comparison of thinned image by proposed method and a method developed by Asai's is shown in Figure 7. Proposed method as shown in Figure 7 can greatly reduce the effect of break in ridges. This Proposed method can reduce error rate about two-third compared with Asai's method. Reason of this improvement is that pseudo-minutiae are reduced especially from low quality of images. This is also worth while to tell that images filtered by the above method are very good and strong if we select narrow band pass filter as proposed in the method. By using such an narrower filters, images are greatly enhanced but some times make wrong ridge connection such as changes from bridges to ending or from endings to bridges. To avoid this erroneous enhancement while keeping the effect of pseudo-minutiae reduction in low quality images, it might be necessary to adopt filter selection to local image qualities of fingerprints, so that images would be filtered weakly in high quality areas and strongly in low quality areas.

Figure 5: Input Image

Figure 6: Filtered and Enhanced Image

Figure 7(*a*): Input Image

Figure 7: Filtered and Enhanced Image

6. CONCLUSION

In this Paper Fingerprint image enhancement method using filter is put for perusal. Filters are designed considering both features of fingerprint image i.e. ridge direction and ridge frequency. Due to this feature, we have proposed two filters, one frequency filter and other a direction filter and this separability of filters increases the process speed of image enhancement. Energy minimization principle used in the proposed method. Using this principle and selecting right filter bank, an enhanced image is produced from the proposed method. In Matching experiment with rolled fingerprints, it was found that this method decreases the matching error rate two-third compared to other method.

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