Fingerprint image enhancement using coherence enhanced diffusion with external and internal angles

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Abstract—An important step in the recognition of an automatic fingerprint system is the extraction of level-2 details. Level 2 details are basically the minutia points. And it includes Ridge bifurcation, termination. Accusation of the ridges and valleys from the digitized images should be accurate and perfect. The irregularities and gaps which come into existence due to the lack of accuracy in the accusation process may lead to many false level 2 details at the later stage in the analysis if not properly rectified. If the fingerprints images are not enhanced properly then they will remain composed of dust, noise etc and this may affect our unique and distinctive details and those are minutia points. To deal with this problem we are proposing a method for enhancing the ridges and valleys so that true minutia points can be extracted from it with accuracy. Our results have shown an improved performance in terms of enhancement by using coherence enhancement diffusion in a particular direction or with respect to those techniques where diffusion doesn’t take place in the specified direction.

Keywords: Image segmentation, Removing noise, Orientation map, Coherence enhanced diffusion with internal and external angles.

I. INTRODUCTION

Identification of individuals from the fingerprint matching is today’s most acceptable and authentic means. Fingerprint images are basically the impressions formed by the series of ridges and valleys on the surface of finger. Ridges are black while valleys are white and they run in parallel as shown in figure 1.

Figure 1: The 3-D view of ridges and valleys [1]

Most of the times automatic system recognition are highly desirable like security, police work etc in the identification of individuals. These automatic systems are mostly based on minutia matching. Fingerprints of an individual don’t change throughout their life and this feature or property makes them attractive for research purpose as shown in figure 2. The two main characteristics of the fingerprint images are its global and local features. Global features can be observed from the naked eye. And the local features which are also known as minutia points are the unique and distinctive feature of every individual. We have a number of types of minutia points but the most acceptable are ridge endings and ridge bifurcations [5]. Generally with the help of global features we do the classification and matching is done with the local features.

Figure 2: Revenue of biometric traits as estimated and published by International Biometric group in 2009 [1]. The fingerprint based systems both forensic and non-forensic applications continue to be the largest biometric technology in terms of the share in market, commanding almost more than 50% of the revenue.

II. WORK AND MOTIVATION

There exist many different kinds of fingerprint enhancing techniques like STFT i.e. short time Fourier transform [19] PCA i.e. Principle component analysis [20] and filtering techniques [21] but they had some drawbacks like while diffusing a particular ridge to overcome the discontinuity at that point they may destroy the surrounding information by diffusion the ridge in an uncontrolled manner and strength. So we need the diffusion in specified direction and with the extent to which the diffusion takes place should be controlled as well. And for achieving this task we are applying here CED with internal and external angels. In CED with Internal angles, the particular angles are calculated by standard equations and it calculates angles between the iterations. Whereas in CED with external angles, we are calculating the angles through some other means and we directly use those angles instead of calculating them between the iterations so that if any error occurs in angles it may not affect the other results in its correspondence. The procedure is shown in figure 3.
1) **Fingerprint Segmentation**

To separate the pattern of sinusoids i.e. scanned black (ridges) and white lines (valleys) from their background, we basically divide the image into two parts. One part is of the background area and the other portion contains information about the sinusoids (scanned black and white lines). The above narrated task can be done by making a window m x n, which is sliding on the image in the overlapping manner through iterations and in each iteration, it is calculating mean and then variance by using

\[
\text{Mean} = \frac{\sum I}{W}
\]

\[
\text{Var} = \frac{\sum (I - \text{Mean})^2}{W}
\]

Where I is the intensity of the original image.

Then we defined the threshold which is approximately an estimated average value of the boundary line which is dividing the grey level values in two major parts. We decided the value of threshold with the help of histogram of fingerprint images giving the boundary line value dividing the grey levels in two major parts i.e. background and data of our interest. We took 0.3 as threshold as shown in figure 4.

![Figure 4: Histogram of figure “101_1.tif” of FVC (DB1_B)](image)

2) **Removal of noise**

The segmented image obtained is a raw image, so we have to remove the noise for further processing. Noise is product of errors in image acquisition process that results in pixel values which do not reflect true intensities of real data of the image. We chose homomorphic Butterworth band pass filter because of the combine advantages of Butterworth band pass filter as well as of homomorphic filter. Butterworth band pass filter is a filter of Fourier domain; gives masking to pick out specific band of frequencies as well as it pick out the selective frequency band smoothly with minimum ripples. Whereas homomorphic filter with the exception of reducing noise also enhance the contrast of image by normalizing the brightness.

The procedure of implementing this filter is shown below in a flow chart:

![Figure 6: The flow diagram of the homomorphic filter.](image)
The frequencies of image contents are low, so they are placed near the origin whereas the frequencies of sharp edges and noise are high, so they are placed farther away as shown in figure 7 (a). We are interested in picking low frequencies of our actual raw image contents and we want to get rid from the noise components. So we computed the width near origin by the use of masking to pick out specific band of frequencies as shown in the figure 7(a). And by using this width’s coordinates the radius D can be calculated by using its equation:

$$D(u, v) = \left[ (u - \frac{W}{2})^2 + (v - \frac{W}{2})^2 \right]^{1/2}$$

Then we implemented the equation of homomorphic Butterworth band pass filter:

$$H(u, v) = 1 - (\text{Gamah} - \text{Gamal}) \left( \frac{1}{1 + (D(u, v) \cdot w.)/(D(u, v)^2) - (b^2)} \right)$$

Where:
- M and N = total number of pixels in image
- D (u, v) = Pixels of frequency domain in image
- Gamah = 1
- Gamal = 0
- W = width of frequency band which we have to pick out. Only in the range of W the signal is 1 otherwise it is zero.
- D = radius of the filter from center

We obtained the required filter of the same width and it makes a circle in 2D view as shown in figure 7 (b).

Then it is multiplied with the FFT of the image, and hence frequencies of our interest are picked out. Then finally the inverse Fourier transform is been applied on the image and the results are shown below in figure 8:

Figure-8 After the segmentation of the image that taken from the data base FVC (DB1_B) and image is 101_1.tif is shown in figure 8(a) and then when the noise is removed the results are shown in figure 8(b)

3) Coherence enhancement diffusion (CED) Using implicit angles

The noise removed image can’t fill up the discontinuities in ridge break so we applied another technique termed as coherence enhanced diffusion (CED). As we know that diffusion is simply the result of mixing particles until the resultant is equally concentrated. Applying this approach on enhancing fingerprints, we say that noise, cuts and bruises/ink clot or any discontinuity present in the orientation of ridge line are the low concentrated points present on the ridge whereas ridge is highly concentrated area so the result of applying diffusion filter will balance the low concentrated area (discontinuity) by blending/smoothing high concentrated area (ridge orientation) to a constant level. We can’t do smoothing or diffusion with Omni directional Gaussian filter, as it will smooth in all directions resulting the minutiae points and noise/discontinuity to get blended in ridges so we have to apply directional filters with respect to ridge orientation gradient-based method so the minutiae points or ridge pattern endings can be preserved. Our target was to complete the gap or the completion of interrupted lines. For this we use a tool which can improve the quality of image without destroying the singularities (like minutiae). This can be achieved if we consider the coherence of image by smoothing along preferred orientation instead of along 90 degree to it. This is called nonlinear coherence enhancement Diffusion which have further two types i.e. Nonlinear Scalar Diffusion and Nonlinear Tensor Diffusion. We chose nonlinear tensor diffusion because of its ability to diffuse along and across ridge without disturbing the other ridges surrounding it. This can be further explained that diffusion across the ridge, which is used for sharpening purposes i.e. preserving the edges, minutiae points and the diffusion along the ridge, is used for averaging purposes i.e. removing the noise which is coming between them. Our results will be best if we diffuse along and across the ridge simultaneously or one after other. For that we use a scale or a tuning parameters in diffusion tensor through which we can control both diffusion along and across direction. The equation of diffusion tensor is:

$$D = \begin{pmatrix} d_{11} & d_{12} \\ d_{12} & d_{22} \end{pmatrix} = R \begin{pmatrix} cu & 0 \\ 0 & cv \end{pmatrix} R$$

This equation will formulate an ellipse moving on the ridge pattern accordingly, and perform coherence diffusion. Where R is the rotation matrix which deals with the orientation of ellipse whereas cu and cv are the scaling parameters that deals with the transformation of major and minor axis of the ellipse. This can be described in the figure below:
Figure 9: A low pass filter which adapts itself with the ridge orientation i.e. it rotates as the specified input angle changes and performs diffusion along the ridge for enhancement purpose and across the ridge for preserving minutiae points.

The structure tensor which implicitly calculates the angles for Diffusion tensor matrix [14] is given by:

\[ S = \begin{pmatrix} s_{11} & s_{12} \\ s_{12} & s_{22} \end{pmatrix} = \begin{pmatrix} Gxx(x,y,\sigma) & Gxy(x,y,\sigma) \\ Gxy(x,y,\sigma) & Gyy(x,y,\sigma) \end{pmatrix} \]

Where, \( Gxx(x,y,\sigma) \), \( Gxy(x,y,\sigma) \) and \( Gyy(x,y,\sigma) \) represents the Gaussian derivative filters.

We computed Eigen values and Eigen vectors [14] of structure matrix \( S \):

\[ \lambda_1 = \frac{1}{2}(s_{11} + s_{22} + \alpha) \]
\[ \lambda_2 = \frac{1}{2}(s_{11} + s_{22} - \alpha) \]

Where:

\[ \alpha = \sqrt{(s_{11} - s_{22})^2 + 4s_{12}^2} \]
\[ C_u = \max((0.01, 1 - e^{-(\lambda_1-\lambda_2)^2/\lambda^2})) \]
\[ C_v = 0.01 \]

Hence all the parameters are calculated. We can conclude the Coherence Enhancement Diffusion is the combination of the local orientation measurement using the Eigen values of structure tensor and eigenvectors of Diffusion tensor and the results are shown below:

<table>
<thead>
<tr>
<th>Noise removed input image</th>
<th>Enhanced image via CED with implicit angles</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

![Image](image3.png)

Figure 10: The input image with the noise removal figure 10 (a) and when we applied the coherence enhancement diffusion with implicit angles then the results has been shown in the above figure 10(b)

4) Coherence enhancement diffusion (CED) using explicit angles

Another method we have applied is by calculating explicit angles through orientation map. The angles are the most important part through which an image can be recovered or enhanced and we calculated them using ridge orientation in orientation map. These explicitly calculated angles are further used to achieve enhancement through coherence edge enhancement method.

The estimation of orientation field is carried out for which we did not compute local ridge orientation at each pixel but instead we used a window of odd size sliding over the whole image. The method we used to obtain local ridge orientation is based on computation of gradients in x, y and xy direction as gradients or derivatives provide a slope at every maximum pixel intensity change. In return gradient phase angles obtained is orthogonal to the edge that crosses in the region of image window. The gradient-based method was introduced in 1987 by M.kass and A. Witkin, [8] and many researchers adopted it like [9],[10],[11],[12]. In general how the orientation map looks like is shown below in figure 11.

![Image](image4.png)

Figure 11: The orientations map of a finger print image.

We computed the x and y gradient component by convolving horizontal and vertical extended Sobel kernel filter on 3*3 neighborhood patches/window of image in overlap masking pattern then angles are being doubled as purposed in [8].

**Gradient in x direction = Gx = 1/32[3 10 3;0 0 0;-3 10 3]*image**

**Gradient in y direction = Gy = 1/32[3 10 3;0 0 0;-3 10 3]*image**

The angles are being doubled and lengths are being squared. The basic theory behind the discontinuity and non-linearity is that the opposite gradient vectors cancel each other when calculated in a neighborhood due to circularity of angles [8], although they are directing towards the same orientation so the angles are doubled and lengths are being squared before finding variance and co variances and hence they direct towards the same direction and reinforce each other. Then variance and co variance is calculated using these equations [13]:

\[ G_{yx} = \sum_{w} G_{x}G_{y} \]
\[ G_{xx} = \sum_{w} G_{x}^{2} \]
\[ G_{yy} = \sum_{w} G_{y}^{2} \]

In the next step gradient component vectors in x, y and xy directions are being smoothed by passing through from Gaussian filter according to approximated image window size and approximated ridge width.

The angles are converted into Polar from Cartesian Co-ordinate system for the purpose of doubling of angles and then they are converted back into Cartesian Co-ordinate system. Using trigonometric identities, the squared gradient vectors in x and y directions are represented in Cartesian Co-ordinate system and those equations are shown below:

\[ G_{x} = G_{xx} - G_{yy} \]
\[ G_{y} = 2G_{xy} \]

And then finally the average ridge valley directional angle orthogonal to ridge orientation [13] is calculated using the equation that is shown below:

\[ \theta(ij) = 90 + \frac{1}{2} \arctan(2G_{xy}, G_{xx} - G_{yy}) \]

As tan is active in first and fourth coordinate, the above average ridge valley directional angles are calculated according to these conditions:
The results are shown below:

\[
\begin{align*}
\zeta(x, y) &= \begin{cases} 
\tan^{-1} \frac{y}{x} & x \geq 0 \\
\tan^{-1} \frac{y}{x} + \pi & x < 0 \text{ and } y \geq 0 \\
\tan^{-1} \frac{y}{x} - \pi & x < 0 \text{ and } y < 0
\end{cases}
\end{align*}
\]

The results are shown below:

<table>
<thead>
<tr>
<th>Noise removed input image</th>
<th>Orientation Map</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Figure 12: The image after the noise removal is shown in figure 12 (a) and the image with the orientation map is shown in figure 12 (b)

After computing this orientation map, this is given in CED using the previous diffusion tensor and structure matrix. And then the Eigen values, Eigen vectors, major and minor axis and scaling parameters are estimated through it. The results are:

<table>
<thead>
<tr>
<th>Noise removed input image</th>
<th>Enhanced image via CED with explicit angles</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Figure 13: The image with noise removal has been shown in figure 13 (a) And CED with explicit angels has been shown in figure 13 (b)

III. COMPARISON OF RESULTS

The minutiae points are further extracted to check the discontinuities and for doing comparison between both methods as shown below:

![Image](image5.png)

The ridge enhancing filter i.e. Coherence Enhanced Diffusion enhanced the image effectively in the results. But the comparison of global externally calculated angles with internally calculated Gaussian gradient angles enhanced our research work. We have come across that the externally calculated angles gave us a better result in terms of preserving minutiae points which is our basic concern as they are the core features used in identification. Whereas Gaussian gradients internal angles gave a better smoothing, it interpolated the broken ridges and removed noise very well but it can’t preserve minutiae points effectively as it can be clearly seen in figure 14.

The reason behind is this that Gaussian gradients calculated angles internally using blocks of the image. As we know that gradients are basically derivatives and derivatives are very much noise sensitive. So by doing the operation within blocks of the image, the increased noise disturbed the minutiae points and they cannot get preserved.

Whereas the external angles are calculated globally without applying the block scheme so the noise can be dealt properly as it get ignored and in return gave us preserved minutiae points. As it can be seen clearly in figure 14, minutiae estimation algorithm could not work well with Coherence enhanced diffusion with internal angles. First of all it could not give all the minutiae points present in the image. Secondly it misinterpreted the minutiae points it got. As we can see in figure 14(a) it estimated the ridge ending as bifurcation because of extra smoothing. Whereas in figure 14 (b) we can clearly notice that the ridge ending is clearly marked.

So it gave a conclusion that the coherence enhanced diffusion with external calculated angles gave us less smoothed but minutiae points preserved result whereas internal angles [14] could not preserve it.

IV. CONCLUSION

In Finger print image enhancement, accurate orientation field i.e. external angles have direct impact on enhancement of noisy images. Results with external angles can also be further improved if we generate accurate angles for much better orientation map which can be used to improve the results of coherence enhancement diffusion. This can improve the coherence enhanced results with the help of providing more reliable and accurate external angles and setting...
accurate values of Cu, Cv of diffusion tensor as they are our tuning parameter to select diffusion along or across the ridge.

V. REFERENCES


[19] Fingerprint Enhancement Using STFT Analysis by Sharat Chikkerur,Alexander N. Cartwright Venu Govindaraju], PCA i.e. principle component analysis [Fingerprint Image


