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The improved fingerprint enhancement algorithm research based on embedded environment

Feng Wang*, Bo Han, Tian Peng Han
School of Computer and Information of Fu Yang Teachers College,
An Hui Fu yang 236037
E-mail : wffync@fync.edu.cn

ABSTRACT

For the problem that existing fingerprint enhancement algorithms computational complexity which is inappropriate in embedded environment, the author proposes polyline large template enhancement algorithm. The algorithm has the following steps: Firstly, we decompose the two-dimensional Gabor function in vertical direction, and combine Bresenham linear fast generate algorithm to realize a one-dimensional Gabor fast enhancement. Secondly, we improve one dimensional fast Gabor template by using a polyline large template method. The algorithm not only improve the enhancement effect in the serious curvature area, but also get a better connection for broken line. Experiments use FVC2004 fingerprint database to validate, the experimental results demonstrate the effectiveness of the algorithm.

KEYWORDS

Fingerprint enhancement; Polyline large template; Embedded environment.

INTRODUCTION

With fingerprint recognition technology development, fingerprint identification products are constantly being used in various authentication fields. More and more manufacturers have begun to develop a variety of fingerprint capture devices which played a good role in promoting the development of fingerprint recognition technology[1,2]. Automated Fingerprint Identification System can be online or embedded, on-line fingerprint identification system running on the PC whose performance is generally higher, so it can support large-scale fingerprint matching, typical applications such as fingerprint attendance. There is another applications beside PC that we call embedded fingerprint identification system[3] With the development of large scale integrated circuit technology and the handling capacity of microprocessors constantly improvement, so all make fingerprint identification system running on the embedded environment possible. Typical applications include fingerprint lock, fingerprint access control system, fingerprint phone, PDA, etc. Relative to the online fingerprint identification system, the embedded fingerprint identification system has a wider application space, so it has become a hot issue in the field of fingerprint identification[4].

Embedded fingerprint identification system has its own characteristics and some practical problems, such as real-time, stability, security and reliability. Real-time refers to response speed of the system, fingerprint identification system extracts features from the input fingerprint image and matches with stored fingerprint features that requires a lot of computing. Generally, fingerprint identification system needs to give matching results within three seconds, so in addition to high-performance CPU for the hardware design, it is necessary to improve the fingerprint recognition preprocessing, matching and retrieval speed for software.

Fingerprint enhancement is a key part in automatic fingerprint identification system (AFIS), its aim is to eliminate image noise and highlight local ridge structure, that is processed to use a certain algorithm which make the ridge structure clear, highlight. Fingerprint enhancement technique is an important part of the system, it can improve the quality of the fingerprint, connect broken line, remove adhesions, improve the success rate of the fingerprint recognition system.

Currently there are a lot of fingerprint enhancement algorithms, such as Gabor filter enhancement method[5], Fourier filter fingerprint enhancement algorithm[6], based on knowledge, nonlinear diffusion pattern, multi-scale filtering methods and so on. In these algorithms Gabor enhancement has a strong advantage by virtue of its frequency and directional selectivity, so it is the most common fingerprint enhancement algorithm. Daugman proposed a two-dimensional Gabor filter theory, and pointed out that the two-dimensional Gabor filter can simultaneously obtain the best resolution in the frequency domain and direction[7,8], L.Hong applied Gabor filter in the fingerprint enhancement and made good enhancement effect[9]. Since then, many researchers proposed some methods for improved Gabor enhancement effect[10]. However, these algorithms time consuming and computing complexity are relatively large, so that they are not suitable for embedded system.

For the problem that existing fingerprint enhancement algorithms computational complexity which is inappropriate in embedded environments, the author proposes polyline large template enhancement algorithm. The algorithm has the following steps: Firstly, we decompose the two-dimensional Gabor function in vertical direction, and combine Bresenham linear fast generate algorithm to realize a one-dimensional Gabor fast enhancement. Secondly, we improve one-dimensional fast Gabor template by using a polyline large template method. The algorithm not only improve the enhancement effect in the serious curvature area, but also get a better connection for broken line. Experiments use FVC2004 fingerprint database to validate, the experimental results demonstrate the effectiveness of the algorithm.

Before fingerprint image enhancement we need to preprocess fingerprint image including normalization, image segmentation, ridge frequency and the directional field acquisition. After obtaining the basic parameters, we construct a one-dimensional Gabor template in both directions, and combine Bresenham algorithm to find a series of points product plus and finally get the enhanced image.

PREPROCESS

Normalization

Because the quality of fingerprint images captured by fingerprint scanner is influenced by many factors, such as dryness and wetness of finger, cleanness of scanner and dryness and wetness of the weather, we firstly use normalization to remove the effects of sensor noise and finger pressure difference[11]:

$$G(i,j) = \begin{cases} Mean_0 + \sqrt{\dfrac{Var_0 * \left(I(i,j) - Mean\right)^2}{Var}}, if I(i,j) > mean \\ Mean_0 - \sqrt{\dfrac{Var_0 * \left(I(i,j) - Mean\right)^2}{Var}}, otherwise \end{cases} \quad (1)$$

$$Mean = \frac{1}{M * N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} I(i, j)$$
$$Var = \frac{1}{M * N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (I(i, j) - Mean)^2 \quad (2)$$

where Mean0,Var0 are the desired mean and variance value, we can conclude that normalization improve the full image contrast and not change fingerprint valleys quality.

before normalization after normalization

Figure 1 : Normalization

Background segmentation

General method for image segmentation is based on the gradation characteristic of the image, but the method is not applicable to the strong texture directional fingerprint image. There is a representative Fingerprint orientation field whose segmentation results depends on reliability of the block pattern, while it is not sensitive to image contrast. For the ridge discontinuous, single gradation direction, rapid change direction and so on, it is often difficult to obtain satisfactory results.

Currently a single characteristic fingerprint segmentation algorithm is difficult to achieve the desired results. To improve segmentation accuracy, by the use of the complementarity between the various segmentation algorithm, Fusing multiple features to determine is a feasible solution. However, the use of multiple features segmentation algorithm results may coincide with each other, but it also has a lot of uncertainties. The DS evidence theory use interval estimation method by depicting uncertainty information, which shows a great deal of flexibility in distinguishing uncertainty information. When different classifiers results are conflicted with each other, it can makes the conflict resolved by "hang" on all targets confidence.

Based on the above analysis, we use image segmentation method based on DS evidence theory[12]. Firstly, according to the characteristics of the fingerprint image, we select the contrast and texture the two effective characteristics to be classified, then the overall verdict is implemented based on the each classifier judgment by using the DS evidence. The algorithm is simple and practical and has an high segmentation accuracy.

Computing orientation field

Fingerprint orientation field reflects true texture features of the fingerprint image, indicating the fingerprint ridge direction. Currently there are a lot of methods to obtain fingerprint orientation field, we use the literature[13] method to compute and smoothed. The steps are as follows:

(1)we divide the fingerprint image into w * w blocks of size and calculate the gradient of each pixel which is calculated to use Sobel operator (w=8).

(2)calculating each block direction as the formula

$$V_x(i, j) = \sum_{i-\frac{W}{2}}^{i+\frac{W}{2}} \sum_{j-\frac{W}{2}}^{j+\frac{W}{2}} 2\partial_x(u, v)\partial_y(u, v) \quad (3)$$

$$V_y(i, j) = \sum_{i-\frac{W}{2}}^{i+\frac{W}{2}} \sum_{j-\frac{W}{2}}^{j+\frac{W}{2}} \partial_x{}^2(u, v) - \partial_y{}^2(u, v) \quad (4)$$

$$\theta(x,y)=\frac{1}{2}\arctan\frac{V_y(i,j)}{V_x(i,j)} \quad (5)$$

Where θ(x,y) is perpendicular to the main direction of the W * W window Fourier frequency.

(3)Filtering: The above orientation field in some areas is not accurate enough due to noise, the impact of disconnection. According to fingerprint ridge changing slowly characteristics (except pattern area), we use a low pass filter for smoothing orientation field. Firstly, we use formula $\phi_x = \cos(2\theta(i,j)), \phi_y = \sin(2\theta(i,j))$ to transform the orientation field into a continuous vector field, the following is filtering:

$$\phi'_x(x,y)=\sum_{-\frac{h}{2}}^{\frac{h}{2}}\sum_{-\frac{h}{2}}^{\frac{h}{2}}\left(l(u,v)\phi_x(i-uh,\ j-vh)\right) \quad (6)$$

$$\phi'_y(x,y)=\sum_{-\frac{h}{2}}^{\frac{h}{2}}\sum_{-\frac{h}{2}}^{\frac{h}{2}}\left(l(u,v)\phi_x(i-uh,\ j-vh)\right) \quad (7)$$

h is a two-dimensional low-pass filter, l (u, v) is the weight value of each point of the filter. Finally we get a smooth block orientation field below:

$$O(i,j)=\frac{1}{2}\arctan\frac{\phi'_y(i,j)}{\phi'_x(i,j)} \quad (8)$$

Ridge frequency

Ridge frequency is an important parameter for the fingerprint enhancement. The ridge distance is the length between the two fingerprint ridge distance whose reciprocal is called ridge frequency, it is an inherent property of a fingerprint image. Ridge frequency can be used in fingerprint enhancement, fingerprint classification. In this paper, the ridge distance is estimated by direction of the window[14].

TRADITIONAL GABOR ENHANCEMENT ALGORITHMS

Gabor function

After completing the above steps, we can construct a Gabor function. Gabor filter can separate from adhesions fingerprints and reconnect broken fingerprint due to the good frequency domain and directional selectivity. L.Hong etc. firstly applied it on the fingerprint enhancement and achieved good results[15]. The following is a two-dimensional Gabor function:

$$G(x,y,\theta,f_0)=\exp\left\{-\frac{1}{2}\left(\frac{x_\theta^{\ 2}}{\sigma_x^{\ 2}}+\frac{y_\theta^{\ 2}}{\sigma_y^{\ 2}}\right)\right\}*\cos(2\pi f_0 x\ ) \quad (9)$$

$$\begin{bmatrix}x_\theta\\ y_\theta\end{bmatrix}=\begin{bmatrix}\sin\theta & \cos\theta\\ -\cos\theta & \sin\theta\end{bmatrix}\begin{bmatrix}x\\ y\end{bmatrix} \quad (10)$$

f_0 is ridge frequency, x, y are the coordinates of corresponding two-dimensional template, θ is ridge orientation, σ_x, σ_y respectively are the Gaussian enveloping constant along the horizontal axis and the vertical axis. x_θ, y_θ respectively are the distances between certain element of enhanced template and the center line.

defining formula(10) as $\sigma_x=\sigma_y$, defining formula (11) as θ=0

$$G(x, y, f_0)_{\theta=0} = \exp\left\{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^{\ 2}}\right)\right\} * \exp\left\{-\frac{1}{2}\left(\frac{y^2}{\sigma_y^{\ 2}}\right)\right\} * \cos(2\pi f_0 y) \quad \textbf{(11)}$$

the above formula is divided into the following forms:

$$G(x, y, f_0)_{\theta=0} = G_L G_B$$

$$G_L(x, f_0) = \exp\left\{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^{\ 2}}\right)\right\} \quad \textbf{(12)}$$

$$G_B(y, f_0) = \exp\left\{-\frac{1}{2}\left(\frac{y^2}{\sigma_x^{\ 2}}\right)\right\}\cos(2\pi f_0 y) \quad \textbf{(13)}$$

G_L (x, f_0) and G_B (y, f_0) respectively are along the ridge directional low-pass filter and the vertical ridge directional band-pass filter. The horizontal filter corresponds to the ridge directional pixels weighted average so it can smooth the fingerprint and play the role of a broken connection. The vertical filter enable the ridges and valleys higher contrast by making around the current point positive, a little further negative.

Selecting convolution points

For the one-dimensional filter how to select the image point with filter template convolution is the key because it affect enhancement performance and speed. The traditional methods including two-dimensional linear interpolation, two-dimensional polynomial interpolation, but these methods require some additional multiplication and division, increasing the complexity of the calculations. In order to maximize the speed of operation and enhancement performance, we use Bresenham fast line drawing algorithm to select the desired pixels, these points are the most close to the line so it get a good enhancement.

Bresenhaln algorithm is considered one of the most effective methods to generate a straight line whose incremental idea can find pixels of the closest line. Given the starting point and endpoint of the line, it is quick and efficient to use only addition and subtraction to finish drawing the line. We use Bresenham algorithm to select the image point quickly[15].

IMPROVED ALGORITHM-POLYLINE LARGE TEMPLATE

A two-dimensional Gabor filter can be considered as a combination of the horizontal directional low-pass filter and the vertical directional band-pass filter. The traditional Gabor enhancement can't handle well serious curvature points and broken line, if you want to enhance the fingerprint pattern area, it is necessary to adopt a small Gabor template to decrease level error, so the effect of a broken connection is bad. But if you want to connect broken line that it is necessary to increase the level of intensity, so the fingerprint pattern area enhancement will exist deviations. In order to take into account the both, we can adaptively adjust the horizontal template according to the ridge curvature change, the horizontal direction as much as possible to get useful points for smoothing so that it can achieve good smoothing effect. Gabor filter is constructed along the horizontal low pass filter template and the vertical band-pass filter template according to the formula (12), (13). Through the analysis we know that the vertical template is related to ridge frequency, the size of the template bound by the size of the ridge frequency, the horizontal template is not limited to the ridge frequency and can connect broken fingerprint. so we propose an improved method based on the above analysis, namely polyline large template method.

The fingerprint orientation field well maintained local ridge trend, its diversification is relatively small in the ridge smoothing place while it varies more violent in the ridge pattern area, and the orientation field generally reflects ridge trend. This paper use Bresenham algorithm and changeable orientation field to simulate the ridge trend to select curved line points. We use polyline large template algorithm that it can enhance well on the pattern area, while the broken line has also a very good connection effect. Algorithm is described as follows:

(1) Image segmentation, normalization, preprocessing

(2) Computing block orientation field (block 8 * 8) and then smoothing it, orientation field depicts accurately the general ridge trend after smoothing.

(3) We construct respectively horizontal linear template and the vertical linear template (twice the length of the ridge width)

(4)According to orientation field diversification we select some pixels to take the convolution with the template. We obtained the horizontal and vertical directional templates according to Gab-or function, according to Bresenhaln algorithm we find some pixels to convolution with template, if the difference is greater than a certain threshold between the current pixel orientation field and the preceding pixel orientation field, and then the current pixel direction as the direction continue to look for the next pixel.

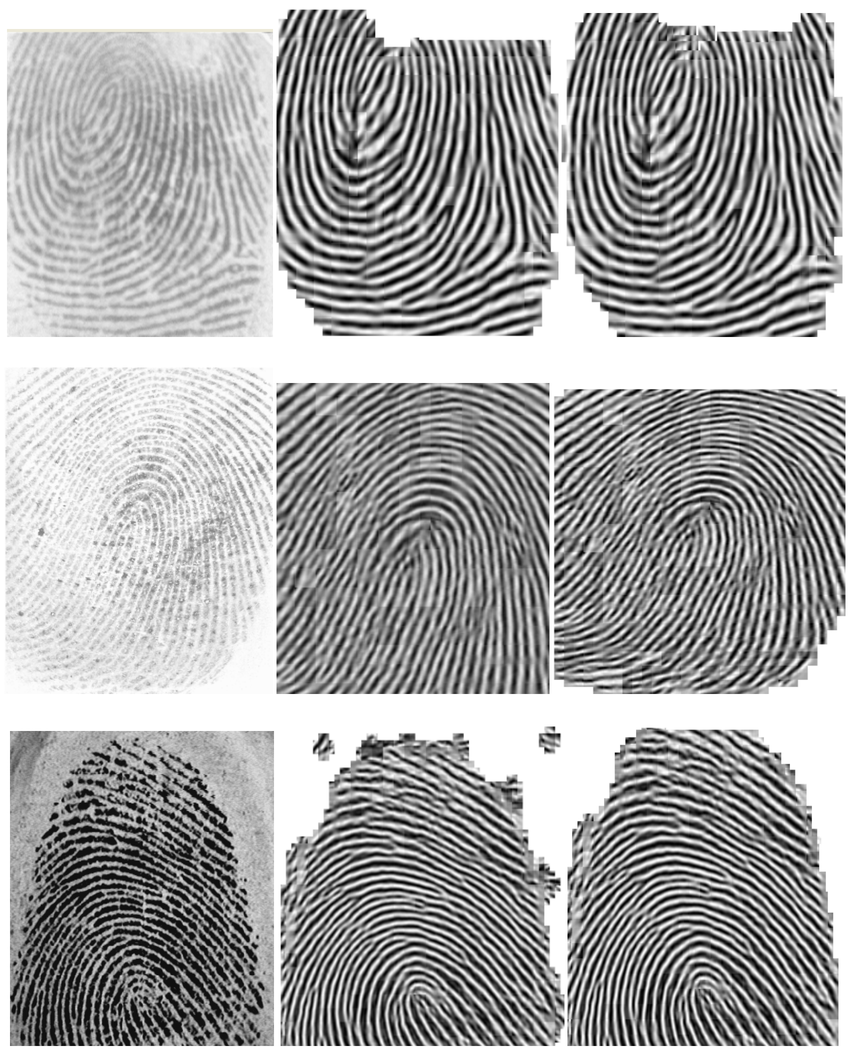
Polyline large template can strengthen a broken connection, while use polyline to approach curved ridge and get a good reinforcing effect, especially near the pattern area.

RESULT AND DISSCUSS

To test the proposed method performance, experiments select some typical images whose purpose is to show the different quality image enhancement effect in different ways; then count the average running time and analysis the time complexity of the algorithm. The experimental data uses the public data FVC2004,which contains four libraries DB_1, DB2_a, DB3_a and DB4_a.

To compare visually different methods enhancement effect, we select respectively the good quality image, the dried fingerprint and the poor resolution image, as shown in Figure 3-2. The results show the polyline template enhancement effect is better than the fast Gabor because it uses more neighborhood information.

Compared to the fast Gabor enhancement algorithms, polyline large template method has a better connection shown in Figure 3-2 which make pattern area structure more clearly. Through testing the fingerprint images of different sizes, we count the average running time of each algorithm, and the different enhancement algorithm takes average time as shown in TABLE 3-1.



(a) Original image (b) Fast Gabor enhancement (c) polyline Large template

Figure 3-2 : Enhancement effect contrast

TABLE 3-1 : Algorithm time-consuming comparison

Image size	Dimensional Gabor	Polyline template
300*300	56	50
320*320	88	72
296*560	274	184
512*480	564	310

Through experiments we can conclude that the two-dimensional Gabor template has good performance because of the relatively abundant information. We propose polyline large template enhancement algorithm which is combined with Bresenham algorithm. Performance is better than traditional Gabor enhancement algorithms because of making use of more useful information.

Thus, selecting the appropriate pixel neighborhood enhancement is very important.

CONCLUSIONS

The algorithm can change the shape and size of the template in accordance with neighborhood pixel condition based on one-dimensional Gabor enhancement so as to accommodate the ridge enhancement of different locations. Fingerprint enhancement algorithm improves the speed, ensures the enhancement effect, and it is able to handle disconnection and pattern area. Results show the effectiveness of the algorithm. In addition, how to determine more accurate involved convolution pixels is very important, it is the direction of our next-depth study.

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