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# ALGORITHM ON EMBEDDED FINGERPRINT IDENTIFICATION SYSTEM

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**ABSTRACT**

Fingerprint identification is divided into fingerprint pretreatment, fingerprint feature extract ion and a fingerprint match. Based on embedded technology and fingerprints processing algorithms, embedded automatic fingerprint identification system fingerprint identification of various processes study the algorithm, this paper expounds the characteristics of various algorithm with using details.

Key Words: Embedded Fingerprint; Identification System; Algorithm

## 1. INTRODUCTION

Fingerprint identification technology is a kind of important biological identity recognition technology; it is also the most mature branch of biological recognition technology development. Comparing with other biometric identification technology, fingerprint identification technology has high efficiency, low cost, convenient collection etc advantages. Now the development of the fingerprint recognition system becomes faster and faster, in order to meet the needs of the society, the development and application of embedded system also should follow closely the development direction of fingerprint identification technology to optimize the fingerprint identification algorithm, and develop with high recognition rate, fast processing speed, good scalability and low cost embedded platform, which has a broad market prospect and research value.

## 2. FINGERPRINT ALGORITHM PROCESS

### 2.1 Hardware features

This system adopts embedded Linux as software platform, hardware platform has the following several parts: FPS200 fingerprint sensor, ARM CPU LPC2214 as the main embedded chip, program memory, data storage and control circuit. From the perspective of hardware, embedded processor is the core part of embedded system, and its peripheral equipment constitutes the embedded system hardware parts. The micro processor chip with ARM structure, its kernel is very small, the chip performance is high, and power consumption is low.

The system structure is shown in figure 1.

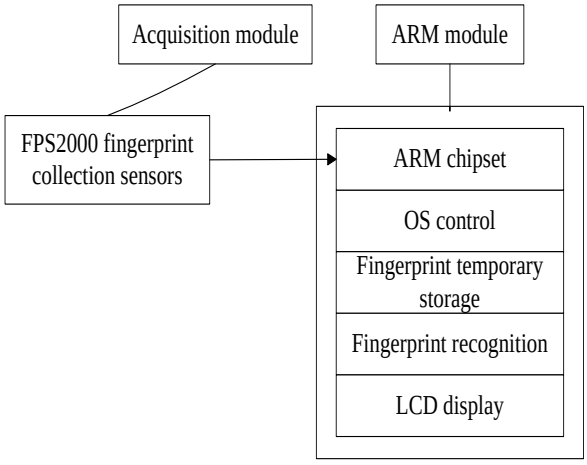


*Figure 1. Construction of embedded fingerprint system*

### 2.2 Fingerprint features

The rough and uneven grain of inside the finger skin can form various kinds of design, breakpoint, and intersection and so on. These different grains are fingerprint, from the physical point of view, grain is the raised part (ridge) of finger skin,

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between the lines, which is part of the recess (valley). There are two levels of structure characteristic:

Global features: The global feature description is the global grain structure of fingerprint, specific classification is as follows: bow type (Arch): plain arch type (plain arch), tented bow type (tented arch); loop type (loop): radioactive loop type (radial loop), ulna shape loop (ulnar loop); bucket type (whorl): plain bucket type (plain-whorl), central symmetry loop (central pocket loop), double loop type (double loop); mixed type.

Local features: endpoint and bifurcation point are the most commonly used fingerprint local structure characteristics, also known as the detail characteristics. An example using this kind of feature is a details-coordinate model, which is using fingerprint minutiae, coordinates and other features to describe the fingerprint.

### 2.3 Algorithm process

Fingerprint recognition algorithm mainly does the fingerprint image preprocessing, fingerprint image feature extraction, and later fingerprint image feature matching these three processes to collected fingerprints:

(1) Fingerprint image preprocessing: the new image just obtained has a lot of noise, this is mainly due to the usual work environment, for instance, finger is dirty, fingers have incised wound, scar, mark, dry, wet or tear, etc. It is not easy to get clear and clean image, which needs to do preprocessing to fingerprint images. The preprocessing of fingerprint image refers to the processing of the collected fingerprint image, and makes the processed image clearly do fingerprint feature extraction process. Image preprocessing steps can generally be divided into image normalization, direction diagram calculation, image enhancement, image binarization and image refining.

(2) The feature extraction of fingerprint expresses the trend of grain, grain line breakpoints, crossing points of grain image, these features of fingerprint uniqueness in the form of the numerical expression. In order to keep the comparison accuracy, feature extraction algorithm should extract the features as much as possible, and at the same time, filter the false features by all sorts of causes.

(3) Fingerprint matching is the comparison between fingerprint characteristic value with new input and fingerprint characteristic value stored in fingerprint storehouse, and find out the most similar fingerprint as the output recognition results. That is the fingerprint verification/identification process. The specific process is the following figure 2.

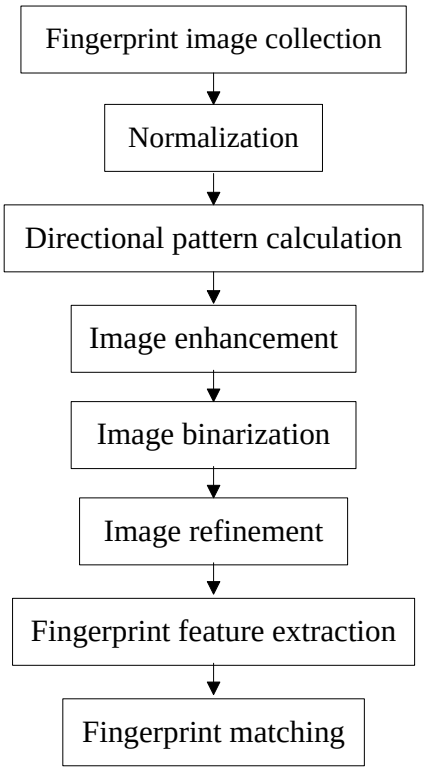


*Figure 2. Algorithm flowchart*

## 3. RESEARCH OF THE PRETREATMENT ALGORITHM

### 3.1 Normalization

The normalization of image is also called image background separation; that is separating the image background and foreground image. The image prospect is fingerprint image, which contains all effective information of fingerprint image, and in the background, there includes many noises which block the effective information. Normalization is processed according to the following expressions:

$$N(i,j)=\begin{cases} M_0+\sqrt{\dfrac{V_{AR_0}(I(i,j)-Mean)^2}{V_{AR}}} & I(i,j)>M \\ M_0-\sqrt{\dfrac{V_{AR_0}(I(i,j)-Mean)^2}{V_{AR}}} & otherwise \end{cases} \quad (1)$$

Among them, $I(i,j)$ is gray value of point $(i,j)$, $Mean$ and $V_{AR}$ is the gray mean and variance of original image, $M_0$ and $V_{AR_0}$ is expected gray mean and variance.

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*Figure 3. The comparison after image normalization*

**3.2 Direction pattern calculation**

Fingerprint is a kind of texture image formed between ridge line and grain line, which has a very strong directivity, and the calculation of direction pattern has very important role to a series of fingerprint image processing and recognition operation, such as fingerprint segmentation, enhancement, binarization, thinning and feature extraction and fingerprint classification and so on. Calculating pattern is used to implement the fingerprint image enhancement, so calculating pattern is an important step, it directly affects the effect of image enhancement, and the wrong direction pattern will eventually lead to wrong image enhancement.

**3.2.1 Normalization treatment**

Before the calculation of fingerprint pattern, the fingerprint image is at first to do normalization. The gray value of normalized image at point $(i, j)$ is confirmed by the following formula:

$$G(i,j) = M_0 + \sqrt{\frac{\sigma_0^2 (G'(i,j) - M)^2}{\sigma^2}} \quad G'(i,j) \geq M \tag{2}$$

$$G(i,j) = M_0 - \sqrt{\frac{\sigma_0^2 (G'(i,j) - M)^2}{\sigma^2}} \quad G'(i,j) < M$$

Hereinto , $G'(i, j)$ represents the gray value of fingerprint images at point $(i, j)$ , $M$ and $Q_0^2$ respectively represent mean and variance of expectations.

**3.2.2 Calculation of fingerprint direction field**

The fingerprint image is divided into blocks with $W * W$ , for fingerprint images with 500 dpi, the general choice of $W$ is 16. The gradient of calculation point $(i, j)$ is $\alpha_x(i, j)$ 和 $\alpha_y(i, j)$ . Here sobel operator is generally chosen to calculate gradient.

To compute each block's direction with the center of $(i, j)$ , the expression is as follows:

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

$$V_x(i,j) = \sum_{u=i-\frac{W}{2}}^{i+\frac{W}{2}} \sum_{v=j-\frac{W}{2}}^{j+\frac{W}{2}} (\partial^2{}_x(u,v)\partial^2{}_y(u,v))$$

$$\theta(x,y) = \frac{1}{2}\arctan\left[\frac{V_y(i,j)}{V_x(i,j)}\right] \tag{3}$$

In the expression (3), $V_x$ is the minimum square estimation along the local grain direction. In the mathematics, it presents the main direction of Fourier frequency perpendicular to the $w*w$ window.

**3.2.3 Enhancement of image filtering**

Enhancement of fingerprint image is to use an algorithm to process fingerprint image, make its grain line structure clear, and try to highlight and keep inherent feature information, avoid producing false feature information. Gabor filter enhancement algorithm is the most common one of fingerprint enhancement algorithms, the basic starting point of this algorithm is based on mathematical model of fingerprint, fingerprints in the local small area can be considered as a set of parallel straight lines with a certain frequency, along the ridge line direction using Gabor window function strengthen the filter, the ridge line information is got strengthened. The detailed algorithm can be described as follows: even symmetrical Gabor filter in airspace can be expressed as expression (4):

$$h(x, y', \varphi, f) = \exp\{-\frac{1}{2}[\frac{(x\cos\varphi)^2}{\delta_x^2} + \frac{(y\sin\varphi)^2}{\delta_y^2}]\}\cos(2\pi fx\cos\varphi) \tag{4}$$

For the Gabor filter direction, $f$ is the frequency of sine wave, $x\delta$ and $y\delta$ respectively represents the constants along the x and y direction of Gaussian envelope on the time domain. Using Gabor filter to do image processing needs to make sure three parameters: the frequency of sine wave; the filter's direction; the standard deviation $\delta_x$ and $\delta_y$ of Gaussian envelope.

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**3.2.4 Image binarization**

Fingerprint image binarization is transforming the gray fingerprint image into the black and white image containing only 0 and 1 two values. The ridge line is treated as the foreground (black), the valley line and background are all processed as the background (white), and therefore the binarization process can also be regarded as fingerprint ridge line extraction process. The advantages: while doing further treatment of image, its geometric properties is only relevant with the location of 0 and 1, no longer involves pixel gray value, which makes the process become simple, and data compression is large. The enhanced image can use a certain threshold to transform the image into binary image in order to do further processing. Algorithm is as follows:

(1) The fingerprint image is divided into $N * N$ blocks;

(2) For each block to calculate the average gray value $E(k,l)$. Calculation expression is:

$$E(k,l) = \frac{1}{w \times w} \sum_{i=1}^{w} \sum_{j=1}^{w} G(i,j) \qquad (5)$$

$$k = 1,2,...,Ml = 1,2,...,N$$

Here $G(i,j)$ is the pixels gray value of line $i$ and column $j$ in sub-block, the value of $M, N$ is determined by the image size and w value.

(3) Set dynamic threshold value as $T$, in statistical sub-block the pixel number is $N_1$ which is equal or greater than $T$, and pixel number is $N_2$ which is less than threshold $T$, then $T = E(k,l)$.

(4) If $|N_2 - N_1| > \delta$, here $\delta = 5$, so T is the threshold; Otherwise if $N_2 > N_1, T = T - 1$, and jump to step (4) to continue; Otherwise $T = T + 1$, and jump to step (4) to continue;

(5) If $G(i,j) \geq T$, then $G(i,j) = 1$ ;If $G(i,j) < T$, then $G(i,j) = 0$ ;You will get the binary map of fingerprint image.

**3.2.5 Image refining**

After binarization the fingerprint line has still a certain width, and there are a large amount of redundant information, based on this the post-processing will greatly influence the processing speed and recognition effect, and fingerprint identification only cares about grain line direction and feature point, through the refinement, the edge pixels of grain line can be deleted, it becomes a single pixel width for extracting features. Refining refers to delete the edge pixels of fingerprint ridge, and make it to have only one pixel width. Good refining is satisfying the following conditions:

Characteristic of protecting grain line;

Valley line only has one pixel wide;

Valley line should be close to the center line;

Don't cause grain line gradually swallowed;

Algorithm is simple, fast.

Currently, the refining method is using template matching method, such as iterative method, OPTA single connection method, etc.

Improved OPTA algorithm: it refers to use two sets of templates with keeping and eliminating to achieve the purpose of refining the image. The improved algorithm adopts the standard 4*4 masterplate. It is shown in figure 4.

| | | | |
|---|---|---|---|
| $P_1$ | $P_2$ | $P_3$ | $P_{13}$ |
| $P_4$ | $P$ | $P_3$ | $P_{14}$ |
| $P_6$ | $P_7$ | $P_8$ | $P_{15}$ |
| $P_{10}$ | $P_{11}$ | $P_{12}$ | $X$ |

*Figure 4. The 4*4 template of improved OPTA algorithm*

Point P is the goal point and the center of template, according to eliminating template and keeping template to make sure if it should be removed or reserved, so 15 adjacent point values containing it should be extracted. This 3*3 template on the top left corner is an eliminate template. X represents the pixels value which can be 0 or 1. The algorithm constructs the unified eliminate template (8) and keeps template (6), to realize image refining processing. Eight eliminate templates are shown in figure 5.

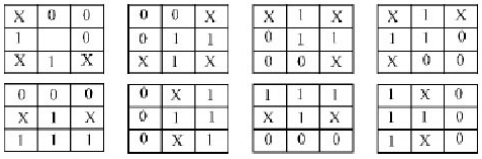

*Figure 5. 8 pieces of eliminating masterplate after improving OPTA algorithm*

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When doing refinement, starting from the top left corner of the image element, each pixel's (in figure it is P) eight neighborhood pixels compare with the eight eliminate template, if it doesn't match, the point P reserves, otherwise, the extracted elements can compare with the six reserved template in figure 4, if it can match with one, then point P is reserved, otherwise point P will be deleted. Repeat the process until no one pixel value is changed so far.

After refinement, generally the processed image needs to be processed after further refining. Because in refining diagram there are burr, short line, breakpoint, small holes and so on four kinds of noises which they will form false feature points. Remove method is filtering based on the characteristics of noise and the corresponding algorithm.

## 4. FINGERPRINT FEATURE EXTRACTION AND FEATURE MATCHING

Feature extraction is the algorithm core of whole fingerprint identification process. The traditional feature extraction algorithm is to extract and process singular points and detail feature points as many as possible, because the singular points are mainly used in fingerprint.

### 4.1 Fingerprint feature extraction

The feature extraction refers to how to express the grain line direction, breakpoint, cross point of fingerprint image which are the fingerprint uniqueness characteristics in the form of numerical expression. In order to keep the accuracy of comparison, feature extraction algorithm is required to extract the effective features as much as possible, and at the same time, filtering all sorts of false features. The frequency characteristic of fingerprint is based on different filter function applied to fingerprint image, thus obtains the characteristics information of fingerprint image. The extraction of frequency characteristics can be divided into seven steps:

(1) Solve direction field and its smooth direction field;

(2) Calculate £, $£(i, j) = \sin(o,(i, j))$;

(3) To each point pitch $(i, j)$ of £ image, calculate the difference of pixel sum of field I $(0^o - 60^o, 120^o - 150^o)$ and field II $(0^o - 120^o)$, and assign the value to $A(i, j)$. The calculation expression is as follows.

$$A(i, j) = \sum_{I} \varepsilon(i, j) - \sum^{II} \varepsilon(i, j) \qquad (6)$$

(4) For the point with maximum value in the image A, it is the reference point needing to find, generally the reference point is the blackest point;

(5) Reduce the size of window and repeat the steps, on the last basis of reference point to find more accurate reference point;

(6) Gabor filtering of fingerprint image;

(7) Extraction of frequency feature of fingerprint image.

Define: mean absolute deviation of eigenvalue is the characteristic value of frequency. Formula is as follows:

$$V_{i\theta} = \frac{1}{n_i}(\sum_{n} | F_{i\theta}(x, y) - P_{i\theta} |) \qquad (7)$$

### 4.2 Fingerprint features matching

Feature matching is comparing the new input fingerprint characteristic value and fingerprint characteristic stored in storehouse, to find out the most similar fingerprint as the output results of recognition. This is the fingerprint verification/identification process. Due to various factors, the characteristics templated for the same fingerprint input twice may be different.

Fingerprint matching algorithm mainly includes matching algorithm based on point pattern, texture pattern, and graph.

The matching algorithm based on point pattern: the classification of fingerprint minutiae matching algorithm has a lot of types.

(1) According to the purpose of the fingerprint identification, the matching can be divided into 1: 1 and 1: n;

(2) According to the difference of operation process, the matching can be divided into automatic matching and interactive matching;

(3) According to the matching adaptability the matching can be divided into elastic matching and rigid matching.

The matching algorithm based on the texture pattern: the matching based on the texture can overcome some shortcomings of detail point

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method, but this method needs to make multiple convolutions for the image, the computation load is very large, and difficult to deal fingerprint image matching with large deformation.

The matching algorithm based on the graph: image matching is a kind of structural pattern recognition method, which can be applied to fingerprint classification, detail index and matching. Using the topology information of fingerprints can overcome the noise of fingerprint, rotation and the interference of deformation on identification.

A good fingerprint matching algorithm needs to satisfy the following requirements at the same time:

(1) Feature vector should be as small as possible in order to minimize the search time.

(2) Matching algorithm should be quickly and accurately in order to meet the needs of real-time system.

(3) Matching algorithm should not be related with translation, rotation, scale expansion of fingerprint.

(4) Matching algorithm should be able to tolerate increasing pseudo feature point and losing the real feature point.

(5) Matching algorithm should not be related with fingerprint nonlinear deformation within the scope.

This algorithm token by the system is as follows:

(1) For the grain line A in template image and the grain line B waiting for matching, their chain code derivative can be expressed as:

$$A:\{x_0, y_0, a_1', a_2', a_3', ...a_N', x_n, y_n, l_n\}$$

$$B:\{x_0, y_0, b_1', b_2', b_3', ...b_M', x_m, y_m, l_m\}$$

(8)

(2) From two grain lines respectively take the sum of clips with length n (n is generally greater than 2/3 of the minimum length between grain line A or B), which begins at No. k edge point of the line A, and No.1 edge point of line B, then the matching degree between sums can be defined as:

$$D_{ld}^{n} = \frac{1}{n}\sum_{j=0}^{n-1}\cos\frac{\pi}{4}(a'_{k+j} - b'_{l+j})$$

(9)

Hereinto:

$$a'_{l+j} = a_{k+i} - \frac{1}{n}\sum_{j=0}^{n-1} a_{k+j}, b'_{l+j} = b_{l+j}\frac{1}{n}\sum_{j=0}^{n-1} b_{l+j}, 0 \le i < n$$

(10)

(3) The best matching pair is as follows while computing lengths

$$(K_n, L_n) = \arg\max_{kl}(D_{ld}^{n}) \quad (11)$$

Hereinto the matching degree can be expressed as $D_{kn\ln}^{n}$.

(4) Calculation of $Max\{|D_{kn\ln}^{n} > D\}$, where $D$ is matching degree threshold (when $D$ is bigger, the matching degree between two stripe lines is more strictly, generally $D = 0.95$). If $N$ is empty set, then grain lines A and B are not matching, otherwise the pair of matching grain lines can be obtained , which are grain line A and B with length $N$, and the starting edge points are $K_N$ and $L_N$.

(5) Repeat steps (1)-(4), the number of matching pair of statistical lines is $M_p$, to two pieces of fingerprint the image matching degree can be calculated as follows:

$$M = \frac{M_p}{M} \quad (12)$$

(12) Among them, $M_p$ is number of grain lines matching pair, $M$ is number of all registered grain lines. If the matching degree of two fingerprint images is greater than a certain threshold $T_m$ ( When $T_m$ is greater, the requirements of matching degree to fingerprint image is more strict, usually $T_m = 0.95$), the two pieces of fingerprint image can be judged as matching.

## 5. CONCLUSION

Aims to algorithm in each flow of embedded fingerprint identification system, this article respectively studies normalization, the direction map, filtering enhancement, binarization and refinement of fingerprint image. In the fingerprint pattern, the normalization is done at first, then fingerprint direction field is calculated. In filtering enhancement, the selection method of each parameter in Gabor filter is improved. In refining, the improved OPTA algorithm is used. The

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extraction of fingerprint feature is based on the extraction of frequency characteristics, the characteristics matching of fingerprint is the matching algorithm based on texture pattern. Throughout the whole fingerprint identification field, although there has made some mature research results, the society is in constant progress, fingerprint identification technology is far from mature on the whole, the algorithm also needs to be continuously improved.

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