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Comparative Analysis of Fingerprint Features Extraction Methods

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Abstract: Human fingerprint features extraction is important for building a fingerprint classification system. The extracted features must be unique and stable by remaining unchanged for the same fingerprint with various rotation degrees. This paper will analyze the most famous methods used to extract fingerprint features. K-means, LBP, WPT, and minutiae methods will be investigated; the obtained experimental results will be analyzed and compared to raise suitable recommendations for using these methods. The process of extracting the fingerprint's characteristics is one of the important things for use in discrimination systems, which requires saving memory and accelerating the classification process to take the appropriate decision and as quickly as possible. The stability of the properties of the fingerprint image, regardless of the different rotations, will lead to the use of a single features vector for the fingerprint with its different conditions and thus treat all the rotated fingerprints as one fingerprint image. This factor will be studied in this research to recommend the experts interested in building fingerprint recognition systems.
Keywords: fingerprint, features, local binary pattern, K-means, wavelet packet tree, bifurcation, ridge, Euclidean distance.

指紋特徵提取方法對比分析

摘要: 人體指紋特徵提取是指紋分類系統構建過程中的一項重要任務，提取的特徵必須是唯一的、穩定的，對於不同旋轉度的同一指紋保持不變。在本文的研究中，我們將分析用於提取指紋特徵的最著名的方法。將研究均值、腰椎间盘突出症、世界巡迴賽和細節方法；將分析和比較獲得的實驗結果，為使用這些方法提出合適的建議。提取指紋特徵的過程是用於判別系統的重要事情之一，它需要節省內存並加速分類過程以盡快做出適當的決定。指紋圖像屬性的穩定性，無論旋轉不同，都會導致對其不同條件的指紋使用單一的特徵向量，從而將所有旋轉的指紋視為一個指紋圖像。在本文的研究中將研究這個因素，以便為對構建指紋識別系統感興趣的專家提出很好的建議。
关键词：指纹、特征、局部二值模式、K-均值、小波包树、分岔、岭、欧几里得距离。

1. Introduction

Digital images are one of the most important and widely used data types. An example of this is the human fingerprint, used in important applications such as banking systems, person identification systems, and many other important computer applications [1-6].

Each person has a unique fingerprint (FP) [7] that does not repeat and does not resemble any other fingerprint and for any other person. The fingerprint usually consists of several objects, varying from one person to another. These objects are diverse. The most important of which is shown in Figure 1.

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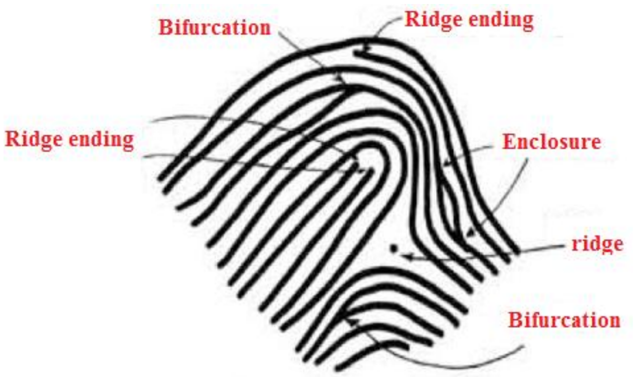

Fig. 1 Fingerprint components

FPs are used in many applications. These applications, such as identifying persons, require features extraction [8] (see Figure 2). These features can be easily used in the recognition system to simplify the process of classification [9-12].

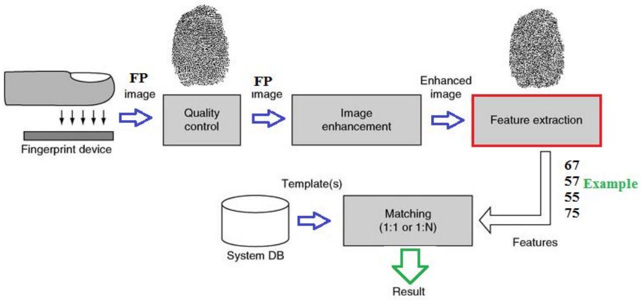

Fig. 2 Fingerprint classification system

FP features is a set of a small number of values [7-10] used to Speed up the person recognition process, and the features array must satisfy the following requirements [1, 2, 12-14]:

- Small size with a small number of values;
- Unique for each FP;
- Not sensitive for FP rotation;
- Small-time of extraction.

The fingerprint is exposed to many influences, negatively affecting its clarity and properties. One of the most important ways to improve the fingerprint image is a local binary pattern (LBP). This method, LBP texture operator applications is its strength to the monotonous changes on the grayscale caused, for example, by lighting differences, Figure 3 shows an example of LBP calculation and LBP operator can enhance the source image by normally distributing the gray values in the image histograms:

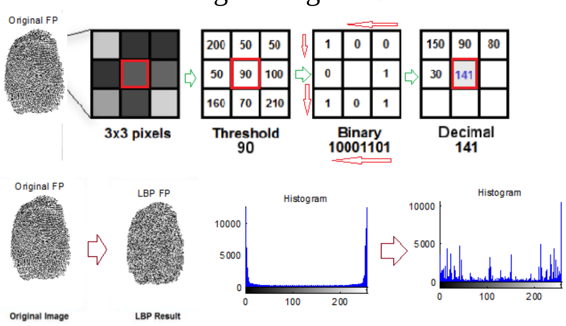

Fig. 3 LBP calculation

This research aims to investigate and analyze the most popular methods used to extract database features of human fingerprints. The results of analyses can be a helpful guide to designing a fingerprint recognition system with a minimum size of features database.

2. Features Extraction Methods

Several methods are used to extract the fingerprint features, and in the following, we will review the most important methods [1-2, 12, 15-21].

2.1. K-means Clustering Method

This method is based on dividing the FP image into clusters. Each cluster will contain a set of points (gray values). Here we can use the clusters' centroids as a feature. Also, we can use them within-cluster sums (WCS) as a feature, this method is not sensitive to the image rotation, and the features will remain without change even if they rotate the image [21].

K-means clustering is simple to implement, and it can be implemented by applying the following steps:

1. Initialization by setting the number of clusters and the initial value of each cluster centroid.
2. For each data item in the input data set, do the following:

- Find the absolute value of the point distant to each cluster.
- Add the point to the cluster based on the minimum distance.
- Find the points average for each cluster's point and replace the associated centroid with the average.
- If there is any change in the centroid values, repeat step 2.

Table 1 shows a clustering of the given data set into two clusters with initial centroids: C1=2; C2=3.

Table 1 K-means clustering

Pass 1				
Data Item	**D1**	**D2**	**Cluster**	**New Centroids**
3	1	0	2	C1=2; C2=8
12	10	9	2	
7	5	4	2	
10	8	7	2	
2	0	1	1	
Pass 2				
Data Item	**D1**	**D2**	**Cluster**	**New Centroids**
3	1	5	1	C1=2.5; C2=9.33
12	10	4	2	
7	5	1	2	
10	8	2	2	
2	0	6	1	
Pass 3				
Data Item	**D1**	**D2**	**Cluster**	**New Centroids**
3	0.5	6.33	1	C1=2.5; C2=9.33 No change: Stop
12	8.5	2.67	2	
7	4.5	2.33	2	
10	7.5	0.67	2	
2	0.5	7.33	1	

2.2. Wavelet Packet Tree Decomposition

Wavelet packet tree (WPT) decomposition can be implemented using various methods; Haar decomposition is the most popular. Haar equations (Equation 1) can decompose the FP pixels values into approximations and details. In the first level of decomposition, we can use the reshaped into one row FP image as an input, and in the next levels, we can use the calculated approximation as an input data set. Figure 4 shows an example of data set decomposition.

Haar scaling (low pass) function:

$$s_{j+1,i} = \frac{even_{j,i} + odd_{j,i}}{\sqrt{2}} \quad \text{Approximation}$$

Haar wavelet (high pass) function:

$$d_{j+1,i} = \frac{even_{j,i} - odd_{j,i}}{\sqrt{2}} \quad \text{details}$$

Equation 1

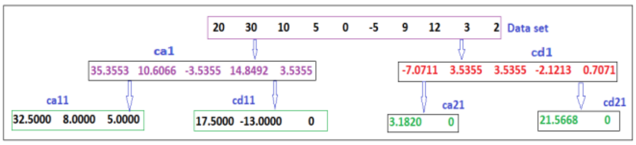

Fig. 4 WPT decomposition

WPT decomposition method faces some problems. It is difficult to select the number of levels needed to approximate a defined number of data items because FP images have various sizes. We can resize the image to get multiple sizes to overcome this problem. Another problem is that the WPT method is sensitive to image rotating, and to overcome this problem, we can use the image histogram as an input data set for decomposition. The histogram can also be used to solve the problem of selecting the number of decomposition levels.

2.3. LBP Based Methods

Features array size can be selected using LBP based method. Here we can reshape the FP image into one row and apply the steps shown in Figure 5. We can represent the FP image by four values:

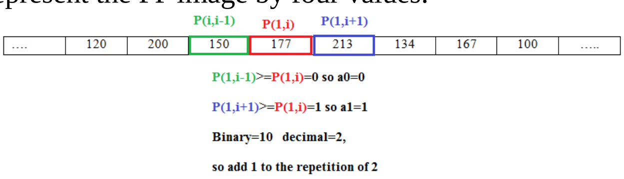

Fig. 5 LBP features calculation

The LBP-based method of features calculation is sensitive to FP image rotation; to overcome this disadvantage, we can use the image histogram instead of the FP image.

2.4. Fingerprint Minutiae Extraction

FP image contains a set of objects. As we said earlier in this paper, the repletion of each object has a fixed number, and it varies from one FP image to another. As shown in Figure 6, the most repeated objects are bifurcation and ridge ending.

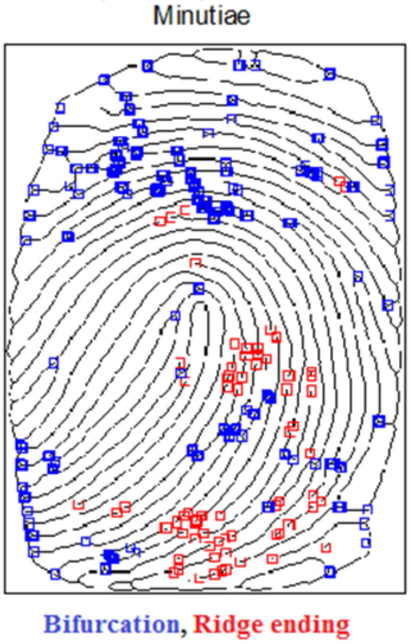

Fig. 6 Most repeated objects in fingerprint image

Here we can use the number of bifurcations, the number of ridge ending, Euclidean distance of the coordinates of each of the bifurcations, and ridge end. This distance can be calculated using equation 2.

$$d(\text{x,y}) = d(\text{y,x})$$
$$= \sqrt{(\text{x1-y1})^2 + (\text{x2-y2})^2 + \cdots + (\text{xn-yn})^2}$$
$$= \sqrt{\textstyle\sum_{i=1}^{n}(\text{xi - yi})^2}$$

Equation 2

Bifurcations and ridge-ending objects can be calculated using crossing numbers (CN). This number can be calculated as shown in Figure 7, each object in the FP image is associated with CN value, and Figure 8 shows the most popular objects and the associate CN value.

P_4	P_3	P_2
P_5	P	P_1
P_6	P_7	P_8

$$CN = \frac{1}{2}\sum_{i=1}^{8}|P_i - P_{i+1}|$$

Figure 7 CN calculation

CN	Object
0	Isolated point
1	Ending point
2	Connective point
3	Bifurcation point
4	Crossing point

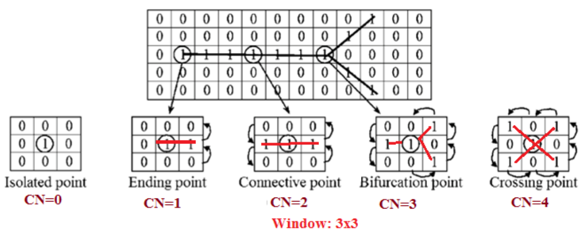

Fig. 8 FP objects and associated CN values

3. Implementation and Experimental Results

Several fingerprint images were taken and treated using the methods mentioned in this paper. Table 2 summarizes the main features of these methods. One can refer to Tables 3-6 to see the prove of Table 2 contents:

Table 2 Methods characteristics

Method	**Efficiency**	**Fixed number of features**	**Sensitivity to image rotation**	**Remarks**
K-means	Good	Fixed	No	Use the histogram to solve the sensitivity problem
WPT	Good	Not Fixed	Yes	Use the histogram and/or image resizing to fix the features number
LBP-based	Excellent	Fixed	Yes	
Minutiae	Good	Fixed	No	Use the histogram to solve the sensitivity problem.

To solve some problems facing FP image features extraction, the image histograms were calculated and used as input data sets, the first three methods were implemented using FP histograms, tables 3, 4, and 5 show the obtain experimental results:

Table 3 K-means results

FP number	**Features (4 clusters, four centroids)**				**Extraction time (seconds)**
1	349	7148	20755	74071	0.089
2	910	11560	55710	758290	0.084
3	153	2229	4752	24605	0.091
4	72	478	4957	16592	0.098
5	81	617	3442	19891	0.087
6	268	5090	14841	70510	0.087
7	460	12500	27750	173850	0.086
8	0.0099	0.0438	0.3847	1.4309	0.088
9	60.1	335.6	718.5	6399.7	0.084
10	9	86	469	21747	0.085
Average					0.0879

Table 4 WPT results

FP number	**Features**				**Extraction time (seconds)**
1	159840	143910	-17890	129860	0.094
2	71500	74800	-180200	1187800	0.091
3	30202	27694	-6067	46811	0.094
4	31664	28476	-3732	27631	0.095
5	22080	19867	-4611	32719	0.092
6	108260	97660	-17040	118320	0.093

Continuation of Table 4

7	876770	785370	-6880	74180	0.091
8	24569	22103	-2870	24075	0.091
9	32499	29223	-1314	12755	0.092
10	-34	-5	-4623	36301	0.092
Average					0.0925

Table 5 LBP-based results

FP number	**Features**				**Extraction time (seconds)**
1	74	46	56	78	0.000001
2	59	59	75	61	0.000001
3	67	51	62	74	0.000001
4	69	47	58	80	0.000001
5	68	52	55	79	0.000001
6	65	51	68	70	0.000001
7	75	54	47	78	0.000001
8	75	42	56	81	0.000001
9	67	57	55	75	0.000001
10	74	38	49	93	0.000001
Average					0.000001

From the above tables, we can see that the three methods gave a unique and fixed-size feature. The FP histogram will fix the features and keep them without change, even if we rotate the fingerprint to any degree.

The same FP images were treated using the minutiae method; table 6 shows the obtained results:

Table 6 Minutiae results

FP number	**Features**				**Extraction time (seconds)**
	Bifurcation count	**Euclidean distance of bifurcation points**	**Ridge count**	**Euclidean distance of ridge points**	
1	5105	555.317	1647	445.0674	0.052
2	1233	1052.1	106	461.7359	0.023
3	259	364.1607	70	353.8361	0.004
4	678	64.3506	27	199.1808	0.006
5	1161	195.5428	72	207.0386	0.01
6	377	311.8349	74	381.2034	0.006
7	1327	867.5788	104	966.6276	0.018
8	4400	72.8354	295	223.7722	0.036
9	729	196.3314	20	223.8928	0.006
10	795	212.3017	128	115.3776	0.007
Average					0.0168

Minutiae method is also efficient, and it gave unique features, this method is not sensitive to image rotation, and instead of using image histogram, we can use a smaller FP image by resizing the image to the required size here, we can reduce the counts of bifurcation and ridge ending.

4. Conclusion

Several popular methods of FP image features extraction were implemented; the obtained experimental results were compared and analyzed. K-means and minutia methods are not sensitive to image rotation, and they give unique features for each fingerprint image. WPT and LBP-based methods are sensitive to image rotation and efficient feature extraction. To overcome the image rotation sensitivity, we can replace the FP image with the image histogram keeping the features unique and unchanged for the FP even if the image was rotated. We can strongly recommend the minutiae method for fingerprint features extraction based on the obtained results. The extracted features can be used later in the process of fingerprint recognition systems, the recommendations done in this paper will help the designer create a recognition system with the minimum requirement of memory and processing time.

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