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RESEARCH ON SYNERGETIC FINGERPRINT CLASSIFICATION AND MATCHING

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Abstract:

Fingerprint recognition is one of the research hotspots of biometrics techniques. And fingerprint classification and matching are key parts in an automated fingerprint recognition system. The traditional fingerprint recognition systems have such disadvantages as high computation complexity, low speed, low recognition rate to uncompleted or defiled fingerprints, and not robust. In this paper, we propose a novel fingerprint classification and matching method based on synergetic pattern recognition, which emphasizes global features of fingerprint. With lots of artificial fingerprint samples, the results show that the proposed method is effective, fast and robust. In the end, experimental results are analyzed and a synergetic fingerprint recognition system is introduced.

Keywords:

Fingerprint classification; Fingerprint matching; Synergetics; Pattern recognition

1. Introduction

With the development of computer and network techniques, information security has become more and more important. Biometrics is suitable for the area of information security. Recently, biometrics techniques develop very fast and obtain much more attention. The fingerprint is unique and unchangeable during one's life, so fingerprint recognition has become an effective method of biometrics, which is the oldest of all the biometric techniques and has been applied to many fields [1~6].

There are four main parts in an automated fingerprint identification system [1~3,5,6]: fingerprint preprocessing, feature extraction, fingerprint classification and matching decision. Specifically, feature extraction means extracting minutia from the input fingerprint image, including [1,2,7~9]: estimation of orientation field, ridge extraction and thinning, minutia extraction, etc. Fingerprint classification is used to enhance the speed of identity verification. Commonly, the relative algorithms [1,2,7,10] are based on sign information such as odd points, information of ridge direction and structure, syntax pattern recognition, neural network method and so on. Matching decision is to determine whether or not two fingerprints belong to the same finger. The methods are as follows [1,2,6,7,9,11,12]: alignment-based matching, Hough transform based matching, 2D dynamic programming based matching, based on graph features of fingerprint or neural network approach. During the last few years, more and more approached have been achieved based on those classification and matching techniques, but many disadvantages still exist such as: high computation complexity, low speed, and low recognition rate to uncompleted or defiled fingerprint images.

Aiming at those problems, we propose a novel fingerprint classification and matching method based on synergetic pattern recognition [13,14]. And an effective fingerprint recognition method has been implemented based on synergetic approach. With lots of artificial fingerprint samples, experimental results show that the proposed method is effective, fast and robust.

In this paper, firstly we briefly introduce the algorithm model of synergetic pattern recognition in section 2, and then the novel synergetic fingerprint classification and matching algorithms based on synergetic pattern recognition will be discussed in detail in section 3. In section 4, the experimental results of several sets of fingerprint images are given to validate the effect of the algorithms. Finally, a conclusion will be given in section 5.

2. Algorithm model of synergetic pattern recognition

In the late 1960s, Prof. Haken, an outstanding German scientist, introduced the basic concept of synergetics[13~16]: an interdisciplinary field of research that is concerned with the spontaneous formation of macroscopic spatial, temporal, or functional structures of system via self-organization. There are large classes of systems in which self-organization obeys the same basic principles. When a system undergoes qualitative macroscopic changes,

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Synergetics is applied as mathematic means to describe this process. In the 1980s, Haken presented a new concept which applies synergetics to pattern recognition [13,14]. Considering the similarity between pattern recognition and pattern formation, he presented an important viewpoint: The process of pattern recognition is actually the process of pattern formation. Synergetics offers a new and different approach to the construction of highly parallel scheme for pattern recognition and decision making, so in contrast to neural networks in which construction is from bottom to up-synergetic pattern recognition (SPR) allows the algorithm scheme from top to town.

In this section we shall briefly describe the algorithm model of SPR. According to the basic theory of synergetics, pattern recognition process can be described as some parameters' evolvement progress. For input pattern q to be recognized, we can construct a dynamic process, which drives pattern q to one of prototype patterns v_k through an interim state $q(t)$. The overall recognition process can be described as $q(0) \to q(t) \to v_k$.

In SPR, patterns are represented by N-dimensional vectors:

$$v_k = (v_{k1}, v_{k2}, \cdots, v_{kN})', \quad k = 1,2,\cdots M \tag{1}$$

All vectors v_k are normalized and centered, that is, they obey the following conditions:

$$\sum_{l=1}^{N} v_{kl} = 0, \quad \|v_k\|_2 = (\sum_{l=1}^{N} v_{kl}^2)^{1/2} = 1 \tag{2}$$

All v_k will be stored into the prototype matrix as prototype vectors. The adjoint vectors v_k^+ of v_k can be calculated from the conditions:

$$(v_k^+, v_{k'}) = v_k^+ v_{k'} = 1 \tag{3}$$

The synergetic approach to pattern recognition can be described by the following dynamic equation:

$$\dot{q} = \sum_k \lambda_k v_k (v_k^+ q) - B \sum_{k' \neq k} (v_{k'}^+ q)^2 (v_k^+ q) v_k - C(q^+ q) q + F(t) \tag{4}$$

λ_k are attention parameters whose values must be positive, v_k are prototype vectors, v_k^+ are adjoint vectors of v_k, B and C are constants whose values are positive, $F(t)$ is fluctuate power.

When test vector q comes to the system, order parameters ξ_k is built as follows:

$$\xi_k = v_k^+ q \tag{5}$$

Then we can rewrite (4) to:

$$\dot{\xi} = \xi_k (\lambda - D + B\xi_k^2), D = (B + C) \sum_{k'} \xi_{k'}^2 \tag{6}$$

Haken has proved that when λ_k =C>0, namely attention parameters are equivalent; the final state is lied on initial value of order parameters. At last v_k with the closest value to the initial vector will win, then the corresponding order parameter ξ_k runs to 1, while all others run to 0.

In practice, the formula (6) is our start point to pattern recognition. In the field of image recognition, SPR model has good recognition performance [5,13,17~20]. The framework of algorithm implementation of SPR is shown in Figure 1.

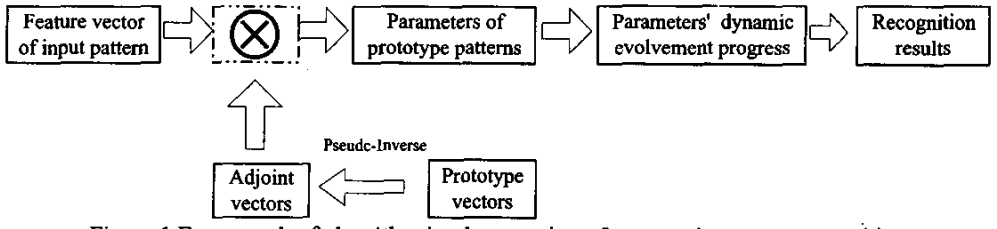
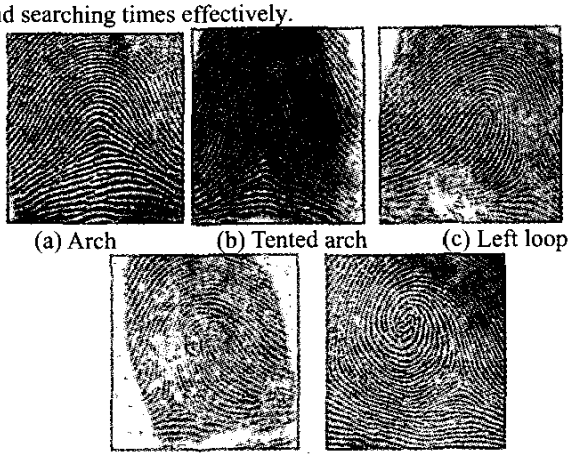


Figure 1 Framework of algorithm implementation of synergetic pattern recognition

3. Synergetic fingerprint classification and matching algorithms

Generally, there are two kinds of features in person's fingerprints [5,6]: global features and minutia features. Based on information in the global patterns of ridges, the fingerprints have been traditionally classified into five classes [2,3,5,6,10]: Arch, Left loop, Right loop, Tented arch and Whorl, as shown in Figure 2. During fingerprint classification process, input fingerprint is firstly assigned to one of the five classes before fingerprint matching process. So it can reduce searching space and improve recognition speed in large-scale fingerprint identification system. After fingerprint classification, the input fingerprint only can match the pre-stored fingerprints (templates) belonged to the same class. Therefore the system may reduce matching

and searching times effectively.



(a) Arch (b) Tented arch (c) Left loop

(d) Right loop (e) Whorl

Figure 2 The five classes of fingerprints

Ideal fingerprint classification and matching algorithms should be fast and have high recognition rate. But for the complexity of fingerprint lines and poor quality of obtained fingerprint images, it's still a challenging work to design such algorithms. In order to achieve best possible features from the original image, we need do lots of preprocessing work, which is time assuming and hard to handle. Due to the presence of noise in the fingerprint image, the extraction of structure features also has its difficulties. When we collected the fingerprint image from a subject, according to the different pressure, different angle to the collector, images may have the following imperfections: smudge, uncompleted, rotated, etc. As a result, it's very difficult to extract perfect features from these images and the accuracy of recognition will fall down dramatically.

However, SPR is a novel image recognition method, and its feature extraction method and recognition algorithm are unique. In the synergetic approach to image recognition, in order to extract the features from the original images, we firstly set grids to the image and a value which represents the gray value of each grid will be evaluated. Therefore the original image will be converted into image matrix. To achieve the input vector, the matrix is pulled down into an N-dimensions vector, which will be introduced into the dynamic process as prototype vectors after the normalizing and centering. Computing adjoint vectors of prototype vectors is the feature extraction method of SPR. Adjoint vectors denotes distinct features of prototype vectors, and it not only extracts the features of single image, but also considers the distinctness of all images. In general, synergetic approach is based on whole image, not necessary to analyze the shape, texture and feature points of each image alone. Synergetic approach is an index method independent of application fields. Furthermore, differing from other transformation methods, it is not necessary to do transformation of each image in databases, and it's an extendable searching method for large-scale databases.

Comparing with traditional fingerprint features, synergetic fingerprint features based on SPR have two global-properties: computing global-property and comparing global-property. Computing global-property means that during computing adjoint vectors process, synergetic approach takes whole image for computation unit. To achieve input vector, the image matrix only need to be pulled down to an N-dimensions vector. This method differs from traditional feature extraction ones which need to search each pixel of the image, and so it has low computation cost and complexity. Moreover, for using of whole image information, it is very suitable to recognition of uncompleted and scratched fingerprints. Comparing global-property means that it not only extracts the features of single image, but also regards interrelated images as an integer and compares with each other. Feature vector contains difference information of interrelated images.

The synergetic offers a new and different approach to the construction of highly parallel structures for pattern recognition. This recognition construction from top to down, which is realized by an effective nonlinear competitive equation, is very close to the recognition model of human beings. So it can improve recognition efficiency and robustness of the system. Due to the unique algorithm structure and well image processing performance of SPR, and its relatively low requirement of input image quality, we propose synergetic fingerprint classification and matching algorithms. The novel classification and matching algorithms have good recognition results and optimistic applicative foreground. Experiments in the next section have testified that the algorithms are effective and superior.

Now we shall briefly introduce the proposed fingerprint classification and matching algorithms. Applying SPR theory to fingerprint classification, we get synergetic fingerprint classification algorithm as follows:

1) Select some representational fingerprint samples from each training fingerprint class, and achieve the cluster center of each class using K-mean cluster algorithm;

2) Convert five cluster centers to prototype vectors v_k;

3) Compute the according adjoint vectors v_k^+ of v_k;

4) Convert the test fingerprint image to input vector $q(0)$;

5) Achieve the according order parameters $\xi_k(0)$ of

prototype patterns by the formula $\xi_k(0) = v_k^+ q(0)$;

6) Evolve by the below discrete form of formula (6) until the system become stabilized to a specific prototype pattern:

$$\xi_k(n+1) - \xi_k(n) = \gamma(\lambda_k - D + B\xi_k^2(n))\xi_k(n) \quad (7)$$

$$D = (B + C)\sum_{k'} \xi_{k'}^2(n) \quad (8)$$

Where γ is iterative rate parameter, B and C are constants, n is iterative step.

7) Present the classification result.

After the fingerprint classification process, it's the fingerprint matching process. Similarly, synergetic fingerprint matching algorithm can be implemented as follows:

1)Convert the training fingerprint images to prototypes vector v_k;

2)Compute the according adjoint vectors v_k^+ of v_k;

3)Convert the test fingerprint image to input vector $q(0)$;

4)Achieve the according order parameters $\xi_k(0)$ of prototype patterns by the formula $\xi_k(0) = v_k^+ q(0)$;

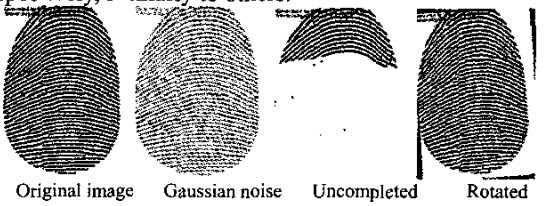
5)Evolve by the formula (7) and (8) until the system becomes stabilized to a specific prototype pattern;

6)Present the matching result.

4. Experiments

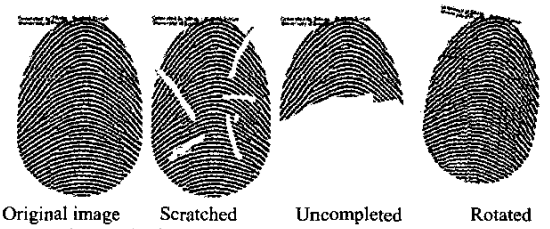
In a practical fingerprint recognition system, when we collected the fingerprint images from an object, due to the different pressure, different angle to the collector, images may have the following imperfections: noisy, smudge, uncompleted, rotated (always 1~4 degree warp after revised), etc. Therefore we have accomplished a group of experiments, mainly aiming at these cases, to test our algorithms under the condition: celeron 333/96RAM PC, MATLAB 5.3 software. Fingerprint images are produced by Synthetic Fingerprint Generator (Sfinge version 2.0, offered by Bologna University). The size of the images is 256 gray scales, 320×240 pixels.

In the fingerprint classification experiments, there are 120 training fingerprint samples, which include five classes: Arch, Left loop, Right loop, Tented arch and Whorl, and each class contains 24 fingerprint images. After we get prototype vector of each class using K-mean cluster algorithm, we accomplish three sets of experiments: Gaussian noise experiments, uncompleted experiments, and rotated experiments. Some of experiment samples are shown in Figure 3, and experimental results in Table 1. Comparing with traditional K-mean cluster fingerprint classification algorithm, synergetic fingerprint classification algorithm is obviously more effective. The 2nd column (0.6, 0.02^2), 20% and 1 degree in Table 1 means that Gaussian white noise on each training sample is zero mean and 0.02^2 variance, about 20% uncompleted and 1 degree rotated, respectively, similarly to others.



Original image Gaussian noise Uncompleted Rotated

Figure 3 Fingerprint classification experiment samples



Original image Scratched Uncompleted Rotated

Figure 4 Fingerprint matching experiment samples

In the fingerprint matching experiments, we test our matching algorithm on three ordinary sets of fingerprint images: Arch, Left loop, and Right loop, and each class contains 24 training fingerprint samples. For every training samples in each set, there are a standard image as prototype pattern and 23 test fingerprint images, which are made up of 8 uncompleted, 3 damaged, 12 rotated (from 1 degree to 6 degree, containing 6 clock wised and 6 counter-clock wised). Experiment samples are shown in Figure 4, and experimental results in Table 2. From the Table 2, we can come to a conclusion that the matching rate of synergetic fingerprint matching algorithm is also excellent.

In the experiments, it takes several seconds for synergetic fingerprint classification or matching algorithms to classify or match a fingerprint image. However, under the same hardware and software conditions, it takes about 42 minutes for traditional fingerprint classification based on orientation field computation. K-mean cluster fingerprint classification algorithm also costs much time. And it also takes long time for traditional matching algorithm based on minutia feature to do. Therefore, synergetic fingerprint classification and matching algorithms have great advantages of recognition speed.

From Table 1 and Table 2, we know that synergetic fingerprint classification and matching algorithms have

excellent recognition rate to uncompleted and defiled fingerprint images, and strong robustness. Moreover, the presented algorithms have low requirement of input images and need not to do complex preprocessing and feature extraction work.

Table1. Fingerprint classification experiments data

Classification / Algorithm / Rate / Input		Synergetic Fingerprint Classification	K-mean Cluster Fingerprint Classification
Gaussian Noise	$(0.6,0.02^2)$	100%	100%
	$(0.7,0.02^2)$	95.8%	83.5%
	$(0.72,0.02^2)$	90.0%	33.3%
	$(0.75,0.02^2)$	66.7%	12.5%
Uncompleted	20%	100%	100%
	30%	100%	84.3%
	60%	90.0%	70.8%
	70%	58.3%	28.6%
Rotated	1 degree	100%	100%
	2 degree	83.3%	83.3%
	3 degree	83.3%	75.0%
	4 degree	83.3%	75.8%

Table 2. Fingerprint matching experiments data

Matching Class / Rate / Input	Arch	Left Loop	Right Loop
Uncompleted	100%	100%	100%
Scratched	66.6%	66.6%	50%
Rotated	98.3%	99.0%	94.1%

Based on synergetic fingerprint classification and matching algorithms, we can construct a synergetic fingerprint recognition system, as shown in Figure 5. The system embodies hierarchy principles, and converts global competition to some local competition. Each time, the number of competitive prototypes is about one fifth of classical Haken model, and the system can overcome the difficulty to compute the adjoint vectors of large-scale prototype patterns. In synergetic fingerprint classifier, the system will accomplish coarse-level but quick recognition process, and then accomplish matching process in the corresponding matcher, namely subtle-level recognition process. Fingerprint matching is based on the classification result, so if the classification result is wrong, the matching result must be also wrong. As we know, order parameters denote the likeness degree between test pattern and prototype patterns. Therefore the system can directly lead the fingerprints that are difficult to classify to the matchers via selecting order parameters. In the fingerprint matchers, it can also prevent lawless fingerprint from intruding into the system via selecting order parameters. Generally, it is regarded as lawless input fingerprint whose likeness degree to prototype patterns is too low. Synergetic fingerprint recognition method has some advantages as follows:

Low computation cost and complexity, high recognition speed, not necessary to do lots of preprocessing and complex feature extraction work;

High recognition rate to uncompleted and defiled fingerprint images, strong robustness, low requirement of input image quality;

Recognition process is hierarchy model, up to town, and there are no spurious states. Using of whole image information, not dependent on prior information much, very close to the recognition model of human beings.

The proposed fingerprint recognition system has excellent recognition performance to artificial fingerprint samples, but some parameters of the system should be optimized. It is also necessary to do research on attention parameter of SPR and order parameters selecting mechanism of the system. And we should accomplish experiments with actual fingerprint images to testify the method in the future. All these are our next research points.

5. Conclusion

Synergetic fingerprint classification and matching algorithms take whole image information for computation unit, and the recognition processes are very close to the recognition model of human beings. Synergetic approach has such distinctive advantages as short pattern training time, low space and time complexity, no spurious states, good associative efficiency, simple preprocessing and feature extraction work, and strong recognition robustness. Based on synergetic fingerprint classification and matching algorithms, we have presented a synergetic fingerprint recognition system, which has excellent recognition performance. But there is still much work to do to apply the system to practical fields.

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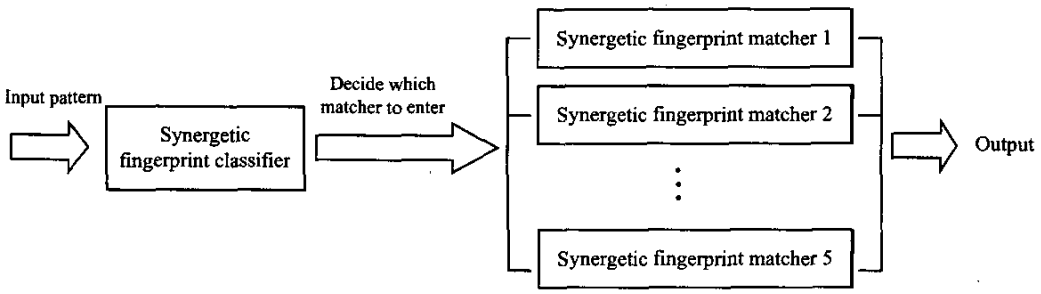

Figure 5 Synergetic fingerprint recognition system

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