A new fast technique for fingerprint identification with fractal and chaos game theory

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A NEW FAST TECHNIQUE FOR FINGERPRINT IDENTIFICATION WITH FRACTAL AND CHAOS GAME THEORY

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Abstract

Fingerprints are one of the simplest and most reliable human biometric features for identification. Geometry of the fingerprint is fractal and we can classify a fingerprint database with fractal dimension, but one can't identify a fingerprint with fractal dimension uniquely. In this paper we present a new approach for identifying fingerprint uniquely; for this purpose a new fractal is initially made from a fingerprint by using Fractal theory and Chaos Game theory. While making the new fractal, five parameters that can be used in identification process can be achieved. Finally a fractal is made for each fingerprint, and then by analyzing the new fractal and parameters obtained by Chaos Game, fingerprint identification can be performed. We called this method Fingerprint Fractal Identification System (FFIS). The presented method

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besides having features of fractals such as stability against turning, magnifying, deleting a part of image, etc. also has a desirable speed.

Keywords: Biometric; Fingerprint Identification; Chaos Game Theory; Fractal Dimension.

1. INTRODUCTION

These days, identification is known as an issue which is so interrelated with human biometric features that signature, face, voice, iris, fingerprint, etc. in human are used for this purpose.[1] Undoubtedly, one of the simplest and most reliable identification methods based on human biometric features is the fingerprint, which has been in use for more than a hundred years in human identification, due to its stability and unity. Identification based on fingerprints is considered as one of popular methods in identification of individuals and the simplicity of the mechanism is the cause of this popularity. Sir Francis Galton and Sir Edward Henry were the first people who worked on identification based on fingerprint.[2,3] Galton focused his studies on fingerprint features and the results of his study led to definition and identification of some features in fingerprint and he called them *Minutiae*. Some of these features are shown in Fig. 1. Unlike him, Henry studied the general structure of fingerprint and the results of his studies led to classification of fingerprints into five categories; Fig. 2 shows this classification for fingerprints. Studies of these two were so much deep and clear that even after a hundred years they are used in researches. Issue of mechanical and automatic identification of fingerprint after extensive studies was authorized by FBI in 1969 and after that this task was given to National Institute of Standards and Technology (NIST). Some other works have been carried out on this subject, for instance we can point to what Maltoni has done for this purpose. He and his colleagues, relying on techniques based on Minutiae which Galton had introduced, worked on basic features of fingerprint and did the identification by the aid of these features.[4] In another work which was presented by Polikarpova, he analyzed fingerprint with fractal outlook. In this report fractal method is used for identification.[5] Also in an article which Karki presented with the assistance of his colleagues in 2007, like Maltoni, by analyzing Minutiae and improvement of popular methods he worked on identification based on fingerprint.[6]

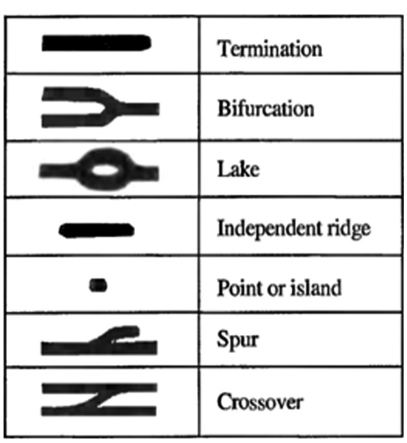


Fig. 1 The most common *minutiae* types.

2. FINGERPRINT

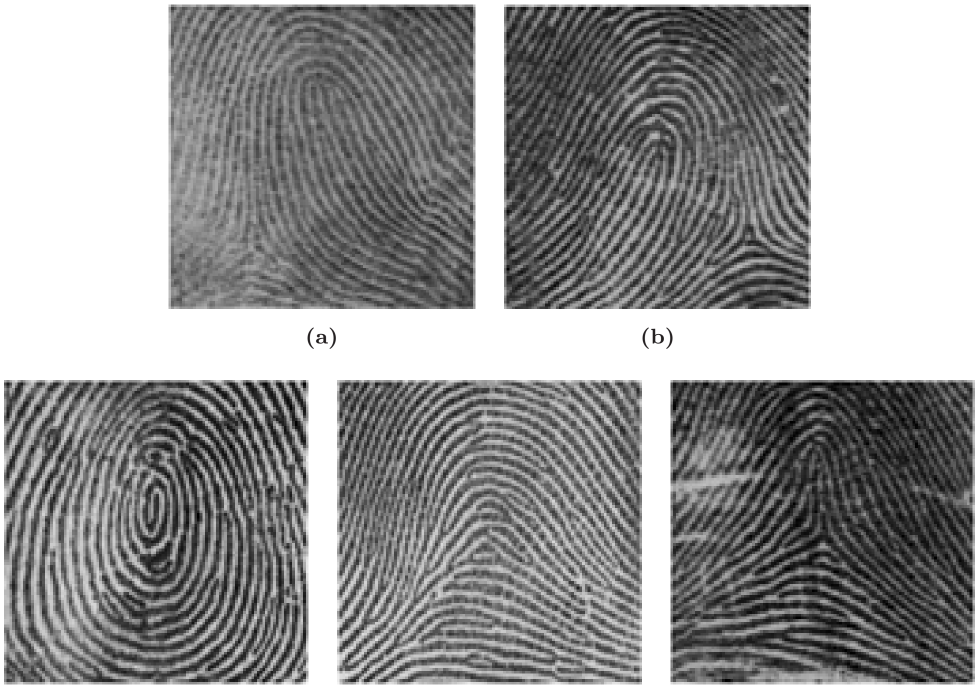
The ins and outs on tip of fingers are called fingerprints. Based on studies of Galton, there are some features in each fingerprint which are different in various samples of fingerprints. These features are called Minutiae and on average there are about 50 to 80 features in each fingerprint.[7–9] Core, delta, bifurcation, ridge, crossover, and island are some of these features.

2.1. Fingerprint Identification Methods

Fingerprint identification methods are often divided into two main groups[10–12]:

(1) Minutiae Based Algorithm (MBA)
(2) Pattern Based Algorithm (PBA)

In the first type a fingerprint becomes ready for processing in a pre-processing stage and then the features of that fingerprint is compared to the features of other fingerprints. However, in a pattern based method, the pattern of fingerprint sample is compared to other samples, level of conformity is calculated and on the basis of that a decision is made.



(a) (b) (c) (d) (e)

Fig. 2 Henry fingerprint classification: **(a)** Right loop; **(b)** Left loop; **(c)** Whorl; **(d)** Arch; and **(e)** Tented Arch.

3. FRACTAL DIMENSION

The term *fractal* was introduced by Mandelbrot for the first time in 1975[13,14] and refers to geometry of objects which have the following features:

(1) Self-similarity;
(2) iterative formation; and
(3) fractional dimension.

It means that components of a fractal object are similar to whole of that object and are produced with a repetitive procedure and more importantly, if we calculate dimension of these objects, unlike objects like a line which has just one dimension or plate for which dimension is two, the dimension of fractal objects is a decimal number. In Fig. 3 a sample fractal is shown; while Fig. 4 shows another fractal which is known as Sierpinski Triangle and it has a dimension of 1.58.

The fractal dimension is a statistical quantity that gives an indication of how completely a fractal appears to fill space, as one zooms down to finer and finer scales. As a mathematical definition it should be said that the base of most definitions of dimension is the idea of measurement in the scale of δ. For each δ, by ignoring irregularities smaller than δ, we measure a collection and we see how these collections behave when $\delta \to 0$. For instance, if F is a surface curve, then our measurement $M(\delta(F))$ can be the number of necessary steps for measurement or covering of F by making use of distance or length of δ.

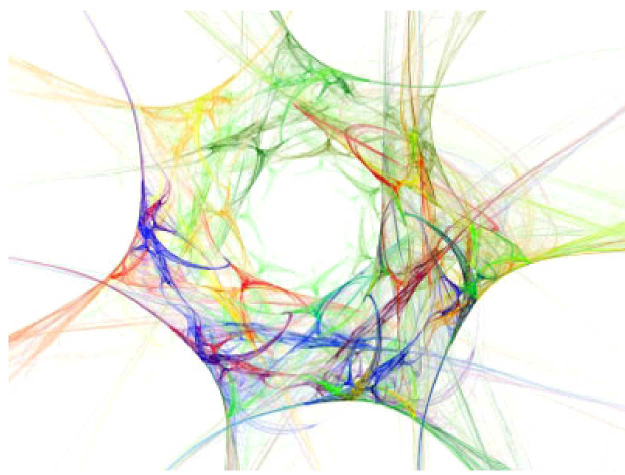


Fig. 3 Farid's fractal. (From Dr. John Daab, http://www.fineartregistry.com/articles/art-technology/fine-art-authenticator-technology.php.)

3.1. Fractal Dimension Calculation Methods

In 1977, for the first time Mandelbrot gave a definition of fractal dimension.[15] Fractals explain some

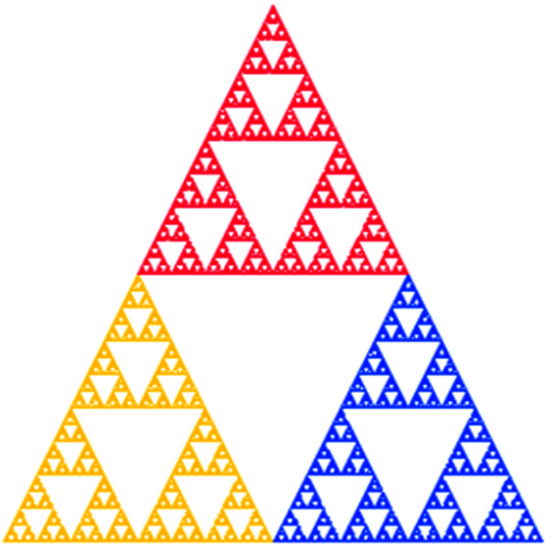


Fig. 4 Triangle, that its dimension is 1.58.

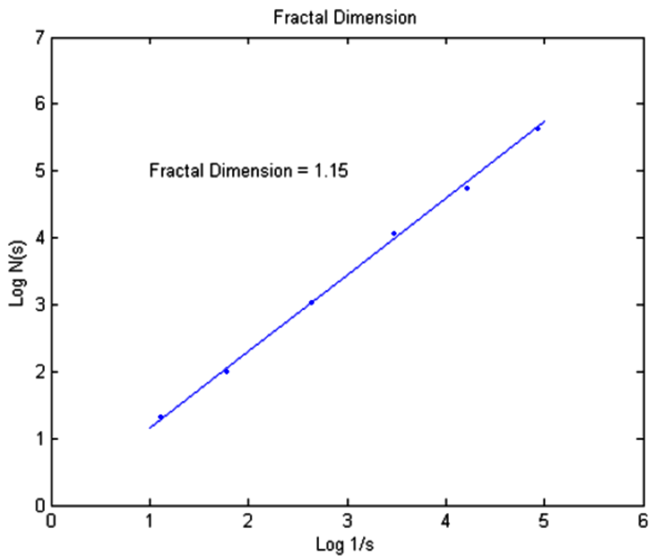


Fig. 5 Calculate fractal dimension with box-counting method.

of irregular geometric features of shapes and solids which seem similar in all scales. Many of the objects around us have such complicated features that measurement of length, area, or volume with common methods are impossible. However, there is a method for measuring their geometric properties so that while measuring with higher accuracy by estimating increase of length (area, volume) this method can be obtained. The main thesis of this method is that two basic quantities — length (area, volume) — on the one hand and level of accuracy in measurement on the other hand do not change by their own will; rather they change in a way which provides the possibility of measurement of fractal dimension. This outlook is in fact the same hidden basic idea in calculation of fractal dimension.

The followings are some of the most important methods of fractal dimension calculation[16]:

(1) box-counting dimension;
(2) Hausdorff dimension;
(3) packing dimension;
(4) Renyi dimension; and
(5) correlation dimension.

For example, in the Box-Counting method the proposed fractal is divided into similar boxes and then logarithm of boxes, which includes the chosen collection, is calculated in relation with logarithm of reversed ratio of size of box. This should be repeated again for other sizes of boxes and after defining the ratio shown in relation (1) in a two-dimensional graph some points would be obtained and the slope of the line which passes these points is considered as the dimension of the proposed object. Figure 5 shows the procedure of fractal dimension calculation with Box-Counting method.

$$D = \frac{\log(N_s)}{\log(1/s)}. \tag{1}$$

3.2. Fingerprint Identification with Fractal Dimension

Fractal dimension is a statistical quantity and a part of fractal properties, and can be considered as a suitable parameter for comparing fractals so that analyzing the calculated dimension for several fingerprint samples shows their difference. However, most of the time calculating fractal dimension for more than four decimal digits is not possible; therefore it can identify at most 10,000 fingerprints and it is not sufficient for identifying fingerprints. Consequently, this fractal dimension cannot be used for fingerprint identification, but after some experiments we concluded that we can use fractal dimension for fingerprint classification, based on Henry's classification.

3.3. Chaos Game Theory

Chaos Game theory was presented by Barnsley in 1988.[16,17] This theory on the strength of Shannon Theorem is presented in a way that by using Random Walk mechanism and by the aid of a polygonal a fractal can be produced. This theory has

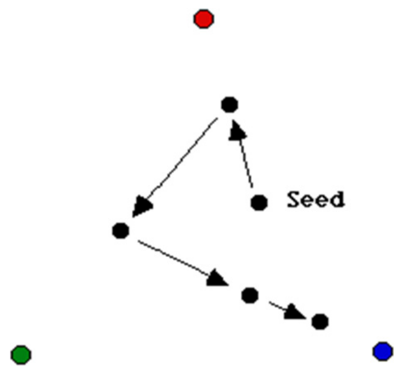


Fig. 6 Chaos Game mechanism on triangle that generate Sierpinski triangle.

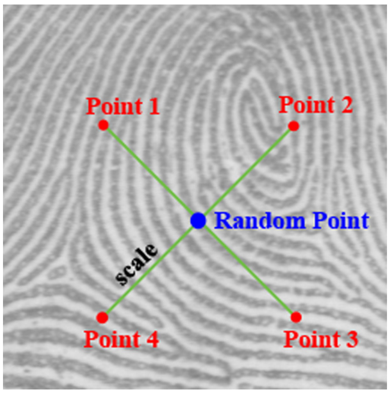


Fig. 7 Position of four assistant point's base on Random Point.

two important points: first, by performing Chaos Game mechanism on a fractal a new fractal can be produced. Second and more important, while performing Chaos Game mechanism for producing the new fractal, besides properties of fractal some parameters can be achieve which would be useful in identification process. If we perform Chaos Game mechanism on a triangle, the procedure will be as the following: first, an accidental point is chosen. This point is the start point and it is not important in what situation it is. Then, in the second step an accidental number in the scope of [1, 2 or 3] is chosen. If 1 is chosen it means summit A, if 2 is chosen it means summit B, and eventually if 3 is chosen it means summit C in triangle. Then, from the present point we step forward half way toward chosen summit and draw a new point. Again, we make an accidental choice and repeat the same process for several times (for example 50,000 times). This way a shape which is the Sierpinski Triangle is drawn. In Fig. 6 four steps of Chaos Game mechanism are shown.

4. MAKING NEW FRACTAL BASED ON FINGERPRINT

A fingerprint is a fractal and from fractal outlook it has fractal dimension parameter which is not sufficient for identification. As mentioned in Sec. 3.2, by the aid of Chaos Game a new fractal can be made and while making the new fractal more parameters can be obtained. As a result, based on a fingerprint and a pattern which will be pointed at afterwards the new fractal is made. The mechanism is such that a pixel of fingerprint is selected by chance. A point has 2 states: first, the pixel can be an in or zero or it might be an out or 1. Both of these states cannot be sufficient for identification, so an accidental point is chosen and based on a new parameter, which is called Scale, we find four points around the aforementioned accidental point. If accidental point is $A[i, j]$, four points will be:

$$\begin{aligned}
\text{Point1} &= A[i - \text{Scale}, j - \text{Scale}];\\
\text{Point2} &= A[i + \text{Scale}, j - \text{Scale}];\\
\text{Point3} &= A[i + \text{Scale}, j + \text{Scale}];\\
\text{Point4} &= A[i - \text{Scale}, j + \text{Scale}].
\end{aligned}$$

These four points are shown in Fig. 7. Having these four points, 16 states are made which we divide into five distinct groups. First group is the state where pixels of all these four points are white, second group is the state where just one pixel from the mentioned points is black and all others are white. Third group is the state where the number of points with black pixels is two, fourth group is the state where the number of points with black pixels is three, and finally fifth group is a group where all four points have black pixels. Considering binary structure, these four points and creation of sixteen possible states, all of them and their assortment based on the mentioned classification are shown in Table 1. Sixteen created states in Table 1 make five groups and for making a new fractal in Chaos Game process we use a square which is shown with five tips in Fig. 8. These five tips are named with alphabets to make the new fractal image which is obtained from the fingerprint. The result of fractal which is made by the above procedure for several samples of fingerprints is shown in Fig. 9.

5. PARAMETERS EXTRACTION

As mentioned before, while making new fractal Chaos Game mechanism, new parameters are

Table 1 Category of Different State of Points.

Points 1–4	Category	Points 1–4	Category
0 0 0 0	1	1 0 0 0	2
0 0 0 1	2	1 0 0 1	3
0 0 1 0	2	1 0 1 0	3
0 0 1 1	3	1 0 1 1	4
0 1 0 0	2	1 1 0 0	3
0 1 0 1	3	1 1 0 1	4
0 1 1 0	3	1 1 1 0	4
0 1 1 1	4	1 1 1 1	5

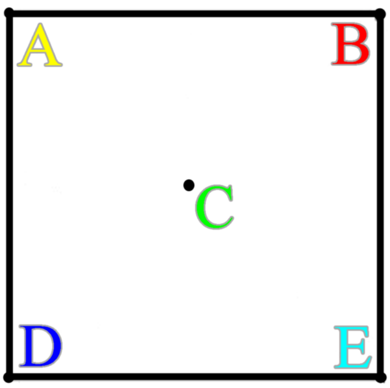


Fig. 8 Five points that are mapped on five categories in Table 1.

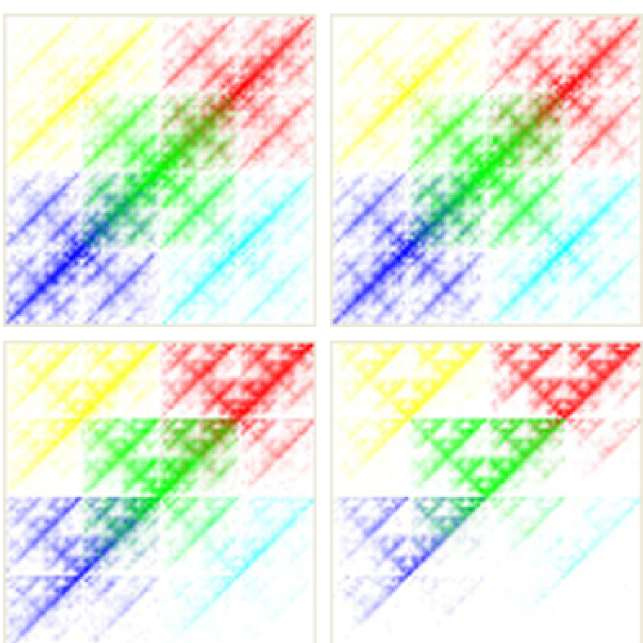


Fig. 9 Four fractals that generated from four fingerprints.

obtained which can be useful in identification. In part four it was cited that regarding four defined points for pixels of those points, five states can be created which are classified into category1 to category5. Then, we repeat Chaos Game mechanism 100,000 times and in each repetition by identifying four pixels of the points one of possible states is chosen and one unit is added to the counter of that category. This way, at the end of Chaos Game mechanism total of all five categories is equal to the number of repetitions, *i.e.* 100,000. By dividing each of categories by 100,000 they are standardized and we state them in the zero to one span. Therefore, for each fixed quantity for Scale parameter, which is the distance of points to the accidental point, five parameters are calculated. As five parameters with accuracy of (0.02) are not enough for identification, the above mentioned procedure is calculated for quantities of 10 and 15 for Scale.

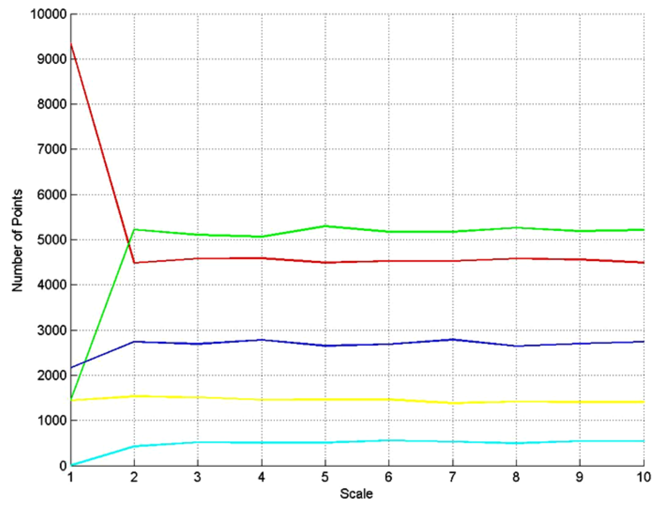


Fig. 10 Spectrums of a fingerprint.

As a result, we will have ten parameters and considering the accuracy of 0.02 in the span of zero to one we will have 50 varieties. By having ten parameters we will reach $50^{10} = 9.76 \times 10^{16}$ varieties for fingerprints, which guarantees unity of fingerprints. On the other hand, if we calculate Scale with different quantities for a fingerprint, we will have five independent spectrums and with the accuracy of 0.02 these spectrums are able to identify fingerprint based on the given mechanism. Figure 10 illustrates spectrums of parameters which are obtained from a sample fingerprint.

6. IMPLEMENTATION

The presented technique in this report (FFIS) has been carried out by MATLAB and has been experimented on 600 samples of fingerprints,[18] of which there are four samples of each. A sample of images used is shown in Fig. 11. Results obtained show

(a)

(b)

Fig. 11 (I) Before preprocessing, and (II) after preprocessing.

Table 2 Result of Search and Feature Extraction.

Fingerprint Name	FEST (ms)*	ST (ms)**
Fig1001B1	1839	32
Fig1152B1	1906	32
Fig1263B1	1870	31
Fig1484B1	1898	34
Fig1545B1	1901	31
Fig1001B2	1885	32
Fig1001B5	1863	33

*FEST: Feature Extraction and Save Time (millisecond).
**ST: Search Time in 600 Samples (millisecond).

100% success for this technique. In another experiment 50 samples of fingerprints for which 20% of image was accidentally deleted were analyzed with the remaining parts, and again 100% success was obtained and this shows stability of the presented method encountering deletion of some parts of image. Table 2 illustrates data related to time of searching in a database, which includes 600 samples, and also information related to time of deciphering and saving features of fingerprint in a database for some fingerprint samples. It must be noted that the experimenting system had a CPU Intel Celeron 2.60, 512 MB RAM and Windows XP as its operating system.

7. CONCLUSION

Identification process by fingerprint based on popular methods such as Minutiae Based Algorithm and Pattern Based Algorithm is a time consuming process; thus, it encourages researchers to study new methods with more efficiency. As the fingerprint is a fractal, properties of fractals can be used in analysis of fingerprints. One of these properties is fractal dimension calculation, which because of low level of accuracy cannot be efficient in identification, but it can be used in classification. From other properties of fractals deciphering features through Chaos Game mechanism can be relied on. In this mechanism, as many as required features of fingerprint are achieved. We have extracted five features with various scales and with accuracies of 0.02. This led to a great variety and in this way we can guarantee keeping the unity of fingerprint in presented technique. Using the presented process in this study has led to expansion of efficiency of automatic systems in identifying human by fingerprints and the speed which is presented in this system is our basic proposed expansion.

8. FURTHER RESEARCH

The outlook presented in this study has provided a new viewpoint for analyzing fractals and by using Chaos Game mechanism new features have been extracting for each fractal. Therefore, it can be useful in cases such as classification of histopathology slides in medicine, generation of new music, generation of various art forms, signal and image compression, fractal antennas, technical analysis of price series, etc.[19,20]

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