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Fingerprints Authentication Using Grayscale Fractal Dimension

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Abstract

Characterizing of visual objects is an important role in pattern recognition that can be performed through shape analysis. Several approaches have been introduced to extract relevant information of a shape. The complexity of the shape is the most widely used approach for this purpose where fractal dimension and generalized fractal dimension are methodologies used to estimate the complexity of the shapes. The box counting dimension is one of the methods that used to estimate fractal dimension. It is estimated basically to describe the self-similarity in objects. A lot of objects have the self-similarity; fingerprint is one of those objects where the generalized box counting dimension is used for recognizing of the fingerprints to be utilized for authentication process. A new fractal dimension method is proposed in this paper. It is verified by the experiment on a set of natural texture images to show its efficiency and accuracy, and a satisfactory result is found. It also offers promising performance when it is applied for fingerprint recognition.

Keywords: Fractal Dimension, Box Counting, Fingerprint, Authentication.

الخلاصة

لوصف الاشكال المرئية دور مهم في التعرف على الأنماط من خلال الشكل العام ولقد تم استخدام عدة أساليب في استخراج المعلومات ذات الصلة من الشكل ولقد كان تعقيد الشكل هو الأسلوب الأكثر استخداماً لهذا الغرض وقد اعتمد البعد الكسوري كمنهج لتقدير درجة التعقيد في هذه الاشكال. يُعد بُعد المربع أحد الطرق المستخدمة في تقدير الابعاد. ويستعمل اساساً لوصف التشابه الذاتي في هذه الاشكال. الكثير من الاشكال تمتاز بخاصية التشابه الذاتي ومنها البصمة والبصمة هي من تلك الاشكال التي يتم فيها استخدام بُعد المربع للتعرف على بصمات الأصابع لاستخدامها في عملية التحقق والمصادقة. في هذا الحث نقترح طريقة بعد كسوري جديد يستخدم للتحقق والمصادقة على صور طبيعية وتظهر في هذه الطريقة الكفاءة والدقة عند تطبيقها والمصادقة على بصمات الأصابع.

Introduction

Almost forty years ago, the word fractal was born when introduced by the mathematician Mandelbrot in 1973 [1]. Fractal has come to have great meaning to people of many different professions since that time. Mandelbrot was found that this type of object needs different type of geometry that did not seem to correspond with any of the existing categories of geometry. Inspired by the new study, Mandelbrot introduced a new kind of geometry called Fractal Geometry. The applications of the Fractal Geometry seem endless [2-4], although that the study of this geometry has just begun, and day after day, mathematicians and scientists know more about this branch of knowledge [5, 6]. There will be more important emerging discoveries regarding the Fractal Geometry in our universe. In real life, there are a lot of phenomena cannot be described by the traditional geometry; self-similarities and objects which have a non-integer dimension. One of the most important properties of the non-integer dimension is the ability to give and characterize a suitable description for objects such as mountains, clouds, coastlines, etc. Due to this importance, many methods have been proposed to estimate non-integer dimension. Mandelbrot in 1982 [1] is the first who described an approach to find the fractal dimension while he tried to find the length of the coastlines. After the developments in computer image processing methods, the principles of estimating the fractal dimension for images are also developed. Peleg in 1984 [5] worked on the 2D images and in this case the image can be represents as a hilly terrain surface. After that, Sarkar and Chaudhuri [6] designed one of the popular methods in box counting theorem it named differential box counting algorithm (DBC), [7-10] which is used to estimate the dimension for gray level images 3D. In this paper, we designed a fingerprint authentication system based on generalized box counting dimension (pixel covering) [11] to estimate the fractal dimension.

The rest of this paper is organized as follows, a brief explanation about what fractal dimension & fingerprints properties is given and was discussed., an improved fractal dimension method (pixel covering) & the algorithm for fractal dimension estimation for some fingerprint images is presented also. Finally we discussed some results & the conclusion is given.

Fractal Dimension

Fractal dimension is used to calculate the complexity of the objects. The most interesting feature of the fractal dimension is the possibility of using it in many applications, such as, image analysis, medical textures, authentication, etc. Several methods have been developed to estimate the fractal dimension and the most popular one is the box counting dimension. In everyday life, human faced a lot of phenomena that concern about events and need to be classified. The complexity of phenomena is one of the features observed by human which is calculated by estimated parameters called fractal dimension. Now, we have to know what fractal dimension basically means. Before we answer this question, we should mention that, the traditional geometry cannot be used to describe these phenomena, such as clouds, mountain, trees etc. [12-15]. The need to describe phenomena led to think in different directions, but the first full original idea was coined by Mandelbrot to find the length of the coastlines. The method considered all point that have ε distance from the coastlines, these points are formed together a 2ε strip width, and the length of the coastlines equal to $L(\varepsilon)$ which is equal to the width of the strip divided by 2ε while ε decreased, $L(\varepsilon)$ is increased. Mandelbrot applied this thought for many coastlines and put the following formula:

$$L(\varepsilon) = F\varepsilon^{1-D} \qquad (1)$$

where F and D are constants for specific coastline, here D represents the fractal dimension of the line. It can be derived from least square linear fit of log $L(\varepsilon)$ and $log\ (\varepsilon)$.

After this great definition of fractal dimension that proposed by Mandelbrot, which is considered, as the cornerstone for other researchers. The developments of computers play an important role in increasing the knowledge about fractal dimension, since it is used to describe the complexity of irregular objects. The most advantage to find the fractal dimension is to get information about the geometric structures of the fractal. The general definition of the fractal dimension is as follows:

Given a bounded set Y which is either self-similar or has some types of self-similarity, i.e, it is a union of N_r different non-overlapping parts each of which is similar to Y scaled down by a ratio of r, then the fractal dimension D is defined as:

$$D = \lim_{r\to 0} \frac{\log(N_r)}{\log(1/r)} \qquad (2)$$

The previous quantity D is a statistical quantity and it is clearly shows how a given fractal Y fills the space when viewed at finer scales. Many researches used this value to measure the complexity of many images even if it is not completely self-similar but at least it contains a type of self-similarity. Fingerprints is one of those objects that have a partial self-similarity since it consist of lines and corners as will be explained in the next section. Due to this point, the fractal dimension is used in this work for fingerprint images to be used for authentication, where the fingerprints are considered as the most important feature for authentication and security with different level of importance.

Fingerprint Properties

Fingerprints can be defined as the impression left by tiptoe and hands and soles of the feet when contact the polished surface or those distinctive lines (Ridges) that parallel with other low lines (Furrows) that take a different form on the skin (fingers, inside hands, soles of the feet).

Fingerprints became an important feature of biometric system authentication because of the following properties:

1- Unexchangeability: the details of the fingerprint cannot be change in time.

2- Uniqueness: every person has different fingerprints that differ from any other person in the world; even the twin persons have different fingerprints.

The details of the fingerprints that mentioned is basically can be classified by Sir Francis [16] as shown in Figure 1, which is called Minutiae.

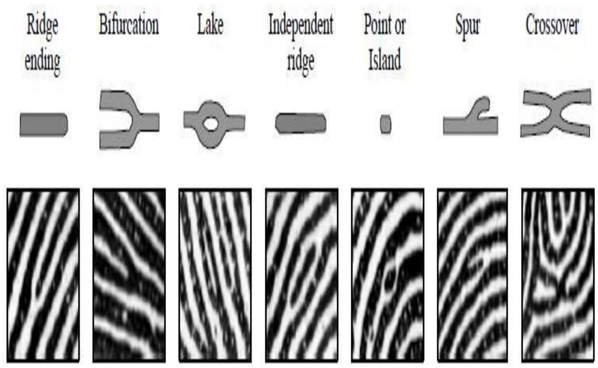


Figure 1: The most important features in fingerprints

The previous features are classified into three types [17]:

1. The interleaved valley's and ridge Figures (2 and 3), such as; arch, whole, loop, etc.
2. The ridge bifurcation and termination known as minutiae.
3. Ridge attributes as a permanent detail, such as breaks, ridge width, scars, shape, and width.

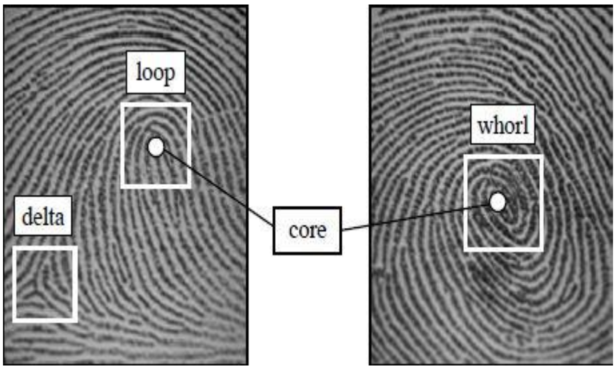


Figure 2: The singularities (loops, delta, and whorl)

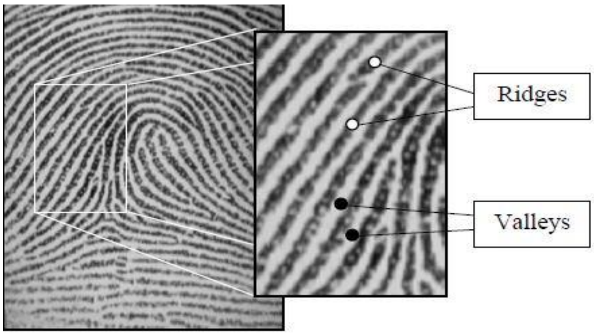


Figure 3: Fingerprint image with ridges and valleys

At last but not least, to get the fingerprints, there are two methods:

- Offline: is a method to have the fingerprints in papers or documents or scanned images and it very popular.
- Online: have the fingerprint by electronic tools.

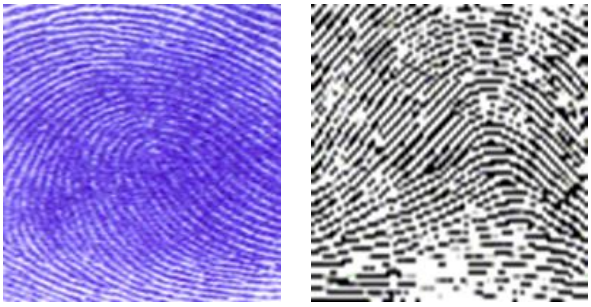
For the previous two types since we deal with the images of dimension two, an existing fingerprint images are used.

The Proposed Fractal Dimension

The box counting method is one of the pixels covering method for estimating fractal dimension and it is used to cover an object in $2D$ image with grids of different box size, and then we calculate the boxes which contain at least one point from the object. The size of the object is estimated for different box-size r, but the final estimation is chosen for a one size r, because we obtained a set of estimations then the dimension is the relation between the number of boxes N_r and the step scale r.

Algorithm

1. At first, the interred image (got by any tool) should be converting to 2D image of type (monochrome) as show in Figure 4.



(a) (b)

Figure 4: a-Original fingerprint, b- After convert to (2D)

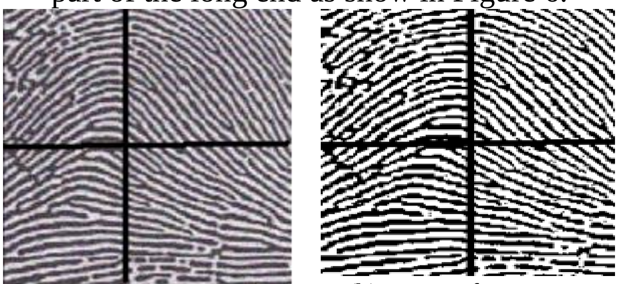
2. After having the (2D) image, we have to make a process of three stages to make the image ready:

a. Sit the center of the image: sine the image (that obtained by fingerprint scanner), by draw two crossed line as shown in Figure 5.

(a) (b)

Figure 5: a- Before add the lines, b- Add the crossed lines

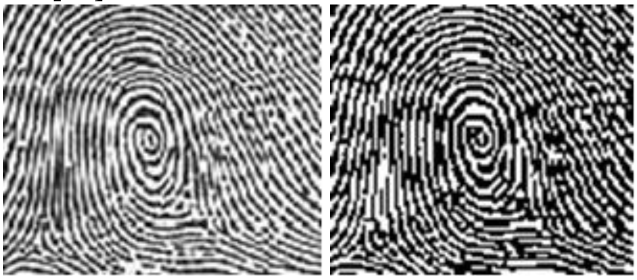
b. The second process is to make the ends of the two lines equal by cutting the additional part of the long end as show in Figure 6.



(a) Image before cutting with size (200×200) (b) Image after cutting with size (163×193)

Figure 6: Sitting the center

c. The last stage of this process is to make the image ready to use for calculation, which is called (lanky process). It is a process to make the image lank and it has been proved that this process is helped to characterize the fingerprint feature and speed in running the process, while the program estimate the fractal dimension and the most important property of this process. It makes us get dimensions with least difference, especially, when we have very closed fingerprints images as shown in Figure 7 **[**18].



(a) Before lanky process (b)After lanky process

Figure 7: Lanky process

3. After making some image processing, the image become ready to estimate its dimension, as shown in the following process. The new process to estimate the fractal dimension by pixel covering.

a. Enter the image Y.

b. Let m, n be the dimension of the image window.

c. Let $d =$ maximum (m, n).

d. Set the resolution to be equal to $(1/d)$.

e. Set N (boxes number)$= 0$, and $s, t = 1$ which are control the movement of the boxes vertically and horizontally.

f. Pick the array I with size (s, t), which represents the test matrix according to the values of s, t and starts in the north-west corner of the image matrix.

g. Check weather $I(s, t)$ contains at least one member from the original image window if it does then put $N = N + 1$, then change the values of (s, t) and go back to 6.

h. Calculate the linear fit between N and resolution.

In the following is an example (hand by hand) to show how we apply the box counting for the processed image.

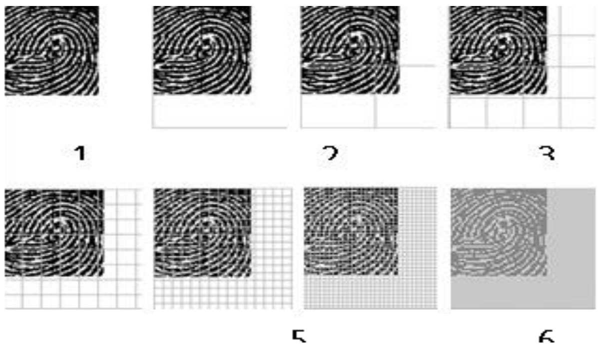


Figure 8: Hand by hand box counting for processed image

After that, the relation between the number of boxes and the scale of the box r represents the dimension. For implementation using Matlab, the interred image is read as the binary matrix Y as the flowing algorithm:

<u>The Algorithm</u>

Input $m, n \in N$, where n is a large positive integer
$p = 2^n$, $q = pm - 1$
Input $t_0 \in Z_q$
Input Y *% the image*
Factor $(t_0)=(k_1,k_2,\ldots k_m) \in Z_q^{\,m}$
For $t_0=0 : 2^{nm}-1$
For $i = 1: m$
$t_{i-1}=t_i p+k_i$
$x_i=k_i/p$
End i
If $x=(x_1,x_2,\ldots,x_m) \in Y$, then $No=No+1$
End t_0
Output $(x_1,x_2,\ldots,x_m) \in I^m$
Output $\hat{\delta} = \frac{\ln No}{n \ln 2}$
Then $\hat{\delta}$ is box dimension of Y, and if $\hat{\delta}$ is non-integer, then Y is fractal.

Implementation and Analysis

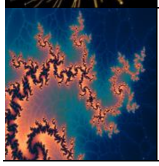
To show the results of the new algorithm, we take five fingerprints image that belongs to one person but with different sizes and Table 1 shows the values of the fractal dimension according to each size of these fingerprint images.

Table 1: Box counting dimension for the fingerprint with different sizes

Processed Image with crossed lines	Image size before cutting additional parts	Image size after cutting additional parts	Fractal dimension for cutting image with lines	Fractal dimension for cutting image without lines
	475*475	445*445	1.7368	1.73594
	475*475	445*445	1.7442	1.74396
	475*475	435*435	1.7409	1.73987
	475*475	425*425	1.7457	1.74489
	475*475	415*415	1.7447	1.7438

After this process the image without crossed lines and the box counting dimension should be save with the name of the person that the fingerprint belongs, so when we interred the name of that person, the computer should return the fingerprint and the box counting dimension to make sure that the person is the specific one. Table 2 shows the comparisons between box counting dimension and the improved fractal dimension. For the next stage and after we have the previous results of fractal dimension for a sample of fingerprints, we found, each fingerprint has been processed and gets its fractal dimension before saving the information about it, we should be certain that there is no such fingerprint has the same information. This is done by make a unique folder for all fingerprints that contains all information about it, such as, the name of the person with this fingerprint, the size of fingerprint image, and its fractal dimension. Therefore, this is a helpful process in the authentication process. When we have another fingerprint for some person who would like to make an access to any secure system, an efficient saving procedure and non-repeated data give a certainty that this fingerprint belong to a specific person not to another.

Table 2: The comparisons between Box counting dimension and the improved fractal dimension

Fractal Image	**Size**	**Box Dim**	**Time**	**proposed FD**	**Time**
	4*4	0.5211	0.00399	0.5199	0.00210
	**5*5**	0.811	0.0081	0.801	0.0078
	6*6	0.992	0.040	0.981	0.00211

Conclusion

This paper has focused on an important mathematical feature called fractal dimension. The most important approach to find the fractal dimension and the fuzzy fractal dimension with its structures are reviewed. Some of the very interesting approaches have been surveyed also. Our main proposed methods are obtained by making some improvements on the classical methods. Satisfactory results have been obtained upon applying these new methods, some useful features are pointed out. The relations between the fractal dimension and many applications are deduced and summarized with some examples. The new algorithm is computationally good and gives satisfactory results on practical data.

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