FRACTAL ANALYSIS METHODS IN INVESTIGATION OF ULTRALOW DOSES EFFECTS

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Abstract

The methods of fractal and multifractal analysis are now widely used because they allow us to analyze and classify digital images with complex structure. We present the results of application of these methods to images obtained by sensitive crystallization method. It was developed for studying blood images and now finds increased use in analysis of medicines, determination of food and soil quality. It seems these methods are rather perspective both in comparing images from different classes and in obtaining a classifying sign for a group of images. Problems arising in images classification are also discussed.

1. INTRODUCTION

Investigation of many natural processes is often based on digital images which show the process states at different instants of time. We consider images of EMF distribution, EEG records, invariant sets of dynamical systems or clusters growing in diffusion process.

As a rule the first analysis of an image we perform visually. Our vision defines differences in image structure by revealing topological invariants – objects that may be considered as image peculiarities. Expert knowledge is based on such a perception: to find an image feature an expert mentally constructs an associative series of images and presents the result of observation as a description of the image structure.

When using mathematical methods of image analysis we also tend to obtain a feature that may be considered as a description of an image structure. Thus our methods are based on formalization of our visual perception – the formalization of expert knowledge. The methods using appropriate formalization that may lead to defining topological invariants seems to be rather promising and give reliable results.

The analysis of images illustrating low doses effects is mainly solved by visual method. By now in this area of research methods of sensitive crystallization and capillary dynamolysis gain wide acceptance. Sensitive crystallization method is based on adding low doses of a matter (blood, plants extract, food) to cuprum chloride solution. By the form of the obtainned crystal one may decide on an organism (for blood crystals) or the added matter state. Capillary dynamolysis method is application of a solution of a matter (made by a definite method) to filtering paper.

Sensitive crystallization now may be successfully applied in the analysis of food, homeopathic preparations [3, 7, 12], and capillary dynamolysis is widely used in the analysis of soil [8]. The images obtained by the mentioned methods have extremely rich and complex structure, but the experience in application of mathematical methods of analysis is mainly concerned with the second order statistics [3].

Our experience in analyzing biomedical preparation images (in [6] we calculated Rényi spectra for images of pharmacological solutions of Ag) testifies that the good separation of spectra results in successful classification of similar images. In this work we apply fractal signature and multifractal methods to analyze crystals of blood. The results of experiments show that this method is reasonably perspective and may lead to obtaining a set of classifying signs. Moreover, the interpretation of these signs may help in understanding of the intrinsic processes generating such crystals.

2. SENSITIVE CRYSTALLIZATION METHOD

The method of sensitive crystallization was developed by Pfeiffer as early as in 1930h [11], but still is pioneer one. The method is based on addition of

whole blood (or plant extracts) to a solution of cuprum chlorides. The foundations of the method and a systematics of experiments with blood crystals are described in detail in [13]. In [14] the author studied influence of metals on human being and assumed that results of the crystallization may be indirect proof of malfunction of metallic processes in a patient blood. The method also results in defining organs malfunctions and pathological processes in organism. For blood the crystallization by cuprum chlorides is a sensitive morphological test. Pfeiffer considered such a crystal as a picture of the state of the whole organism and connected parts of the body with areas of the test image. The studying of extensive experimental materials resulted in revelation and classification of specific forms in crystallization images, being every class may be matched to a type of disease and the location of a form on the test image corresponds to location of an organ.

It seems the blood formulation (low doses of some substances) defines the type of crystal. Currently the method has attracted considerable interest of many scientists. B. Waldburger [16] assumes that crystal structures demonstrate a dynamic of processes in human organism and discusses perspectives of blood crystal analysis.

The application of rigorous mathematical methods to various kinds of blood crystal images allows us to extract many features such as regular areas, cavities and structures, and find informative classification signs.

3. IMAGE ANALYSIS METHODS

3.1. Multifractal spectrum calculation

Multifractal spectrum of a digital image is a set of fractal dimensions of its fractal subsets. We consider a special density function [17] to calculate the singularity power for every pixel. Then we combine all the pixels with close values of density function, which results in partition of the image on the subsets – so called level sets. For each level set we calculate its fractal dimension.

Let μ be a measure defined through pixel intensities. For $x \in R^2$ we denote $B(x,r)$ a square of length r with center x. Let $\mu\big(B(x,r)\big) = kr^{d(x)}(x)$, where $d(x)$ is the local density function of x and k some constant. Then

$$d(x) = \lim_{r\to 0} \frac{\log \mu(B(x,r))}{\log r}$$

The density function measures the non-uniformity of the intensity distribution in the square $B(x,r)$. The set of all points x with local density α is a level set $E_\alpha = \{x \in R^2 : d(x) = \alpha\}$. In practice, not to increase the number of level sets, one really consider the sets $E(\alpha,\varepsilon) = \{x \in R^2 : d(x) \in [\alpha, \alpha+\varepsilon]\}$.

Then we calculate fractal dimensions of level sets E_α and obtain the multifractal spectrum $f(\alpha)$.

3.2. Fractal signature method

The described method may be applied to calculate (approximately) the area of gray level surface for an image. The technique was described in [4], used for solving various application problems in [10, 9, 5]. We applied this method in different variants to analyze biomedical preparation images [1, 2].

Let $F = \{X_{ij}, i = 0,1,\dots,K, j = 0,1,\dots,L\}$ be a gray level image and X_{ij} be the intensity of the (i,j)-th pixel. In a certain measure range the surface of the function F can be viewed as a fractal. In image processing the function F is a nonempty bounded set in R^3. The surface area A_δ may be calculated using the volume of a special δ-parallel body ("blanket") with the thickness 2δ.

For $\delta = 1, 2, \dots$ the blanket surfaces are defined iteratively as follows:

$$u_\delta(i,j) = \max\left\{ \begin{matrix} u_{\delta-1}(i,j) + 1, \\ \max\limits_{|(m,n)-(i,j)|\le 1} u_{\delta-1}(m,n) \end{matrix} \right\},$$

$$b_\delta(i,j) = \min\left\{ \begin{matrix} b_{\delta-1}(i,j) - 1, \\ \min\limits_{|(m,n)-(i,j)|\le 1} b_{\delta-1}(m,n) \end{matrix} \right\}.$$

The volume of the blanket Vol_δ is

$$Vol_\delta = \sum (u_\delta(i,j) - b_\delta(i,j)).$$

The formulas for the surface area are: $A_\delta = \frac{Vol_\delta}{2\delta}$ or $A_\delta = \frac{Vol_\delta - Vol_{\delta-1}}{2}$. Basing on these formulas one may calculate fractal dimension of the surface, vector of fractal signatures that is the set of values $\frac{\log A_\delta}{\log \delta}$ or divide the area on cells and calculate the dependence of surface area on the size of a partition cell. For color images all experiments are performed in different components of a palette and the component choice may influence on the result considerably.

4. EXPERIMENTS

Experiments were performed for typical images of blood crystals and images obtained by magnification of a part of image.

4.1. Typical forms of blood crystals

The images of crystals correspon-ding some organ malfunctions [15] are shown on Figure 1.

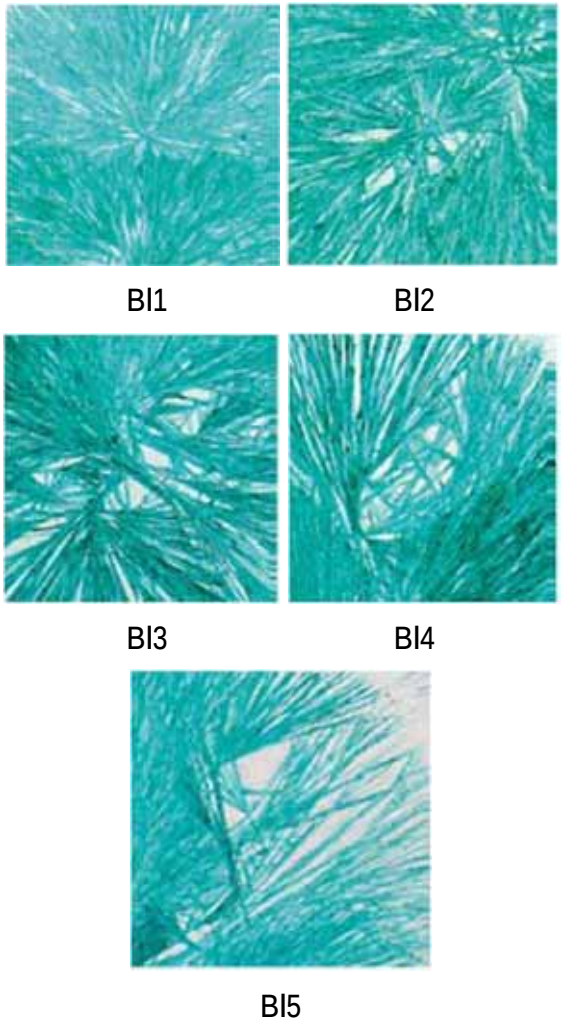


Figure 1. Typical forms of blood crysrtalls

Here Bl1 – crystallization in the star form with hole structure, typical for acute inflammatory process; Bl2 – crystallization in the star form with hole structure, chronic inflammatory process; Bl3 – hole structure of crystals, degenerative processes; Bl4 – hollow form of the crystal, benign tumor; Bl5 – hollow form of the crystal with transversal structures, malignant tumor.

4.1.1. Fractal signature method

The calculation of the dependence of surface area on cell size leads to the following results.

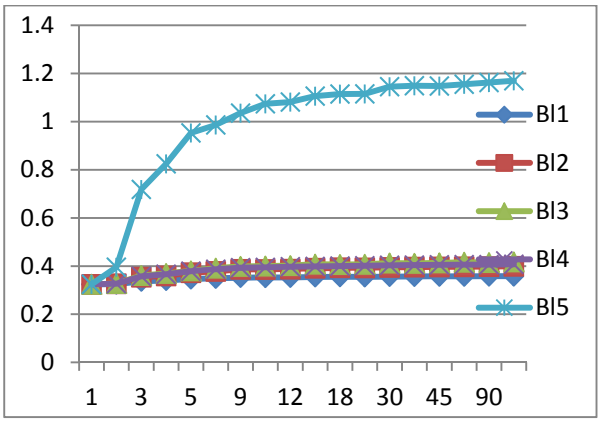
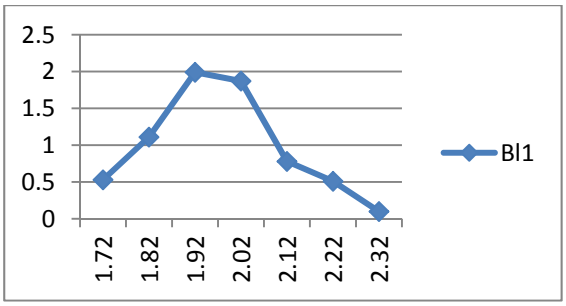
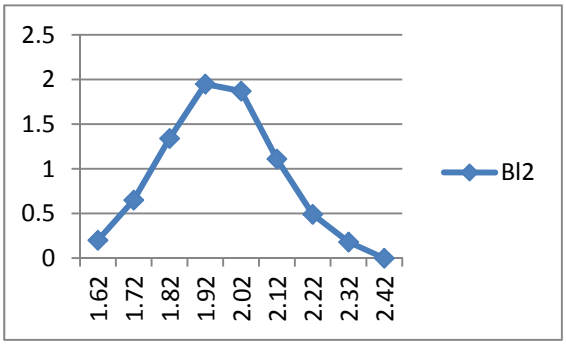


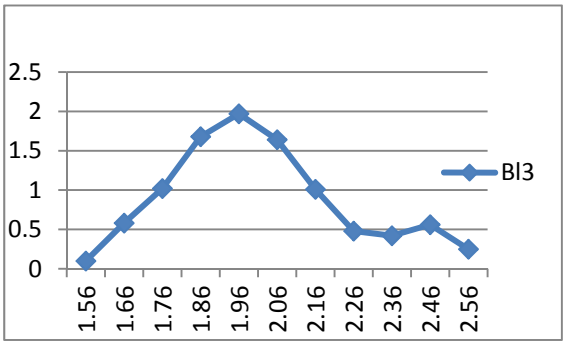
Figure 2. The graphic for malignant tumor is considerably differ from others

4.1.2. Multifractal spectra

On the following graphics singularity values α are on X-axis, and fractal dimensions $f(\alpha)$ — on Y-axis.







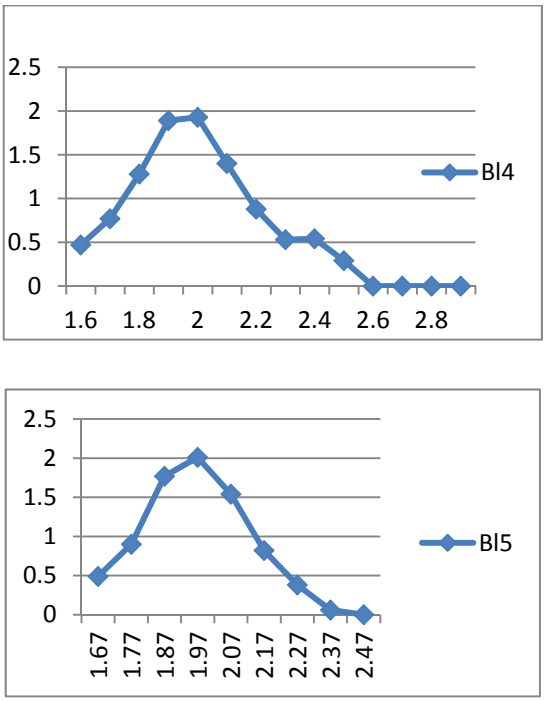
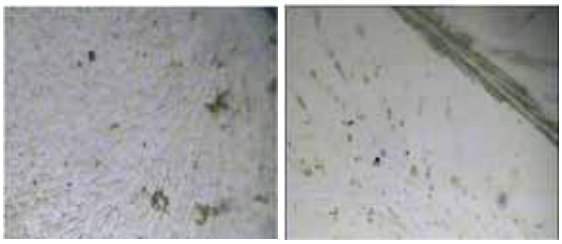


Figure 3. Multifractal spectra calculated by density function

4.2. Magnified images

4.2.1. Fractal signature method

Now we compare the images of blood crystal and carrot crystal.



A3 B3

Figure 4. Magnified parts of crystals, blood (left) and carrot (right)

For both images we calculated the dependence the surface area on cell size. The corresponding graphics are shown on Fig. 5.

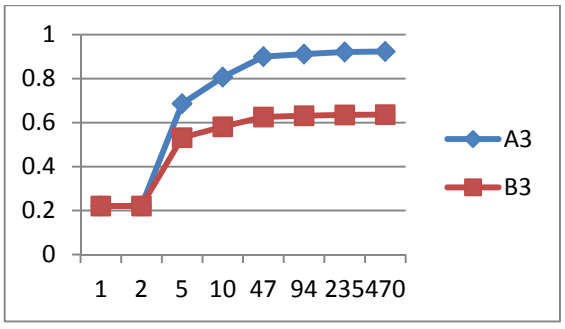
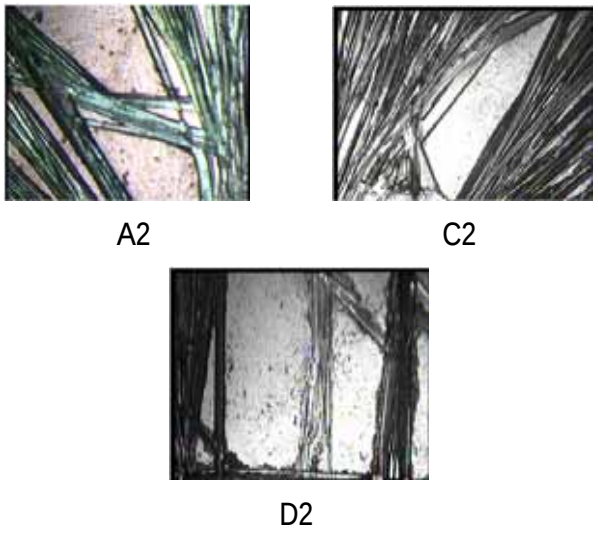


Figure 5. Application fractal signature method to magnified images

4.2.2. Multifractal spectra

Now we consider magnified parts of blood crystal images (parts were taken at the same places) for 3 patients.



A2 C2

D2

Figure 6. Images obtained by magnification of parts of initial crystals

The results of multifractal spectra calculations are shown below.

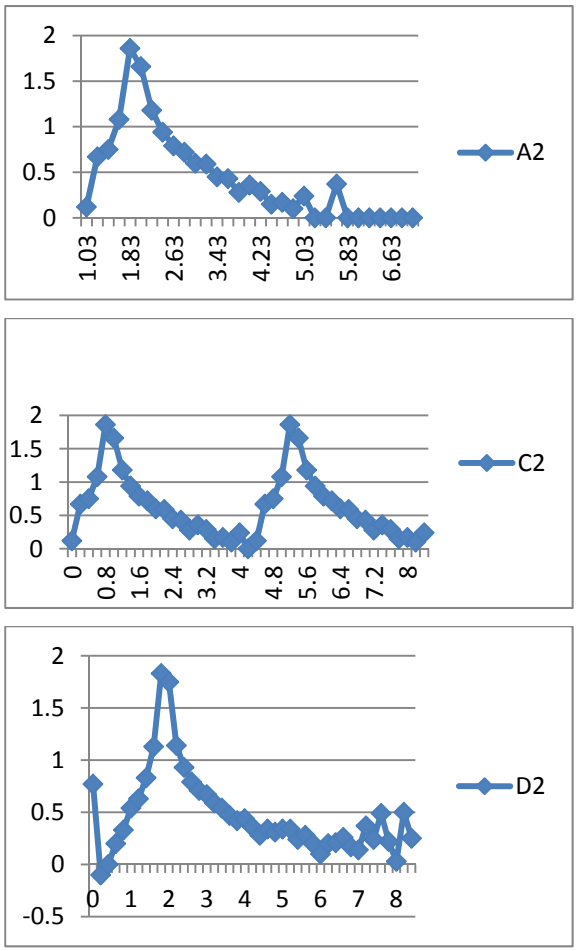


Figure 7. Calculation of multifractal spectra

5. CONCLUSION

The use of multifractal methods to images obtained by sensitive crystallization seems to be very perspective. One may compare images from different classes or find a common sign for a group.

It should be noted that the context is important, because images obtained in different experiments may have similar structures. Hence the classification problem should be solved in collaboration with researchers, and the image structure may be not unique feature to take into account.

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