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FRACTAL ANALYSIS IN ELECTROGRAPHY FOR BIOLOGICAL SYSTEMS DIAGNOSING

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Pentru a pune în evidență aplicațiile şi posibilitățile largi oferite de metodele electrografice în diagnosticarea medicală, cât şi în cercetarea din domeniul biologiei am desfăşurat o serie de experimente având ca obiect prelucrarea imaginilor electronografice cu ajutorul analizei fractale şi statisticii.

In order to point up the wider applications and opportunities offered by the electrographic methods in diagnosing and also in biological research we conducted a series of experiments covering electronographic imaging by means of fractal analysis and statistics.

Keywords: electrography, fractals, fractal dimension.

1. Introduction

A complementary approach in medical diagnosing is provided by the bioelectrographic technologies which explore the human biological energy field and that of living bodies. It was observed and validated the fact that within the biological energy field there occur the first disease triggering changes which further lead to pathological modifications in the physical body. By estimating the modifications in the biological energy field, there can be taken caution measures in order to anticipate the actual manifestation of the disease in the body.

The biological energy field is the carrier space of energy and information formed through the multiple reflections phenomenon, beyond the limit of the physical body and it represents the resultant of fields of different origin: electromagnetic fields, acoustic fields, etc.

This field was pointed up to by using electrographic techniques, namely by exciting the living body/organism under investigation with high frequency and high voltage impulses.

The interaction between the biological energy field and the electromagnetic one generated by the high voltage impulse can be captured in the form of electromagnetic images which are unique for each investigated organism and variable according to the state.

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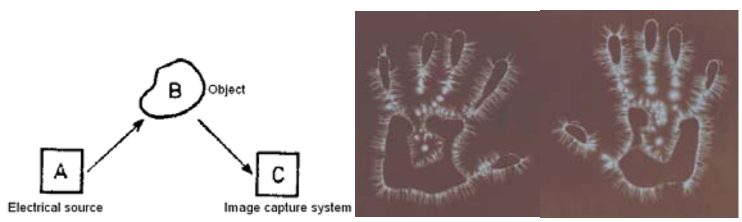
The general purpose of the paper is to point up the possibilities offered by the electrographic techniques in biological and medical research and, in particular, to set a new methodology for processing and interpreting the electrographic images.

1.1. Electrography investigation

Electrography is an investigation technique of the living bodies which is realized by stimulating these by means of electric signals and whose signification is an image response of the investigated subject (fig. 1) [1]. Electrography represents the transposition into image of one or more electric characteristics of the investigated subject, in certain conditions at a given or continuous moment. Electroluminescence electrography is based on the luminescent ionization at the separation point of two different electrical media. Two of the most well-known electrography techniques based on the electroluminescence phenomenon are the Kirlian photography and electronography. In our studies and researches, we used electronography.



(a) (b)

Fig. 1. a) General scheme in electrography; b) EnG - electronographic images (electronographic imprints)

The electronographic technique used in our studies is adequate for studying the radiative fields of the living bodies. These fields are amplified by exposing the investigated organism to an electromagnetic field, generated through a unique monopolar positive or negative triangle-shaped impulse, of high voltage (*e.g.* 4-35kV) and of very low intensity (3-50 mA) with a abruptly ascending and rising slope (5-30 microseconds) and a slowly descending slope (100-500 microseconds). The images generated by the investigated subject stored in a device called electronograph are recorded on radiological film. By the specific electromagnetic impression on the ultra-sensitive film, electrography (or electronography) shows the form of some radiative phenomena generated through certain structures in their entire dynamics - in the subject's tegument and can provide new data about the form and the structure of the electromagnetic field surrounding the investigated subject [2].

One can consider that the electronographic images describe the bioelectromagnetic and informational interaction between the investigated body and the medium.

1.2. Fractal techniques for the electronographic images analysis

The electronographic images (EnG) due to their complexity, to a high degree of non-linearity and fragmentation, ramifications and streamers, have a preponderantly fractal aspect. Because of these facts we chose the fractal technique as an analysis procedure in the electronographic imaging.

The fractal technique, based on the calculation of the fractal dimension of these EnG recordings, offers an appropriate, especially useful, possibility for the automated processing of the electronographic images. In the specialty literature there are many assessment technologies for the fractal dimensions, but the one which is more used and also offers numerical implementation facilities is the box-counting technique.

The „box-counting" dimension is calculated according to the dependence of the contour of the studied object on a used scale factor. The method consists in covering the object's contour with – *s* side squares of the same size (2, 4, 8,...), counting each time the - *N(s)* number of the squares covering the object's contour.

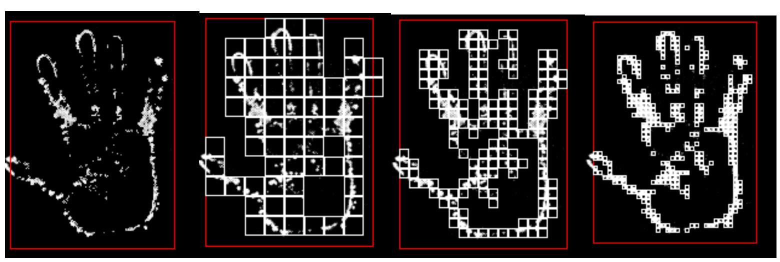


Fig. 2. The covering the object's contour with – *s* side squares

In a logarithmic scale graph the coordinates points (log(N(s)), log(1/s)) are represented according to a line whose slope will represent the "box-counting" fractal dimension. This will be given by the approximation:

$$D \approx \frac{\log(N(s))}{\log(1/s)} \qquad (1)$$

It is supposed that, for small *s*, the following approximation is much better:

$$D = \lim_{s \longrightarrow 0} \log \frac{N(s)}{\log(1/s)} \qquad (2)$$

If the limit exists, it is considered that it is the box-counting fractal dimension of the analyzed object. Since usually this limit converges quite slowly an alternative solution is used. Expression (3) can be considered to be the equation of a straight line described by the coordinate points (log(N(s)), log(1/s)).

$$\log(N(s)) = D \cdot \log\left(\frac{1}{s}\right) \tag{3}$$

The D slope of this straight line is the searched fractal dimension. Through a linear regression procedure, the distribution of the coordinate points (log(N(s)), log(1/s)) is approximated in the direction of the smallest squares through the regression line:

$$Y = a \cdot X + b \tag{4}$$

where: the straight line slope (the value of the „a" coefficient), represents the searched fractal dimension.

As the electronographic images are converted in the final stage in binarized images, a more extended procedure is used in order to calculate the fractal dimension [3]. In a synthetic representation, the „box-counting" algorithm determining the fractal dimension for binary images is the following:

a) the (binary) original image is read;

b) the analysis zone is selected;

c) the box-counting dimension is calculated by counting each time the number *N(s),* which contains at least one point of the object's form. The obtained values are calculated by logarithmation and are represented graphically as a curve whose slope represents the box-counting dimension.

2. The experimental working methodology

In order to point up the applications and the large possibilities offered by the electrographic technologies for diagnosing and research in medicine and biology, in general, we conducted a series of experiments covering electronographic imaging by means of fractal analysis and statistics.

The electronographic images in this article are provided by Dr. Cornelia Guja from the „Fr. I. Rainer" Institute of Anthropology of the Romanian Academy.

For the purpose of the EnG images fractal analysis and for setting a specific methodology for the investigated subject, there were tested more methods and algorithms belonging to the following software: Fractalyse 2.4, Benoit and Fractop (Frankhauser P. *et all* (2005), Trusoft-International.com and Cornforth D. and Jelinek H. (2003)).

There were analyzed 15 algorithms for the numerical calculus of the fractal dimension and of the specific fractal indices [4]: Box Counting grid (Df1), Box Counting free (Df2), Lacunarity (L), Mass Radius (Df5), Dilation (Df6), Correlation (Df7) – Fractalyse; Box Counting (Df3), Perimeter-Area (Df8), Information (Df9), Mass Radius (Df10), Ruler (Df11) – Benoit and a set of methods and algorithms especially designed for dendritic images- Box Counting (Df4), Mass Radius (Df12), Cumulative Intersection (Df13), Convex hull mass radius (Df14), Convex hull intersection (Df15) – Fractop.

The algorithms analysis was done according to criteria such as: robustness, run time, results consistency, memory necessary and the trust level it presents.

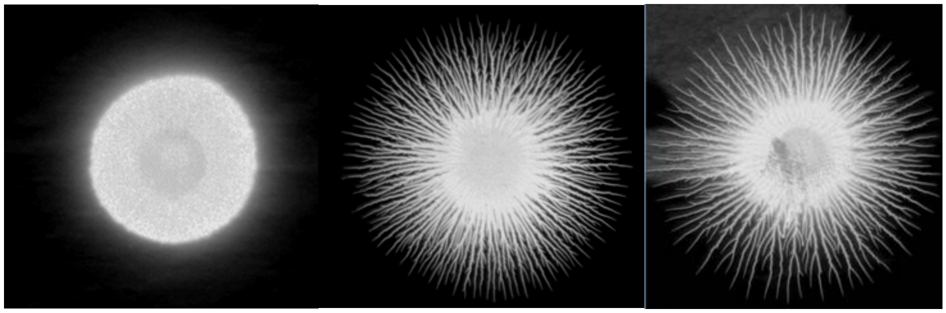
- In the first stage for calibration purposes there were studied the algorithms performances by using a standard trial image – the Sierpinski's triangle. We know this image's analytical fractal dimension $D_f = \frac{\log 3}{\log 2} = 1,58496$.

The initial size of the colour image (4000x4000 pixels, 96 dpi resolution, 15627 MB) was progressively decreased by 10%; thus there was obtained a sample of 10 images for studying the stability and the consistency results provided by the algorithms.

By using usual processing procedures, each BMP type colour image (24-bit) was converted into a grayscale image (8-bit) and then binarized, thus extracting the contour. The contour was extracted for the maximum observed frequency in the histogram (threshold 255) by using the COREL 12 program. After that we went on to calculating the morphologic descriptors and the fractal dimensions for the extracted contours.

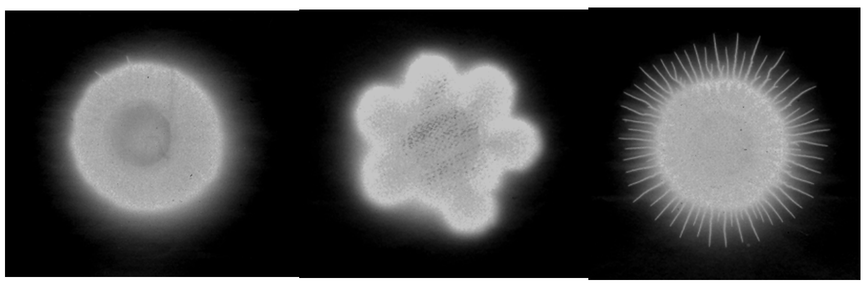
The algorithms selection was made by means of statistic analysis using a control sample, represented by the theoretical fractal dimension analytically determined D_f=1.58496 and it was compared with the other samples formed from the resulted values for the calculated fractal dimensions by means of the researched algorithms.

- In the second stage, after eliminating the inefficient algorithms (Df10 - Df15), there was analyzed a typical EnG image in order to set some biometric indicators and descriptors characteristic to this type of image, to the processing methodology of the EnG images and also to the selection of the most adequate algorithms for this research topic.
- In the third stage, there were studied by means of the fractal and electronographic techniques, the possibilities of the biological substances differentiation. For this purpose there were processed EnG images coming from 3 samples of water: distilled water, water sweetened with sugar and water with salt; the distilled water sample is the control sample. The analyzed electronographic images were of two types, anodic (fig. 3.) and cathodic (fig. 4.)



(a) (b) (c)

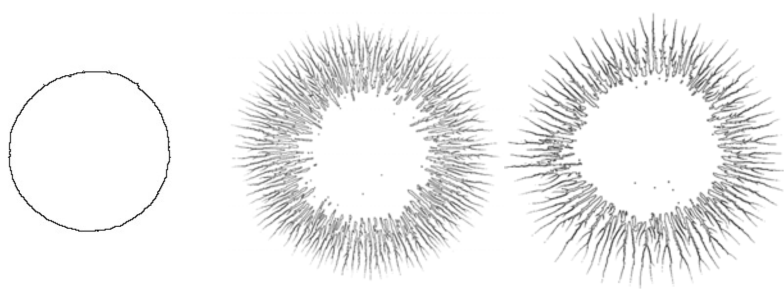
Fig. 3. Examples of the EnG anodic images of the samples a) distilled water, b) water and sugar, c) water and salt



(a) (b) (c)

Fig. 4. Examples of the EnG cathodic images of the samples a) distilled water, b) water and sugar, c) water and salt

By processing the EnG images similarly with the first stage, we found that the cathodic EnG images have a reduced streamers density, compared with the anodic ones. The obtained results proved inconclusive which determined us not to use them.



(a) (b) (c)

Fig. 5. Contour extractions examples of the EnG anodic images of the samples a) distilled water, b) water and sugar, c) water and salt

There were calculated the dimensions and the fractal indicators for the EnG images and the useful results are presented in tables 1, 2, and 3.

Further on we will do the statistical analysis of the data for Df4, Df5, Df6, Df7, Df9 and L.

Table 1

Fractal indicators of the anodic EnG images - distilled water

EnG	L	Df3	Df4	Df5	Df6	Df7	Df9
1	0.9104	1.0400	1.0690	1.2770	1.0140	1.0470	1.0000
2	0.8568	1.0600	1.0800	1.9250	1.0170	1.0070	1.0100
3	1.1036	1.0700	1.0900	1.6610	1.0180	1.0210	0.9900
4	0.9151	1.0300	1.0560	1.4970	1.0370	1.0700	0.9700
5	0.8859	1.0500	1.0810	1.6450	1.0150	1.0540	0.9600
m	**0.9344**	**1.0500**	**1.0752**	**1.6010**	**1.0202**	**1.0398**	**0.9860**
s	**0.0871**	**0.0141**	**0.0117**	**0.2127**	**0.0085**	**0.0228**	**0.0185**

Table 2

Fractal indicators for anodic EnG images – water and salt

EnG	L	Df3	Df4	Df5	Df6	Df7	Df9
1	18.1400	1.4900	1.5210	1.6710	1.1120	1.3600	1.6000
2	22.0518	1.5100	1.5480	1.6320	1.1520	1.6880	1.6150
3	20.8206	1.5100	1.5410	1.7300	1.1520	1.3880	1.6050
4	19.6750	1.5066	1.5334	1.7094	1.1374	1.3674	1.6100
5	21.0000	1.5000	1.5400	1.6460	1.1400	1.5900	1.6034
m	**20.3375**	**1.5033**	**1.5367**	**1.6777**	**1.1387**	**1.4787**	**1.6067**
s	**1.4899**	**0.0085**	**0.0101**	**0.0415**	**0.0164**	**0.1507**	**0.0059**

Table 3

Fractal indicators for anodic EnG images - water and sugar

EnG	L	Df3	Df4	Df5	Df6	Df7	Df9
1	27.7558	1.5800	1.6340	1.4670	1.1550	1.6520	1.6300
2	26.6610	1.5300	1.5841	1.5575	1.1480	1.3698	1.5900
3	25.0920	1.5550	1.6080	1.6500	1.1520	1.4000	1.6100
4	27.4604	1.5600	1.6140	1.8500	1.1588	1.3500	1.6000
5	24.9643	1.5500	1.6012	1.7380	1.1600	1.3820	1.6200
m	**26.3867**	**1.5550**	**1.6083**	**1.6525**	**1.1548**	**1.4308**	**1.6100**
s	**1.3040**	**0.018**	**0.0182**	**0.1498**	**0.0049**	**0.1250**	**0.0158**

3. Results and discussion

In the first stage there were eliminated the Df10 – Df15 algorithms since these do not provide repeatable results or have Df $\leq$ 2.

In the second stage, the remained algorithms selection was made by taking into account the criteria presented above on point 2, by using, similarly with first stage, for the purposes of data processing and statistical interpretation, the following: average (m), standard deviation (s) and the relative errors [%] to the average.

It was found for most algorithms that the relative errors to the average are below 5%. This fact practically proves that the fractal dimension remains constant when the scale is modified, thus confirming the fractal character of the EnG images and the justness of choosing the fractal analysis for their processing.

By studying the Df1- Df9 calculated dimensions from the point of view of the run time for large images processing, the best results are obtained by using the algorithms for Df1, Df4, Df5, Df6 and Df9 (fig. 6).

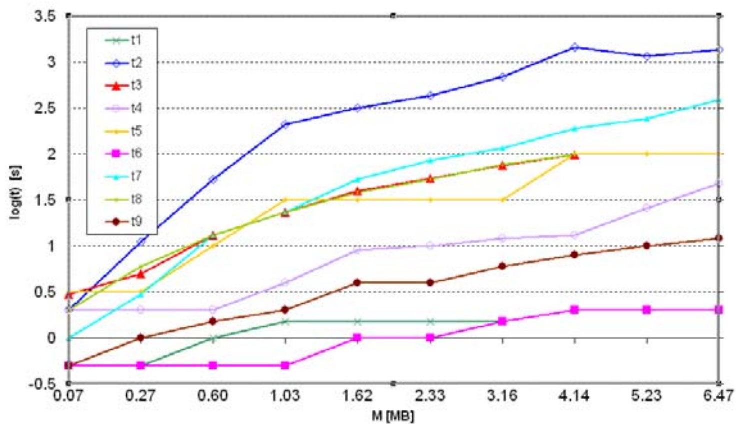
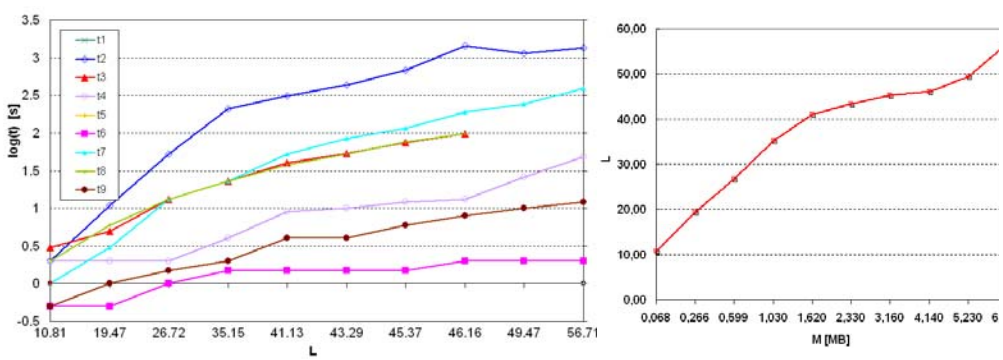


Fig. 6. Run time – t versus images size – M



(a) (b)

Fig. 7. a) Run time – t and the lacunarity index – L; b) Images size – M and index – L

Further on we studied comparatively the obtained results for the box-counting class of algorithms and we found that the best performances are obtained for Df4, Df3 and Df1.

One can also notice a positive correlation between the algorithms' lacunarity index and run time, given in (fig. 7a), and also between the images size in [MB] and the lacunarity index (fig 7b).

For verification, the data for Df1-Df9 were represented in the form of a Turkey box-plot for visual statistical interpretation, thus confirming once more the detailed findings for each fractal dimension (fig. 8).

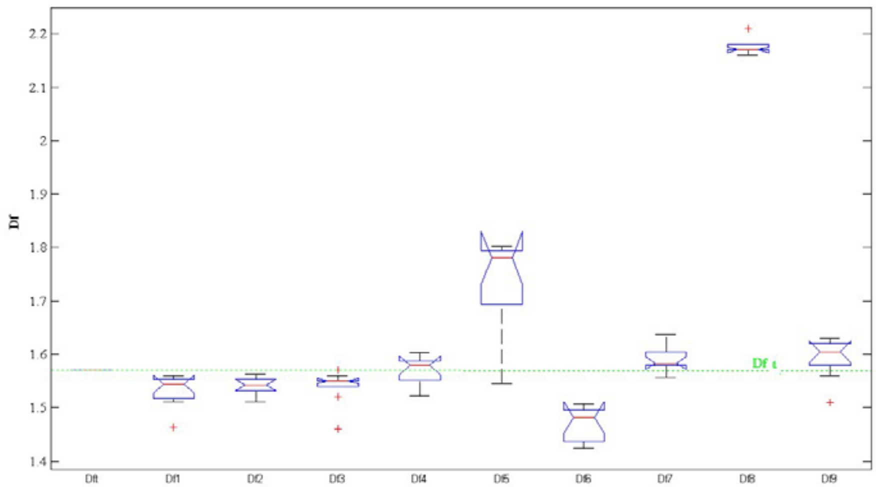


Fig. 8. Turkey box-plot data representation for the left EnG of subject L-49

From the same Turkey box-plot one can observe for the Df1-Df9, except for Df5, Df6 and Df8, that the obtained results for the above mentioned fractal dimensions do not differ very much from the theoretical fractal dimension - Df_t.

By taking into account the results above, for the final experiment of the biological substances differentiation, we made a statistical analysis of the data for Df4, Df5, Df6, Df7, Df9 and L.

We interpret in the first stage the anodic images by using the ANOVA statistical analysis for the data corresponding to the Df4 box-counting fractal dimension.

First we formulate the statistical hypotheses: null and alternative (or the scientific, research hypothesis).

Alternative hypothesis I_1: the Df values for the cases of salty water and sweetened water differ significantly from the case of distilled water;

Null hypothesis I_0: the Df values for the cases of salty water and sweetened water do not differ significantly from the case of distilled water;

In order to establish if there exist on the average significant differences between these cases, one first verifies for each sample if they belong to the normal distribution. For this we used the Lilliefors test (matlab function – lillietest (y1,0.05,'norm')), thus obtaining the confirmation of normality ($p>0.4$).

Another prerequisite for using the ANOVA analysis is that all the samples should have approximately equal variances. For this purpose we used the Bartlett test and the corresponding matlab function - vartestn(X). According to the obtained results (Bartlett's statistics = 1.2283, p>0.54) we conclude that the samples come from normal distributions with approximately equal variances.

Since having the confirmation of the normal distribution conditions and approximately equal variances we can do the ANOVA analysis for the independent samples by using the matlab functions: anova1(X) and multcompare(stats). The results are presented in table 4 and fig. 9.

Table 4

ANOVA results for Df4

Source	SS	df	MS	F	Prob>F
Columns	0.83707	2	0.41853	2069.93	5.55112e-016
Error	0.00243	12	0.0002		
Total	0.83949	14			

One can notice that the Df4 average values for the cases of salty water and sweetened water differ significantly, statistically speaking, from the distilled water case with a more than satisfying probability of p= 5.5511e-016.

This thing can also be seen in the Turkey box-plot representation in fig. 9.

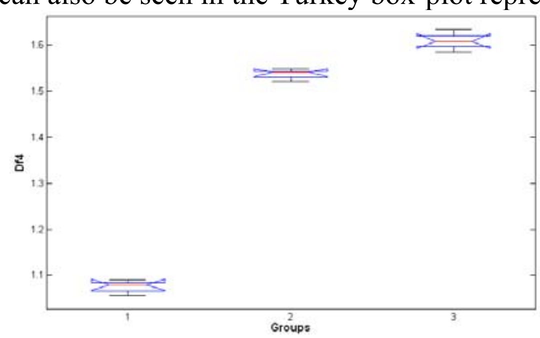


Fig. 9. ANOVA Turkey box-plot data representation of the water groups (samples)

The ANOVA analysis reports us that we have significant global differences between the averages (so the I_1 research hypothesis is correct) but it does not also tell us if the particular average of a group differs significantly from that of another particular group.

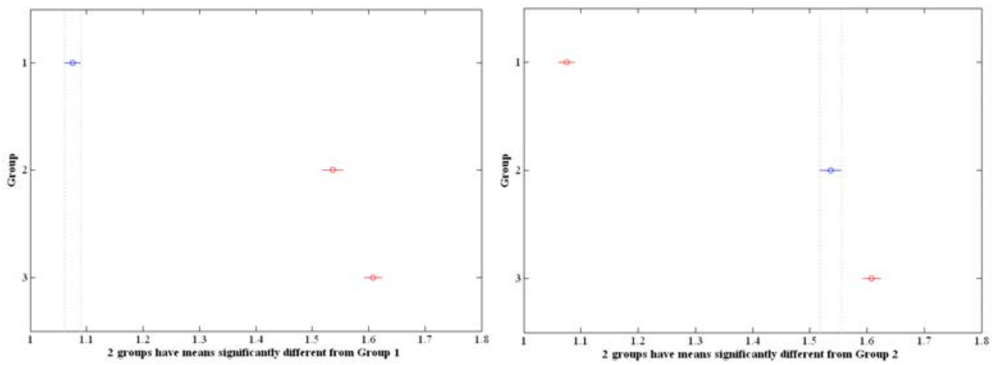


Fig. 10. Comparisons between group 1 or 2 and the other groups (samples) for Df4

We establish this fact post-ANOVA by doing multiple comparisons between pairs of groups by using the HSD Turkey tests in order to set the differences between the averages of each group (sample). We used the multcompare (stats) matlab function and we obtained the results below and the ones presented in fig. 10.

```
>> [c,m] = multcompare(stats)
c =                                                          m =
   1.0000   2.0000  -0.4855  -0.4615  -0.4375                   1.0752   0.0064
   1.0000   3.0000  -0.5571  -0.5331  -0.5091                   1.5367   0.0095
   2.0000   3.0000  -0.0956  -0.0716  -0.0476                   1.6083   0.0082
```

In the *c* matrix there is indicated how to compare the groups averages between themselves (*e.g.* in the first line from *c* there is compared group 1 with group 2, it is estimated that the average of group 1 minus the average of group 2 equals -0.4615, and the trust interval of 95% for this difference is [-0.4855, -0.4375]. Since this interval does not contain 0, we can conclude that the average of groups 1 and 2 differ significantly. The other groups are compared in the same manner. The *m* matrix contains the standard averages and errors for each group.

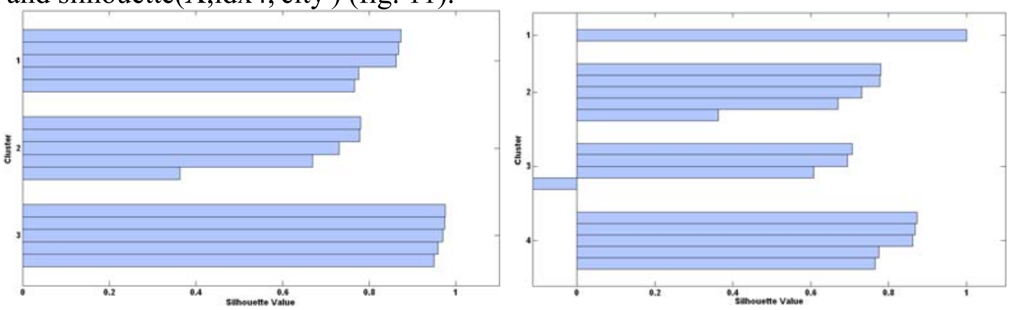
We also applied in order to verify the HSD Turkey test according [5], and we obtained the critical parameters $HSD_{0.05}$= 0.02512 and $HSD_{0.01}$= 0.03453, corresponding to the 0.05 and 0.01 level of statistical significance, and the statistical variables for the comparisons between the groups averages are the following: Q_{12}= 72.5715, Q_{13}= 0.9234, Q_{23}= 0.0555. One can observe that Q_{12}, Q_{13}, $Q_{23} > HSD_{0.01}$, which demonstrates that all the averages vary significantly having a level of statistical significance under 0.01.

From these statistical data and fig. 10 one can observe that the averages of all groups differ significantly.

We determined statistically the correct number of significant groups from the recorded data for Df4 and the distribution of the data in the groups.

First we established which is the number of groups (clusters), most probably, by increasing the number of clusters and by verifying which of the matlab functions - kmeans(X,3,'dist','city','display','iter') and kmeans(X,4,'dist,'city','replicates',4), lead to a better data grouping.

For this we used the following matlab functions - silhouette(X,idx3,'city') and silhouette(X,idx4,'city') (fig. 11).



(a) (b)

Fig. 11. Silhouette value for a) k=3; b) k=4

It was observed in fig. 11 that the silhouette average value – average (silh3)= 0.8195, in the situation k=3, is greater than the average (silh4)= 0.6907, in the situation k=4. Still here in the situation k=4, the silhouette value of the data from cluster 3 is smaller than 0.7, thus suggesting that this is not separate enough compared to the other groups. Consequently, we adopted k=3.

By using the kmeans function (X,3,'Distance','city', 'Replicates',5,..) for the data grouping according to Df4, there was obtained the following distribution of the data grouping:

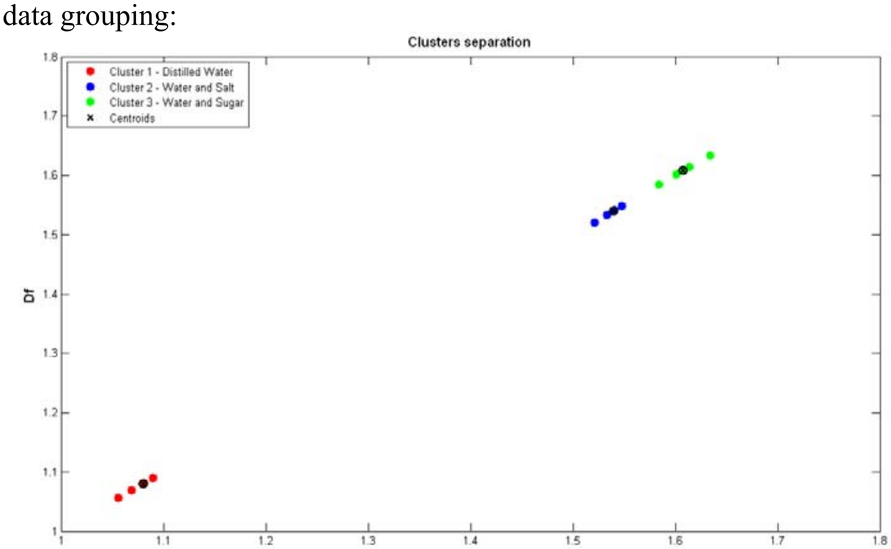


Fig. 12. Data Grouping for Df4

We can thus conclude that the data obtained in this experiment are grouped in 3 clusters: 1) distilled water; 2) salty water; 3) water sweetened with sugar, thus being demonstrated that the electrographic techniques combined with the fractal and statistical analysis can be certainly used for the differentiation of biological substances.

Further on we analyzed statistically the data for the Df5 dimension.

There were applied the same tests as above and the ANOVA analysis in order to establish the existence of the significant differences between the 3 water samples. As the level of statistical significance is $p=0.8434 > 0.05$, it was concluded that the results for Df5 are not significant in order to differentiate the substances.

We then analyzed statistically the data for the Df6, Df7 and L indicators.

It was applied the Lilliefors test – lillietest (y1, 0.05,'norm'), thus being obtained the infirmation of normality ($p<0.017$, $p<0.04$ and $p<0.024$) for the water samples. We decided to renounce using Df6, Df7 and L.

There were further on interpreted the cathodic images as well by analyzing statistically the data for the Df4 box counting fractal dimension. We used as above the ANOVA analysis in order to establish the existence of the significant differences between the 3 water samples. As the level of statistical significance is $p=0.0904 > 0.05$, we concluded that the results in the case of the cathodic images for Df4 are not significant enough in order to differentiate the substances.

4. Conclusions

Fractal and statistical analysis processing brings, as we proposed to show, valuable characterization and evaluation possibilities of the multitude of data and information contained by the EnG images.

The presented experiments practically demonstrate that the fractal dimension remains constant when the scale modifies, thus confirming our correct choice i.e. fractal analysis for electronographic images processing.

Significant results were observed only for the anodic EnG images; in what concerns the cathodic images the differentiation between categories is weak and because of this reason we decided to use in the future only the anodic EnG images especially relevant from the fractal analysis point of view.

According to the results obtained during the last presented experiment, we can consider that by using the electronographic diagnosing techniques combined with the fractal and statistical analysis, we managed to distinguish among the investigated classes of biological substances and to point up the physico-chemical modifications corresponding to above mentioned classes, through a new methodology. It was thus confirmed the validity of the proposed research methodology for the differentiation of the organic substances. The methodology's purpose is the processing of the electronographic images by different fractal techniques, the interpretation of the results and, also, the validation of the research hypotheses by means of statistical analysis.

Similarly, one can do research for the other biological substances: blood, urine, etc.

This thing pleads for the usage of the electronographic techniques combined with the statistical and fractal analysis in order to discover other elements in medical diagnosing (in addition to the physico-chemical analysis).

The above mentioned techniques produced positive results when they were used in delimiting certain disease categories [6] (*e.g.* patients suffering from affections of the nervous system: spasmophilia and schizophrenia).

The electronographic methods combined with the fractal and statistical analysis could also be successfully used in psychology, psychiatry, virusology, forensic medicine and also in other fields relying on energetic and informational aspects.

In the same direction, we would like to point out other possible topics: water and food quality; the assessment of a person's emotional states; human reactivity to different medical treatments, physical exercises, stress, alcohol and drugs influence; tissular, cellular and intracellular microbiological research; bacteria, fungi and viruses investigation.

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