The Use of Computer Visualization in the Analysis of Breathing Curves

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***Abstract*— Researchers in diverse domains use advanced computer techniques to describe complex entities and processes and impressively visualize those which are often unavailable for direct observation. However, one should emphasize that computer visualization conception implies more than just a convenient, impressive, or high rate information transfer. It also considers a problem of perception, processing, and further cultivation of such important personal qualities as intuition, professional "talent", and figurative thinking which are of value for experts in any domain. Computer visualization comprises traditionally such sophisticated techniques as computer graphics, animation and virtual reality. Traditionally, computer graphics has delivered strong instruments for creating, processing, and interacting with data representations. Interactive paradigm has led to emergence of a new scope within the problem of artificial intelligence, which is called cognitive computer graphics. The use of cognitive graphics allows physicians, analyzing modest volume of information, to draw significant conclusions. In whole, cognitive graphics forms a separate subfield in medical research. Visualization provides experts with data in current state of patients just to monitor their conditions continuously. In this article, we show the use of computer visualization to study characteristics (including network imprints) of such a common disease as bronchial asthma. The patients were grouped according to influence degree of psychological factors to the occurrence, progression and course stages of the disease. The study focuses on comparison and analysis of the patient' spirograms and demonstrate presence of physiological and psycho-physiological features among patients with diagnoses of bronchial asthma. In this respect computer visualization provides a solid platform for thorough research and deep analysis in spirometry.**

Keywords—Spirometry, bronchial asthma, volume-time cureves, computer visualization, spectral images, network analysis.

I. Introduction

Bronchial asthma (the word "asthma" is from the Greek ἆσθμα, which means "heavy breathing", "smothering") represents chronic respiratory disease affecting people of all age groups. It can occur in the form of single, episodic attacks or has a severe course with asthmatic status and fatal outcome. According to medical statistics, in recent years the incidence of bronchial asthma in most countries has increased significantly. The increased rate of the disease among young people indicates a continuing trend of increasing progression of this disease. The pity fact is that, in spite of advances in the sphere of etiology and availability of new medicines, the incidence and mortality from bronchial asthma is constantly increasing. This is typical for most countries of the world.

The role of psychosocial, emotional factors in the progression of bronchial asthma is estimated by various experts contradictory and the mechanisms are unclear. This is probably due to the fact that all patients with BA are regarded by them as a homogeneous population of people in terms of somatic status, but with different psychological states. In addition, clinicians (pulmonologists, therapists) do not always payattention to the fact that different emotional states and mental disorders bring different physiological reactions in healthy and sick asthma. So the variety of psychological effects causes a variety of psychological and somatic changes in different groups of patients with BA. Because of this it is necessary to study psychological (mental) and social factors in close relationship with clinical ones. On this basis, E. V. Nemerov classified bronchial asthma, taking into account psychological and social factors. The following classification was proposed [1]: BANP - Bronchial asthma is not psychogenic; BASP – Bronchial asthma somatopsychogenic; BAPI – Bronchial asthma psychogenically induced.

Employees of the Siberian State Medical University and Tomsk Polytechnic University during several years were making researches to detect significant differences between groups of patients (physiological and psychological indicators) with bronchial asthma, divided by the degree of influence of psychosocial factors on the occurrence, progression and course of the disease [1, 2, 3, 4, 5, 6]. To identify hidden patterns in the experimental facts, methods of structural data analysis were used, including methods of scientific visualization [7, 8, 9, 5, 10, 11].

The subject of this study is the patients' process of breathing with various forms of bronchial asthma. It is known, bronchial asthma is, first of all, a disease of the respiratory tract, because of it, a study of the patient's reayhing rhythm, the shape of the breathing curve, the presence of apnea, the duration of the inhalation-exhalation cycle, etc. It has great significance [12, 3, 13, 14, 15].

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Accounting for psychological and social factors, it has some importance [16–21].

II. Materials and Methods of Research.

The experimental data consisted of patient' breathing curves with different types of bronchial asthma and in a group of conditionally healthy people registered with the "MONITOR" instrument. This device recorded the values of the breathing (volume-time) curve with a sampling frequency of 6 Hz (Fig. 1). Indicators were taken both in patients with bronchial asthma and in healthy people for 3 hours at night.

Volume-time curves can be represented as a sequence of values taken at discrete points in time ti (where i is the index). The time intervals between successive samples (sampling intervals) $\Delta ti = ti - ti - 1$ are constant and in our case are equal $\frac{1000 \cdot i \cdot \tilde{n}}{6}$.

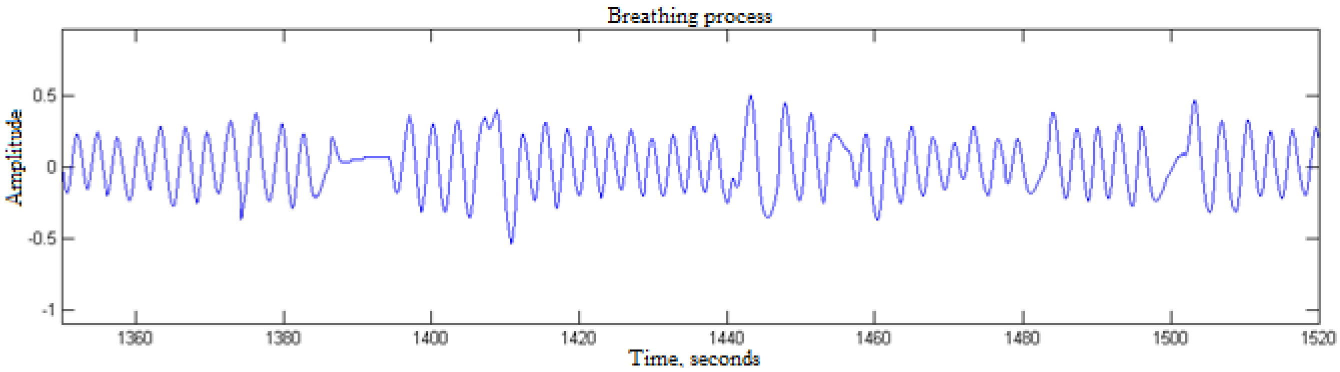


Fig. 1. Spirogram : breathing (volume-time) curve example

Previously, the original signals were filtered by frequency. A triangular filter was used for filtration. Below is the developed algorithm implemented in the structure MatLab [6]:

```
clear;
filename_open = 'path/to/file.txt';
fo = fopen(filename_open);
signal = fscanf(fo, '%f');
fclose(fo);
count = 20000; % Signal length
count_start = 0; % Indent from the beginning
fs = 6; %  Frequency
dt = 1/fs;
df = 1/(dt*count) ; % Hertz
x=0:dt:(count-1)*dt;
row_count = 200; % Number of filters
signal_cut = zeros(count, 1); % Cut signal
new_signal_cut = zeros(count, 1); % Cut signal is normalized by amplitude
for c = 1:count
   signal_cut(c) = signal(count_start+c);
end
% normalization of the amplitude of breathing
max_value=abs(max(signal_cut));
min_value=abs(min(signal_cut));
if max_value<min_value
   max_value=min_value;
end
for c = 1:count
   new_signal_cut(c) = signal_cut(c)/max_value;
end
signal_fft = fft(new_signal_cut);
a1 = 4 ;
a2 = 8 ;
a3 = 16 ;
k1 = 0:a1:a1*(row_count-1);
k2 = a1:a2:(a2*(row_count-1)+a1);
k3 = a2:a3:(a3*(row_count-1)+a2);
 M = zeros(row_count, 1);
 signal_out = zeros(row_count, 1);
 i = 0;
 for i = 1:1:row_count
   for j = 1:1:count
     signal_out(j) = signal_fft(j)* my_filter(j, k1(i), k2(i), k3(i),count);
   end
      T = ifft(signal_out);
   [siz_resp, row] = size(T);
   for r = 1:siz_resp
      M(i, r) = abs(T(r));
   end
end
y=k2*df;
```

```
figure;
subplot(2,1,1);
imagesc(x,y,M)
colormap(bone);
title(' Spectral image)
xlabel('Time, sec')
ylabel('Frequency, Hz')
subplot(2,1,2);
plot(x,new_signal_cut);
title('Breathing process)
xlabel('Time, sec')
ylabel('Amplitude')
```

Implementation function of triangle filter:

```
function m = my_filter(k, k1, k2, k3,N)
if k < N/2
  n = k ;
else
  n = N-k-1 ;
end
  if n < k1
    z = 0;
  else
    if (n > k3)
    z = 0;
    else
      if n < k2
        z = (n - k1)/(k2 - k1);
      else
        z = (n - k3)/(k2 - k3);
      end
    end
  end
 m=z;
end
```

Additionally breathing curves were converted into networks for further analysis with powerful network instruments. First, the curves were put under digitizing by Engauge Digitizer 4.1 [22] (Fig.2).

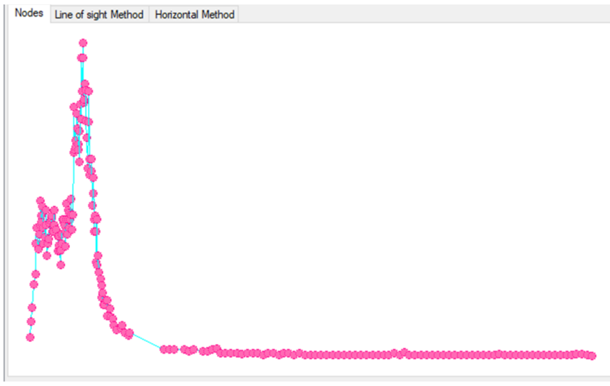


Fig. 2. Example of digitized volume-time curve

Second, a conversion code (C#) was developed and applied to realize natural visibility algorithm (NVG, [23]):

```
{
    class LineOfSightMethod
  {
    private List<Point> points;
    private int[,] adjencencyMatrix;
    public LineOfSightMethod(List<Point> points)
    {
      this.points = points;
    }
    public int[,] getAdjecencyMatrix()
    {
      return adjencencyMatrix;
    }
    public void buildAdjecencyMatrix()
    {
      adjencencyMatrix = new int[points.Count, points.Count];
            foreach (Point point in points)
      {
        testPoint(point);
      }
    }
    private void testPoint(Point point)
    {
      adjencencyMatrix[point.getId(), point.getId()] = 0;
      if (point.getId() < points.Count - 1)
      {
        adjencencyMatrix[point.getId(), point.getId() + 1] = 1;
        adjencencyMatrix[point.getId() + 1, point.getId()] = 1;
      }
```

```
            if (point.getId() < points.Count - 2)
            {
                        for (int i = point.getId() + 2; i < points.Count; i++)
                {
                        if (testTwoPoints(point, points[i]))
                    {
                        adjencencyMatrix[point.getId(), i] = 1;
                        adjencencyMatrix[i, point.getId()] = 1;
                    }
                    else
                    {
                        adjencencyMatrix[point.getId(), i] = 0;
                        adjencencyMatrix[i, point.getId()] = 0;
                    }
                }
            }
        }
        private bool testTwoPoints(Point point1, Point point2)
        {
            for (int i = point1.getId() + 1; i < point2.getId(); i++)
            {
                Point tempPoint = points[i];
                    if (tempPoint.getY() >= (point1.getY() + ((point2.getY() - point1.getY()) * (tempPoint.getX() - point1.getX()) / (point2.getX() - point1.getX()))))
                {
                    return false;
                }
            }
            return true;
        }
    }
}
```

Third, we used an effective free tool Gephi [24] to visualize and analyze network imprints. The tool delivers structure plots and diverese metrics for each node and link, and for an analyzing graph in whole : The following metrics were taken into account : size (number of vertexes **N** and edges **L** in a graph **G(V,E)**, where **V** is set of vertexes, so that N=|**V**| and **E** is set of edges); diameter (the length $\max_{ij} d(v_i,v_j)$ of the "longest shortest path" any two vertices v_i,v_j, where $d(v_i,v_j)$ is a shortest path length, we examine the graph diameter **D** of the largest connected cluster); Clustering coefficient distribution and Average clustering coefficient (C_i for a node **i**, is a measure of the degree to which nodes in a graph tend to cluster together: $C_i=2e_i /\{k_i(k_i-1)\}$, where k_i is the number of neighbours of the i'th node, and e_i is the number of connections between these neighbours. Average clustering coefficient is noted as $<C> =\Sigma C_i/N)$. Average path length is $\lambda =< d(v_i,v_j)>$.

III. Findings

At the first stage, the frequency spectrum of the breathing curve of each patient was evaluated. The results are presented in Fig. 2–5.

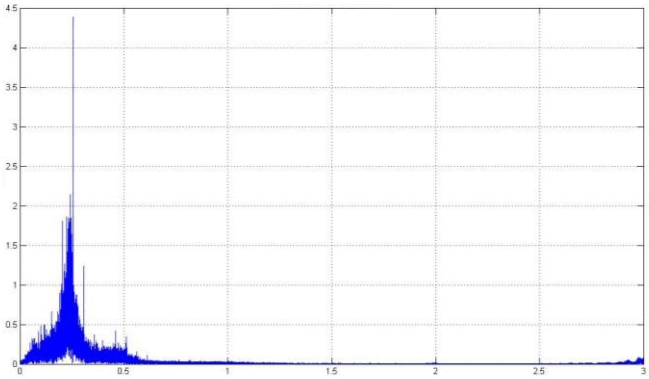


Fig. 3. The frequency spectrum of the healthy person's breathing curve

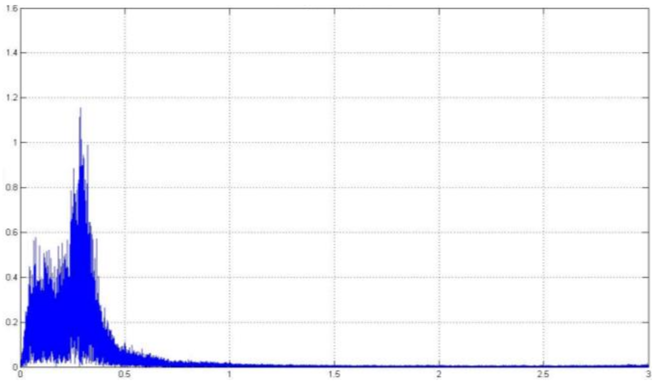


Fig. 4. The frequency spectrum of the patient's breathing curve with a diagnosis BANP

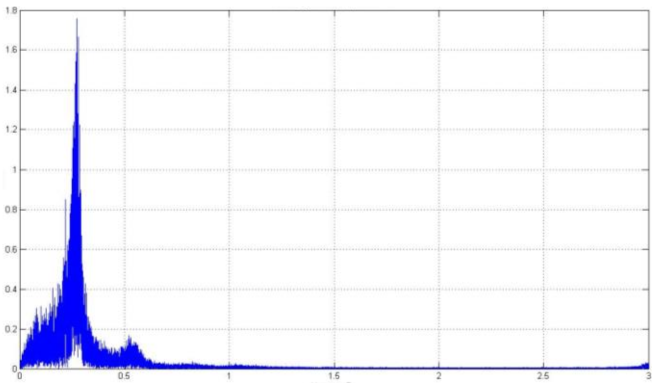


Fig. 5. The frequency spectrum of the patient's breathing curve with a diagnosis BAPI

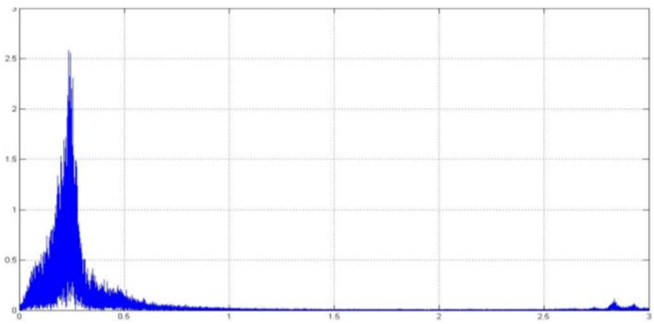


Fig. 6. Frequency spectrum of patient' breathing curve with a diagnosis BASP

As we can see from figures 2–5, the patients' main frequency spectrum with various forms of the disease with bronchial asthma is concentrated in the range from 0 to 0.6 Hz.

The obtained results are also confirmed by the analysis of spectrograms (Fig. 6-8), plotted in the time-frequency plane (the level of the frequency components of the signal is set in color).

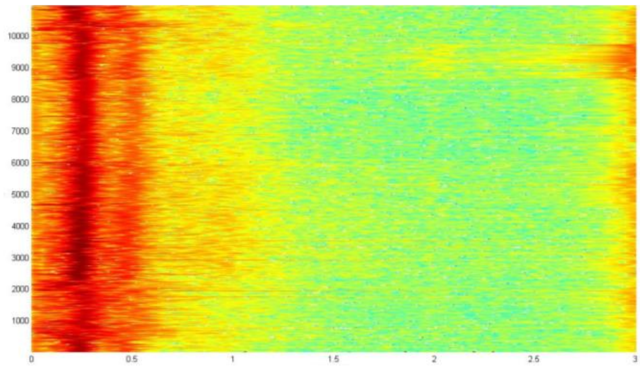


Fig. 7. The healthy person's spectrogram of breathing curve

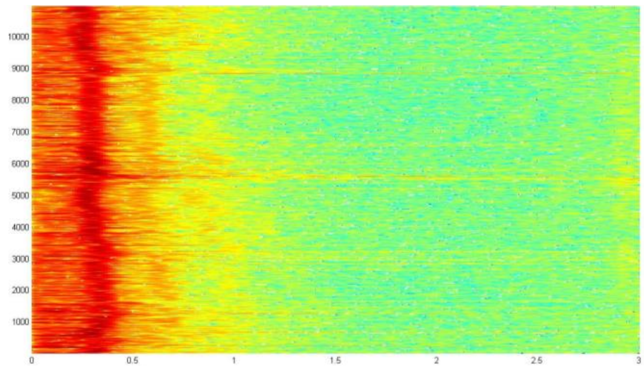


Fig. 8. The patient with a diagnosis BANP's spectrogram of the breathing curve

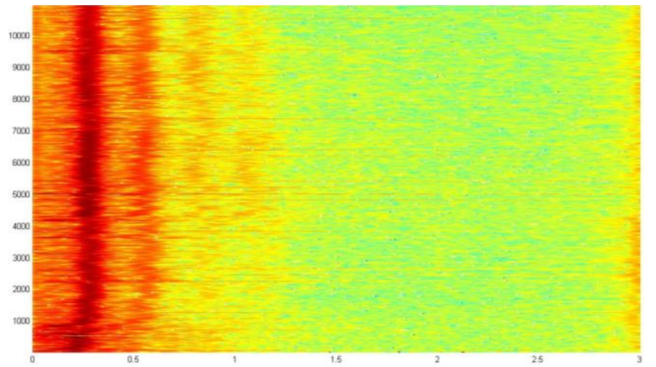


Fig. 9. The patient with a diagnosis BAPI's spectrogram of the breathing curve

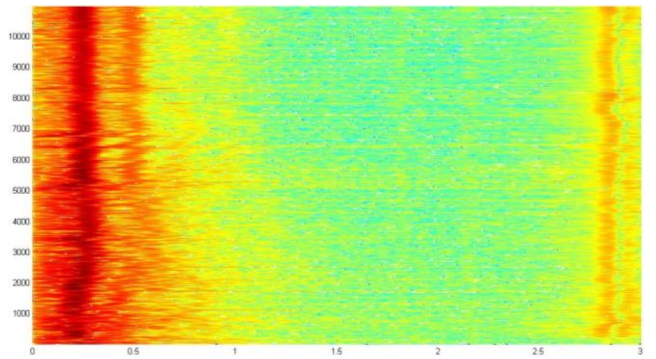


Fig. 10. The patient with a diagnosis BASP's spectrogram of the breathing curve

Analysis of the spectrograms showed that the highest level of the frequency components of the signal is in the range from 0.15 to 0.40 Hz. The essence of the proposed method is to filter the signal with a set of triangular filters at certain frequencies with a further presentation of the result in the form of a spectral image. In fig. 10 we show a flowchart of the algorithm of this method

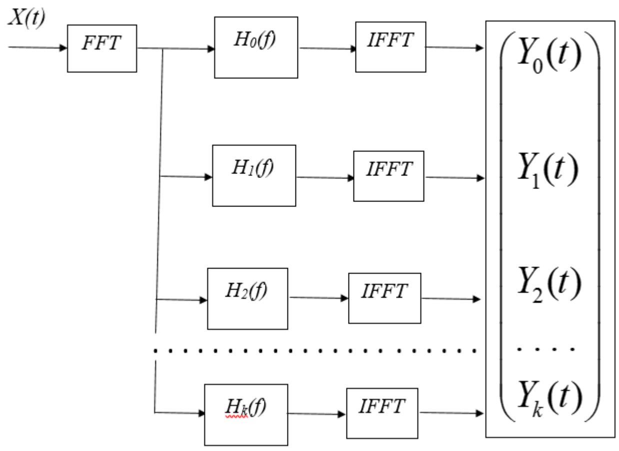


Fig. 11. The block diagram of the algorithm of the method of spectral-temporal analysis of breathing curves

$H_k(f)$ – filter transfer function.

$$H_k(f) = \begin{cases} 0, f_k^3 < f < f_k^1 \\ \dfrac{f - f_k^1}{f_k^2 - f_k^1}, f_k^1 \le f \le \\ \dfrac{f - f_k^3}{f_k^2 - f_k^3}, f_k^2 \le f \le \end{cases}$$

f – signal frequency, f_k^i – filter frequency (i=1, …, k).

FFT – fast Fourier transform.

IFFT – return fast Fourier transform.

After filtering a signal at a certain frequency, the filtering frequency changes and the procedure is repeated. The result of the algorithm is a matrix of values, on the basis of which, spectral images of breathing curves are formed. The result is represented as an image, where each element of the matrix corresponds to a rectangular area in the image, and the value of the elements of the matrix determine the color of the current palette.

The algorithm is implemented in the structure MatLab. Figures 10–13 show the results of the algorithm.

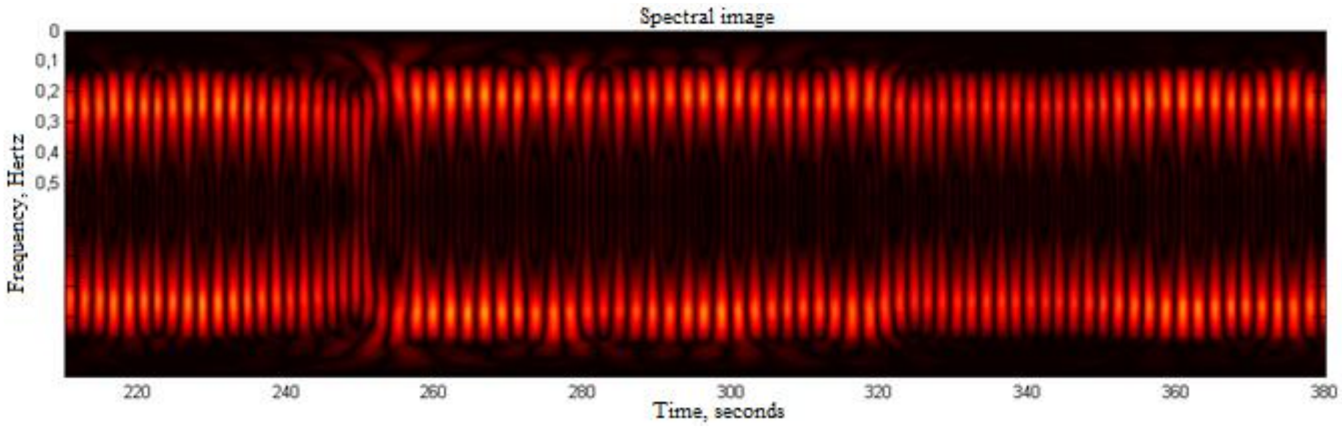


Fig. 12. The healthy person's spectral image of the process of breathing

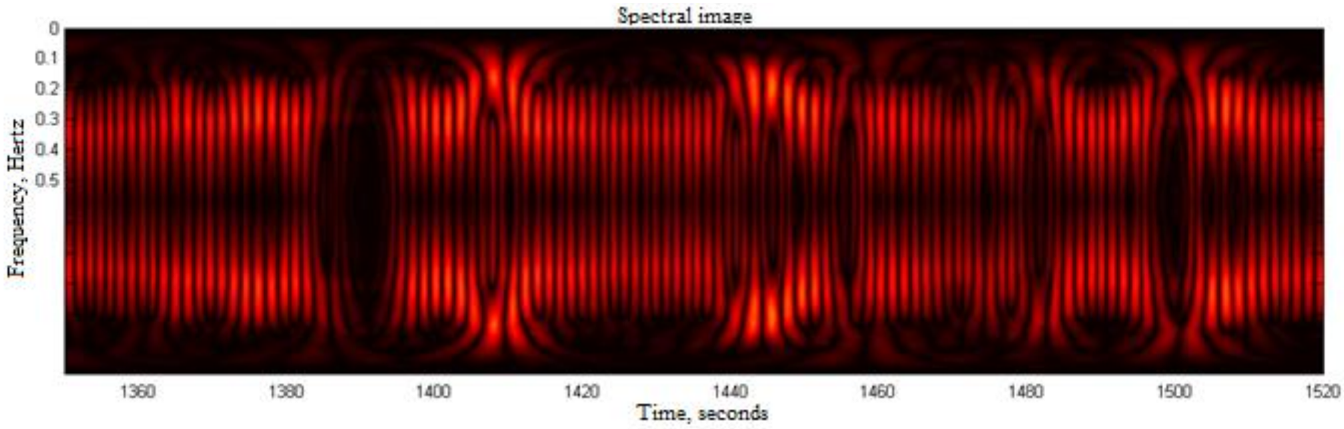


Fig. 13. The patient's spectral image of the process of breathing with a diagnosis BANP

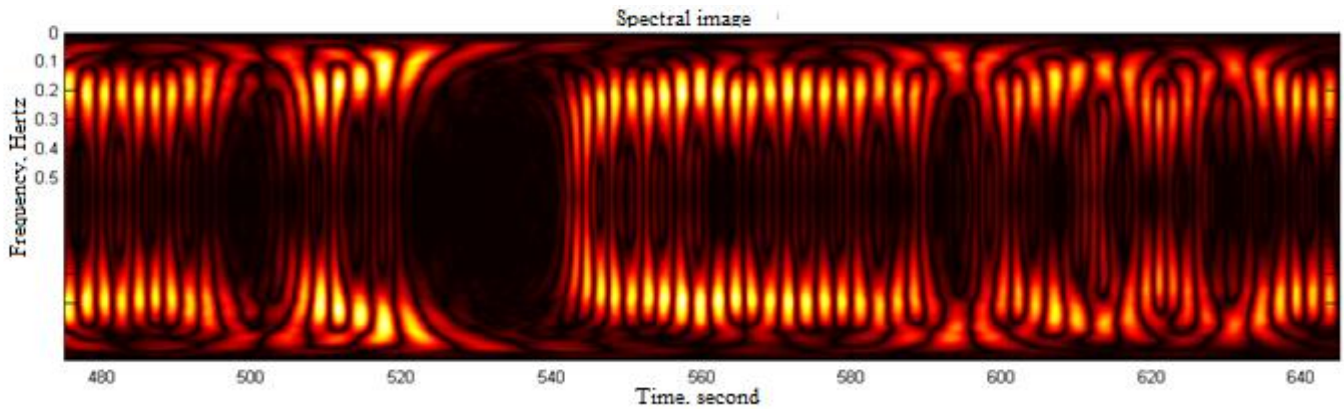


Fig. 14. The patient’s spectral image of the process of breathing with a diagnosis BAPI

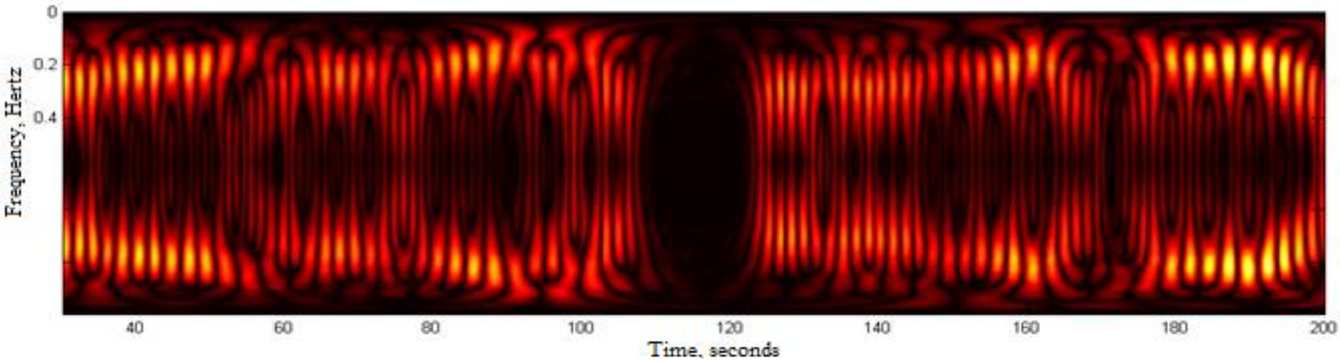


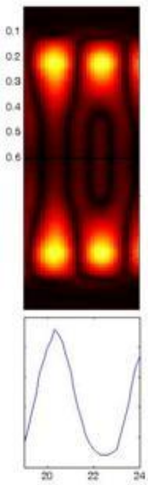
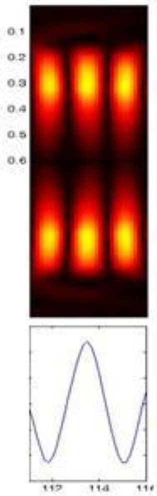
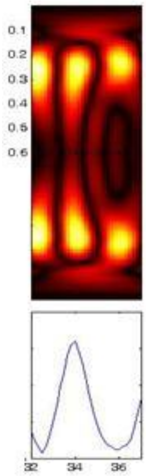
Fig. 15. The patient’s spectral image of the process of breathing with a diagnosis BASP

IV. Discussion

After a careful study of the different groups patient’ spectral images of the breathing curves, we successfully managed to isolate several characteristic “single” graphic images (corresponding to one respiratory cycle) for patients with various forms of bronchial asthma and conditionally healthy people. The results are presented in Table I.

Network analysis conveys and enforces spectral image study (Table II)

TABLE I. "Single" graphic images for different patinen’groups.

Diagnosis	Characteristical graphic for one breathing cycle
Almost healthy	
Non-psychogenic bronchial asthma (BANP)	
Psychogenic bronchial asthma (BASP)	

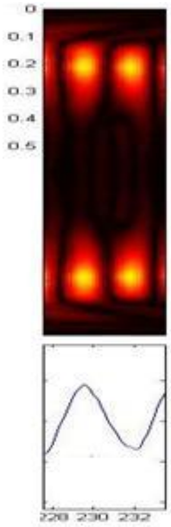
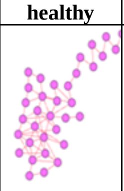
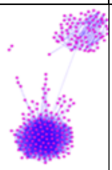
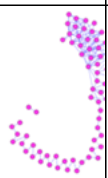
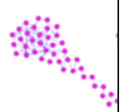
Inducted bronchial asthma (BAPI)	

TABLE II. NETWORK IMPRINTS FOR DIFFERENT PATIENT'GROUPS .

NVG algorithm	Almost healthy	BANP	BAPI	BASP
				
D	20	11	34	44
<C>	0.134	0.56	0.35	0.22
λ	7.1	3.7	12.	17.

V. CONCLUSION

The spectral-time analysis makes it possible to obtain characteristic "single" graphic images of patient' spirogtams with various forms of bronchial asthma. The Table 1 portrays that a healthy person' spectral image of the volume-time curve is noticeably different from almost all images that are typical for patients with various forms of asthma disease. However, patients from the BASP spirogram group are most similar to the spectral image characteristic for the group of "relatively healthy"; there is some similarity with the patient' spectral images diagnosed with BAPI. The patient' characteristical spectral image of the BANP breathing curve differs markedly from the others.

Strikingly the network imprints are in balance with the fact that is inferred above (see the Table II).

The results confirm the earlier conclusions [7, 3, 10, 11, 6, 14] about presence of characteristical physiological and psycho-physiological features among patients with diagnoses of BASP, BAPI and BANP.

In this respect computer visualization provides a solid platform for thorough research and deep analysis in spirometry.

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REFERENCES

[1] E. V. Nemerov, K. G. Yazykov, O. G. Berestneva, and O. S. Zharkova , "Analysis of temporal events among patients with bronchial asthma " Information and mathematical technologies in science and management: works of the XX Baikal All-Russian Conference and School - Seminar of Scientific Youth, Irkutsk, June 30 - July 7, 2015. - Irkutsk: ISEM SB RAS, 2015, vol. 3, pp. 241–246.

[2] O. G. Berestneva, O. S. Zharkova, E. V. Nemerov, K. G. Yazykov, and V. A. Fokin, "Support system for scientific research of psychogenic forms of bronchial asthma " Works of the Baikal All-Russian Conference "Information and Mathematical Technologies in Science and Management". Part III. - Irkutsk: ISEM SB RAS, 2014.

[3] P.V. Karpenko, O.G. Berestneva, and D.Y. Stepanov, "Computer analysis of patients with bronchial asthma's spirogram " Information technologies in science, management, social sphere and medicine: Collection of scientific papers of the International Conference. Part I. - Tomsk: TPU publishing house, 2014, pp. 211–220.

[4] O. G. Berestneva, K. A. Sharopin, N. G. Abdulkina, N. P. Stepanenko, A. L. Yumasheva, and O. S. Zharkova, Mathematical methods and information technologies in problems of assessing the state of biosystems - Tomsk: TPU publishing house, 2015.

[5] I. A. Osadchaya, O. G. Berestneva, and E. V. Nemerov, "Analysis of multidimensional medical data using pictographs of "Chernov's faces" Bulletin of Siberian medicine, 2014, vol.13,# 4, pp. 89 –93.

[6] O. G. Berestneva, I. A. Osadchaya, E. V. Nemerov , "Methods for studying the structure of medical data" Bulletin of Siberian Science: electronic scientific journal / Tomsk Polytechnic University (TPU), 2012, #1 (2), pp. 333–338.

[7] I. A. Osadchaya, O. G. Berestneva, V. A. Volovodenko, and O. V. Marukhina, "Multidimensional Data Visualization Methods Based on Generalized Graphic Images " Communications in Computer and Information Science, 2014, vol. 466, pp. 568–576.

[8] I. A. Osadchaya and R. O. Prokopev, "Visualization technologies in problems of assessing the functional State " Engineering messenger of Don, 2014, #4 , pp.2.

[9] O. G. Berestneva, N. A. Osadchaya, and A. L. Burtseva , Methods of analysis and visualization of multidimensional data. - Tomsk: Publishing House of Tomsk Polytechnic University, 2014.

[10] V. A. Volovodenko, O. G. Berestneva, E. V. Nemerov, and I. A. Osadchaya , "Use of visualization methods in the study of the structure of experimental multidimensional data " Bulletin of Tomsk Polytechnic University, 2012, vol. 320, # 5, pp. 125–130.

[11] N. A. Kinash, A. I. Trufanov, A. A. Tikhomirov, O. G. Berestneva, and O. N. Fisochenko , "Network vulnerability in two-phase evolution " International Siberian Conference on Control and Communications, SIBCON , 2016 , Proceedings, 2016, URL: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7491785 (accessed August,5, 2019).

[12] D. Devjtykh, O. Gerget, and O. G. Berestneva , "Sleep Apnea Detection on Dynamic Neural Networks " Communications in Computer and Information Science, 2014, Vol. 466, pp. 556–567.

[13] Y. Vilunas, Crying breath cures bronchial asthma and other respiratory diseases. SPb . Peter, 2013.

[14] P.V. Karpenko and E.V. Nemerov , "Investigation of the respiratory rhythm among patients with bronchial asthma during a night's sleep " Proceedings of the VI International Student Electronic Scientific Conference "Student Scientific Forum", URL: http://www.scienceforum.ru/2014/482/2949 (accessed August,5, 2019).

[15] R. X. Zulkarev Cardiorespiratory variability in diseases of the respiratory organs. Thesis for the degree of Doctor of Medical Sciences. M, 2007. URL: http://www.dissercat.com/content/kardiorespiratornaya-variabelnost-prizabolevaniyakh-organov-dykhaniya.

[16] I. L. Shelekhov, "System approach as a methodological basis of personality-oriented psychological research" (Pedagogical Review), 2017, vol. 2 (16), pp. 9–20.

[17] T. G. Gadelshina and I. L. Shelekhov , Methodology and methods of scientific research: Tutorial - Tomsk: Tomsk State Pedagogical University Publishing House, 2017.

[18] I. L. Shelekhov and G. V. Belozerova , "Interaction of the systems "personality" - "society" (Pedagogical Review), 2017, Vol. 3 (17), pp. 117–126.

[19] I. L. Shelekhov, G. V. Belozerova , and O. G. Berestneva , "The human psyche as an object of interdisciplinary research " Information

technologies in science, management, social sphere and medicine: Collection of scientific papers of the V International Scientific Conference (17–21 December 2018). - Tomsk: TPU Publishing House, 2018, Part 1, pp. 160–167.

[20] I. L. Shelekhov, G. V. Belozerova , and O. G. Berestneva , "Systemic theory of personality " Information technologies in science, management, social sphere and medicine: Collection of scientific papers of the V International Scientific Conference (December 17–21, 2018 .). - Tomsk: TPU publishing house, 2018, Part 2, pp. 376–390.

[21] I. L. Shelekhov and G. V. Belozerova , Personal aspects of adaptation in the study of images, symbols, plots of dreams: - Tomsk: Tomsk State Pedagogical University Publishing House, 2016.

[22] Engauge Digitizer 4.1 URL: https://markummitchell.github.io/engauge-digitizer/ (accessed August,5, 2019).

[23] L.Lacasa, B.Luque, F.Ballesteros, J.Luque, and J.C.Nuño, From time series to complex networks: the visibility graph, Proc.Natl.Acad.Sci.U.S.A. , vol. 105 , pp. 4972-4975, October 2008. URL: https://arxiv.org/pdf/0810.0920.pdf (accessed August,5, 2019).

[24] The Open Graph Viz Platform , Release 0.9.2/ 26 September 2017) URL: https://github.com/gephi/gephi (accessed August,5, 2019).