Detection of Borderline Mental Disorder On Electrocardiosignals Using EMD

Alexander Yu. Tychkov
Research Institute for Fundamental and Applied Studies
Penza State University
Penza, Russia
tychkov-a@mail.ru

Alan K. Alimuradov
Research Institute for Fundamental and Applied Studies
Penza State University
Penza, Russia
alansapfir@yandex.ru

Pyotr P. Churakov
Data Measuring Equipment and Metrology Department
Penza State University
Penza, Russia
churakov-pp@mail.ru

Alexey V. Ageykin
Data Measuring Equipment and Metrology Department
Penza State University
Penza, Russia
keokushinkai@yandex.ru

***Abstract*—The goal is to develop a method for determining the final number of intrinsic mode functions (IMF) in electrocardiosignals (ECG) in patients under borderline mental disorder (BMD) to increase the reliability of diagnosis of cardiovascular diseases. Informative parameters of ECG, namely, IMFs, were used as the source materials. The empirical mode decomposition method of the Hilbert-Huang theory was used for effective processing of ECG. A method for determining the final number of IMFs in ECG in patients under BMD has been developed. The nature of the method is the adaptive processing of ECG using the EMD method, and determination of the finite number of IMFs and comparison with the threshold value. A block diagram of the developed method and a mathematical description are presented. The study of the method using the formed verified signal base of conditionally healthy patients and patients under BMD was carried out. In accordance with the results of the study, the developed method for determining the finite number of IMFs provides an increase in the accuracy of the determination of the BMD with a sensitivity factor of 93,7%, and a specificity of 96,9%.**

Keywords*—*ECG, decomposition of empirical modes, borderline mental disorders

I. Introduction

An extremely disturbing situation has developed in Russia and worldwide today. As a rule, every patient with cardiovascular diseases either has already suffered or is susceptible to the development of psychiatric disorders in the rehabilitation and post-rehabilitation period [1].

Changes in the heart function, including the period of mental disorders, can be recorded using a biological signaling system, an electrocardiosignal (ECG) being a carrier of useful information. Early diagnosis of borderline mental disorders can prevent the development of heart disease and take measures for prevention and treatment.

An ECG is a complex structured signal consisting of a set of informative-significant parameters and sections representing the QRS complex, P and T waves.

The problems of efficient processing of ECG for the purposes of functional diagnostics have been discussed in a large number of works dealing with pre-processing [2, 3], and analysis of informatively significant parameters [4, 5]. The accuracy of diagnostics depends on the results of processing and analysis of the investigated signals, including in the presence of external disturbances and free motor activity of the patient.

The use of modern signal processing techniques will allow bringing medicine to a new level of development of diagnostic systems [6], which are indispensable helpers for long-term, non-invasive and wireless monitoring of human health in the presence of various psychotraumatic situations.

The main objective of the study is to develop an original method for analyzing ECG under borderline mental disorder (BMD) using modern methods of mathematical processing and analysis of medical signals.

In this paper the authors solve two main problems: an application of adaptive methods for ECG signal processing[1], and search for novel signs of BMD[2].

II. Formation of Patient Signal Base

To conduct the studies of ECG in patients under BMD, a database of medical signals has been formed based on the Health Medical Center (Penza, Russia).

The database of ECG is formed from the number of patients different in gender (male, female) and age (in adolescents, able-bodied population with high psychoemotional load – military personnel, teachers, and doctors – and elderly people). To form the base of ECG under BMD, 95 patients who applied on the first day of hospitalization without drug exposure were selected.

In terms of clinical symptoms, the selected group of patients is represented mainly by four diagnostic categories:

[1]Scientific and research work was carried out with the financial support of the Russian Science Foundation, project No. 17-71-200291 and [2]Grant Council of the President of the Russian Federation, project No.SP-246.2018.52.

F48.0 - neurasthenia; F45.3 - somatoform dysfunction of the autonomic nervous system; F43.2 - disorder of adaptive reactions; F41.2 - mixed anxiety and depressive disorder.

The registration of the ECG was carried out by means of an EEGA-21/26-Encephalograph-EEG analyzer-Encephalon-131-03 in three standard and three augmented leads, and a sampling frequency of 500 Hz. Thus, 580 ECG were registered for conducting studies with a selected group of patients.

III. Materials and Methods

A. Amplitude-time analysis of ECG

Based on the review [7, 8] and own studies [9, 10], it was noted that in patients under psychotraumatic situations, the loss of blood pressure stabilization, sinus arrhythmia, an increase in the *ST* segment and changes in the *T* wave are recorded in the ECG. The ECG signals may vary depending on the clinical picture of the individual patient. Variants of the ECG with visually allocated periods of BMD in the amplitude-time domain are shown in Fig. 1.

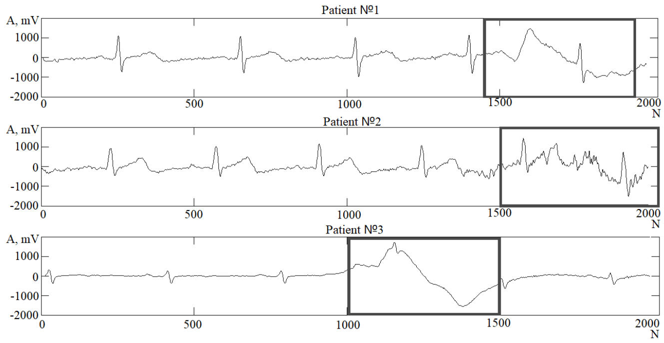

Fig. 1. ECG with visually distinguishable periods of BMD

The conducted studies of the ECG showed that in the amplitude-time domain of signal analysis, it is not always possible visually to compute the time (period) of the occurrence of a psychotraumatic situation (Fig. 2). The patient and the signal being examined can be influenced by various external disturbances (from movement, electrode bias, network interference, etc.) that can distort the signal beyond recognition.

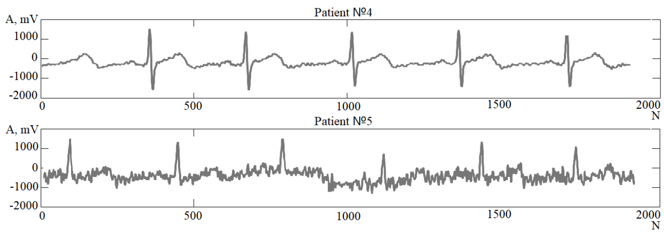

Fig. 2. ECG of patients under BMD without visual changes

In the works of many authors [11, 12] it is confirmed that the analysis of the ECG in the amplitude-time domain is weakly informative. It is noted that when processing ECG in the frequency-time domain, especially in the conditions of long-term monitoring and automatic analysis, it is possible to achieve a reduction in the level of interference, and to reveal new features (indicators) of the BMD in the ECG, thereby increasing the reliability of diagnostic conclusions.

B. Frequence-time analysis of ECG

An analysis of well-known studies [13, 14] has shown that most of the methods and algorithms used to determine various ECG informative parameters in the time-frequency domain are based on Fourier and wavelet transform.

Wavelet transform allows us to construct the spectral characteristic of an ECG in an amplitude-time domain with a specified cutoff frequency. However, in the known works [13, 14] this solution is used in the presence of a priori information about the signal being studied (the diagnosis of a particular patient), and the interference present. In addition, the wavelet transform has certain drawbacks, mainly related to the inability to build an adaptive basis for the ECG under investigation, and the reverse signal reconstruction without losing its quality. The error in the ECG recovery using wavelet transformation can reach 5% or more [15], which is unacceptable in conditions of functional diagnostics of the state of the cardiovascular system and automatic ECG analysis.

A necessary condition for the effective determination of BMD informative parameters in ECG is the possibility of forming an adaptive basis that is functionally dependent on the content of the signal itself. This approach is realized by the Hilbert-Huang theory.

The Hilbert-Huang theory is a combination of the empirical mode decomposition method (EMD) and Hilbert spectral analysis.

The use of the EMD method makes it possible to represent the ECG in the form of a sum of empirical modes [16, 17]:

$$x(t) = \sum_{i=1}^{I} ATC_i(n) + r_i(n) \tag{1}$$

in which $ATC_i(n)$ are empirical modes (IMFs) of the ECG, $r_i(n)$ is a final signal envelope, n is discrete ($0 < n \leq N$, N is the number of discrete time samples in the signal), i=1, 2, …, I is a number of the signal ATC.

The analysis of the known works on the processing and analysis of ECG using the Hilbert-Huang theory [18, 19] and our own studies [20] has shown that the EMD is a promising method that has found its application in solving various problems of interference suppression and the detection of informatively significant parameters of EEG signals to improve the reliability of medical diagnostics.

IV. Description of the Method

A new method for analyzing the IMFs of the ECG under BMD has been developed using the EMD. A block diagram of the method is shown in Fig. 3.

The nature of the method is to perform the following actions.

Input of the ECG (Fig. 3, block 1, 2) was carried out by recording the signals in patients under BMD. To conduct adequate studies, additional ECG were recorded for conditionally healthy patients from 95 students and employees of Penza State University, accepted for the reference (Fig. 3, block 5).

The implementation and investigation of the method was carried out in the R programming environment and Matlab mathematical modeling, with the support of RStudio Desktop and the decomposedPSF software package.

Decomposition of the ECG (Fig. 3, block 3) into IMFs was carried out according to the equation 1. Based on the results of the decomposition, a set of IMFs – amplitude-time components of the signal with a different cutoff frequency is formed. Due to the adaptability of the EMD method, in contrast to the wavelet transform, the reverse reconstruction of the ECG is carried out without loss of its quality.

Based on the calculation of the number of IMFs of ECG in patients under BMD, the same indicator is compared in conditionally healthy patients (Fig. 3, block 6).

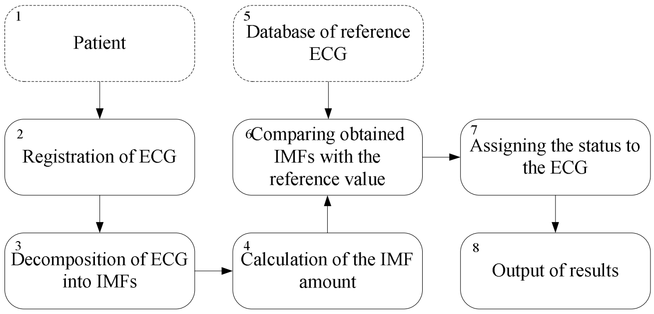

Fig. 3. Block diagram of the method

Research of registered ECG by the EMD method has revealed the correlation dependence of the number of IMFs of ECG in patients under BMD and conditionally healthy patients. Table 1 shows the results of calculating the number of IMFs of ECG in both groups of patients in three standard (SL) and three augmented leads (AL).

TABLE I. RESULTS OF DETERMINATION OF BORDERLINE MENTAL DISORDERS

Leads of ECG in patients under BMD						
No.	***1 SL***	***2 SL***	***3 SL***	***1 AL***	***2 AL***	***3 AL***
1	10	11	9	13	12	13
2	12	13	11	11	10	12
3	11	12	10	12	12	11
4	10	9	12	11	11	10
5	12	12	11	10	12	12
…						
94	11	10	13	9	11	12
95	10	12	11	12	12	10
Leads of ECG in conditionally healthy patients						
No.	***1 SL***	***2 SL***	***3 SL***	***1 AL***	***2 AL***	***3 AL***
1	8	9	7	10	9	8
2	7	8	9	9	8	9
3	8	9	9	8	9	8
4	8	8	7	8	10	8
5	8	8	9	8	9	8
…						
94	8	7	9	10	8	7
95	9	9	8	8	9	7

The conducted studies showed that the number of IMFs varies from 10 to 12 in the ECG in patients under BMD . The number of IMFs varies from 7 to 9 for ECG of conditionally healthy patients.

Some IMF emissions in patients of both groups may be associated with interference recorded in the ECG as a result of electrode bias and interference from movement. In previous researches of the author it was shown [21] that the amount of IMFs resulting from the decomposition of the ECG is in linear dependence on the duration (time or number of samples) of the signal itself, the presence of various interferences and their intensity. Therefore, the more intense the interference in the signal, the more the signal IMF number will be.

Thus, the research results of the proposed method for the IMF analysis of the ECG under BMD showed that based on the calculation of the amount of the signal IMF, it is possible to detect signs of BMD in a patient with a probability of 94%, and to consult a specialist in time, thereby reducing the likelihood of developing cardiovascular diseases. In addition, in conditions of free motor activity and automatic analysis of ECG in mobile systems for diagnosing the health state, it is necessary to improve algorithms and programs for suppressing intense interference of various kinds.

Figure 4 shows a diagram of the distribution of the number of IMFs in patients of different groups: ECG in conditionally healthy patients (black); ECG in patients under BMD (white).

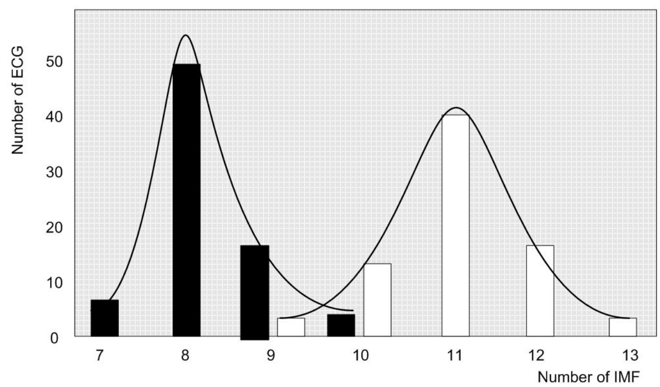

Fig. 4. Diagram of the distribution of the number of IMFs in patients of different groups

As it can be seen from Fig. 6, the law of the distribution of the number of IMFs in patients of both groups is normal. Some IMF emissions in patients of both groups can be associated with interference recorded in ECG as a result of electrode bias and interference from movement. In previous studies of the author [20], it was shown that the amount of IMFs produced as a result of the ECG decomposition is linearly dependent on time or the number of samples of the signal itself, the presence of interference of various types, and their intensity. Therefore, the more intense the interference in the ECG, the more the amount of signal IMF will be.

To confirm the results of the study, we suggest using the following criteria

- sensitivity (%) is the proportion of ECG under BMD of the total number of signals studied, calculated using expression:

$$Se = \frac{TP}{TP + FN} \cdot 100\% \quad (2)$$

in which TP is the number of correctly detected signals under BMD; TP+FN are the total number of signals under BMD.

- specificity (%) is the proportion of ECG in conditionally healthy patients of the total number of signals studied, calculated using expression:

$$Sp = \frac{TN}{TN - FP} 100\% \quad (3)$$

in which TN is the number of correctly detected signals in healthy patients; TN+FP are the total number of signals from healthy patients.

Table 2 shows the results of detection of BMD signs in ECG.

TABLE II. RESEARCH RESULTS

Condition	**Detection result**		***Se and Sp coefficients, %***	
	Presence of signs	***Absence of signs***		
Presence of signs	95 pers.	6 pers.	Se	93.7
Absence of signs	3 pers.	95 pers.	Sp	96.9

Thus, the research results of the proposed method for the analysis of IMF in ECG under BMD showed that the sensitivity of the method is 6.3%, and the specificity is 3.1%

The developed method can be successfully used in diagnostic systems for detecting borderline mental disorders, and is introduced into the clinical practice of physicians.

CONCLUSIONS

The article suggests a method for analyzing IMFs in ECG in order to determine the presence of BMD in patients, by applying a modern mathematical method of empirical mode decomposition. The nature of the method consisted in adaptive processing of ECG using the EMD method, determination of the finite number of IMFs, and comparison with the threshold value. According to the results of the study, the developed method provides an increase in the accuracy of determining the BMD with a sensitivity factor of 93.7%, and a specificity of 96.9%.

REFERENCES

[1] Ushakov G.K. “Borderline neuropsychiatric disorders”. Medicine. 1987. 304 p.

[2] Sornmo, L. “Time-Varying Digital Filtering of ECG Baseline Wander”. Medical and Biological Engineering and Computing. 1993. PP. 503-508.

[3] Bodin O.N., Kramm M.N., Krivonogov L.Yu. “New technology for suppressing in electrocardiogram signals”. Proceedings in Cybernetics. 2017. № 4 (28). PP. 122-130.

[4] Agrafioti F. “ECG in Biometric Recognition: Time Dependency and Application Challenges”. Ph.D. Dissertation. University of Toronto. 2011. 172 p.

[5] Kaplan A.Ya. “The variability of the heart rhythm and the nature of the feedback as a result of operator activity in man”. I.P. Pavlov Journal of Higher Nervous Activity. 1999. № 48. PP. 345-350.

[6] Kuzmin A., Safronov M., Bodin O. “Device and software for mobile heart monitoring”. Proceedings of the 19th Conference of Open Innovations Association, FRUCT 2016. 2017. PP. 121-127.

[7] Purushothaman S., Salmani D., et al. “Study of ECG changes and its relation to mortality in cases of cerebrovascular accidents”. SciBiol Med. 2014. №5. PP. 434-436.

[8] Olbrish S. “EEG biomarkers in major depressive disorder: Discriminative power and prediction of treatment response”. International Review of Psychiatry, Vol. 25(5), 2013. pp. 604–618.

[9] Kuzmin A.V., Tychkov A.Y., Alimuradov A.K. “Development of effective noise biomedical signals processing method”. International journal of applied engineering research. 2015. Volume 10, № 4. PP. 8527-8531.

[10] Tychkov A.Yu., Ageikin A.V., et al. “Modern ideas about the specifics and problems of diagnosis of borderline mental disorders”. Mental Health. 2017. № 5. PP. 69-75.

[11] X. Zhuang, K. Sekiyama, T. Fukuda “Evaluation of Human Sense by Biological Information Analysis”. International Symposium on Micro-NanoMechatronics and Human Science. 2009. 74-80 p.

[12] Kuzmin, A.V., Tychkov, A.Y., Alimuradov, A.K. “Development of effective noise biomedical signals processing method”. International journal of applied engineering research. 2015. Volume 10, № 4. PP. 8527-8531.

[13] US Patent 11/376603 “Automated analysis of a cardiac signal based on dynamical characteristics of the cardiac signal”. Korzinov, Lev. 06.01.2010.

[14] US Patent 10/984200 “Method and apparatus for electro-biometric identity recognition”. Lange, Daniel H. 30.03.2010.

[15] Tychkov A.Y., Alimuradov A.K., Churakov P.P. “Development of novel methods for noise cancellation in ECG”. International journal of applied engineering research. 2017. Volume 12, № 18. PP. 7455-7458.

[16] Huang N. “The Hilbert-Huang transform and its applications”. World scientific publishing. 2005. 526 p.

[17] Huang N. “An Introduction to Hilbert-Huang transform: a plea for adaptive data analysis”. Research center for adaptive data analysis. 2007. 257 p.

[18] Benitez D. “The use of Hilbert Transform in ECG Signal Analysis”, Comput. Biol. 2002. pp. 399-406.

[19] Blanco-Velasco M., Weng B. “ECG signal denoising and baseline wander correction based on the empirical mode decomposition”. Computers in Biology and Medicine. 2008. pp. 272-277.