

HHT-based Analysis of ECG Signals of Patients with Borderline Mental Disorders

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Abstract—This paper describes a solution for borderline mental disorders detection. This approach is based on the ECG processing by Hilbert-Huang Transformation. The described approach allows to develop an additional module for mental disorders diagnostic systems. The research is based on the fact that in the conditions of borderline mental disorders there are changes in patients' heart function. Detection of significant ECG informative parameters is based on the effective and accurate measurement of amplitude, time, frequency and energy parameters of the ECG signal. A verified and registered database of 780 ECG signals of patients with borderline mental disorders and healthy people is used. The proposed method is described and the results are shown. The errors of the method with current sampling do not exceed 4%. The developed approach using volumetric spectral surfaces has showed a high probability of determining the period of occurrence of psycho-traumatic situations in various patients using the ECG.

I. INTRODUCTION

Evaluation of human mental health is an interdisciplinary direction of research at the intersection of medical and engineering sciences.

Currently, there is an extremely disturbing worldwide situation: cardiovascular diseases and cancer dominate in the structure of pathologies and mortality of the population, in which, as a rule, each patient either has suffered, or is susceptible to the development of mental disorders.

Researches of various authors [1], [2] state that in the conditions of borderline mental disorders there are changes in patients' heart function: automaticity, conduction, excitability and contractility. It is noted in [2] that in any psycho-traumatic situation there are irregularities in functioning of the heart, even in the absence of pathological abnormalities.

Particular attention is paid to the critical states of a patient in [3] arising at the very beginning of the impact of the psycho-traumatic emotional factor. During the period of borderline mental disorders and the duration of the psycho-traumatic situation, there is a loss of the ability for

stabilization of blood pressure (BP) and heart rate (HR) in patients. As a result of [4] research, it is revealed that in 93% of the observed patients there are heart rhythm disturbances, more often ventricular tachyarrhythmia, turning into flutter or ventricular fibrillation, in 12% of the observed patients an increase of ST segment and changes of the T-wave on the electrocardiogram (ECG) are recorded.

There are other changes in ECG signals under mental disorders, namely, sinus arrhythmia, brady- and tachycardia, and ventricular extrasystoles, in rare cases paroxysmal tachycardia and atrial fibrillation are recorded [5]. It is noted in [6] that a person's stress level and his nervous system state can be estimated from the heart rate variability, and time series derived from the time difference of the R-peaks sequence of the ECG.

The effectiveness for detection of significant informative parameters of mental abnormalities of health status using ECG signals is determined by the efficiency and accuracy of measuring amplitude, time, frequency and energy parameters of the ECG signal, as well as the reliability of detection and recognition of its individual elements.

II. STATE OF THE ART

The objectives for ECG processing are mostly solved by a physician through the analysis of signals in the time domain, which is due to the complex structure of the signal itself and the increased response time in decision making [7]. Even in the absence of factors for the development of mental disorders, there are various variants of ECG signals, which greatly complicate the approaches to their processing and analysis in the time domain [8]. In the conditions of digital signal processing development, the methods of ECG frequency analysis become traditional in order to increase the reliability of diagnosis of critical conditions of the patient [9].

The conducted analysis of the known works [10], [11], [12] has showed that the majority of solutions for determining

the informative parameters of mental abnormalities are based on the use of such methods for ECG signals analysis as Fourier and wavelet transform. The use of a specific maternal wavelet enables users to allocate detail factors in the signal in certain frequency ranges, with subsequent comparison with the threshold value (a threshold level of the informative parameter of the ECG signal). The main disadvantages of the known solutions are: processing of ECG signals with a constant delay, without the possibility to evaluate the entire duration of the recorded data; the use of wavelet transformation not adaptive to features of ECG signals; the absence of reliable information on the results of the study based on the level of threshold processing, as a critically important factor for determining the informative parameters of the investigated ECG signal.

A necessary condition for the effective determination of informative parameters of mental abnormalities on ECG signals is the possibility of forming an adaptive basis that is functionally dependent on the content of the signal itself.

The main objective of the study is development of an original method for determining informative parameters of human borderline mental disorders by eliminating the shortcomings of existing methods and applying new approaches to the analysis of ECG signals in the energy-frequency-time coordinate systems.

III. SOLUTION VISION

The Hilbert-Huang theory (*HHT*) founded its application for the development of digital signal and data processing in 1999 [13], [14]. The *HHT* theory has found its application for the processing of various medical signals, such as: ECG [15], EEG [16], fluorography [17], speech signals [18], etc. All known methods are directed at effective interference suppression in signals and searching for new informative parameters to increase the reliability for diagnosis of heart diseases.

The *HHT* theory, in itself, includes two methods: signal empirical mode decomposition (*SEMD*) and Hilbert spectral analysis (*HSA*). The first papers on processing of ECG signals using *HHT* were presented in 2002 [19], [20].

The use of *HHT* allows representing the ECG signal as a sum of amplitude-time components:

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

where $ATC_i(t)$ are the amplitude-time components of the signal, $r_i(t)$ is the final envelope of the signal, t is the time counting ($0 < t \leq N$), N is the number of discrete samples in the signal), $i=1, 2, \dots, I$ is the *ATC* signal number.

When conducting *HSA*, an instantaneous frequency for each *ATC* of the ECG signal is calculated, being applied to the surface of energy density (*SED*), and calculated according to the following formula:

$$E(t) = \sum_{i=1}^I ATC_i^2(t) \cdot e^{q \int \omega_i(t) dt} \quad (2)$$

where $q = \sqrt{-1}$ is the imaginary unit; ω is the value of the cyclic frequency of each component of the ECG signal.

The *HHT* theory is used for the development of original method for determining the informative parameters of borderline mental disorders.

III. VERIFIED SIGNAL DATABASE

To analyze ECG signals with the help of *HHT*, a verified database of researched ECG signals in patients under borderline mental disorders has been developed and patented (Certificate of state registration of the database, No. 2017620266, Russia).

An experimental group of subjects of various gender and age characteristics was formed on the base of K.R. Evgrafov Regional Psychiatric Hospital (Penza, Russia). To form the experimental group of subjects with mental disorders, 60 patients applied on the first day of hospitalization were selected. A control group of 70 subjects without signs and clinical manifestations of mental illness was formed.

According to clinical signs, each group of subjects was presented mainly by four diagnostic categories:

- 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.

Recording of ECG signals was carried out using certified equipment of K.R. Evgrafov Regional Psychiatric Hospital: Neuro-spectrum-1, which is an electroencephalograph-cardiograph, registering three standard and three amplified ECG leads with a signal sampling frequency of 500 Hz. When examining the control and experimental groups of subjects, 780 ECG signals were recorded. The user interface allows downloading the recorded ECG signals in digital form, displaying the signal under study, and also systematizing data into patients' mental health, age and sex groups.

Patients were asked to fulfill a special task and pronounce some phrases. It provokes a psycho-traumatic situation (or stress). Signal areas before, during and after psycho-traumatic

situation are selected and examined. The starting moment of this situation is known and it is marked on the ECG. The duration of experimental ECGs is 50 seconds. It is strictly bounded.

Examples of ECG of different patients with signs of disturbances are shown in Fig.1. Areas with visible disturbances are marked with frames.

Preliminary visual analysis of experimental ECG signals shows that specific changes in ECG concerned with psycho-traumatic situation look different and cannot be visually identified in all the cases.

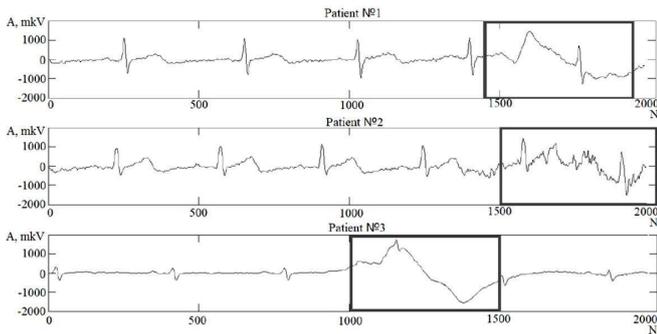


Fig. 1. Examples of ECG with the signs of disturbances

IV. DEVELOPMENT AND INVESTIGATION OF THE METHOD

With the purpose of effective determination of mental deviations in human state of health using the ECG signal, a method is proposed, the block diagram for which is shown in Fig. 2. The nature of the algorithm is to perform the following actions.

- 1) Input of the ECG signal. The signal input is carried out from the formed signal database of patients under borderline mental disorders;
- 2) Decomposition of the ECG signal into *ATC*. The nature of the decomposition is described in the previous section.

An example of the ECG signal decomposition into amplitude-time components is shown in Fig. 3. The results of the decomposition show that the signal is decomposed into nine amplitude-time components and the resulting residue, the sum of which will allow obtaining the ECG signal under study without loss of its quality.

- 3) Measurement of the *ATC* amplitude difference level. Within the framework of this stage, a sliding window with a step of at least 1000 samples of the *ATC* of the ECG signal is used. The result of this step will be the

allocation of individual informative *ATC*, which amplitude difference value exceeds two orders within 1000 samples.

- 4) Threshold processing of individual *ATC* of the ECG signal is carried out according to the following expression:

$$ATC_i(t) = \begin{cases} x(d_j(t)) \times (|d_j(t)| - ATC_{thr}(t)), & \text{if } |d_j(n)| > ATC_{thr}(t) \\ 0, & \text{if } |d_j(n)| \leq ATC_{thr}(t) \end{cases} \quad (3)$$

where $ATC_{i\ thr}(t)$ is the threshold value; d_j is the detail factor.

Threshold value $ATC_{i\ thr}(t)$ is empirical. It is defined on the base of experimental results.

- 5) Threshold processing of *SED* is performed on the entire area of the recorded ECG after restoration of *ATC*.

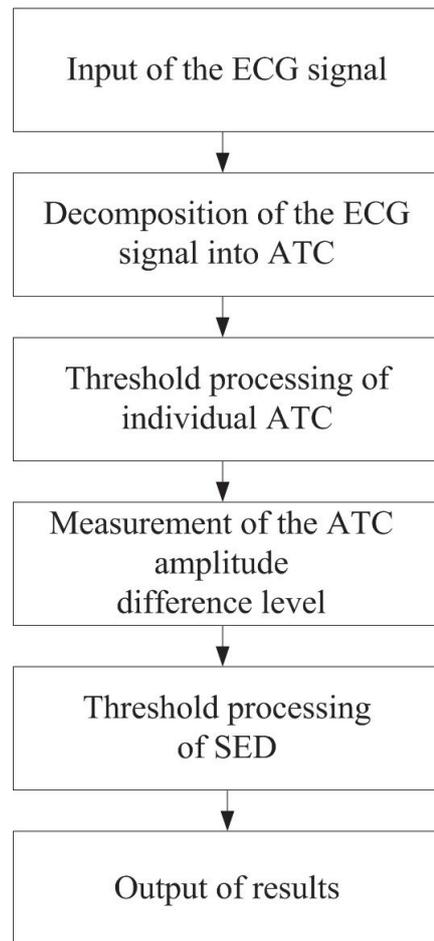


Fig. 2. Algorithm for determining borderline mental disorders using the ECG signal

An example of *SED* constructing of the ECG signal of patients with borderline mental disorders is shown in Fig. 4. It follows from the Fig.3 that the ECG signal being studied is nonlinear and non-stationary, the characteristics of which are variable in its various representations in the energy-frequency-time coordinate systems.

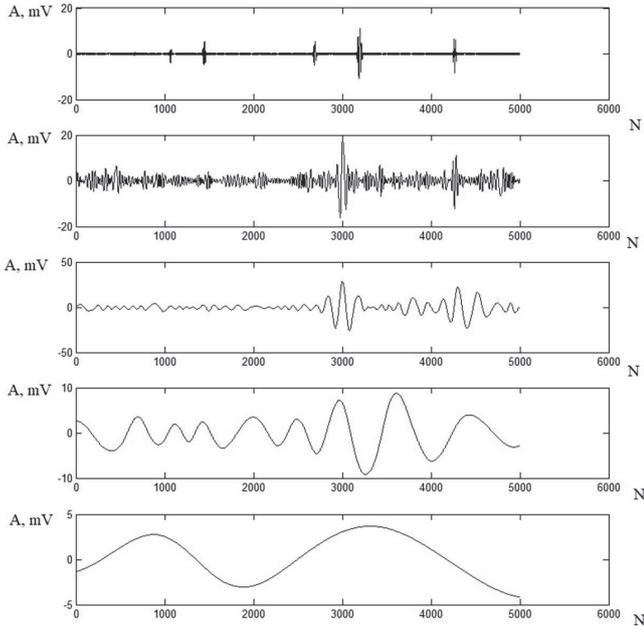


Fig. 3. *ATC* of the ECG signal

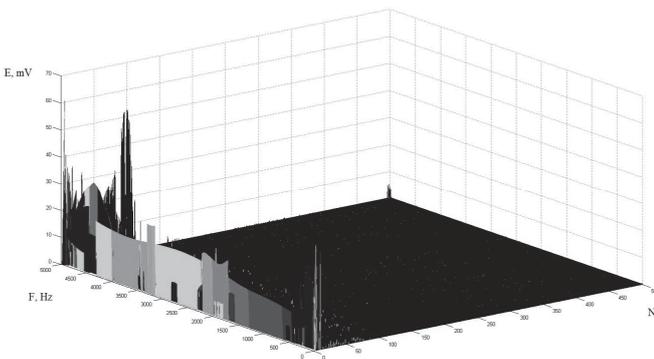


Fig. 4. *SED* of the ECG signal

V. RESULTS

The operation result of the method for determining borderline mental disorders using the ECG signal is the determination of the maximum value of the amplitude and energy characterizing the time of the onset of the psycho-

traumatic situation:

$$ATC_{max}(t) = \sum_3^4 ATC_i(t) - d_j(t) \tag{4}$$

$$SED_{max}(t) = \sum_{i=1}^I ATC_i^2(t) \cdot e^{q \int \omega_i(t) dt} - SED_{thr}(t) \tag{5}$$

The research of the developed method for determining borderline mental disorders using the ECG signal showed that the time period for the appearance of borderline mental disorders is accurately determined by the *ATC* and *SED*. Thus, the value of the ECG amplitude at the third *ATC*₃(*t*) and the fourth *ATC*₄(*t*) of the patients from the experimental and control groups at the time of the onset of the psychotraumatic situation is 3.5 times higher than the value of the amplitude before its occurrence, and is in the limit of 20 to 70 mV for the third *ATC*₃(*t*), and of 30 to 90 mV for the fourth *ATC*₄(*t*) (Fig. 5).

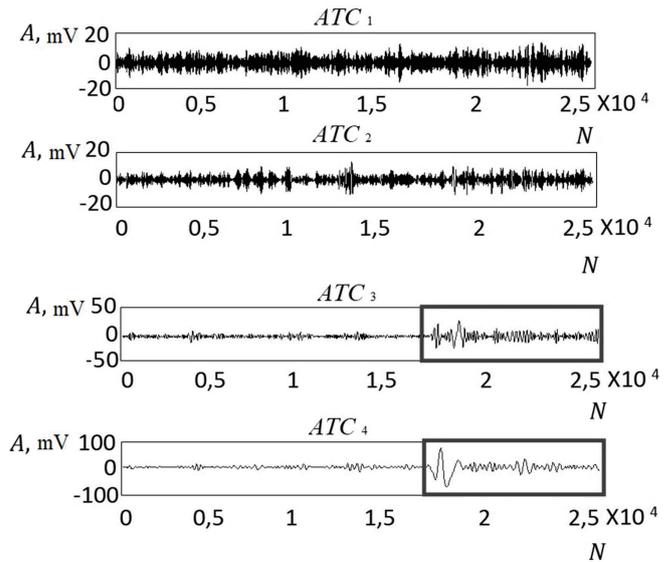


Fig. 5. *ATC* of the ECS during the psychotraumatic situation

During volumetric threshold *SED*(*t*) processing of the ECG, the signal energy values of the patients from the experimental and control groups are extracted at the time of the appearance of the psycho-traumatic situation (after provocation) exceeding the *SED*(*t*) energy of the ECS by 2.5 times until its occurrence, and is in the limit of 1200 to 1900 mV² (see Fig. 6).

As a criterion for evaluating the proposed approach for determining the period of occurrence of psycho-traumatic

situation, errors of the first and second kind are used. The main objective is correct definition of the patient’s mental disorder, so the first kind error was false assignment of the ‘norm’ status to the signs of the patient with pathologies in the central nervous system, and the second kind error was false assignment of the ‘pathology’ status to the signs of a conditionally healthy subject.

Table I shows the results of the proposed approach for determining the time of occurrence of psycho-traumatic situation. The value of the first and second kind errors does not exceed 4%, which indicates the possibility of its adoption as a decisive criterion for determining the period and the moment of occurrence of human borderline mental disorders.

Current experimental results are general for all patient groups and not specified for age, sex etc. More detailed investigation of the proposed analysis method is the task for the future work.

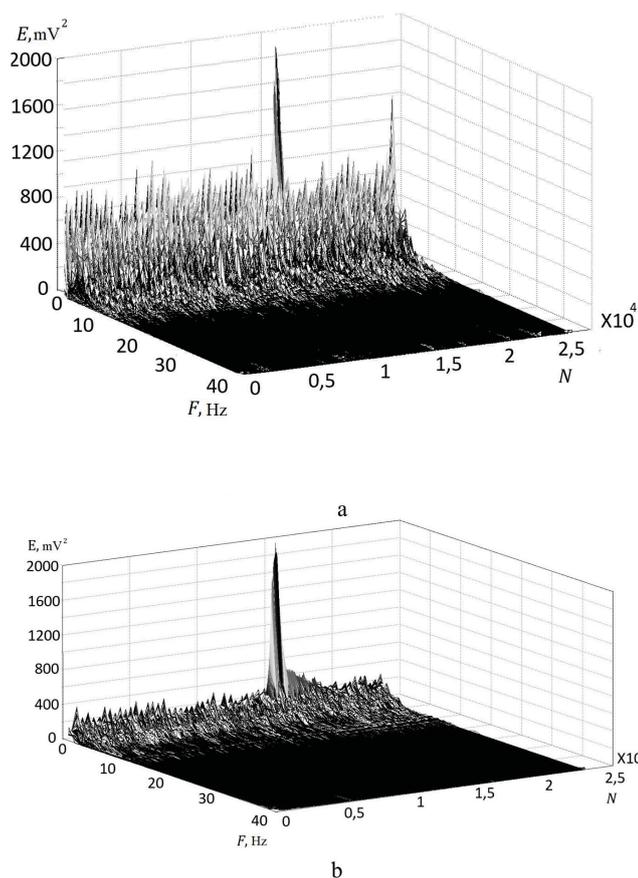


Fig. 6. SED of the ECG signals: a - patients of the experimental group; b - patients of the control group

TABLE I. EXPERIMENTAL RESULTS

Condition	Patients number	Pathology detections	Norm detections	Error type	Error rate
Pathology	400	388	12	II	3 %
Norm	380	15	365	I	3,9 %

VII. CONCLUSION

Based on the conducted review and own research, it is determined that *HHT* is effectively used for processing the ECG signal of patients with borderline mental disorders. The developed approach to the analysis of ECG signals using volumetric spectral surfaces has showed a high probability of determining the period of occurrence of psycho-traumatic situations in various patients using the ECG.

ACKNOWLEDGMENT

The work has been supported by the Russian Science Foundation (project № 17-71-20029).

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