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ARCHITECTURE AND APPLICATION OF A BIOTECHNICAL SYSTEM FOR HUMAN PSYCHOPHYSIOLOGICAL TESTING

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This article examines the architecture and practical application of a biotechnical system for human psychophysiological testing, designed to objectively assess the functional and psychoemotional state of an individual during psychological testing. The relevance of this research stems from the increasing role of the human factor in ensuring the reliability and safety of modern technical and organizational systems, as well as the need to integrate instrumental diagnostic methods into professional selection, personnel certification, and functional state monitoring.

The proposed biotechnical system implements an integrated approach combining hardware recording of physiological signals (electrocardiograms and photoplethysmograms) and software automation of psychological testing, followed by intelligent data processing. The system' s architecture is modular and includes a hardware subsystem for recording biomedical signals, a microprocessor-based primary processing module, a data transmission interface, and a software platform for analysis, visualization, and reporting.

The study developed algorithms for digital processing of biomedical signals, including multi-stage filtering, artifact suppression, cardiac cycle segmentation, detection of characteristic ECG points, photoplethysmogram analysis, calculation of heart rate variability parameters, wavelet analysis of non-stationary components, and the generation of an extended vector of diagnostic features. An ensemble classification model is used for intelligent data interpretation, ensuring robust recognition of psychophysiological states in the face of interindividual variability in physiological parameters.

The results of the experimental testing confirm the viability of the proposed architecture and the practical applicability of the biotechnical system for tasks of professional selection, personnel certification, and functional monitoring in technically complex and socially responsible areas of activity.

Keywords*:* biotechnical system, psychophysiological testing, electrocardiogram, photoplethysmogram, heart rate variability, digital signal processing, intelligent diagnostics.

АДАМНЫҢ ПСИХОФИЗИОЛОГИЯЛЫҚ ТЕСТІЛЕУІНЕ АРНАЛҒАН БИОТЕХНИКАЛЫҚ ЖҮЙЕНІҢ АРХИТЕКТУРАСЫ ЖӘНЕ ҚОЛДАНЫЛУЫ

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Бұл мақалада психологиялық тестілеу кезінде жеке тұлғаның функционалдық және психоэмоционалдық жағдайын объективті бағалауға арналған адамның психофизиологиялық тестілеуіне арналған биотехникалық жүйенің архитектурасы мен практикалық қолданылуы қарастырылады. Бұл зерттеудің өзектілігі заманауи техникалық және ұйымдастырушылық жүйелердің сенімділігі мен қауіпсіздігін қамтамасыз етудегі адам факторының рөлінің артуынан, сондай-ақ аспаптық диагностикалық әдістерді кәсіби іріктеуге, персоналды сертификаттауға және функционалдық жағдайды бақылауға біріктіру қажеттілігінен туындайды.

Ұсынылған биотехникалық жүйе физиологиялық сигналдарды (электрокардиограммалар мен фотоплетизмограммалар) аппараттық жазуды және психологиялық тестілеуді бағдарламалық автоматтандыруды біріктіретін интеграцияланған тәсілді жүзеге асырады, содан кейін интеллектуалды деректерді өңдеу жүзеге асырылады. Жүйенің архитектурасы модульдік болып табылады және биомедициналық сигналдарды жазуға арналған аппараттық ішкі жүйені, микропроцессорға негізделген бастапқы өңдеу модулін, деректерді беру интерфейсін және талдау, визуализациялау және есеп беру үшін бағдарламалық платформаны қамтиды. Зерттеу барысында биомедициналық сигналдарды сандық өңдеу алгоритмдері әзірленді, оның ішінде көп сатылы сүзгілеу, артефактіні басу, жүрек циклін сегменттеу, ЭКГ-ға тән нүктелерді анықтау, фотоплетизмограмманы талдау, жүрек соғу жиілігінің өзгергіштік параметрлерін есептеу, стационар емес компоненттердің толқындық талдауы және диагностикалық белгілердің кеңейтілген векторын жасау. Ансамбльдік жіктеу моделі физиологиялық параметрлердегі жеке аралық өзгергіштік болған кезде психофизиологиялық күйлерді сенімді тануды қамтамасыз ететін интеллектуалды деректерді түсіндіру үшін қолданылады.

Эксперименттік сынақ нәтижелері ұсынылған архитектураның өміршеңдігін және биотехникалық жүйенің техникалық тұрғыдан күрделі және әлеуметтік жауапты салаларда кәсіби іріктеу, персоналды сертификаттау және функционалдық мониторинг үшін практикалық қолданылуын растайды.

Түйін сөздер: биотехникалық жүйе, психофизиологиялық тестілеу, электрокардиограмма, фотоплетизмограмма, жүрек соғу жиілігінің өзгергіштігі, сандық сигналдарды өңдеу, интеллектуалды диагностика.

АРХИТЕКТУРА И ПРИМЕНЕНИЕ БИОТЕХНИЧЕСКОЙ СИСТЕМЫ ПСИХОФИЗИОЛОГИЧЕСКОГО ТЕСТИРОВАНИЯ ЧЕЛОВЕКА

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В статье рассматривается архитектура и практическое применение биотехнической системы психофизиологического тестирования человека, предназначенной для объективной оценки функционального и психоэмоционального состояния личности в процессе выполнения психологических тестовых заданий. Актуальность исследования обусловлена возрастающей ролью человеческого фактора в обеспечении надёжности и безопасности современных технических и организационных систем, а также необходимостью внедрения инструментальных методов диагностики в процессы профессионального отбора, аттестации персонала и мониторинга функционального состояния человека.

Предложенная биотехническая система реализует интегрированный подход, объединяющий аппаратную регистрацию физиологических сигналов (электрокардиограммы и фотоплетизмограммы) и программную автоматизацию психологического тестирования с последующей интеллектуальной обработкой данных. Архитектура системы построена по модульному принципу и включает аппаратную подсистему регистрации биомедицинских сигналов, микропроцессорный модуль первичной обработки, интерфейс передачи данных и программную платформу анализа, визуализации и формирования аналитических отчётов.

В работе разработаны алгоритмы цифровой обработки биомедицинских сигналов, включающие многоэтапную фильтрацию, подавление артефактов, сегментацию кардиоциклов, детектирование характерных точек ЭКГ, анализ фотоплетизмограммы, вычисление параметров вариабельности

сердечного ритма, вейвлет-анализ нестационарных компонент и формирование расширенного вектора диагностических признаков. Для интеллектуальной интерпретации данных применяется ансамблевая модель классификации, обеспечивающая устойчивое распознавание психофизиологических состояний в условиях межиндивидуальной вариабельности физиологических параметров.

Результаты экспериментальной апробации подтверждают работоспособность предложенной архитектуры и практическую применимость биотехнической системы для задач профессионального отбора, аттестации персонала и функционального мониторинга в технически сложных и социально ответственных областях деятельности.

Ключевые слова: биотехническая система, психофизиологическое тестирование, электрокардиограмма, фотоплетизмограмма, вариабельность сердечного ритма, цифровая обработка сигналов, интеллектуальная диагностика.

Introduction. The current stage of scientific and technological progress is characterized by rapidly increasing levels of automation, increasing complexity of technical systems, and increasing volumes of processed information. Under these conditions, the role of the human factor in ensuring the reliability, safety, and efficiency of complex ergatic and cyber-physical systems is increasing. Despite the widespread implementation of intelligent control algorithms, final decision-making in many critical areas still rests with the human operator, necessitating constant monitoring of their functional and psycho-emotional state.

In aviation, transport, energy, telecommunications, industry, law enforcement and the military, the professional activities of personnel are associated with high responsibility, the need to quickly respond to emergency situations and process large volumes of information under time pressure [1,2]. In such conditions, decreased concentration, fatigue, emotional stress and disruption of psychophysiological adaptation mechanisms can lead to operator errors and, as a consequence, to emergency situations with severe socio-economic consequences.

In this regard, the task of objectively assessing a person’ s functional state and their ability to effectively perform professional duties under conditions of increased psycho-emotional stress is particularly relevant [3]. Traditional methods of psychological diagnostics based on questionnaires, surveys, and expert assessments have a number of limitations due to the subjectivity of self-reports, the influence of the subject’ s motivational attitudes, and social desirability effects. Furthermore, such methods do not allow for the detection of latent stress reactions manifesting at the level of the autonomic nervous system and cardiovascular regulation.

One promising area is the development of biotechnical systems that integrate a biological object and a technical device into a single system for recording, processing, and interpreting information. Such systems allow for the integration of psychological methods with hardware-based recording of physiological parameters, ensuring greater diagnostic reliability.

In recent years, instrumental methods of psychophysiological diagnostics based on the recording of objective physiological indicators reflecting the state of the body’ s regulatory systems have become increasingly widespread [4]. These indicators include electrocardiograms, photoplethysmograms, galvanic skin responses, respiratory parameters, electroencephalograms, and other biosignals. Their analysis allows us to identify signs of sympathoadrenal system activation, assess autonomic balance, and diagnose the degree of psychoemotional stress.

The electrocardiogram is of particular interest as one of the most informative and accessible biomedical signals [5-7]. Heart rate and heart rate variability parameters are widely used in medical and psychophysiological practice to assess the body’ s functional state, stress resistance, and adaptive reserves. Analysis of the temporal and spectral characteristics of the ECG allows for the acquisition of objective information on the state of

central and autonomic regulatory mechanisms.

At the same time, recording physiological parameters in isolation without considering the psychological context does not allow for a full interpretation of the observed responses. To obtain a reliable psychophysiological picture, it is necessary to correlate the body' s physiological responses with specific cognitive and emotional stimuli. In this regard, integrating psychological testing with the synchronous recording of physiological signals is a promising approach.

This integrated approach is implemented within biotechnical systems, which are complex ergatic assemblies that unite a biological object (a human) and technical means for recording, processing, and interpreting information. A biotechnical psychophysiological testing system forms a closed loop: "human - measurement system - analytical system – specialist," ensuring objective and reproducible diagnostics of functional state.

Currently, various hardware and software systems for psychophysiological diagnostics exist worldwide, including polygraph systems and functional monitoring systems [8,9]. However, most of them are focused either on lie detection or medical diagnostics and do not provide close integration with psychological testing for professional selection and personnel certification. Furthermore, many foreign solutions are expensive, require specialized maintenance, and are not always adapted to the operating conditions of departmental and corporate information systems.

In this regard, the development of domestic biotechnical psychophysiological testing systems focused on professional selection, pre-shift and pre-trip inspection, functional monitoring, and scientific research is urgent. Such systems must combine reliable hardware, flexible software, high diagnostic information yield, and ease of use.

This paper is devoted to the development of an architecture and analysis of the practical application of a biotechnical system for human psychophysiological testing, implementing an event-driven approach to the integration of psychological testing and segmented electrocardiogram recording [10]. The paper examines the principles of system construction, the organization of information flows, algorithms for digital processing of biomedical signals, and methods for intelligent data interpretation.

The aim of the study is to create a universal biotechnical platform that provides an objective assessment of the functional and psycho-emotional state of a person during the performance of psychological test tasks and is suitable for widespread implementation in applied and departmental information environments.

Materials and methods. The biotechnical system of psychophysiological testing being developed is intended for the automated conduct of psychological tests with the simultaneous recording of the physiological reactions of the subject' s body and belongs to the class of ergatic biotechnical systems and is intended to automate the procedure of psychophysiological testing with the synchronous recording of the physiological reactions of the body.

Three people participate in the testing process: 1) the test subject, 2) the BTS operator, and 3) the psychologist. Figures 1-2 show the interaction diagrams.

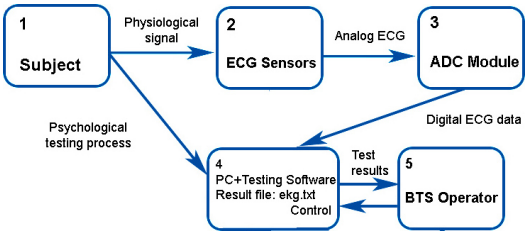


Fig.1- Scheme of interaction between the BTS operator and the subject

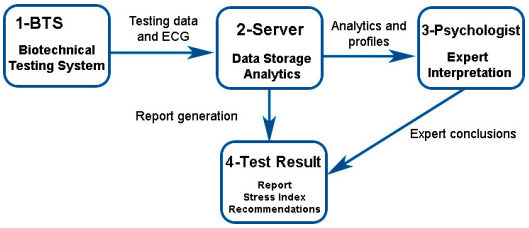


Fig.2 - Scheme of processing testing results by a psychologist

The system architecture is built on a multi-level modular principle and includes two key functional blocks:

1) a psychological testing block;

2) a block for recording, synchronizing, and writing the electrocardiogram to a results file.

In general, the system consists of the following functional levels: 1) recording of biomedical signals, 2) analog-to-digital conversion, 3) microprocessor processing, 4) data transmission and storage, and 5) intelligent analysis and visualization.

The system includes:

1) ECG and photoplethysmogram sensors;

2) analog-to-digital converter;

3) microcontroller module;

4) USB interface;

5) personal computer with analysis software platform;

6) results database and report generation module.

The integration of these blocks ensures the formation of an objective psychophysiological profile of the individual and allows for the analysis of physiological reactions to each individual stimulus (test question).

Results and discussion. The psychological testing unit automates the psychodiagnostic examination procedure and ensures standardized presentation of stimulus material, recording of the subject' s responses, and recording of the time parameters for completing tasks.

The unit performs the following main functions:

- formation of a battery of psychological tests;
- sequential presentation of questions (stimuli);
- recording the start and end of each question;
- recording the selected answer;
- measuring the reaction time of the subject;
- synchronization with the ECG recording unit.

The testing process includes the following steps:

- loading the test battery from the database;
- initializing the testing session;
- displaying instructions to the subject;
- sequential presentation of questions;
- recording responses and reaction times;
- transferring time stamps to the ECG recording unit;
- generating a psychological testing protocol.

Each test question is considered as a separate psychophysiological stimulus, to which the subject's body forms an individual physiological response.

For each question, the following information is recorded: question number q, start time t_{sq}, end time t_{eq}, reaction time t, and the selected answer option. These parameters are subsequently used to synchronize with physiological signals and generate diagnostic features.

The physiological data recording unit is designed for continuous recording of an electrocardiogram during the psychological test and the formation of a result file containing segmented ECG fragments for each question.

The ECG signal is collected from the body surface using non-invasive electrodes and fed to the analog-to-digital converter (ADC) of the microprocessor module. The following steps are performed:

- preliminary analog filtering;
- analog-to-digital conversion;
- transmission of digital readings to the software subsystem.

The software registration module ensures continuous reception of digital ECG readings and their storage in a text file of results in real time.

The results of electrocardiogram recording are saved in a text file of ekg.txt format, in which the values of the ECG signal amplitude at discrete moments in time are recorded line by line.

To ensure synchronization of physiological data with psychological stimuli, a special *separator marker is used*, inserted into the file at the end of each question.

Each fragment between two markers corresponds to one test question.

The use of segmented ECG recordings divided by test questions provides the following advantages:

- analysis of the body' s response to each stimulus;

- identification of hidden stress reactions;

- comparison of physiological parameters with specific psychological scales;

- formation of an individual psychophysiological profile;

- increased diagnostic reliability.

This approach allows us to move from an integrated assessment of a person's condition to event-oriented psychophysiological diagnostics.

One of the key features of the developed biotechnical psychophysiological testing system is the use of event-driven electrocardiogram recording during psychological testing tasks. Unlike traditional physiological monitoring methods, which analyze the subject' s holistic state throughout the entire examination session, the proposed system utilizes event-driven synchronization of physiological data with individual psychological stimuli. Each test question is considered a distinct psychophysiological event, eliciting an individual response from the body' s regulatory systems. This approach allows for a shift from an average assessment of functional status to a detailed analysis of responses to specific cognitive and emotional stimuli, significantly increasing the diagnostic sensitivity and prognostic value of the system.

Experimental testing of the developed biotechnical system for psychophysiological testing was carried out with the aim of assessing the performance of the hardware and software architecture, verifying the algorithms for processing biomedical signals, and determining the diagnostic information content of the proposed psychophysiological indicators.

The main objective of the experimental studies was to confirm the possibility of objectively recording the physiological reactions of the body during the performance of psychological test tasks, as well as to evaluate the effectiveness of the event-segmented approach to the analysis of the electrocardiogram, synchronized with individual test questions.

The experimental studies were conducted in a laboratory setting at the Educational and Scientific Center for Psychophysiological Research. Volunteers aged 18 to 30 with no diagnosed cardiovascular or neurological conditions participated in the trial.

Before testing, subjects underwent a briefing explaining the study' s objectives, the procedure, and the rules for using the system' s hardware. Each participant provided informed consent for the processing of personal and biomedical data.

The testing procedure included the following steps:

1. Registration of an individual background profile in a resting state (3–5 minutes).

2. Conducting a battery of psychological tests with synchronous ECG recording.

3. Formation of the resulting ECG file with segmentation by questions.

4. Automatic processing of physiological data.

5. Formation of a psychophysiological conclusion.

During the experiment, standard requirements of biomedical ergonomics were observed: a comfortable position for the subject, a stable room temperature, and the absence of external irritants and electromagnetic interference.

During the testing, a battery of psychological tests was used, aimed at diagnosing:

- anxiety level;

- aggressiveness of personality;

- neuropsychic stability;

- stress resistance and cognitive load.

Each test included 20 to 40 questions, presented in random order to minimize habituation. For each question, the following were recorded:

- question number;

- the moment of beginning and end;

- selected answer option;

- the reaction time of the subject.

Simultaneously with the presentation of questions, continuous ECG recording was carried out, followed by recording of data in a text file of ekg.txt format with division of segments by marker.

The processing of experimental data was carried out automatically and included the following steps:

1. Import of the resulting ECG file.

2. Signal segmentation by FFFF markers.

3. Digital filtering of each segment.

4. R-peak detection and cardiac cycle segmentation.

5. Calculation of RR intervals and heart rate variability indices.

6. Formation of a vector of psychophysiological characteristics.

7. Normalization relative to the background profile.

8. Intelligent classification of states.

9. Calculation of the integral index of psychophysiological stress.

For each test question, a set of indicators was formed that reflect the body' s physiological response to the corresponding stimulus.

The experiment yielded representative arrays of event-segmented physiological data. Analysis revealed consistent patterns of changes in cardiovascular regulation indicators depending on the emotional significance of the stimuli.

For questions related to the anxiety and aggression scales, the following were observed:

- increase in heart rate by 10-18%;

- reduction of SDNN and RMSSD values by 15-25%;

- growth of the integral energy of the cardiac signal;

- increasing the reaction time of the subject.

For neutral questions, physiological parameters remained close to background values. The application of the ensemble classification model provided the following average accuracy rates:

- Accuracy: 91- 93%

- Sensitivity: 88 - 92%

- Specificity: 94 - 97%

- F1 score: 0.88-0.91

The obtained values confirm the high stability of the algorithms and the correctness of the selected set of diagnostic features.

The results of the pilot study showed that the developed biotechnical system can detect both overt and covert psycho-emotional reactions, which are not always consciously recognized by the subjects. This confirms the diagnostic value of the instrumental approach and its advantages over traditional survey methods.

Event-segmented ECG analysis provides a detailed picture of the body' s reactions to individual psychological stimuli and allows for the formation of individual psychophysiological profiles suitable for practical use in professional selection and functional monitoring systems.

Conclusions. This paper examines the design principles, architecture, and practical application of a biotechnical system for human psychophysiological testing. This system is designed to objectively assess the functional and psychoemotional state of an individual while completing psychological testing tasks. The developed system implements an integrated biotechnical approach, combining an automated psychological testing unit and a hardware unit for recording physiological signals, followed by intelligent data processing.

The relevance of the research conducted is determined by the growing role of the human factor in ensuring the reliability and safety of modern technical and organizational systems [11-14]. Given the increasing information load, the increasing complexity of professional activities, and the increasing responsibility of personnel, traditional psychodiagnostic methods, based primarily on survey methods, do not always provide the necessary level of objectivity and predictive value. Therefore, the development of psychophysiological testing tools based on the recording of the body' s physiological reactions is an important and sought-after scientific and technical task.

A key feature of the developed biotechnical system is the event-driven organization of the testing procedure, in which each question in the psychological test is treated as an individual psychophysiological stimulus, eliciting a specific response from the body' s regulatory systems. The psychological testing unit ensures standardized presentation of stimulus material, recording of the subject' s responses and the timing of task completion, as well as the generation of a testing protocol containing data on the sequence of questions, reaction times, and selected answers.

This study developed and tested a set of algorithms for digital processing of biomedical signals, including multi-stage filtering, artifact suppression, cardiac cycle segmentation, detection of characteristic ECG points, heart rate variability analysis, and the generation of an extended vector of diagnostic features. The use of an event-based segmentation approach allows for the calculation of psychophysiological indicators separately for each test question and the comparison of physiological responses with specific psychological scales.

The study places particular emphasis on individualizing diagnostics through the use of a background profile of the subject, formed at rest. Normalizing diagnostic features relative to the individual background allows for accounting for interindividual variability in physiological parameters and ensures accurate comparison of the same individual' s responses under different conditions. This approach improves the robustness of state recognition algorithms and the reliability of diagnostic conclusions.

Experimental testing of the system confirmed the operability of the hardware and software architecture, the correctness of the implemented signal processing algorithms, and the high diagnostic value of the event-based segmentation approach. The results demonstrate the ability to detect both overt and covert psychoemotional reactions that are not always consciously recognized by subjects and not reflected in their subjective self-assessments. This confirms the fundamental advantages of the instrumental psychophysiological approach compared to traditional survey methods.

The practical significance of the developed biotechnical system lies in its potential for use in professional selection systems and periodic certification of personnel in technically complex and socially responsible fields, such as aviation, transportation, energy, industry, telecommunications, law enforcement, and the military. The mobility of the hardware and the versatility of the software allow the system to be used in both stationary laboratories and mobile settings, including pre-shift and pre-trip inspections.

The use of event-segmented ECG recording during psychological testing paves the way for the development of individual digital psychophysiological profiles of employees and the implementation of long-term monitoring systems for their functional status. Integration of the system with corporate and departmental information platforms enables the automation of data analysis, report generation, and decision support processes in the areas of human resources management and occupational safety.

Further development of the biotechnical system includes expanding the sensor suite by incorporating galvanic skin response, respiratory parameters, and accelerometry, which will improve diagnostic robustness and the accuracy of psychophysiological response interpretation. The implementation of deep learning methods for automatically generating diagnostic features and adapting classifiers to the individual characteristics of test subjects is also promising.

Thus, the developed biotechnical system for psychophysiological testing represents a modern and effective tool for objectively diagnosing a person' s functional and psychoemotional state. Event-driven integration of psychological testing and segmented ECG recording provides a fundamentally new level of detail and reliability in psychophysiological diagnostics and forms the basis for the creation of intelligent systems to ensure professional safety in the face of increasing psychoemotional and informational stress.

References

1. Chernorizov AM, Isaychev SA, Zinchenko Yu. P. Psychophysiological methods for the diagnostics of human functional states: New approaches and perspectives // Psychology in Russia: State of the Art. – 2016. - Vol.9(4).- P.23-36. DOI 10.11621/ pir.2016.0403.

2. Lohani M, Payne BR, Strayer DL. A Review of Psychophysiological Measures to Assess Cognitive States in Real-World Driving//Front Hum Neurosci. - 2019. doi 10.3389/fnhum.2019.00057.

3. Tiberio L., Cesta A., Olivetti Belardinelli M. Psychophysiological Methods to Evaluate User' s Response in Human Robot Interaction: A Review and Feasibility Study. //Robotics.- 2013. -Vol.2(2). - P.92-121. DOI 10.3390/robotics2020092.

4. Schmälzle R., Grall C. Psychophysiological Methods: Options, Uses, and Validity. // The International Encyclopedia of Media Psychology, J. Bulck (Ed.). - 2020. DOI 10.1002/9781119011071.iemp0013.

5. Li K, Rüdiger H, Ziemssen T. Spectral Analysis of Heart Rate Variability: Time Window Matters// Front Neurol.- 2019.-Vol.10. doi 10.3389/ fneur.2019.00545.

6. Estévez M., Machado C., Leisman G., Estévez-Hernández T., Arias-Morales A., Machado A., Montes-Brown J. Spectral analysis of heart rate variability //International Journal on Disability and Human Development. - 2016. -Vol.15(1). - P.5-17. DOI 10.1515/ijdhd-2014-0025.

7. Pradhan BK, Neelappu B. Ch., Sivaraman J., Kim D., Pal K. A Review on the Applications of Time-Frequency Methods in ECG Analysis// Journal of Healthcare Engineering. - 2023.-Vol.1:3145483. DOI 10.1155/2023/3145483.

8. Zyout A, Alquran H, Mustafa WA, Alqudah AM. Advanced Time-Frequency Methods for ECG Waves Recognition. Diagnostics (Basel). -2023.-Vol.1:308. doi 10.3390/diagnostics13020308.

9. Kei H., Satoshi Y., Yasuya I., Ryota Y., Ryo W., Naoki T., Noriyuki S. Time-frequency analysis of high-frequency power profile within the QRS complex in patients with ventricular tachycardia using wavelet transform //Journal of Electrocardiology. -2025.-Vol.91:154027. DOI 10.1016/j.jelectrocard.2025.154027.

10. Amekran Y., Damoun N., El H. Analysis of frequency-domain heart rate variability using absolute versus normalized values: implications and practical concerns // Frontiers in Physiology. -2024.-Vol.15:1470684. DOI 10.3389/fphys.2024.1470684.

11. Mazakova A.T., Daribayeva G.D., Amirkhanov B.S., Zholmagambetova B., Abdirazak B.K. Biotechnical system of psychophysiological diagnostics of personality conflict// Bulletin of KazUTB. - 2019. - No.4. - P.2-19.

12. Mazakova A.T., Amirkhanov B.S., Daribaeva G.D., Ziyatbekova G.Z., Abdirazak B.K. Программно-аппаратный комплекс психофизиологического тестирования// Вестник КазУТБ. -2019.-№ 1.-С-2-9

13. Mazakova A. T., Amirkhanov B.S., Mussabek G.K., Abdirazak B.K., Daribaeva G.D. Expansion of psychological test battery biotechnical psychophysiological diagnostic system // Bulletin of the Kazakh-British Technical University. -2021.-Vol.18(3).-P.51-55. DOI 10.55452/1998-6688-2021-18-3-51-55.

14. A.s. No.5499, 2019, September 26. Mazakov T.Z., Ziyatbekova G.Z., Mazakova A.T., Daribaeva G.D., Әbdirazak B.K., Amirkhanov B.S., Zholmagambetova B.R. A set of psychophysiological testing programs. Computer program.

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