THE METHODS OF BIOSIGNALS PROCESSING AND THEIR IMPLEMENTATION IN THE STRUCTURE OF THE SYSTEM OF IMPAIRED HUMAN COMMUNICATIVE FUNCTION COMPENSATION

Oksana Dozorska,[1] Vasil Dozorskyi,[1] Evhenia Yavorska,[1] Yuriy Kapatsila,[1] Iryna Pankiv,[1] Andriy Kubashok[1]

[1]Ternopil Ivan Puluj National Technical University, Rus'ka str. 56, 46001, Ternopil, Ukraine; vasildozorskij1985@gmail.com

Abstract: The methods of biosignals processing and structure of the system of impaired human communicative function compensation are proposed. The methods of biosignals processing are based on the application of spectral-correlation analysis methods using the sliding window method and include preparatory and main stages. The sequence of steps of biosignals processing at the preparatory and main stages is substantiated. Also technical parameters and features of practical realization of constituent elements of the system of impaired human communicative function compensation are offered. The principle of operation of the system is based on the parallel selection and processing of electroencephalographic and electromyographic signals. At the same time the features of electrode constructions for selection of electroencephalographic signals, which are widespread today, as well as possible artifacts that will arise in the process of selection of these signals are analyzed. The design of electrodes for registration of electroencephalographic and electromyographic signals is proposed, the selection and processing of which is the basis of the method of indirect compensation of the impaired communicative function, which is realized by this system. A variant of realization of the functional diagram of the block of biosignals selection is proposed. The proposed design of the system of impaired human communicative function compensation can be manufactured using 3D printing technology, which will reduce its cost.

Keywords: *human communicative function, compensation system, processing methods, spectral-correlation analysis, electrodes, block of biosignals selection*

1. Introduction

The communicative function is the most important means of exchanging information between people.Given the significant increase in the number of people with disabilities or complete loss of ability to speak (exchange information) due to various injuries or diseases of organs that realize the human communicative function, it is important for medicine to develop technical means to compensate for violations of this function. Such a system can be implemented through the use of indirect methods of compensation, which will make it possible to obtain sufficient information to recognize what the person was trying to say.

Promising in this case is the use of a method based on the selection and processing of biosignals that control the work of organs and systems that directly implement the communicative function in the state of medical norm. These signals occur in certain areas of the cerebral cortex in the form of nerve impulses, which move along the nerve fibers innervate the organs of the articulatory apparatus, vocal folds, organs of the respiratory system. At the same time it becomes possible to recognize speech - to identify in the structure of these biosignals informative features of individual elements of speech when patients try to say something. Analysis of known studies shows that different types of biosignals and methods of their selection and next processing are used for speech recognition, in particular electroencephalographic (EEG) signals [1-4]; electromyographic (EMG) signals of facial muscles [5-9]; EMG signals selected from the surface of the patient's neck [10]. In this case, the methods of statistical and spectral-correlation analysis are used for processing when presenting such biosignals in the form of a stationary random process. However, in the case of processing EMG signals of facial muscles, it is possible to obtain information only about the processes of innervation of the articulatory apparatus, in the case of processing of EMG signals from the neck - only about the processes of innervation of the vocal folds. EEG signal processing involves the elimination of all artifacts associated with the work of other parts of the brain, taking into account the methods of coding and transmission of speech information in the flow of nerve impulses in the neural structures of speech centers of the brain and the reflection of these processes on the patient's head. The use of a stationary model and appropriate processing methods is possible only for short implementations of these signals lasting 0.2-10 sec, while to compensate the impaired human communicative function it is necessary to process much longer implementations of biosignals.

For indirect compensation of impaired communicative function is particularly promising to use a method based on the parallel selection and processing of a group of biosignals, in particular EEG signals recorded from the surface of the head near speech centers, and EMG signals recorded from the neck of patients near vocal folds [11]. On the basis of methods of processing of such biosignals algorithms of functioning of biotechnical system of compensation of the impaired human communicative function can be realized.

Actually, the method of compensation of the impaired communicative function involves the formation of a sequence of time intervals that correspond to vowel, consonant vocalized and non-vocalized sounds (based on the results of EEG and EMG signals processing). In this case, the method of selection of the obtained intervals can be matched to a particular word that the patient tried to pronounce, and which best fits the resulting combination of sounds. Then, to compensate the impaired communicative function, it will suffice to obtain such a sequence of time intervals.

The division into individual sounds is proposed to be performed according to the presence of signs of the main tone (MT) in the structure of EMG signals (for vowel sounds) and changing the value of MT (for vocalized consonant sounds). However, if a mentally spoken word begins with one or more unvoiced consonant sounds, the probability of error in recognizing this word only by EMG signals increases.

It is proposed to form a conditional time interval of the beginning and end of a mentally spoken word based on the results of EEG signal processing, followed by segmentation of this interval into sections corresponding to vowel, consonant vocalized and unvocalized sounds, based on the results of EMG signal processing.

The use of this method will allow the selection of biosignals, the structure of which will contain sufficient information for subsequent identification of individual structural elements of speech in patients with impaired communicative function, and implement a biotechnical system of indirect compensation of this function.

2. The methods of biosignals processing

To implement the algorithms of functioning of the system of impaired communicative function compensation, the methods of EMG and EEG signals processing have been developed [11]. EMG signal processing is performed to detect time intervals for the presence of signs of MT and includes two stages, namely: preparatory and main. The purpose of the preparatory stage is to estimate the approximate value and interval of the MT frequency existance by analyzing the test EMG signal. Such a signal must be pre-recorded from the patient trying to pronounce test sounds and phrases at strictly defined intervals. In this case, the EMG signal areas where the signs of MT should be present become known and it becomes possible to isolate these signs and, accordingly, to estimate the approximate value of the MT frequency and the interval of its existence.

The purpose of the main stage is to actually find time intervals of the presence of signs of MT in the structure of EMG signals, which are recorded in real time from the same patient who tries to pronounce arbitrary sounds and phrases at arbitrary moments of time.

For processing of EMG signals it is expedient to use methods of spectral-correlation analysis of stationary random processes, and processing of signals to be carried out on time intervals of a certain duration - within the sliding window.

The preparatory stage includes the following substages: 1) the formation of a sliding window of a given width, which is moving in time on the test part of the registered EMG signal; 2) within each translation of the sliding window, the distribution of the spectral power density of the EMG signal is estimated; 3) estimation of the presence of the maximum in the distribution of the spectral power density in the range of 80-450 Hz (the range of the MT frequency). The frequency of placement of the first maximum in the estimates of the distribution of the spectral power density corresponds to the frequency of MT (formant analysis); 4) estimation of the approximate value of the MT frequency; 5) estimation of the interval of existence of the MT frequency.

The main stage includes the following substages: 1) the formation of a sliding window with a specified width, which is translating in time on the main register of the EMG signal; 2) within each translation of the sliding window, the distribution of the spectral power density of the EMG signal is estimated (similarly as for the preparatory stage); 3) averaging estimates of the distribution of the spectral power density of the EMG signal in the range of the MT frequency; 4) the formation of the criterion for deciding on the presence of signs of MT in the structure of EMG signals.

Substantiation of the choice of sliding window parameters as well as estimation of the approximate value and interval of the existence of the MT frequency was carried out in works [11, 12].

The method of EEG signals processing to detect the time moments of the beginning and the end of the speech process by detecting signs of changes in brain activity when trying to implement the communicative function has also been developed. The method includes the following steps: 1) the formation of a sliding window of a given width, which is moving in time on the registered EEG signal; 2) within each sliding window, the distribution of the power spectral density of the EEG signal is estimated in the same way as for the processing of the EMG signal; 3) averaging of estimates of the distribution of power spectral density; 4) on the basis of the received average estimations of distribution of power spectral density formation of criterion of decision-making on existence of signs of communicative function realization is carried out. As a criterion, it is proposed to use the variation of the average estimates of the power spectral density distribution with the assumption that the values of variation of these estimates for the state of rest will differ significantly for the state of attempt to implement the communicative function and will not overlap.

The method is based on the calculation of estimates of the power spectral density distribution of EEG signals registered in leads in the immediate vicinity of the speech centers of the brain. The calculation is performed within a sliding window, the width of which is selected in the same way as for the case of processing EMG signals. Next, the averaging of the obtained estimates of the power spectral density distribution within each translation of the sliding window.

The proposed method also includes two stages: preparatory and main. The purpose of the preparatory stage is the selection of EEG signals, when the patient tries to mentally pronounce certain test sounds and words at certain intervals. Through a set of test statistics and its subsequent analysis, ranges of numerical values of averaged estimates of the distribution of power spectral density for EEG areas during the mental pronunciation of test sounds and words and areas for rest are formed.

During the main stage, the EEG signals are constantly selected and the average estimates of the power spectral density distribution within the sliding window translations are calculated. The numerical values of these estimates are used to calculate the time intervals of the presence or absence of signs of the speech process (attempts to mentally pronounce arbitrary sounds or words or silence) based on the results of these values in the appropriate ranges of numerical values of these estimates.

Using the two described methods of EEG and EMG signals processing, it becomes possible to implement the proposed method of compensation for impaired human communicative function and to develop the structure of a biotechnical system that will implement this method.

3. The structure of the system of impaired human communicative function compensation

To implement the described method of indirect compensation of impaired communicative function, it is possible to use an electroencephalograph and electromyograph. However, the use of an electroencephalograph to solve this problem in practice will be difficult for physicians and inconvenient for patients, because in the process of experimental selection of EEG signals found imperfections in the design of the cap for fixing electrodes and imperfections in the design electrodes, which significantly affects the quality of selected statisticals material and the final result. According to the first type of imperfections, most modern electroencephalographic complexes use caps made of silicone or rubber tubes to which electrodes are attached. However, in the selection process it is especially difficult to ensure reliable fixation of the electrodes to the cap in the necessary places (according to the system of imposition "10-20%") and reliable contact with the surface of the patient's head. The use of 16 leads (or more) requires control of fixation and contact of each of the electrodes. Also, the registration method is sensitive to involuntary movements of the head, eye movements of the patient, etc., which leads to the appearance in the structure of selected EEG signals of movement artifacts, which during further processing can be mistaken as signs of trying to implement the patient's communicative function.

After analyzing the design of EEG electrodes, it was noticed that most modern complexes for EEG research are equipped with cup electrodes, which work on the principle of creating a capacitive system between the conductive surface of the electrode and the skin surface. The electrodes are placed on the surface of the scalp through the hair. This degrades the quality of contact of the electrodes with the scalp and causes a noise component in the structure of the selected signals, the appearance of movement artifacts and more. When using the wetting method or special conductive gel, the last is squeezed out from under the electrode and spreading on the hair or scalp and as a result the contact area is increasing . The use of the gel is uncomfortable for the patient when it comes to long-term selection of EEG signals. Features of the design of cup electrodes are shown in Fig. 1 and Fig. 2.

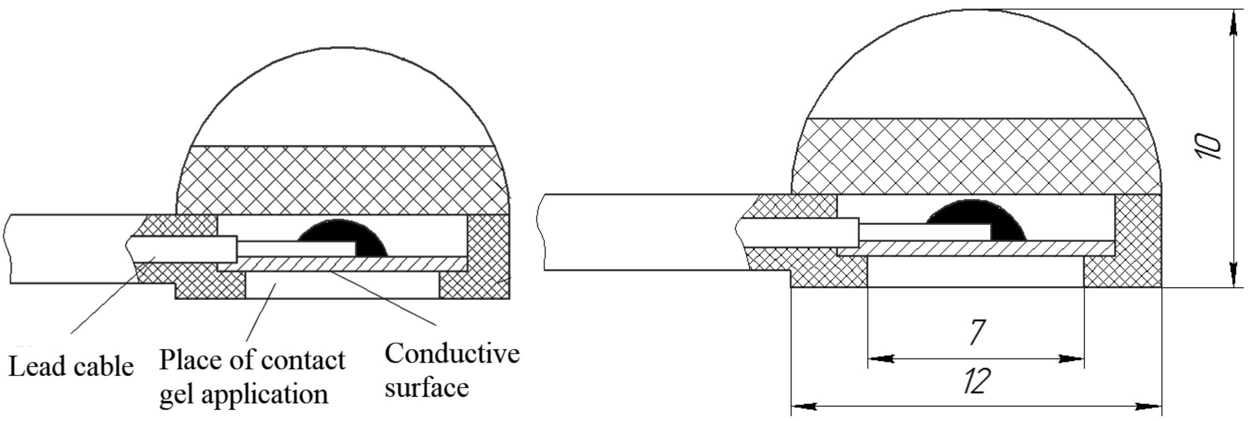

Fig.1 Design of cup electrodes of the encephalograph

It is proposed to use a design that will be a block of biosignals selection and amplification, which will be located on the back of the neck. From the upper frequency of the block will go two long plates (with bends according to the shape of the head) to the left and right temple.

At the ends of these plates will be placed three electrodes (because the speech centers in different people can be located on the right and left side of the brain and the electrodes are proposed to be placed on both sides). Two short plates will protrude from the lower part of the block and will completely wrap around the neck. Electrodes for selection of EMG signals in the area of vocal folds will be placed on them. Both the upper and lower plates will be able to adjust their length and bending to ensure maximum fit to the head (head sizes may vary from person to person) and reduce patient discomfort. Inside the plates will be conductors that connect the electrodes to the corresponding inputs of the block of biosignals selection. The view of the proposed design is shown in Fig. 3.

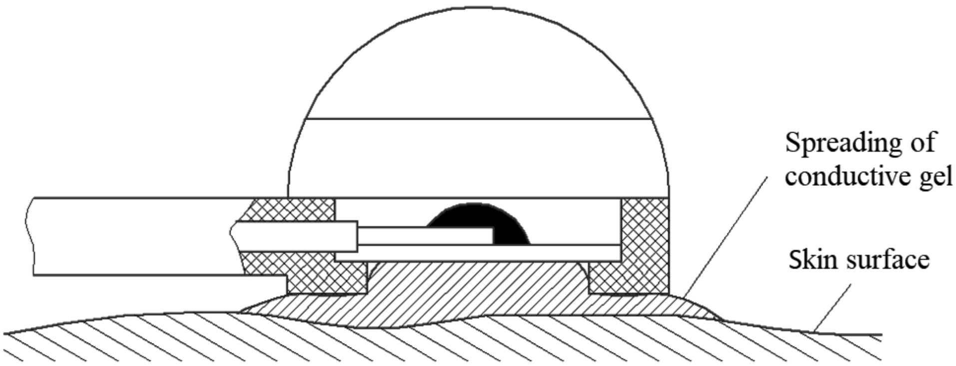

Fig. 2 Spreading of conductive gel on the skin surface

It is proposed to make electrodes with an uneven shape of the sensitive surface, in particular in the form of small needles with rounded tips, which will freely penetrate through the hair to the surface of the patient's scalp. This eliminates the need for conductive gel, which will be more comfortable for patients.

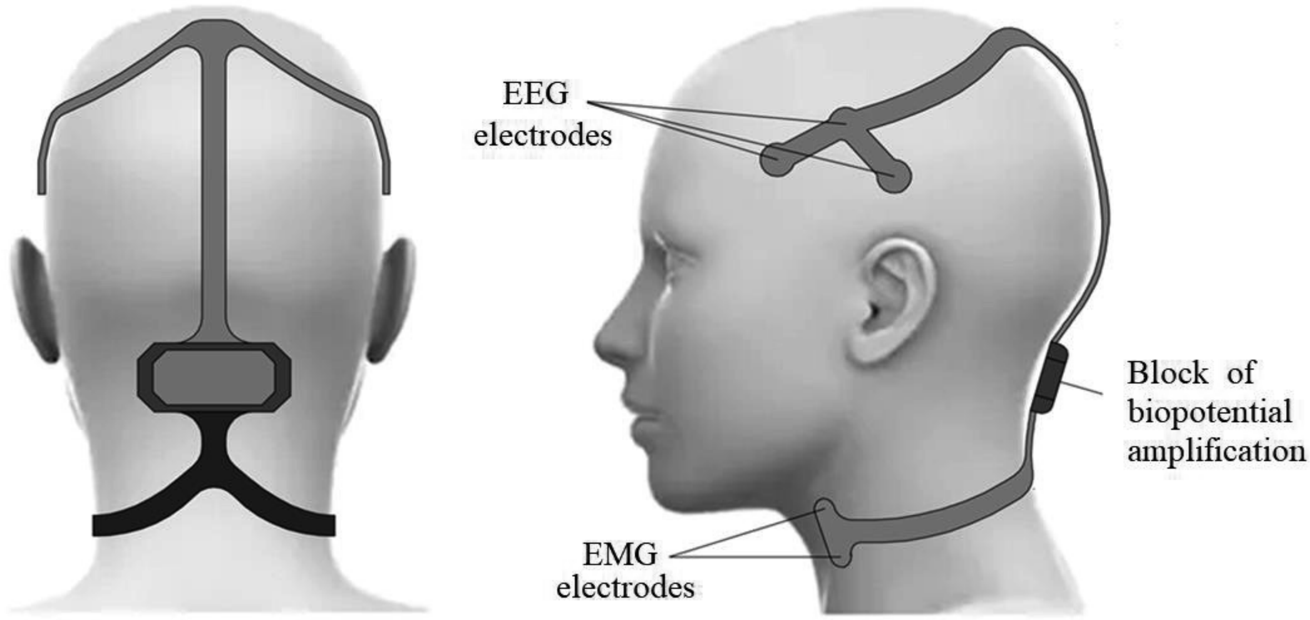

Fig. 3 The design of the system of impaired communicative function compensation

An example of the proposed design of such dry electrodes is shown in Fig. 4. The same electrodes are proposed to be used for the selection of EMG signals. Since the use of such electrodes will significantly reduce the area of contact of the sensitive surface of the electrode with the skin surface, the resistance of the lead will increase significantly (up to tens of megohms). Therefore, it is proposed to install in the design of the electrodes operational amplifiers with high input resistance, which are included in the circuit of the voltage repeater. This will increase the input resistance of the sampling unit and match it with the resistance of the signal source. As such operational amplifiers can be used amplifiers from Texas Instruments TLC272CP, the input resistance of which is 10^{12} Ohms, or similar. In the design of the electrode shown in Fig. 4, provides for the installation inside such an amplifier in SMD version.

In fact, the block of biosignals selection will include two identical selection modules, each of which will contain 4 gain channels - three of which are designed to select EEG signals in monopolar mode (relative to the signal common output SGND) and one channel to select EMG signals. Each amplification channel is constructed by analogy with the amplification channels of the electroencephalograph "Neurocom". Amplified EEG and EMG signals are fed to the inputs of an analog multiplexer, which alternately switches them to the output (TDM - Time Division Multiplexing technology).

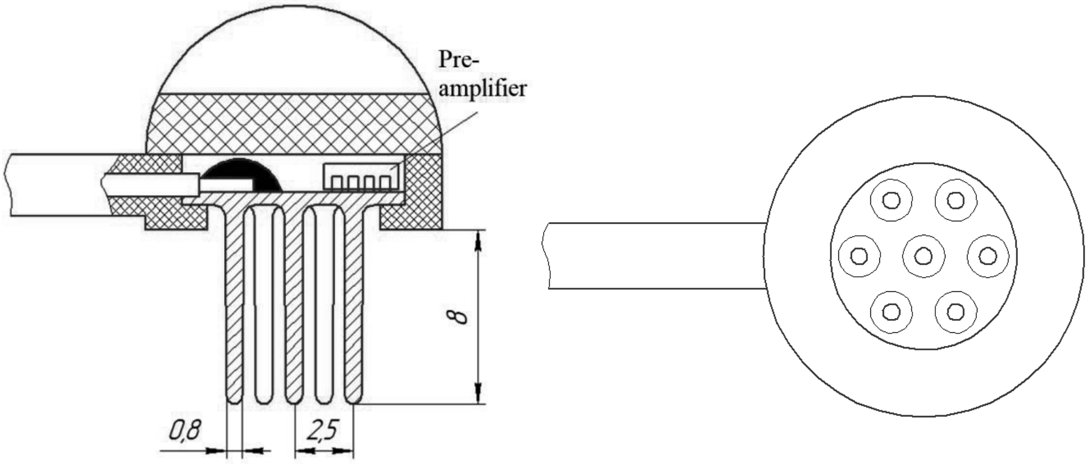

Fig. 4 The proposed design of the dry electrode

The received signal is digitized and fed to the computer through the interface module. For autonomous operation, a small battery and a power supply unit are included in the block of biosignals selection, which generates the required values of supply voltages of the component units of the block. The functional diagram of the proposed block is shown in Fig. 5. Between the amplifiers in each channel there are RC links, which are HPF tuned to a cutoff frequency of 0.7 Hz to prevent the passage of a constant component, that can appear in the structure of EEG and EMG signals. The gain of surgical amplifiers will also be different for EEG and EMG signals and will require individual selection due to the individual characteristics of patients (skin conductivity, the magnitude of the potential applied to the skin surface, etc.). The use of two modules is provided for the selection of EEG and EMG signals from both the left and right surfaces of the neck and head.

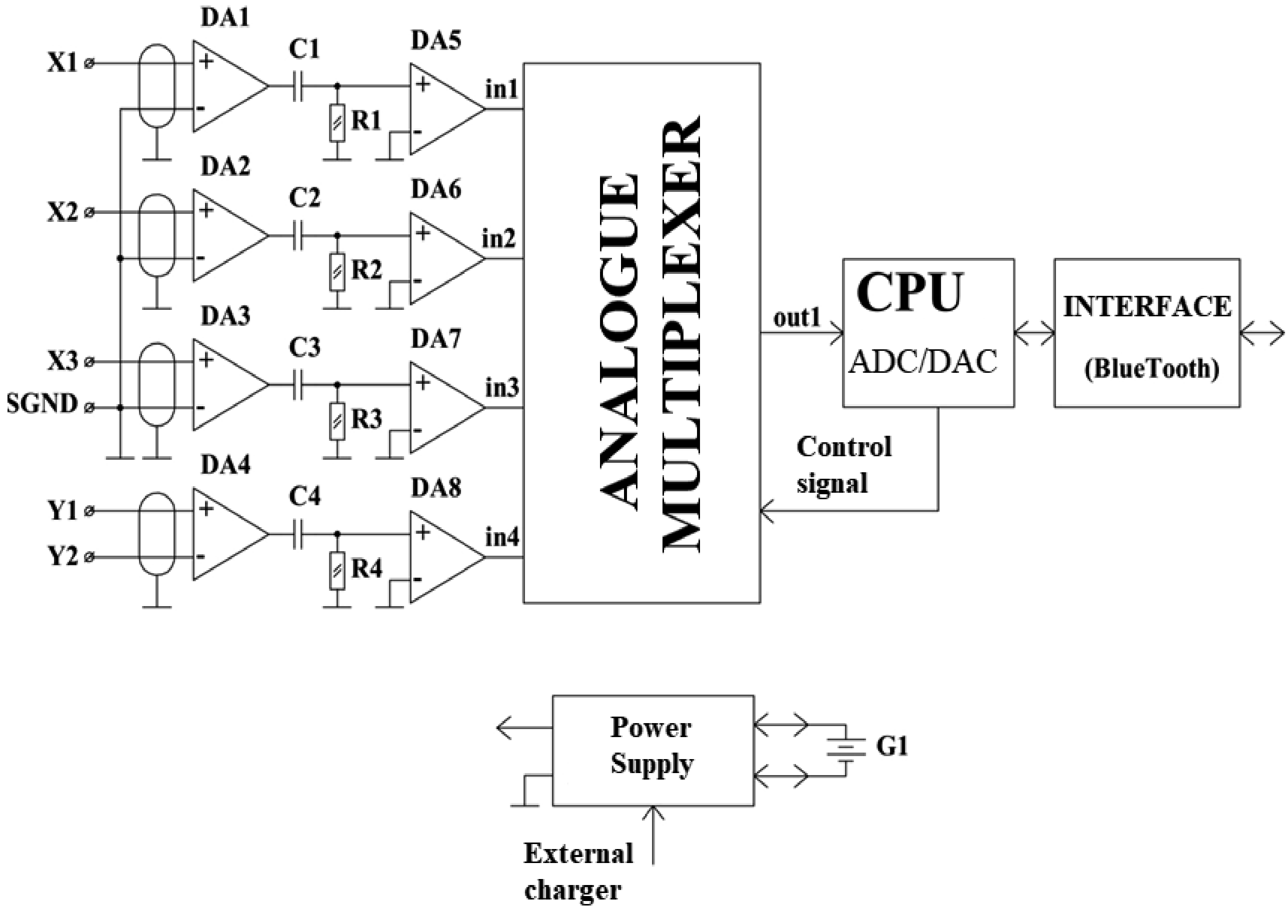

Fig.5 Functional diagram of the proposed block of biosignals selection

Using the interface module (BlueTooth) and a stand-alone power supply will eliminate the need to use any wires to connect the system to the computer, other than charging the internal battery. A personal computer or smartphone can be used as a computing tool, on which software will be installed, which will process the selected signals by the developed methods. The results of the processing (according to the third stage of the proposed method of compensation for impaired human communicative function) will be displayed on the screen of a smartphone or personal computer in the form of text that the patient tried to say, or on speakers placed on short plates of the proposed system.

As a power source can be used a battery from a smartphone with a working voltage of 3.7 V, followed by the use of a booster converter, which will charge the battery via a USB port of a computer or portable charger, and get voltages greater than 3.7 V, including a voltage of 5V to power all the chips of the sampling unit.

The structural elements of the system of impaired communicative function compensation and the electrodes themselves are proposed to be made using 3-D printing technologies from special biologically stable antistatic materials, such as ABS Antistatic or nylon. The sensitive surface of the electrodes must be coated with a sparingly soluble conductive material, such as silver chloride.

4. Conclusion

The paper describes methods of processing biosignals, in particular electroencephalographic and electromyographic, which can be used to develop a biotechnical system for compensation of impaired human communicative function. They include the preparatory and the main stage. The purpose of the preparatory stage is to obtain data on the features of the manifestations of the signs of the speech process by analyzing the test statistics of such signals. These data are necessary for the correct processing of electroencephalographic and electromyographic signals at the main stage, when the mental recognition of sounds or words spoken by patients and their translation into text or spoken language. A method of implementing these methods into the structure of the system of compensation of impaired communicative function is also proposed. The design of dry electrodes is proposed, which is better in comparison with the common designs of electroencephalographic electrodes and allows to reduce the number of artifacts in the structure of such biosignals.

Thus, the proposed method of indirect compensation of impaired human communicative function, methods of processing biosignals, including electroencephalographic and electromyographic, as well as the option of technical implementation of the biotechnical system for such compensation will allow creating an effective rehabilitation system to compensate the impaired communicative function. and the use of the proposed design of electrodes and 3-D printing technologies will reduce the cost of the system and increase its accessibility to the public.

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