Virtual Tools for Fast Registration, Processing and Presentation of Biomedical Signals in “Multimag” Complex

S.G. Gurzhin, V.I. Zhulev, M.B. Kaplan, V.G. Kryakov, Ye.M. Proshin, A.V. Shulyakov
Faculty of Automation and Information Technologies in Control
Ryazan State Radio Engineering University, RSREU
Ryazan, Russia
gurzhin@mail.ru

***Abstract* — The article covers structural realizations of hardware and software parts of virtual tools of fast registration, processing and presentation of biomedical signals in “Multimag” complex. Methods for recording cardiac and respiratory rhythms, main properties of heart rate variability and diagnostic indices are shown.**

***Keywords* — biofeedback, chronomagnetotherapy, photoplethysmogram, pulsogram, rhythmogram, histogram, ultrasound echolocation.**

I. Introduction

The system of complex magnetotherapy of “Multimag” family is a hardware-software complex, which allows to create an almost infinite number of different configurations of the magnetic field affecting a patient. A certain configuration of the magnetic field (a method of treatment) is formed by a control program on a computer included in the complex.

The usage of biotechnical feedback sensors in complex magnetotherapy systems is helpful primarily for patient's functional state diagnostics, for controlling dynamics of his state change during a session, and for correcting the therapeutic effect depending on received diagnostic information of a patient. This correction, which determines changes in frequency-time parameters of the magnetic field (MF) in accordance with patient's recorded biorhythms, significantly increases the effectiveness of the therapeutic effect called chronomagnetotherapy [1]. On the other hand, the correction of the influence can occur in terms of fast change of the effect intensity over time during the corresponding dynamics of a patient's state.

The functional state of a patient's body has a tonic component – basic level of activity of main physiological systems and physical components that are formed when it is necessary to implement certain types of activities. One of the most common methods for controlling the functional state of the body is heart rate variability (HRV) analysis, which has been widely used in clinical practice and applied physiology [2].

Thus, biotechnical feedback sensors of a patient allow to promptly analyze the functional state of the organism, to signal and disable MF in case of patient’s state worsening during the session, to increase the effectiveness of treatment due to adjustment of the influence parameters and its synchronization with patient's biorhythms [3].

II. Registration of Biomedical Signals

To obtain diagnostic information about patient’s condition, “Multimag” complex implements virtual diagnostic devices that are software-controlled data collection systems in which simulation models of real or hypothetical diagnostic devices are organized. Moreover, not only control tools and displaying tools are software, but also the device’s operation logic. Communication between the program and technical means of biomedical signals registration is carried out through the interface nodes, which are drivers of external devices.

Hardware implementation of the biomedical signal recording channel can be represented as a generalized structure (fig. 1).

S – the sensor is a structurally separated converter of the recorded physical quantity into an electrical signal.

MT – the measuring transducer performs a number of analog and digital transformations of the signal, and as a result forms a sequence of coded signal values.

MC – the microcontroller registers a digital measuring signal, processes it and sends it to PC.

I – the interface is a hardware-software unit which provides communication between MT and PC.

PC – the personal computer registers biomedical signals from different measuring channels, processes them, accumulates them and presents them to the operator in a convenient form.

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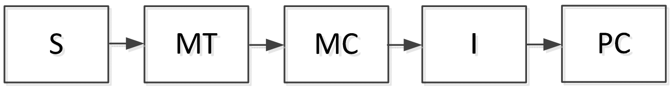

Figure 1. General structure of the hardware implementation of the biomedical signal recording channel

Registration of biotaxis parameters is carried out during the whole session of magnetotherapy. The methods and means used for this purpose should provide technical possibility of collecting biotechnical information to determine desired parameters under conditions of the magnetic field and, at the same time, they should create comfortable conditions for the patient and staff.

Biomedical signal sensors in most cases should be fixed on the patient's body during the session. However, to improve convenience of using the complex, it is better to consider contactless methods of collecting biomedical signals, as a result of which there is no inconvenience to the patient, and electrical safety requirements for the magnetotherapeutic complex are reduced due to the absence of direct contact with the patient's body.

The measuring signal from the sensor's output is transformed according to the type of biomedical signal being registered and according to the method used in the recorder. The main biomedical signal transformations are amplification, demodulation, filtering, scaling, analog-to-digital conversion, etc.

Then digitized biomedical signal is registered by the microcontroller. The main task of the microcontroller is to translate the signal into the control program on PC. In addition to physical implementation of the communication channel, it is necessary to ensure compatibility of data formats on transmitting and receiving sides. This is organized by data transfer protocol. In order to do this, the signal is "packed" according to the specified data transfer protocol and transmitted to the data transfer interface. In addition, the microcontroller can perform digital signal processing and calculate required diagnostic parameters, as well as transfer them through the interface to the PC. The basic requirements are that the microcontroller must have sufficient hardware resources for recording, processing and transmitting this biomedical signal with specified metrological characteristics.

Currently, there is a group of standards which describes the interaction between personal medical devices and computer systems, defines a set of information objects and functions which are necessary to obtain data on basic indicators of body state from personal medical devices and management of these devices [4]. ISO/IEEE 11073 standard describes an objects interaction protocol irrelevant to physical implementation of the communication channel. It allows to implement the interaction between medical devices connected via wired or wireless channel.

When choosing an interface between the microcontroller and the PC, one should consider if it is supported by the hardware on both sides, provides required data transfer speed and stability of the data transmission channel in operating conditions of the magnetotherapeutic complex. For connecting to PC, USB2.0 is the most common interface, it allows to build a virtual COM port to connect most universal microcontrollers.

Transition to wireless transfer of data gathered from sensors has obvious advantages, because it eliminates wires "entangling" the patient and the diagnostic examination is becoming faster and more comfortable for both the patient and medical staff conducting the examination with this device.

For software implementation of an appropriate communication channel within ISO/IEEE 11073 standard, corresponding communication channel drivers are necessary. For different implementations, these drivers are developed at the level of communication channel profiles. The profiles are general mechanisms (protocols and functions) through which available devices interact with other devices within the communication channel.

For Bluetooth connection between medical portable devices within ISO/IEEE 11073 standard, HDP (Health device profile) profile was developed. HDP is designed to regulate and control the interaction between various medical devices and sensors via Bluetooth. To develop this profile, the world's leading manufacturers of Bluetooth equipment have formed an international Medical Device Working Group. The main purpose of this organization was development and creation of a Bluetooth profile which allows to interconnect medical sensors and medical measuring devices of different manufacturers. As a result, two main normative documents were created and approved in 2008: Multichannel Adaptation Protocol (MCAP) and Bluetooth Health Device Profile (HDP). In 2009 they were accepted for implementation by the majority of the world's leading manufacturers of Bluetooth equipment [5].

There are also other technologies for wireless transmission of medical data. Thus, in 2009, ZigBee alliance – the developer of ZigBee technology, suitable for building wireless networking solutions – announced the completion of a medical device profile (ZigBee Health Care public application profile). The new ZigBee profile establishes a global standard for data exchange between wireless devices from different manufacturers for safe and reliable monitoring of non-critical medical parameters [6]. It provides full support of IEEE 11073 devices, including glucometers, heart rate meters, electrocardiographs, medical scales, thermometers, blood pressure monitors and breathing parameters meters.

III. BIOMEDICAL SIGNAL REGISTRATION CHANNEL SOFTWARE

Software implementation of the channel for recording, processing and presentation of biomedical signals in a control program can be represented as the following generalized structure (fig. 2).

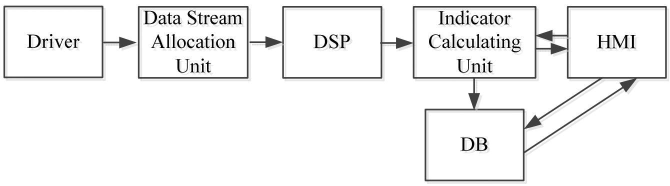

Figure 2. General structure of the software implementation of the biomedical signal recording channel

The driver is the program part of the interface for registering input data.

The data stream allocation unit generates a measurement data stream from input data (bytes) according to the transmission protocol.

DSP – digital signal processing, where all necessary transformations of the measuring signal are carried out. As in the hardware part of the channel, the main transformations are: amplification, filtering, detection, integration, differentiation, etc.

The indicator calculating unit – carries out allocation and evaluation of required diagnostic parameters and properties of the measuring signal.

DB – the database of accumulated diagnostic data. With general transition of modern clinics to electronic medical patient records supporting cloud storage of medical information, there is a clear tendency of saving accumulated diagnostic data for a given biomedical signal recording channel into a single patient database in the clinic.

HMI – the human-machine interface, which implements presentation of diagnostic biomedical patient data under control of an operator.

IV. Biotechnical Feedback Channel of “Multimag” Complex

To solve the task of creating biotechnical feedback within complex chronomagnetotherapy “Multimag” device, there is a number of measuring tools aimed to determine specific physiological parameters of a person for their further analysis and processing. At the same time, magnetotherapeutic technique and intensity must adapt to instantaneous and trend values of these physiological indices. The first regulation circuit, which implements the mechanism of bio-adaptation, is synchronization of magnetotherapeutic effects with human biorhythms. The main physiological indicators, which can determine the overall functional state of a person and are convenient for registration, are cardiac and respiratory rhythms. Therefore, during the magnetotherapy session, “Multimag” complex determines patient's pulse and respiratory rhythm, which allow to diagnose patient's condition and to implement the influence adaptation mechanism.

V. Registration and Analysis of Pulse Indicators

Today there is a large number of cardiac monitoring tools, numerous families of electrocardiographs, rheographs, photoplethysmographs, tomographs, etc. However, considering features of chronomagnetotherapy associated with a significant level of dynamic electromagnetic field around the patient, photoplethysmography is relatively acceptable in terms of noise resistivity. It is enough to fix a pulse wave sensor on a patient’s finger. In addition, most of these sensors, besides controlling the pulse, can simultaneously control oxygen saturation of blood.

Pulse oximetry is the most accessible method of fast monitoring of patient condition in many cases. It allows to calculate oxygen saturation of arterial hemoglobin and pulse frequency and thus to evaluate the efficiency of heart and lungs, to diagnose various hypoxic conditions.

The pulse signal is recorded photometrically by measuring the intensity of infrared radiation transmitted through the patient’s distal phalange. This value depends on the optical permeability of finger tissues, which changes when blood vessels filling changes during the pulse cycle. The output signal of the photometric sensor is an electrical signal called pulsogram.

An informative parameter in the recorded signal is oscillation periods, which are defined as time intervals between certain characteristic points of the signal. It is convenient to use the maximum value of a signal during a period – systolic maximum. However, because of the small amplitude of oscillations compared to the constant component of the signal, as well as many artifacts affecting signal recording conditions, there are certain difficulties in determining the moments of the signal maximum, especially if it is necessary to do this in real time. Some special methods should be considered for detecting the signal.

To register the pulse, “Multimag” complex includes a “Contec” photometric pulse oximeter. This sensor registers the pulsogram and determines pulse rate and oxygen saturation of arterial hemoglobin. The sensor contains a built-in microcontroller which processes the recorded pulsogram and determines heart rate and saturation. Information from the sensor is transmitted to the control program on PC via USB interface, the data packet format is described in the specification for this sensor. Each packet consists of 5 data bytes and contains pulse values, saturation, pulse signal counts, status flags and synchronization bits. Packing frequency is 60 Hz. Thus, at this stage the pulse signal is not processed – instantaneous pulse values determined by the sensor’s controller are used instead.

A sequence of pulse values forms a rhythmogram, which is used for determining the characteristics of heart rate variability (HRV). These characteristics are divided into graphic and spectral characteristics in the time domain [2].

Time domain characteristics include:

1) *mRR* – average duration of cardiointervals (CI) during the observation period, integrally characterizing the level of circulatory system functioning, expressed in ms.

2) *SDNN* – standard deviation (expressed in ms) of CI values for the entire reviewed period, estimates total power and reflects all cyclic fluctuations in HRV structure.

3) *RMSSD* – square root of the mean square of the differences between the values of consecutive CIs of the analyzed time series, indicates activity of the parasympathetic link of vegetative regulation.

4) *NN*50 – number of pairs of consecutive CIs which differ by more than 50 ms, obtained for the entire recording period.

5) *pNN*50 – percentage of *NN50* to the total number of consecutive CIs received for the entire recording period (expressed in %).

6) *CVr* – variation coefficient, which is a normalized estimate of the variance (expressed in %).

7) ΔX (*MxDMn*) – variation range equal to the difference between extreme (largest and smallest) values of the attribute in a given set, expresses the range of neurohumoral regulation influences.

8) *Mo* – mode, CI value most often encountered in a given sample (expressed in ms).

9) *AMo* – the fraction of CI durations values corresponding to the mode value to the total number of CIs (expressed in %).

10) Index of vegetative balance (IVB) indicates the ratio between the activity of sympathetic and parasympathetic parts of autonomic nervous system (ANS).

11) Regulatory processes adequacy index (RPAI) reflects correspondence between the activity of the sympathetic division of ANS and the leading level of sinus node functioning. This indicator allows, by comparison with the pulse rate, to judge whether there is excessive or insufficient centralization of cardiac rhythm control. An increase in IVB and RPAI values reflects activation of the sympathetic division of ANS, its predominance over the parasympathetic one, that is a nonspecific adaptive mechanism under the stress of various etiologies.

12) Tension index (TI). Informs about the tension of compensatory resources of the body, reflects the functioning level of the central contour of heart rhythm regulation and characterizes the initial vegetative tonus.

13) Vegetative rhythm index (VRI). Reflects activity of the autonomous circuit of heart rate regulation, calculated mathematically.

HRV graphic methods, defined during the operation of “Multimag” control program:

1) Rhythmogram – variation of cardiac contraction period over time.

2) Histogram of CI probability distribution (variation curve).

3) Scatterogram (correlation rhythmogram). Representation of consecutive pairs of CI (triples – previous, current and subsequent) in a two-dimensional (or three-dimensional) coordinate plane. The current CI value is plotted along the absciss and the next CI value is plotted along the ordinate. The area of points on the scatterogram is called Poincaré or Lorentz spots.

“Multimag” control program interface displays characteristics recorded from the pulse oximeter sensor during the magnetotherapy session: oxygen saturation (in %) of blood, pulse rhythmogram, initial pulsogram, HRV characteristics in the time domain, and graphical HRV characteristics.

VI. Control of Patient Respiratory Parameters with Complex Chronomagnetic Therapy

As the first stage of creating a device for complex physiological state diagnostics by patient’s respiratory rhythms, a non-contact ultrasonic respiratory sensor was integrated into “Multimag” complex. The developed sensor contains both hardware and software parts and allows to record parameters of patient’s breathing during the session of complex magnetotherapy, as well as to identify phases of inhalation/expiration. The principle of recording the respiratory rhythm is based on periodic measurement of the distance to patient’s thorax in the process of breathing.

Structurally, the breathing sensor is located in the upper segment of “Multimag” inductors in such a way that when the upper segment is installed above the patient, the transmitting and receiving transducers face the central part of patient's thorax.

The principle of the sensor is based on ultrasonic echolocation. Two different ultrasonic transducers built into US-100 or similar ultrasonic unit are used for radiation and ultrasound reception.

The principle of registering the respiratory rhythm is based on periodic measurement of the arriving time of the ultrasonic echo of the signal after its emission because this value will vary depending on the location of patient’s thorax in the process of breathing.

Informative parameters in the recorded signal are temporal characteristics, such as: period (frequency) of respiration, duration of inhalation and exhalation phases, starting moments of inhalation and expiration phases. These characteristics are used for patient’s condition diagnostics during the magnetotherapy session, as well as for synchronizing magnetic effects with respiratory phases in terms of bio-adaptive regulation.

Next, the duration of each phase is determined by the time difference between the beginning and the end of a current phase. Based on the results of digital processing, the rhythmogram of breathing showing the duration of inhalation and expiration phases is constructed.

VII. Conclusion

Virtual tools for patient functional state diagnostics during the magnetotherapy session allow to gather received diagnostic information into a single program. In this case, information from different sensors can be presented in one program interface, stored in a single database, used together in decision-making algorithms for bio-adaptive regulation of magnetic effects.

The methods considered above implement the task of obtaining diagnostic information about characteristics of heart and respiratory rhythms. This information accumulates during the magnetotherapy session and allows to study changes in patient's condition. When taking the possibility of saving the accumulated data from session to session, it becomes possible to evaluate the effectiveness of treatment course as a whole.

In order to implement the effective synchronization of magnetotherapeutic effects with patient's biorhythms, device-patient models are being developed and studied.

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