Wireless three-channel Holter monitoring system

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Wireless three-channel Holter monitoring system

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Abstract. The article describes the principles of construction of a wireless automated system of Holter monitoring of cardiac activity which is focused on the minimum power consumption for use at home. This article proposes the method of wireless transmission of electrocardiosignals based on the use of a dual-processor transmitting Wi-Fi device. It also presents the algorithms of wireless transmission of electrocardiosignals providing high reliability of the transmitted information and develops the structure of the Holter monitoring system in three deflections using the multiplexing method in the formation of such deflections. The proposed methods and algorithms shall provide high-quality and multi-day wireless transmission of electrocardiosignals with low energy consumption.

1. Introduction

Holter monitoring (HM) is a continuous during-the-day recording of an electrocardiogram (ECG) of several ECG deflections on a solid-state storage media in conditions of free activity of the patient, followed by decoding with the help of special decoders in the off-line mode.

Such an ECG monitoring is used in the diagnosis of cardiac rhythm and conduction disorders, which cannot be detected by the standard procedure of ECG recording. Typically, HM involves ECG recording on an off-line storage media during the day [1]. However, the recorded data become available and can be analyzed only after the registration period is over. Therefore, it is advisable to use wireless ECG transmission from patients to a general server (in a cardiac center) or to a separate minicomputer (at home) in order to continuously monitor the ECG of patients and further interpretation of the ECG in real time under outpatient treatment or at home use. This system shall allow to quickly inform the patient and (or) the doctor about abnormalities in cardiac activity.

2. Problem statement

Currently, there are wireless ECG signal transmission systems operating under the Zigbee standard described in [2,3], or under the Bluetooth standard [4]. The disadvantages of such systems are low data transfer speed and a limited number of subscribers (in relation to the Bluetooth standard). Wi-Fi network is free of these shortcomings but its application has previously been limited by high power consumption. However, among the wireless devices there recently appeared transceivers which have low power consumption while preserving the required performance.

Representatives of such devices are transceivers of Chinese companies based on ESP8266 chips, described in detail in [5]. These devices are designed specifically for low-power systems. Today, WeMos releases a new version of the Wi-Fi module based on the ESP8266EX – WeMos d1 mini pro chip, which has an increased range, 16 MB memory and the connection capability at a current consumption of about 1mA. The operating current of such devices is 60 mA, and it does not exceed 180 mA at the maximum output power. The four times increased memory compared to the previous modification of the Wi-Fi module (NodeMcu v3) [6] allows to place a part of the software for the ECG interpretation in the memory of the Wi-Fi transmitter. This reduces the amount of data transmitted to the receiver, minimizes the active transmitter operation time and lowers the power consumption of the transmitting part of the system.

3. Theoretical part

According to accepted standards the basic part of the HM method involves the ECG registration in two or three deflections [7]. However, in a step-by-step review of the proposed HM technology, it is advisable to analyze a single-channel system, i.e. a system of measurement and transmission of a single ECG deflection.

Figure 1 shows a functional diagram of a single-channel dual-processor HM ECG system designed for a home use.

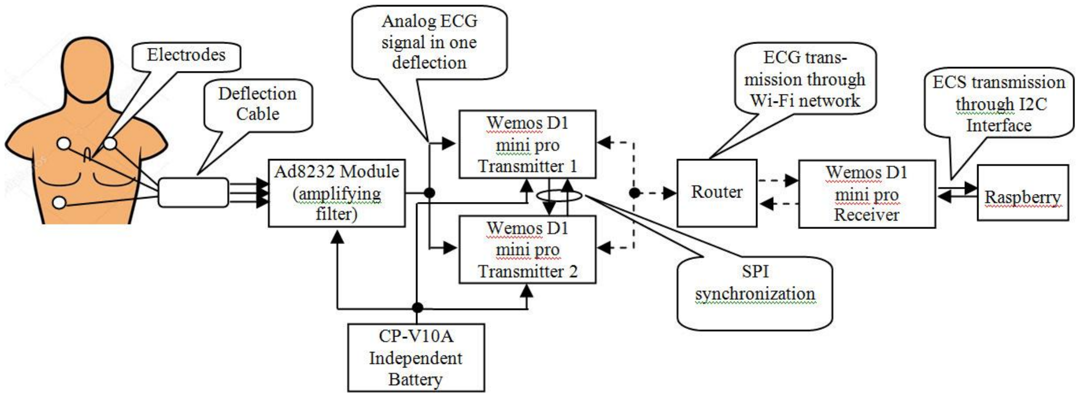

Figure 1. Functional Diagram of a Single-Channel HM System.

The main components of the system shown in figure 1 are described below.

- Deflection cable for HM including disposable electrodes.
- Module with AD8232 chip [8], which is an integrated ECG signal processing unit and is designed to receive, amplify and filter weak biopotential signals under the influence of strong interference.
- Two Wi-Fi transmitters, the analog inputs of which receive the amplified and filtered ECG signal. The transmitters are synchronized with each other by the SPI.
- Router that provides wireless communication between transmitters.
- Wi-Fi receiver receives an electrocardiosignal coming from the router and transmits them to a Raspberry mini-computer through the I2C bus.
- Sony CP-V10A battery to power the elements of the system autonomous part.

The previous construction of the wireless ECG system was based on the digital data acquisition Board Adas1000 [9]. However, this approach was characterized by difficulty in matching with NodeMcu v3wireless modules. It was therefore decided to abandon the Adas1000platform and to transmit the electrocardiosignals to the Wi-Fi transmitters reinforced by AD8232 chip.

The peculiarity of the program execution algorithm for the scheme in figure 1 is to reduce the time of Wi-Fi transmission. Since the processor of the Wemos D1 mini pro transmitter is not designed for

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parallel computing, it is impossible to simultaneously execute Wi-Fi transmission and ECG signals recording [10]. Therefore, the authors propose to add a second transmitter operating in the electrocardiosignal recording mode to the Wi-Fi transmission device. At the same time, the first transmitter shall transmit data to the receiver. And to the contrary, when the first transmitter records ECG data, the second transmitter shall operate in transmission mode. Thus, the two transmitters shall operate alternately in active mode. The high-speed SPI interface is used to synchronize the operation of the two transmitters. This hardware solution allows for parallel execution of the basic tasks of the HM program.

The software solution aimed at reducing the active operation time of the autonomous part of the system in question is equally important. It consists of transfer of the part of the ECG interpretation program to the Wi-Fi transmission unit of the device.

Figure 2 shows the general structure of the program execution algorithm for two Wi-Fi transmitters.

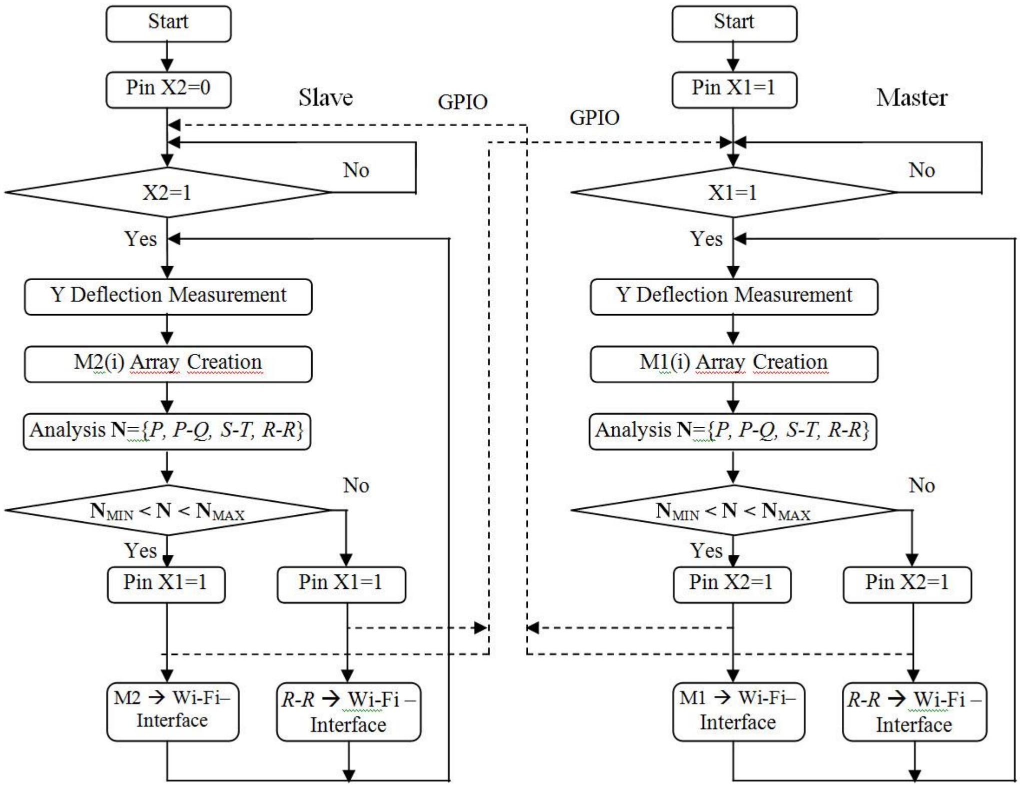

Figure 2. ECG Transmission Algorithm for Single-Channel HM System.

The peculiarity of the algorithm of wireless transmission of the electrocardiosignal signal is that the ECG information is transmitted over the Wi-Fi interface through data packets, including 30,000 measurements with a period of 1 millisecond between the measurements or 1 kHz frequency, which corresponds to about 15 cardiac cycles. The choice of this number of measurements is determined by the memory capacity of the selected WeMos d1 mini pro transmitter, which is 16 MB.

It is worth noting that a large number of measurements contained in a data packet leads to lower power consumption during wireless transmission of the ECG cycle (this increases the efficiency of the Wi-Fi transmitter). This is due to the fact that the Wi-Fi transmitter in passive mode (in the absence of data transmission) consumes at much less energy than in the transmission mode.

A distinctive feature of the proposed algorithm is the information selectivity of the transmitted data. This means that at the moments when the electrocardiosignal does not contain deviations of the measured ECG components (shape and duration of the *P* wave, duration of the *P–Q* segment and *S–T* *and R–R* intervals (figure 3)) from the components of the normal ECG [11], the Wi-Fi transmitter transmits only the digital value of the R–R intervals once per cardiac cycle, excluding the transmission of the entire data array.

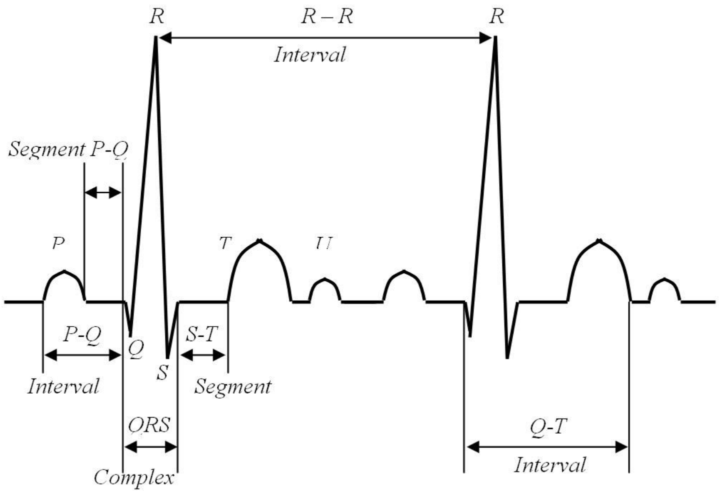

Figure 3. Components of the Normal ECG.

This fragment corresponds to the cycles "Analysis **N**={*P*, *P-Q*, *S-T*, *R-R*}" and "$\mathbf{N}_{\mathrm{MIN}} < \mathbf{N} < \mathbf{N}_{\mathrm{MAX}}$" (figure 2). In case of deviation of the measured ECG components from the normal ECG components, a full ECG is transmitted to the Wi-Fi receiver and then to the Raspberry mini-computer in the form of an array of 2000 measurements for full interpretation and analysis of the ECG. Activation of X1 and X2 flags in the two subroutines is necessary for the mutual transfer of controls between the two transmitters. This transfer is carried out via the GPIO interface [12].

Figure 4 shows the overall HM structure in three deflections using the Wi-Fi technology described above. Wi-Fi ECS transmission system (figure 4) includes the following units: two Wi-Fi transmitters, a router and a Wi-Fi receiver (figure 2).

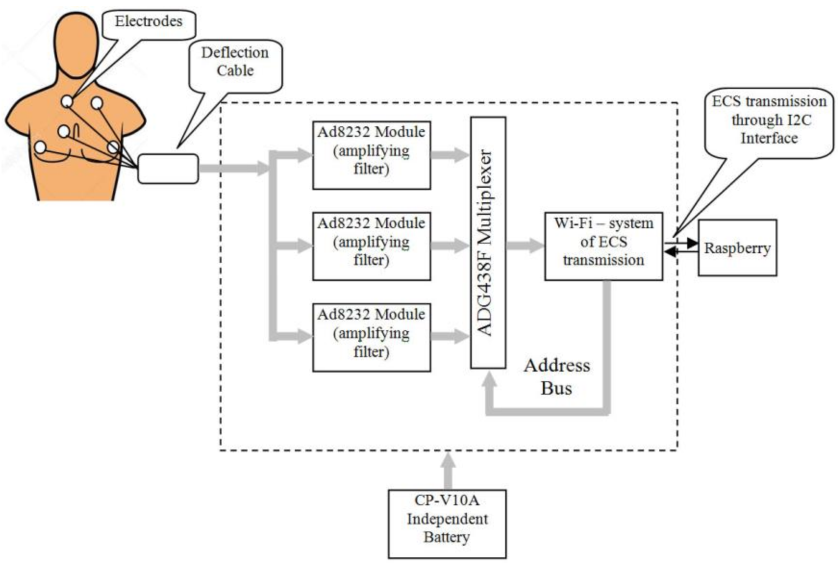

Figure 4. Structure of the Three-Channel Holter Monitoring System.

The specificity of the presented system consists in multiplexing the input ECG signal to create conditions for the use of two transmitters for a three-channel HM system. With this purpose, the system includes an ADG438F multiplexer. The multiplexer alternately connects the transmitters to each of the three deflections received at the output of three AD8232 modules, imitating the synchrony of recording and simultaneous transmission of three monitor deflections. Figure 5 shows the algorithm of HM program execution for three deflections for one Wi-Fi transmitter (the second one flips the algorithm of the first one).

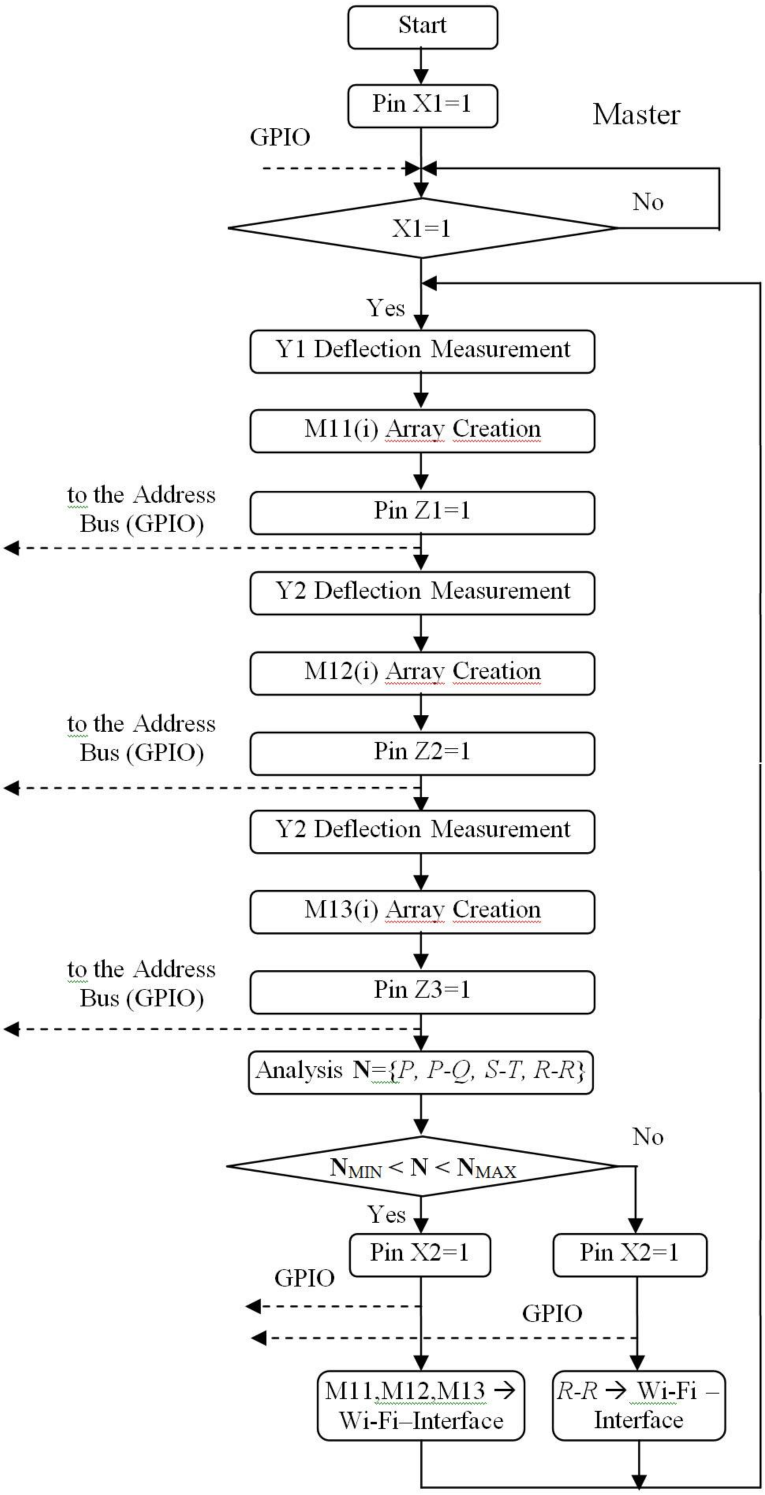

Figure 5. ECG Transmission Algorithm for the Three-Channel Holter Monitoring System.

IOP Conf. Series: Materials Science and Engineering **537** (2019) 032090 doi:10.1088/1757-899X/537/3/032090

Wi-Fi transmitters with a clock frequency of 3 kHz (with a sampling frequency of the analog input) give the address (Z1, Z2, Z3) for multiplexers through the GPIO interface, alternately switching the deflections coming to the input of Wi-Fi transmitters. Compared to the single-channel system, the polling rate increases three times. As a result, the sampling rate of one deflection, as in the case of a single-channel system, is 1 kHz.

The advantage of the proposed structure of the HM system is the use of components of Analog Devices in the autonomous part of the Wi-Fi device: an ADG438F multiplexer and an Ad8232 module, including a deflection cable, which have ultra-low power consumption (the maximum total current consumption does not exceed 400 µA).

The program for signal transmission is written in Arduino IDE. The main task of the program is to minimize the transmission time of the array of ECS measured values of one cardiac cycle. The purpose of the minicomputer is to receive and process electrocardiosignals and issue a preliminary diagnostic report, as a support of a cardiologist in decision-making. The ECS interpretation program for Raspberry shall be pre-created on a personal computer and then transferred to Raspberry.

4. Experimental results

In order to demonstrate the operation of the HM system it was decided to present a single-channel structure (shown in figure 1), as it forms the basis of both single-channel and three-channel systems and at the same time clearly reflects the principle of operation of both schemes. Figure 6 shows the experimental single-channel HM system.

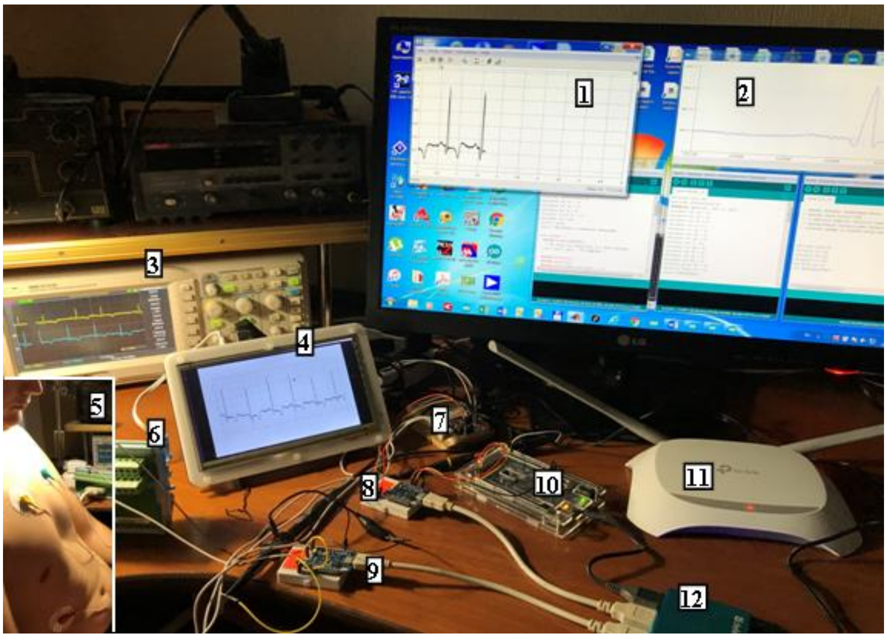

Figure 6. Experimental Single-Channel HM System.

The following system components are numbered in figure 6:

1 – diagram of the real output electrocardiosignal, obtained using the Matlab-Simulink Desktop Real-Time package and ADAM-3968-6 terminal connector, connected via cable to the multi-function PCI-1710HG I/o Board [13], installed in the PCI slot of a personal computer;

2 – oscillogram obtained using the “plotter for serial connection” tool of Arduino Due platform;

3 – oscillograms of input (AD8232 module output) and output (12-bit analog output of Arduino DUE) electrocardiosignals;

4 – diagram of the output ECS on the Raspberry monitor received from the Wi-Fi receiver via the SPI interface;

5 – installation diagram of the ECG electrodes on the patient's body to obtain a bipolar monitor deflection formed by the AD8232 module;

6 – ADAM-3968 connector;

7 – AD8232 module;

8 – WeMos d1 mini pro Wi-Fi receiver;

9 – WeMos d1 mini pro Wi-Fi transmitter;

10 – Arduino DUE platform – the technological component of the system required for accurate measurement and output of the output signal to the oscilloscope;

11 – TP-LINK Wi-Fi router;

12 – USB splitter to connect Wi-Fi transceivers and Arduino to the computer.

Thus, in accordance with the functional diagram shown in figure 1, the potentials from the patient's body are transferred to the AD8232 module through a three-electrode system, where they are amplified, processes through a program three-pole band-pass filter, formed into a bipolar monitor deflection and are transmitted to Wi-Fi transmitters in the form of ECS. Then according to the algorithm (figure 2) the electrocardiosignals are formed into arrays of two-byte signals and transmitted to the receiving side. The Wi-Fi receiver sends each value of the received array via the I2C interface to the Arduino Due and then the electrocardiosignals arrive at the oscilloscope. At the same time, the Wi-Fi receiver sends the ECS via the SPI interface to the Raspberry minicomputer, where the ECG data are finally processed in order to form a diagnostic conclusion. The obtained preliminary diagnosis serves as the basis for the final decision of the cardiologist.

5. Results and discussion

The result of the research work is the creation of the three-channel wireless ECG HM system designed for daily monitoring of the cardiovascular system that allows for better morphological analysis in rhythm and conduction disorders. The experimental complex for demonstration of the system of wireless ECS transmission using measuring and debugging tools and software, including specialized packages of Matlab system was presented here.

Circuit solutions for the use of a dual-processor Wi-Fi transmitting device for wireless transmission of an electrocardiosignal are proposed. The algorithms developed for wireless transmission of electrocardiosignals ensuring the synchrony of recording and simultaneous transmission of three monitor deflections and the high reliability of the transmitted ECG information.

The possibility of transmission of individual blocks of the program for the analysis of ECG data to the processor of Wi-Fi transmitter is also considered in the article.

The presented work is aimed at creating a high-speed hardware-software ECG HM system. With the aim of increasing the effectiveness of the program, providing the process Wi-Fi transmission of ECG data, it is planned to gradually switch from the Arduino IDE programming environment to the C language and the Assembler language of the specific microcontroller used in the receiver-transmitters in the future.

6. Summary and conclusions

The analysis of the results of experiments and the obtained diagrams of the real ECG shows that the use of the AD8232 module to amplify and ECS filters X, Wi-Fi transceivers of the new generation, as well as original circuit and software solutions aimed at minimizing the energy consumption of the Wi-Fi device, allows to create an effective and economical ECG HM system.

Delegation of part of the authority to interpret ECG data to the processor of the Wi-Fi transmitter shall significantly reduce the amount of data transmitted to the receiver, reduce the time of active operation of the transmitter and, accordingly, reduce the power consumption of the transmitting part of the system.

In the future, it is also planned to expand the use of ECG data for solving the problems of secure authentication of users to various information systems, determining the emotional state and hidden intentions of a person.

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