The influence of skin-electrode contact on the quality of ECG recording for personal telemedicine systems

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Abstract. In this article are presented the results of the study of the Tele-ECG system. Presented system automatically records the ECG signal and transmits it to the server, where occurs process of the decryption (automatic detection of R-waves and ST-segments on the ECG). A distinctive feature of the system is the use of it includes devices with capacitive sensors. The results quality research of the signal received through different dielectrics. The necessity of revision of sensors that will allow to avoid the interference caused by man and external factors. As a result, this refinement will allow to receive a signal for automatic diagnostics with the least loss of information due to the presence of interference in the signal.

1. Introduction
To date, telemedicine gadgets are tightly embedded in our daily lives. Fitness trackers have not only athletes, but also ordinary people who take care of their health. It appeared on the market a wide variety of portable cardiographs [1–6]. But because of the small diagnostic value of such devices have not found popularity among cardiologists and patients of medical institutions.

Tele-electrocardiography (tele-ECG) is one of the most important areas of preventive cardiology. In the Russian Federation, telemedicine is one of the state priorities in the development of medicine, as well as in other growing countries with a large territorial divide (India, Brazil, Indonesia, China). The widespread introduction of such systems is significantly complicated by both the lack of suitable technical means and the insufficient scientific and evidence base for the medical use of these agents. To date, such systems are not implemented everywhere.

The prototype of the Tele-ECG system developed at the Tomsk Polytechnic University has the following structure (Figure 1): the server ensures reception of records from ECG-Express devices and stores them in a database. The database also stores the results of an automatic ECG analysis, interpretations of doctors and other additional information.

The server module for the analysis of ECG records also provides processing of ECG records in order to extract informative parameters from the ECG curve, in particular, the calculation of time and amplitude parameters.

Figure 1. Structure of the Tele-ECG system.
The ECG-Express device used in this tele-ECG system is fully automatic and operates on the “one-button” principle. The user doesn’t need to think about the location of the sensors. Registration of an electrocardiogram, after pressing the start button is conducted within 30 seconds, then the data is sent to the server where the automatic ECG decoding occurs. As part of the prototype, were implemented the main functions: automatic detection of R-waves and ST-segments on the ECG.

2. Review of capacitive electrodes

Portable electrocardiographs use two types of electrodes: sticky disposable silver chloride electrodes or ordinary metal pads. Regular use of a cardiograph with sticky disposable electrodes causes difficulties, since for its use a person needs to take off clothes, glue electrodes to the right place, get rid of hair. For these reasons, such cardiographs not find mass use in the home. The advantage of such cardiographs is that the ECG signal has more information, compared with the signal obtained from metal electrodes. Portable cardiographs with conventional metal electrodes, due to the lack of a conductive gel, cannot provide the necessary contact and ensure the required accuracy.

An alternative solution is to use capacitive electrodes of company Plessey. These electrodes allow you to get an ECG that is comparable in quality to an ECG obtained from disposable sticky electrodes, despite the presence of interfering factors on human skin (hair, sweat, etc.), which complicate the process of ECG recording with other electrodes. Registered ECG obtained using Plessey [7] sensors through the ECG-Express cardiograph [8] were presented to doctors Rehabilitation Departments of the Research Institute of Cardiology of the Tomsk National Research Medical Center of the Russian Academy of Sciences in Tomsk [9], which confirmed the accuracy of the data.

The principle of operation of capacitive sensors (electrodes) is based on the ability of electric capacitors to conduct alternating current. Between the surface of the skin and the metal contacts of the sensor there is a dielectric layer, thus forming a flat capacitor. The ECG signal, the main power of which is concentrated in the frequency band 0.5 - 40 Hz, passes through a capacitor and causes a current in the input circuit of the signal amplifier. Figure 2 shows a simplified, universal model for a capacitive sensor, indicated its location on the device. A full description of the scheme is presented in the article "Wireless Non-contact EEG / ECG Electrodes for Body Sensor Networks" by Yu. M. Chi and Gert Cauwenberghs [10].

Another distinctive feature of Plessey electrodes is the ability to record ECG through clothing, which will allow the use of the device in virtually any environment, even when not at home. The only drawback is the excessive susceptibility to myographic interference.

Since 2016, Plessey sensors have fallen into the category of electronics, the import of which is prohibited on the territory of the Russian Federation. In the course of the work carried out as part of the study, it was decided to develop their own analogs of Plessey sensors with detuning from the skin-electrode contact. This refinement will allow the sensors to avoid interference created by man and
external factors. In order to find out the effect of various factors and conditions on the sensor readings were carried out a series of experiments.

3. Experimental methods
All electrocardiograms presented below were obtained using the ECG-Express portable electrocardiograph. Cardiograms were passed through special digital filters in order to get rid of the interference that arises from network interference. Filters were made in the program of mathematical modeling - MATLAB. Presented cardiograms are also visualized in MATLAB. Figure 3 shows an electrocardiogram from a “naked” chest that has no hair.

![Figure 3. Electrocardiogram from a “naked” human chest.](image)

For the study, two healthy students who have no disruption of the heart were selected. Proof of student health was a medical examination by a cardiologist. The main difference between the students was: the presence and absence of hair on places where electrodes are applied (on the chest). Figure 3 shows the electrocardiogram of a person with the presence of hair.

Figure 4 shows ECG from the chest of a man with the presence of hair, the cardiogram becomes difficult to read, but the QRS complex is clearly visible, which means that with the correct selection of digital filter values, it will be possible to improve the quality of the ECG.

![Figure 4. Electrocardiogram from the chest of a man with the presence of hair.](image)

Figure 5 shows the electrocardiogram from the human chest obtained through the shirt.

![Figure 5. Electrocardiogram from a man’s chest through a shirt.](image)
The electrocardiogram shown in Figure 5 was obtained from a person’s chest through a shirt (fabric material is cotton). This cardiogram demonstrates that the indications are of good quality, with the same disadvantages as when registering from the chest without hair.

The last experiment was the registration of the ECG through any tissue in addition to the material. Figure 6 shows an attempt to register an ECG through a sheet of paper.

![Figure 6. Electrocardiogram from a person’s chest through a sheet of paper.](image)

The signal received through a sheet of paper at the moment can’t be filtered to find a useful signal. Probably, a significant distortion of the ECG signal when using paper as an additional dielectric is associated with a significant decrease in the capacity of the skin-electrode contact. Necessary to conduct detailed studies of the effect of contact capacity on the recorded signals, including using mathematical modeling methods. Thus, by means of field experiments, we managed to clarify the behavior of the Plessey sensors through various materials. The use of capacitive sensors allows you to build on the quality of electrical contact with the skin, as well as to measure ECG through clothing. In the course of the research, the reasons were found that caused irreducible distortions in the ECG signal - microvibration and inconstancy of contact with the body.

4. Description of the model

For the purpose of detailed studies of the effect of the capacitance of a contactless electrode on the recorded signal have been developed models of skin-electrode contact and the circuit for recording ECG signals. The simulation was held in the application package “OrCAD”. The registration scheme is constructed using operational amplifiers and represents the instrumental amplifier of a difference signal from two capacitive electrodes. Figure 7 shows a circuit simulating skin-electrode contact.

![Figure 7. Equivalent circuit of the skin-electrode contact.](image)

The elements R1, C1 represent the coupling layer. It’s a layer between the electrode and the stratum corneum. The elements R2, C2 simulate the stratum corneum. The ECG signal comes from the V1 source. The capacitive electrode is modeled by a capacitor C3. Fig. 8 shows the simulation results.
In this case, the presence of a dielectric (tissue) in the simulation was carried out by lowering the electrode capacitance - C3 [8].

![Figure 8. Simulation results: a - normal conditions (C3 - 600 pF), b - with a reduced capacity of the skin-electrode contact (C3 - 10 pF).](image)

In the process of modeling the addition of an additional dielectric (Figure 8b) i.e. a decrease of capacitance of the electrode leads to a change in the ECG signal. Moreover, these changes that were similar to those in experimental studies (Figures 3 and 5).

5. Results
As a result of the work, a scientific hypothesis was formulated on how to improve the quality of measurement and reduce interference in the signal. This requires further research and development of a sensor with an electronic detuning system from the effect of sensor capacitance based on feedback in the measurement circuit.

In the further development of capacitive electrocardiogram measurement sensors will be the most promising technology for the development of portable and personal electrocardiography.

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