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Multichannel ECG Recording from the Surface of the Female Torso and Visualization of Heart Characteristics

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Abstract

The major target of processing the electrocardiogram (ECG) signals from multiple unipolar leads is the visualization of electrical potential distribution maps on the surface of the torso and epicardium. Such distributions allow to identification of arrhythmogenic zones and areas with impaired conductivity, characteristic of coronary heart disease. The development of a hardware and software complex for recording an electrocardiogram of a woman's bust with 46 pre-installed electrodes, as well as for processing and visualizing the characteristics of the heart based on the data obtained is the goal of this work. The prototype of the electrocardiographic women's vest involves the selection of suitable components and materials, the calculation of errors in electrode placement angles depending on torso parameters, and the development of algorithms for recording ECG. As part of the work, a study was conducted to research the possibility of recording cardiac signals from the mammary gland. The hardware-software complex makes it possible to construct potential distribution on the surface of the body and epicardium. The current registration system helps improve the quality of cardiovascular disease's diagnostics.

Keywords: electrocardiography, electrical potential distribution, electrocardiographic vest.

Introduction

Modern medicine sets itself the challenges associated with the development of methods and devices, the goal of which is to reduce the number of diseases through early diagnosis of cardiovascular diseases. One of the most accurate ways to obtain information about condition of the heart‘s electrical field is the registration of multiple leads for ECG mapping [1,2,3]. This approach contains a high number of electrodes that are located over the entire body surface. Allowing you to record a cardiac signal with multi-electrode leads and to construct potential maps along the epicardium surface, software, and hardware are required to solve a current problem associated with receiving the parameters of the equivalent electric heart generator (EEHG) and information about the heart electrical activity [4, 5, 6, 7]. It’s also necessary to take into account the features of the female bust. The current paper presents a working prototype of a women's electrocardiographic vest and also presents test results.

1. Comparison of heart signals at feature points

The mammary gland is a paired organ that belongs to the type of apocrine glands of the skin. There are many unstriated muscle fibers in the vicinity of the nipple. According to the type of its structure, the mammary gland belongs to the complex alveolar-tubular glands [8]. Some electrodes of the measuring system are located on the mammary glands, the electrical conductivity of which makes it possible to estimate the density of the tissue and take into account attenuation during subsequent processing. While electrical resistance decreases, electrical conductivity tends to increase over the years. In addition, the density of breast tissue depends on many factors such as age, menstrual cycle, lactation period, etc. (Stojadinovich et al 2005; Korotkova et al 2007).

Figure 1 shows the location of the electrodes for classical cardiography, which is the same for both male and female patients. The cardiac signal in the elaborated system is recorded from electrodes located on the mammary glands. We assume that this system will allow us to build higher quality and more detailed potential maps.

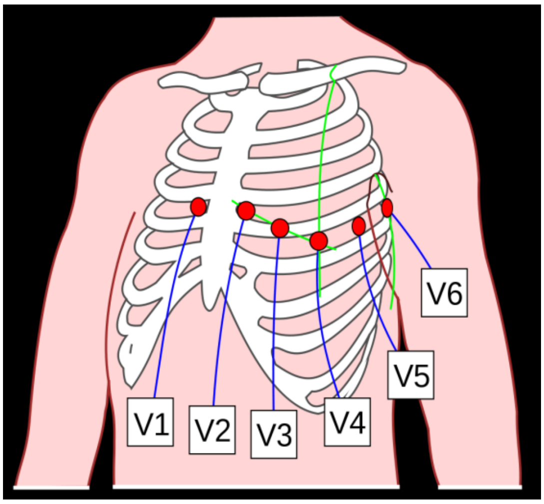

Figure 1. Standard electrode placement for classical cardiography

Research was carried out to study the possibility of getting a cardiac signal from the mammary gland. For this purpose, a series of experiments were conducted. In the first part, the electrode was installed above the breast, which is the approximate position of V2, according to Wilson's chest leads, and the second electrode was located near the center of the chest. This position of electrodes helps to compare the influence of tissue properties on the recorded signal. The results are presented in Figure 2.

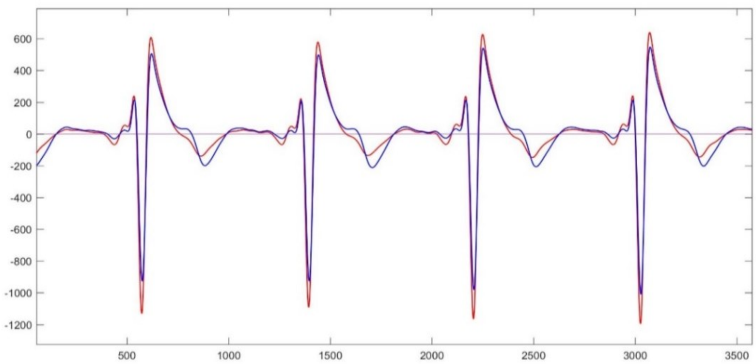

Figure 2. Cardiac signals on and above the breast. Red - the electrode is located above the mammary gland, blue - on it

The signal from the electrode located above the mammary gland is shown in red, and on it in blue. Note that the amplitude in the signal on the mammary gland is smaller, despite its proximity to the heart. It can be seen that the blue graph is not smaller in amplitude in all places. This is explained by the position of the dipole in space [10, 11]. The signals are identical to each other and differ only in amplitude.

In the second part, the electrode was installed on the lower part of the chest, and the second electrode was located on the upper. The results are shown in Figure 3.

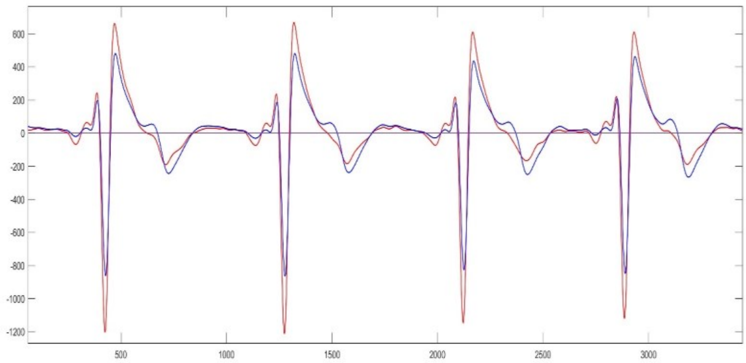

Figure 3. Cardiac signals on and below the breast. Red - the electrode is located above the mammary gland, and blue – is below it

The signal from the lower part of the breast (blue, Fig. 3) is smaller in amplitude than the red one (above the mammary gland). The difference in the signals is due to the attenuation of the signal in the dense tissue of the breast. This can be seen in the previous experiment.

The signal in the breast tissue attenuates is slightly.

2. Women's ECG Vest

2.1 Description

A cartographic signal acquisition system is a vest with holes for electrodes. Tight placement of electrodes with their angle fixation is the major task. Stretch straps are used to ensure correct and constant positioning of the vest. Fig.4 exhibits a vest prototype where 1 is a pair of shoulder straps, 2 is a pair of stretch straps and 3 are holes for placing electrodes.

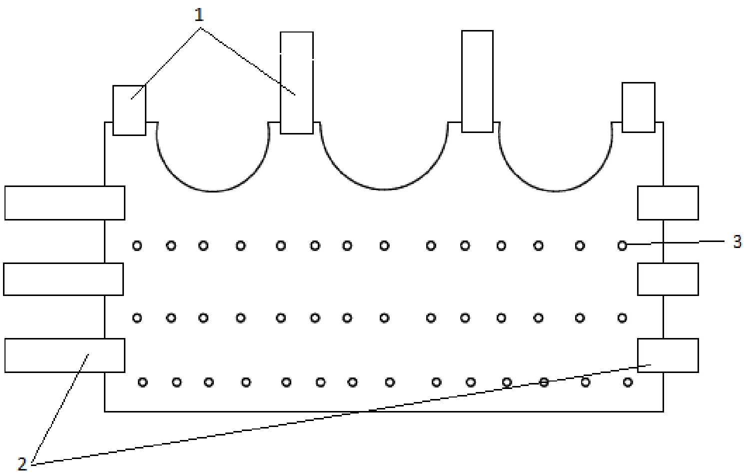

Figure 4. Electrocardiographic vest model

A small area of the current-collecting surface is the major requirement for electrodes (units of square millimeters). The employ of conventional electrodes with an area of 170 mm2 is unacceptable, therefore MCScap-E electrodes from the manufacturer «Medical Computer Systems» are utilized, which are intended for studies that require frequent installation and rapid removal. MCScap-E has a universal 1.5 mm Touch Proof connector that is suitable for most EEG amplifiers.

Since the electrode-skin contact depends on the fixation on the patient's body, fasteners are an important part of the vest. The designed vest has shoulder and back straps that can be adjusted based on the patient.

Noise-reducing conductive gel is implemented to ensure good contact between skin and the electrodes.

2.2 Electrode positions

To place the electrodes, it is necessary to punch holes into the fixing rings which are inserted. The holes are placed at a specific angle on the patient's body, which is viewed as an elliptical cone. The map of electrodes is presented in Figure 5.

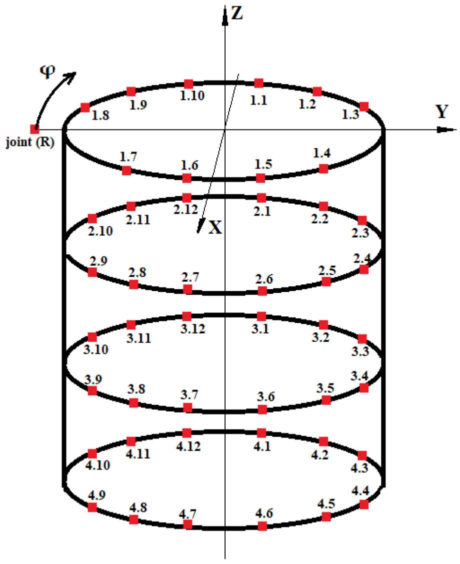

Figure 5. Vest electrode map

Two NVX-24 biopotential amplifiers are used in the registration system. The neutral electrode (GND) is placed on the patient's right leg. An additional electrode is mounted to the right hand for synchronizing recordings. The first 24 electrodes are connected to the first amplifier, electrodes from 25 to 48 to the second. Electrodes 24 and 48 are connected to the "joint" electrode. Thus, each amplifier provides the operation of 23 monopolar leads. The 1st and 2nd rows contain 22 electrodes in total and are fully serviced by the first amplifier. At the same time, the 2nd and 4th rows of electrodes contain 24 electrodes in total, the last missing electrode 4.12 is connected to the free connector (O2) of the first amplifier.

At the first stage of the recording algorithm, the upper rows are recorded. At the second stage: record the bottom rows. This approach will allow increasing the number of monopolar leads from 24 to 48.

2.3 Dependence of the angle error on the ellipse stretch ratio

Much attention has been paid to the ability to measure over a wide dimensional range. The primary purpose is to employ a vest for a large range of sizes, however, it is worth taking into account that the electrodes located at fixed angles are displaced. It was previously noted that the patient's body is considered as an ellipse, so its compression ratio changes for different torso parameters (the ratio of the length of the major semi-axis to the length of the minor semi-axis). If the ellipse stretch ratio changes, then the arc length also changes at the given angles. Then, we consider how the angle changes when the ellipse stretch ratio changes for a fixed arc length.

Since the maximum estimate of the difference is important for the study, the difference in angles is calculated at critical values of the ellipse stretch ratio and in several intermediate cases (Table 1).

Table 1. Angle difference depending on the ellipse stretch ratio.

Stretch ratio, k	Angle, φ °	Difference, Δφ °
2	45	0
1.25	44.95	4
1.5	50.5	5.5
1	54.5	9.5

Table 1 shows that the calculated error is small. In addition, for most people, the ellipse stretch ratio is in the range of 1.5-2. Minor differences will not affect the results of the study, as correction angles are made in the software based on the patient's size (a, b). Minor differences will not affect the results of the study, as correction angles are made in the software relying on the patient's size (a, b). This minimizes error and makes it possible to cover a larger number of patients, which makes the device more versatile.

2.4 Algorithm

The registration system carries out automated data capture, visualization, transmission, processing, and storage of measurement information. Figure 6 demonstrates the algorithm for recording ECG, which is divided into three stages.

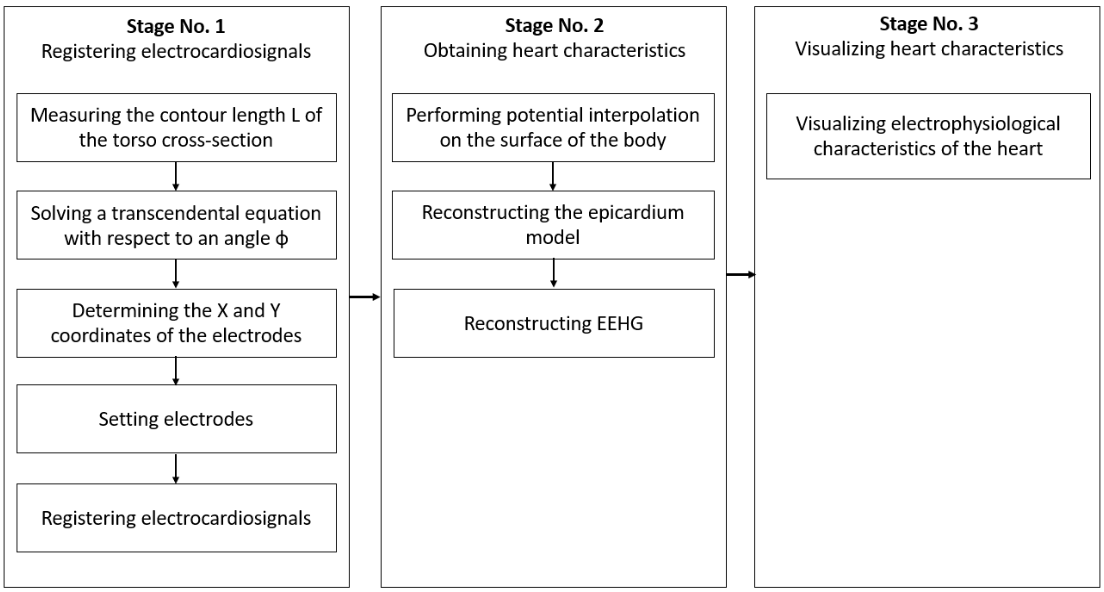

Figure 6. Registration system algorithm

The first stage is data capture using a multi-channel recording system. The second stage involves processing the received data and transforming them to build potential distribution maps. The third stage involves constructing static and dynamic images relying on the obtained data, which makes it possible to evaluate the heart state.

To further develop the recording system, it’s an appropriate to add animation of the propagation of heart signals for continuous monitoring. In addition, the ability to restore potentials on the epicardium is required, as well as the selection of the most optimal algorithms and methods for compressing and restoring information for storing the results of multichannel recording and its transformations.

3. ECG results

It is required to filter and interpolate signals, as well as form a torso structure to visualize the distribution of the patient's potential. Obtaining potential maps on the surface of the torso is not only an intermediate stage in reconstructing potentials on the epicardium. These distributions contain diagnostic information suitable for analysis; examples of analysis of such maps are given in the work of I.P. Polyakov [3]. Figure 7 shows the results of constructing the potential distribution on the surface of the torso, where here and below the distribution a dynamic color palette is used, which shows the magnitude of the potential.

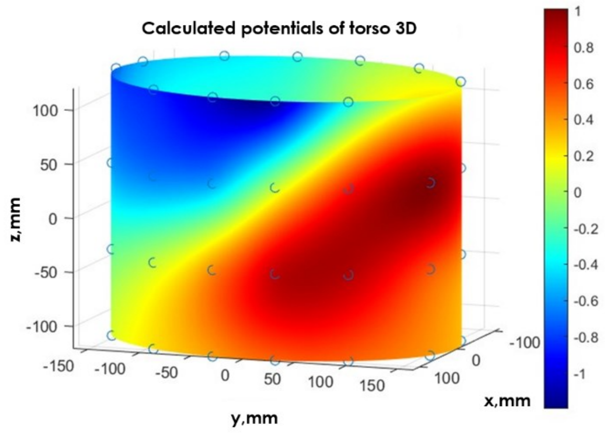

Figure 7. The result of calculating the torso potentials

The construction of potential maps occurs on the basis of the potential distribution of the body. The construction of the potential distribution is based data from the ECS employing a women's vest. The results are presented in Figures 8 and 9 for R-wave apex moment.

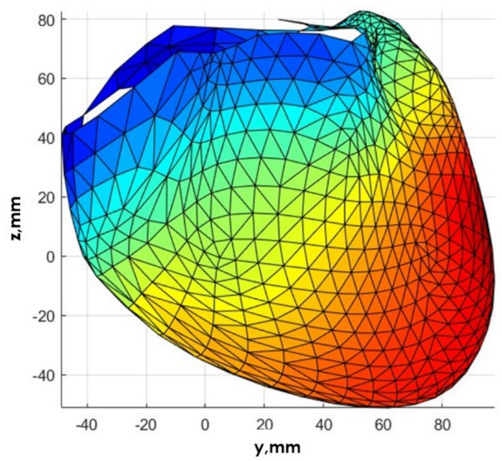

Figure 8. The potential distribution on the surface of the heart epicardium

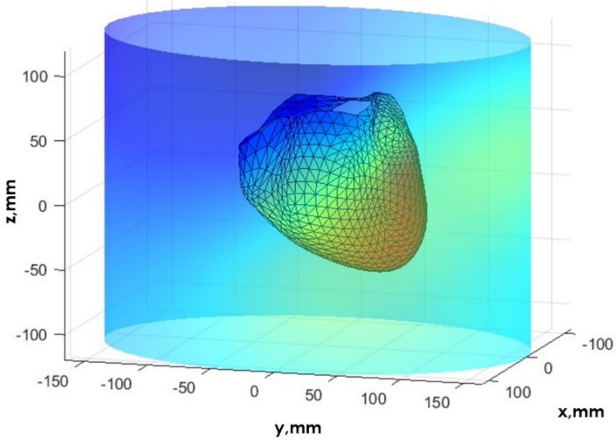

Figure 9. The potential distribution on the surface of the heart epicardium

The distribution of potentials at each moment of the cardiac cycle on the surface of the chest describes the electrophysiological processes in the heart that can be abnormal and normal. The color of the potential value depends on the sign and amplitude: the blue palette has negative value, red one is positive; the higher the amplitude, the higher the color saturation.

The distribution of potentials on the heart surface reveals localization of arrhythmogenic areas and areas with impaired conductivity, which are typical for cardiac ischemia.

Conclusion

This article considers the theoretical foundations of multichannel ECG recording. The physiological characteristics of the female bust were analyzed. This stage was fundamental for the development of the vest design in the registration system.

The elaborated multichannel system is a promising direction for cardiac diagnostics. In the future, a dynamic potential map helps to identify arrhythmogenic areas on the surface of the myocardium, thereby providing early diagnosis of such diseases associated with impaired conduction of heart tissue.

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