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MONITORING THE HEALTH OF PATIENTS USING A NODAL POTENTIAL MAP

MONITOROWANIE STANU ZDROWIA PACJENTÓW Z WYKORZYSTANIEM MAPY POTENCJAŁÓW WĘZŁOWYCH

Abstract

Purpose: The article presents the developed device and methods for monitoring the heart's condition using a nodal potential map. The proposal enables monitoring of the patient's health condition.

Methods: Testing the heart's electrical activity in our device's case uses a *nodal potential map* BSPM (Body Surface Potential Mapping) technique. This is an extended version of the standard ECG measurement, which, instead of 12 leads, uses several dozen or even several hundred measurement electrodes placed in appropriate locations on the front and back of the chest.

Results: The developed solution enables monitoring of heart function in a noninvasive way and is more precise than a standard ECG test. The collected measurements allowed us to determine the health and condition of the patient's heart—no anomalies were detected during its operation.

Discussion: The next stage of work will be the development of machine learning algorithms trained on the measurements obtained from the vest. The results obtained so far indicate the potential of models classifying heart diseases.

Streszczenie

Cel: Artykuł prezentuje opracowane urządzenie i metody służące do monitorowania kondycji serca, z wykorzystaniem mapy potencjałów węzłowych. Propozycja umożliwia monitorowanie stanu zdrowia pacjenta.

Metody: Badanie aktywności elektrycznej serca w przypadku naszego urządzenia wykorzystuję metodę zwaną *mapą potencjałów węzłowych* BSPM (Body Surface Potential Mapping). Jest to rozszerzona wersja standardowego pomiaru EKG, w której zamiast 12 odprowadzeń wykorzystuje się kilkadziesiąt lub nawet kilkaset elektrod pomiarowych, rozłożonych w odpowiednich lokalizacjach na przedniej i tylnej części klatki piersiowej.

Wyniki: Opracowane rozwiązanie umożliwia monitorowanie pracy serca w sposób nieinwazyjny i bardziej precyzyjny niż standardowe badanie EKG. Zebrane pomiary pozwoliły określić stan zdrowia i kondycję serca pacjenta – nie zostały wykryte żadne anomalie podczas jego pracy.

Omówienie: Kolejnym etapem prac będzie rozwój algorytmów uczenia maszynowego uczonych na pomiarach otrzymanych z kamizelki. Dotychczas otrzymane wyniki wskazują na potencjał modeli klasyfikujących jednostki chorobowe serca.

Keywords: *body surface potential mapping, health, nodal potential map, heart condition, data analysis, signal processing*

Słowa kluczowe: *mapowanie potencjałów powierzchni ciała, zdrowie, mapa potencjałów węzłowych, kondycja serca, analiza danych, przetwarzanie sygnału*

Introduction

Regular heart health checkups are essential for several reasons. Many heart diseases may not present obvious symptoms in their early stages. Regular examinations allow for early detection of abnormalities, increasing the chances of effective treatment. Untreated heart disease can lead to severe complications such as heart attack, stroke, or heart failure. Systematic monitoring of heart health and implementing appropriate treatment can minimize the risk of complications and improve the patient's quality of life. It is worth paying attention to the importance of prevention because preventing cardiovascular diseases is as important as treating them. Changing your lifestyle and healthy eating habits are the basic steps in this process. Controlling cholesterol and blood pressure is also crucial to maintaining heart health.

The most common heart diseases are severe conditions that can significantly affect health and quality of life:

- Coronary artery disease is when the coronary arteries that supply blood to the heart muscle become narrowed or blocked. This leads to hypoxia in the heart and may cause chest pain and heart attack.
- Heart attack is a sudden stopping of blood flow to part of the heart muscle. A heart attack can lead to permanent heart damage and is one of the leading causes of death worldwide.
- High blood pressure can put stress on the heart and blood vessels, increasing the risk of heart diseases such as heart attack, heart failure, and stroke.
- Heart failure is when the heart cannot pump enough blood to meet the body's needs. Symptoms include shortness of breath, swelling, and fatigue.
- Cardiac arrhythmias are heart rhythm disorders, such as atrial fibrillation or tachycardia. They can lead to severe complications such as heart attack or stroke.
- Heart defects are congenital or acquired abnormalities in the structure of the heart or blood vessels. They can affect blood flow and heart function.

Research Methodology

Body surface potential mapping (BSPM) is a non-invasive method for assessing cardiac bioelectrical activity with a rich history of practical applications in research and clinical trials. BSPM enables a comprehensive collection of bioelectric signals over the entire chest, allowing for a more complex and extensive analysis than a standard electrocardiogram (ECG). It is a valuable research tool and an input for other analysis methods such as electrocardiographic imaging and, increasingly, machine learning and artificial intelligence (Przysucha et al., 2022; Wójcik et al., 2023).

Body surface potential mapping is generally considered a safe method. It is a non-invasive procedure that does not require inserting electrodes into the patient's body. BSPM carries no risk of tissue damage or other physical hazards to the patient. Electrodes are placed on the skin surface, and signals are collected outside. Unlike other diagnostic procedures such as computed tomography or X-ray, BSPM does not use ionizing radiation. The electrodes used in BSPM are low voltage and low current, which minimizes the risk of electric shock (Bergquist et al., 2021; Kloosterman et al., 2023). The patient does not feel any pain or discomfort during BSPM. Nevertheless, as with any medical procedure, there are some general precautions. The performance of BSPM should be entrusted to qualified medical personnel. The patient should be adequately prepared for the examination, and the electrodes should be placed as directed. Individual reactions may occur in some cases, such as electrode material allergies. Therefore, the patient must inform the medical staff about his health condition and possible allergies (Doguet et al., 2023; Kusche et al., 2022; Pandozi et al., 2024).

Vest Design

The project's result is a device in the form of a vest equipped with the electronics necessary for its functioning (Figure 1). The vest comprises 102 textile electrodes connected to electronics control via cables and connectors (Kiczek et al., 2023).

Control electronics using the mentioned electrodes measures:

- by impedance tomography using 32 electrodes in a 2x16 electrode configuration,
- nodal potential maps using 102 electrodes,
- impedance cardiography using a pair of electrodes,
- with 24-bit resolution and power consumption below 175 mA.

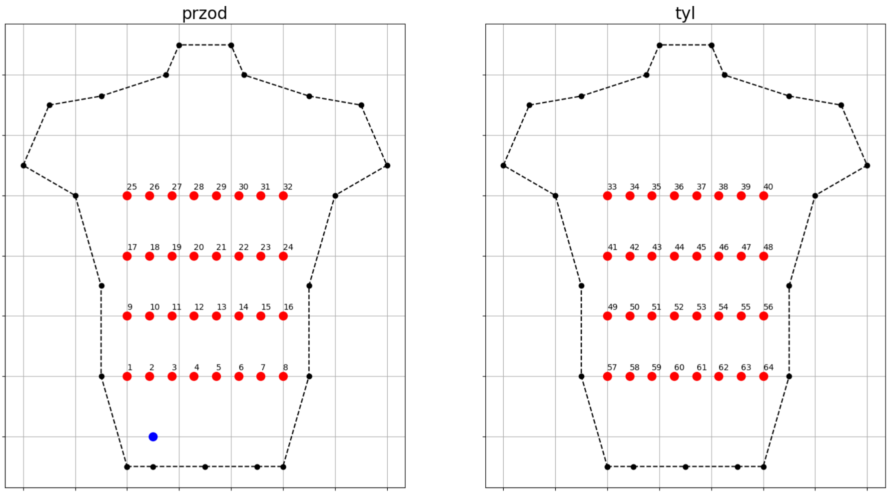
Figure 1. *The inner part of the vest. The electrodes and their location are visible*

Nodal Potential Map

To receive the electrical activity of the heart in the case of our device, a method called *nodal potential map* was implemented. A nodal potential map is a graphical representation of the distribution of electrical potentials in specific areas of the heart related to its nodes and impulse conduction. Nodal potential maps help plan electrophysiological procedures such as ablation. They help identify areas of abnormal electrical activity (Rymarczyk et al., 2022; Wójcik et al., 2021).

It is an extended version of the standard ECG measurement, which, instead of 12 leads, uses several dozen or even several hundred measurement electrodes (Sedova et al., 2022) distributed in appropriate locations on the front and back of the chest (Figure 2).

Figure 2. *The chest outline has 32 measurement electrodes on the chest's front (left) and back surface (suitable). The reference electrode is marked in blue*



The BSPM measurement methodology (Ivonina et al., 2024; Ivonina and Roshchevskaya, 2023; Sedova et al., 2021) involves differential potential measurement between the reference electrode and a given signal electrode (0-1, 0-2, 0-3, …, 0-64). Assuming that the measurement will take place simultaneously for all electrodes, the result will be a map of the potential distribution on the chest surface at a given moment of time . By performing a series of measurements at a rate of, e.g., 1 kHz (i.e., 1000 measurements per second) for several seconds; we will obtain a spatiotemporal record of changes in the heart's electrical activity covering several hemodynamic cycles (Gonçalves Marques et al., 2020; Martin et al., 2019). After initial filtering, the collected results are displayed as a color map representing the distribution of the surface potential spread over the nodes of the measurement grid. The problem is that the potential values are only known at the grid nodes and not between them (Bai et al., 2019; Konrad et al., 2014; Zhong et al., 2022).

To determine the potential values over the entire mesh area, with the interpolation method, the procedure is as follows:

- loading a 3D mesh,
- designation of interpolation areas,
- potential simulations/loading measurements,
- 3D interpolation with weight functions,
- visualization on a 3D grid,
- visualization with isobars.

The interpolated points are the nodes of the 3D mesh from the area limited by the electrode coordinates:

$$P \in \left\{(x, y, z): \min_{P_e} x_e \le x \le \max_{P_e} x_e, \min_{P_e} y_e \le y \le \max_{P_e} y_e, \min_{P_e} z_e \le z \le \max_{P_e} z_e\right\},$$

where: P_e – electrode coordinates (interpolation points) , P – interpolated points.

To illustrate interpolation, a matrix was used for simulation $A \in R^{Mx2M}$ whose values were simulated using two Gaussian distributions such that:

$$\sigma_1 = \frac{M}{10} + \varepsilon_1, \qquad \sigma_2 = \frac{-M}{15} + \varepsilon_2,$$

where: ε_i – values from $N(0, 1)$ for i=1,2. Following interpolation was used:

$$F(P) = \sum_{k=1}^{N_{ele}} \pi_k(P) \cdot V(P_k),$$

for:

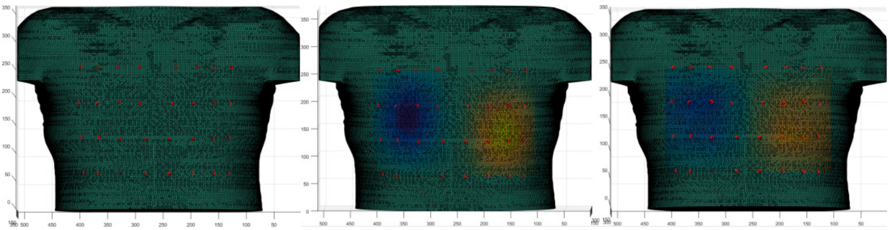
$$\pi_k(P) = \prod_{\substack{i=1 \\ i \neq k}}^{N_{ele}} \frac{\varphi(P, P_i)}{\varphi(P_i, P_k)},$$

$$\varphi(P, Q) = \begin{cases} d(P, Q), P \neq 0 \\ 0, P \equiv Q \end{cases},$$

where: $d(P, Q)$ – selected distance between points in Euclidean space.

Figure 3 shows a 3D model of the chest created based on a patient's CT scan with 32 electrodes marked on the anterior part of the chest (a), then plotted with a potential distribution simulated using two Gaussian distributions (b), and the result of potential interpolation over the entire area of interest (c).

Figure 3. *a) Chest model with 32 electrodes, b) model with two Gaussian distributions in the examined area, c) potential interpolation over the entire area*



The numerical model consists of no less than 300 potential grid elements. The word *potentials* in this case means the purpose of the mesh model (nodal potential map). The aspects of the potential grid signify a numerical model on which the potential values are calculated by solving a partial differential equation, e.g., using the finite element method at a given power source. The main element of each model is developing a numerical mesh model. The case of a nodal potential map is a potential mesh model consisting of triangular elements of the finite element method (Chudáček et al., 2005; Sedova et al., 2023; Zhang et al., 2018). The torso mesh comprises 7330 triangular elements, and the heart mesh comprises 924 triangles.

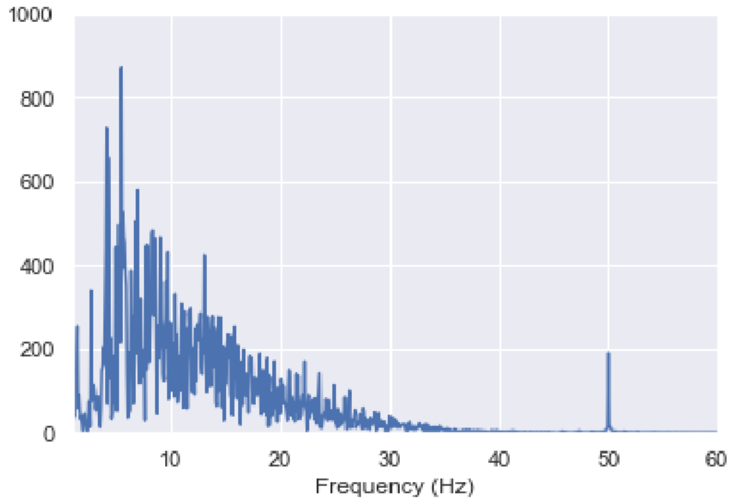
Results

Figure 4 presents the Fourier spectrogram of the received signal. There is a powerful component with a frequency close to 0, i.e., a constant throughout the signal. We, therefore, see many frequencies that appear in the signal in the range from 0 to 30 Hz. These are naturally occurring components of physiological origin that result from cardiac activity. However, a component with a frequency of 50 Hz is also visible, originating from the electricity grid. It is responsible for the small vibrations visible approximately in the image signal graph. This component can easily be removed using filtering.

There are no visible anomalous points that would indicate problems with the patient's heart condition. Descriptive statistics also show no anomalies. The mean of the signal is 35938 with a standard deviation of level 2565. The second and third quartiles contain values from 35202 to 37033,

a condition close to the basic one for the device. The most significant deviations correspond to the minimum and maximum, 23421 and 42400, respectively, which is naturally related to the heart function of the examined patient. The device works stably, and the collected data is reliable.

Figure 4. *The Fourier spectrogram of the signal*



Conclusions

Although BSPM is not widely used in clinical practice, it may have future applications, especially when combined with computer modeling and artificial intelligence. In the clinic, it can be used in combination with modern methods of modeling and statistical analysis of data. BSPM is a rich source of information that can serve both clinical and research purposes. It allows for more accurate monitoring of the heart's electrical activity than a standard 12-lead ECG. It is important to note that BSPM is a safe method of assessing cardiac activity. Of course, standard medical procedures and guidelines should always be followed.

The paper presented the developed device and methods for monitoring the condition of the heart using a nodal potential map (a diagnostic tool that allows for observation and analysis of the heart's electrical activity in specific areas). The solution enables supervising the patient's health condition. The analysis of the collected data concluded that the patient's heart was working correctly, without any anomalies. The next stage of work will involve the development of new machine-learning algorithms classifying heart disease entities based on BSPM measurement data.

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