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BPM DETECTION ALGORITHM IMPLEMENTED ON A MOBILE DEVICE

Key words

ECG, algorithm, BPM, mobile device.

Summary

Mobile devices are steadily increasing their position in the field of new inventions, such as monitoring the work of the heart. The need for monitoring and control the patients' health, especially the aspects related to normal cardiac function (measurement of rhythm), is one of the main directions in the field of ongoing research. Development direction, determined with the advancement of technology, is to find a way of linking the technique with medicine. In this article, the conducted of analysis covered the various algorithms used in the process to determining the value of BPM, providing the heart rate. The aim of the authors was to determine the possibility of their use in relation to a variety of mobile devices, such as tablets, smartphones, and also processors for embedded devices. This task consisted of the evaluation of the signal processing by each device. In further steps, based on the data collected, the authors analysed the possibility of using the specific devices to evaluate the ECG signal recording in real time. The summary of the study was to identify the effectiveness of the detection of BPM using various algorithms on designated devices.

Introduction

In many areas of medical diagnosis, measurement and analysis of electrophysiological signals have an important role. They are an invaluable source of information for the methods and the correct functioning of various organs in living organisms. One of aspects measured is mapping the signals of the heart known as electrocardiogram [6].

Electrocardiography is a graphic record of changes in electrical potential, which is registered from the surface of the chest during depolarization and repolarization of cardiac muscle cells. Typical ECG allows specifying the location of the P wave, QRS complex, T wave and U wave. Amplitude, the frequency of occurrence, and the interval between each wave are the parameters used to define a number of abnormalities of the heart. The ability to interpret the ECG wave is a very important element of knowledge, because decisions that are based on it determine further treatment strategy, influencing both the quality and length of the patient's life [5, 6].

Currently available tools in the field of medical science provide many opportunities that can lead to the correct diagnosis of the cause of the patient state. Analysis of the literature in the field of cardiac devices points to deficiencies in mobile use of them. In addition, a more and more common limitation is the lack of functionality associated with simultaneous, automatic, and personalized computer analysis, directed to a user and disease. Given the rapid development of new technology, there are no obstacles to provide this functionality [6].

After analysing of the needs, the authors have developed and tested (on a variety of mobile devices) the algorithms used in the process of determining the value of BPM (Heart Rate) described in this article. The process of determining the value of BPM is based on measuring the distance between two R peaks [4]. There are three modes of heartbeat (used to identify a variety of cardiac dysfunction). Standard duration is 60-80 beats per minute, and anomalies are as follows: bradycardia < 50 beats per minute, and tachycardia > 100 beats per minute. Depending on the length of the RR, there are three modes of operation of the heart, which are used to identify the activity of various disorders. According to the latest research, the heart rate is new therapeutic target in clinical cardiac. Reduction in heart rate is undoubtedly a necessary way to proceed in the treatment of many diseases of the circulatory system [1, 2, 8].

1. Material

The shape of the ECG signal recorded by the electrocardiograph depends primarily on the measurement system, which means how to connect the electrodes to the patient. The example of an ECG for the purpose of this article is based on three unipolar limb leads. These leads record the heart's electrical field changes, which are based on signals from the positive electrode (examiner), located at the measuring electric potential, and the neutral electrode voltage (equal to zero). The absolute value of the potential is measured at the point of the application of the positive electrode. A scheme of electrode placement is as follows: lead aVR – right upper limb, lead aVL – left upper limb, and lead aVF – left lower limb. Indifferent electrodes consisted of a combination of lead aVR with right lower limb and lead aVF also with the right lower limb [6].

2. Methods

The study was conducted in three stages. The first stage of the research included registration of the ECG signal, pre-processing, and the design of the algorithms for heart rate detection (BPM).

The pre-processing consists in a set of operations on the magnitude of retrieved signals, and it provides a numerical value to work within the following steps. In general, within these activities two stages are distinguished: normalization and filtering of the resulting signal. Part of the first step is to remove interference – the power network 50 Hz frequency, noises such as breathing movements, and other. Then, the sample was analysed in two ways [1, 8].

The first is the FFT. The popular way of the frequency analysis of the ECG signal has been the Fourier Transform, which is usually performed by the Fast Fourier Transform (FFT) algorithm. Fast Fourier Transform is a fundamental transform in digital signal processing with applications in frequency analysis, signal-processing limitations of high-gain amplification, and signal filtering [7].

The second is the WT. Wavelets Transform, which is a method to analyse a signal in time and frequency. It allows the representation of the signal in the range of time scale by means of "wavelet coefficients" that reflect the degree of correlation between the signal and wavelet. The most commonly used is Discrete Wavelet Transform (DWT). DWT gives the decomposition of a signal. To implement DWT, the iterative algorithm Mallata is used, i.e. a simple and fast algorithm for the decomposition of the analysed signal [3]. In the output of scaling function, it is the input of next level of decomposition. In the context of this article, the study was based on the characteristics of the Daubechies Wavelet, which has a shape similar to the morphology of the components sought, i.e. symmetric Gaussian wavelet [1, 4, 9]. The study used the 4 and 6 types of this wavelet (db4, db6).

2.1. Heart Rate detection algorithms

- Difference Algorithm (Diff BPM Algorithm):

It analyses the derivatives ECG waves, which are defined based on the difference in values of the two adjacent samples.

The value of the R-peaks is computed according the following equation:

$$s_i^{'} = s_{i+1} - s_i \qquad (1)$$

where

$s_x^{'}$ – the value of new sample x,

s_x – the value of sample x.

- Threshold Algorithm:

This algorithm determines the threshold above which further steps are indicated and the positions of R-peaks are counted. The threshold value is determined for a certain portion (sliding window) or for all of the ECG wave (Fig. 1).

The value of threshold is indicated at the point as follows:

$$t_i = (\max{}_w - avg_w) * R + avg_w \qquad (2)$$

where

t_x – the threshold value at the point x,

$\max{}_w$ – the maximum value for the area w,

avg_w – the arithmetic mean of the area w,

R – constant value of 0.6.

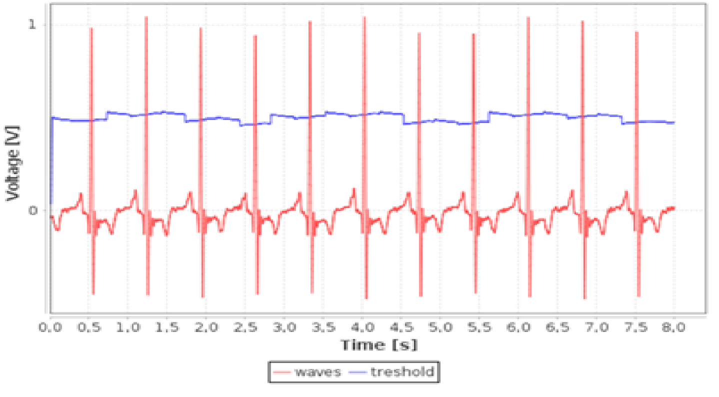

Fig. 1. The sample of ECG wave with the threshold

- Counting Algorithm:

The algorithm counts the position of R-peaks that are above the threshold. After that, it divides the number of occurrences by the time in which they occur, thereby obtaining the value of BPM.

The second stage of the study included the statistical analysis of the data, which was performed using the tools of Statistica software 10 Site License. Statistical inference is started by identifying the characteristics of the variables. Determining the distribution of the variables was based on the Shapiro-Wilk test. In view of the obtained results' non-parametric distribution of the variables was confirmed (score $p < 0.05$), and further analysis was based on non-parametric tests. Hereafter, based on descriptive statistics, the following were determined: the mean, standard deviation, median, quartiles, and percentiles. The obtained data scatter was confirmed by statistical tests Grups (score $p < 0.05$). Correlation analysis, due to non-parametric distribution, was performed by Spearman rank tests.

The third stage of the study focused on tests of the algorithms performance. For this purpose, the authors described algorithms implemented on a few different devices with different processors and memory size. All devices had processors with ARM architecture. The best of them was a quad-core ARM Cortex-A15 clocked at 2500 MHz, having a total capacity of 35.000 DMIPS. The worst of them are single-core ARM11 700 MHz clocked at 900 DMIPS, having 900 DMIPS. In any case, all of the algorithms were employed in real time. The results presented algorithm execution times for the worst case.

3. Results

In this paper, the analysis of the data was performed using the following abbreviations:

Fast Fourier Transform – F, Wavelet Transform DB4 – W44 (4-level), Wavelet Transform DB6 – W64 (4-level), Wavelet Transform DB4 – W45 (5-level), Wavelet Transform DB6 – W65 (5-level), 1, 2 - 1s, 2s width of the window, N – the entire signal of ECG, D – Diff BMP Algorithm.

- Evaluation of algorithms in statistical terms:

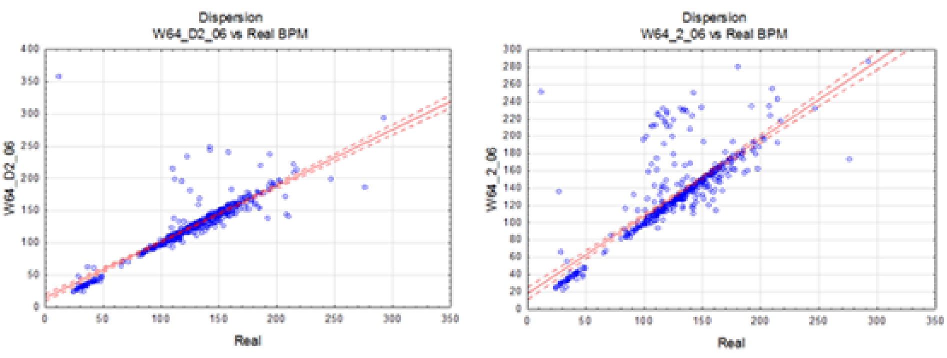

Fig. 2. The best algorithms for Wavelet Transform

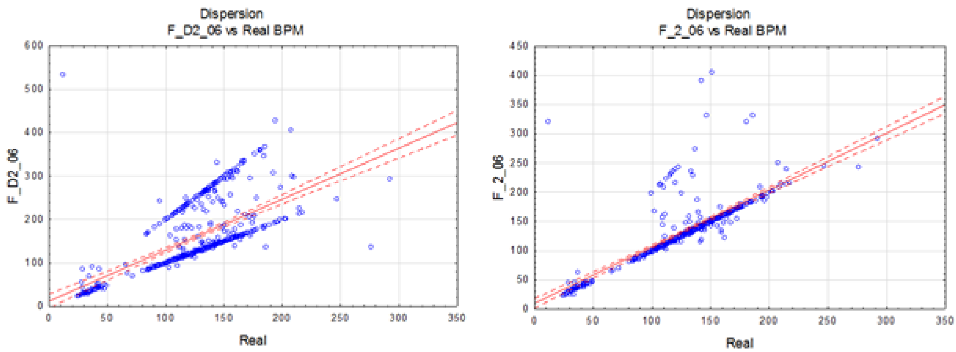

Fig. 3. The best algorithms for Fourier Transform

The obtained results demonstrate the statistical significance. Correlation analysis performed by Spearman rank tests demonstrated for W64_D2_06 that the best score for Wavelet Transform was r = 0.94, and for W64_2_06 the value r = 0.83 (Fig. 2). Correlation analysis performed by Spearman rank tests demonstrated value r = 0.71 for F_D2_06, and for F_2_06 the best score for Fast Fourier Transform was r = 0.89 (Fig. 3).

- Evaluation of algorithms in terms of performance: Tests were conducted to determine if signal processing is possible in real time on a variety of devices.

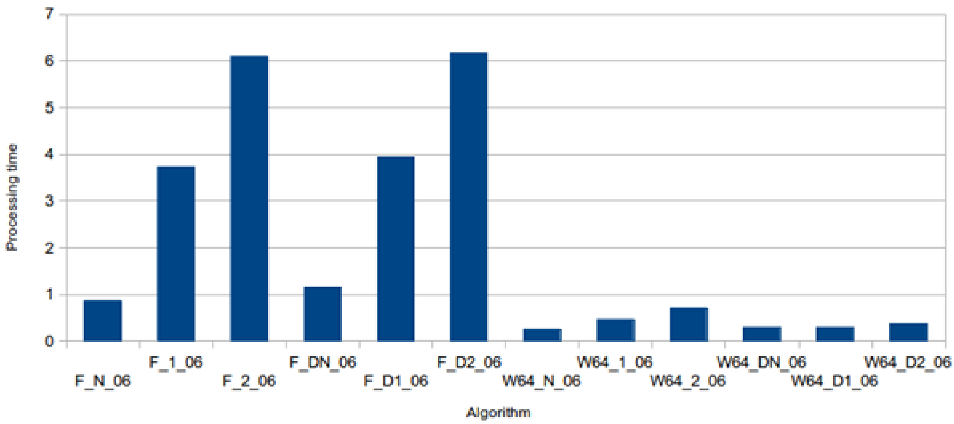

Fig. 4. Processing time of algorithms

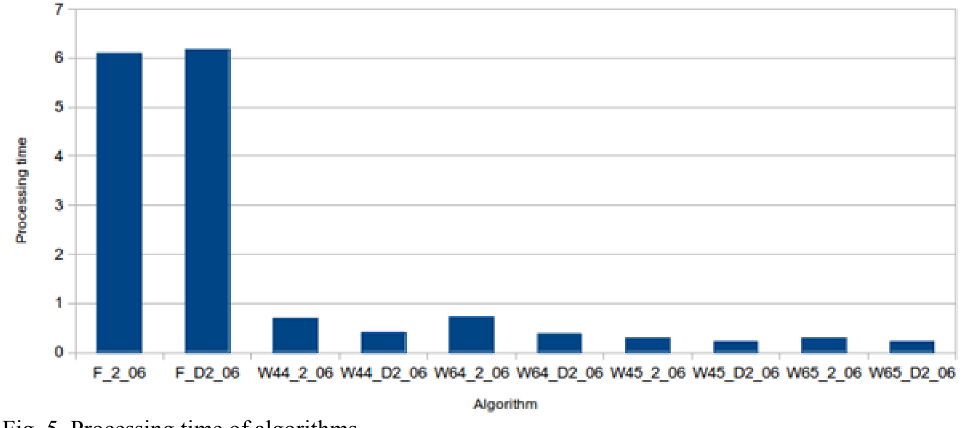

Fig. 5. Processing time of algorithms

Conclusion

The paper presents the possibility of using Fourier Transform and Wavelet Transform to detect BPM on the example of recorded ECG waves. The range of capabilities of mobile devices in terms of processing algorithms for the detection of BPM was also indicated. The performed analysis, both in statistical and performance terms of the mobile devices, is the first of this type. Analysis of literature indicates that other researchers focused solely on determining the value of BPM. Two ways of examining the recorded ECG waves, in terms of their effectiveness in detecting value of BPM, provided the opportunity to compare and demonstrate the effectiveness of these transforms.

The significance of the application of the reported methods for the detection of BPM confirms the obtained results. Their analysis suggests that the best application in the detection of BPM for the assumed boundary data was obtained by Wavelet Transform. The effectiveness of its application confirms the time calculations, efficiency and quality of their implementation, as well as the obtained effect. In contrast to the Wavelet Transform, the Fast Fourier Transform presents much poorer results. The proposed wavelet shape with similar morphology to the ECG provides the best accuracy in determining the location of R peaks, and thus the value of BPM. This fact is confirmed by the tests carried out. The best results were obtained for Daubechies Wavelet 6 (db6). A little worse results were in terms of db5 and db4. Analysis of possible levels of decomposition based on the select wavelet presents the best for level 4. Both higher and lower levels of decomposition obtained much worse results. Analysis of algorithms developed in terms of the detection of R peaks showed that the highest efficiency for the Diff BMP Algorithm was obtained the ECG waves after Wavelet Transform. In both cases, analysis of ECG waves were the best for 2s slider window.

Any of the described algorithms can be executed in real time, at least on a mobile device with a 700 MHz ARM11 processor. This is due to the characteristics of the device and the analysed transform (DWT). Each level of decomposition in Wavelet Transform causes that the signal has half as many samples. Therefore, algorithms using 5-level Wavelet Transform executes faster than the algorithms using 4-level Wavelet Transform.

Both methods allow one to determine the location of R peaks, and thus the value of BPM. However, the greatest accuracy, in the correct interpretation of the electrocardiogram, which allows recognizing the value of BPM, is provided by the Wavelet Transform.

Analysis of the results confirms the importance of their use in the cardiological diagnosis.

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Algorytmy wykrywania BPM realizowane w oparciu o urządzenia mobilne

Słowa kluczowe

ECG, algorytm, BPM, urządzenia mobilne.

Streszczenie

Mobilne urządzenia stale zwiększają swoją pozycję w zakresie tworzenia nowych wynalazków, m.in. do monitorowania pracy serca. Potrzeba monitorowania i kontroli stanu zdrowia pacjenta, a zwłaszcza aspektów związanych z prawidłową pracą serca (pomiarem jego rytmu) jest jednym z podstawowych kierunków w zakresie prowadzonych prac badawczych. Kierunkiem rozwoju wyznaczanym wraz z postępem technologii jest znalezienie drogi łączącej technikę z medycyną. Analizując te potrzeby, w ramach niniejszego artykułu poddano analizie różne typy algorytmów wykorzystywane w procesie wyznaczania wartości HR, świadczące o częstotliwości pracy serca. Celem autorów było określenie możliwości ich wykorzystania w odniesieniu do różnorodnych urządzeń mobilnych typu: tablet, smartfon, a także w procesorach urządzeń wbudowanych. Realizacja tego zadania polegała na ocenie czasu przetwarzania sygnału przez poszczególne urządzenia. Na dalszych etapach, w oparciu o zgromadzone dane, analizie poddano możliwość wykorzystania wybranych urządzeń w ocenie zapisu sygnału EKG w czasie rzeczywistym. Podsumowaniem przeprowadzonych badań było wskazanie skuteczności wykrywania HR, poprzez zastosowanie wybranych algorytmów, na wyznaczonych urządzeniach.