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ECG SIGNAL ANALYSIS FOR DETECTION BPM

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Summary: The methodology in this article is focused on the development intelligent algorithms in the area of biomedical engineering, or more precisely, on the biomedical signal. The purpose of these activities is generally counteraction to occurring the problem of diagnosing cardiac diseases based on the ECG signal. This paper proposes various algorithms to detect the BPM, which can be used for diagnosis of cardiovascular abnormalities. These algorithms detects the R-peaks in signal ECG and on their basis computes the BPM. Proposed solutions allow to select three algorithms to determine R-peaks. As part of this method have been used function of threshold, the derivative signal, and the slider window.

Keywords: ECG analysis, algorithm, R-waves, BPM.

1. INTRODUCTION

The proper functioning of the human body requires efficient transmission of information, both between the organism and the environment, as well as inside the body. The flow of these messages is based in most cases on the transmissions of electrical impulses, which are the source of biomedical signals. Carriers transferred electrical impulses are ions, which are arranged along the cell membranes are the different structures, which is found in the human body. The flow of ions, causes membrane depolarization often been compared to the flow of electric current in a wire.

One of the many methods of recording the biomedical signals, which combines these relationships is electrocardiography. Electrocardiography recording the ECG signal, in the clinical aspect is a graphical record of changes potentials recorded from the surface of the chest, during depolarization and repolarization of cardiac muscle cells. However, in the technology aspect is a graphical notation for the electrical signals, generated during a heartbeat [4].

A typical ECG (fig. 1) waves allows to specify the location of the P-wave, QRS complex and T-wave and U-wave. Amplitude, frequency of their occurrence, and also the interval between each of peak are the parameters used to define a number of abnormalities of the heart, which significantly affect the state of our lives [3].

The most important from a medical point of view is the RR interval. The distance between two peaks of R, is a meaningful factor used to determine the abnormality in the cardiovascular system, for example, to assess heart rate (BPM). According to ongoing clinical research, the heart rate is a new therapeutic target of cardiac. Reduction the frequency of the heart rate is undoubtedly necessary the way to proceed in the treatment of many diseases of the circulatory system. This leads to saving produced of energy, and elongation of life span, which affects to the reconstruction of myocardial. The typical duration of RR, called standard is in the range of 600-1200 ms. Depending on the length duration of the RR, there are three modes of heartbeat (used to identify a variety of cardiac dysfunction): standard (60-80 beats per minute), and her anomalies: tachycardia (rapid heart rate, > 100 beats per minute) and bradycardia (slow heart rate, < 50 beats per minute).

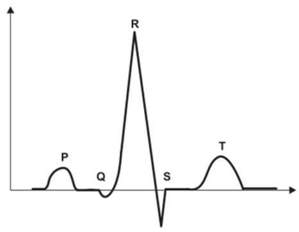

Fig. 1. ECG signal

Analysis of the heart rate is used not only in medicine to evaluate the health status of patients [1]. The measurement of the heart rate is also used in many areas of sports, in which performs endurance tests. The position to measure stress test, assesses physical fitness of athlete. During the stress test is measured, inter alia, activity of the heart. The obtained results assess the ability the body's to the performance of hard work and long-term physical, involving large muscle groups. The measure of this unit for sports applications is physical fitness. The smaller of the value of RR, that the body is more prepared to perform tasks requiring a lot of effort and/or extraordinary physical condition and reduced the likelihood of a heart attack. The stress test is also a technique that has found application in basic medical diagnostics. Repeatedly used to assess the health status of patients (after numerous treatments of coronary artery) determines the degree of threat of another attack, and facilitates the development of a program of rehabilitation of post-infarction. Analysis of frequency heart rate is also found application in music. Carried in this direction work was to design an algorithm, which on the basis record of the song, detects the stronger sound, called as BPM (beats per minute). On the basis collected of such measurements, was created algorithms, which allows to modifying the pace of each song, changing their frequency, and the addition/subtraction of other effects [1, 7].

In the literature is many various methods used to detect the frequency of heart rate. Regardless of the application, the authors together confirm the difficulty in determining the BPM. In this article, the above issues are related with characteristics of the ECG signal. Analysis of the available literature indicates on multitasking in the consideration of this signal. By joining to analysis the ECG signals in the first steps must to remove artifacts, which are affect the quality of the signal, resulting from the mains frequency 50Hz and respiratory muscle work [8]. Available algorithms detection of BPM are based on the determination of location of complex QRS and computes the distance of RR. The QRS detection are implemented via algorithms with the field of artificial neural networks, genetic algorithms, and wavelet transform. The using of matching filtration [5] is also preferred to analysis of special shapes of signal under impact of interferences. Most of the operations was performed based on the Matlab software. A disadvantage of prior methods, is their complicated performs and/or implementation, and the low efficiency (positive predictive accuracy of 88.08 %, 75.06 %) in relation to the variable characteristics of the recording of this signals, which results the various diseases [2, 6].

The aim of this article was to design various algorithms, which takes a sample of the ECG waves, and after that computes of BPM (Beats Per Minute). The methodology in this article basically describes two different processes, where the ECG waveforms are considered. First is the filtering and normalization. Second is the calculation the heart rate (BPM).

2. PROPOSED METHODOLOGY

To evaluate the processing algorithms we used the MIT database, which allows to work with ECG's signals (format conversion, part selection, frequency conversion, etc.). All these signals and functions are accessible through the PhysioNet society, where all the available resources are publicly offered. One of this resources is PhysioBank. PhysioBank comprises around 26 different ECG databases. In this paper we used The PTB Diagnostic ECG Database.

The selection of databases was made according on their characteristics, and to the number of available registries and their duration. We used a total of 485 registries of 100ms for each of the selected pathologies. These pathologies consist: Myocardial infarction, Cardiomyopathy, Heart failure, Bundle branch block, Dysrhythmia, Myocardial hypertrophy, Valvular heart disease, Myocarditis, Miscellaneous, Healthy controls. These signals were digitized at 1000 samples per second per channel with 16-bit resolution.

The choice of this database was based on the need to obtain the illnesses diversity. This allows to identify the variable characteristics of the ECGs signal, and also proper interpretation. Dimension reduction in the features space is mostly due to the quality and precision requirements when representing functional status, thus making necessary methods of feature selection and extraction as a fundamental step in the classification process. The figure 2 represents a scheme of the process, divided in five blocks.

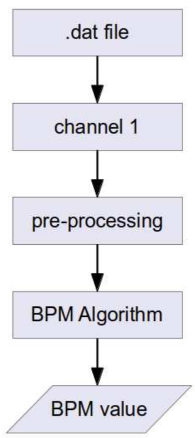

Fig. 2. Scheme of the process

2.1. PRE-PROCESSING

The pre-processing consists in a set of operations on the magnitude of retrieved signals, and provides a numerical value to work within the following steps. The first steps is required for removal of noises such as breathing movements, the power supply network 50 Hz frequency [6], which usually is the main of the problem, etc. As part of these activities, the pre-processing stage involves normalization and filtering. It's realize to optimize in a set of values of ECG signals, containing the most representative data (dimension reduction) for the next task. These artefacts have to be removed before the signal is used for next data processing like heart rate frequency determination, which has been achieved in this work [7].

2.2. HEART RATE DETECTION ALGORITHMS

In this part there are described algorithms for heart rate detection which have been designed in Scilab, environment of Java, Python. These algorithms carry signs algorithms based on statistical and differential mathematical methods.

The first algorithms are detecting heart rate (BPM) as difference between R waves in ECG. These waves are filtrated at the first steps in pre-processing, for example by band pass filters. The wave's peaks are detected by signal thresholding, and after that the algorithm counted the amount of detected R-peaks.

The second and third algorithm is modification the algorithm of the Simple BPM Algorithm. In the algorithm of the Simple BPM Algorithm all the values are determined separately for each sample, in the field $[i - t, i + t]$. After that, the algorithm proceed as before. First determines the signal threshold, later computes parts of the waves (R-peaks), and Calculation of the BPM. In the algorithm of the Diff BMP Algorithm are analyzes the derivatives of the ECG waves. Calculation of the BPM, is the same, as in the case of the first algorithm.

2.2.1. Simple BPM algorithm

The first algorithm computes heart rate frequency using the signal thresholding. The threshold is computed according the equation (1). The threshold is used for finding the signal parts, where are R-peaks. The first step of algorithm determines the maximum value (called max) and the arithmetical mean value (called avg) of all the samples. On this basis, the algorithm determines the ratio of maximum value to the average value, which in the context of the present work is 0.4-0.9. After that, the algorithm computes the number of detected R-peaks, which are above defined threshold value.

$$Thr = (max - avg) * r + avg \qquad (1)$$

where:

Thr – threshold;
r – relation factor.

The BPM is computed according the equation (2):

$$bpm = \frac{n*60}{t} \qquad (2)$$

where:

n – R-peaks, which are above defined threshold value;
t – time signal in seconds.

In the figure 3 shown some of the patient, with the threshold, R-peaks timestamps and the calculated heart rate.

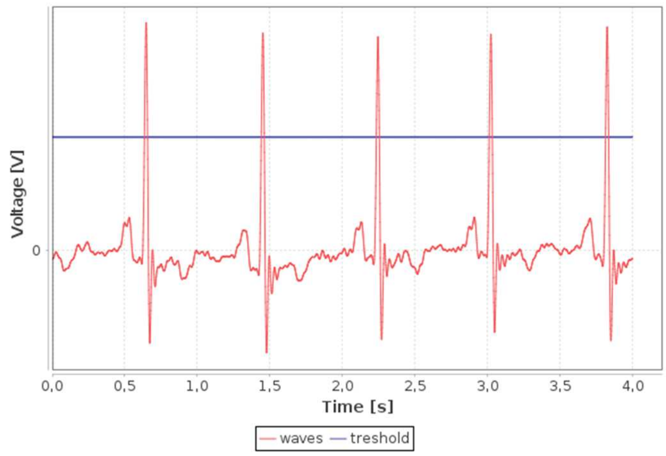

Fig. 3. The Simple BPM Algorithm

2.2.2. Slider window BPM algorithm

The second algorithm is modification the algorithm of the Simple BPM Algorithm. In the first of algorithm the maximum value and average value, and the threshold were been determined for all the samples. In the algorithm of the Slider Window BPM Algorithm all the values are determined separately for each sample. The first step of algorithm determines the maximum value, arithmetical mean value and the threshold for the ECG waves. After that, the algorithm takes into account only the samples in the range $[i - t, i + t]$. The coefficient t is time, for example 100 ms. On this basis, the algorithm determines the signal threshold (Fig. 4). After that, the algorithm computes parts of the waves (R-peaks), which are above defined signal threshold. Calculation of the BPM, is the same, as in the case of the first algorithm. In the algorithm of the Slider Window BPM Algorithm were fixed window width 1000 and 2000 samples.

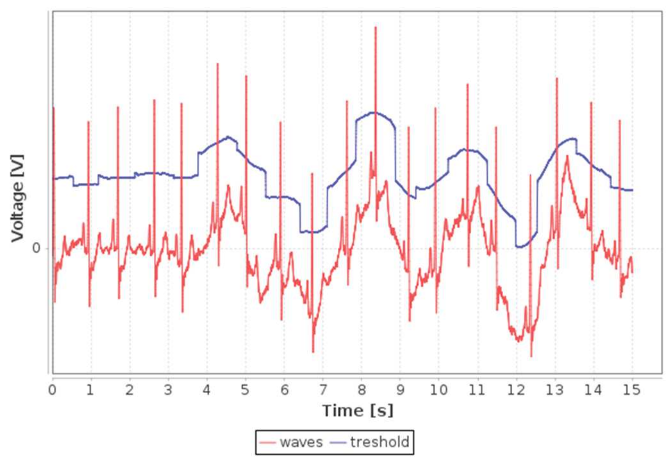

Fig. 4. The Slider Window BPM

2.2.3. Diff BPM algorithm

The third algorithm is modification the algorithm of the Simple BPM Algorithm. In contrast to the BPM Simple Algorithm, the Diff BMP Algorithm analyzes the derivatives ECG waves (Fig. 5). On the basis of the selected waves, the Diff BMP Algorithm determines the position of R-peaks. After that, the algorithm counts localized peaks, and computes value of the BPM.

The value of the R-peaks is computed according the equation (3):

$$d_i = s_{i+1} - s_i \tag{3}$$

where:
- d_i – the value of the x sample of the tested wave;
- s_i – the value of the x sample of the original wave.

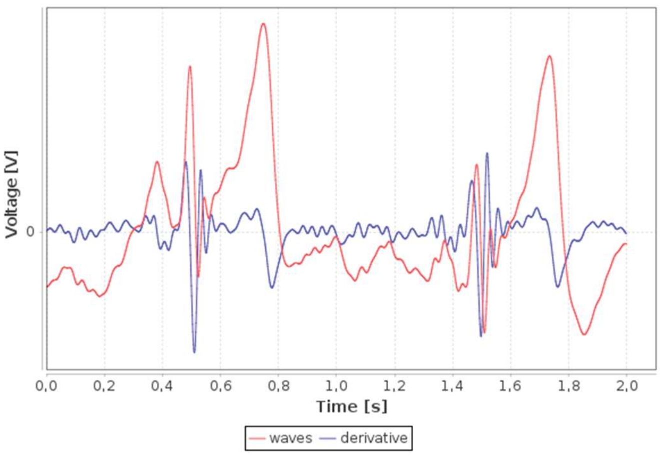

Fig. 5. The Diff BMP Algorithm

2.3. METHOD OF ASSESSMENT ALGORITHMS

Before starting the test, for each ECG waves from database, the real value of BPM were determined and corrected by specialist. Included in this work algorithm were tested for all available ECG waves. For each tested ECG waves were determined the approximation error.

The approximation error is computed according the equation (4):

$$e_i = \frac{bpm_{ri} - bpm_{ai}}{bpm_{ri}} * 100\% \tag{4}$$

where:
- e_i – the approximation error of the tested wave;
- bpm_{ri} – the real value of the BPM;
- bpm_{ai} – the value determined by the algorithm.

Then, the algorithm calculated the average approximation error (5):

$$d = \sum_{i=0}^{n} \frac{|e_i|}{n} \tag{5}$$

where:

n – number of tested waves;

e_i – the approximation error of the tested wave.

3. RESULTS

Minimum relative error for each algorithm (Fig. 6).

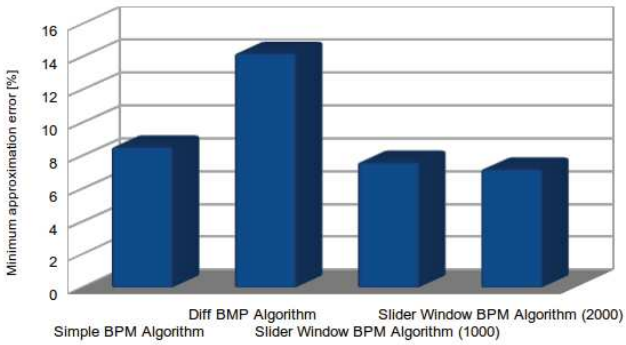

Fig. 6. Minimum relative error for each algorithm

The relative error in the function relation factor (Fig. 7).

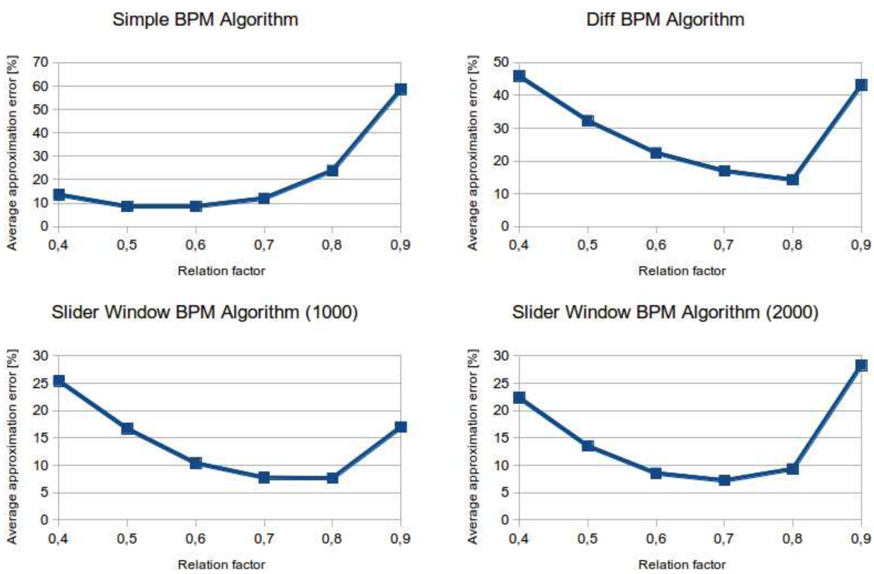

Fig. 7. The relative error in the function relation factor

The distributions errors for the different algorithms (Fig. 8).

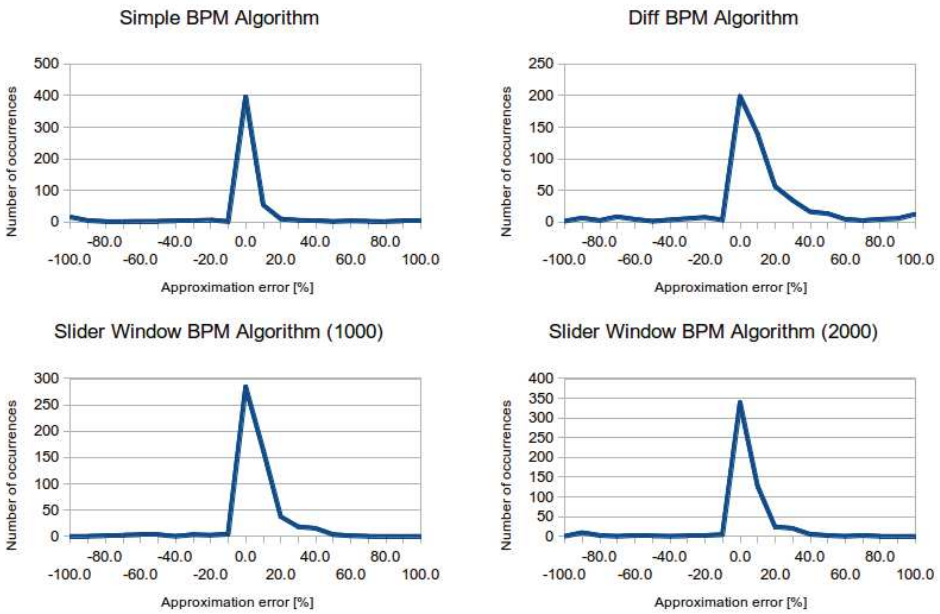

Fig. 8. The distributions errors for the different algorithms

4. CONCLUSION & FUTURE PLANS

This work proposes both a simple, fast, as demanding methods for determining the heart beat based on ECG signals. The proposed methods proved to be the best for Slider Window BPM Algorithm, the total classification relative error was approximately for 1000 samples 7.62% and for 2000 samples 7.20%.

Relatively good detection results had the Simple BPM Algorithm. Despite the lack of complex mathematics computations, it is very effective for processing the ECG signal, what saves the computing time. The total classification relative error was approximately 8.55%. The worst in this classification fell the Diff BMP Algorithm (14.24%), which showed the lowest-reliability to detection of the BPM.

The application of the Slider Window Algorithm causes the increased requirements, in the field of the computing power especially for the wide window. At the expense of more computation are obtain a good detection results of BPM. It is the reason why these algorithms could not be easy implemented in some applications that do not have such computing power. Accordingly, we proposed other algorithms.

In cases, when the R-peaks have not the largest value relative to the other peaks (for example, the T-peaks are higher), should be used the Diff BPM Algorithm, because for this algorithm a derivative of the R-peak has the highest value (it is shown in Figure 5).

The study showed, that for each of presented algorithms should be chosen experimentally relation factor. For each algorithm there is an optimal value (Figure 7).

This paper presents a largely appoints of the R-peaks on the basis of the signal threshold. Accordingly, the algorithms presented in this work, could be used to search for R-peaks in ECG waves. For this purpose, for each section, which are above defined threshold value, should be appoint a maximum local.

The aim of further work will be apply the developed algorithms in cardiological diagnosis.

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WYKRYWANIE HR NA PODSTAWIE SYGNAŁU EKG

Streszczenie

Przedstawiona w pracy metodologia badawcza koncentruje się na rozwoju inteligentnych algorytmów w obszarze inżynierii biomedycznej, a ściślej w zakresie przetwarzania sygnałów biomedycznych. Celem realizowanych w pracy algorytmów jest ogólnie występujący problem diagnozowania chorób serca, w oparciu o zapis EKG. Niniejszy dokument prezentuje różnego rodzaju algorytmy wykrywające wartości HR, świadczące o częstotliwości pracy serca, które mogą stanowić oparcie dla lekarzy w diagnozowaniu zaburzeń sercowo-naczyniowych. Analizowane algorytmy wykrywają załamki R z zapisu EKG, aby w dalszym etapie obliczyć HR. Proponowane przez autorów rozwiązania umożliwiają wybór jednej z trzech omówionych metod. W każdej z nich został zastosowany inny algorytm wyznaczania załamków R. Wprowadzono m.in. funkcję progu, wyznaczanie pochodnej sygnału oraz okno przesuwne.

Słowa kluczowe: EKG, algorytm, załamek R, HR.