T-wave Alternans Analysis In Ambulatory ECG Monitoring

Jakub Chłapiński, Marek Kamiński, Bartosz Sakowicz, Rafał Kotas

Abstract – **The aim of the research presented in this paper was to test and evaluate the possibility of T-wave alternans (TWA) detection with the use of standard ambulatory ECG monitors. In development work there is proposal of author's advanced method allowing to remove from signal any distortion and disturbances making impossible further analysis.**

Keywords — **ECG signal analysis, T wave, ECG signal segmentation**

I. INTRODUCTION

Nowadays the only credible method of T wale alternans detection is a medical test using the Cambridge Hart [1]. Effectiveness of this method was granted by the medical society and was approved by the Food and Drug Administration (FDA - a Government agency of the United States Department of Health and Human Services). In spite of its great functionality and credible results it has one major disadvantage which is a high price. According to that fact a software tool was designed to support doctors and reduce the cost of the analysis. At the same time it has to satisfy all the requirements of the most efficient T wave alternans detection. This computer program is called "Cardio" and was designed in the Department Of Microelectronics and Computer Science at the Technical University of Lodz [5, 6].

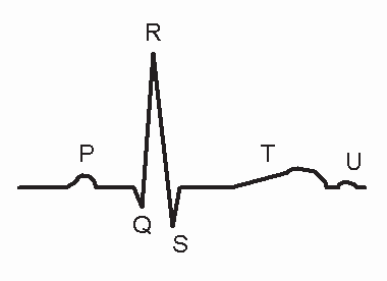

Fig.1: Course of signal with noted waves of ECG

A concept of an electric alternans has a wide meaning. It is associated with variations occurring in following heartbeats. These changes could involve all of the recorded heartbeat components (waves, segments or intervals). For example a peak value, a duration or polarization of every single component could vary. Most frequently the alternans concept is associated with the amplitude fluctuations. The T wave alternans (TWA) are periodic beat-to-beat variations in the amplitude of the T wave (Fig. 1) in an electrocardiogram (ECG). The amplitudes of the following waves are alternately high and low. This heart pathology is shown on the figure below (Fig. 2).

The T-wave alternans is a process associated with a heart ventricles repolarization. Moreover it could occur at the same time with sudden variations of a heart rhythm and prolonged QT interval. So far, medical tests show that T wave alternans is associated with many serious heart diseases: congenital long QT syndrome, hypocalcemia, hypocalemia, hypomagnesemia, cardiac hypertrophy, alcoholic cardiomyopathy, congestive heart failure, pulmonary embolism. The presence of the TWA might be a signal for a doctor, that tested patient is at high risk of developing a potentially lethal cardiac diseases (sudden cardiac death, cardiac arrhythmia, permanent ventricular tachycardia, ventricular fibrillation, cessation of blood circulation) [2, 3]. As the research shows, 98 percent of patients without TWA have a very low risk of sudden cardiac death [4].

II. IMPROVEMENT OF A DETECTION OF THE R WAVES POSITION

Two essential modifications were applied to the division algorithm detecting every single heartbeat. So far it leads to many errors in the segmentations process of the ECG signal. These modifications eliminate the most common abnormalities: skipping QRS complexes which are not satisfying the requirements insignificantly and confusing numerous voltage spikes in the interfered ECG signal with R waves.

New method bases on the duration length of a previous and current heartbeat. It is started only in the case when the duration time of the current heartbeat appears to be much longer than the duration of the previous one. This situation could occur in two specific cases: a patient has an arrhythmia or the R wave was skipped by mistake in the ECG segmentation process.

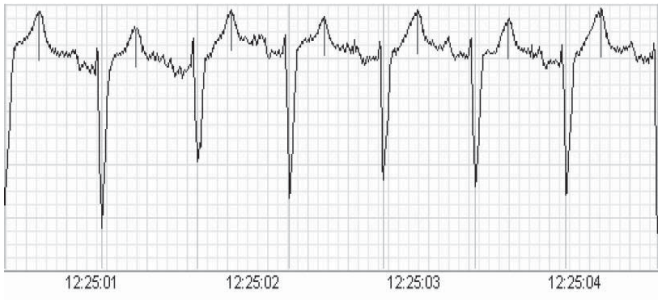

Fig.2: Example ECG strip with T-wave alternans (repeating pattern of higher-lower T-wave amplitude)

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Started procedure once again checks that area of the ECG signal for the presence of the QRS complex. But this time the requirements are insignificantly decreased. If a new position satisfying new requirements of the R wave is found, it is set as the end of the heartbeat. In the case of assumption that none of QRS complexes were skipped the heartbeat is tested for a presence of cardiac arrhythmia (Fig. 3).

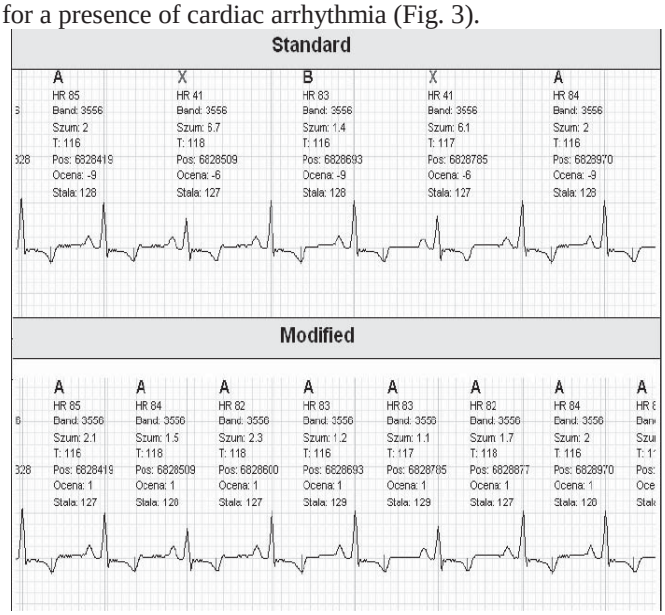

Fig.3: Improvement of a detection of the R waves position

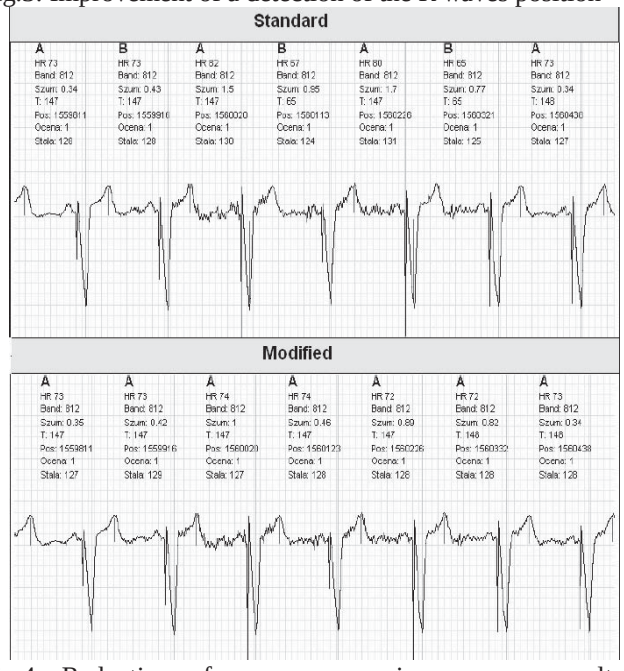

Fig.4: Reduction of errors concerning numerous voltage spikes

Reduction of errors concerning numerous voltage spikes bases on a modification of a method looking for QRS complexes. In the previous version of the procedure the basic requirement for the signal division was detecting QRS complexes. It is characterised by two features: a high amplitude and significant changes of the signal (A significant inclination of R wave curves). In that case every high voltage spike will satisfy this requirement and will be marked as R wave. To avoid these situations the user of "Cardio" could set the maximum inclination of signal curves in the nearest area of calculated point. If the inclination of a signal curve is higher than the chosen parameter it is skipped (Fig. 4). This method appears to be a simple, software noise filter.

III. MODIFICATION OF THE METHOD OF T WAVE DETECTION

In the previous version of "Cardio" the user was choosing a fragment of a heartbeat to look for T wave. It was very simple and convenient solution which gives correct results in many cases. However this algorithm appeared to be useless when dealing with longer period of the ECG signal. Particularly once chosen time leads to many errors if the heart rhythm varies in wide range during the ECG recording. Of course it happens very often because of the character of the Holter monitor test. As the result P wave was taken by mistake as T wave. That is a direct reason of many errors in the process of T wave alternans detection.

Carried tests show the need of modification of this algorithm. It was decided that the duration time of a chosen fragment should depend on duration of every heartbeat. This solution appeared when some ECG pattern signals were analysed. It is obvious that QT interval changes according to the heart rhythm variations. A standard duration of a QT interval varies between 300 and 440 milliseconds. However many patients have cardiac disorders: short QT interval (shorter duration than 300 ms), long QT interval (longer duration than 450 ms). Furthermore there are many different formulas which are calculating normalized QT-Duration (e.g. Bezzet's formula, Fredericia's formula, formulas based on regression analysis). According to all of these formulas the limiting parameters of T wave detection are 0.15 to 0.65 of a heartbeat duration. He lower limit is associated with the presence of the ST segment and the higher limit comes off the QT-Duration. These values are optimal, so that maximum T wave detection effectiveness is achieved for many different frequencies of patient's heartbeats. (Fig. 5)

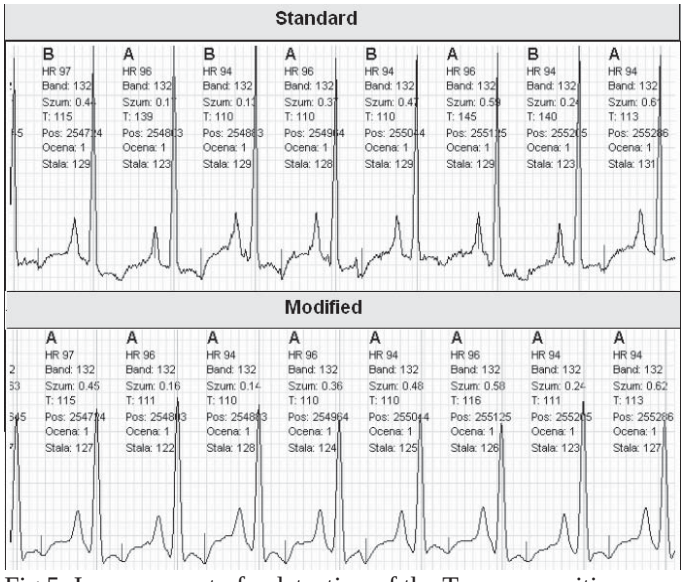

Fig.5: Improvement of a detection of the T waves position

IV. MULTICHANNEL ANALYSIS

Because of the fact that the standard ECG test uses at least three electrodes, data from all of these channels could be used in the ECG segmentation process. A multichannel analysis is used to improve effectiveness and correctness of this process.

An idea of this method bases on the comparison of the segmentation results from all of the channels. And then the most probable result is chosen. First and most important decision to make before the multichannel analysis is a choice of a leading channel. Data from this channel are used for most important calculations in alternans detection procedure (parameters of a single heartbeat and T waves amplitudes). From the further analysis point of view it is recommended to make a conscientious choice of a leading channel. The leading channel signal should have possibly similar features as standard ECG signal (high amplitudes of R and T waves and low level of noise).

According to the algorithm requirements if in the set of the positions from all of the channels is an appropriate amount of similar values that position should be marked as next R wave position. The amount of similar positions determining final result depends on the total amount of the ECG channels. Maximum number of channels in this procedure is 12. In most popular case of 3-channel analysis two similar ECG segmentation results are sufficient to accept it as credible.

Very important aspect of the multichannel analysis is its duration. It is considerably longer than in a conventional, single channel analysis. The difference comes off the necessity of filtering all of the ECG signal channels. This process in comparison with the calculating issues takes much more time. This time rises directly proportional to the number of the ECG channels. (Fig. 6)

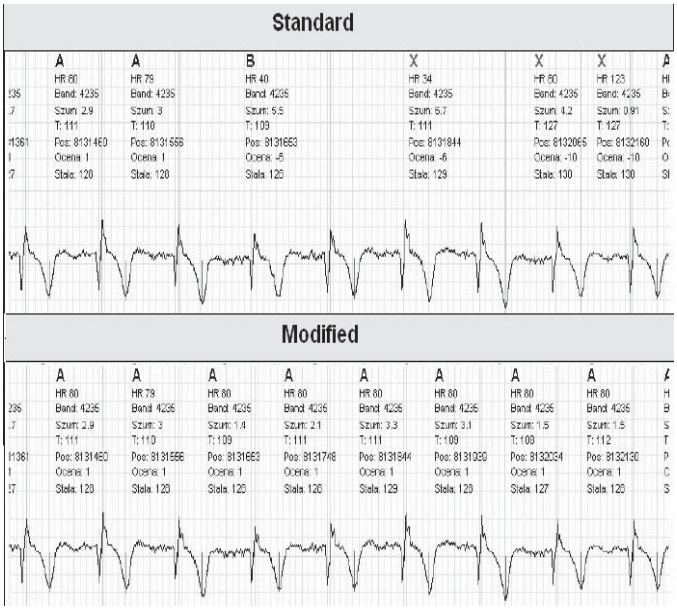

Fig.6: Improvement of a detection of the R waves position based on multichannel analysis

V. RECOGNITION OF HEARTBEAT PATTERNS

Observations and analysis of available electrocardiograms lead author to an idea of developing "Cardio" by an algorithm of recognition of characteristic for every patient heartbeats. According to these observations every patient has his own unique ECG. In a large number of signal parameters there are some which tends to be similar for all of patients. The most important parameters are the shape of QRS complex and specific features of T wave. And the recognition algorithm bases on these two attributes. There are several basic patterns of the QRS complex shape in medical practice. Its nomenclature is directly associated with the shape and the magnitude of every wave in the complex. (Fig. 7)

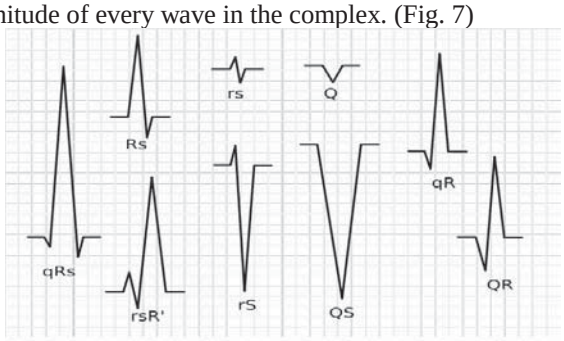

Fig.7: Basic patterns of the QRS complex shape

From the programistic point of view the recognition of so large number of patterns is very complex. Furthermore the differences between some patterns are almost insignificant. Because of that fact author decided to use only four, major shapes of the QRS complex. The user of "Cardio" has to choose an appropriate pattern by setting *R shape* parameter. There are four values of this parameter (Fig. 8):

- POSITIVE (qRs, qR);
- NEGATIVE (QS, Q, rS);
- POS-NEG (Rs, rs);
- NEG-POS (rsR', QR).

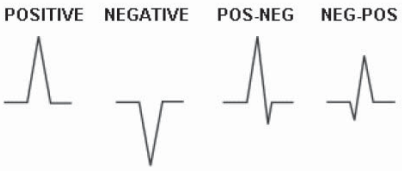

Fig.8: Patterns of the QRS complex shapes in "Cardio"

The choice of the pattern should be conscientious and precede with observation of wide range of the ECG. If an algorithm detects a heartbeat which is different than the pattern, it is marked and skipped in the process of the ECG analysis. Second important aspect associated with the characteristic heartbeat recognition algorithm is a polarization of T wave in the ECG signal recorded from one channel (Fig. 9). In a standard ECG signal this feature should be constant. Possible changes in T wave polarization can identify patients who are at increased risk of serious cardiac diseases. (Fig. 10)

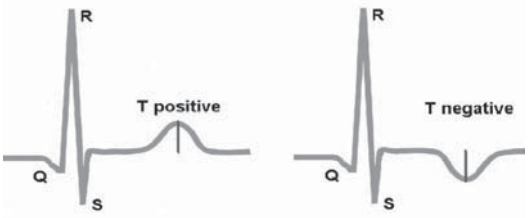

Fig.9: Polarization of T wave in the ECG signal

VI. CONCLUSION

The improved version of "Cardio" is a software tool which offers substantial support to the doctor in the analysis of

24-hour ECG recorded by Holter monitor. “Cardio” is designed not only to visualize, divide into QRS complexes and asses the ECG but first of all it is designed to detect T wave alternans. Two ideas of “Cardio” improvements were described this article. Implemented multichannel analysis (used in the optimisation of the ECG segmentation) and the heartbeat pattern recognition algorithm eliminate majority of the problems which appeared during tests. The effectiveness of “Cardio” increased significantly. Moreover “Cardio” has many other improvements, e.g. development of an individual wave detection and more precise calculation of wave’s amplitudes. The final result of the research is the latest version of “Cardio’. It is very efficient and inexpensive software tool used in medical tests of T wave alternans.

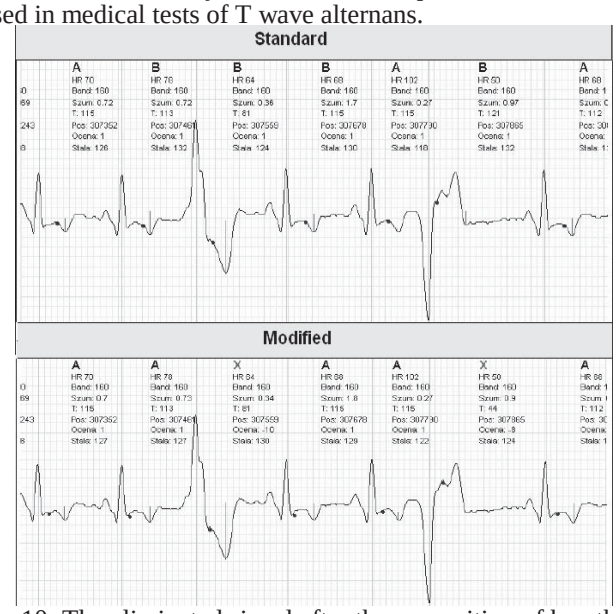

Fig.10: The eliminated signal after the recognition of heartbeat patterns

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