Detection of Artifacts in Oscillometric Pulsations Signals*

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***Abstract*— A measurement of blood pressure is a basic diagnostic technique for examining of the cardiovascular system. There are a lot of methods for determination of the blood pressure, but an oscillometric measurement (investigation of oscillometric pulsations) is one of the most frequent methods used in modern electronic tonometers. The results given by oscillometric measurements are very dependent on the cleanness of the signal. The method is very sensitive for example for motion artifacts, which produce significant damage of the signal. For the proper processing of the signal it is very important to detect all artifacts precisely before signal processing. The paper deals with the methods for artifacts detection in oscillometric pulsations signals. The methods based on predicted heart rate detection, heart rate variability (standard deviation method) and comparison of oscillometric pulsations with ECG signal are described in the paper. The section Results includes a comparison of the methods and a discussion of their advantages and disadvantages. The authors conclude that the algorithm based on detection of heart rate variability (standard deviation method) seems as the most suitable algorithm for automated detection of artifacts in the signal of oscillometric pulsations.**

I. INTRODUCTION

One of the basic physiological parameters of human body is a blood pressure. The measurement of blood pressure is a part of routine investigation which is done during a visit in an ambulance of a practitioner.

The blood pressure is a significant marker for many diseases. It relates directly with many cardiovascular diseases and also with other significant illnesses such as obesity, diabetes mellitus etc. As is general known these diseases (and especially cardiovascular diseases) are one of the most frequent causes of death in developed countries. [9]

A measurement of blood pressure is a basic diagnostic technique for examining of the cardiovascular system. There are a lot of methods for determination of the blood pressure such as an auscultatory method, an oscillometric method and a method of unloading artery (Penaz's method) etc. [6], [3]

The auscultatory method is a manual method which uses a cuff and a phonendoscope for determination of the blood pressure. This method is often considered as a reference method. The oscillometric method is a method based on an investigation of oscillometric pulsations, small pressure changes in the cuff during the deflating of the cuff. This method is a method used in the most of electronic tonometers. [8], [1]

In clinical practice, a measurement using electronic tonometer is one of the most frequent methods. The measurement using electronic tonometers is quick, cheap and easy, and due to these reasons it is favourite in many cases.

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II. OSCILLOMETRIC MEASUREMENT

The oscillometric method used in electronic tonometers is based on an investigation of an envelope of oscillometric pulsations, which are measured during the deflating (or inflating) the cuff. Usually the method is implemented as a method for direct measurement of mean arterial pressure (MAP), which is determined as a pressure in the cuff at the moment when the maximal oscillometric pulsations are observed. The systolic (SBP) and diastolic (DSP) blood pressures are determined consequently from the shape of the envelope of the oscillometric pulsations. This means that the method is critically dependent on the precisely determined envelope of the oscillations. [2], [4], [7]

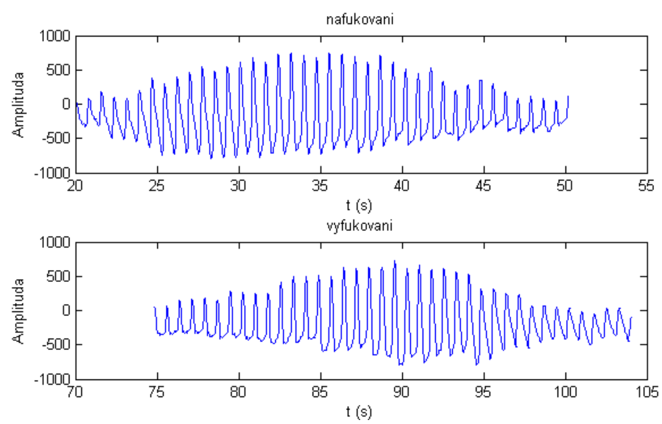

Fig. 1. Oscillometric pulsations observed during an inflation and deflation of the cuff

The typical behaviour of oscillometric pulsations observed during an inflating and deflating the cuff is shown in Fig. 1. The signal is not affected by any artifact. The envelope of the signal is smooth without any rapid changes.

Unfortunately, the signal of oscillometric pulsations is often affected by various artifacts, especially by motion artifacts produced by sensed person during the measurement. Examples of oscillometric signal affected by typical artifacts are shown if the Fig. 2.

Sometimes happened, and it is not exceptional, that the artifact is directly in the significant part of the signal like it is shown in the Fig. 3 (see the artifact in the middle of the first part of the signal). It is evident that the processing of signals damaged by artifacts could produce false blood pressure values, because it is very difficult to estimate the proper shape of signal envelope. The methods based on the these reasons the peak detector used in this research is based on the fact that the local extreme could be determined as a point where surrounding values are significantly lower (for local maximum) or higher (for local minimum). Significantly means higher than a predefined value Δ in this meaning. The value Δ is determined for each signal based on absolute values of the signal as

$$\Delta = 0,25 \cdot (s_{max} - s_{min}), \tag{1}$$

where s_{max} and s_{min} are the third greatest and lowest extremes in the signal. This equation was determined empirically and fits the appropriate local extremes in oscillometric signals in best way. The typical result of the peak detection is shown in the Fig. 4.

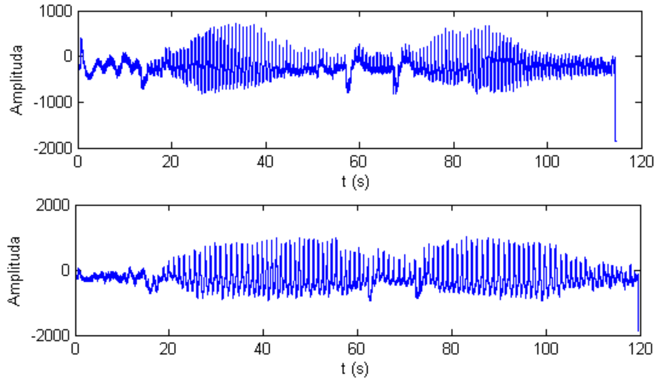

Fig. 2. Oscillometric pulsations with artifacts

investigation of signal envelope like oscillometric method fails with these signals. [4]

The main aim of this paper is to describe and compare methods for a detection of artifacts in oscillometric pulsations signals before the processing of these signals.

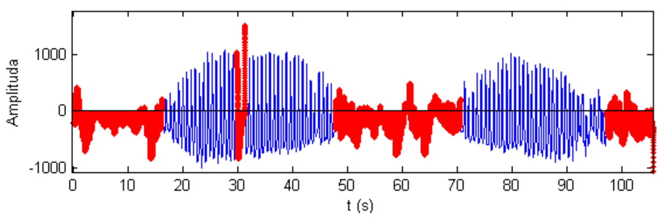

Fig. 3. Oscillometric pulsations with an artifact damaging the maximum of the envelope

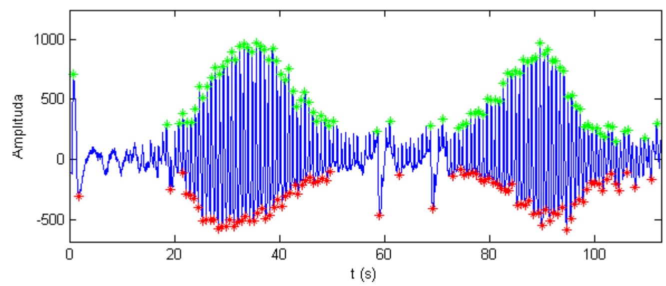

Fig. 4. Oscillometric pulsations with detected peaks

III. METHODS

Three methods for artifacts detection in the signals of oscillometric pulsations have been developed and compared. The first method is based on a predicted heart rate, the second one is based on a classification of heart rate variability and the last method is based on comparison of the oscillometric pulsations with electrocardiography signal (ECG). All the methods are developed as methods with low computational demands. It allows to implement the methods to portable and embedded devices such as mobile tonometers, smart devices etc.

The first step of all three methods is a detection of peaks in observed oscillometric signal.

A. Peak Detection

The goal of peak detection is to determine all significant local extremes of the oscillometric signal. There are a lot of peak detectors based on various principles. The often used principles are the searching for zero derivation (searching for inflections) and comparison of signal with fixed threshold. The zero derivation detectors are very sensitive, but produce excessive number of peaks for signals with noise or artifacts. The detectors based on the comparison with fixed threshold are very simple, but for real signals it is very difficult (or really impossible) to determine the proper threshold. Due to

B. Predicted Heart Rate Detection

The first method for artifact detection is based on the comparison of distance between consequent peaks in oscillometric signal with the predefined threshold. As each peak in oscillometric signal belongs to one pulse wave, the distance between two consequent peaks corresponds with the heart rate. It is fully accomplished for the signal without artifacts, but it is not right for the signal with artifacts. For the artifacts classification the upper and lower thresholds for heart rate have to be specified. Typically values of these thresholds should be about 50 and 120 bpm.

C. Standard Deviation Method

The second method for artifact detection is similarly based on comparison of distance between consequent peaks in observed oscillometric signal with the predefined threshold, but in this case the threshold is determined as a maximal standard deviation of the distance. Because the standard deviation is the root mean square deviation, it corresponds with the heart rate variability (HRV). For signals without artifacts the HRV will be very small (the distance between consequent peaks will be very similar for all peaks), but for signals damaged by artifacts HRV will be significantly higher. The standard deviation of distances between peaks is computed for every sliding window with length about 5 peaks. This technique produces reliable results with low sensitivity to influence by a specific behaviour of the signal. The threshold for standard deviation is determined empirically, but the determination is easier and more reliable than the determination of thresholds in previous method.

D. Comparison with ECG Signal

The last method for artifact detection is based on a comparison of oscillometric pulsations with ECG signal. As the each peak in the oscillometric signal corresponds with one heart pulse, the peaks in observed oscillometric signals have to be preceded by R–peaks in ECG. It is clearly seen in the Fig. 5.

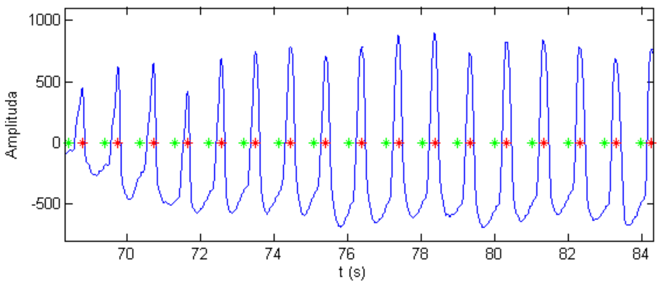

Fig. 5. Detail of oscillometric pulsations with the detected peaks and the R-waves from ECG

Due to this fact each peak in oscillometric signal which is not preceded by the R–peak in ECG signal is determined as an artifact in this method.

IV. SIGNAL DATABASE

The described methods were evaluated using the signals from the signal database of the cardiovascular system related signals. The database was created in the authors workplace in last few years and consists of oscillometric signals, ECG signals and photoplethysmography (PPG) signals. All signals from one person were measured synchronously. The signal database actually includes signals from more than 90 persons in wide age range. The signals were measured on two main groups of persons, in young healthy people aged about 23 years (university students) and in oldies aged between 65 and 90 years (seniors in one of the Prague's senior houses). The database offers sufficient width of various signals which represents all types and behaviours of oscillometric signals. [5]

V. RESULTS

Three methods for artifacts detection were compared in this study. Each signal in signal database was processed with each artifact detection method and all results were subjectively evaluated. For each method the sensitivity and reliability have been studied. The typical result of signal processing with correctly recognized artifacts is shown in the Fig. 6.

The method based on predicted heart rate detection and the standard deviation method are easy to use and produce reliable results for the most of signals. The standard deviation method seems to be better than the predicted heart rate detection method because of the better recognition of the

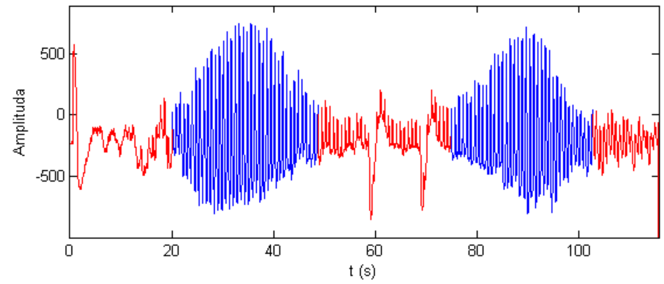

Fig. 6. Oscillometric pulsations with detected artifacts

oscillometric pulsations. Moreover this method is more rigorous to the quality of the signal and it seems as an advantage for the precise automated blood pressure determination.

The method based on the comparison with the ECG signal produces also very reliable results, but the significant disadvantage of this method is the necessity of synchronous ECG recording. In clinical practice the ECG is not recorded during the investigating of the blood pressure.

VI. CONCLUSION

The methods for artifacts detection in the oscillometric pulsations signal were investigated in this study. During the research thee methods were developed and described in this paper. The methods were evaluated using the signals from the database of cardiovascular system related signals and the results of signal processing were subjectively compared. The standard deviation method was indicated as the most suitable method from the described ones for automated detection of oscillometric signals artifacts.

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