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Detection algorithm for pacemaker impulses identification and localisation

Abstract. *The article concerns the description of effective pacemaker excitations detection and remover signal processing. The main goal was to provide reliable software module which will be implemented in real industrial cooperant's medical system. Considered DSP algorithm was tested with CSE database signals mixed with contaminations stated in EN 60601-2-51.*

Streszczenie. *Artykuł skupia się na prezentacji efektywnego algorytmu detekcji i usuwania impulsów kardiostymulatora z sygnałów EKG. Główny cel jaki sobie postawiono był ukierunkowany na opracowanie pewnego i stabilnego modułu softwarowego pozwalającego na wykorzystanie go w rzeczywistym systemie medycznym kooperanta z branży medycznej. Przedstawiony algorytm został dodatkowo przetestowany na danych zaburzonych sygnałami definiowanymi przez normę EN 60601-2-51. (**Algorytm do identyfikacji i lokalizacji impulsów kardiostymulatora**).*

Keywords: ECG signal automated analysis, PM detection, Removing PM impulses form ECG data, EN 60601-2-51
Słowa kluczowe: Automatyczna analiza sygnału EKG, Detekcja zespołów kardiostymulatora, Usuwanie zespołów kardiostymulatora z danych przeznaczonych do detekcji zespołów QRS, EN 60601-2-51

The paper deals with signal processing devoted to pacemaker excitations detection/removal from sampled ECG signals, used prior to the followed diagnosis oriented DSP.

With presented DSP two goals are achieved:

- The presence of active cardiac pacemaker can be detected for the case of the non-cooperative patient,
- The standard, diagnosis oriented following DSP (and ECG instrumentation) can be used for the wide spectrum of patients, independent of their heart treatment history (PM installations).

With the development in modern cardiology there is a growing implementation of extremely low-power, strong DSP equipped cardiac pacemakers which process and generate direct heart signals using OEM developed algorithms and methods [1,2]. Designed for battery life span (non-serviced mode) of 10+ years in spite of low voltage/low power supply they excite the heart with “high voltage output pulse generator” delivering to the pacing electrodes 0.5 ms long exciting impulses with the regulated/programmed level in the range of volts (0.5-7.5V [1]).

The paper deals with PM signals treatment which are accessible on the outer surface of skin for standard ECG instrumentation. The ideal, computer generated PM heart exciting impulses are transferred out from the heart trough the active body transfer function: they change shape and stay polluted with physiological signals (ECG) which serve for diagnostic purposes. More advanced pacer solutions use multi-phasic excitations and deliver ECG observations as discussed in [3,4] and defined in the standard ANSI/AAMI EC11. Sometimes the pacemaker activity is hardly observable (see Fig. 1 in [4]), even if high frequency (range of tens of kHz) ECG signal sampling rates are used. In modern ECG instrumentation for pacemaker oriented DSP such a high frequency sampling is recommended and used [4,5].

The processing considered in the paper is focused on low frequency sampled signals (the range of 1 kHz, much less then tens of kHz used in modern instrumentation [4]), as such a processing is implemented in the instrumentation developed by the medical cooperant. The developed algorithms were verified with the use of Matlab, transferred to C++ and implemented in Intel Atom processor system built in the electrocardiograph instrumentation.

Pacemaker Impulses (PMI) presence detection is important in the first stage of non-cooperative patient treatment (i.e. unconscious victim of the traffic accident). The paper focus was on the detection of relatively weak PMI for the case of phantom patient with the ECG heart rectangular impulse response of 0.5ms/2mV. Such the excitation forms the lowest energy monophasic pacer pulse specified by the ANSI/AAMI EC11 standard [5] so serves as good description of the weak pacemaker activity. The phantom patient signals were registered with the use of standard ECG sampling instrumentation, so stay noised as in figure 1a.

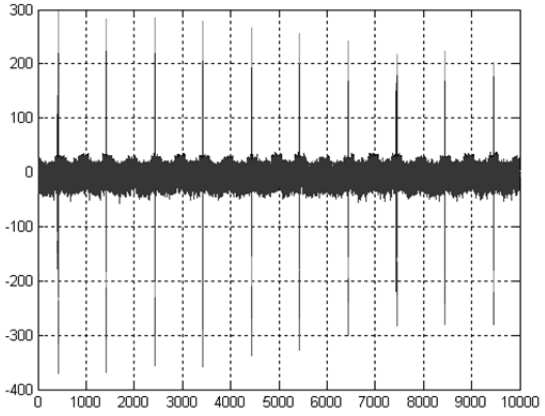

Fig. 1a. PMI testing signal used in DSP development

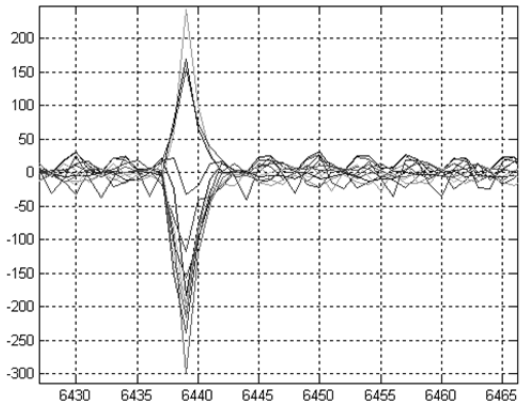

Fig. 1b. The details of the signal from figure1a - 7th excitation.

Due to the body transmittance and due to the low sampling rate only few samples long response signal is

observed (Fig. 1b), which should be separated from the background “noise”. As the background noise the full set of the ECG signals from The Common Standards of Electrocardiography (CSE) database [7], enriched with the standard defined pollutions proposed by EN 60601-2-51 standard [6] has been used (Fig.3).

The first test of developed Matlab scripts was performed on about 200 ECG records from The CSE Measurements sub database (files marked with MO_ - original record and MA_ - artificial records composed of corresponding original) with addition of noise proposed by normative document. All detected PMI was marked with the blue dots. There was a 100% certainty of finding pacemaker impulses.

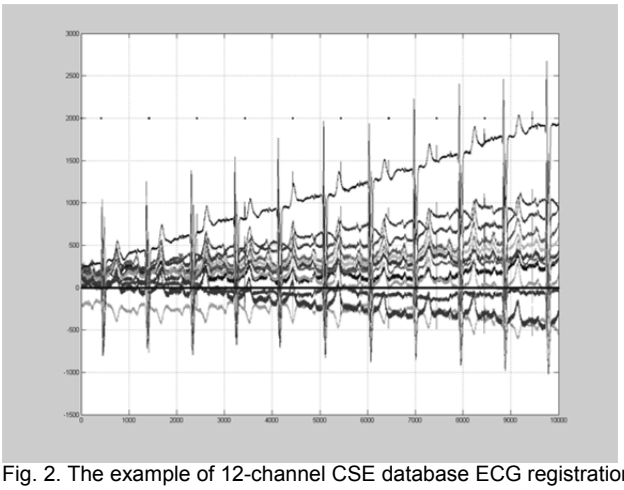

Fig. 2. The example of 12-channel CSE database ECG registration

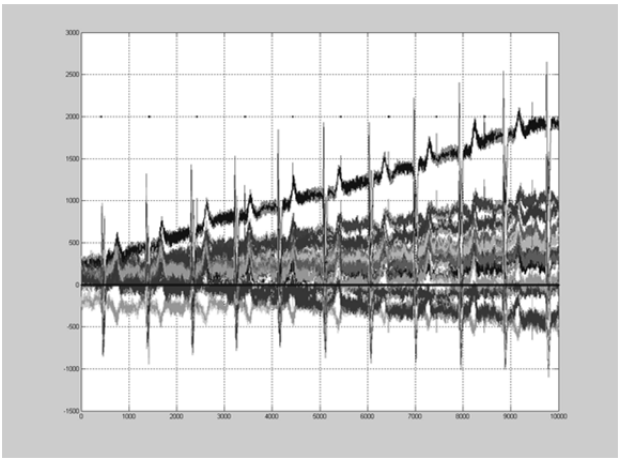

Fig. 3. ECG registration enriched with the full set of polluting signals according to the standard EN 60601-2-51: with the dots on the level of 2000 given/detected positions of PMI are marked

For the signals as in figure 3 the DSP has been elaborated, with the aim to separate PM excitations from the ECG + pollutions + noise background signal. As it has been mentioned, the sampling rate of 1 kHz was forced to be used, as no special higher sampling frequency PM processing signal path is planned to be implemented into developed ECG instrumentation.

The PMI excitations response signal consist of few samples of triangle-like shape (Fig. 1b), buried in high level noise (Fig. 3). From the signals as in figure 3 with the pacemaker detection DSP the internal “PMI excitation presence signal” as in figures 4 and 5 is obtained. For data from figure 4 the easiest PMI detection differential DSP was used – it resembles the Harleikson differential high-pass filter [3,6], and in spite of simplicity assures quite good s/n detection ratio. So simple algorithm performs well for the presented signals case however fails (few % of erroneous classifications) if the full set of ECG records is tested.

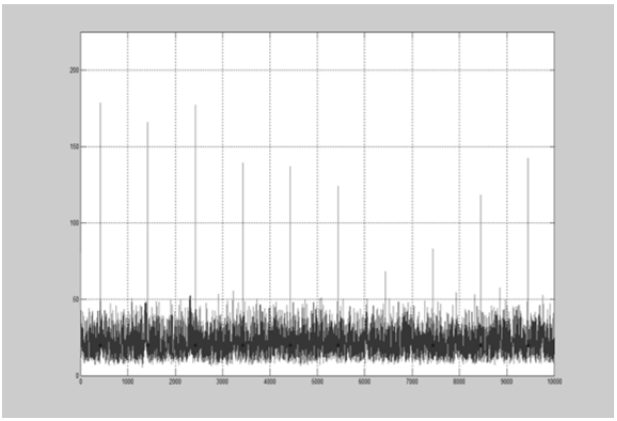

Fig.4. The PMI filter/detector output signal, differentiating DSP

A few different complexity detection algorithms were implemented in which different FIR/IIR digital filters were used for improving detector quality. Except of differentiation, the 4th order elliptic IIR, and high order FIR high-pass filters were tested with the final implementation of especially designed low order (8 coefficients) linear-phase FIR filter (Fig. 5).

The details of the design are not given here as form the copyright protected know-how of the ECG manufacturer. The final choice of linear phase FIR signal filtering (with time domain shifting property) simplifies the process of PMI elimination from the recorded ECG signal samples (Fig. 6), and makes the DSP time/stability efficient (fixed point arithmetic).

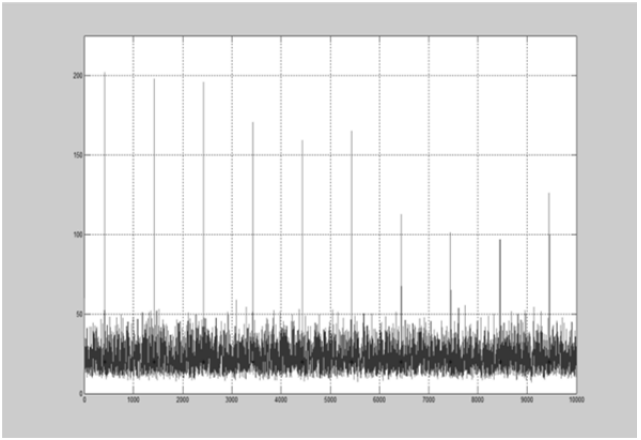

Fig. 5. The ECG instrumentation implemented low order FIR filter/PMI detector output signal

In the figures 4 and 5 the ECG records (Fig. 3) processing results are shown, which are based on two methods designed to exclude PM impulse components. As we see, in figure 4 the derivative based filter algorithm had poorer signal to noise ratio and there is no chance to detect correctly all impulses. The second one, based on a FIR filter (8th order) gave us the desired sureness that is able to detect properly all PMI in evaluated data. In both cases of used methods the detected impulses are marked with blue dots. The assay was performed on a source signal (ECG record) with additional noise signals stated by [6] (150Hz bandwidth white noise, 0.3 and 50 Hz artificial sinusoidal components and similar describer in the annex HH of [6]).

Basing on detector output information the PMI removal median filter was designed. It works on figure 5 signals from which dynamic decisive threshold is calculated with

the use of signal histogram. The threshold is directly applied to detector output signal from which potential positions of the PMI samples are marked. The additional adaptive marked samples processing is used to form continuous sets of samples which are finally treated as PMI affected. With the use of noised interpolation the PMI affected samples are rejected from the ECG signal and replaced with the interpolated ones (Fig. 6).

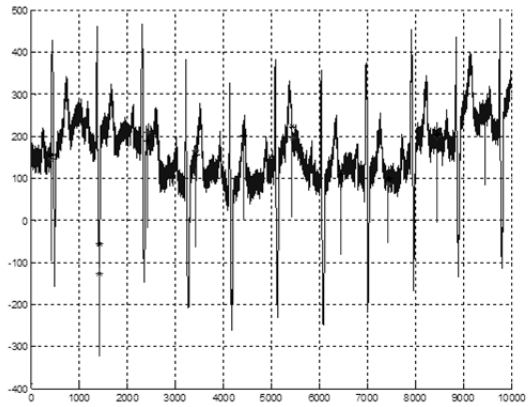

Fig. 6a. Typical ECG signal with no synchronized PMI detected (red) and removed (blue).

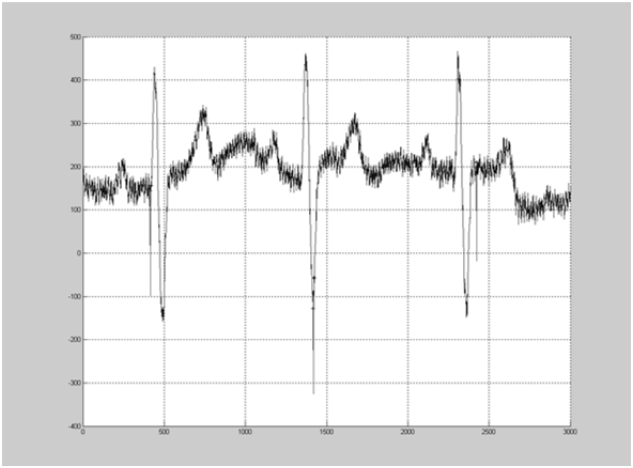

Fig. 6b. The details of the figure 6a.

Statistic test of the detector/remover performance on rich set of mixed combinations of hundreds of ECG data base signals and tens of phantom patient recorded PMI signals made on Matlab and embedded software verified the excellent quality of the detector for the border (0.5ms/2mV) and stronger PMI excitations. It was checked that detection and elimination of stronger (wider and/or higher) impulses is excellent, while the border excitations, even if not removed from the ECG records does not deteriorate the quality of the ECG processing software.

The presented algorithm was implemented in a pure C++ as a sub class of user modules container - a crucial part of the professional environment for the evaluation stage of developed algorithms. This module also contains QRS detector and additional DSP toolkits used to perform many normative test stated by the standards. The implementation was equipped with standardized method prototype and was included as a step in a larger detection process. The complete algorithm stored under C++ classes was tested automatically with more than 1700 10s CSE database ECG recordings with good effectiveness of finding PM impulses. No deterioration of post PMI processing for finding QRS complexes was observed too.

The open question is the detector performance for modern multiphase pacemakers generated signals to which the authors of the publication had no access [1]. That question touches the representativeness of the presented solution to the modern trends of medical instrumentation development.

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