Electronic System for Measuring and Optimization of Pacemaker Pulses

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Abstract: - A pacemaker is a small electronic device implanted under the skin near the collarbone. Pacemakers monitor the heart’s electrical activity. If the heart is beating too slowly or pausing too long between beats, the pacemaker will provide electrical impulses that stimulate the heart to beat. The pacemaker itself consists of a small box (the pulse generator) and one to three leads that are placed in the heart. This paper is devoted to electronic evaluating system which enables to find (in coordination with physician) an optimal pacemaker electrical impulses, e.g. pulse width, amplitude, delay and lead (or leads) position in heart to reducing the delivered energy. Inputs of electronic evaluating system are taken from ECG (electro cardio graph) and Finapres (system for continuous measuring of blood pressure). Results will be helpful for prolonging battery longevity and reducing the stimuli pain on patients with implantable medical devices. There are present results of different approach based on e.g. Hilbert and wavelet transformation, but one of the simplest and best was derived from heart rate variability and synchronization.

Key-Words: - blood pressure, evaluation system, ECG; frequency spectrum, heart pulse, Hilbert transformation, resynchronization, wavelet transformation.

1 Introduction

A pacemaker is a device which takes over the timing control of the ventricular contraction from the body’s natural system to ensure a rate fast enough to allow an active life for the patient. Pacemakers basically consist of a battery, a timing device and electrodes. The battery must be capable of supplying enough current to stimulate or excite the muscles in the ventricles and perhaps the atria for a number of years. As the heart beats approximately 70 times per minute, the battery life must be able to provide stimulation of $70 \times 60 \times 24 \times 365 \times$ the number of years it will survive. Therefore, the requirements for the battery are quite strict. Battery life is expected to be in the range of 3 - 10 years. Usually 4 to 6 volt pulses are used to excite the heart with duration of between 1.5 and 2.5 milliseconds. The electrical connection is made from the pacemaker to the patient’s heart by leads. These must be rigorously designed as they must withstand a large number of contractions which result in flexing throughout their lifetime. The electrodes are either implanted in the heart or stitched to the surface of the heart. As a temporary measure, electrodes may be floated into the ventricles of the heart in the same way as a catheter is introduced during blood pressure measurement. The pacemaker itself is situated underneath muscle in the chest; see Fig. 1 [1, 2].

Fig. 1. The body, heart, pacemaker (Pace) and pacemaker leads situation.

Pacemakers are used to treat several heart conditions: Slow heart rate (bradycardia). There are several types of bradycardia: Sinus bradycardia - the heart beats to slowly
**Sinus pause** - the heart pauses too long between beats

**Bradycardia/tachycardia syndrome** - the heart alternates between being too slow and too fast

**Heart block** - Impulses from the top chamber conduct only intermittently to the lower chamber, resulting in a slow effective heart rate.

**Heart failure** - This is a relatively new use for pacemakers and a special type of pacemaker, called a biventricular pacemaker, is used [3].

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The electronic evaluation system (EES) is used for real time signal processing from ECG and Finapres. The delays of the Finapres and ECG signals are different and must be balanced by means of EES. The results can be used for pacemaker optimization.

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Fig. 3. The frequency response (magnitude and phase) of 4-th order high-pass filter.

Fig. 4. The frequency response (magnitude and phase) of 4-th order high-pass and low-pass filter

### 2 System for data acquisition

The block diagram of whole measuring system is shown in Fig. 2. Finger arterial pressure was measured non-invasively with a Finapres [4, 5] (Finapres Medical Systems, Amsterdam, The Netherlands). This technique uses a cuff that is placed around the finger, a built-in photoelectric plethysmograph and a volume-clamp circuit that dynamically follows arterial pressure. This technique is well validated for measuring instantaneous changes in blood pressure. An ECG signal was also recorded. These signals were acquired through a 12 channel ECG. EES consists of analog conditioning systems ACO1 and ACO2 (amplifiers and analog low-pass filters) and
multichannel 12 bit analog/digital converters A/D1 and A/D2. The microcontroller (Freescale family) is used for digital signal pre-processing, digital filtering and transfer of the data from EES to personal computer (PC) by means of universal serial bus (USB). It is possible change some parameters, e.g. change sampling frequency etc. The amplitude and phase response of high-pass and band-pass filters are used in Fig. 3 and 4.

![Fig. 5. The iteration of wavelets "gaus4". The wavelets are shifted from bottom to top.](image)

![Fig. 6. The ECG signal (top) and blood pressure signal (bottom), signal without pacemaker pulses.](image)

![Fig. 7. The discrete time Hilbert transform of ECG signal, signal without pacemaker pulses.](image)

![Fig. 8. The frequency spectrum of ECG signal without pacemaker pulses.](image)

![Fig. 9. The WS of ECG signal without pacemaker pulses. Maximal energy is 3.10^-3.](image)

### 3 Methods

In heart failure, inadequate cardiac output response to exercise is a key driver of symptoms. In patients with badly coordinated ventricular and atrioventricular (AV) timings, cardiac resynchronization therapy (CRT) has been shown to improve these timings and thereby improve acute hemodynamics [1, 2] and consequently symptoms, morbidity, and ultimately mortality.[5, 6] Exactly which timings of AV and interventricular delay are best for an individual patient is difficult to establish with standard clinical methods. As a result, most centers do not routinely optimize these settings, and those that do usually limit the process to resting heart rates while the patient remains inactive. It is not known whether the optimal AV delay determined at rest corresponds to the optimal delay determined during exercise [7, 8, 9]. It is during exercise that it is likely to be the most important to program the AV delay to the most efficient setting for an individual patient. One technique, which has potential to permit optimization during exercise, is beat-by-beat noninvasive blood pressure, measured using a calibrated digital photoplethysmograph such
as the Finapres. We can use this method to identify the AV delay that corresponds to peak hemodynamics in the resting state, with the heart rate either left in the normal resting state or elevated by atrial pacing [10].

In this work are examples of measured signals without pacemaker pulses, with hidden pacemaker pulses, i.e. pulses of small amplitude, which are not visible on the ECG during and pulses visible in the ECG signal. In the last example, the pacemaker generated two pulses. It should be noted that the amplitude of the signals (ECG, pressure curve) is adapted for simultaneous display in one image and therefore is not to scale. It is usually displayed waveform in time domain, frequency spectrum, signal after Hilbert transform of ECG waveform (real and imaginary part) and wavelet scalogram. The continuous wavelet analysis to compute the scalogram of wavelet coefficients using the wavelet "gaus4" was used. WS - (wsaclogram), see Fig. 5, for wavelets.

![Fig. 10. The ECG signal (top) and blood pressure signal (bottom), signal with hidden pacemaker pulses.](image)

![Fig. 11. The discrete time Hilbert transform of ECG signal, signal with hidden pacemaker pulses.](image)

4 Results

Fig. 6 to 9 are an examples without pulses of pacemaker (signals in time domain, Hilbert transform, frequency spectrum and WS). Fig. 10 to 13, are examples of hidden pulses, Fig. 14 to 17 with a single pulse, and Fig. 18 to 21, even with two pulses. This is a special situation. Some pacemakers can watch themselves whether stimulation is effective (in the English jargon is called "if it captured"). After application of the stimulus is usually a current of small capacitor is applied to the electrode polarization cancellation and this is set to a shooting mode. If you own records heart activity is OK, everything is fine. If not, then after about 70 ms other stimulus with high energy is applied to ensure stimulation. The lowest voltage that does not require an application backup pulse is the threshold voltage. From the figures you can see that shape of the pulse of pacemaker, i.e. amplitude and width, is also reflected in the Hilbert transform ECG signal. This does not possible apply to hidden pulses.
Fig. 14. The ECG signal (top) and blood pressure signal (bottom), with pacemaker pulses.

Fig. 15. The discrete time Hilbert transform of ECG signal, with pacemaker pulses.

Fig. 16. The frequency spectrum of ECG signal with pacemaker pulses.

Fig. 17. The WS of ECG signal with pacemaker pulses. Maximal energy is $14 \times 10^{-4}$

Fig. 18. The ECG signal (top) and blood pressure signal (bottom), signal with 2 pacemaker pulses.

Fig. 19. The discrete time Hilbert transform of ECG signal, signal with 2 pacemaker pulses.

Fig. 20. The frequency spectrum of ECG signal with 2 pacemaker pulses.

Fig. 21. The WS of ECG signal with pacemaker pulses. Maximal energy is $5.5 \times 10^{-4}$
According to the experimental results, however, heart rate variability can be used for proof of sufficient pacemaker pulse energy. In case of insufficient pacemaker function (or for persons without pacemaker) usually the distance QRS complexes are changing, in case of successful pacemaker function, however, the heart rate is synchronized with the pulses of the pacemaker, which are regular and distance QRS complexes is nearly constant. Fig. 22 shows the principle of generation of the pulse on falling edge of the QRS complex. In Fig. 23, the evaluation of variation, in case of insufficient pacemaker function signal (signal according Fig. 6). On the other hand, Fig. 24 shows the low variability of the signal (signal according to Fig. 10) if the pacemaker function is sufficient, but pulses are hidden (low energy of pulses is sufficient).

Fig. 22. Derivation of pulses on falling edge of ECG signal, software generated (with adaptive threshold).

Fig. 23. Example of measured heart rate variability without pacemaker pulses, mean value = 75.3; standard deviation =10.2.

Fig. 24. Example of measured heart rate variability with pacemaker pulses, mean value = 70.4; standard deviation = 0.45

5 Conclusions
In this paper, was described an evaluation system which enables verification function of pacemakers with different energy values of pulses (pulse width and amplitude) and phase and also the lead (or leads) position in heart. Using this system and software, the doctor can find optimal values of pacemaker's pulses and thus reduce the energy consumption of such a pacemaker, its longer function, etc.

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