Pacemaker Leads Place Optimization Based on Vectorcardiography Signal Processing

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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 with battery) and usually two leads that are placed in the heart and most important are right places of leads tips. This paper is devoted to system and software which can support physician find almost optimal place of pacemaker lead's tips in heart. Results will be helpful for prolonging battery longevity and reducing the stimuli pain on patients with implantable medical devices.**

Keywords – pacemaker; perimeter; 3-D ECG;; heart; resynchronization; stimulation; vectorcardiography.

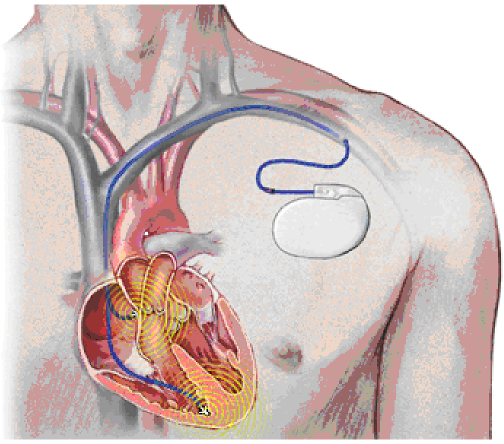

Fig. 1. The body, heart, pacemaker (Pace) and pacemaker leads situation

I. 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. 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, see Fig. 1. 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.

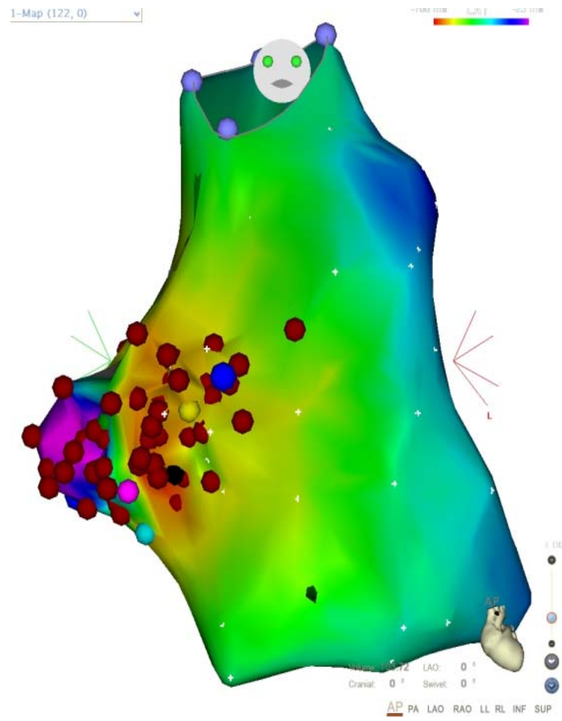

Fig. 2. The example of 3-dimensional map of heart of the patient

The increasing prevalence of devices specifically designed to improve timings within the cardiac cycle (i.e. cardiac resynchronization therapy) has created a clinical need to accurately monitor the effects on cardiac performance of changes to pacing configurations. Optimization of pacemaker atrioventricular (AV) and interventricular delay settings for individual patients maximizes the hemodynamic benefit of pacing [1–4] and might be approached by monitoring stroke volume or BP, while changes are made to the settings. The most widely used quantitative approach for pacemaker optimization uses echocardiography to measure cardiac output using Doppler; however, this is time consuming, relies on experienced operators, and has limited reproducibility [3].

This research has been supported by the European Regional Development Fund and the Ministry of Education, Youth and Sports of the Czech Republic under the Regional Innovation Centre for Electrical Engineering, project No. CZ.1.05/2.1.00/03.0094 and by the internal project SGS-2015-002.
ISBN 978-80-261-0386-8, © University of West Bohemia, 2015

II. METHODS

For AV optimization of cardiac resynchronization therapy (CRT) in this paper is based on evaluation of vectorcardiographic signal. For the signal acquisition from the patient, the non-invasive system CARTO is used for the reconstruction of map.12-electrodes are applied to the patient’s torso and connected to the non-invasive imaging system and surface potentials are recorded [4, 5, 6]. The 3D epicardial bicameral (atria or/and ventricles) geometries are reconstructed from segmental CT images. The relative positions of body surface electrodes can be visualized on the torso geometry. The system reconstructs epicardial potentials, unipolar electrograms, and activation maps from torso potentials [7 - 12].

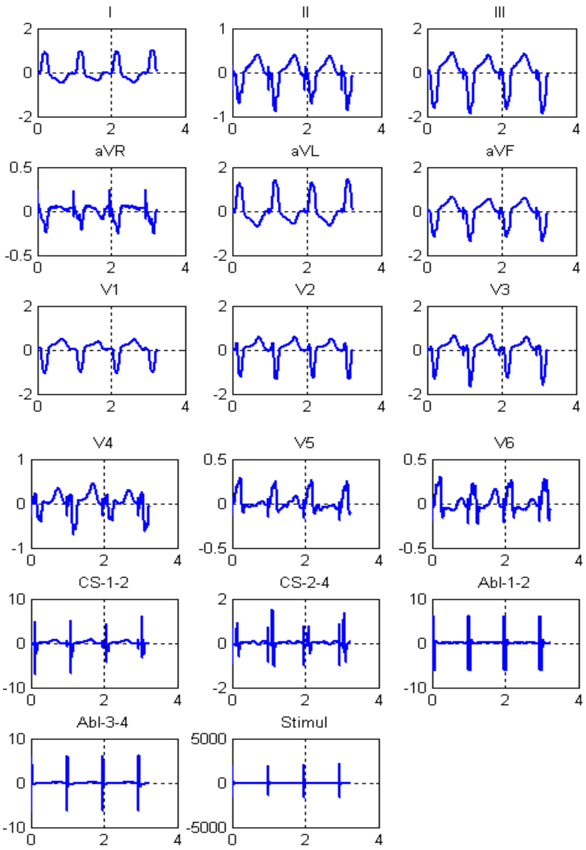

Fig. 3. The example of ECG and stimulation signals of the patient for one point of heart map (see Fig. 2)

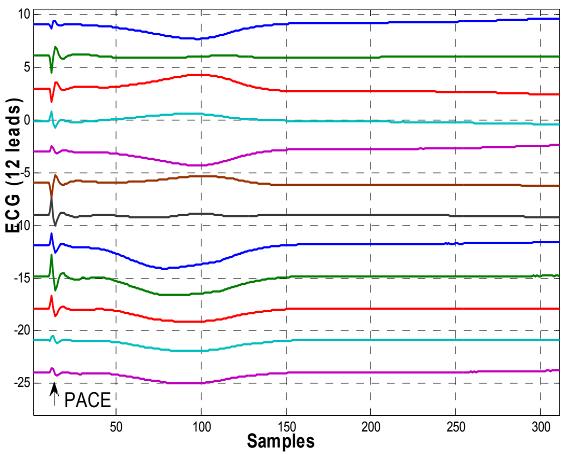

Fig. 4. The one period of raw 12 leads ECG signals with pacemaker stimulation pulse (signed as PACE).

The example 3-dimensional map of patient is shown in Fig. 2. The small circles are successive positions of catheter. For each of this position the 12 leads ECG signals were measured sampled and stored in memory (together with stimulation signals) of the personal computer (PC). The example is shown in Fig. 3.

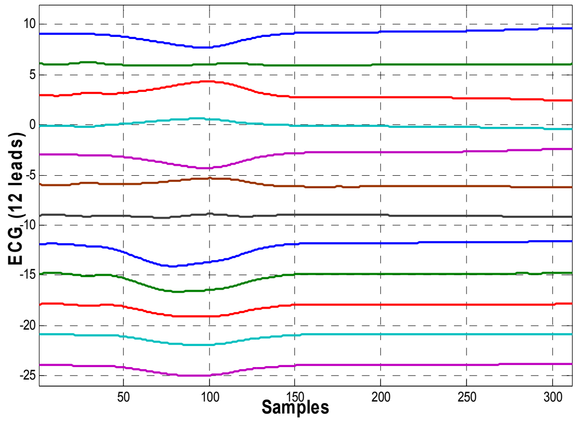

Fig. 5. The 12 leads ECG signals (from Fig. 4) after filtration by 6-th order Butterworth filter. The stimulation pulses from pacemaker are removed

From 12 leads ECG signals the one period is taken for next processing. Raw signal (without filtration) is displayed in Fig. 4. This signal is filtered by 6-th order Butterworth filter for stimulation pulses suppression. The filtered signal is presented in Fig. 5. From filtered signals the 3 dimensional ECG signal is calculated

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = D^{-1} \begin{bmatrix} V_1 \\ \vdots \\ V_6 \\ I \\ II \end{bmatrix} \qquad (1)$$

where D is Dower matrix [13, 14]

$$D^{-1} = \begin{pmatrix} -0.172 & -0.073 & 0.122 & 0.231 & 0.239 & 0.193 & 0.156 & -0.009 \\ 0.057 & -0.019 & -0.106 & -0.022 & 0.040 & 0.048 & -0.227 & 0.886 \\ -0.228 & -0.310 & -0.245 & -0.063 & 0.054 & 0.108 & 0.021 & 0.102 \end{pmatrix} \qquad (2)$$

The example of 3-D ECG signal calculated by (1) is shown in Fig. 6 and signal area in Fig. 7.

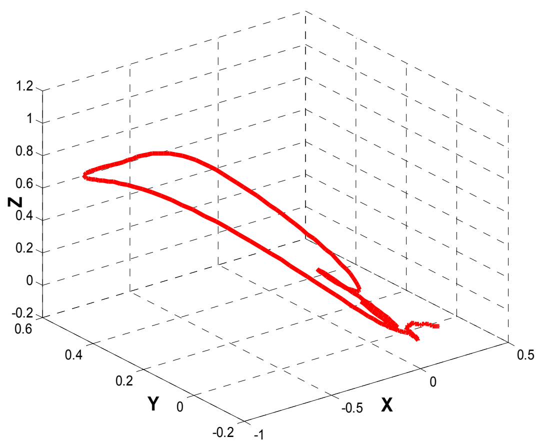

Fig. 6. The example 3-D ECG calculated by (1)

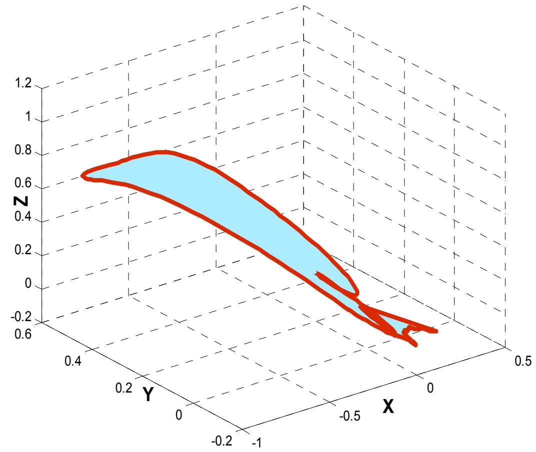

Fig. 7. The area and perimeter (L=4.11) of 3 D-ECG signal.

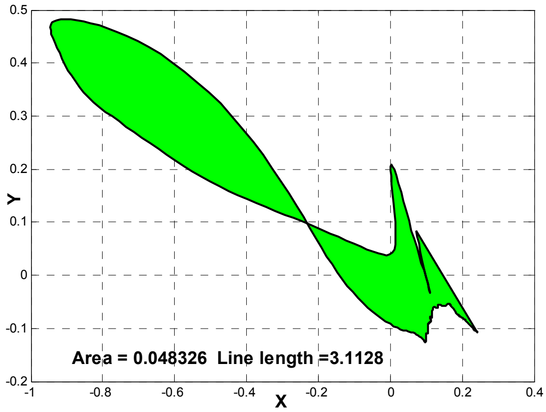

Fig. 8. The projection of 3-D ECG signal to 2-D XY area

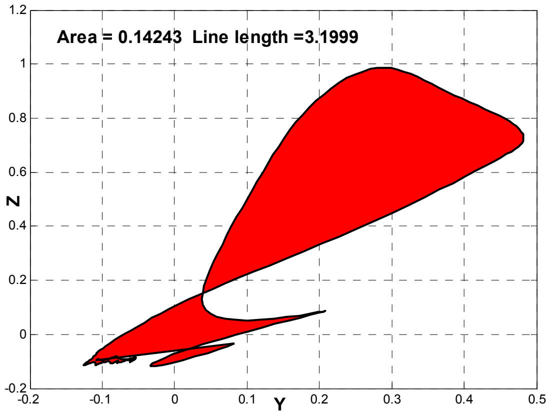

Fig. 9. The projection of 3-D ECG signal to 2D YZ area

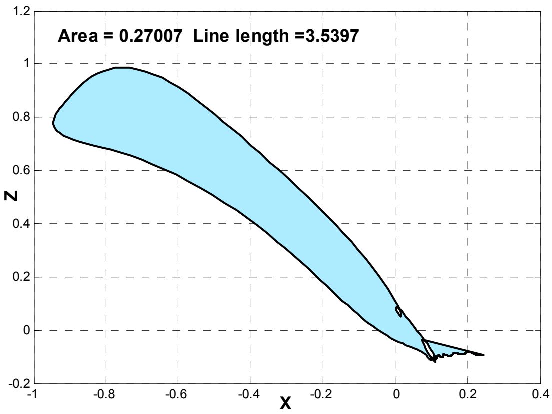

Fig. 10. The projection of 3 D-ECG signal to 2D XZ area

III. Results

The previous approach was used for evaluation of ECG signal by means of "area". The projection of 3-D signal (Fig. 7) on separate areas of XY, YZ and XZ is shown in Fig. 8 (projection XY), Fig. 9 (projection YZ) and Fig. 10 (projection YZ). In Fig. 8 – 10, the area and length of the line for 1 period of filtered ECG (stimulation pulses are removed) is presented in Tab. I.

TABLE I. Area and length of perimeter for projection ECG in XY, YZ and XZ

Projection	Area	Perimeter length
XY	0.05	3.1
YZ	0.14	3.2
XZ	0.27	3.5

From previous results can be seen, that area is changed more rapidly than lengths of the ECG perimeter. The lengths of perimeter for 3 dimensional ECG signals for 10 patients are shown in Tab. II. The patient's No. 2 and 5 are out of mean value (approx. 4±0.6 for normalized 1 period of 3-D ECG) and amplitude of stimulation pulse (generated by pacemaker) or place of PACE electrodes in heart can be changed for optimal function.

TABLE II. Length of Perimetr of 3 D-ECG (for 10 patients)

Patient No.	Perimeter
1	4.07
2	**→ 8.50**
3	3.68
4	4.00
5	**→ 6.56**
6	4.11
7	3.65
8	4.57
9	3.58
10	5.52

According to the experimental results, the optimization of pacemaker's pulse or pacemakers leads places in heart can be recommended. From result of the study (so fare only 10 patients with pacemakers) can be shown, that areas of ECG and 3-D ECG perimeter lengths probably has some almost optimal value. The physician can changed places of pacemaker's leads, amplitudes of pulses or delay for optimal function.

IV. Conclusion

In this paper, the evaluation system based on ECG signal processing was described. The method is based on 3 dimensional ECG projections in three 2 dimensional planes, area of the projections and length of 3-D ECG perimeter. Using this system and software, the physician can find optimal values of pacemaker's pulses and thus reduce the energy consumption of such a pacemaker, its longer function, etc. So fare sufficient number of patent was not tested, therefore further studies are necessary to validate this study.

ACKNOWLEDGMENT

This work was supported by the project Ministry of Health, Czech Republic for conceptual development of research organization 00669806—Faculty Hospital in Pilsen, Czech Republic and by the European Regional Development Fund and the Ministry of Education, Youth and Sports of the Czech Republic under the Regional Innovation Centre for Electrical Engineering (RICE), project No. CZ.1.05/2.1.00/03.0094 and by the internal project SGS-2015-002..

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