AUTOMATED LAPLACIAN ECG MOMENT OF ACTIVATION DETERMINATION ALGORITHM DURING PACING

WALTER G. BESIO
Department of Biomedical Engineering
Louisiana Tech University
Ruston, LA-71270, USA

ASHA K KOTA
Department of Computer Science
Louisiana Tech University
Ruston, LA-71270, USA

Abstract—Laplacian ECG (LECG) is a unique technique for detecting cardiac electrical activity. The recurrent property of ECG is exploited by this unique algorithm for the detection of the QRS complexes by cross (auto) correlation. Further, the algorithm calculates the time offset of the LECG signal from the ECG peak. This offset is termed the moment of activation (MoA) and is determined automatically. LECG body surface isochronal maps depict information about cardiac activation patterns. Besio related the ECG QRS complex to the LECG isochrones by mapping the body surface MoAs. This unique automated algorithm during pacing, detected QRS complexes correctly 99.3% and mapped isochrones.

1 Introduction

Laplacian ECG (LECG) is a unique high-resolution technique for detecting cardiac electrical activity. LECG records the second order spatial derivative, which enhances information that may not be apparent in normal ECG. It sharpens the image.

We record LECG from an array of LECG sensors located on the body surface over the heart area. When depolarization spreads over the surface of the heart this activity reaches the surface below sensors in an array at different times. The time offset of this wave front relative to that of ECG we termed moment of activation (MoA) shown in Fig. 1. Our algorithm determines the MoA's automatically, for each of thirty-five sensors, decreasing the time taken to generate body surface isochornal maps and removing operator subjectivity.

Duration of the QRS complex is a key characteristic of ECG signals used in analysis and classification. It's duration is approximately 100ms [4] in the human heartbeat. The ECG signal is recurrent approximately every 800ms in the healthy humans but varies between subjects. Laplacian ECG MoA maps differ between subjects and have been shown to poses clinical value [1]. By utilizing a database of MoA maps, subjects can be screened for cardiac diseases.

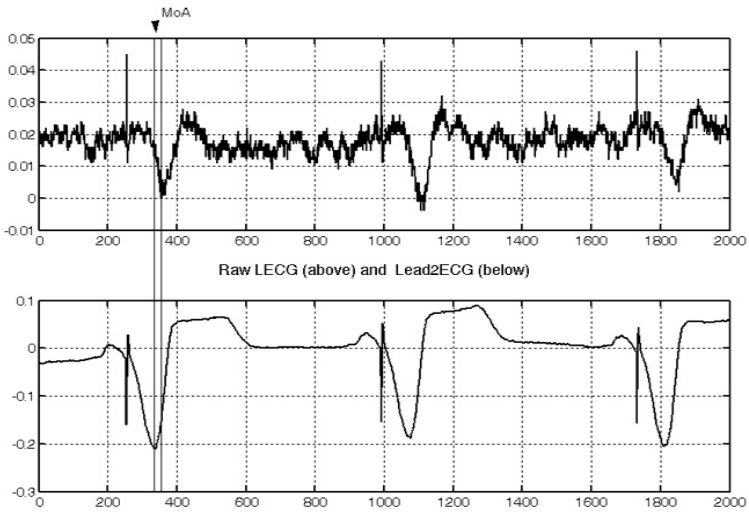

Fig.1 Time offset from Lead II ECG peak to LECG correlation, the MoA.

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2. Methodology

All data were recorded under the guidelines of our institutional review board approved protocol. Laplacian ECG was recorded for 30 seconds from active Laplacian sensors at thirty-five different recording sites on the surface of human subject's chests. Lead II ECG was recorded and used for synchronization. These signals were band pass filtered and sampled at 1000 samples per second. We developed an adaptive algorithm in Matlab that detects QRS complexs during pacing and automatically determines MoAs. The algorithm uses the following techniques:

- Differentiation: Detects first QRS peak by differentiation of the signal and applying a threshold. Then that QRS complex will be used as a template.
- Cross-correlation: Detects the remaining QRS peaks and also detects where over time in the Laplacian channel the cardiac activity has occurred to determine MoAs using cross correlation. The correlation between two signals (cross correlation) is the standard approach to feature detection [2, 3]. We utilized the cross correlation as a match filter for automatically detecting the QRS peaks and MoA's. The cross correlation function used is:

$$\frac{\sum (X_i - M_x)(Y_i - M_y)}{\sum [X_i - M_x]^2 \sum [Y_i - M_y]^2} \qquad \text{Eq. (1)}$$

where X and Y are the two signals of interest and M is the mean of the signal.

The first QRS complex is detected by differentiation and the remaining using autocorrelation. A 200 point window centered on the location with the highest differentiate is used as a template to match filter detect the remaining QRS complexes in the recording. This template is cross-correlated with the signal in 800ms windows. The algorithm takes the location with the highest correlation coefficient as the R-wave peak. The 200-point window is an adaptive mechanism to update the match filter template with each new QRS complex.

Surface recordings are subject to noise contamination. The Laplacian signal must be filtered prior to determining the temporal location of the cardiac activity. A Weiner adaptive filter similar to one used by Bertrand et. al. [5] is implemented to process the Laplacian signal. The ECG QRS complexes are cross correlated with the filtered Laplacian ECG to determine MoAs. Isochronal maps are formed from the MoAs. Fig. 2 is such an isochronal MoA map. This is a body surface map from a person with a pacemaker active. The contours show one area of early activity and two later areas.

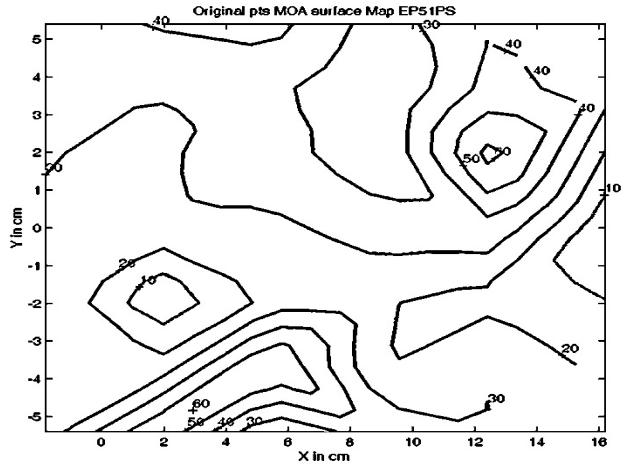

Fig.2 Isochronal body surface map during pacing. Location A is the earliest occurrence while B and C are later.

3. Results

The efficiency of the algorithm has been tested on two data sets. The first set is simulated data. The simulated data consists of the same QRS complex repeated, but varying the amount of noise (0 to 75 percent of white noise) and the time

location (0 to ± 100) of the complexes. The MoAs were recognized correctly 100% of the time with noise levels below ten percent. For a typical offset of 10ms the MoA means were from 9.979 to 10.245, standard deviations were from 0.059 to 0.498 with noise from 10% to 75% respectively. The second set of data was recorded from subjects with active pacemakers. The pacemaker caused much artifact that would not normally be discriminated from QRS complexes with common threshold detection methods. Four typical subjects were tested and the pattern matching algorithm correctly detected 2587 out of 2604 QRS complexes in our dataset for a percentage correct of 99.34.

4. Discussion and Conclusion

The algorithm automatically detected MoAs correctly even with up to 75% additive noise and is adaptive to small variations in the signal. The algorithm has high detection and low false positive rates even during pacing. Presently the algorithm can detect QRS complexes that are between 400ms and 1200ms apart with high efficiency. In the future the algorithm can be made adaptive to variable heart rate by adjusting the size of the windows automatically, which will improve the detection of QRS complexes.

Acknowledgment

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