Discrete Wavelet Transform-based Baseline Wandering Removal for High Resolution Electrocardiogram

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ABSTRACT

A High Resolution Electrocardiogram (HRECG) is used as a noninvasive technique for detecting very small cardiac signals called Ventricular Late Potentials (VLPs) from patients with myocardial infarction. One of the most common problems of High Resolution ECG recordings is the baseline wandering in the ECG signals during data collection. In this paper, the discrete wavelet transform (DWT) at level 10 was applied to the HRECG signals and decomposition of the HRECG signals was performed. The baseline wandering was found in the low frequency components of the approximation A10 of the DWT. Removal of the baseline wandering can be achieved by a reconstruction of the DWT without A10. As a result, a detection of VLPs was obtained with high performance.

Keywords: discrete wavelet transform; high resolution electrocardiogram; ventricular late potentials

1. INTRODUCTION

Patients with heart disease have any disturbance in the depolarization conduction system within the myocardium muscle, resulting in very small cardiac signals called Ventricular Late Potentials. VLPs may be found in patients with myocardial infarction. The studies in clinical cardiology have shown that the occurrence of VLPs is prevalent in post-myocardial infarction (MI) patients at risk of developing ventricular tachycardia (VT). Consequently, the detection of VLPs has become a topic of great interest in cardiology for over three decades. The standard method for detecting VLPs was proposed by Simson [1]. It is difficult to detect VLPs because they are normally masked by noise and motion artifact, including baseline wandering. Hence, removal of baseline wandering makes analysis of VLPs easier and improves poor signal quality. The VLPs can be revealed from the High Resolution ECG. In the study of VLPs, HRECG is recorded from X, Y, and Z leads on the body surface of the patient.

The Simson method consists of three main steps: ECG averaging, ECG filtering, and vector magnitude combination. In a signal averaging technique, noise will be reduced, whereas the VLPs will be enhanced. Each of the XYZ leads is averaged. VLPs are low-amplitude, high-frequency signals. High pass filtering is thus required to remove low frequency components. A high pass filter with a cutoff frequency of 40 Hz is used. Each filtered XYZ lead is then combined to form a vector magnitude.

Three parameter measurements are computed from the vector magnitude and they are used to identify the presence of the VLP activity for classification of patients with and without VLPs. These are the filtered QRS duration (QRSdur), the root mean square voltage (RMS) of the terminal 40 ms of the filtered QRS complex (RMS40), and the duration of the terminal QRS complex voltage under 40 µV (LAS40). The presence of VLPs is characterized as follows: (1) QRSdur > 114 ms, (2) RMS40 < 20 µV, and (3) LAS40 > 38 ms. It is proposed that of these three measurements at least two criteria above should be fulfilled in order to identify that the patient has VLPs.

In this study, the discrete wavelet transform was utilized to decompose the High Resolution ECG and then the low frequency components related to the ECG baseline wandering were removed for each XYZ lead. The resulting ECG leads were further processed to detect the VLPs, as already described in the Simson method.

2. METHODOLOGY

2.1 ECG Data

The ECG signals used in this study were taken from the Physionet which is a web-based resource for free access to study of physiological signals [2]. The database contains records from subjects with healthy controls and myocardial infarction. The signals were digitized at 1000 samples per second with 16 bit resolution.

2.2 Discrete Wavelet Transform

The discrete wavelet transform has become a powerful technique in biomedical signal processing [3,4,5].
It uses the wavelet function and scaling function to analyze the signal of interest. In discrete wavelet transform analysis, a given signal \( s(t) \) is decomposed on multi-resolution levels as follows:

\[
s(t) = \sum_{k=-\infty}^{\infty} c_j(k) \phi_{j,k}(t) + \sum_{j=1}^{J} \sum_{k=-\infty}^{\infty} d_j(k) \psi_{j,k}(t)
\]

where \( \psi_{j,k}(t) \) is the wavelet function and \( \phi_{j,k}(t) \) is the scaling function. They are defined as:

\[
\phi_{j,k}(t) = 2^{j/2} \phi(2^j t - k)
\]

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\]

In wavelet analysis, \( d_j(k) \) and \( c_j(k) \) are computed by using the filtering operation. \( d_j(k) \) denotes the detailed signals or wavelet coefficients and \( c_j(k) \) represents the approximated signals or scaling coefficients at each level of decomposition. The DWT has the capability of decomposing a signal of interest into an approximation and detail information. It can thus analyze the signal at different frequency ranges with different resolutions. The DWT is implemented by means of a pair of digital filter banks where the signal is successively decomposed. The two filters are a high pass filter and a low pass filter. Scaling function and wavelet function are associated with low pass and high pass filters, respectively, and they are used in the DWT algorithm. These filters provide the decomposition of the signal with different frequency bands by recursively applying filters to the signal. The signal is then split equally into its high and low frequency components, called details and approximations, respectively. In the DWT algorithm, the input signal \( s(t) \) is first passed through the high pass filter and low pass filter, and subsequently the outputs of both filters are decimated by a factor of two. The input signal to the filters is the HRECG. The high pass filtered data set is the detail coefficients at level 1 and the low pass filtered data set is the approximation coefficients at level 1. This process can continue for further decomposition at level 2,3,4, until the limit of data length is reached. In addition, it is possible to reconstruct the original signal from the approximation and detail coefficients.

2.3 Data Analysis

The ECG signals of XYZ leads were decomposed by the DWT at level 10. The approximations (A) and details (D) at level 1–10 were computed for each X, Y, and Z lead. The DWT decomposition three at level 10 is shown in Figure 1. In this paper, the Daubechies 2 wavelet was used because this mother wavelet has already been investigated for good analysis of the high resolution electrocardiogram [6, 7].

3. RESULTS

Figure 2 shows the ECG signals from a subject with myocardial infraction for X, Y, and Z leads, respectively. It can be seen that baseline wandering appears in each X, Y, and Z lead. In Figure 3, it displays a close up of the ECG segments in Figure 2 at samples between 25000 and 35000 for X, Y, and Z leads, respectively. It illustrates the effect of the baseline wandering on the ECG signals and thus it makes the R wave detection difficult for the analysis procedure of VLPs. The DWT decomposition was applied to the ECG signals for each X, Y, and Z lead and then the approximations and details at level 1–10 were computed. The approximation signals in DWT decomposition of the ECG signals were used to identify the baseline wandering.

In Figure 4a and b, it plots the original signal of the X lead and its level 10 approximation (A10). It can be observed that the activity of baseline wandering was found in the A10, since the baseline wandering is low frequency activity. In order to remove the baseline wandering from the ECG signals, the synthesis process of the inverse DWT was performed. In this paper, the original signal was reconstructed without the A10 information and the synthesized result is shown in Figure 4c. Figures 5 and 6 demonstrate the results of DWT decomposition and synthesis at level 10 for the Y and Z leads, respectively. As a result, it exhibits the ECG signals after baseline wandering removal, as shown in Figures 4c, 5c, and 6c for the XYZ leads, respectively. As compared to Figure 3, Figure 7 indicates the zoomed portions of the synthesized XYZ leads in Figures 4c, 5c, and 6c at samples between 25000 and 35000.
Following baseline wandering removal, the synthesized XYZ leads were used to form the vector magnitude, as recommended in the Simson method. The three parameter measurements were then computed. Figure 8 displays the vector magnitude of the myocardial infarction patient with the three parameter measurements. The three parameters of this patient were the QRS duration of 158 ms, RMS40 of 8.04 µV, and LAS40 of 79 ms. It means that this patient showed the presence of VLPs. Moreover, Figure 9 illustrates the ECG signals from a healthy subject for X, Y, and Z leads, respectively. It can be observed that baseline wandering occurred in the ECG signals.

The Y lead showed the large baseline wandering. The level 10 DWT decomposition and reconstruction of the ECG signals in Figure 9 were performed, as mentioned above. As a result, Figure 10 displays the ECG signals with removal of baseline wandering for the XYZ leads, respectively. It can be seen that removal of baseline wandering of X, Y, and Z leads can be achieved. The baseline was very stable for each lead. The resulting XYZ leads were then applied to the Simson method and the vector magnitude was computed. In Figure 11, it exhibits the vector magnitude with the three parameter measurements. The three parameters were the QRS duration of 102 ms, RMS40 of 22.5 µV, and LAS40 of 34 ms, suggesting that this patient did not show the presence of VLPs.

In addition, another subject with myocardial infarction was investigated for the DWT-based baseline wandering removal. Figure 12 shows the ECG signals with baseline wandering for X, Y, and Z leads of this subject. In Figure 13, it plots the reconstructed XYZ leads after baseline wandering removal for X, Y, and Z leads, respectively. Figure 14 reveals the presence of VLPs computed from the vector magnitude of the synthesized XYZ leads in Figure 13.

Furthermore, another normal subject was studied for the removal of ECG baseline wandering. This subject displays the ECG baseline wandering, as shown in Figure 15. Figures 16 and 17 illustrate the synthesized XYZ leads and the resulting vector magnitude with the three parameters, respectively.

4. DISCUSSION AND CONCLUSION

 Patients who have suffered myocardial infarction may undergo future life-threatening arrhythmias. It is documented that VLPs are related to patients with myocardial infarction and they have been successfully
One problem of HRECG recordings is baseline wandering which may be caused by large movement of the chest during breathing and it may make analysis of VLPs inaccurate. In order to accurately detect the VLPs, it is necessary to obtain good quality of the HRECG signals.

This study has attempted to investigate any possibility of using the DWT decomposition and reconstruction for removal of baseline wandering to detect VLPs. Baseline wandering is a low-frequency activity in the ECG signals. Its frequency component is usually in the range below 1 Hz and it mainly appears in the approximation A10 of the DWT. Thus, the A10 will be subtracted from the original HRECG signal in the reconstruction process. The approximation A10 would be appropriate for removal of baseline wandering. In conclusion, the DWT-based removal of baseline wandering in the ECG signals was shown to be useful in revealing the VLP activity. It may improve the diagnostic performance of the VLPs detection.

References
Fig. 9: Normal ECG signals with baseline wandering of X, Y, and Z leads.

Fig. 10: The synthesized XYZ leads after baseline wandering removal for X, Y, and Z leads, respectively.

Fig. 11: The vector magnitude of the control healthy subject.

Fig. 12: ECG signals with baseline wandering from the myocardial infraction patient.

Fig. 13: The synthesized XYZ leads after baseline wandering removal in Figure 12.

Fig. 14: The vector magnitude computed from the synthesized XYZ leads in Figure 13.
Fig. 15: Normal ECG signals with baseline wandering.

Fig. 16: The synthesized XYZ leads after baseline wandering removal in Figure 15.

Fig. 17: The vector magnitude computed from the synthesized XYZ leads in Figure 16.


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