Detecting ECG Characteristic Points by Novel Hybrid Wavelet Transforms: An Evaluation of Clinical SCP-ECG Database

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Abstract

The morphologic analyses of ECG waveforms have been used often by physicians. A robust ECG delineator that can identify the characteristic points under different kinds of diseases with various noise interferences is crucial in clinical ECG waveform analyses. In this study, hybrid wavelet transforms (WT) were used to develop a tool for ECG delineation. The decomposed detail levels of d4 and d3 based on the Haar discrete WT were used to locate the QRS complex. After finding the R wave, the QRS duration, the onset- and end-points of P and T waves were identified by a multilevel Haar wavelet packet analysis in a moving search window. Approximately 10000 beats based on four categories of 12-lead ECG records including normal (N), acute myocardial ischemia (AMI), hyperkalemia (HK), and atrial fibrillation (AF) were randomly selected from the previous established SCP-ECG database to evaluate the algorithms on detecting QRS complex and delineation. The results showed (1) the sensitivities of QRS complex detection were 100%, 99.51%, 99.72%, and 99.65% in N, AMI, HK, and AF ECG records with various noise interferences respectively; (2) the positive predictivities of QRS complex detection were 100%, 99.46%, 99.66%, and 99.88% in the previous 4 categories of ECG records; and (3) the onset- and end-points of P, T waves can also be detected based on wavelet packet analyses when signals were interfered by noise and baseline wandering. The algorithms developed in this study can be applied directly onto clinical 12-lead ECG records for waveform analyses with their high accuracy on characteristic point detection in various leads and diseases. They can also be applied onto Holter ECG systems for QRS detection because of their robust ability for single-lead detection.

1. Introduction

The automatic identification of E.C.G. characteristic points including P wave, T wave, and QRS complex has been crucial for developing E.C.G. diagnosis system. As most E.C.G. diagnoses were based on the morphology of E.C.G. signals, to develop a robust E.C.G delineator to identify the characteristics of E.C.G. is critical. Specially, the accurate detection of R-wave in noisy interferences is very important to develop the Holter system in medical industry. In 1985, Pan and Tompkins [1] used digital filters to detect QRS from MIT/BIH E.C.G. database with the 93% accuracy. The Tompkins's method has been applied extensively in the medical industry since then. In 1995, Li et al. [2] successfully used continuous wavelet transform to identify the characteristic points of E.C.G. from MIT/BIH database. In Li's study, wavelet transform was demonstrated by its superior ability to detect signals in noisy interferences. However, the continuous wavelet transforms of E.C.G. could result in large oscillations of coefficients around the R wave. These large oscillations can lead to difficulties in detecting the R wave, because there is no proper threshold to identify the R wave which can induce one pair of large positive and negative peaks. As shown in Figure 1, non-R wave induced several large oscillated peaks around R wave after the wavelet transform. In this study, a novel hybrid wavelet transform was developed to avoid the difficulty of R wave detection resulted from the continuous wavelet.

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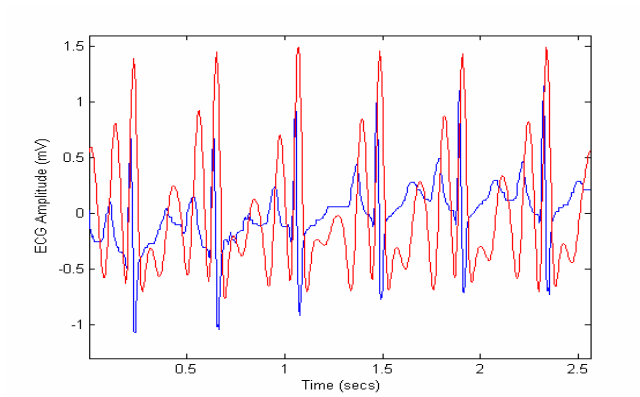

Figure 1. Non-R waves induced large positive and negative peaks abound R waves by the continuous wavelet transform.

2. Methods

2.1. Clinical SCP-ECG database

In this study, several thousands of SCP-ECG files collected in Wei-Gon Memorial Hospital, Taiwan, were the resources of E.C.G. signals. The recorded SCP files were decoded to extract the raw data of E.C.G. based on the SCP-DECODE methods we developed [3]. The SCP-ECG files contained various abnormal and normal cases. These cases were evaluated directly by algorithms we developed to identify the characteristic points of E.C.G.

2.2. Detection of characteristic points of E.C.G.

The wavelet transform was described by the equation (1)

$$W(a,b) = \frac{1}{\sqrt{a}}\int S(t)\varphi\left(\frac{t-b}{a}\right)dt \qquad (1)$$

Where W represents the coefficients after transformation, a represents dilation parameter, b represents shift-parameters in time-axis, S represents the signal, and Φ represents the wavelet function. In this study, the Haar wavelet was selected as the mother wavelet function in packet wavelet and discrete wavelet transform. In packet wavelet transform, the original signal S can be detached into the part of low frequency (A) and the part of high frequency (D). The coefficient D20 was used to indicate the locations of R-waves as shown in Figure 2.

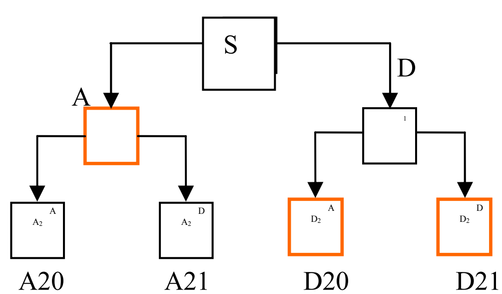

Figure 2. The coefficient D20 was used to indicate the locations of R waves.

An alternative discrete wavelet transform was used to locate the R waves when previous packet analyses failed. The coefficients D4 and D3 were used to indicate the locations of R waves shown in Figure 3.

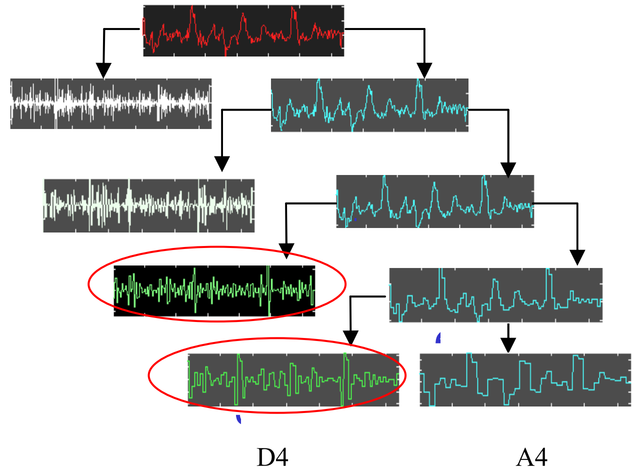

Figure 3. The coefficients D4 and D3 of discrete wavelet transform can be used to locate R-waves.

3. Results

3.1. Case study

In Figure 4, the R waves were detected accurately despite of the high S-T wave from the acute myocardial infarction case. The R waves were first located by coefficients of D20. The positive-negative peaks were identified accurately after redundant removal. Finally, the R waves were located within the positive-negative peaks.

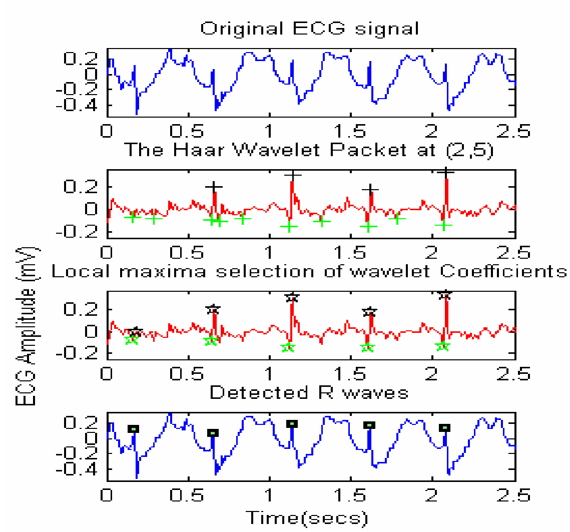

Figure 4. The detection of R waves of acute myocardial infarction.

The E.C.G. of hyperkalemia with baseline drift is shown in Figure 5. In Figure 5, the packet wavelet transform was used to identify R-wave induced peaks.

After removing the redundant peaks, the accurate R waves were located.

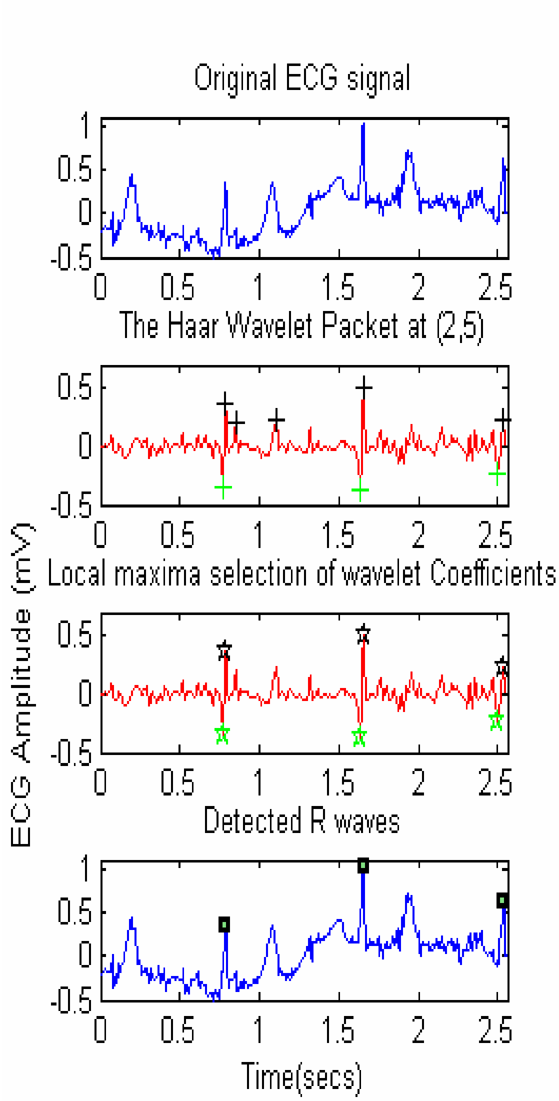

Figure 5. The detection of R waves using packet wavelet transform in hyperkalemia with baseline drift.

In Figure 6, the hyperkalemia with widen QRS complexes and higher frequency noises were used to locate the R waves. In previous packet wavelet analyses, it was found that the high frequency noises induce many positive-negative peak pairs. Therefore, it is necessary to identify the correct peaks by removing the unwanted peaks. In the following case, the R wave detection algorithm was switched to discrete wavelet transform from packet analyses. When there were too many inductions of positive-negative pairs in packet wavelet analyses, the program was switched to discrete wavelet transform. In Figure 6, the E.C.G. was interfered by noises whose frequency bands were close to R waves, resulting in many positive-negative pairs. The coefficient D3 by discrete Haar wavelet transform was used to locate the R waves. By doing so, the positive-negative pairs induced by noises were reduced largely.

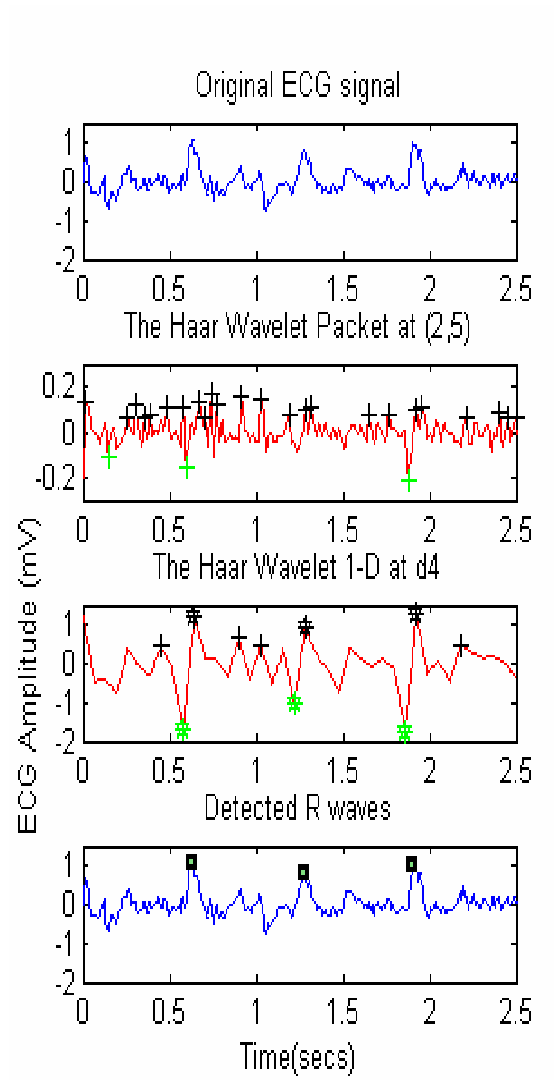

Figure 6. The detection of R waves by discrete wavelet transform.

3.2. Accuracy of R-Wave Detection

The statistical results of QRS detection are listed in Table 1. In the normal cases, the sensitivity and productivities were 100%. The sensitivities of QRS complex detection were 99.51%, 99.72%, and 99.65% in the cases of AMI, HK, and AF. The positive predictabilities of QRS detection were 100%, 99.46%, 99.66%, and 99.88% in AMI, HK, and AF.

Table 1. The Statistical Analyses of R-Wave Detection

Types of Heart Disease	TP	FN	FP	Se	P+
Normal	483	0	0	100%	100%
Acute Myocardial Infarction	1839	9	10	99.51%	99.46%
Hyperkalemia	1763	5	6	99.72%	99.66%
Atrial Fibrillation	864	3	1	99.65%	99.88%

TP = the number of true positive detections
FN = the number of false negative detections
FP = the number of false positive misdetections
Se = TP / (TP+FN)
P+ = TP / (TP+FP)

4. Discussion

In this study, clinical E.C.G. data was used instead of MIT/BIH E.C.G. The data was categorized into four groups including normal, acute myocardial infarction, hyperkalemia, and atrial fibrillation. Most of the data in the four groups was interfered with noises. Using clinical data was crucial to develop a robust algorithm to detect the characteristic points of E.C.G. Based on the statistical results shown in Table 1, the sensitivity and accuracy reached 99.5 %. In the same manner, the onset- and end-points of P, T waves can also be detected based on different levels of decomposition of wavelet packet analyses when signals were interfered with noises. In the future, the algorithms developed in this study will be applied directly onto 12-lead E.C.G. records for waveform analyses with their high accuracy for characteristic point detection in various E.C. G. leads and diseases. They will also be applied onto the Holter E.C.G. systems for QRS detection if real-time processing was done.

Acknowledgements

This project was granted by NSC 94-2213-E-216-011 and NSC 94-2213-E-216-030 (National Science Council, Taiwan) and supported by Chung Hua University, Hsin-chu, Taiwan.

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