Real-Time Classification of Heartbeats using Least Square Acceleration Filter for Ambulatory Monitoring

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Abstract

This paper describes a novel algorithm for real-time heartbeat classification based on the least square acceleration filter (LSAF) and the linear discriminant function (LDF). QRS complex was detected by LSAF with 30th order and the features were extracted. The performance of the proposed algorithm was evaluated using the MIT-BIH Arrhythmia database. The results showed the detection rate of 99% of the QRS complex and classification rate of 97% of various heartbeats such as normal beat, premature ventricular contraction, atrial premature contraction, left bundle branch block beat, and right bundle branch block beat. The algorithm was implemented on DSP chip in real time. We also compared the performance of the floating point simulation with that of fixed point simulation. There was no difference in the performance of the classification between the floating and fixed point simulation. But the computational cost of fixed point simulation was remarkably reduced than that of floating point simulation. It showed the possibilities that the proposed algorithm can be used effectively in the ambulatory monitoring.

1. Introduction

The electrocardiogram (ECG) remains the simplest non-invasive diagnostic method for various heart diseases. Physicians interpret the morphology of the ECG waveform and decide, whether the heartbeat belongs to the normal sinus rhythm or to the appropriate class of arrhythmia.

For the methods of heartbeat classification, there has been correlation related method [1], frequency analysis method [2], time-frequency method such as wavelet transform [3], and so on. Even though other existing methods are recognized as a powerful and promising technique for heartbeat classification, it needs, however, to be learned with much data and has structural complexity.

In this study, we proposed a novel heartbeat classification algorithm in which features are extracted from the least square acceleration filter (LSAF) and linear discriminant function (LDF) was designed to classify heartbeats into corresponding arrhythmia categories. The concerned arrhythmia categories are normal beat (N), premature ventricular contraction (PVC), atrial premature contraction (APC), left bundle branch block beat (LBBB), and right bundle branch beat (RBBB).

2. Methods

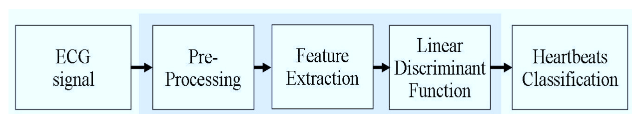

Figure 1. Block diagram of proposed algorithm.

The proposed algorithm includes preprocessing, feature extraction, and LDF based for heartbeat classification. The pre-processing is divided into noise cancellation and R peak detection. Fig. 1 shows a block diagram of the proposed algorithm.

In this study, for removal of power noise of 60Hz, we designed a digital adaptive notch filter. Fig. 2 is an example of raw ECG signal of 119 recode in the MIT-BIH Arrhythmia database (MITDB) and filtered ECG signal are presented.

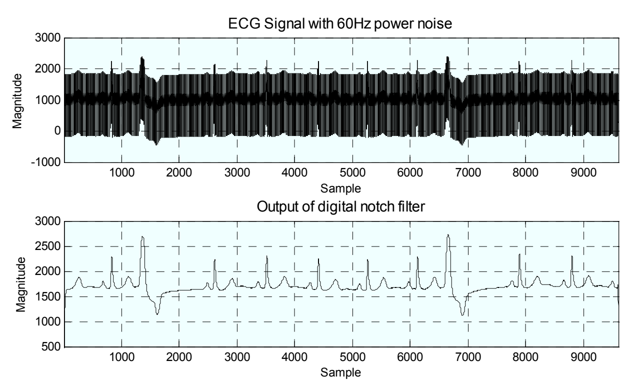

Figure 2. An example of filtered ECG signal

We used LSAF as a QRS detector and feature extractor. LSAF is a simple mathematical algorithm to detect sharpness that is the most morphologically distinct [4].

Table 1. Comparison of QRS detection performance.

QRS detector	# annotations	TP	FP	FN	% err	Se %	P^+ %
Our work	100940	100612	162	370	0.52	99.63	99.83
Martinez et al. [3]	109428	109208	153	220	0.34	99.80	99.86
Afonso et al. [6]	90909	90535	406	374	0.86	99.59	99.56
Hamilton et al. [7]	109267	108927	248	340	0.54	99.69	99.77
Pan et al. [8]	109809	109532	507	277	0.71	99.75	99.54
Poli et al. [9]	109963	109522	545	441	0.90	99.60	99.50

Fig. 3(a) shows a 5.5s of ECG signal with PVC and (b) shows the output of LSAF of order 30 applied to this signal. The larger-order (30) LSAF detects less sharp waves (lower frequency) [4].

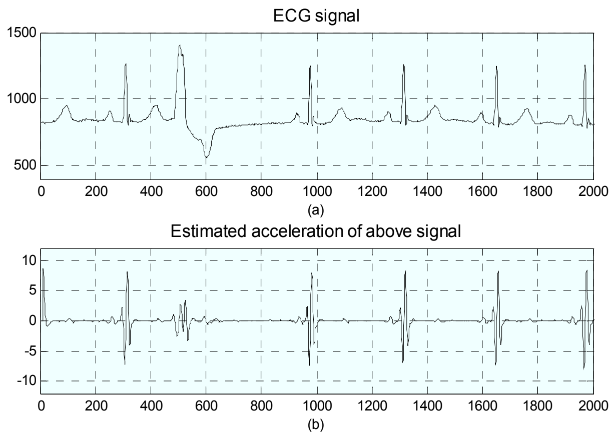

Figure 3. An example of processed by LSAF

For detection of R peaks and feature extraction, we applied the multiplication of LSAF with order 20 and 30 to ECG signal. The LSAF filtered signal for 5 types of heartbeats are shown in Fig. 4. For each type of beats, it can be found that they have their own characteristic.

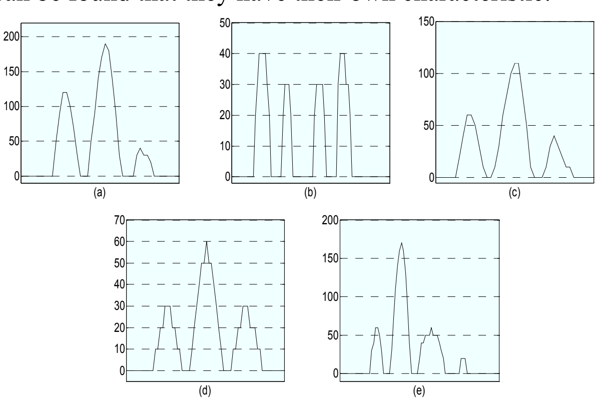

Figure 4. The LSA filtered signal for different types of heartbeats. (a) N (b) PVC (c) APC (d) LBBB (e) RBBB

The extracted features are input to LDF so that the beat is determined to what category it belongs to.

Linear discriminant function searches for those vector in the underlying space that best discriminate among classes rather than those that best describe the data. And, LDF can maximize the ration of between-class scatter to the within-class scatter so that it could separate with keeping good classification performance [5].

3. Results and discussions

To evaluate the performance of the proposed algorithm, 1) a detection of QRS complex, 2) a classification of heartbeats, and 3) real-time implementation of this algorithm and comparison of performance of floating point simulation and fixed point simulation were analyzed. For these purposes, we used MIT-BIH Arrhythmia database (MITDB). To assess the performance we calculated the sensitivity Se = TP / (TP+FN), and positive predictivity P+ = TP / (TP+FP), where TP is the number of true positive detections, TN is the number of true negative detections, FN is the number of false negative detections, and FP is the number of false positive detections.

For QRS detection, we compared the result of the proposed algorithm with those of other published works [3][6-9]. Table 1 shows the detection performance obtained by proposed algorithm and other published detectors. The proposed algorithm shows 0.52% of errors, Se = 99.63%, and P+ = 99.83% and then it means good performance on the MITDB database comparatively.

For classification of heartbeats, we divided into the training dataset and test dataset respectively from the MITDB which contains the concerned 5 types of beats mainly. For individual type of heartbeats, the numbers of beats used for test are listed in Table 2. Table 2 shows the results of heartbeat classification by our work and published works [10]. By the proposed algorithm, we got the average error rate of 2.25%. The proposed method shows satisfactory performances in discriminating five types of arrhythmia beats. Particularly, classification performance of N, APC, LBBB was improved.

For real-time implementation, we used the 6711 DSK based TMS320C6711 DSP processor. And we compared the performance of the floating point simulation with that of fixed point simulation of before and after optimum.

Table 2. Comparison of heartbeats classification.

Beat type	this work			Osowski et al. [10]		
	# testing beats	# errors	% error	# testing beats	# errors	% error
N	2790	11	0.39	2000	44	2.20
PVC	1014	34	3.35	1237	23	1.86
APC	1379	71	5.15	418	29	6.94
LBBB	2080	24	1.15	500	17	3.40
RBBB	1779	21	1.18	400	4	1.00

In result, there is no difference in the performance of the classification between the floating and fixed point simulation. But the computational cost of optimized fixed point simulation was remarkably reduced than that of floating point simulation. Table 3 shows execution clock and time of optimized fixed point simulation. Fig. 5 shows total execution clock of three simulations. This comparison indicates high efficiency of the optimized fixed point simulation.

Table 3. Result of real-time implementation.

Algorithm	Clock	Time (ms)
Main	135042	0.90028
Pre-processing	41	0.00027
Filter	178	0.00118
QRS detection	32	0.00021
Feature extraction	38174	0.25449
Classifier	23	0.00015

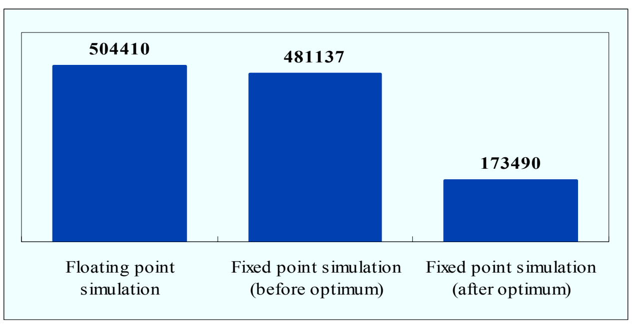

Figure 5. Comparison of total execution clock

4. Conclusions

In this study, we proposed a novel heartbeat classification algorithm based on the least square acceleration filter and the linear discriminant function. To evaluate the classification performance, the proposed algorithm showed better performance than other published methods for QRS detection and satisfactory performances in discriminating five types of arrhythmia beats. And this method has an advantage of offering a good performance of real-time implementation with relatively fast computation time and structural simplicity.

It showed the possibilities that the proposed algorithm can be used effectively in the ambulatory monitoring.

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