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Time-Frequency Analysis for Arrhythmia Discrimination Using Human Atrium Electrogram

Hangsik Shin, Chungkeun Lee, Benjamin Youngmin Choo, Myoungho Lee

Abstract— ***Detection methods for atrial tachycardia and fibrillation on the time axis have the advantages of light operational load and are easy to apply to various applications. Despite these advantages, arrhythmia detection algorithm on the time axis cannot stand much noise such as motion artifacts, moreover the peak detection algorithm has high complexity. In this paper, we use a spectrum analysis method for the detection of atrial tachycardia and fibrillation. By applying spectrum analysis and digital filtering on obtained electrogram signals, we can diagnose cardiac arrhythmia without using peak detection algorithm.***

I. Introduction

Medical treatments for irregular heart beat such as bradycardia, tachycardia, and fibrillation are classified into two groups according to the cause of arrhythmia, treatment of drug or implantation of pacemakers or ICDs(Implantable Cardioverter Defibrillators) [1]. In general, SVT(Supra Ventricular Tachycardia) cases, rapid heart rate originating above the ventricles, can be relieved with drugs but in other cases implantable pacemakers or ICDs are used for controlling cardiac arrhythmia [2].

Nowadays pacemakers have been developed to a dual-chamber system, where electrodes are inserted into both the atrium and the ventricle chambers to capture electrogram and to stimulate each chamber. Pacemakers make a regular heart beat possible through electrogram capturing, heart condition analysis, and electric stimulus [3].

In this paper, we propose a diagnosis algorithm for detection of the heart condition using time-frequency spectrum analysis. Commercial pacemakers are applying peak-duration detection algorithms on the time axis. These methods detect cardiac dysfunctions by capturing electrograms peaks and peak-to-peak durations.

However, time-domain analysis procedures are easy to contain noise figures such as motion artifact, power line noise, and these artifacts effect peak detetion as interferences in detecting peak. Moreover, time-domain analysis has a somewhat complex signal processing process in reducing noise and detecting peak, and these problems still remain to be solved.

Diagnosis algorithm using spectrum analysis has robust noise characteristics and does not perform peak detection, therefore the diagnosis algorithm can be simplified.

H. Shin is with Department of Electrical and Electronic Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea (e-mail: glority@yonsei.ac.kr)
C. Lee is with Department of Electrical and Electronic Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea (e-mail: micon78@yonsei.ac.kr)
Y. Choo is with Department of Electrical and Electronic Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea (e-mail: ymchoo@yonsei.ac.kr)
M. Lee is with Department of Electrical and Electronic Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea (corresponding author to provide phone: +82-2-2123-4946; fax: +82-2-312-2770; e-mail: mhlee@yonsei.ac.kr).
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II. Clinical Data

The Volume I Electrogram Libraries from Ann Arbor Electrogram which is a sister company of Ann Arbor Biomedical, is used by more than ten pacemaker companies and is a key in the proof checking of next-generation ICDs. The U.S. Food and Drug Administration (FDA) has also acquired parts of Volume I in devising a performance standard for ICDs. Volume I includes electrogram data from 63 patients (some patients were measured more than once) with a baseline sinus rhythm(SR)[2] passage, and one or more arrhythmia passages with a calibration pulse added at the end. The data are sent through a wideband filter setting (1-500Hz), the gains remain constant for each recordings, and was sampled at 1000Hz for digital storage.

To ensure constancy of electrode placement and gain settings, protocol was followed with extreme care during data collection. The database has two or three surface leads, a unipolar high right atrial lead, a bipolar high right atrial

TABLE 2.1
HUMAN ATRIUM ELECTROGRAM DATABASE FOR SPECTRUM ANALYSISS

Patient	Footage	Symptom
AAEL173	670	AFb
	697	VT (Atrium AFt)
AAEL181	345	AFt
	370	VT (Atrium AFt)
AAEL182	430	AFb
	465	SR
AAEL201	578	SR
AAEL208	480	AFb
AAEL221	708	SR
	734	AFt
AAEL245	168	SR
	263	AFb
AAEL286	63	AFb
	500	SR
AAEL288	86	AFb
	323	AFb

AFb = Atrial Fibrillation, Aft = Atrial Fultter, SR = Sinus Rhythm, VT = Ventricular Tachycardia

TABLE 3.1
FILTER CHARACTERISTICS ON PRE-PROCESSING STAGE

Band pass filter	· Pass band : 6 Hz ~ 150 Hz · Filter Order : 100 · Filter type: FIR(Finite Impluse Response)
CIC filter	· Stage : 2 · LPF order : 6 · HPF order : 8
Moving average filter	· Point : (sampling frequency)/20
Low pass filter	· Pass band : 0 Hz ~ 10 Hz · Filter Order : 50 · Filter type : FIR(Finite Impluse Response)

lea, a unipolar right ventricular apex lead, and a bipolar right ventricular lead. Noticeable difference from other databases is the inclusion of atrial electrograms. A recently marketed ICD, the ELA Defender (Le Plessis Robinson, France) is capable of two channel sensing and pacing, and other manufacturers such as Medtronic (Minneapolis, MN), Ventritex (Sunyvale, CA), and CPI-Guident (St. Paul, MN) are expected to release their versions of a two-channel device. We used 16 electrograms from 9 patients to analyze the atrial signal frequency, of which 7 electrograms were normal sinus rhythm signals and others were arrhythmia signals. Table 2.1 shows the atrium electrogram database information that we used.

III. SIGNAL CONDITIONING AND TIME-FREQUENCY ANALYSIS

For effective spectrum analysis, it is necessary to pre-process the electrogram. Pre-processing procedures are made up of a five stage filter, and each filter characteristics is as follows.

A. Band pass filter

An electrogram is the signal from the ventricle or the atrium. We have to consider the frequency range to extract a chamber-optimized signal. In general, it is known that the frequency range of the atrium signal is 40 Hz~80 Hz, and the frequency range of the ventricle signal is 20 Hz~60 Hz[4].

B. CIC(Cascade Integrator Comb) filter

To enhance the P or R peak, we use a CIC filter proposed by T. Kotama et al., 1999[5]. This filter was originally used for R or P enhancement of surface electrocardiogram but in this paper we use this filter for enhancement atrium or ventricle electrogram.

C. Moving Average Integrator

The CIC filtered signal is a multi-peak signal which contains high frequency components. For spectrum analysis, a moving average integrator is used as a smoothing low pass filter. Using this filter a large number of peaks are merged, and it shows a small number of wide peaks.

D. Low pass filter

In arithmetic viewpoint, most beat information is in 0 Hz ~ 10 Hz range. Thus, we consider just the 0 ~ 10 Hz range of pre-processed signals. Therefore, we use a low pass filter to reduce artifacts from redundant frequency ranges.

E. Time-Frequency Analysis

We perform time-frequency analysis for spectrum analysis. For time-frequency analysis, we use the hanning windowing and AR(auto-regressive) model. In computing the AR coefficient, we used the 35th burg method, and spectrum analysis is performed on every second of the previous 5 seconds.

F. Arrhythmia Detection Algorithm

Fig. 1 shows the arrhythmia diagnosis algorithm for an atrium electrogram. For arrhythmia diagnosis, we compute the arrhythmia frequency range using an AR model and compute the power of each arrhythmia and normal signals. Cardiac status is decided by comparing the power of each condition.

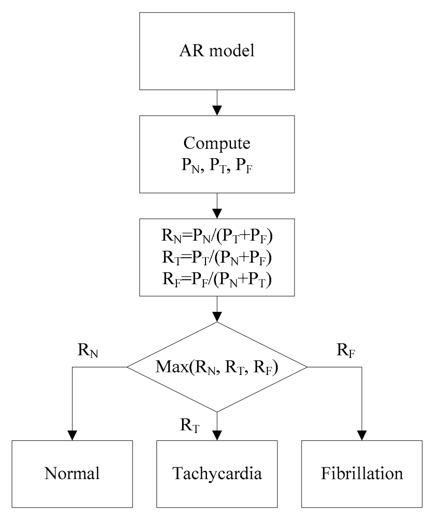

Fig. 1 Diagnosis algorithm using spectrum analysis; P_N = Power of SR condition, P_T = Power of Tachycardia Condition, P_F = Power of Fibrillation Condition, R_N = Relative power of SR condition, R_T = Relative power of tachycardia condition, R_F = Relative power of fibrillation condition.

IV. SIMULLATION

A. Electrogram Acquisition and Simulation

We used 16 Ann-Arbor electrogram databases and MATLAB for simulation. Fig. 2 shows the frequency spectrum of the SR case, Fig. 3 shows the arrhythmia (atrial flutter) case, and Fig. 4 shows the fibrillation case of atrium electrogram. From 16 electrogram analysis results, we considered the frequency range of each heart condition. The SR signal is contained between 2 ~ 4 Hz, atrial tachycardia is contained between 3 ~ 5 Hz, and atrial fibrillation is contained between 5 ~ 7 Hz range. Therefore, we set the frequency range for power estimation of each signals accordingly.

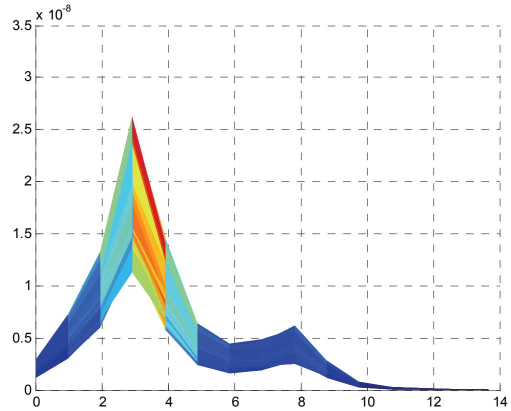

Fig. 2 Frequency analysis results of SR cases from atrium electrogram. In this case, we can see that the power is concentrated within the 2 ~ 4 Hz bands. (AAEL221, footage 708)

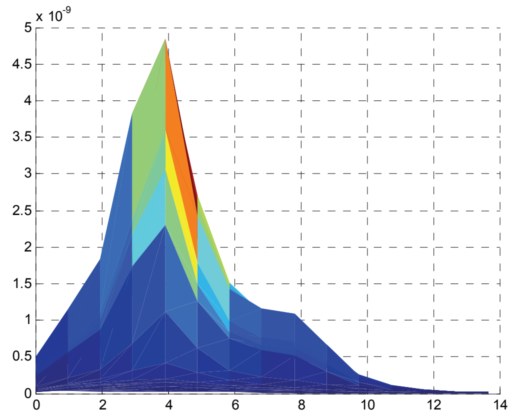

Fig. 3 Frequency analysis results of arrhythmia cases of atrium electrogram. In this case, we can see that the power is concentrated within the 3 ~ 5 Hz bands. (AAEL221, footage 734)

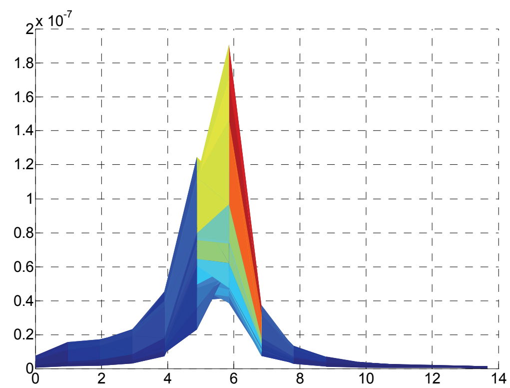

Fig. 4 Frequency analysis results of arrhythmia cases of atrium electrogram. In this case, we can see that the power is concentrated within the 5 ~ 7 Hz bands. (AAEL173, footage 670)

B. Testing with arrhythmia database

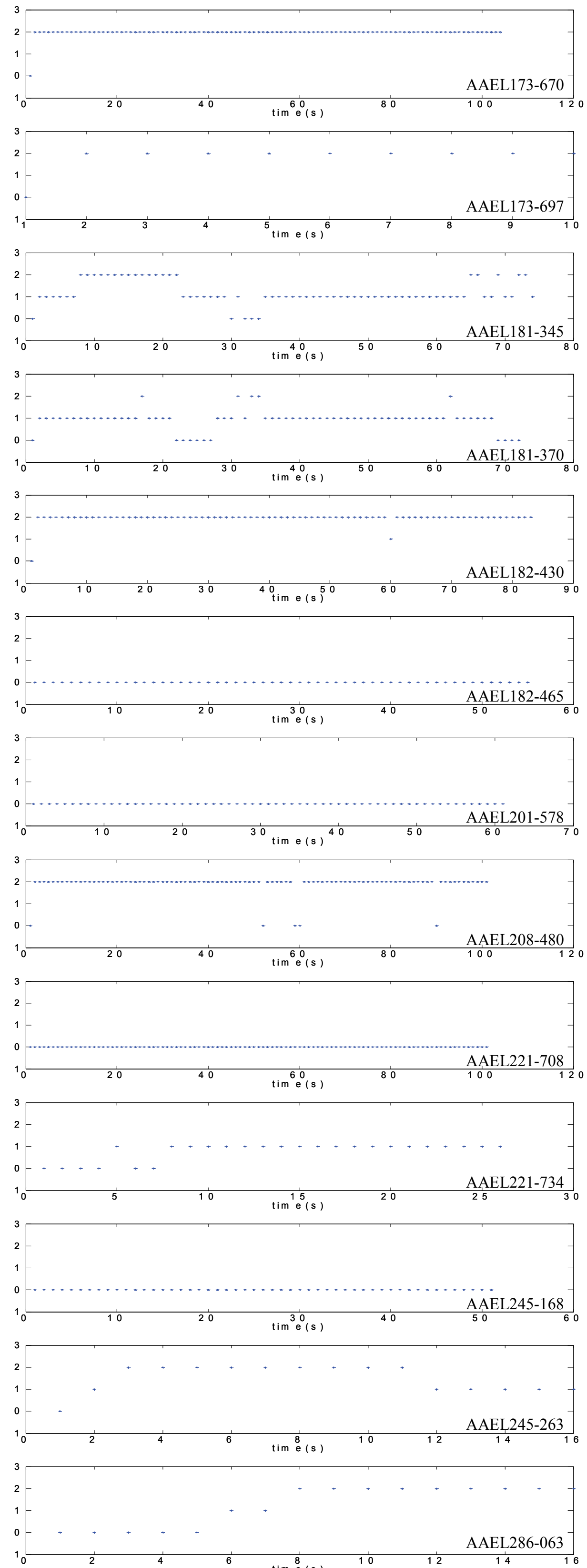

Fig. 5 Simulation results of proposed algorithm. Each SR, tachycardia, and fibrillation is mapped to 0, 1, and 2 respectively.

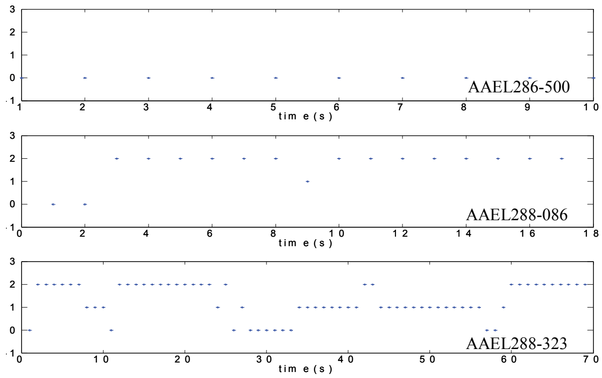

Fig. 5 Simulation results of proposed algorithm. Each SR, tachycardia, and fibrillation is mapped to 0, 1, and 2. (Continued)

To verify the proposed algorithm, we applied the proposed algorithm to SR and arrhythmia databases. Fig. 5 shows the simulation results.

In this simulation, we need to consider the training period of 5 seconds in which diagnosis results are discarded.

From the above results, we can find the performance of the proposed algorithm. It shows proper diagnosis in most results but it still has errors in some situations. In spite of these problems, we prospect the proposed algorithm deserves to be develop with additional diagnosis algorithms.

V. CONCLUSION

The proposed algorithm is capable of detecting cardiac arrhythmia without the peak detection procedure. In this point of view, spectrum analysis methods have some advantages, but many problems such as complexity, stability, and safety still remain in applying this method. Yet, this method secures stability for clinical use and also relieves the complexity for application to implantable devices. Moreover, safety must be guaranteed to be used in actual daily life.

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