Removing artifacts from atrial epicardial signals during atrial fibrillation

Jian-Hung Liu *Tsair Kao*

Institute of Biomedical Engineering
National Yang-Ming University
Taipei, Taiwan, R.O.C.
E-mail: kevinlau@bme.ym.edu.tw

Abstract

Atrial fibrillation (AF) is the most common arrhythmia encountered in clinical practice. Adaptive noise canceller (ANC) and independent component analysis (ICA) are powerful tools for separating signals from their mixtures. For better understanding of the mechanism and characteristics of AF, the artifacts were eliminated in the measured signals from atrial. We use ANC to subtract the influences of ventricle from the recorded signals, and manipulate the ICA technique to remove other artifacts so as to improve the signal-to-noise ratio of atrial signals.

Keyword: Atiral fibrillation; Adaptive noise canceller; Independent component analysis

1. Introduction

Atrial fibrillation (AF) is an irregular heart rhythm. The prevalence is expected to increase as a higher proportion of the population reaches older age. AF is characterized by fast, uncontrolled heart rhythm caused of the atrial quivering instead of beating [1]. Therefore, AF leads to the ineffective atrial transportation and the loss of atrial contribution to the cardiac output. Blood is not pumped completely out of atria, and may pool and clot. When a piece of the blood clot in the atria leaves the heart and becomes lodged in an artery in the brain, a stroke happens [2].

The recording of the atrial electrical activity can be obtained by placing electrodes on the epicardial surface in the animal experiments. Those electrodes are single-ended (unipolar), and can reflect the electrical activation around the tissue where the electrodes placed on. During sinus rhythm, the characteristics of recorded signals are regular activation sequence in the atria. During AF, the recorded signals have a constantly changing timing as well as morphology, and reflect the irregular, complex activation in the atria (Figure 1).

The electrodes of sensor have highly sensitive, so the detection and characterization of AF are easily affected by artifacts when recording signals. These artifacts may seriously interfere with actual atrial signals. Many attempts were carried out to eliminate corrupting artifacts from true atrial signals when measuring the signals. In general, during AF, the frequency of ventricular contraction is lower and the frequencies of other artifacts are higher than that of atria, respectively. If we directly use band-pass filter, it would fail to remove the artifacts since they have the same frequency range as that of the signals. In addition, recorded signals are often discarded when ventricle is beating. However, when the available data are limited, it might be unacceptable if a certain amount of data of ventricular signal lost.

Adaptive noise canceller (ANC) [3] and independent component analysis (ICA) [4] are good tools to cancel noise. ANC is the technique that employs the reference channel to perform noise cancellation in the primary channel. ICA recovers the original source signals from a linear combination of the mixed signals in blind manner. We used these methods to improve the signal-to-noise ratio so as to get the better signals.

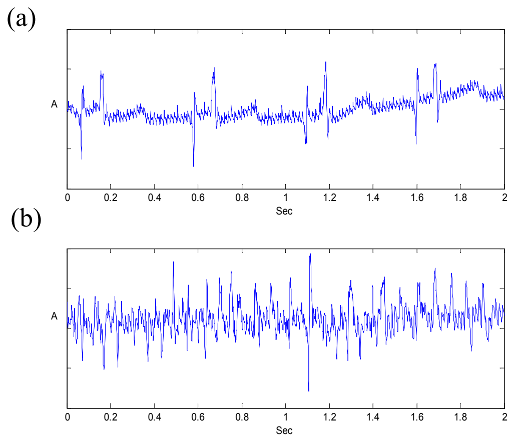

Figure 1. Two seconds of unipolar epicardial signals during sinus rhythm (a) and during atrial fibrillation (b).

2. Data Acquisition

All animal experiments were approved by the Taipei Veterans General Hospital, Taiwan. Dogs weighted 10±5 kg were used. AF was induced by electrical stimulation and methyl-acetylcholine (0.5

μ g/kg/min) was injected continuously to sustain AF.

120 electrodes are arranged into 15×8 matrixes, called an electrode arrays, on the spoon-shaped plate of Cardio Mapping System. The electrodes are metallic dots that have conduction wires to record the potential of cell membranes into the computer. There are 3 mm between any two adjacent electrodes. The measurable area is about 21 mm ×42 mm. It was used to record the epicardial signals of the right atrium from canine during AF (Figure 2). Signals were digitized with a sampling rate of 1 KHz. Hence, all 120 channels were decompressed in binary code by Prucka's program (Cardiolab 4.1, Prucka GE Marquette). Analyses were performed on the MATLAB (The Math Works, Inc.) environment.

(a) (b)

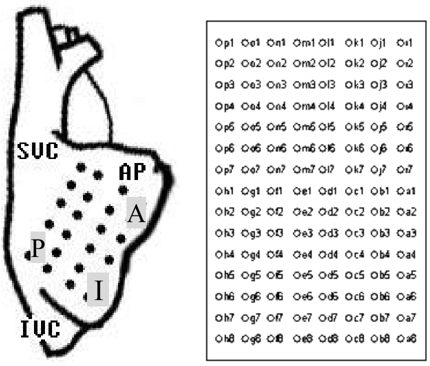

Figure 2 (a) Mapping of the free wall of the canine right atrium using 120-channel epicardial mapping electrodes. (b) The electrodes were arranged from A to P. Position A is close to the right atrial appendage (AP), positions I and P are close to SVC (superior vena cava) and IVC (inferior vena cava), respectively.

3. Methods

The block diagram of the proposed algorithm is shown in Figure 3. Firstly, the artifacts from ventricles are eliminated by ANC [5] and then the other artifacts can be separated by ICA. The pure atrial signals can be obtained from the recorded signals, which are contaminated by the measurement of artifacts [6-8].

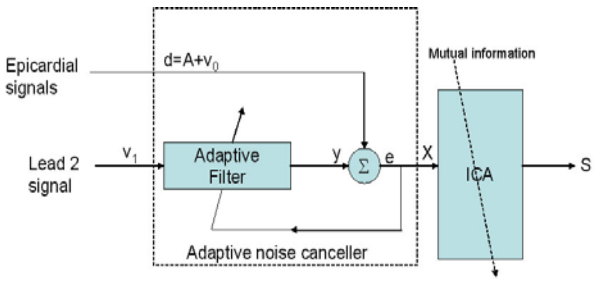

Figure 3. Block diagram shows two steps in signal analysis, ANC is used to cancel the ventricular signal and then ICA is used to remove the other artifacts.

3.1 Adaptive noise canceller (ANC)

The ANC used consists of an adaptive FIR filter (32nd order, 0.98 forgetting factor) that operates on the reference channel to produce an estimate of the noise, which is then subtracted from the primary channel. The primary channel is the recorded epicardial electrograms of right atrium that consists of atrial and ventricular signals.

$$d(n) = A(n) + v_0(n) \quad (1)$$

where $d(n)$ is the epicardial signal, $A(n)$ and $v_0(n)$ are atrial and ventricular signals recorded simultaneously in epicardial signals. Reference channel is the lead II signal $v_1(n)$ that clearly shows ventricular activity as spiky waves. Ventricular signal passes through different pathways with different time delay to become $v_0(n)$ and $v_1(n)$ at the primary and reference channels, respectively. During AF, atrial signal $A(n)$ and ventricular signals $v_0(n)$ at the primary channel are uncorrelated. However, the ventricular signal $v_1(n)$ of lead II at the reference channel is correlated with the ventricular signal $v_0(n)$ of epicardial signals at the primary channel. Output signal $y(n)$ of the adaptive filter is

$$y(n) = \Sigma_{k=0}^{M-1} w_n(k) v_1(n-k) \quad (2)$$

where M is the adaptive filter order, w is the weight value. Estimation error $e(n)$ is the subtraction of filtered signal from the epicardial signal, which is defined as

$$\begin{aligned} e(n) &= d(n) - y(n) \\ &= d(n) - \Sigma_{k=0}^{M-1} w_n(k) v_1(n-k) \end{aligned} \quad (3)$$

The system output of the canceller is used to adjust the weights of the adaptive filter. The adaptive canceller used recursive least squares (RLS) algorithm to minimize the mean square value of the system output. After the ANC process, the effects of ventricular signals on atrial electrograms can be reduced.

3.2 Independent component analysis (ICA)

We denote the source signal matrix as $S = [s_1, s_2 \ldots, s_n]^T$ and the observation matrix for signals with reduced ventricular activity as $X = [x_1, x_2, \ldots, x_m]^T$,where ,s_i and x_i are vectors. X is the linear combination of the source signals, and assume

$$X=AS \quad (4)$$

where A is an unknown mixing matrix of full rank.

An ICA solves the blind source separation (BSS) problem by determining a linear transformation of the observation matrix as

$$S=WX \quad (5)$$

where W is a demixing matrix that linearly inverts the observation matrix. The matrix W is determined as that the mutual information of the transformed component s_i is minimized.

Principal component analysis (PCA) is a common pre-processing technique for signal processing before using ICA. The first step is to center X, subtract its mean vector to make X a zero mean variable. The second is using PAC to find a smaller set of variables with less redundancy. Using the eigenvalue decomposition of the covariance matrix

$$C_x = E\{XX^T\} = VDV^T \quad (6)$$

where C_x is the covariance matrix of zero mean X. V is an orthogonal matrix. Find a linear transformation M into another vector $\widetilde{X}$ such that $\widetilde{X} = MX$. Matrix M is a linear whitening transform give by

$$M = D^{-1/2}V^T \quad (7)$$

The covariance of $\widetilde{X}$ is the unit matrix, hence $\widetilde{X}$ is white. ICA algorithm involves two parts: a cost function and an optimization algorithm. In this study, cost function is finding minimization of mutual information that roughly equivalent to finding directions in which the negentropy is maximized. Optimization algorithm is using fixed-point algorithm to achieve cost function [9] [10].

In this ICA algorithm, the row of the input matrix X are epicardial signals recorded at different electrodes, with reduced ventricular signals and the columns are measurements recorded at different time points. The ICA finds a demixing matrix W, which decomponents or linearly demixes the input signals. The rows of the ICA output matrix S are time courses of activation of the ICA component. The columns of the inverse demixing matrix, give the relative projection strengths of the respective components at each of the electrodes on the epicardial surface.

According to the results of ICA, components were separated from epicardial signals of atrium. The power spectrum of each component was calculated by a 1000-point Hamming windowed FFT function, overlapping 50%. Artifacts were defined by comparing frequency spectrum. If the separated component is artifact, then the artifact component is set to zero [11]. In other words, the column of artifact component in the source signal matrix is zero can result in a new source signal matrix. The new source signal matrix which is multiplied by the inverse demixing matrix can obtain the reconstructed signal that eliminates other artifacts from filtered signals by ANC.

4. Results

Lead II and simultaneously recorded epicardial electrograms are shown in Figure 4. The first channel is lead II and others are epicardial signals of the right atrium during AF from canine. The plate is close to right atrium so the measured activation potential of atrial and ventricular signals are nearly equivalent. Furthermore, proportion of beat from atrial and ventricle is not a regular pattern. Therefore, ventricular signals are hard to distinguish from epicardial electrograms. But we can recognize ventricular signals from lead II easily. In order to eliminate the artifacts from ventricles, we used ANC to filter the epicardial signals. In the ANC structure, epicardial signals are in primary channel and the lead II signal is in reference channel. The filtered epicardial signals are shown in Figure 5. Ventricular influences on epicardial signals are reduced. Figure 6 shows the components of filtered signals separated by ICA. Each component is analyzed by using power spectrum (Figure 7). The power spectrum of the sixth component shows a peak near to 60 Hz. It's considered as a powerline interference. This component can be removed by setting it to zero, so we can get a new source matrix. The new source matrix and inverse demixing matrix are multiplied together to get a reconstructed signals as shown in Figure 8. Original amplitude of panel D in the Figure 8 is almost equal to zero, so we amplify it 10 times for easy observation. Comparing the panel D in the Figure 5 and 8, the panel D in the Figure 8 is much clearer than in the Figure 5. The artifacts have been reduced in the reconstructed epicardial signals.

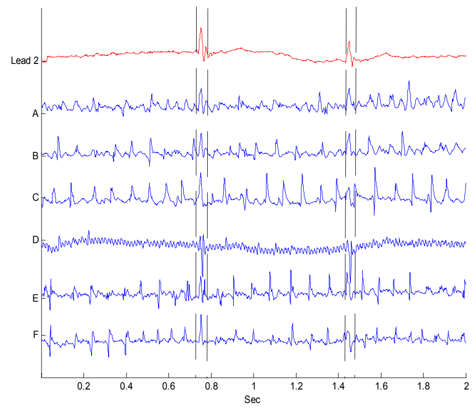

Figure 4. Lead II and some channels of epicardical signals. Only 6 channels are shown. Signals between two dashed lines have ventricular signals.

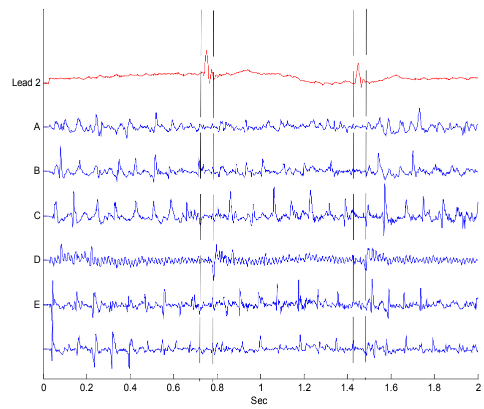

Figure 5. Epicardial signals were filtered by ANC. Ventricular influences on these signals are reduced. Compared with Figure 4, spiky wave between two dashed lines (A to F panels) is disappeared.

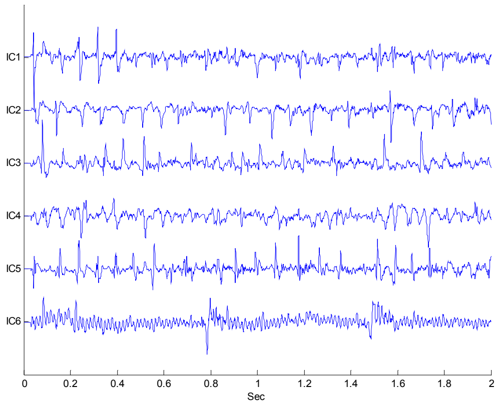

Figure 6. Separated components of filtered signals by using ICA.

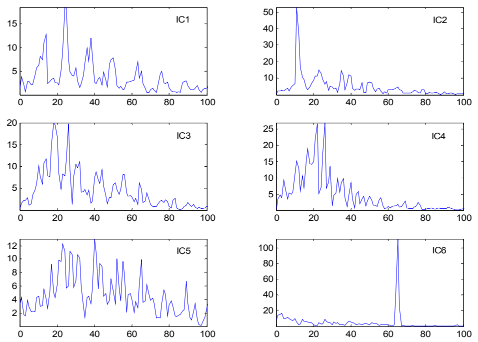

Figure 7. Power spectrum of each component in Figure 6. Component IC6 has a domain frequency near to 60Hz, and is considered as an powerline interference.

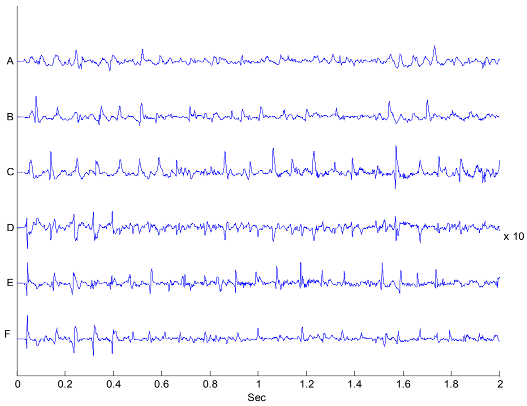

Figure 8. Reconstructed signals. Note the gain of panel D is 10 times larger than others.

5. Discussion

We have attempted to separate ventricular artifacts from eipcadial signals only by using ICA. The input matrix *X* of ICA is the combination of lead II signal and other epicardial atrium signals. Components are firstly separated from input signals matrix, and then continue with removed the components which belong to ventricle from the separated components. The reconstructed signals are shown in Figure 9. Although spiky waves were disappeared at lead II and some channels but there are still spiky waves in some channels during ventricular contraction (between two dashed lines).

Comparing the effect of ICA and the ANC in removing ventricular signals, in this case, we have a good reference signal, where outcome of only using ICA to remove the ventricular component is worse than using ANC. Hence, we propose the separation of ventricle component should use ANC before ICA. After ANC process, each channel signal is decreased in magnitude when the Lead 2 spiky waves arise, which expresses the ventricle component has been eliminated. We used ICA to separate components from the signals filtered by ANC. If the separated component is artifact, we will set this artifact component in source signal matrix to zero. Then the inverse demixing matrix is multiplied by the source signal matrix to get the reconstructed signals. We can get pure atrial signals during AF by processing signals with ANC and ICA.

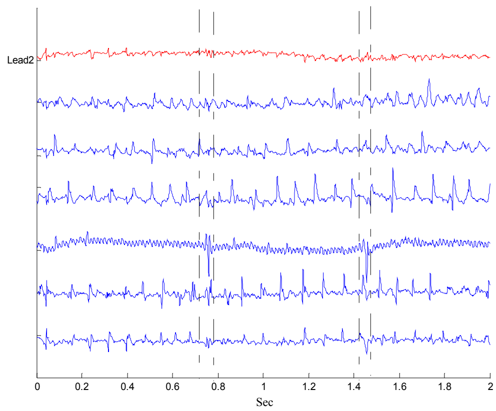

Figure 9. Ventricular signal is separated only by using ICA. First channel is lead 2. Other channels are epicardial signals. There are still many spikes between the two dashed lines in other channels (Comparing with Figure 5).

Although ANC and ICA are excellent ways to remove the artifacts in measured signals, but they also have some inherent limitations. In the ANC structure, the quality of reference signal is very important. The filtered signals will have serious distortion when reference signal is interfered with the noise. In the ICA cannot be satisfied when the recording signals are too small, or when the topographically can't be separated, which always occurs concurrently in the recording signals.

6. Reference

[1] S. Nattel, “New ideas about atrial fibrillation 50 years on,” Natrue, vol.415, pp. 219-226, 2002

[2] M.M. Scheinman, “Mechanisms of atrial fibrillation: Is a cure at hand?” J Am Coll Cardiol, vol.35, pp.1687-1692, 2000.

[3] S. Haykin, Adaptive filter theory, Tom Robbins, Canada, fourth edition, 2002.

[4] A. Hyvärinen, J. Karhunen and E. Oja, Independent component analysis, John Wiley and Sons, New York, first edition, 2001.

[5] P. Akkiraju and D. C. Reddy, “Adaptive cancellation technique in processing myoelectric activity of reparatory muscles,” IEEE Trans. Biomed. Eng, vol.39, pp.652-655, 1992.

[6] L. D. Lathauwer, B. D. Moor and J, Vandewalle, “Fetal electrocardiogram extraction by blind source subspace separation,” IEEE Trans Biomed Eng, vol.47, pp. 567-572, 2000.

[7] J. S. Black and D. F. Lovely, “A comparison of ECG cancellation techniques applied to the surface recording of somatosensory evoked potentials,” Med. Eng. Phys, Vol.19 pp. 297-285, 1997.

[8] A. K. Barros, A. Mansour and N. Ohnishi, “Removing artifacts from electrocardiographic signals using independent component analysis,” Neurocomputing, vol.22, pp.173-186, 1998.

[9] A. Hyvärinen, “Fast and robust fixed- point algorithms for independent component analysis,” IEEE Trans Neural Networks, vol.10, pp. 626-634, 1999.

[10] A. Hyvärinen and E.Oja, “A fast fixed-point algorithm for independent component analysis,” Neural Computation, vol. 9, pp.1483-1492, 1997.

[11] T. P. Jung, S.Makeig, M. Westerfied, J. Townsend, E. Courchesne and T. J. Sejnowski, “Removal of eye activity artifacts from visual event-related potentials in normal and clinical subjects,” Clinical Neurophysiology, vol.11, pp.1745-1758, 2000.