ECG SIGNAL PROCESSING USING BASIS FUNCTION OF INDEPENDENT COMPONENT ANALYSIS

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ABSTRACT
This paper is about the study on signal processing of electrocardiogram (ECG) using basic functions extracted by independent component analysis (ICA). The study assumed ECG signals were mixed signals that combined various source signals linearly and used 12 channel signals at sampling rate of 600Hz. Using Independent Component Analysis (ICA), basis functions were extracted that could isolate and detect source signals of ECG signals - QRS complex, P wave, T wave and so on. By applying extracted basis functions to normal and abnormal waveforms, it provided the feature points necessary for diagnosis and separating normal and abnormal signals. It not only showed the method to resolve the problem that signals with specific frequencies were hardly isolated in the ECG signal processing using a wavelet transformation technique, but also indicated ICA could be a useful technique in the ECG signal analysis.

KEY WORDS
Electrocardiogram signal processing, independent component analysis and basis functions

1. Introduction
Major ECG signal processing processes are classified into pre-processing filtering, feature point detection, waveform classification and diagnosis. ECG signals include baseline wandering, power line noise, and muscle artifacts. Pre-processing filtering technique includes IIR filter, FIR filter, adaptive filter and wavelet transformation [1],[2]. Feature points are QRS complex, P wave, T wave and ST-segment and the peak point detecting technique using differential wave is used mainly [3],[4]. Pattern classification methods such as pattern matching, fuzzy technique and neural network are frequently used in diagnosis algorithm that separates normal and abnormal waveforms [5], [6].

These ECG signal processing techniques are based on the assumption that ECG components such as QRS complex, P wave and T wave are linearly combined and use the characteristic that each component has a different frequency band. The reason for the frequent application of Principal Component Analysis (PCA) or wavelet transformation to ECG signals is that using frequency uniqueness, various results can be obtained. Wavelet transformation separates frequencies in a dyadic way and obtains signals within the frequency band by offering every data on time and frequency. However, it is not proper to obtain signals in a special single frequency. That is, basis functions used for wavelet transform such as Haar, Daubechies, and Symmlet seem to have dyadic characteristics.

To overcome the limitation of such basis function that is used for wavelet transformation, ICA studied in various signal processing areas is more popular approach than PCA and becomes an algorithm for Blind Signal Separation (BSS) [7]. ICA is actively studied in the neural network or pattern recognition and biosignal processing sectors. PCA is one of de-correlation techniques that separate unique signals from various mixed signals when various signals are linearly combined and orthogonal characteristics are present. However, ICA can separate mixed signals if signals are linearly combined. ICA was tried in voice signal processing in a way to separate a specific voice when many speakers are conversing in a cocktail party. In particular, ICA selected a basis function useful to separate a specific signal through learning process and applied voice processing, image processing and pattern recognition to eliminate and separate noise and improve voice quality. In addition, this technique was applied to biosignal processing such as fetal electrocardiogram and electroencephalography [8],[9], but studies on the application to various biosignals are insufficient.

In this paper it was determined a basis function to detect feature points of ECG signals such as QRS complex, P wave and T wave using fast fixed point algorithm, one of methods used for ICA, and proposed a new technique for ECG signal processing that could separate normal waveforms and abnormal waveforms like arrhythmia with obtained basis functions.
2. Methods and Materials

2.1 Independent Component Analysis (ICA)

ICA is to recover $q$ source signals from $p$ input signals linearly combined. Provided that $q$ independent signals $s_1(n), s_2(n), \ldots, s_q(n)$ are $p$ input signals $x_1(n), x_2(n), \ldots, x_p(n)$ linearly combined, an input mixed signal is $p$th-order signal and the original signal is a $q$th-order time serial. It is expressed as shown in equation (1) and (2) (LEE, 1998).

\[
s(n) = [s_1(n) \ s_2(n) \ldots \ s_q(n)]^T \quad (1)
\]
\[
x(n) = [x_1(n) \ x_2(n) \ldots \ x_p(n)]^T \quad (2)
\]

It is assumed that source signals are mixed by a instant linear time-invariant system (LTI) without feedback on a time axis. Random additive noises can be added in the process of signal mixture. Equation (3) and (4) are for mixed signals and separated signals.

\[
x(n) = As(n) + e(n) + b \quad (3)
\]
\[
y(n) = W(x(n) - b) \quad (4)
\]

Where, $s$ is source signal prior to mixture, $x$ is input signal that combines source signals, $A$ is mixing matrix and $e$ is an additive noise changing with time and probability vector with average zero $(0)$. $b$ is a constant deviation that is added with additive noise $e$ in a mixing process and adjusts input signals mixed with source signals to zero on average.

ICA is a process to find separating matrix $W$ so as to separate $q$th-order independent component signal, $y(n)$, that is closest to source signal, $s$. Flowchart of ICA is shown in Fig. 1. Here, $s'(n)$ is an estimated source or independent component signal of source signal, $s(n)$.

For ICA, the methods to make signal components independent include entropy maximization, mutual information minimization, and maximum likelihood and Kullback-Liebler divergence minimization. ICA algorithm uses these methods and induces signal components to be independent of one other [10],[11]. This study used the fast fixed point algorithm based on Kurtosis maximization and minimization, the most popular method among ICA methods that are simple, effective and fast to compute.

2.2 Selection of basis function for ECG

Fig. 2 is a block diagram for the selection of basis function to detect feature points and to classify waveforms with ICA that consists of learning and test parts. 12 channel ECG signals at 600 Hz obtained from Marquette equipment were used. After a separating matrix $W$ is obtained by applying input ECG signals to the fast fixed point algorithm, the basis function is obtained for feature point detection and waveform classification using this separating matrix.

Assuming that ECG signals are linearly combined, signals from 10 channels out of 12 channels are analyzed using the fast fixed point algorithm. Feature points are detected by selecting a basis function to classify feature points of ECG signals such as QRS complex, P wave and T wave. Waveforms are classified by selecting a proper basis function that separates abnormal waveforms such as arrhythmia from normal waveforms.

3. Results and Discussion

3.1 Learning to get a basis function for ICA

ICA transforms mixed signals inputted from multiple sources into original source signals. Fig. 3 shows the result of ICA and is classified into source signals, mixed signals and estimated signals. Source signals include curve waves, sine waves, and sawtooth waves. $A$ is mixed matrix to incur mixed signal, and estimated signals are obtained by computing mixed matrix and source signals. The estimated signals are obtained by computing mixed signals with separating matrix $W$ obtained by ICA. As a result, estimated signals are evaluated by comparing source signals.

Equation (5) is a separating matrix $W$ and becomes a basis function to separate source signals.

\[
W = \begin{bmatrix}
-0.9680 & -0.0297 & -0.0413 \\
-0.1389 & 0.5999 & 0.1343 \\
0.0155 & 0.0141 & -0.7693
\end{bmatrix} \quad (5)
\]

3.2 Basis function of ICA for ECG signals

ECG signals are assumed to be a linear combination of QRS complex, T wave and P wave that have various frequencies and can include 60Hz power line noise or baseline wandering or muscle artifacts.

This study assumed ECG signals contained various signal components and acquired a basis function proper
for ECG signal processing using ICA after outside 60Hz power line noise is added.

\[ x(t) = QRS + Twave + Pwave + 60Hz \text{noise} \]  

(6)

This experiment used 10 channels out of 12 channels. After separating matrix \( W \) is obtained by applying the fast fixed point algorithm to 10 channels of mixed ECG signals, an estimated signal of each source signal, \( y(t) \), shall be obtained by computing the separating matrix \( W \) with mixed signals.

Fig. 4 indicates a basis function to get estimated signals, that is, feature points signal to be extracted from mixed signals. The scale from one to ten on the \( x \)-axis of each signal indicates the size of a matrix and any matrix that can be used for a special purpose shall be used as a basis function. Of the six basis function waveforms, the first to fourth waveforms are basis functions related with QRS complex and the fifth waveform is a basis function related with P and T waves. The sixth waveform is a basis function related with 60Hz power line noise. As shown above, ICA is effective to get unique basis functions and produces desired independent components using the basis function.

### 3.3 Detection and classification

Fig. 5 shows the result of applying the basis functions acquired from learning to ECG signals. As ECG signals are assumed as mixed signals of source signals, Fig. 5(a) is independent signal extracted by computing mixed signals and separating matrix \( W \) (basis function) by ICA. The upper signals in Fig. 5(b) are mixed ECG signals inputted and the rest are enlarged signals of independent signal of QRS complex, 2nd from the top in Fig. 5(a), and independent signals containing T and P waves, 7th signals. Three straight lines in Fig. 5 indicate each feature point. Therefore, computing \( W(2,1:10) \) and \( W(7,1:10) \) with mixed signals, estimated signals of QRS complex, T wave and P wave can be obtained. As a result, P or T waves that have smaller waveforms than wavelet basis function stand out as independent components.

In case of detecting QRS complex, error rate goes up if there are various noises and T or P waves are large. However, the extraction of signals with ICA will contribute to the improvement of feature point detection. In this sense, the rest of the signals can be regarded as noise. That is, \( W(4,1:10) \) is a basis function for noise that shows remarkably base line change and \( W(5,1:10), W(8,1:10) \) and \( W(9,1:10) \) are basis functions representing random noise such as neighboring noise. Except such basis functions that represent noise, a proper combination of the rest basis functions and mixed signal can give noise-clear signals.

Fig. 6 is an example of classifying ventricular premature beat (VPB) in estimated signals. Like feature points detection, ICA was used to analyze 12 channel ECG signals and separate into 10 channels. By acquiring basis functions that can separate normal and abnormal waveforms, estimated signals of normal and abnormal signals are distinguished. Fig. 6(a) shows VPB signals that normal waveforms are separated with mixed waveforms and fig. 6(b) is estimated signal and fig. 6(c) is estimated signal that indicates abnormal waveforms.

As shown in Fig. 6, ICA is very effective to separate signals that have similar frequencies and normal and abnormal waveforms that are similar in size. If a basis
function for normal waveform is obtained, signals having normal waveforms are clearly distinguished. Therefore, it is expected ICA is effective in detecting arrhythmia. In particular, as VBP signal is smaller than normal waveform, error occurs when detecting feature points. As a result, it becomes difficult to obtain VBP signal. However, only if a basis function is obtained with ICA, the size of a signal doesn't prohibit signal classification any more.

This study proposed a method to separate signals with a specific frequency in ECG signal processing using wavelet transformation technique and obtained a basis function that can extract independent components of a signal using ICA. In addition, based on the basis function, this study suggested a new technique to process ECG signals and a study would be conducted for the evaluation of various ECG signal processing.

4. Conclusions

This study assumed ECG signals were mixed signals linearly combined by various source signals, and separated mixed ECG signals into each source signals using ICA. Using separating matrix in the process, basis function suitable for the purpose was extracted. As the extracted basis function showed a possibility of detecting feature points and classifying signals needed for diagnosis, a technique was proposed to resolve the shortcoming that signals with a specific frequency were hard to separate in ECG signal processing using the existing wavelet transformation technique.

Fig. 6. Example of wave forms using ICA
(a) ECG signals with VPB  (b) Normal wave form
(c) VPB wave form

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