Design of ICA to Extract Respiration Signal From PPG Signal

Ju-Won Lee, Byeong-Ro Lee, *Member, KIMICS*

Abstract— **Respiration signal of the vital signs is an important parameter in clinical parts. To extract the respiration signal from PPG signal for mobile healthcare system is difficult because the bands of the motion artifacts and respiration in the frequency domain are overlapped. This study to improve this problem suggested a respiration extraction method using the independent component analysis and evaluated its performances. In results of evaluation, the ICA method showed better performance than LPF suggested recently.**

Index Terms— **mobile healthcare, respiration signal, photoplethysmograph, independent component analysis.**

I. INTRODUCTION

IN the mobile healthcare system, the most popular kinds of vital signs for monitoring are heart rate, skin temperature, blood pressure, respiration rate, etc. Specially, respiration rate of these vital signs is an important parameter for many clinical uses including detecting sleep apnea, sudden infant death syndrome, and chronic obstructive pulmonary disease, and measurements of the respiration rate are indicated in many intensive care and operative settings [1]-[3]. The respiration rate should be measured by intermittent manual counting, by a nasal-oral air temperature sensor, or continuously by transthoracic impedance (TTI) via ECG electrodes. Devices based on airflow detection or chest girth have also been used [2][3]. These methods besides TTI method are unsuitable apply to the mobile healthcare system. On one side, the TTI method how the electrodes or sensors are in contact with user's chest makes the complaint to users. Recently, the signal processing algorithms using PPG sensor are developing by many researchers to improve the problems [4]-[8]. The PPG signal is a non-invasive optical technique that measures changes in skin blood volume and perfusion. The PPG signal contains components that are synchronous with respiratory and cardiac rhythms. In extracting the respiration signal from PPG signal, an important signal processing is to remove the motion artifact generated by user's motion. However, it is difficult to remove the motion artifact because the bands of the motion artifacts, respiration, and heart pulsation in the frequency domain are overlapped [8]. In last few years, to extract the respiration rhythm in PPG signal, several researchers proposed methods such as the low pass filter [8][9]. These methods shown the good performance on PPG signals of a rest state, but performance on PPG signals included the motion artifacts is reduced. Therefore, this study suggests a method using the independent component analysis to extract the respiration applicable to mobile healthcare, and evaluate its performances.

II. RELATIONSHIP BETWEEN RESPIRATION, PPG SIGNAL AND MOTION ARTIFACTS

The PPG signal is a non-invasive optical technique that measures variations in skin blood volume and perfusion, and contains components that are synchronous with respiratory and cardiac rhythms. The PPG is signal acquired by illuminating skin with light generated from an infrared or red light emitting diode (LED) and then measuring the amount of light either transmitted or reflected to a photo diode. If the measured PPG signal, $s(k)$ at k time can assume to be the sum of the PPG signal, $p(k)$, respiration signal, $r(k)$ and motion artifact, $m(k)$, and it is defined as follow:

$$s(k) = r(k) + p(k) + m(k) \quad (1)$$

The frequency bands of the respiration, PPG, and motion artifacts are 0.04~0.5[Hz], 0.8~4[Hz], and 0.1~5[Hz]. Specially, these frequency bands are overlapped [8]. Thus, it is difficult to extract the respiration signal by linear filters, and need the new filtering algorithms to improve performance of the respiration rhythm extraction.

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Ju-Won Lee is with the Department of Medical Engineering, Andong Science College, Andong, 660-758, Korea (Tel: +82-54-851-3573, Email: bioee52@empas.com). Byeong-Ro Lee (corresponding author) is with the Department of Electronics Engineering, Gyeongnam National University of Science and Technology (Email: voyager@gntech.ac.kr).

III. DESIGN OF ICA FOR RESPIRATION SIGNAL EXTRACTION

Independent Components Analysis (ICA) is the method known as the blind source separation. The blind source separation problem is to find the set of original sources from an observed mixture. In this problem, the goal is to separate a series of individual signals from observed mixtures [10]. To extract the respiration signal in the measured PPG signal, this study proposes a method using the ICA as shown in Fig. 1. The proposed method consisted of a band pass filter with bandwidth of 0.04~2[Hz], two's envelope detection filter, low pass filter (f_c=0.8[Hz]), PPG kernel, ICA, and a maximum correlation selector for selecting optimal respiration signal.

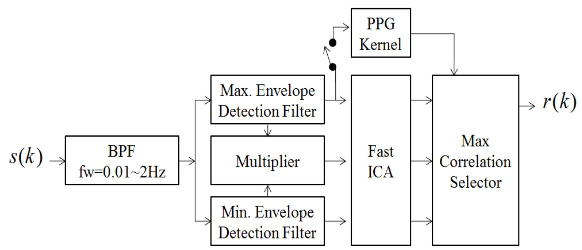


Fig. 1. Proposed method to extract respiration signal.

In the proposed method shown in Fig. 1, a band pass filter (BPF) that is 2nd-order Butterworth IIR (infinite impulse response) filter is used in order to remove the high frequency noises of PPG signal $s(k)$ sampled at k. One side, the two's envelope detection filters and mean operator are used for extracting the features of respiration signal from PPG signal. The envelope signals are upper envelope signal $r_U(k)$ and lower envelope signal $r_L(k)$ obtained by Eq. (2)~(5) as follows :

$$r_{\max}(k) = \max(r_{BPF}(k-m), \cdots, r_{BPF}(k-M-1)) \quad m = 0,1,2,\cdots,M-1 \tag{2}$$

$$r_U(k) = \sum_{q=0}^{Q-1} b(q) r_{\max}(k) \tag{3}$$

$$r_{\min}(k) = \min(r_{BPF}(k-m), \cdots, r_{BPF}(k-M-1)) \quad m = 0,1,2,\cdots,M-1 \tag{4}$$

$$r_L(k) = \sum_{q=0}^{Q-1} b(q) r_{\min}(k) \tag{5}$$

where, M is a block size to detect maximum points of the filtered PPG signal $r_{BPF}(k)$, and $b(k)$ is the coefficient of 2nd-order LPF with cutoff frequency 0.8[Hz] to interpolate $r_{max}(k)$ and $r_{min}(k)$. The mean operator computes mean value $r_M(k)$ by envelope signals as follows :

$$r_M(k) = r_U(k) r_L(k) \tag{6}$$

These signals [$r_U(k)$ $r_L(k)$ $r_M(k)$] computed from Eq. (2)~(5) inputs to ICA to extract respiration signal. The $\mathbf{x}(k)$=[$r_U(k)$ $r_L(k)$ $r_M(k)$]^T can be modeled using the following instantaneous model [10]:

$$\mathbf{x}(k) = \mathbf{A}\mathbf{s}(k) \tag{7}$$

where, **A** is an unknown matrix called the mixing matrix, and $\mathbf{s}(k)$ is the original signal vector such as respiration signal and motion artifacts. To recover the original signals from the observation vector, an unmixing matrix **W** can estimate the source signals by using the following equation:

$$\hat{\mathbf{s}}(k) = \mathbf{W}\mathbf{x}(k), \ \mathbf{A}^{-1} \approx \mathbf{W} \tag{8}$$

In this study, we consider the number of sensors equal to the number of sources and the observations are zero-meaned signals. To update an unmixing matrix **W**, the used leaning rule that is Informax learning rule [11] is as follows:

$$\Delta\mathbf{W} \propto \frac{[I - \tanh(u)u^T - uu^T] \times \mathbf{W} : \text{super-Gaussinan}}{[I - \tanh(u)u^T - uu^T] \times \mathbf{W} : \text{sub-Gaussinan}} \tag{9}$$

The estimated output from ICA is multi-channel output. Therefore, in this study we used a maximum correlation selector to extract an optimal respiration signal. The maximum correlation selector is to find a channel with the maximum coefficient by comparing a reference respiration signal and each ICA output signal as following equations:

$$c_q = \frac{\sum_{i=0}^{N-1}(s_{qi} - \bar{s}_q)(P_i - \bar{P})}{\sqrt{\sum_{i=0}^{N-1}(s_{qi} - \bar{s}_q)^2}\sqrt{\sum_{i=0}^{N-1}(P_i - \bar{P})^2}} \quad q = 1,2,\ldots,Q \tag{10}$$

$$I = Index_{\max}([c_1, c_2, \ldots, c_Q]) \tag{11}$$

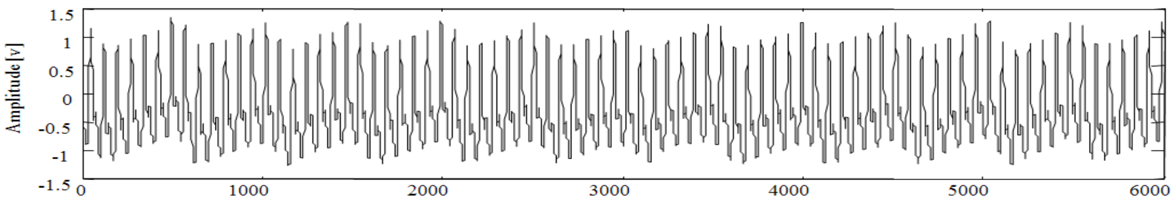
where $\bar{s}_q$ is a mean value of ICA output $\mathbf{s}(k)$ for q-channel, $\bar{P}$ is a mean value of N sampled reference respiration signal. The reference respiration is the measured signal when the motion artifacts did not exist. The function $index_{\max}(.)$ is to find a channel number with maximum correlation value. From the channel number obtained in Eq. (11), we have the estimated respiration signal as follows:

$$O_{resp}(k) = s_I(k) \tag{12}$$

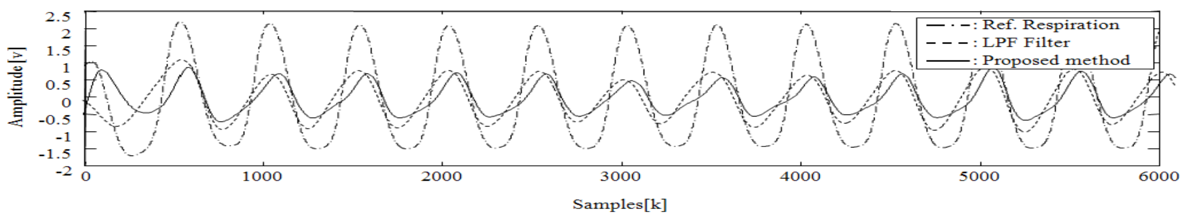
IV. EXPERMENTS AND RESULTS

In the study, the performance of the proposed method is evaluated by the algorithm programmed using MATLAB.

The used PPG signals are two's signal of PhysioBank's MIMIC databases that are signal 05500001 and 23700002 known as the standard clinical data. The sampling frequency of the PPG signals is 125[Hz]. The PPG signals 0550001 and 23700002 are used for evaluating the performances of the proposed ICA method and LPF (cutoff frequency = 0.5[Hz]) suggested in Ref. [7], and are signals measured in the rest state (without motion artifacts) and motion state. The results of experiments showed in Fig. 2 and Fig. 3. In results of ICA and LPF as shown in Fig. 2, the types of waveforms in comparison with the reference respiratory signal showed a little difference, but it is possible to extract the rhythm of breathing. In Fig. 3, signal distortion of proposed method was smaller than LPF method. For a more detailed evaluation, we calculated Pearson's correlation coefficients between reference signal and each output of LPF and ICA, and showed in Table I. In the results, the ICA method was higher than LPF method. Thus, we are considered that the proposed method than LPF will provide a more stable performance.

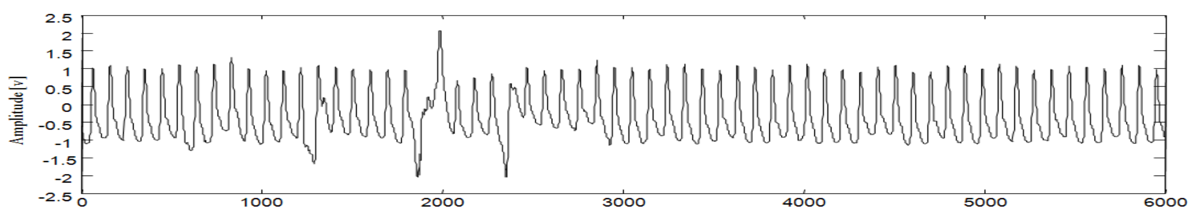


(a) PPG signal without motion artifacts

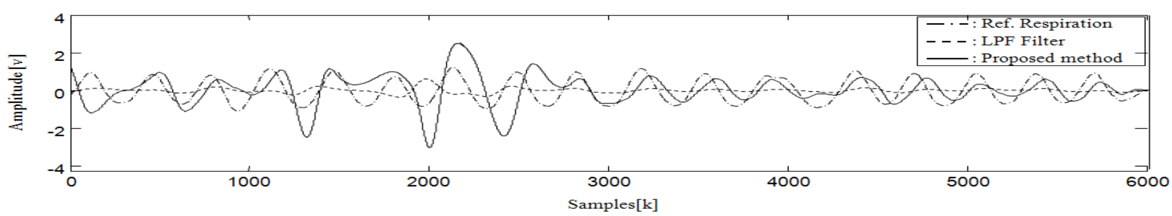


(b) Outputs of filters

Fig. 2. Results for PPG signal without motion artifacts.



(a) PPG signal with motion artifacts



(b) Outputs of filters

Fig. 3. Results of experiment for PPG signal with motion artifacts.

TABLE I
RESULTS COMPARED BY PEARSON'S CORRELATION

Pearson's Correlation	PPG signal		PPG signal With motion	
	LPF	ICA	LPF	ICA
Reference Respiration Signal	0.482	0.782	0.155	0.34

IV. CONCLUSIONS

The respiration rate of the vital signs is an important parameter in clinical parts and usually monitored by a nasal-oral air temperature sensor or continuously by transthoracic impedance. These methods are difficult to apply in the mobile healthcare system because it leads to users' complaint. In this study, we proposed an ICA method to extract respiratory signal from PPG signal and evaluated its performance. In evaluation, the ICA method showed better performance than LPF with cutoff frequency 0.5[Hz]. Therefore, the proposed method will provide the stable performance in extracting respiration signal from PPG signal.

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Ju-Won, Lee is received the Ph.D. degree in electronic engineering form Gyeongsang National University in 2003. He is currently a full time lecturer of medical engineering at Andong Science College. His current interests include biomedical signal processing, ubiquitous healthcare system, and human computer interface.

Byeong-Ro, Lee is received the Ph.D. degree in electronic engineering form Gyeongsang National University in 1998. He is currently a professor of electronic engineering at Gyeongnam National University of Science and Technology. His current interests include mobile communication, signal processing, and ubiquitous system.