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인체 움직임에 강인한 IR-UWB 레이더 기반의 호흡속도추정

(Respiration Rate Estimation using IR-UWB Radar Signals Robust to Body-Rocking)

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요 약

본 논문에서는 IR-UWB 레이더 신호의 크기와 도달시간을 결합한 새로운 방법의 호흡속도추정 방법을 제안한다. 특히 이 논문에서는 분석을 통해서 인체의 흔들림이 호흡속도추정에 왜곡을 일으키지 않음을 증명한다. 분석을 바탕으로 레이더 신호의 크기 정보 신호와 도달시간 정보 신호의 컨볼루션 방법을 제안한다. 하드웨어 실험을 통한 분석을 통해서 호흡속도성분의 추출 능력이 기존의 추정 방법에 비해서 10dB 이상 향상됨을 보인다.

Abstract

This paper presents a novel respiration rate estimation method based on joint amplitude and time of arrival (TOA) using impulse-radio ultra-wideband (IR-UWB) radar signals. Through analysis of the affect of body-rocking, it is shown that body-rocking information does not distort the respiration rate and exists at integer multiples of the body-rocking rate from the respiration rate. Based on the analysis, the convolution of the temporal sequence of the maximum amplitude and that of the TOA is proposed. The analysis results show that the frequency components of respiration are improved more than 10dB compared with those obtained using other existing methods.

Keywords : IR-UWB, 호흡, 채널응답, TOA.

I. 서 론

Since Federal Communications Commission (FCC) approval and standardizations, ultra-wideband (UWB) signals have been considered for various system applications, such as wireless communication, radar, telemetry, and biomedical instrumentation.[1~3] UWB technologies are based on either multiband orthogonal frequency division multiplexing (MB-OFDM), or on impulse-radio UWB (IR-UWB).[3~4] MB-OFDM signals are used for high speed wireless data communication. An IR-UWB signal is generated using a sub-nanosecond pulse generator. Since the IR-UWB signal has a high range-resolution with a very short pulse, it can be used to measure the distance of an object from the IR-UWB transmitter.* Hence, IR-UWB technology can be used to measure respiration rate.

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* According to FCC, an UWB signal occupies an absolute bandwidth of at least 500MHz. In general, UWB signal has a bandwidth of from 500 MHz to several GHz.

In previous papers, several methods were used to measure respiration rate with IR-UWB signals. The first method used the amplitude of the reflected IR-UWB signals.[5] Respiration causes changes in the body cavity, lung volume, and the contour of the anterior chest wall, resulting in changes in the characteristic impedance, which affects the signal reflection, and in the reflection pattern, thus also changing the amplitude of the reflected IR-UWB signals. The second method used the time of arrival (TOA) to determine respiration rate.[6] During respiration, the lungs and chest wall contract or relax, resulting in change in the TOA. Some other methods were related to the optimization or application of TOA information as follows: a) Wavelet transform based position selection in the reflected IR-UWB signals for optimization of TOA analysis; b) TOA analysis using correlation receiver; and c) TOA analysis based on the correlation of successive reflected IR-UWB signals.[7-9] Existing methods utilize either the amplitude characteristic or the TOA characteristic of the reflected IR-UWB signals.

This paper presents a joint amplitude- and TOA-based respiration rate estimation method using IR-UWB radar signals. The proposed method utilizes two characteristics of reflected IR-UWB signals. First, both the maximum amplitude and TOA of reflected IR-UWB signals provide respiration rate information regardless of the body movement. Second, the frequency components of the respiration are concentrated in a narrowband. By combining the amplitude and TOA information obtained using existing methods, the discrimination of respiration information can be significantly improved over those of existing methods.

In Section Ⅱ, joint amplitude- and TOA-based respiration rate estimation method is proposed. Section Ⅲ presents the experiment results. Finally, conclusions are presented in Section Ⅳ.

Ⅱ. Joint Amplitude- and TOA-based Respiration Rate Estimation

This section analyzes how the spectral characteristics of various types of body-rocking affect the respiration rate. In [5], it was shown that the temporal sequence of the maximum amplitude related information of reflected IR-UWB signals provides respiration rate information. The maximum amplitude of reflected IR-UWB signals is written as

$$r_a(t) = MAX\{r(t,\tau)\} \quad (1)$$

where $r(t,\tau)$ denotes the reflected IR-UWB signals. t

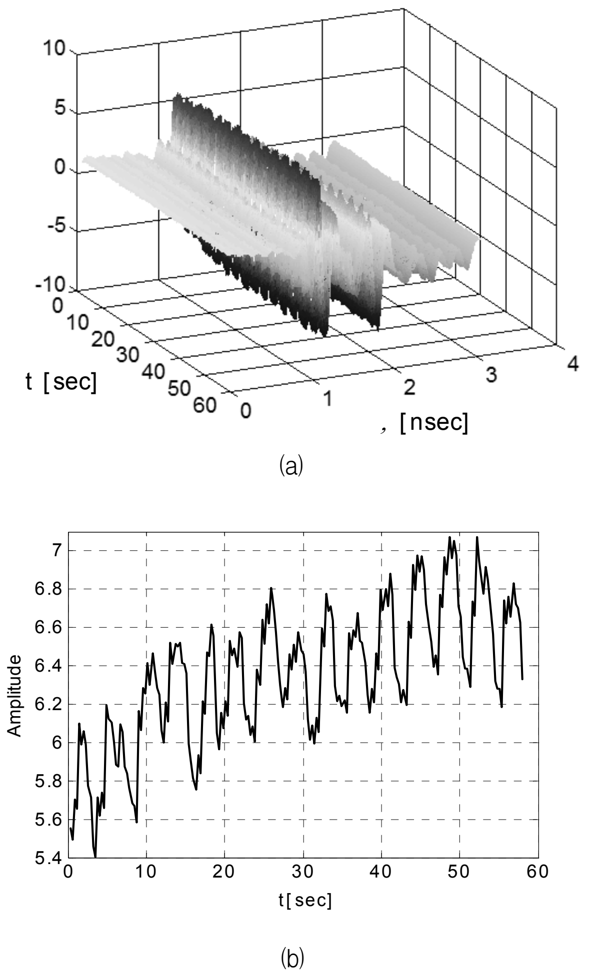


그림 1. IR-UWB 신호의 반사 신호의 측정결과.
(a) $r(t,\tau)$ and (b) $r_a(t)$

Fig. 1. Measured reflected IR-UWB signals.
(a) $r(t,\tau)$ and (b) $r_a(t)$

denotes slow time in the order of seconds. t is used to represent the information between received IR-UWB signals. τ denotes fast time in the order of picoseconds. τ is used to represent the information within each received IR-UWB signal. Fig. 1 shows $r(t,\tau)$ and $r_a(t)$.** We find that respiration rate information may be obtained from $r_a(t)$. $r_a(t)$ is affected by the characteristic impedance of the human body; the variation of body cavity and lung volumes by breathing varies the distance between biological tissues such that the dielectric properties are varied [6]. Consequently, the characteristic impedance is varied. In addition, $r_a(t)$ is affected by the reflection pattern, which is related to the contour of the anterior chest wall.*** Now, we analyze how body swing, twist (b_{st}) affects the respiration rate. If breathing is stable, then the characteristic impedance and the reflection pattern may vary periodically. However, in reality, these periodicities may be varied due to b_{st}, so that $r_a(t)$ can be written as

$$r'_a(t) = (1 + e_m(t))r_a(t) \tag{2}$$

where $r'_a(t)$ denotes the temporal sequence of the maximum amplitude of reflected IR-UWB signals with b_{st} and $e_m(t)$ denotes the relative scale factor for $r_a(t)$ due to b_{st}. The Fourier transform of $r'_a(t)$ is written as

$$R'_a(f) = R_a(f) + E_m(f) * R_a(f) \tag{3}$$

where $R_a(f)$ and $E_m(f)$ are the Fourier transform of $r_a(t)$ and $e_m(t)$, respectively. * denotes the convolution operation. By analyzing (3), we find that the Fourier transform of $r'_a(t)$ can be modeled as the sum of $R_a(f)$, which provides the respiration rate information regardless of b_{st}, along with weighted superposition of frequency-shifted copies of $R_a(f)$.

In [6], it was shown that the temporal sequence of the TOA of IR-UWB signals provides respiration rate information. The received IR-UWB signal can be modeled as the convolution of the transmitted IR-UWB pulse and the channel impulse response, which consists of static environmental components and time-varying respiratory components. Thus, it is written as [3]

$$r_T(t,\tau) = p(\tau) * h(t,\tau) = \sum_i \alpha_i p(\tau - \tau_i) + \alpha_b p(\tau - \tau_b(t)) \tag{4}$$

where $p(\tau)$ denotes the transmitted IR-UWB pulse and $h(t,\tau)$ denotes the channel impulse response. τ_i and a_i denote the channel impulse delays and corresponding channel impulse response coefficients, respectively, associated with static environment. And, $\tau_b(t)$ and a_b are the impulse delay and impulse response coefficient associated with respiration, respectively. In order to estimate respiration rate information from reflected IR-UWB signals, it is necessary to eliminate background clutter. $r'_T(t,\tau)$ is the background clutter removed signal of $r_T(t,\tau)$. The Fourier transform of $r'_T(t,\tau)$ at $\tau=\tau_0$ with respect to t is written as [6]

$$R'_T(f,\tau_0) = \alpha_b \sum_{l=-\infty, l\neq 0}^{\infty} \delta(f + lf_r) G_l(2\pi\tau_d) + (\alpha_b G_0(2\pi\tau_d) - r'_{T,0}(\tau))\delta(f) \tag{5}$$

where

$$G_l(\beta) = \int_{-\infty}^{\infty} J_l(\beta v) P(v) dv \tag{6}$$

where τ_d denotes the maximum deviation of TOA, and $J_l(x)$ is the Bessel function of first kind of l-th order. $P(\upsilon)$ is the Fourier transform of $p(\tau)$ with respect to τ. $r'_{T,0}(\tau)$ denotes the average of the time varying component $p(\tau-\tau_b(t))$ along the slow time t. However, if a body rocks back and forth (b_r), then the channel impulse response may be delayed or

** In Fig. 1, the respiration rate of the participant is approximately 16 breaths per minute. A reflected IR-UWB signal is sampled using 1024 points with a sampling period of 3 psec. Two-hundred reflected IR-UWB signals are measured, and the time interval between temporal sequences is equal to 0.3 sec.

*** The reflection pattern indicates the effect of body shape on the radar cross section (RCS).

advanced independent of the respiration. Now, we analyze how b_r affects the respiration rate. In reality, the channel impulse response with b_r is written as

$$h_w(t,\tau)=\sum_i \alpha_i \delta(\tau-\tau_i)+\alpha_b \delta(\tau-\tau_b(t)-w(t)) \tag{7}$$

where $w(t)$ denotes the delay or advance in time due to b_r. Using (7), $r_T(t,\tau)$ in (4) is written as follows:

$$\begin{aligned} r_{T,w}(t,\tau) &= p(\tau)*h_w(t,\tau) \\ &= \alpha_b p(\tau-\tau_b(t)-w(t))+\sum_i \alpha_i p(\tau-\tau_i) \end{aligned} \tag{8}$$

Utilizing the method described in [6], the Fourier transform of the background clutter removed signal of $r_{T,w}(t,\tau)$, designated as $r'_{T,w}(t,\tau)$, at $\tau=\tau_0$ with respect to t is written as****

$$\begin{aligned} &R'_{T,w}(f,\tau_0)= \\ &\alpha_b \sum_{l=-\infty}^{\infty}\sum_{k=-\infty}^{\infty} \delta(f+lf_r+kf_w)\int_{-\infty}^{\infty} J_l(2\pi v\tau_d)J_k(2\pi v\tau_w)P(v)dv \\ &-r'_{T,0}(\tau)\delta(f) \end{aligned} \tag{9}$$

where f_w denotes the rate of b_r. τ_w is the variation in TOA due to b_r.

By analyzing (3) and (9), we find that body-rocking information does not distort the respiration rate and exists at integer multiples of the body-rocking rate from the respiration rate, consequently some portion of the signal power is concentrated in respiration rate and its integer multiples. And, since the affect of body-rocking to the maximum amplitude and the TOA information is different according to the body-rocking types, i.e., b_{st} or b_r, spectral characteristics of body-rocking are different for the maximum amplitude and the TOA based respiration rate information. Hence, the amplitude and the TOA information can perform bandpass filtering to each other. It is different from a conventional bandpass filtering, in which the center frequency of input signal and BPF is not varied. On the contrary, a respiration rate varies depending on people and breathing conditions. In order to decrease the unwanted frequency components in the maximum amplitude and the TOA information, it is necessary a BPF, varying the center frequency according to the respiration rate. Consequently, the respiration frequency components are remarkably increased. In the proposed method, the output temporal sequence is written as

$$r_c(t,\tau_0)=r'_a(t)*r'_{T,w}(t,\tau_0) \tag{10}$$

where * denotes the convolution operation.

Ⅲ. Measurement Results

표 1. 하드웨어 실험 환경
Table 1. Hardware measurement setup.

Parameter		Value
Transmission waveform		Monocycle
Transmission signal bandwidth		3-4GHz (@-6dB level)
Transmission power		24 dBm
Pulse repetition frequency (PRF)		250 kHz
Antenna	Type	Bow-Tie Phase-array antenna with reflector
	Frequency range	3.1-10.6 GHz
	Gain	4.5 dBi @ 3.1 GHz
	Dimension (WxHxL)	115 x 145 x 30 mm

Table 1 summarizes the hardware measurement setup. Fig. 2 shows the fast Fourier transform (FFT) of $r_c(t,\tau_0)$ with respect to t. Additionally, FFT of the signals obtained using the existing methods is also presented for performance comparisons. Fig. 3 shows, for another measured data, the measured temporal sequence of reflected IR-UWB signals and the FFT of $r_c(t,\tau_0)$ with respect to t.***** Using the proposed

**** In (9), $w(t)$ is modeled as a sinusoidal signal to facilitates the analysis of the affect of body-rocking on the respiration rate estimation in frequency domain.

***** In Fig. 3, the actual respiration rate of participant is 28 breaths per minute. A reflected IR-UWB signal has 1024 points with a sampling period of 3 psec. Two-hundred reflected IR-UWB

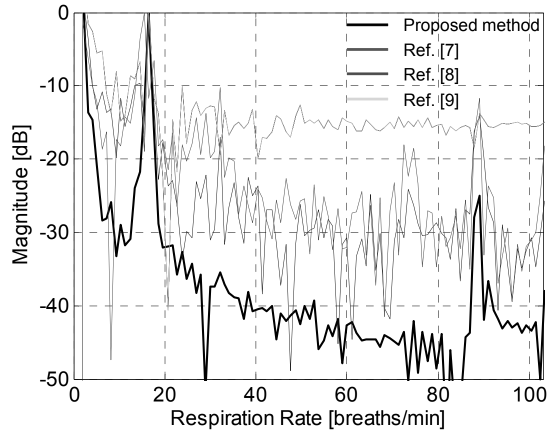


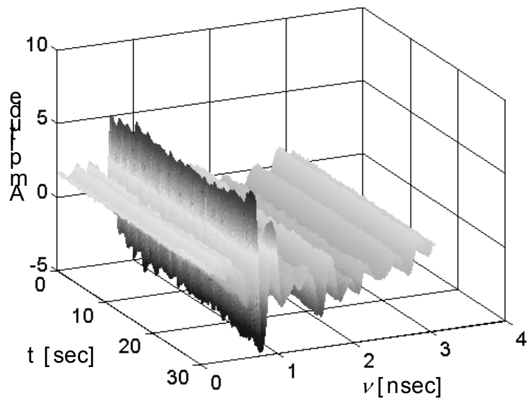
그림 2. Fig.1의 측정 신호로부터 추출한 시간 정보 신호의 FFT 스펙트럼 및 기존 방법과의 비교.
Fig. 2. FFT spectrum of the output temporal sequence of proposed method and other existing methods for the reflected IR-UWB signals shown in Fig. 1.

method, any unexpected frequency components are reduced, and thus the respiration frequency components are improved by more than 10dB compared with those obtained using other existing methods.

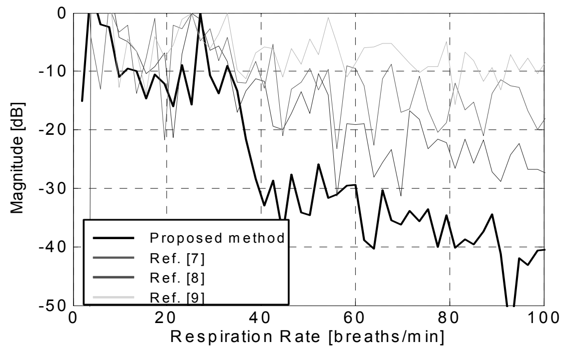
Ⅳ. Conclusions

This paper has proposed a joint amplitude- and TOA-based respiration rate estimation method for IR-UWB radar signals. It has shown that body-rocking information does not distort the respiration rate and exists at integer multiples of the body-rocking rate from the respiration rate. Utilizing this analysis result, the convolution of the temporal sequence of the maximum amplitude and that of TOA has been proposed. The analysis results of the measured data have shown that the respiration frequency components are improved by more than 10dB compared with those obtained using other existing methods.

signals are measured, and the time interval between temporal sequences is equal to 0.15 sec.



(a)



(b)

그림 3. 두 번째 측정 신호에 대한 분석 (a) IR-UWB 반사 신호의 출력 시간 정보 측정 결과, (b) 측정 신호로부터 추출한 시간 정보 신호의 FFT 스펙트럼 및 기존 방법과의 비교.
Fig. 3. Analysis of second measured data (a) Measured temporal sequence of reflected IR-UWB signals, (b) FFT spectrum comparison of the output temporal sequence of proposed method and other existing methods.

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