

HEARTBEAT AND RESPIRATORY MONITORING USING STANDING WAVE RADAR AND INDEPENDENT COMPONENT ANALYSIS

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Abstract - In this paper, we propose a non-contact vitals monitoring method, applying the independent component analysis (ICA) to the standing wave radar. In the proposed method, by observing a standing wave generated by the transmitted wave from the radar and the reflected wave from a target, it is possible to detect respiration and heartbeat. Although it was difficult to detect the small heartbeat component, compared to the respiratory component, application of the time delayed signals in the ICA, made it possible to separate the two components from the mixed signal. It is confirmed by simulation and experiment that the proposed method is effective.

Index Terms — standing wave radar, independent component analysis, vitals monitoring.

1. Introduction

For the health management of hospitalized patients and the bedridden elderly, the monitoring of heartbeat and respiration is important. Previously, heartbeat and respiration were monitored using wired contact sensors. However, wired contact sensors constrain the motion of the patient, and thus tie him to the bed. It is possible to perform the monitoring of cardiac and respiratory signs by using non-contact radar, which has no restraining effects. Although various monitoring methods using a radar have been proposed, accurate separation and detection of a heartbeat with a small motion remain a problem.

In this paper, we propose a non-contact vitals monitoring method using a standing wave radar [1]. In the proposed method, breath and heartbeat is detected by observing a standing wave, caused by the emitted wave from the radar and the reflected wave from the target. By applying the independent component analysis (ICA) [2] to the distance measuring results by the radar directly, it is possible to separate the two components from the mixed observation signals (consisting of the respiratory component and the cardiac component). As many observation signals are required in the ICA, a delayed version of the observed signal is used as a virtual observation signal. We show the effectiveness of the proposed method by simulation and experiment [3].

2. STANDING WAVE RADAR

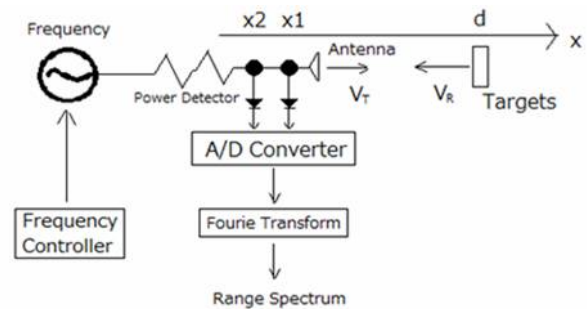


Fig.1 Standing wave radar

The configuration of the standing wave radar is shown in figure1. When the amplitude and frequency of the incident wave, and speed of light are denoted by $A, f,$ and $c,$ the incident wave is expressed by

$$V_T(f, x) = A e^{j2\pi f(t - \frac{x}{c})} \quad (1)$$

where, the coordinates of an arbitrary point on the x - axis is defined as $x = 0$. We change the frequency, stepwise, from $f = f_0 - f_w/2$ to $f = f_0 + f_w/2$. When the distance to the k -th target, the amplitude ratio, and phase difference between the reflected wave and the emitted wave at an arbitrary point on the x - axis is denoted as $d_k, \gamma_k,$ and $\varphi_k,$ respectively, the reflected wave is expressed by

$$V_R(f, x) = A \gamma_k e^{j\varphi_k} e^{j2\pi f(t - \frac{2d_k - x}{c})} \quad (2)$$

When we use the standing wave power $p(f, x_1)$ at $x = x_1$ as the real part and the standing wave power $p(f, x_2)$ at $x = x_2$ as the imaginary part, and assume that $\gamma_k \ll 1,$ and $f = f_0 - f_d, (-f_w/2 < f_d < +f_w/2),$ then, the composite signal $p_a(f_d)$ can be expressed as a function of $f_d,$

$$p_a(f_d) = 2A^2 \left\{ \sum_{k=1}^n \gamma_k \frac{4\pi d_k}{c} e^{j\left(\frac{4\pi(f_0 + f_d)d_k}{c} - \varphi_k\right)} \right\} \quad (3)$$

As $p_a(f_d)$ is a periodic function, whose period is inversely proportional to the distance from the target, the distant spectrum ($P(x)$), can be achieved using Fourier transform. We can estimate the distance to the target based on the peak position.

$$P(x) = 2A^2 f_w \sum_{k=1}^n \gamma_k \frac{4\pi d_k}{c} e^{-j\varphi_k} e^{j\frac{4\pi f_0 d_k}{c}} \text{sinc} \left(\frac{2\pi f_w}{c} (x - d_k) \right) \quad (4)$$

3. INDEPENDENT COMPONENT ANALYSIS

ICA is a method that estimates the original signal source by using only the observed data. Here, a plurality of signal sources that are statistically independent is assumed. When $N(\geq 2)$ signal sources $\mathbf{s}(t) = [s_1(t), s_2(t), \dots, s_N(t)]^T$, and N observations $\mathbf{x}(t) = [x_1(t), x_2(t), \dots, x_N(t)]^T$, are expressed using the unknown transform matrix (A) by,

$$\mathbf{x}(t) = A\mathbf{s}(t) \quad (5)$$

then, in the separated modeling, the separated signal, $\mathbf{u}(t) = [u_1(t), u_2(t), \dots, u_N(t)]^T$, is expressed using the separated matrix (W) by

$$\mathbf{u}(t) = W\mathbf{x}(t) \quad (6)$$

An ICA algorithm generates the separated signal ($\mathbf{u}(t)$) by sequentially updating the separation matrix (W) such that $\mathbf{u}(t)$ is statistically independent from the mixed signal ($\mathbf{x}(t)$). In the frequency domain, the separation model can be expressed as,

$$u(\omega, t_s) = W(\omega)x(\omega, t_s) \quad (7)$$

In this study, W is estimated by applying the FastICA algorithm to each component in the spectrogram $x(\omega, t_s)$

4. Experiments

(1) Experimental System

PSR148 by the PTM Corporation is used as the standing wave radar. Specifications of the radar are shown in Table 1. We performed the measurements in real time by inputting the response of the radar into the PC. C # is used to communicate between the radar and the PC. ICA Accord .NET Framework of Independent Component Analysis Class has been used. The measurement results are sent to the PC every 70ms. The experimental scenery is shown in figure 4. The distance between the target and the radar is 1.2 m. The heart rate was 1.19 Hz before the experiment.

Table 1. Specification of PSR148

Frequency	24.05~24.25GHz
Bandwidth	180MHz
Output	4mW
Beam width	12°(horizontal) 25°(vertical)
Sidelobe	-15dB
Aperture	30 element patch array
Range	0~100m
Range resolution	10μm or less

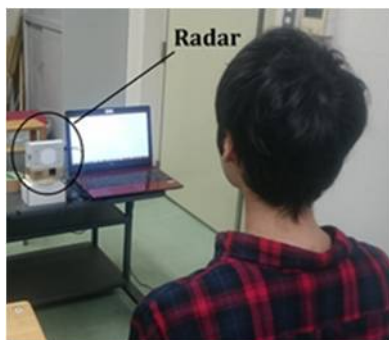
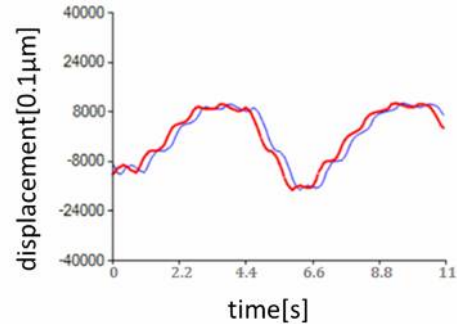


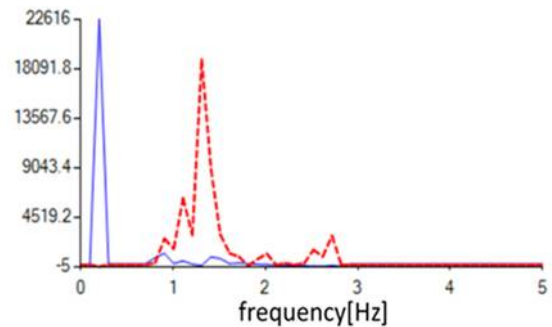
Fig.2 Experiment Scene

(2) Experimental Results

The distance measurement results in the case of a real person are shown in figure 3. In the time domain display in figure 3(a), the measurement results and 3-sample delayed waveform are overlaid. We treated these signals as two observation signals. By applying the proposed method, the spectrum clearly appears at 0.33 Hz and 1.17 Hz, as shown in figure 3(b).



(a) Measurement results (red) and 3-sample delayed waveform (blue)



(b) Spectrum for heartbeat (red) and respiratory (blue)
Fig.3 Experimental Results

5. Conclusion

By applying ICA to the standing wave radar, it was possible to detect the small heartbeat vibrations in addition to the breathing. At present, it is not possible to detect the heartbeat accurately when electromagnetic waves are not irradiated in the front upper body. In the future, we would like to perform improvements.

References

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