Path Loss Compensation Method for Multiple Target Vital Sign Detection with 24-GHz FMCW Radar

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***Abstract*—Over the past few decades, Doppler radar has attracted attention in biomedical and healthcare applications because of the benefits of a non-contact vital sign sensor. Though Doppler radar has the high sensitivity for physiological signals, multiple target problem is one of the inevitable issue in a non-contact vital sign sensor. In this paper, we proposed a non-contact vital sign sensor for multiple subject based on 24 GHz frequency-modulated continuous-wave (FMCW) radar. Since FMCW radar can extract the range and velocity of the target, it is possible to detect each vital sign by signal separation according to the position of the target. A signal amplitude difference from a plurality of targets is corrected by the signal processing according to the radar equation. The measured results validate the possibility of multiple vital sign sensor. We expect that our proposed method can be feasible to utilize the application such as a driver monitoring system and a medical monitoring system.**

Keywords—FMCW radar, vital sign sensor, multiple subject, radar equation

I. Introduction

As the interest in a healthcare system increased, lots of studies are performed with regard to a sensing method of the physiological signal, such as respiration, heartbeat, blood glucose, and so on. Among these studies, continuous-wave (CW) Doppler radar has received attention owing to an advantage of microwave characteristics including non-contact and penetration characteristics [1-3].

The principle of CW Doppler radar, which uses a single frequency, is the phase shift detection caused by vibrating body. The phase shift can be transformed into vital signs including respiration and heartbeat. Because Doppler radar has high sensitivity and long detection range, it can be used for disaster relief by detecting survivors buried underground. In medical application, it is feasible to monitor sudden infant death syndrome (SIDS) and sleep apnea, or to diagnose patients with severe burns that are difficult to wear a sensor. However, When CW Doppler radar receives multiple signals from a plurality of subjects, it is hard to distinguish where each signal comes from because of the impossibility of the range detection. To solve this problem, FMCW radar with rotating system is proposed [5]. This system can detect the vital signs of multiple subjects at different angular positions. However, it is still difficult to detect multiple targets within a beam width. In this paper, we proposed a vital sign sensor based on FMCW radar with a simple signal processing to distinguish multiple targets.

II. Theory of Operating System

The fast-time Fourier transform of the baseband beat signal can be written as [6]

$$S_b(f) = A\exp\left[j\left(\frac{4\pi f_c R(\tau)}{c}+\phi_0\right)\right]\mathrm{sinc}\left[T\left(f-\frac{2mR(\tau)}{c}\right)\right] \quad (1)$$

where A is the amplitude of the received signal, f_c is the carrier frequency, τ is the slow time, m is the frequency modulation slope, and ϕ_0 is the residual video phase, which is insignificant factor. The beat frequency f_b inferred from (1) can be transformed into the target range. In addition, the vital sign can be detected from the phase history of $S_b(f_b)$ in slow time domain once the beat frequency is accurately detected.

For multiple targets, the baseband signal is the sum of the beat signal generated from each target. It can be expressed as

$$S_b(f) = \sum_{n=1}^{N} A_n \exp\left[j\left(\frac{4\pi f_c R_n(\tau)}{c}\right)\right]\mathrm{sinc}\left[T\left(f-\frac{2mR_n(\tau)}{c}\right)\right]. \quad (2)$$

Since the beat signal is the sum of the sinc function, the global maximum of the m-th sinc function is interfered with the local maximum of the other sinc functions. Besides, A_n becomes smaller as the target range is farther. It means that it is difficult to detect the range of a distant target when there are multiple targets.

To resolve this problem, the signal processing is performed to minimize the effect of A_n. In consideration of the radar equation for a distributed target [7], A_n is

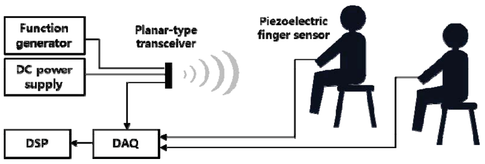

Fig. 1. Configuration of measurement setup.

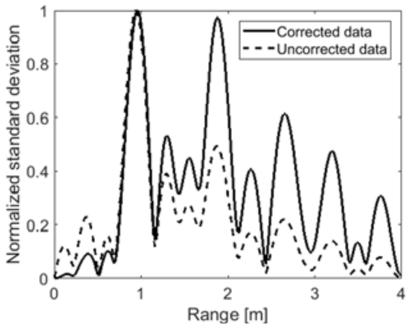

Fig. 2. Standard deviation of the range spectra when the target is at 1 m and 1.8 m.

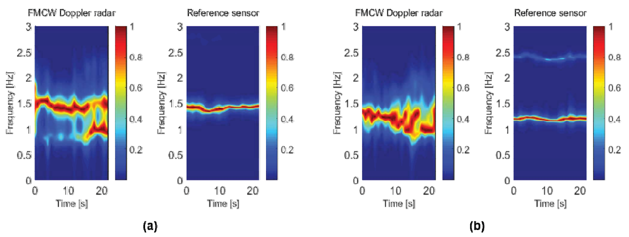

Fig. 3. Vital sign monitoring data filtered with 1-3 Hz bandpass filter. (a) target 1 at 1 m. (b) target 2 at 1.8 m.

$$A_n \simeq \sqrt{\frac{P_t G^2 \lambda^2}{(4\pi)^3 R^4}\sigma} = \sqrt{\frac{P_t G^2 \lambda^2}{(4\pi)^3 R^2} \frac{\pi c \theta^2}{16 B \ln 2} \sum_{\text{unit volume}} \sigma} \quad (3)$$

where P_t is the transmitted power, G is the antenna gain, s is the radar cross section (RCS), λ is the wavelength, θ is the angular beam width, B is the bandwidth. According to the radar equation, when the beat signal is corrected by multiplying R, the vital sign sensor using FMCW radar can detect each target range regardless of the target range.

III. Experimental Results

Experiments are performed in an indoor environment with two people sitting on each chair. To assume a simple situation, two people were sustaining a stationary state. The modulation frequency is 100 Hz. The frequency sweeps from 24.05 GHz to 24.25 GHz, that is, 200 MHz bandwidth. The distance between the targets is farther than the theoretical range resolution of 0.75 m. They are located at 1 m and 1.8 m respectively. To validate the measured results, the commercial piezoelectric finger sensor (UFI-1010) is used for reference data.

To suppress the clutters, the standard deviation of the range spectra. Fig. 2 represents the results of range estimation by the normalized standard deviation of range spectra. In uncorrected data, it is unrecognizable to be located at 1.8 m because the signal is buried in the local maximum of another sinc function. The range of the two targets appears clearly in the data multiplied by the range. The peaks without the target range are surrounding clutter and the sum of sinc function's local maxima.

The vital signs are extracted the phase history of each peak point. To compare with the reference data, the signals are filtered with 1-3 Hz bandpass filter to remove respiration and its harmonics. The continuous time data with window size is 8 s having 7 s overlap is shown in Fig. 3. Fig 3. shows good agreement between the vital sign sensor using FMCW radar and the reference sensor. The strongly appearing signals in other frequency are estimated to be caused by motion artifacts.

IV. Conclusion

This paper proposed the multiple vital sensor with a simple signal processing based on FMCW radar. Using the radar equation for the distributed target, a weak signal, which comes from a distant target, is simply corrected. It can supplement a weak point of conventional vital sensor based on FMCW radar. This system can detect the target range for the multiple targets within the beam width of antenna. In addition, vital sign sensor can extract the vital signs according to each range. We expect that this system is used in various biomedical system such as medical surveillance and driver monitoring system.

Acknowledgment

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2017R1A2B2011724).

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