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Radar Signal Processing Scheme for Human Identification

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Abstract. This paper proposes a radar signal processing scheme to simultaneously detect gait-rate of moving human and vital signal of stationary human. To verify the algorithm, we implement as control software a data acquisition system (DAQ) and algorithm in a Personal Computer (PC) for real-time working. The results show the extracted breathing rate and gait-rate. Based on the feature vectors, we can classify each human with 82% accuracy.

Keywords; radar, CW radar, radar signal processing, human detection

1. Introduction

Radar sensors are a major defense technology used to detect the range and velocity of objects using microwave echo signals. Today, in the commercial area, radar sensors have been used in various applications. However, current killer applications of radar sensors have been limited to smart cars [1]. Recently, with smart platforms such as smart buildings, smart homes, and smart cities, radar sensors are being applied to various fields such as home appliances, lighting, and security[2]. Optical based sensors such as camera and lidar are very sensitive the external environment, including weather and lighting conditions. Moreover, because sensors can generate privacy concerns, consumers are sometimes reluctant to use them [3]. Despite such concerns, radar sensors are robust against external conditions, and can directly detect range between radar and object and radial velocity of moving target.

Radar sensors can detect human vital signs [3]. But, because radar sensors have very low angle resolution compared with camera sensors, there is a limitation in classifying types of objects [3]. Moreover, unlike camera sensors, since radar sensors require

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customized hardware for individual applications, it is difficult to apply radar sensors to various areas. In spite of these limitations, radar sensors are very attractive solutions to detect humans. If radar sensors can easily classify humans among other objects, they can be applied to various smart applications. In addition, if radar sensors can identify individual persons using detected vital signs and motion signatures, radar sensors can become major sensors for surveillance and security applications.

One of the popular radar methods in the commercial area is the FMCW (Frequency Modulated Continuous Wave) method. FMCW can detect both ranges and velocities of multiple objects. However, the transceiver circuit is complicated and more power is consumed, due to the PLL (Phase Loop Look) component, than is consumed in CW (Continuous Wave) radar [4].

CW radar can be designed with a simple architecture, but it has a limitation in that it can detect only the velocity of a single object. However, the presence of moving humans and the vital signs of stationary humans can be easily measured with simple signal processing method [4]. Because the breathing signal has a very low frequency, which is close to the DC (Direct Current), it is difficult to design a sharp filter to remove only the DC signal and allow the vital signal to pass. Therefore, to detect vital signals using CW radar, we must install an LPF (Low Pass Filter) to remove only high frequency signals such as those of human motion. On the other hand, to detect a moving object with weak echo at long range, the amplifier must be connected to the baseband. At this time, DC and low-frequency signals must be removed to prevent signal saturation. It is thus impossible to simultaneously detect the motion of a moving human and the breathing signal of a stationary human using the conventional transceiver circuit of CW radar with a single baseband.

In this paper, we propose a human identification scheme using the detected breathing signal of a standing human and the gait-rate of a moving human with the designed CW radar front-end.

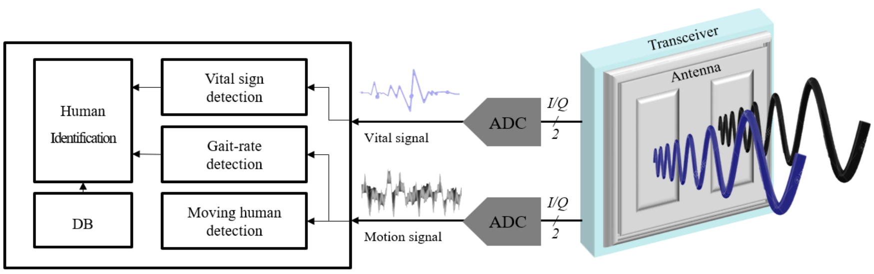


Figure 1. Designed radar platform concept

2. Proposed Method and Measurement Results

We employ the designed radar front-end module of the previous work [4]. The front-end module consists of trx antennas, an RF board, and an IF board, as shown in Figure 2. In the IF board, one I/Q channel is used to extract the vital signs and another I/Q channel is used to detect human motion. For that, in the first channel, by using a low-pass filter (LPF), only low frequencies including DC is allowed to pass. In the second channel, the DC signal is removed and only high frequencies pass through the DC block filter.

The center frequency of the radar front-end sensor is 5.8 GHz, the modulation method is CW, the antenna's field of view (FOV) ranges from -15° to +15°, and the maximum detection range is 15 m for moving targets and 1 m for respiration signals.

The designed radar front-module interface with an NI (National Instruments) vendor's DAQ (Data Acquisition) device. Two I/Q channels have a maximum sample rate of 1.25 MS/s through four analog input ports, and a timing resolution of 10 ns [5]. The software for DAQ control and the algorithm was implemented using the MATLAB tool in a PC for real time processing

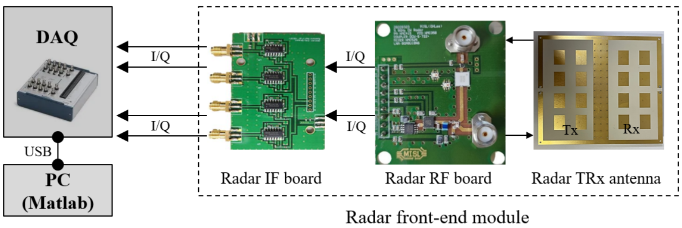


Figure 2. Designed radar verification configuration with front-end module

Figure 3 shows the designed radar signal processing concept. First, we designed the respiration signal detection scheme. Low frequency radar signals received from the front-end module were filtered out using a digital filter for noise cancellation. Then, the frequency spectrum was extracted through FFT (Fast Fourier Transform) and the vital frequency was extracted using peak detection.

Next, we designed a gait-rate detection method for a moving human using the high frequency radar signal. The sampled signal was applied to a low-pass digital filter including DC blocking; the frequency spectrum was generated using FFT. Then, we completed the micro-Doppler images together with a sliding window and conducted another FFT using data over the entire time frame to complete the cadence-velocity diagram (CVD). We also extracted two feature vectors from CVD: gait-rate and micro-Doppler.

We finally designed algorithms to classify between moving humans and other moving targets, and to extract velocity and movement direction. For the classification algorithm, we employed one from a previous work [6].

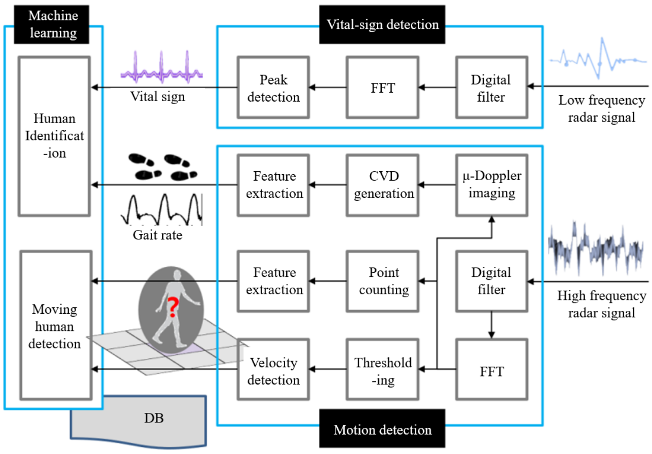
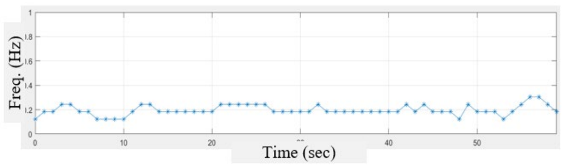


Figure 3. Designed radar signal processing concept

To verify the implemented system, experiments were conducted indoors. First, we considered the case of a stationary human at a 1m range in front of the radar module.

Figure 4 shows the measured breathing rate for three humans. The horizontal axis represents time, while the vertical axis represents frequency. In the results, we can find that the average vital frequencies are 0.196 Hz, 0.172 Hz, and 0.202 Hz, respectively.



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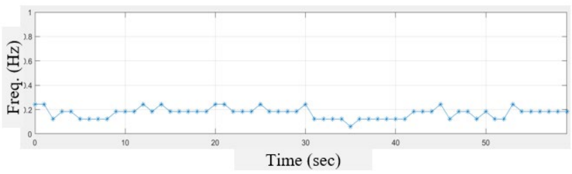

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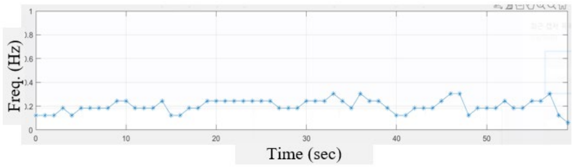
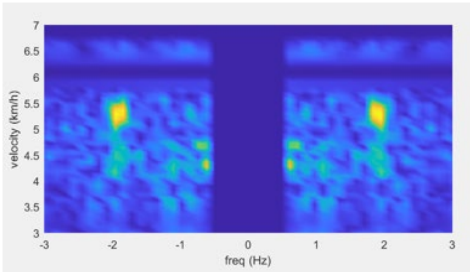


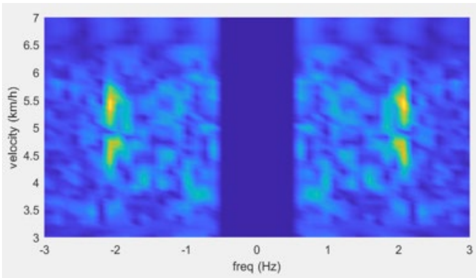
(c)

Figure 4. Extracted breathing signal of sationary human for three scenarios (a)~(c)

Figure 5 shows the generated CVDs for three moving humans. The x-axis shows gait-rate; y-axis is velocity. We can find difference of shapes and micro-Doppler bandwidths.



(a)



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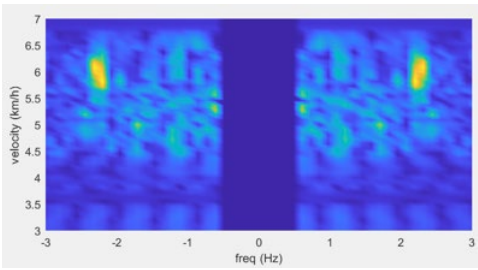

(c)

Figure 5. Generated CVD of moving human for three scenarios (a)~(c)

Based on the results shown in Figures 4 and 5, we extracted vital frequency, gait-rate, and micro-Doppler bandwidth. Using three feature vectors, we trained a database for binary-decision-tree machine learning. For that, we measured 100 frames for each human. We then randomly separated the three features for each human, with 80% for the training data set and 20% for the test set. We were able to obtain 82% classification accuracy to identify each human.

3. Conclusions

This paper proposed a human identification scheme using a designed Doppler radar. We designed algorithms to measure respiration signals of stationary humans and to extract gait-rate of moving humans.

We implemented a DAQ module and PC software to log the data in real-time and verify the algorithms. We conducted experiments in an indoor environment with three human subjects. We extracted the breathing rate of a stationary human, and gait-rate and micro-Doppler bandwidth of a moving human. Based on the feature vectors, we were able to obtain a classification accuracy of 82 % using machine learning.

Future research will consider various humans and many scenarios.

Acknowledgments

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