Cardiopulmonary Effective Radar Cross Section (ERCS) for Orientation of Sedentary Subject Using Microwave Doppler Radar

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***Abstract*— Effective radar cross-section (ERCS) for microwave Doppler radar, is defined by the reflected power from sections of the human body that undergo physiological motion. This paper investigates ERCS for human cardio-pulmonary motion of sedentary subjects at three different positions (front, back and side with respect to radar). While human breathing and heartbeat can be measured from all four sides of the body, the characteristics of measured signals will vary with body orientation. Thus, continuous wave radar with quadrature architecture at 2.4GHz was used to test a sedentary subject for three minutes from three different orientations: front, back and side with respect to radar. The results obtained from the tests showed that physiological motion could be obtained and that distinct patterns emerge due to the differences in the ERCS for each orientation. For the seated subject, back ERCS was higher than for front and side positions. Determining ERCS changes with position may enable determining body orientation with respect to the radar. This research opens further opportunities for development of high-resolution occupancy sensing and emergency search and rescue sensing, where the orientation of a human subject may be unknown ahead of time.**

***Keywords*—ERCS (Effective Radar cross-section), Radar cross section, Doppler radar, Orientation, Sedentary, Smart building**

I. Introduction

Physiological Doppler radar is a promising tool for medical monitoring, security applications, and smart buildings. Characterization of heartbeat and respiration rates and patterns at a distance is made possible with Doppler radar. Research studies have investigated optimum demodulation of the phase variation in the wave backscattered off a human torso [1]. Signal processing techniques were developed to successfully separate heart and respiratory signals, and accurately detect rates [2-3]. However, to recognize physical characteristics of the subjects such as orientation and body response to the illuminating wave, in order to make calibrated assessments of respiratory volume and other physiological quantities, under realistic monitoring conditions, radar cross-section is of immense importance. Previous studies of radar cross section of humans have included a man swinging on a platform [4] and pedestrians, to detect walking people in automotive applications [5]. The cardiopulmonary radar cross section of a human is a measure of the magnitude of the electromagnetic wave echoing back from the portion of the body moving due to cardiopulmonary activity. Similarly, to conventional radar cross section, it is affected by target geometry, orientation, and material composition. Prior research has investigated cardiopulmonary effective radar cross section (ERCS) [6] for recumbent subjects for sleep studies. In smart building systems, Doppler radar may be used to help control heating, ventilation, air conditioning (HVAC), and lighting, to help optimize energy use [8]. For such applications it is expected that human subjects will be mostly sedentary, and body orientation with respect to radar is not known ahead of time. Research has also been done also on measurement of physiological motions from four different body orientations for sedentary subject [9]. However no prior work has been done to investigate the effect of different body orientations on ERCS for sedentary subjects. In this paper, we investigate the ERCS changes due to different body orientations for sedentary subject using microwave Doppler radar system Theory.

A. *Quadrature Doppler Radar*

The CW Doppler radar motion sensor operation is based on capturing phase changes in the backscattered wave off the subject's torso that is phase modulated by the torso movement.

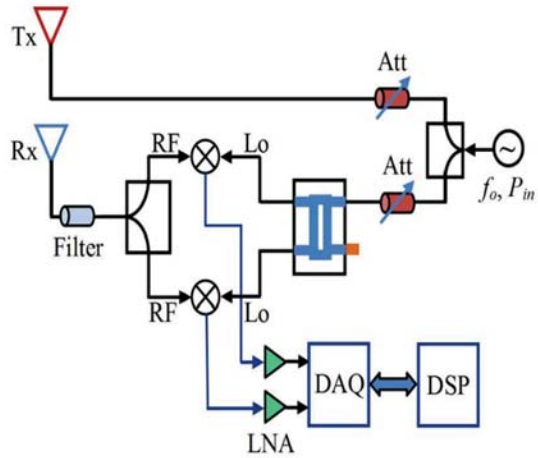

Fig. 1. Schematic diagram of the CW Doppler system deployed for human testing. The quadrature receiver acquires the in-phase and quadrature baseband signals independently (From [6]).

By comparing the phase of the reflected wave with the transmitted one, a baseband signal proportional to the displacement in the line of sight is obtained. In quadrature receiver configuration, shown in Fig. 1, the baseband signal is obtained from the two orthonormal components, namely the I-channel and Q-channel. I and Q channels may be combined using linear or non-linear demodulation technique. For ERCS purposes, non-linear or arctangent demodulation is used [3Mixing the local oscillator signal with the RF reflected wave results in the baseband signal, which in its quadrature form can be represented as:

$$I_{BB} = A\cos\left[\frac{4\pi f}{c}x(t) + \phi_{tot}\right] \quad (1)$$

$$Q_{BB} = A\sin\left[\frac{4\pi f}{c}x(t) + \phi_{tot}\right] \quad (2)$$

This configuration avoids having the phase demodulation accuracy highly fluctuating with distance, bouncing between null and optimum points [3]. In (1) & (2), x(t) is the chest motion composed of heartbeat and respiration, f is the local oscillator frequency, A is amplitude of the complex baseband signal, and ϕ_{tot} is the constant phase due to the fixed roundtrip distance and any initial phase.

B. *Effective Radar Cross section*

The measure of the power of the wave bouncing off a radar target with respect to the incident one is defined as the radar cross section (RCS). In human cardiopulmonary testing, the target is the surface of the torso moving due to respiration and heartbeat and results in an effective radar cross section (ERCS) [7]. In RCS, the wave reflected from the whole target is considered for measurement but in ERCS only wave reflected from the moving part of the chest due to cardiopulmonary motion of human is considered. The equation to calculate effective radar cross section, σ from all radar measurement parameter is:

$$\sigma = \frac{R^4}{Pin} \times \frac{1}{\Re} \times \left(\frac{A}{G}\right)^2 \quad (3)$$

where · includes total fixed loss in the system, G is low noise amplifier gain, P_{in} is input power, R is range of the radar. On the complex I-Q plot, the baseband quadrature signals (Eq. 1-2) form an arc that belongs to a circle centered at the origin. The radius of the circle is A, and the angle scanned by the arc corresponds to the time-varying phase in the argument of both the cosine and sine. The radius A is estimated using the center estimation algorithm implemented in three steps [6]. The role of center estimation algorithm is to find the circle to which the arc belongs and bring the center of the circle to the origin of the complex I-Q plot. The radius of the circle A is the magnitude of the baseband signals and corresponds to the reflected wave power which is proportional to the radar cross section. The radius is obtained by taking the root mean of $(I^2 + Q^2)$.

II. Experimental setup

A 2.4-GHz quadrature Doppler radar system was used for the experiment. The measuring system is monostatic included a signal generator and the following off-the-shelf coaxial components: antenna specialist patch antenna ASPPT 2988, with 60º by 80º beamwidth, two 0° power splitters (Mini Circuits ZFC-2-2500), one 90° power splitter (Mini Circuits ZX10Q-2-25-S+), and two mixers (Mini- Circuits ZFM-4212). The retrieved signal from human subject is split and fed into two mixers. The local oscillator is connected to a quadrature power divider, providing in phase and quadrature version of the signal. The post processing is performed in MATLAB platform.

Fig. 2. Setup for experiment inside an anechoic chamber. A subject sitting comfortably in front of doppler radar facing front at 1.1 m distance from radar

A healthy male subject was seated comfortably at 1.1 m from the radar (Fig. 2) on a chair without back support. The experiment procedures involving human subjects described in this paper were approved by the University of Hawaii Institutional Review Board, under protocol number CHS 14884. The radiating plane of transmitting and receiving antenna was perpendicular to the floor plane. The subject was measured while seated for three minutes in three different orientations (front, back, side) relative to Doppler radar. In each measurement scenario, the quadrature baseband signals were dc-coupled to the LNA's and dc cancelation was used. A system calibration procedure using spherical target [6] was used to quantify and compensate amplitude and phase imbalance for IQ channels.

III. Experimental Results

The sampling frequency of the data acquisition (DAQ) was 100 Hz. Baseband signals were filtered using FIR filter of the order of 1000. FFT was used on arctangent demodulated signal to find the breathing rates. Fig. 3 illustrates the raw data, demodulated signal and the FFT of the demodulated signal. The center estimation algorithm is applied to each data segment and the corresponding arc radius is obtained. For the subject, the calculated arc radius in back, front and side sitting positions with respect to the radar are 3V, 0.8V and 0.2V, respectively.

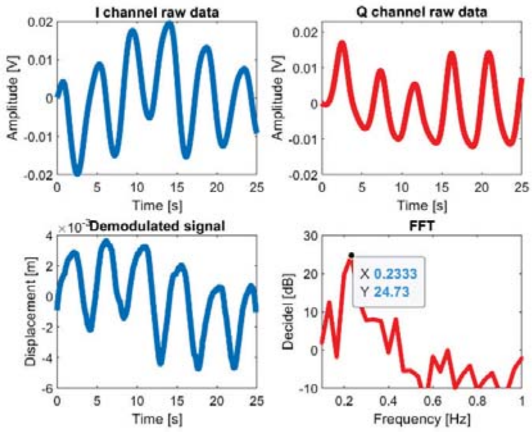

Fig. 3. Radar captured raw data channel signal (a) In-phase (I) channel signal (b) quadrature phase (Q) signal (c) arctangent demodulated signal of chest displacement (d) FFT of the signal where peak of the signal illustrates the breathing rate of .23 Hz.

In Fig. 4 radius of arc plots are shown for different subject orientations. From (3) it can be shown that, for a certain system ERCS is directly proportional to square of radius of arc. Since radius of arc for back is 3V, the largest and 0.2 V, the smallest for side orientation thus it is evident that ERCS is largest for the back orientation, and smallest for the side orientation. ERCS in back position is the largest due to difference in geometrical shapes of the front, back and side of the body. This result agrees with previous work on ERCS for recumbent subject where ERCS for lying face-down is larger than face-up [6]. As for the back of the body, the surface is flat enough to be modeled as a sheet with an area roughly equal to the chest breadth square. From literature [10] the RCS of a flat conducting sheet is larger than that of a cylinder of the same physical cross section area.

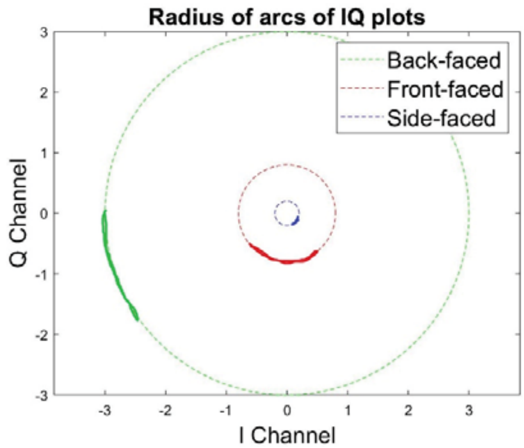

Fig. 4. Center-tracked radius of arcs for the subject in the front-faced, back-faced and side positions at 1.1-m range with 2.4 GHz carrier.

IV. Conclusion

Results showed that the effective RCS for three different seating orientation relative to Doppler radar is different. Back orientation exhibited the largest ERCS, while the side orientations resulted in the smallest ERCS. These results are consistent with previous findings for recumbent subjects. Further research will include more extensive human testing. These findings significantly extend the function of human Doppler radar cardiopulmonary monitoring, to provide robust comprehensive physiological monitoring capabilities for unattended subjects.

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