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Parametric Study of Antennas for Long Range Doppler Radar Heart Rate Detection

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Abstract—**This research presents results obtained from long range measurements of physiological motion pertaining to human cardiac and respiration activity. A pulse pressure sensor was used as reference to verify the results from radar signals. A motion detection and grading algorithm was used to detect the presence of heart rate. In addition to showing that human heart rate and respiration can be measured at distances of 21 and 69 meters respectively, the effect of antenna size, radiation pattern and gain on the range of the radar has also been studied.**

I. INTRODUCTION

Research involving Doppler radar monitoring of physiological motion has progressed from initial technology demonstration [1], to include developments relating to hardware [2-3], signal processing [4], and characterization [5-6]. A critical aspect of this research has been to examine the applicability of such monitoring for long range detection of life signs including respiration and heart rate. [7], heart rate variability assessment [8], as well as physiological monitoring of underwater subjects [9].

Characterization of these radar systems has often involved human (or animal) test subjects, which offers both benefits and drawbacks. Some of the benefits include realistic subject behavior and real world characterization, but these come at the cost of reduced repeatability in experiments over time and a general lack of control over the essential input to the system as it is tested.

Using artificial sources of motion (or phantom subjects), researchers can characterize radar systems under controlled conditions and compare details in performance that would otherwise be obscured by inter test variations of a human test subject. While prior work has already introduced this performance assessment technique for Doppler radar physiological sensors [5], the characterization was limited to a maximum antenna–target range of 30m and did not include results from human tests for comparison.

The use of a large antenna with high gain and narrow beam-width is very common for systems made for long range measurements. Antenna size is a very important factor is deciding the portability and the performance of a radar system. The research presented here discusses the results from new parametric analysis made in order to assess the tradeoffs between antenna size, pattern, transmit power and range for long range Doppler radar heart rate detection and suggests that better system performance can be obtained with the use of a smaller antenna with a lower gain as compared to a larger antenna with a high gain.

II. BACKGROUND

A. Doppler Radar

Doppler radar systems generally transmit a continuous wave signal while receiving and demodulating the signal's reflection from a target. Technically, Doppler theory works based on targets time varying movement with zero net velocity and echoed signal is phase-modulated in comparison to the position of the target rather than the velocity. The transmitted signal is a simple unmodulated carrier (continuous wave), and can be expressed as:

$$T(t)=cos\left(2\cdot\pi\cdot f\cdot t\right) \tag{1}$$

When reflected off the subject with small signal motion of x(t) at range d_0, the received signal will be [3]:

$$R(t)=cos\left(2\pi ft-\frac{4\pi d_0}{\lambda}-\frac{4\pi x(t)}{\lambda}+\phi\left(t-\frac{2d_0}{c}\right)\right) \tag{2}$$

With the RF wavelength of $\lambda=\frac{c}{f}$.

The demodulated signal can be expressed for one of the channels, with simplification, as [3]

$$B_I(t)=cos\left(\theta+\frac{4\cdot\pi\cdot x(t)}{\lambda}\right) \tag{3}$$

With the other channel, $B_Q(t)$, offset by $\lambda/4$ [3]

$$B_Q(t)=sin\left(\theta+\frac{4\cdot\pi\cdot x(t)}{\lambda}\right) \tag{4}$$

For the other using terms: $x(t)$ for subject range, λ for wavelength, and θ for the constant phase offset (all sources). The sources accounted in θ include: phase shift at reflection, phase delays in the radar hardware and the phase offset from the constant portion of the radar–subject range simplifying

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$x(t)$ to the small signal changes in range — the motion of the heart.

III. Experiment Setup

A. Radar

Quadrature Doppler radars at 2.45 GHz were used for this study. Two kind of the transmitting and receiving antenna used for experiment, 1) PA24-16, 380700279 panel antennas (29 cm x 29 cm x 2.5 cm) from Laird Technologies having 16 dBi gain and 26° E plane beam width, 2) ASPPT 2998 from Antenna Specialist™ (10.5 cm x 10 cm x 4 cm) having 8 dBi gain and 60° E plane beam width. The radar was constructed using connectorised parts from Mini-Circuits (ZFSC 2-2500 splitters, ZFM-4212 mixers and a ZX10Q-2-27 90splitter). An Agilent E4433B RF signal generator provided the LO and transmit power. The baseband data obtained from radar was passed through a low noise amplifier after which an NI USB-6009 data acquisition card was used with a computer and Labview software to record the data at a sampling rate of 100 Hz. Fig.1 shows the difference in the physical size of the two antennas used for experiments and the radar system arrangement is shown in Fig.2.

Experiments were performed in the hallway of college of engineering building of University of Hawaii at Mānoa to facilitate greater radar–target ranges (Fig.3). Experiments were performed mostly during night time to reduce clutter motion from other people nearby. Subject was located at 1, 3, 6, 9, 12, 15, 18, 21 and 24 meters from the radar and his heart rate was measured with a finger pulse sensor for reference. The subject was in a seated position and was asked to hold his breath for the duration of the experiment. The duration of measurements was 30 seconds.

B. Analysis and motion detection

The data obtained from radar was filtered using a bandpass filter with cutoff frequencies between 0.5 and 3.5 Hz for heart rate detection. After performing a Fast Fourier Transform on the data, a peak detection algorithm was used to find peaks. An assumption was made to consider the maximum signal content in the frequency range to be originating from cardiac activity of the subject. This was verified against the reference pulse pressure sensor. The detection algorithm is shown in Fig.4. The radar data was analyzed using MATLAB.

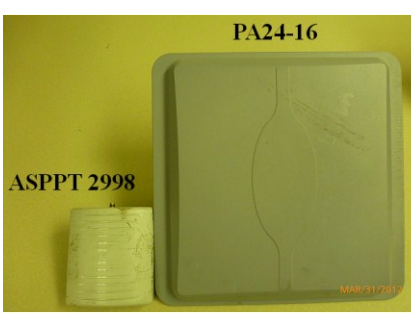

Fig.1. A photograph showing a comparison between physical size of PA24-16 (29 x 29 x 2.5 cm^3) and ASPPT 2998 (10.5 x 10 x 4 cm^3).

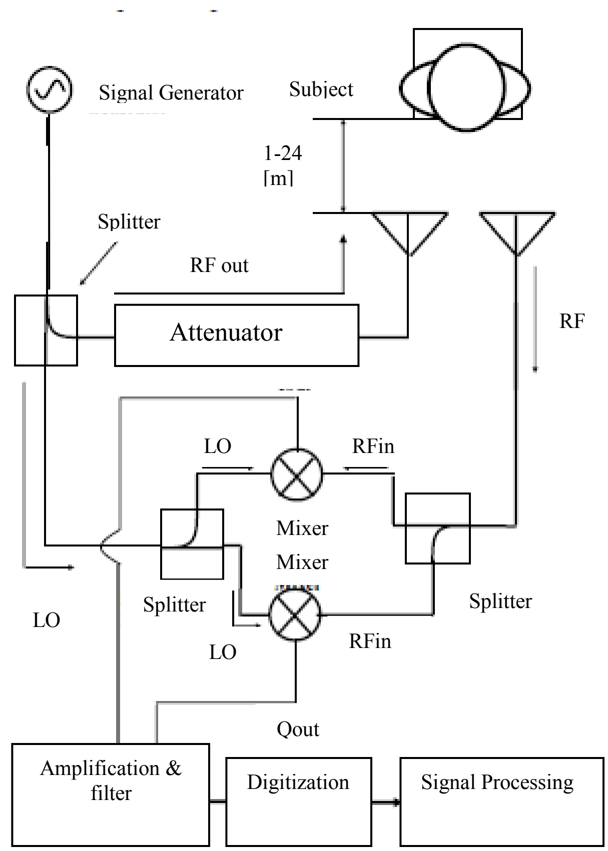

Figure 2. Block diagram of Doppler radar system with long rang approach

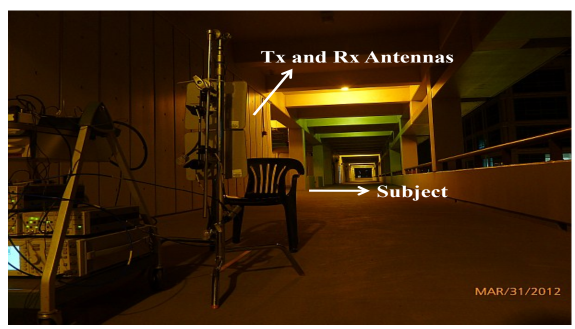

Fig.3. Experiment set up at night in the hallway of college of engineering. Note that the building is not completely isolated from variations in weather outside.

IV. Result

A. PA24-16 results

The transmitted power from signal generator was set to 13 dBm keeping in mind 16 dBi gain of the antenna. With PA24-16 antenna, the system was able to detect respiration at 69 m and heart rates at a distance of 18 m. Fig. 5 and Fig 6. Fig 6 shows the FFT of the linear demodulated data at 1m and 18 m respectively. Table I shows the result of the detection algorithm for different ranges. The algorithm failed to detect a heart rate at distances of 12 and 15 meters for one set of data. However, repeated measurements indicated that as an isolated problem since heart rates were detected successfully. This again highlights the usefulness of a phantom to characterize a system before human testing. Part of the problem could also be attributed to the use of bistatic radar system with large antennas having narrow beam-width.

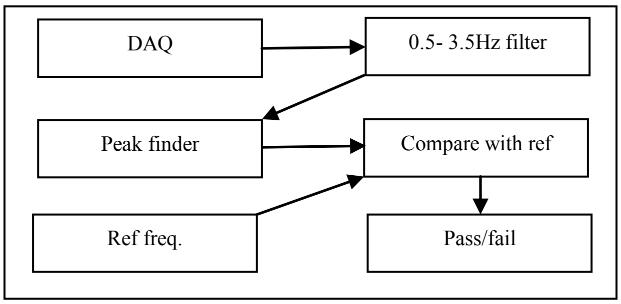

Figure 4.Motion detection and grading algorithm for heart rate detection.

A. *ASPPT 2998*

The measurements were repeated with ASPPT 2998 (Antenna B) that had a different radiation pattern and gain. Since the gain of the antenna is only 8 dBi, the transmitted power from the signal generator was increased to 18 dBm. Use of antenna B increased the maximum range to21 m as shown in Fig.5. The results of the motion gradient algorithm for ASPPT 2998 at different distances are also shown in table I. Again, the detection algorithm failed to detect heart rate at 12 meters for one set of data but was successfully detected in subsequent measurements.

Table I: Output from heart rate detection grading module

Range m	Antenna type A	Antenna type B
1	Pass	Pass
3	Pass	Pass
6	Pass	Pass
9	Pass	Pass
12	Fail/Pass	Fail/Pass
15	Fail/Pass	Pass
18	Pass	Pass
21	Fail	Pass
24	Fail	Fail

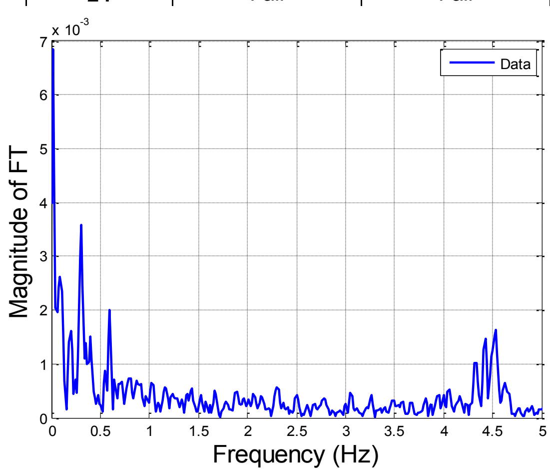

Fig.5. FFT of linear demodulated data showing detected respiration rate at approximately .27 Hz for 69m distance

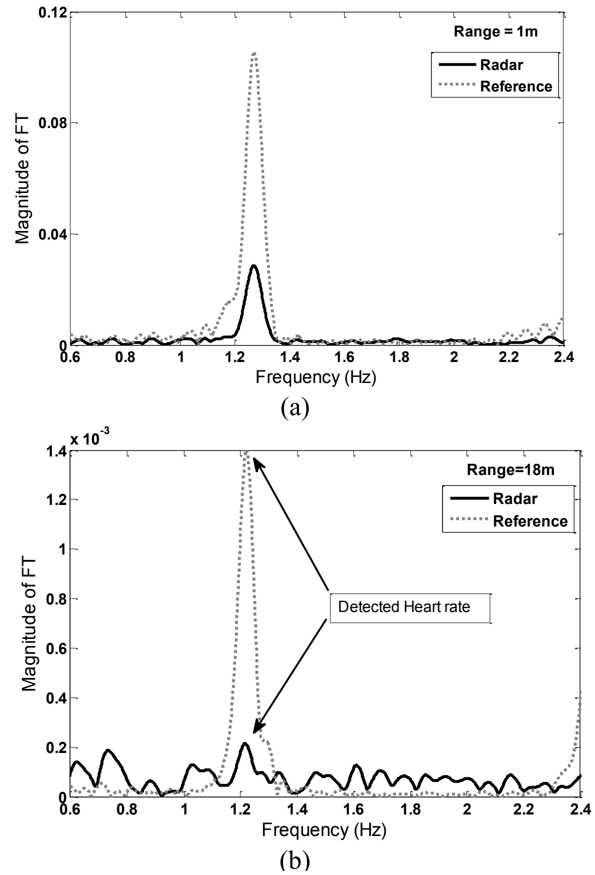

Figure 6. FFT of linear demodulated data showing detected heart rate at approximately 1.3 Hz for 1m distance (a) and for 18 m distance (b). Note that for 18 m distance, the reference FFT amplitude was divided by 100 in order to clearly display radar data.

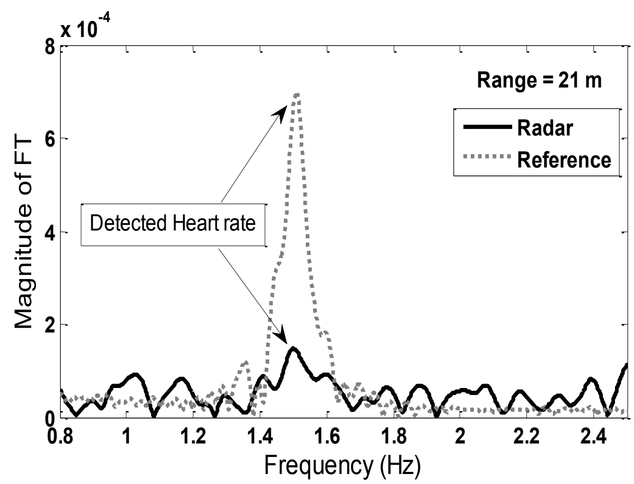

Fig.7. Detected heart rate at a range of 21m for ASPPT based system. The Reference amplitude was scaled down by 100 to display the data together with radar data.

V. CONCLUSION

Successful measurement of heart rate and respiration of a human subject at distances of 21 and 69 meters was made. It was observed that using a large antenna with narrow beam-width does provide some challenge in obtaining proper measurements with a bistatic radar system. The signal processing technique used to detect the presence of heart rate was very basic involving frequency analysis. Improvements in signal processing techniques could significantly improve the detection accuracy of the algorithm and may also help in extending the range of the radar. It would also be interesting to study long range heart rate detection system using a monostatic radar system with antenna A and antenna B.

The tradeoff in using a smaller antenna with a smaller gain is the availability of a higher power signal source or the inclusion of an rf amplifier in the transmitting chain. With PCB fabrication technology and surface mount components, circuits can be made very small and hence the size of antenna becomes an important factor. This study shows that smaller antennas could be positioned better for long range cardiac activity monitoring.

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