35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Packet Radar Spectrum Recovery for Physiological Signals

Ehsan Yavari, *Student Member,* Bryson Padasdao, *Student Member, IEEE*, Victor Lubecke, *Senior Member, IEEE*, and Olga Boric-Lubecke, *Senior Member, IEEE*

***Abstract*— Packet Doppler radar is investigated for extracting physiological signals. System on Chip is employed as a signal source in packet mode, and it transmits signals intermittently at 2.405 GHz to save power. Reflected signals are demodulated directly by spectral analysis of received pulses in the baseband. Spectral subtraction, using data from an empty room, is applied to extract the periodic movement. It was experimentally demonstrated that frequency of the periodic motion can be accurately extracted using this technique. Proposed approach reduces the computation complexity of the signal processing part effectively.**

I. Introduction

Doppler radar motion sensing system senses radio signal, which is back scattered from a target and then demodulates it in the receiver [1-2]. Physical movement caused by respiration and heartbeat of the human subject modulates the phase of the reflected signal, where it will be phase demodulated in the receiver to yield heart and respiration rate of the subject [3]. Non-contact vital sign monitoring has many potential applications such as: search and rescue for survivors under the rubble, infant monitoring [4], burn injury victims, sleep monitoring [5], tumor tracking [6], occupancy detection [7] and home healthcare monitoring [8].

Continuous wave (CW) radar systems transmit electromagnetic radiation at all instances while a pulsed radar system transmits signal intermittently and has wider bandwidth because of the pulses. CW radar can measure the instantaneous rate-of-change in the target's range and has a simpler topology; the narrow-band nature of the CW radar alleviates the requirements for the filters at each stage of the receiver and signal processing is straightforward for calculating velocity or displacement.

However, constantly transmitting and receiving make the separation of reflections impossible and increase power consumption. Leakage and clutter add unwanted DC offset and low-frequency noise [9]. Pulse radar can discriminate temporally leakage and echoes. Another advantage of pulsed radar is the ability to measure target range in addition to velocity [10]. Pulse radar is employed in [11] to get respiratory rate. However, due to non-uniform sampling rate of the receiver, a computationally expensive method is used to reconstruct the signal and extract the rate.

In this paper, the use of pulse radar, using packet data transmission is explored for detection of periodic motion. A frequency domain method based on subtraction of the clutter is proposed which is more straightforward and alleviate the signal processing part in the receiver. This method is used for recovering the periodic motion of the target which is buried in noise. Both simulation and experimental results using the mechanical target simulating respiratory and heart movements, demonstrate the proof of concept.

II. System Overview

The block diagram of a quadrature Doppler radar which is used to make measurements is shown in Fig.1. An RF transceiver from Texas Instruments was employed to transmit signal at 2.405 GHz. TI CC2530 chip uses ZigBee technology, which is a short-range, low power, and low data rate wireless network technology. The modulation format for the chip CC2530 is offset –quadrature phase shift keying (O-QPSK) with half-sine chip shaping. This is equivalent to MSK modulation. Each byte is divided into two symbols, 4 bits each. Each symbol is mapped to one out of 16 pseudorandom sequences, 32 chips each. The chip period is 1 us. Finally, the chip sequence is transmitted at 2 Mchips/s. The chip has the multiple access capability and uses carrier sense multiple access with collision avoidance [12].

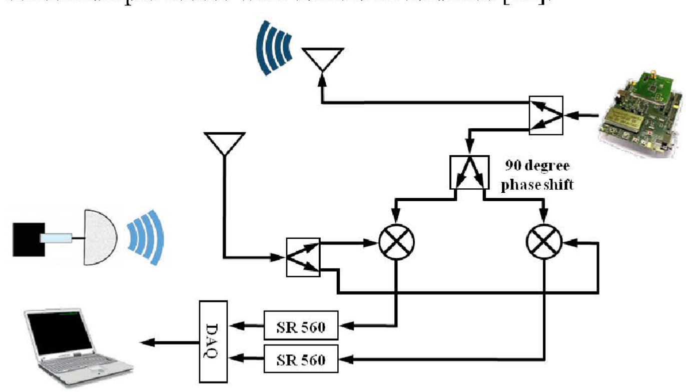

Figure 1. Block diagram of a quadrature Doppler radar system. The LO signal is divided by a two-way 90 power splitter to get two orthonormal baseband signals (I and Q).

A Minicircuits power splitter, part ZFSC-2-2500 provided 17 dB of isolation between input and output signals was used to split the signal source output into the transmitter antenna and local oscillator paths with 90 degree phase

* This work was supported in part by National Science Foundation under grants ECS-0702234 and ECCS-0926076, by the University of Hawaii Renewable Energy and Island Sustainability (REIS) Program, and by Department of Energy grant DE-OE0000394.

Ehsan Yavari is a PhD student at the Electrical Engineering department of University of Hawaii at Manoa, Honolulu 96822 USA (e-mail: ehsan@hawaii.edu).

Victor Lubecke is with Department of Electrical Engineering at University of Hawaii at Manoa, Honolulu 96822 USA (e-mail: lubecke@hawaii.edu).

Olga Boric-Lubecke is with Department of Electrical Engineering at University of Hawaii at Manoa, Honolulu 96822 USA (e-mail: olgabl@hawaii.edu).

difference. For reducing baseband residual phase noise, the same signal source is used for transmitter and receiver's local oscillator. The Antenna Specialist (ASPPT2988) antenna was used with 8 dBi gain and 60 degree E-plane beamwidth for transmitting and receiving antenna.

The received signal is mixed down with Minicircuits ZFM4212 mixer. After down conversion, baseband signals are filtered and amplified with Stanford research low noise amplifier SR-560. The physiological signals' frequency is fairly low around 0.1 to 2 Hz. However the filter bandwidth is set to 1KHz, due the large band width of received pulses. Then the data is recorded by a data acquisition device with 4 KHz sampling frequency.

A mechanical target with periodic movements simulating heart signal has been employed as a target for our measurements. The frequency of the mechanical subject periodic movement was 1 Hz. The radar usable range depends on several factors such as transmitting power, antenna characteristics, and oscillator phase noise. For our measurement, the target was placed one meter away from the antennas.

III. Simulation Results

Reflections from moving targets will results in phase/frequency shifts. Depending on the radar pulse width and target's Doppler frequency, it may be possible to detect the Doppler frequency shift within a single pulse or multiple pulses [10]. Fig. 2a illustrates the backscattered RF pulse train, while Fig. 2b shows the baseband demodulated signal. When the Doppler frequency is large enough, it can be detected within one pulse. To recognize a Doppler shift on the basis of a single pulse of width T generally requires that there be at least one cycle of the Doppler frequency f_d within the pulse; or that $f_dT > 1$. However, this condition is not usually met when detecting respiration and heart signals due to slow changing rate of physiological signals. Fig. 2c shows the case when baseband Doppler frequency shift after down conversion is small or $f_dT < 1$. The envelope of multiple pulses is the actual Doppler signal.

First respiratory signal with 0.2 Hz frequency is simulated. Since the Doppler frequency is much smaller than the pulse repetition frequency of the pulse radar, the Doppler is actually sampled at the pulse repetition frequency (prf) according to the following equations:

$$b_I[n] = b_I\left(\frac{n}{prf}\right) \qquad (1)$$

$$b_Q[n] = b_Q\left(\frac{n}{prf}\right) \qquad (2)$$

where b_I and b_Q are in-phase and quadrature components of baseband signals. As it is shown in the Fig. 3(a), the envelope of the signal carries the Doppler frequency shift. The spectrum of the received signal is depicted in Fig. 3(b). The spikes in the spectrum are due to pulse repetition frequency. However, the Doppler frequency is detectable close to DC (0.2 Hz) or even close to the first couple of harmonics which

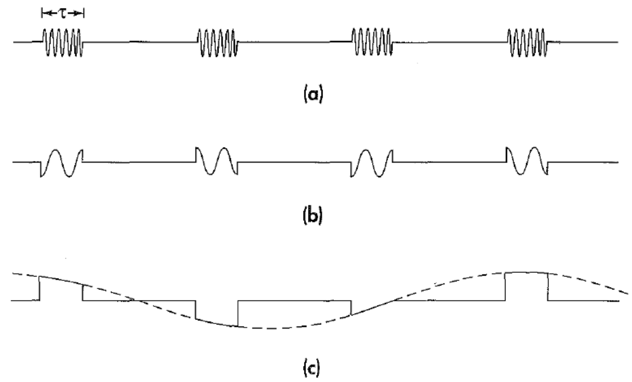

Figure 2. (a) RF back scattered pulse train; (b) baseband demodulated signal when the Doppler frequency is large and recognizable within a pulse (c) baseband signal for the Doppler frequency when pulse period is smaller than Doppler signal's period, which is usually the case for the physiological signals with frequency less than 2 Hz. The Doppler frequency signal is shown dashed.

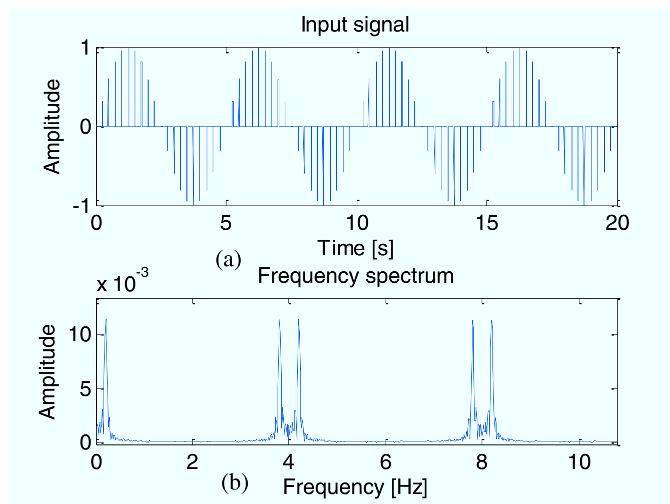

Figure 3. (a) Simulated received signal modulated by respiratory signal; simulated respiratory rate is 0.2 Hz (b) spectrum of the received signal, pulse repetition frequency is 4 Hz and Doppler frequency shift is 0.2 Hz.

are moved from 4Hz (prf) to 3.8 Hz and 4.2 Hz due to Doppler effect.

IV. Experimental Result and Discussion

Fig. 4(a) shows received signal after amplification, filtering, and digitization. The amplitude of the signal is modulated by the mechanical target motion. The pulse repetition frequency is 7.4 Hz which is large enough for detecting the target's frequency of 1Hz, in this case. After amplification, bandpass filtering and digitalization the output signals are post processed using MATLAB to extract target periodic movement's rate. Fig. 4(b) shows the spectrum of the received signal when the mechanical target is in motion. Fig. 4(c) shows the recorded spectrum when there is no movement in the room.

The Doppler effect can be observed in the envelope of the signal, as amplitude modulation on the pulses. The multiple access scheme of the chip causes the non-uniform distribution of the peaks. To reconstruct the signal envelope, computationally intensive interpolation is needed [11]. After reconstructing the signal, FFT is applied to calculate target's movement rate during the measurement interval. Fig. 5(a) shows reconstructed envelope according to the method which is used in [11] and Fig. 5(b) shows the spectrum of the signal; Doppler frequency at 1Hz is noticeable.

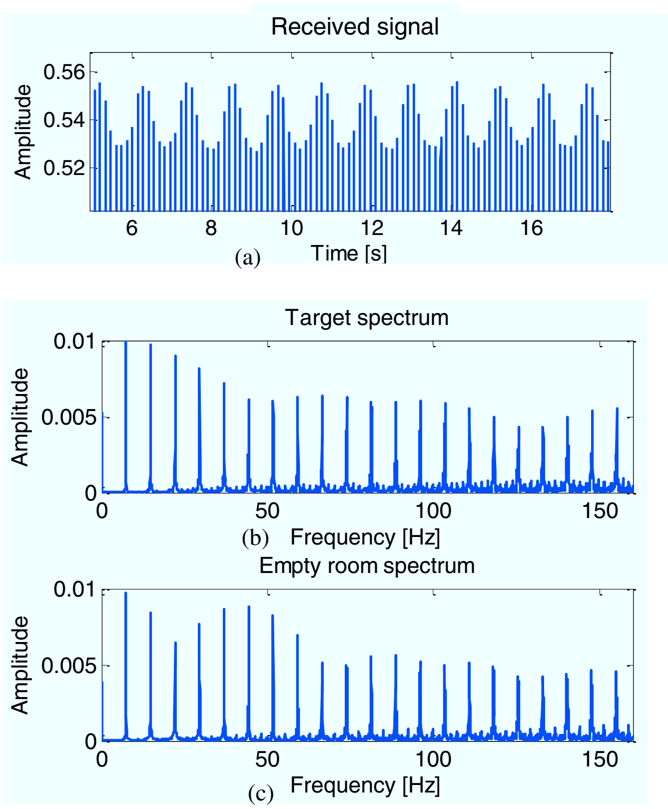

Figure 4. (a) Baseband received signal in time domain; periodic movement of the mechanical target modulated the amplitude of the received signal (b) spectrum of the received signal; pulse repetition frequency is 7.4 Hz. (c) recorded spectrum of the empty room with no target motion

However, an alternative method for detecting target's periodic motion is to investigate the spectrum of the raw received signal before reconstructing the envelope which is computationally more effective. As opposed to simulation, due to jitter in the receiver or non-uniform sampling the target rate is buried in noise and cannot be extracted directly. To resolve this issue, Fourier Spectral Subtraction is employed which is an effective method for additive noise reduction [13]. First the Fourier spectrum without the target has been recorded as it is shown in Fig. 4(c). Then the experiment is conducted within the target in the range of radar (Fig. 4(b)). Finally, Fourier spectrum of the moving subject is subtracted from the Fourier spectrum of the empty room. The baseband signals in time and frequency domain can be represented by:

$$b_T[n] \xleftrightarrow{DFT} B_T(e^{j\omega}) \quad (3)$$

$$b_E[n] \xleftrightarrow{DFT} B_E(e^{j\omega}) \quad (4)$$

$$B_{SS}(e^{j\omega}) = B_T(e^{j\omega}) - B_E(e^{j\omega}) \quad (5)$$

where $B_T(e^{j\omega})$ is the Discrete Fourier Transform of the target and $B_E(e^{j\omega})$ is DFT of the empty room's baseband signal; $B_{SS}(e^{j\omega})$ is the spectral subtraction output. Fig.6 shows spectral subtraction which shows the target's periodic motion at 1 Hz (1st marker) which was buried in noise before subtraction. The periodic motion is also detectable at both sides of the pulse repetition frequency at 6.4 and 8.4 Hz which are illustrated with 2nd and 3rd markers.

This approach can be very effective if calibrated for different environments. In addition it reduces the computational complexity of the signal processor.

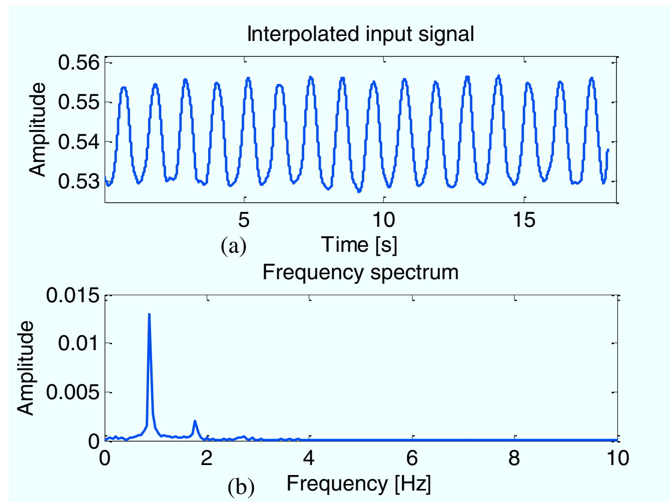

Figure 5. (a) Envelope of the received signal reflected which contains the target's rate (b) spectrum of the reconstructed signal (f = 1 Hz).

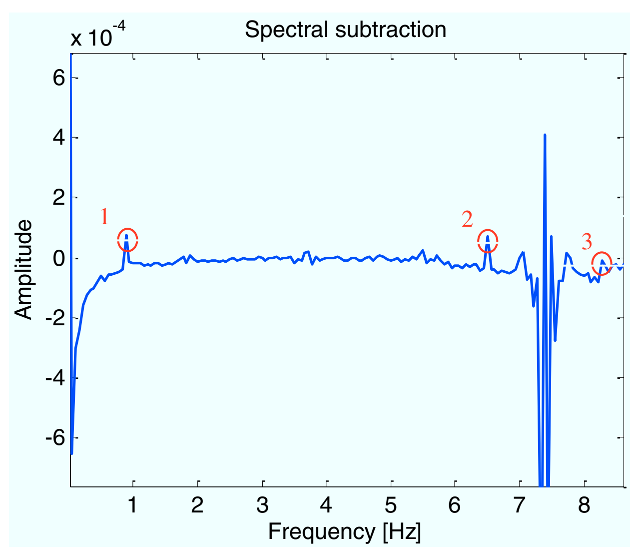

Figure 6. The spectrum of the received signal is subtracted of the spectrum with no target in the environment. Target's rate is visible at 1 Hz (1st marker), as well as, around pulse repetition frequecy at 6.4 Hz and 8,4 Hz (2nd and 3rd markers).

V. CONCLUSION

Frequency domain analysis is an important part of the physiological Doppler radar for estimating the heart and respiratory rate. Spectrum of the pulse radar is investigated for estimating the rate. This approach reduces computation complexity as compared to the interpolation method, and provides accurate frequency estimation of periodic target motion.

REFERENCES

[1] J.A J. Thijs, J. Muehlsteff, O. Such, R.Pinter, R. Elfring, C.H. Igney, "A Comparison of Continuous Wave Doppler Radar to Impedance Cardiography for Analysis of Mechanical Heart Activity," in *Engineering in Medicine and Biology Society, ,2005, 27th Annual Conference,* Shanghai, China, pp. 3482-3485, September 1-4, 2005.

[2] M. Y. W. Chia, S.W. Leong, C.K. Sim, and K.M. Chan, "Through-wall UWB radar operating within FCC's mask for sensing heart beat and breathing rate," *2005 European Micrpwave Conference*, pp Volume 3, 4-6 Oct. 2005.

[3] J. C. Lin, "Microwave Sensing of Physiological Movement and Volume Change - a Review," *Bioelectromagnetics,* vol. 13, pp. 557-565, 1992.

[4] N. Hafner, I. Mostafanezhad, V. M. Lubecke, O. Boric-Lubecke, and A. Host-Madsen, "Non-Contact Cardiopulmonary Sensing with a Baby Monitor," in *Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE*, 2007, pp. 2300-2302.

[5] C. Li, J. Lin, and Y. Xiao, "Robust Overnight Monitoring of Human Vital Signs by a Non-contact Respiration and Heartbeat Detector," in *Engineering in Medicine and Biology Society, 2006. EMBS '06. 28th Annual International Conference of the IEEE*, 2006, pp. 2235-2238.

[6] C. Li, C. Gu, R. Li, and S. B. Jiang, "Radar Motion Sensing for Accurate Tumor Tracking in Radiation Therapy," in *12th Annual IEEE Wireless and Microwave Technology Conference*, Clearwater, FL, 2011.

[7] E. Yavari, H. Jou, V. Lubecke, O. Boric-Lubekce, "Doppler Radar Sensor for Occupancy Monitoring," Radio Wireless *Symposium* 2013, 20-23 Jan. 2013.

[8] O. Boric-Lubeke, V.M. Lubecke, "Wireless house calls: using communications technology for health care and monitoring," *Microwave Magazine*, IEEE , vol.3, no.3, pp. 43- 48, Sep 2002

[9] A. A. Abidi, "Direct-conversion radio transceivers for digital communications," *IEEE J. Solid-State Circuits*, vol.30, pp. 1399-1410, Dec. 1995.

[10] M. I. Skolnik, "Introduction to Radar Systems," New York: McGraw-Hill, 3rd edition, 2001.

[11] E. Yavari, C. Song, V. Lubecke, O. Boric-Lubecke, "System-on-Chip based Doppler radar occupancy sensor," *Engineering in Medicine and Biology Society, EMBC*, 2011 *Annual International Conference of the IEEE* , pp.1913-1916, Aug. 30 2011-Sept. 3 2011

[12] "CC253x System-on-Chip Solution for 2.4-GHz IEEE 802.15.4 and ZigBee® Applications' user guide," Texas Instruments.

[13] Y. Denda, T. Nishiura, H. Kawahara, T. Irino, "Speech recognition with wavelet spectral subtraction in real noisy environment," Signal Processing, 2004. Proceedings. *ICSP '04. 2004 7th International Conference on* , vol.1, no., pp. 638- 641 vol.1, 31 Aug.-4 Sept. 2004