Signal Processing Techniques for Vital Sign Monitoring Using Mobile Short Range Doppler Radar

Ashikur Rahman, Ehsan Yavari, Xiaomeng Gao, Victor Lubecke, and Olga Boric-Lubecke

University of Hawaii at Manoa, Honolulu, Hawaii – 96826, USA

***Abstract* — This paper investigates mobile noncontact vital sign monitoring device for short range application. The radar module is mounted on a programmable linear stage, and precise stage movements are monitored by an optical tracking system. The motion artifacts due to radar system movements are removed using IIR filter and adaptive noise cancellation techniques. The system is capable of extracting respiration rate even in the presence of radar module motion. In many applications, vital sign measurement from a mobile platform will be very useful, i.e., using unmanned vehicle as a first responder in battlefield including other military and medical applications. Our experiments and theoretical techniques provide a baseline that can be potentially used to measure vital signs from any arbitrarily moving radar system.**

***Index Terms* — Doppler radar, IIR filters, Phase distortion, Demodulation, Adaptive noise cancellation.**

I. Introduction

Short range microwave Doppler radar has been employed for noninvasive monitoring of human cardiopulmonary activity [1]. A Doppler radar motion sensing transceiver transmits a continuous microwave signal and demodulates the signal reflected from a target. According to Doppler theory, if the target has a time-varying displacement having zero net velocity, the reflected signal is phase-modulated in proportion to the position of the object rather than the velocity [2]. Thus the phase of a reflected signal will be directly associated with positional changes of the chest surface due to the lungs and heart movements [2]. However, vital sign detection from mobile radar system is challenging due to possible aliasing, phase distortion and occurrence of null point. These problems occur due to variable traveling distance from radar antennas and target. If tracked radar motion is simple and precisely detected, IIR filtering techniques could remove the motion artifact. However, in cases of extreme aliasing advanced noise cancellation techniques are required. Some works have been published addressing motion artifact due to body movement of the subject [3] . Some research addressed motion artifact due to hand shaking of radar sensor module itself during operation. One way of tackling this problem is using a sensor node [4]. Empirical mode decomposition techniques were discussed for removing fidgeting interference in Doppler radar life signs monitoring devices [5]. Our work further analyzes the noise compensation not only for transmit antenna, but also the whole radar module for continuous motion of larger amplitude in order to use the system in vehicle mounted devices. Sensor node technique is not always feasible because it requires additional device nearby a subject. In EMD method intrinsic mode functions (IMFs) should be selected manually which is not always possible and it is more computationally complex.

II. Analysis

While performing demodulation of radar output signal null case problem may cause distortion [2]. Quadrature receiver can overcome this issue by using two 90 degree phase apart channels [6]. Linear demodulation can be used afterwards to combine these two channels and select the optimum channel at any given instance. After applying linear demodulation technique small signal approximation is valid for the received data that will directly relate motion that modulates the phase [6]. However, received data has two motion signature one coming from radar itself and the other from human respiratory effort. Experimentally the motion of the radar is determined using optical tracker. Further advanced filtering techniques can be applied to filter the net effect of radar movement and extract heart rate in addition to respiration rate. The experimental assembly including radar system has been shown in Fig. 1. The local oscillator generates 2.4 GHz signal which is transmitted through antenna, the reflected signal from the subject whose vital signal is to be measured is then mixed with local oscillator signals to generate quadrature outputs. The output signals $B_I(t)$ and $B_Q(t)$ of the radar system are given by [6],

$$B_I(t) = A_{BI}\cos\left(\theta + \frac{4\pi x(t)}{\lambda} + \Delta\emptyset(t - d(t)/c)\right) \qquad (1)$$

$$B_Q(t) = A_{BQ}\sin\left(\theta + \frac{4\pi x(t)}{\lambda} + \Delta\emptyset(t - d(t)/c)\right) \qquad (2)$$

$$x(t) = x_1(t) - x_2(t) \qquad (3)$$

$$d(t) = |d_0 + x_1(t) - x_2(t)| \qquad (4)$$

where θ , λ and $\Delta\emptyset$ represent constant phase shift, wavelength and residual phase noise of the oscillator. Constant phase shift depends on the nominal distance between the target and radar antenna. $x(t)$ is composed of two displacements, one coming from human respiratory effort and the other from radar's movement itself which are denoted by $x_1(t)$ and $x_2(t)$ respectively. d(t) is distance between target and radar at any given time, and d_0 denotes the nominal distance between the radar and target. After filtering, amplification, and performing linear demodulation the received baseband signal can be approximated by [6]

$$\mathrm{B(t)} \approx \mathrm{A_B}\left(\frac{4\pi \mathrm{x(t)}}{\lambda} + \Delta\emptyset(\mathrm{t})\right). \tag{5}$$

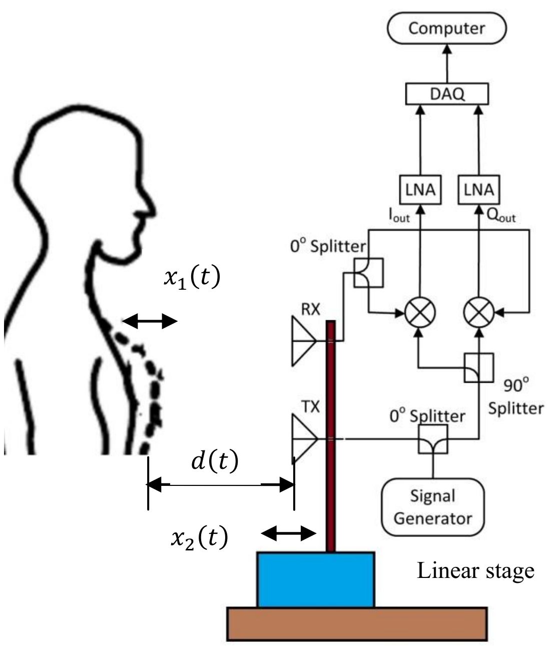

Fig 1: Mobile quadrature Doppler radar system. The transceiver is mounted on linear stage which can move the radar.

Since $x(t)$ is resultant of two motions, once radar's motion is known the other (respiratory) motion can be determined using fixed or adaptive filtering techniques.

III. Experiment

A 2.4-GHz quadrature Doppler radar system was used for the experiment. The assembly included a signal generator and the following off-the-shelf coaxial components: transmit and receive antennas (Antenna Specialist ASPPT2988), 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 reflected back signal from human subject is split and fed into two mixers. The local oscillator paths that are connected to mixers have 90 degree phase shift, providing inphase and quadrature versions of the signal. After down conversion filtering and amplification are performed. Finally the data is recorded by data acquisition device for further signal processing with MATLAB. The two channel output signals were pre-conditioned by SR560 low-noise amplifiers. Radar transceiver was mounted on a precision linear stage (Single-Axis Series CDS-3310) from Galil that provided motion in front of the human target. The linear stage was programmed to have periodic motion with 8 mm displacement having 0.2 Hz, 1.2 Hz and 2 Hz frequencies. For capturing the motion of the radar system, an infrared camera based tracking device has been utilized. For testing and respiration measurement a human subject was sitting stationary (1 m away) on a chair and breathing normally. A standard respiratory belt transducer (contains a piezo-electric device) is strapped around the chest to derive breathing rate. The output from the Doppler radar system, optical tracking system and respiratory belt transducer were connected to SR560 low noise amplifier via coaxial connectors. A National Instrument data acquisition tool was used to record and synchronize data from various sensors.

IV. Results

While the radar was moving in 2 Hz and 1.2 Hz, IIR low pass filters showed good results in extraction of respiratory rate showing an accurate match with respiratory belt. A 4th order Butterworth filter was applied that returns the filter coefficients of low pass digital infinite impulse response (IIR) filter. The filter coefficients are generated based on the cutoff frequency approximation from the tracked motion of the radar. As shown in Fig. 2 and Fig. 3, the effect of the radar motion was filtered out successfully to extract respiration rate for 1.2 Hz and 2Hz radar motions. However, with 0.2 Hz motion fixed IIR filters were not very useful due to extreme aliasing as respiration rate was roughly about the same. An adaptive noise cancellation (ANC) filter was applied for this case. Adaptive filtering results in optimal noise reduction without distorting the signals as could be the case with direct filtering. Least mean square algorithm is employed for ANC due to its simplicity and real-time capability with 0.008 constant step size and an order of 8. The results are shown in Fig 4.

V. Conclusion

Vital sign detection for mobile radar system has been successfully tested for various cases. These experiments lead to the conclusion that once radar motion is known, applying filtering algorithms vital signs can be detected. Butterworth IIR filter and adaptive filter are used for radar movement cancellation. Infrared tracking system is employed for tracking radar module movements and training the adaptive filter. By applying filtering techniques desired motion signature can be traced even in the presence of unwanted radar module motions.

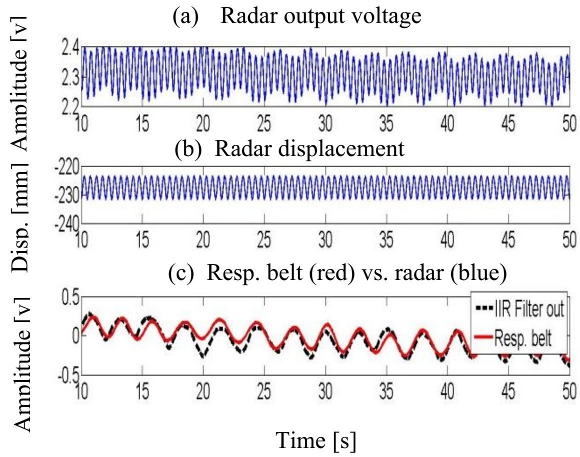

Fig. 2. Linear stage mounted radar system moving with 2 Hz sinusoidal having 4 mm amplitude. a) Linear demodulated signal from radar system b) radar displacement (mm) from nominal reference position with infrared tracking system c) comparison of extracted respiration rate using IIR filter (blue) and respiratory belt transducer (red).

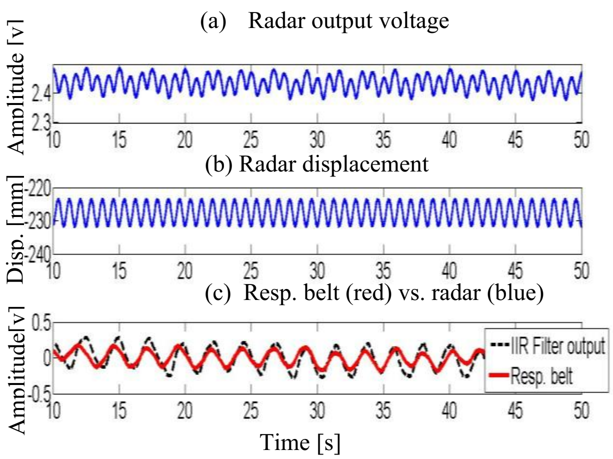

Fig. 3. Radar system moving with 1.2 Hz sinusoidal having 4 mm amplitude.

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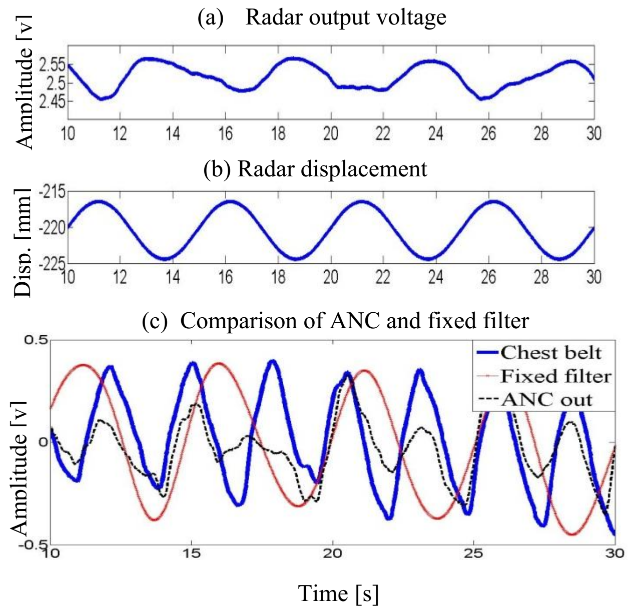

Fig. 4. Mounted radar system moving with 0.2 Hz sinusoidal having 4 mm amplitude. a) Linear demodulated signal from radar system b) radar displacement (mm) from nominal reference position c) plot showing respiration rate from ANC (black) filter, IIR notch filter with 0.2 Hz center (red) and chest belt (blue) reference. In extreme aliasing case (0.2 Hz radar motion) ANC showed much better performance in respiration measurement.

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