Detection of bio-signals from body movement based on high-dynamic-range Doppler radar sensor (Invited)

Doppler radar sensor has been widely used in non-contact bio-signal monitoring. This paper aims at recovering bio-signals from body movement. To solve the severe phase wrapping and saturation problems in large-scale body movement, as well as unwanted DC offsets and gradual changes of received microwave power problems, curve fitting technology is employed to compensate for the large-scale body movement to recover small-scale bio-signal based on a digital-IF structured, high-dynamic-range Doppler radar sensor and linearized demodulated algorithms. Experimental validations show weak bio-signal hidden in the strong body movement noise can be well extracted.

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SECTION I
Introduction

The continuous-wave Doppler Radar Sensors (DRS) have been extensively studied due to its crucial potential in human healthcare and monitoring applications [1] [2]. Researchers have made many admirable progresses to improve the performance of DRS [4]. Nevertheless, detection for bio-signal, including respiration as well as heartbeat, still remains very difficult when there exists body movement, especially in the strong case. Under the circumstance, large body movement will conceal the small bio-signal, and likely result in signal clipping in conventional DRS. Some contributions have been done to deal with body movement problem [5] [6]. Unfortunately all of the work presents complex hardware architecture and is limited in the study of relative small RBM.

In this paper, we propose a simplified and convenient approach to detect Doppler bio-signal under small and large body movements, such breathing and as walking. A digital-IF Doppler radar sensor is employed in our work as shown in Fig. 1. The gradient descent algorithm and the extended differentiate and cross-multiply (DACM) algorithm is demonstrated to effectively solve the DC-offset and phase wrapping problems [7], which guarantee the large dynamic range of DRS and avoid signal clipping caused by large body movement. After curve fitting procedure, body movement can be compensated in time domain and bio-signal is possible extracted properly.

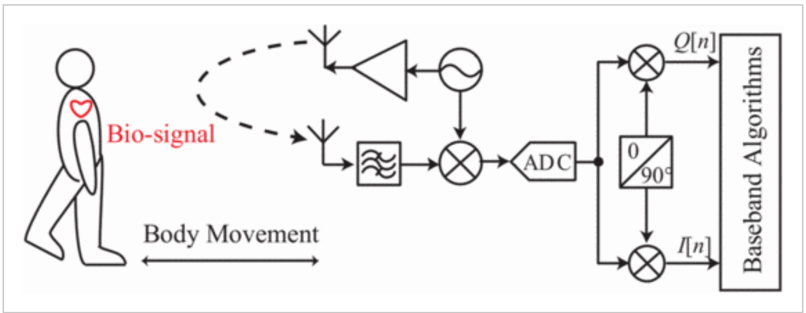

Fig. 1. A digital-IF, quadrature baseband down-conversion DRS for bio-signal detection from body movement.

SECTION II
Theory

The basic principle of DRS is the reflection of continuous wave modulated by moving target, such as human chest. The motion $x(t)$ can be mathematically expressed as:

$$x(t)=\frac{\lambda}{4\pi}\left\{\arctan\frac{[Q(t)-DC_Q(t)]/A_Q(t)}{[I(t)-DC_I(t)]/A_I(t)}-\theta_0-\varphi_0(t)\right\} \quad (1)$$

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where $DC_1(t),\ DC_Q(t)$ denote the direct current offsets, $A_I(t), A_Q(t)$ denote the alternate current amplitudes, both of the output I/Q signals, respectively. $\varphi_0(t)$ denotes the residual phase noise of the receiver, θ_0 represents the phase shift accumulated due to the initial distance and transceiver system.

A linearized high-dynamic-range DRS is presented for noncontact measurements of biological signals. Large-scale motion is divided into sub-wavelength segments. For each segment, DC offset removal is accomplished by gradient descent algorithm. Then extended DACM algorithm can retrieve the phase without phase wrapping problem in equation (2). That is, motion recovered by DACM will never encounter signal saturation or clipping. As a result, the instantaneous motion in each time slice can be linearly reconstructed.

$$\Phi(\mathrm{t})=\int_0^t\omega(t)dt=\int_0^t\frac{I(t)\dot{Q}(t)-\dot{I}(t)Q(t)}{I(t)^2+Q(t)^2}dt \quad (2)$$

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Traditionally, to recover a weak scale motion from a strong hybrid motion, a high pass filter is applied. While in our case, a conventional filer may result in the loss and distortion of information. To solve the problem, a polynomial fitting procedure was established. It was found that, the strong body movement mainly contributes to the “tendency” of $x(t)$, while the bio-signal contributes to the details of the hybrid motion. After smoothing the raw data, it is possible to retrieve a more accurate model for the bio-signal motion pattern.

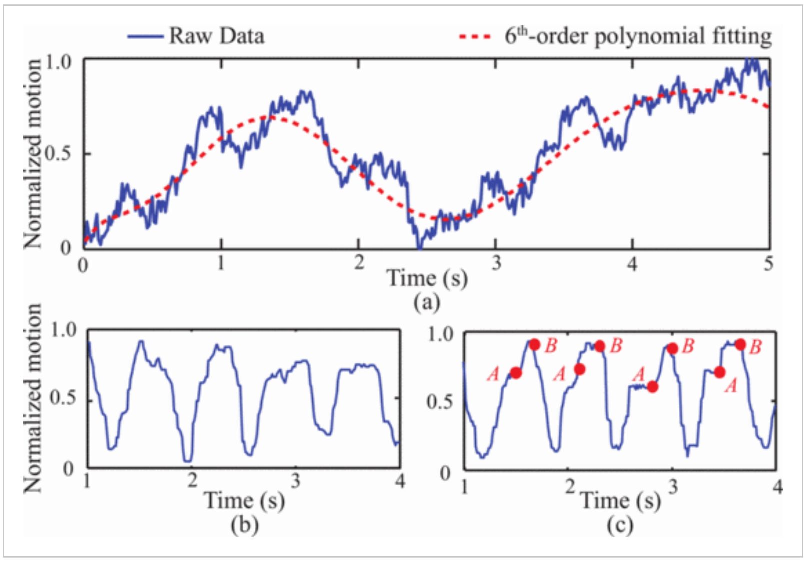

Fig. 2. Experiment results when the subject was breathing: (a) Data recovered by DRS, (b) the cardiac motion reconstructed by a high pass filter, (c) reconstructed cardiac motion based on a polynomial curve fitting technique.

SECTION III
Experiments and Discussion

Two experiments were conducted in order to validate the proposed approach. Firstly, cardiac signal is retrieved from hybrid motion of normal breath. To show more detailed bio-signal, 15 GHz DRS is employed. More generally, we reconstruct bio-signal when body moves as large as 1 m, with DRS operating at 2.4 GHz

Fig. 2 shows the experiment results when the subject was breathing normally. In Fig. 2(a), the cardiac motion is super-positioned with the respiration motion, which has a much lower fundamental frequency. In Fig. 2(b), the hybrid motion has been filtered by IIR filter with a 1-Hz cutoff frequency. While in Fig. 2(c), the hybrid motion is compensated by the fitting method, resulting a more detailed and accurate cardiac motion with characteristic points A and B [3].

Furthermore, a complicated experiment is done when a human subject walks in a range more than 1 m. Fig. 3(a) shows the walking progress mixed by body movement and bio-signal. The recovered bio-signal after fitting technology as shown in Fig. 3(b), which is much smaller than the strong body movement. The respiration as well as its harmonic wave is clearly observed in the spectrum in Fig. 3(c). And heartbeat is relative weaker, but still complies well with pulse sensor.

SECTION IV
CONCLUSION

In our work, using the high-dynamic-range motion imaging DRS and curve fitting method, bio-signal can be reconstructed from strong body movement noise. Experiments have validated the proposed approach. More advanced techniques extended from his approach will be explored in the future work, especially to increase the SNR of weak heartbeat signal.

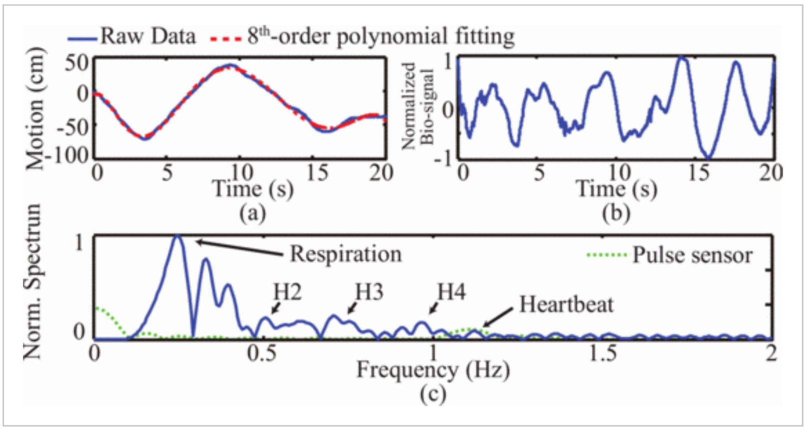

Fig. 3. Measurement of bio-signal while human walking: (a) Walking process recovered by DRS, (b) reconstructed bio-signal based on curve fitting technique, (c) spectrum of bio-signal in (b).

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FOOTNOTES

No Data Available

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KEYWORDS

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Curve fitting, Doppler radar, Fitting, Heart beat, IIR filters, Legged locomotion, Microwave technology

INSPEC: Controlled Indexing

Doppler radar, bioelectric potentials, biomechanics, curve fitting, demodulation, medical signal detection, medical signal processing, motion compensation, patient monitoring

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curve fitting technology, high-dynamic-range Doppler radar sensor, large-scale body movement compensation, linearized demodulated algorithms, microwave power problems, noncontact bio-signal monitoring, noncontact biosignal detection, phase saturation problems, phase wrapping problems

Authors Keywords

DACM algorithm, Doppler radar, bio-signal, curve fitting, gradient descent algorithm

CORRECTIONS

None