

Motion Artifact Removal for Moving FMCW Radar-Based Vital Sign Sensing Using IMU

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Summary:

We propose an IMU-based motion artifact removal algorithm for non-contact vital sign monitoring, in which a frequency-modulated continuous-wave (FMCW) millimeter-wave (mm Wave) radar and an inertial measurement unit (IMU) are co-mounted on a moving platform. A least mean squares (LMS) adaptive filter exploits the correlation between IMU acceleration and radar phase disturbance to suppress motion-induced artifacts. Phantom experiments demonstrated a mean signal-to-noise ratio (SNR) improvement of 31.85 dB after calibration, while the cardiac signal at 1 Hz was preserved.

Keywords: radar, vital sign sensing, motion artifact removal, IMU, adaptive filter

Introduction

In Japan, the rapid aging of society and the growing prevalence of single-person elderly households have created an urgent need for unobtrusive health monitoring systems. Companion animals and social robots offer a natural mobile platform for such monitoring, as they move freely within the living space without requiring the user to wear any device. Non-contact vital sign sensing using mm Wave FMCW radar has emerged as a promising approach, detecting subtle skin displacements caused by cardiorespiratory activity without wearables [1]. Recent studies have explored mounting radar on mobile platforms to enable room scale monitoring [2].

However, existing approaches assume that either the subject or the radar is stationary. When mounted on a moving platform, carrier motion introduces phase artifacts that are indistinguishable from vital sign signals.

In this paper, we propose co-mounting an FMCW mm Wave radar and an IMU on a pet collar, using IMU-acquired acceleration as a reference signal to suppress motion-induced artifacts via an LMS adaptive filter, as shown in Fig. 1.

Materials and Methods

The proposed vital sign monitoring system is shown in Fig.2. An FMCW mm Wave radar (Acconeer XE125) and an IMU (Adafruit Feather nRF52840) are co-mounted on a pet collar, enabling continuous cardiac monitoring in home environments. For a stationary radar, the phase shift due to small skin displacement $d(t)$ caused

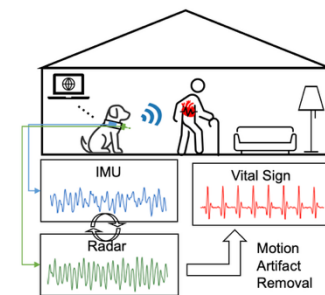


Fig.1. Overview of the proposed pet-collar mounted mm Wave radar system for non-contact vitals sign monitoring

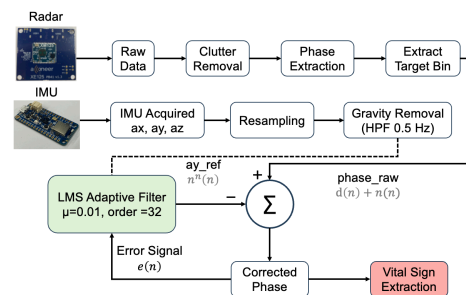


Fig.2. Block diagram of the proposed IMU-based motion artifact removal algorithm

by respiration and heartbeat can be expressed as eq. (1), where λ is the wavelength of the transmitted signal.

$$\varphi(t) = \frac{4\pi}{\lambda} d(t) \quad (1)$$

However, when the radar itself undergoes motion, an additional phase component arising from the carrier's movement is superimposed, such that the measured phase becomes eq. (2).

$$\varphi_{\text{meas}}(t) = \frac{4\pi}{\lambda} [d(t) + d_{\text{noise}}(t)] \quad (2)$$

Since $d_{\text{noise}}(t)$ is correlated with the IMU-measured acceleration, it can be estimated and suppressed using the IMU signal as a reference, regardless of its spectral content.

To address this, the IMU simultaneously records the three-axis acceleration of the platform. The IMU-derived acceleration signal is resampled to match the radar frame rate and high-pass filtered at 0.5 Hz to remove gravitational components. The processed signal is fed as a reference input to an LMS adaptive filter ($\mu = 0.01$, order = 32), which adaptively estimates and subtracts the motion-induced phase artifact via an error signal feedback loop, yielding a corrected phase signal. Heart rate is subsequently extracted through vital sign extraction.

To evaluate the proposed method, a phantom experiment was conducted in a controlled laboratory environment as shown in Fig.3. A chest phantom (servo motors driving a gel-padded surface at 1Hz) simulated cardiac motion, while a mechanical shaker vibrating at 3 Hz provided motion artifacts to the co-mounted radar and IMU. Data were collected simultaneously at approximately 54 FPS over 30 minutes and segmented into 35 non-overlapping 50-second windows for analysis. The SNR is defined as the ratio of PSD at the cardiac frequency (1 Hz) to that at the artifact frequency (3 Hz).

Results and Discussion

Figure 4 shows the PSD of the radar phase signal before and after calibration. The artifact component at 3 Hz was reduced by 24.2 dB, while the cardiac signal at 1 Hz was preserved with a change of only +0.13 dB. This selective suppression demonstrates a key advantage of the LMS adaptive filter: by exploiting the correlation between the IMU reference signal and the motion-induced phase artifact, the algorithm can remove the artifact without prior knowledge of its frequency.

Figure 5 shows the distribution of SNR across 35 measurement windows. Without calibration, the mean SNR was 0.42 ± 0.28 dB, indicating that artifact power was comparable to the cardiac signal and that heart rate estimation would be unreliable. After applying the proposed LMS-based motion artifact removal method, the SNR improved to 32.27 ± 4.25 dB, a mean improvement of 31.85 dB.

Conclusion

We proposed an IMU-based motion artifact removal method for non-contact vital sign monitoring using a co-mounted FMCW mm Wave radar and IMU. An LMS adaptive filter exploits the correlation between IMU acceleration and radar phase disturbance to suppress motion-induced

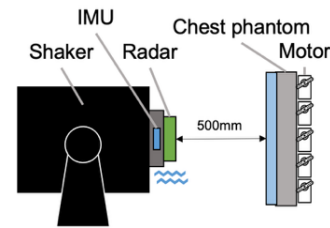


Fig.3. Experimental setup for evaluation

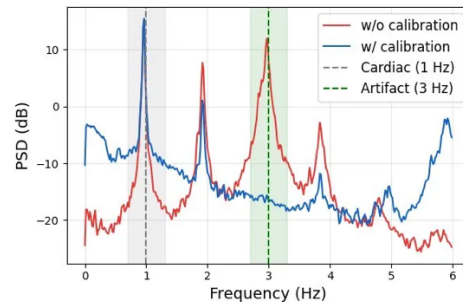


Fig.4. PSD of the radar phase signal before and after IMU-based calibration.

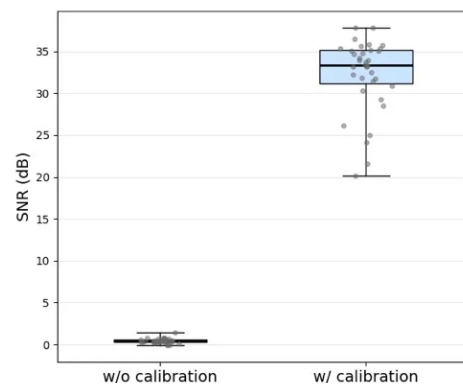


Fig.5. SNR comparison before and after IMU-based motion artifact removal ($n = 35$).

artifacts without prior knowledge of the artifact frequency. Phantom experiments demonstrated a mean SNR improvement of 31.85 dB while preserving the cardiac signal with a PSD change of only +0.13 dB at 1 Hz. Future work will focus on validation with animal subjects and extension to scenarios where motion artifact and vital sign frequencies overlap.

References

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