Robust Breathing Rate Estimation During Sleep From FMCW Radar in a Real-World Clinical Dataset

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Introduction

Continuous monitoring of breathing rate (BR) is crucial for sleep research and the management of chronic conditions such as obstructive sleep apnea, diabetes, or cardiovascular diseases. While polysomnography (PSG) remains the gold standard for respiratory monitoring, its contact-based sensors can disturb natural sleep and are unsuitable for long-term use. Non-contact techniques, such as frequency-modulated continuous wave (FMCW) radar, offer unobtrusive alternatives [1]. However, accurate BR estimation in real-world overnight settings remains challenging due to motion artifacts and environmental interferences.

Materials and Methods

An FMCW radar sensor (RADIQ-1, QUMEA AG) was employed in an observational study investigating nocturnal physiology in individuals with diabetes. The analysis included radar recordings of 19 participants, each monitored for approximately nine nights, resulting in 179 nights of data. Participants slept in their home environments, where the radar was mounted above the bed. Simultaneously, participants wore a Garmin Venu 2 smartwatch, providing BR estimates from wrist-based physiological signals as reference data. A robust signal processing algorithm was developed, introducing a new range bin selection method, a signal quality index (SQI), fast Fourier transform based BR estimation, and Kalman filtering. The algorithm also incorporates out-of-bed event detection. In addition to the signal processing algorithm, a deep learning-based approach was implemented and evaluated.

Fig. 1 Illustration of the Moonwalk study setup for non-contact sleep monitoring in a home environment using an overhead radar sensor (image source: https://samlab.org).

Results

Across all nights, the proposed algorithm achieved a mean RMSE of 1.4 bpm, a mean MAE of 1.04 bpm, a mean accuracy of 92.8 %, and a mean Pearson correlation coefficient of 0.46. Applying SQI filtering rejected on average 15 % of the windows, resulting in improved performance metrics. Out-of-bed event detection achieved a precision of 0.83 and sensitivity of 0.89.

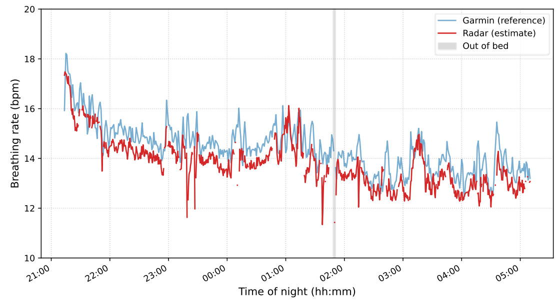

Fig. 2 Example of overnight BR trajectories from one study participant. The radar-based BR estimate (red) is shown together with the Garmin reference (blue). The nightly RMSE is 0.74 bpm.

Discussion

The proposed range bin selection method exploits characteristics of noise, waveform structure, and signal periodicity in the phase signal, rather than relying on spectral power or reflected magnitude as in previous studies, which explains its superior performance. Future work should explore motion-compensated phase recovery to enable BR estimation in low-SQI segments (e.g., during turn-overs) and validate radar-derived BR against certified medical devices such as PSG. Overall, these findings demonstrate the potential of the proposed algorithm for unobtrusive, long-term FMCW radar-based BR monitoring in both sleep and clinical settings.

References

[1] Kebe M., Gadhafi R., Mohammad B., Sanduleanu M., Saleh H. and Al-Qutayri M., Human vital signs detection methods and potential using radars: A review, Sensors 20(5): 1454, 2020.

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