Remote Cardiopulmonary Activity Detection Based on Biomedical Radar

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***Abstract*—The field of biomedical radar has witnessed significant advancements in recent years, paving the way for innovative and transformative applications in clinical settings. Most medical instruments invented to measure human activities rely on contact electrodes, causing discomfort. Thanks to its non-invasive nature, biomedical radar is particularly valuable for clinical applications. A significant portion of the review discusses improvements in radar hardware, with a focus on miniaturization, increased resolution, and enhanced sensitivity. Then, this paper also delves into the signal processing and machine learning techniques tailored for radar data. This report summarizes my recent work on biomedical radar technology, shedding light on its transformative potential in shaping the future of clinical diagnostics, patient and elderly care, and healthcare innovation.**

***Index Terms*—biomedical radar, clinical application, cardiopulmonary activity, displacement detection, medical internet of things**

I. INTRODUCTION

OVER the past decade, significant strides have been made in the development of biomedical radar systems, propelled by advancements in signal processing, machine learning, and sensor technologies. In the early phase, emphasis was placed on statistical detection of fundamental physiological parameters. The concept of noncontact detection of vital signs has been successfully demonstrated in this field before 2000, pioneering a series of theoretical and applied studies.

Previous research has predominantly focused on obtaining basic statistical indicators such as heart rate and respiratory rate, falling short in capturing the fine-grained temporal evolution characteristics of cardiac micro-movements. Ongoing research in the field of bio-radar cardiac and pulmonary micro-movement detection is gradually deepening [1]. The perceptible information hierarchy is shifting from basic, singular statistical indicators towards a more nuanced analysis of the intricate temporal changes in multidimensional features of cardiac micro-movements. These advancements have initiated preliminary health assessments for both healthy individuals and those with cardiorespiratory conditions. In this report, we summarize our recent research involving the analysis of respiratory and heartbeat rhythms, fine-grained time-varying feature parameter detection.

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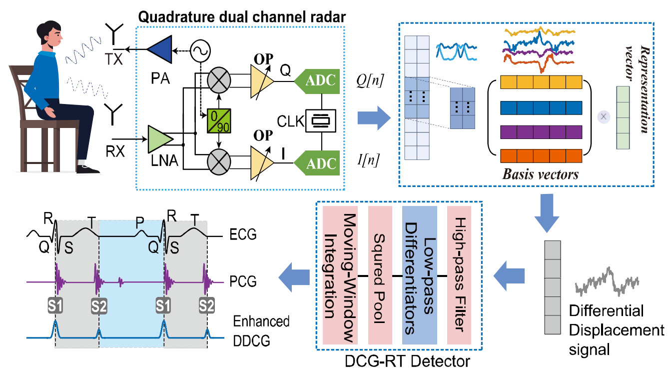

Fig. 1. Detailed block diagram of the proposed VAD-based cardiac timing detection technique.

TABLE I

RR NRMSES WITH DIFFERENT TECHNIQUES WITH RESPECT TO ECG SIGNALS

Subject	This work[2]	VAD with PRF[1] technique	MDACM-IPR[3] with DCG-RT detector	MDACM-IPR with PRF technique
1	0.55%	2.14%	11.96%	13.48%
2	0.42%	1.91%	1.02%	3.51%
3	1.21%	3.28%	2.31%	4.27%
4	1.77%	2.54%	1.91%	3.04%
5	2.03%	4.13%	7.73%	10.03%

II. ACCURATE CARDIAC WAVEFORM DETECTION

Robust contactless Doppler cardiogram (DCG) detection in practical scenarios encounters challenges arising from radar hardware performance limitations and signal processing effectiveness. In my recent work [2], through an analysis of IQ mismatch signals, we proposed a novel vectors analytic demodulation (VAD) method which employing the original radar signal to generate four basis vector signals, to linearly obtain the target's differential displacement signal, as shown in Fig. 1. Simulation experiments confirm the efficacy of VAD algorithm in achieving efficient linear phase demodulation under IQ mismatch and time-varying DC offset, surpassing the performance of existing linear demodulation algorithms. Subsequently, based on the demodulated differential

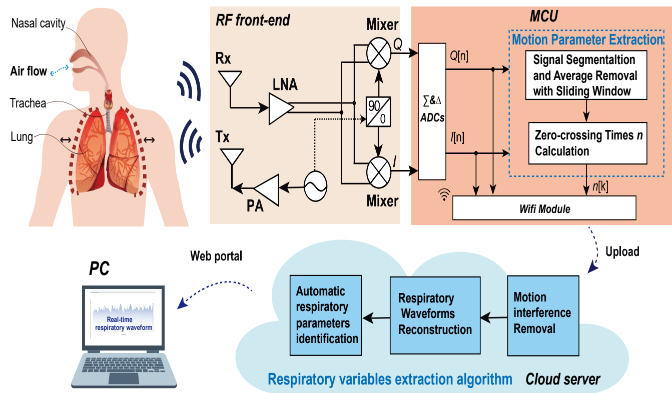

Fig. 2. Detailed block diagram of the proposed remote respiratory variables extraction system.

displacement signal, we develop a Doppler cardiogram based QRS and T wave (DCG-RT) detector to enhance the characteristic waveforms corresponding to QRS- and T-wave for automatic cardiac timing like QRS-wave to QRS-wave (RR) interval and QRS-wave to T-wave (RT) interval calculation. This algorithm achieves easily identifiable cardiac feature waveforms with minimal computational resources. Using a 24 GHz Doppler radar and medical device, the synchronous acquisition experiments were conducted on five subjects. Comparative analysis of the enhanced signals extracted by the algorithm with PCG, ECG, and other signals, reveals a remarkable 98% accuracy in cardiac timing detection. Table I shows comparative outcomes between the popular methods.

III. Respiratory Variables Detection

Nocturnal respiratory function assessment is essential for inpatients' daily healthcare. However, the nasal cannula commonly used in hospitals can affect the patient's breathing pattern and cause discomfort to the patient. Radar-based contactless detection technique provides a non-contact monitoring way to overcome such limitation. However, to be an alternative to airflow, the radar system requires highly accurate respiratory waveform detection. In my recent work [4], a custom-designed biomedical radar-based internet of things (IoT) system integrated with automatic respiratory variables identification algorithm is developed to provide accurate long-term measurement of respiratory phases and amplitude during sleep, as shown in Fig. 2. The overnight experimental data from biomedical radar and polysomnography was simultaneously recorded for 10 adults, a total duration of approximately 3851 minutes. Data from adults with suspected sleep apnea were also included. Considering the instability of respiratory activity during REM sleep, we compared the performance of the system's measurements during REM and non-REM sleep. The results demonstrate the continuous measurement can provide the long-term respiratory variables for sleep analysis. The total experimental measurement reveals a remarkable 97%, 93% and 92% accuracy in respiration-to-respiration interval (RRI), inhale duration (ID) and exhale (ED), respectively.

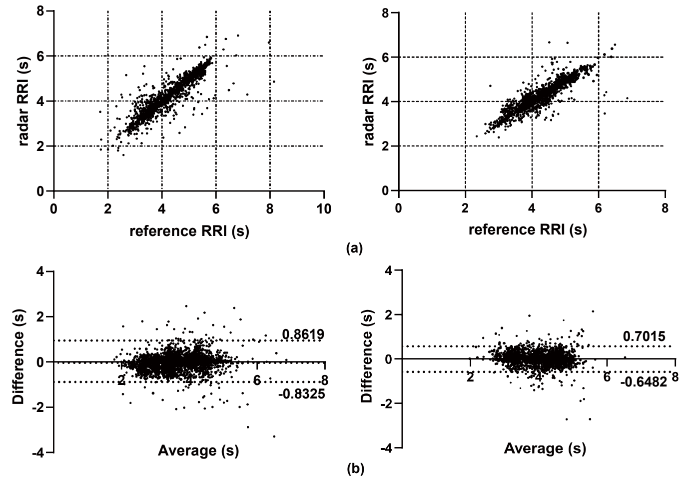

Fig. 3. (a) The correlation scatters plot of the RRIs detected by the radar system and the airflow device during REM sleep (left) and non-REM sleep (right). (b) The Bland-Altman diagram of the RRIs detected by the radar system and the airflow device during REM sleep (left) and non-REM sleep (right).

VI. Career Plan, MTT Fellowship Impact and IMS

I plan to continue my academic career, focusing on research in the intersection of microwaves and biomedical fields. I look forward to quickly growing into a qualified teacher, becoming an expert in this field, expanding and strengthening my research direction, and cultivating more talents in this field.

For young scholars, receiving the IEEE Graduate Fellowship award is a significant encouragement. It provides substantial spiritual and financial support for me to continue exploring the intersection of microwaves and biomedical fields. Winning this award is a great positive feedback for my choice to pursue research in this area and has further strengthened my determination regarding my career choice.

The IMS conference is a grand event that can quickly broaden the horizons of young scholars. I highly recommend fellow students to attend the conference in person. At the IMS conference, you will meet leading experts in the field, with scholars from all over the world gathering here, helping scholars build connections. As a young scholar, I have greatly benefited from this experience.

References

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