Spectral Binning Approach to Classification of Non-Sedentary Human Activity

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***Abstract*—This paper proposes a spectral binning method for the classification of locomotion and extraneous body motion (EBM) that may occur during Continuous Wave (CW) Doppler radar motion sensing of human subjects. The method analyzes the spectral content of the arctangent demodulated displacement signature, generating an activity classification based on the magnitude of the spectral content for each of several frequency bins. The choice and number of bins used for the overall classification of data were determined by analyzing experimental data. The method successfully classified sedentary, EBM, and locomotion states for 5 subjects. The method can be used both for determining the presence and type of activity, and for recognizing when data segments are not suitable for monitoring sedentary vital signs.**

***Index Terms*—sedentary, non-sedentary, extraneous body motion, spectral domain, arctangent demodulation.**

I. Introduction

This paper proposes a spectral binning method for the classification of locomotion and extraneous body movements of human subjects using Continuous Wave (CW) Doppler radar. This study supplements the importance of human activity recognition (HAR) using micro-Doppler signatures from Frequency Modulated Continuous Wave (FMCW) Doppler radar, demonstrating effectiveness regardless of environmental geometry [1]. Prior works by Valdes et al. on classifying human activities with single-channel CW radar [2], and Singh et al. on animal movement detection using CW radar [3], showcase its versatility. Additionally, non-invasive Doppler radars have proven essential in monitoring vital cardiopulmonary signs for health changes [4]. Research by Sacco et al. introduces a hybrid CW and FMCW radar system for precise human localization in enclosed spaces [5].

This research assesses the use of a single CW Doppler radar in distinguishing between three distinct states of motion. It emphasizes the suitability of using a singular CW radar for indoor movement detection alongside reduced demodulation and system design complexity when compared to FMCW systems. Previous research predominantly explored the time-domain characteristics of CW radar signals for differentiating between sedentary and active states [6]. Our focus is on categorizing movements as sedentary, Extraneous Body Motion (EBM), or active locomotion by examining the spectral content of radar signals. The findings demonstrate a distinct separation between locomotion, EBM, and stationary states, with implications for the reliability of accurate respiratory rate monitoring inspite of locomotion and EBM.

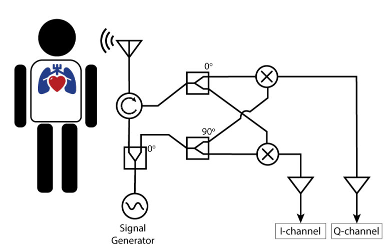

Fig. 1. Block Diagram of Quadrature Radar Setup

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II. Theoretical Background

A CWs Doppler radar emits a directional, single-frequency signal. When the incident wave reflects off a moving target, it modulates the phase of the reflected wave. This phase modulation reflects the target's displacement. In sedentary humans, the chest wall's periodic movement from cardiopulmonary activity is captured by demodulating this received wave. The outputs from a CW quadrature Doppler radar are expressed as,

$$B_I(t) = A_B cos(\theta + \frac{\pi}{4} + \frac{4\pi x(t)}{\lambda} + \Delta\phi(t)) \tag{1}$$

$$B_Q(t) = A_B sin(\theta + \frac{\pi}{4} + \frac{4\pi x(t)}{\lambda} + \Delta\phi(t)) \tag{2}$$

where the target's motion variation is given by $x(t)$, A_B represents the baseband amplitude due to receiver and mixer gain, θ is the constant phase shift related to the phase change at the surface of a target and the phase delay between the mixer and antenna, and the residual phase shift is represented by $\Delta\phi(t)$.

A. Arctangent Demodulation

The displacement information from quadrature channels can be extracted in terms of phase utilizing the arctangent demodulation as,

$$\phi(t) = arctan(\frac{V_Q + B_Q(t)}{V_I + B_I(t)}) \tag{3}$$

where V_I and V_Q represent the dc offset caused by leakage in the radar system and the clutter in the environment.

Implementation of an appropriate circle fitting algorithm during arctangent demodulation allows for nullifying the effect of dc offset and enables the extraction of proper phase information from the arc. For periodic motion, the dc offset values change during non-sedentary activity, effectively moving the center of the periodic arc.

B. Spectral Analysis

The Discrete Cosine Transform (DCT) may be utilized as an alternative to the Fast Fourier Transform (FFT) to extract the spectral information in terms of real cosine components. Previously, advanced DCT methods have been used in continuous monitoring of cardiorespiratory signal rates [7], [8]. The DCT-II type algorithm is expressed by,

$$X[k] = \sum_{n=0}^{N-1} x[n] \cdot \cos\left[\frac{\pi}{N}\left(n + \frac{1}{2}\right)k\right] \tag{4}$$

The frequency resolution of DCT is given by,

$$f = \frac{k \times f_s}{2N} \tag{5}$$

DCT has a higher frequency resolution compared to FFT over a fixed window. When actively analyzing the spectral domain for non-sedentary motion, it is advantageous to use a smaller window. Hence, DCT is implemented to generate a spectrogram in this work.

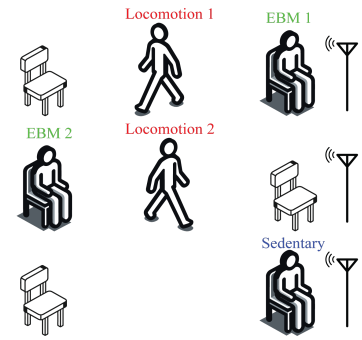

Fig. 2. Data collection steps for locomotion and EBM over 230 s

III. Experimental Setup & Data

Fig. 1 shows the block diagram of the quadrature CW homodyne radar system used for data acquisition. An E4433B signal generator transmitted a signal of 2.4 GHz and at an amplitude of 16dBm. The received signal was driven through a 90-degree ZX10Q-2-25-S+ splitter, ZFM4212 mixers from Mini-circuits, and a Narda 4923. Next, the I and Q mixers' outputs are low pass filtered and amplified by passing through a SR560 Low Noise Amplifier (LNA).

The experimental procedure involving human subjects was approved by the University of Hawaii Institutional Review Board (IRB). In this experiment, data was collected from 5 volunteers across 3 sessions, each exhibiting a distinct EBM. At the start of each session, participants were asked to sit in the chair 1.5m from the radar and maintain a breathing rate of 15 bpm for the entire 230s experiment duration. At the 45s mark, subjects initiated a specific EBM. After 90s, subjects moved to a chair placed 3.5m away from the radar. The protocol required the subjects to initiate a second EBM at 135s and a locomotion to the nearer chair at 180s. The final 50s were spent in a stationary position. Fig. 2 shows a graphical representation of the EBM and locomotion actions performed by a subject for each data instance. Fig. 3 shows the spectrogram generated from the DCT of arctangent demodulation of one session.

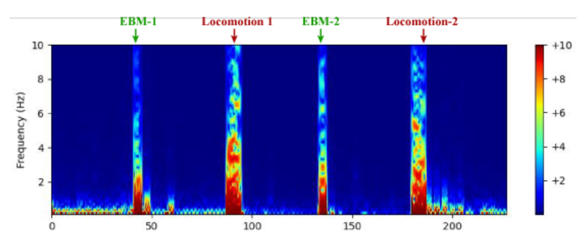

Fig. 3. Spectrogram of arctangent demodulated signal with EBM and Locomotion events marked with respect to the time domain.

The subjects performed three distinct types of EBM: forward-to-back movement, chair readjustment, and side-to-side movement. In the chair readjustment, the subjects briefly lifted themselves from their seats before sitting back down, achieving a slight positional change.

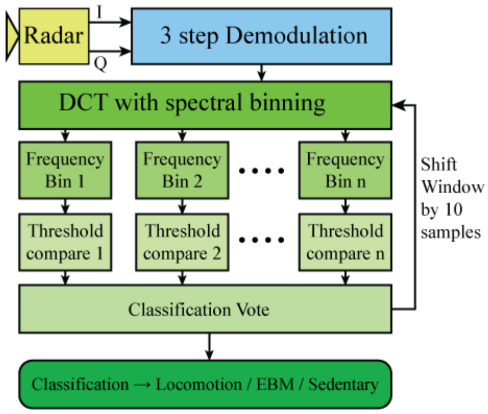

Fig. 4. Flowchart of proposed algorithm

IV. Proposed Method

The flowchart of the proposed method is shown in the Fig. 4. The input data was first imbalance corrected, dc offset compensated, and arctangent demodulated.

The resultant data is then analyzed using DCT using a 4000 sample window with a 3990 sample overlap. Afterward, the resultant frequency magnitudes are summed according to the corresponding frequency bins. Each resultant bin is then compared to previously set thresholds to classify between sedentary, EBM, and locomotion. A maximum voting scheme between the decision of the bins is used to classify the state of motion. Fig. 5 shows an example of time vs. classification of activity type by implementing the proposed algorithm.

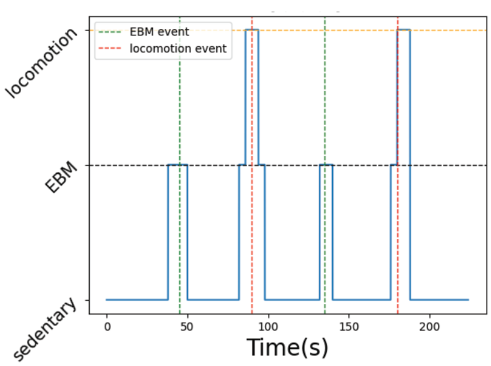

Fig. 5. Time vs. Activity Classification implementing proposed algorithm

V. Results and Discussions

Table I shows the accuracy results of Locomotion and EBM classification utilizing the proposed method for different number of selected frequency bins. It is noted from the table that the frequency bin classification can accurately identify locomotion in the presence of forward-to-back and readjustment EBM. The 3 bins classification can accurately identify locomotion in side-to-side EBM scenarios as well.

For EBM classification with respect to different types of fidgeting, it is observed that 3 bins and 4 bins methods have high accuracies for forward to backward movement and for readjustment EBM. However, side-to-side EBM classification has a low accuracy. Due to the radial movement of the body with respect to the Doppler radar, the side-to-side movement creates very low amplitude phase change.

TABLE I
Table of Locomotion and EBM accuracy values (in percents) in presence of three types of EBM

Target Classification	EBM Type	2 bins	3 bins	4 bins	5 bins
Locomotion	forward to back	90	100	90	100
Locomotion	re-adjustment	80	100	90	100
Locomotion	*side to side*	*60*	*100*	*60*	*90*
EBM	forward to back	90	100	100	80
EBM	re-adjustment	60	90	90	40
EBM	*side to side*	*50*	*30*	*30*	*50*

A spectral domain-based frequency bin algorithm is proposed for the classification of sedentary, non-sedentary, and extraneous body motion. The algorithm was tested using different numbers of frequency bins to produce maximum accuracy of classification. Locomotion, forward-to-backward EBM, and readjustment while seated EBM were all classified with reasonable accuracy. The method provides a useful record of non-sedentary events and a means of identifying data suitable for sedentary vital signs monitoring. The method provides a reliable technique to isolate baseline vital sign data in an unregulated environment using a single CW radar. The system can be further improved by an iterative method to determine a ubiquitous threshold value for each frequency bin.

References

[1] S. A. Shah, and F. Francesco, ”Human activity recognition: Preliminary results for dataset portability using FMCW radar,” International radar conference (RADAR), pp. 1-4. IEEE, 2019.

[2] J. J. Valdés, Z. Baird, S. Rajan, and M. Bolic, ”Single channel continuous wave doppler radar for differentiating types of human activity,” International Joint Conference on Neural Networks (IJCNN), pp. 1-8. IEEE, 2018.

[3] A. Singh, S. K. L. Scott, M. Butler, and V. Lubecke. ”Activity monitoring and motion classification of the lizard Chamaeleo jacksonii using multiple Doppler radars,” 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 4525-4528. IEEE, 2012.

[4] M. Hravnak, M. A. DeVita, A. Clontz, L. Edwards, C. Valenta, and M. R. Pinsky, ”Cardiorespiratory instability before and after implementing an integrated monitoring system,” Critical care medicine 39, no. 1, p. 65, 2011

[5] G. Sacco, E. Pittella, E. Piuzzi and S. Pisa, ”A radar system for indoor human localization and breath monitoring,” 2018 IEEE International Symposium on Medical Measurements and Applications (MeMeA), Rome, Italy, 2018, pp. 1-6, 2018.

[6] M. S. Ishrak, J. N. Sameera, O. Boric-Lubecke and V. M. Lubecke, ”Parametric Classification of Recoverable Radar-Assessed Respiratory Rate Data,” 2024 IEEE Radio and Wireless Symposium (RWS), San Antonio, TX, USA, 2024, pp. 109-111

[7] J. Park, et al. ”Polyphase-basis discrete cosine transform for real-time measurement of heart rate with CW Doppler radar,” IEEE Transactions on Microwave Theory and Techniques 66.3, pp. 1644-1659, 2017

[8] J. Y. Shih, and F. K. Wang. ”Quadrature cosine transform (QCT) with varying window length (VWL) technique for noncontact vital sign monitoring using a continuous-wave (CW) radar,” IEEE Transactions on Microwave Theory and Techniques 70, no. 3, pp. 1639-1650, 2021