Proceedings of the 2020 Design of Medical Devices Conference
DMD2020
April 6, 7-9, 2020, Minneapolis, MN, USA

DMD2020-9087

RESPIRATORY ARREST MONITORING: A NON-INVASIVE APPROACH FOR EARLY DETECTION OF BREATHING COMPLEXITIES IN PSYCHIATRIC PATIENTS

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ABSTRACT

Background: *Current protocol for monitoring high-risk patients in psychiatric hospital calls for a staff member to enter each room every 15 minutes to visually ensure that each patient is still breathing. This protocol has been set up for fast intervention in the case of a patient's self-inflicting harm. However, this procedure is disruptive to the patients and a burden for the care providers.*

Objective: *Continuous and automated overnight monitoring of psychiatric patients for a complete cessation of breath, that eliminates the need for frequent in-person checks.*

Method: *An IRB approved study conducted in a simulated lab environment, with a radar device placed in the ceiling above the bed. 14 volunteers simulated episodes of respiratory arrest.*

Results: *The extracted radar signal not only tracks the episodes of complete breath cessation but also estimates the respiration rate with more than 92% accuracy, during normal breathing.*

Conclusion: *Our proposed approach provides the means for care providers in psychiatric hospitals to ensure the patients can breathe without disturbing the patients' sleep.*

Keywords: Respiratory Arrest, Psychiatric, Radar Systems.

BACKGROUND

The leading cause of death for inpatient admissions at psychiatric hospitals include cardiovascular system disorders (43.6%), respiratory system disorders (14.9%), nervous system disorders (9.9%), infections (10.1%), and suicides (7%) [1]. Psychiatrists report that it is often difficult to assess the amount of risk involved in letting their patients stay alone, especially during the night, thus, they typically need to monitor all patients in a psychiatric ward every 15 minutes. Current protocols call for a staff member to physically enter each room and put a light on patients to make sure they still breathe.

In addition to the staff burden, this procedure is also disruptive to patients who often are light sleepers. The psychiatrists at Missouri Psychiatric Center asked for a non-obtrusive way to monitor patients breathing while preserving the patient's privacy concerns. In response, we propose the current remote monitoring technique by means of radar systems.

Radar systems have been previously used to measure and monitor vital signs, including respiration [2-4], heart rate [5, 6], heart rate variability [7], and sleep monitoring [8, 9]. Ultra-Wide Band Radar (UWB) systems gained specific attention with the works of [3, 10] due to their high level of precision in the measurement which causes high accuracy estimations if the vital signs. Yet these systems mostly stayed at prototypes and subjects were always asked to stay in a specific distance and posture.

In this paper, remote radar sensing is used for non-invasive assessment of patients' ability to breathe. Our method utilizes commercially available radars to continuously monitor the patient's status and reduces the need for in-person well checks. It also describes how our approach provides additional information such as respiratory rate regardless of the patient's body posture or distance from the radar.

MATERIALS AND METHODS

A. Study Design

Fourteen young, healthy volunteers were recruited under IRB number 2010920 at the University of Missouri Columbia. The subjects were asked to lay on the bed on different sleep postures (Supine, prone, left and right lateral). They were asked to perform 4 minutes of normal breathing with multiple episodes of hold breath for 20 seconds to simulate the respiratory arrest.

The respiratory band was wrapped around their chest and connected to the AD Instruments PowerLab to collected gold standard respiratory waveforms for reference. There were no restrictions on their placement on the bed.

B. Sensor device

A commercial handheld Ultra-Wide Band (UWB) radar from Vayyar Imaging Ltd was installed on the ceiling heading down toward the bed to record data in a 5-meter range at 20 fps. We first recorded raw radar data from the entire field of view, and then applied multiple arena localizations to generate high-resolution 3D imageries, from smaller regions on the bed to investigate the potential regions of interest (Figure 1).

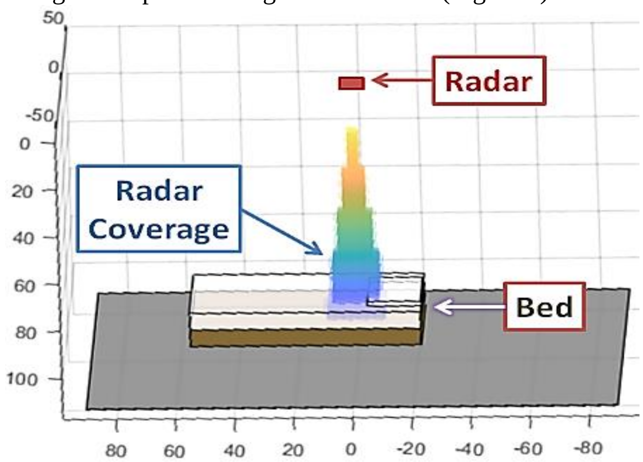

FIGURE 1. FOCUSING ON SMALLER REGIONS ON THE BED SURFACE, TO INCREASE THE DEPTH RESOLUTION.

Not all the subjects have the same breathing pattern, and some may show more movements in their chest or abdomen area. So, multiple regions on the bed were selected as the optimal areas to capture the respiratory movements, including the chest and abdomen. we even divided the entire bed into 6 grids and studied the best possible case to explore the upper bound for the accuracy of our approach for different body postures.

C. Respiratory Waveform Extraction

When the chest (or abdomen) expands during inhalation, an elevation of about 2cm appears in the location of high-intensity points in the radar imageries. By computing the relative interframe variations at any time t, a cyclic movement observed in the location of high-intensity reflection of the radar (1):

$$\Delta F_{ijk}(t) = F_{ijk}(t) - F_{ijk}(t-1) \qquad (1)$$

The energy of interframe variations at time t then computed for the 3D radar image, according to the following formula (2):

$$Energy(t) = -\sum_{i}\sum_{j}\sum_{k}\left(\Delta F_{ijk}(t)\right)^2 \qquad (2)$$

A time series (signal) then created by coupling these energy values and their corresponding recording timestamp. The temporal variations in this signal are caused by the respiratory-related movements of the chest (or abdomen).

D. Extracting the breathing status

After filtering and smoothing, the signal is used to detect the periods of hold breath (complete breath cessation). The temporal variation of the extracted signal reduces during these periods. Matlab's movmad function is used to compute the moving median absolute deviation for three-second windows (3):

$$MAD(t) = median\left(\left|En_i(t) - median\left(En(t)\right)\right|\right) \qquad (3)$$

By thresholding the deviation and discarding the periods of low deviation (hold-breath), the rest of the signal is used to estimate the respiratory rate. The magnitude spectrum of the Fourier transform is computed with a Kaiser window in Matlab. Then the highest peak of the spectrum in the frequency band of 0.1 to 0.6 Hz gets selected as the estimation of respiratory frequency.

RESULTS

Figure 2 shows on top the ground truth respiratory signal from the chest band synchronized with the original radar signal (bottom) and its smoothed version (middle). Thresholding the MOVMAD of the smoothed signal results in the periods of minimal deviation corresponding to the hold breath episodes (highlighted in pink).

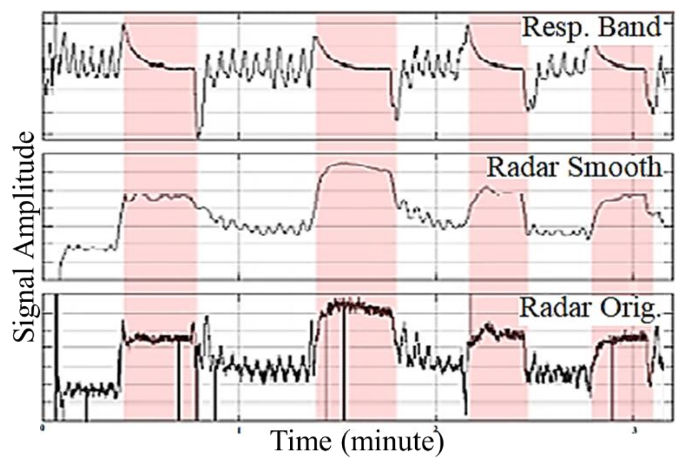

FIGURE 2. EXAMPLE OF DATA COLLECTED USING THE RADAR SYSTEM AND THE RESPIRATORY CHEST BAND AS THE GROUND TRUTH. THE SUBJECT WAS CONDUCTING MULTIPLE PERIODS OF HOLD BREATH.

Discarding the hold-breath episodes, the estimated respiratory rate for each of the 14 volunteers was compared to the ground truth estimates, and an average error computed in beat per minute (BPM) overall. Table 1 shows both the average error and average percentage error of the estimations for difference postures and over different regions of interests (chest or abdomen). Rows of Table 1 correspond to the region of interest (abdomen, chest), and columns are separating different sleep postures.

The third row (best region) computed by dividing the entire bed into 6 equally spaced wide regions include the head region, chest region, and abdomen region following by three regions over the legs. A computationally intensive process of all grid cells provides the possibility to choose a single grid for each configuration that has the lowest error in the estimation. While not practical in the real world, this row provides an upper bound on the accuracy of our method. We plan to investigate more about designing fast and automatic grid selection techniques.

TABLE 1. AVERAGE ERROR OF ESTIMATED RESPIRATORY RATE FROM RADAR COMPARED TO THE GROUND TRUTH CHEST BAND.

	Absolute Error (BPM)				Percentage Error (BPM%)			
Posture	**Left**	**Right**	**Supine**	**Prone**	**Left**	**Right**	**Supine**	**Prone**
Abdomen	2.2	1.5	1	1.7	13%	9%	7%	13%
Chest	1.5	2.9	2.1	3.2	10%	17%	15%	22%
Best Region	1.2	1.4	0.6	1.6	8%	8%	4%	12%
Average	**1.2**				**8%**			

* BPM: Beats per minute.

DISCUSSION

This paper presents the application of UWB radars in monitoring psychiatric patients for adverse events of complete respiratory cessation. After preprocessing the data gathered using a commercially available radar and constructing the 3D images for any specific region of interest, the hold-breath episodes were extracted by thresholding and compared in time and location to the reference signal (Figure 2).

The proposed method not only detects the target periods of hold-breath, but our preliminary studies also show an accuracy of up to 92% in estimated respiration rates (8% error) in different postures. This accuracy is comparable to the reported values in the literature, where they had multiple constraints on the body posture and distance from the radar. Respiratory rate estimates are beneficial as they provide additional information for the physicians about the sleep quality of their patients.

Our approach considers the privacy concerns of patients and their families compared to other imaging devices and can be used seamlessly during the day and night.

FUTURE WORK

Upon achieving these high accuracy results, we have recently started a new IRB approved data collection from real patients in a ward at Missouri Psychiatric Center, Columbia, MO, USA. We plan to study the potentials for extracting more micro-level activities (i.e., in bed restlessness) and macro-level activities (i.e., sitting or walking periods in the night).

ACKNOWLEDGMENT

This project was funded by part through a donation from Nokia Bell Labs. We would also like to show our gratitude to Nokia Bell Labs and specifically Ravi Swami for sharing their pearls of wisdom with us during the course of this research.

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