Respiratory Feature Extraction for Radar-Based Continuous Identity Authentication

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Abstract — **Radar is an attractive approach for identity authentication because it requires no contact and is unobtrusive. Most reported results have focused only on sedentary breathing patterns, without considering how respiratory patterns may change due to physiological activities or emotional stress. In this research the feasibility of extracting identifying features from radar respiratory traces was tested, for sedentary subject conditions as well as just after performing physiological activities (walking upstairs). Respiratory breathing dynamics related features (breathing rate, spectral entropy, breathing depth, inhale/exhale area ratio, mean and standard deviation of the peaks) were extracted from radar captured respiration patterns, and variations in feature parameters after physiological activities were assessed. Experimental results demonstrated that, after short exertions dynamically segmented respiratory pattern exhale area and breathing depth increased by more than 1.4 times for all participants, which made evident the uniqueness of residual heart volume after expiration for recognizing each subject even after short exertions. Our proposed approach is also integrated with a Support Vector Machine (SVM) with a radial basis function kernel to demonstrate an identification success rate of almost 98.55% for sedentary-only conditions and almost 92% for a combined mixture of conditions (sedentary and after short exertion). While the efficacy was reduced, the method still shows significant potential. The proposed identity authentication approach has several potential applications including security/surveillance, IOT applications, virtual reality and health monitoring as well.**

Index Terms — **Respiratory features, Fast Fourier Transform (FFT), breathing depth, identity authentication.**

I. Introduction

Non-contact continuous identity authentication methods using microwave Doppler radar are gaining attention due to limitations in more traditional methods (e.g. passwords, facial recognition) for addressing modern challenges including efficiency, security, privacy and accuracy [1-2]. In addition, radar has advantages over other physiological biometric based approaches (Pulse response, ECG and EEG) which require direct contact to the body, which can be uncomfortable and disruptive and requires intentional engagement with the authentication system [3]. All the attempts in literature for physiological biometric based approaches require that the human body be in direct contact with the sensor [1]. Remote sensing of respiratory signals using microwave Doppler radar has shown growing potential in healthcare applications for about four decades [4-5]. However, respiratory based identity authentication is not yet mature and requires extensive analysis and investigations. A radar captured respiratory motion based authentication system has been reported in literature which basically analyzes radio wave echo patterns from human subjects [1] [2] [6]. All reported attempts utilized a controlled environment where subjects were seated and breathing regularly [1] [2] [6]. However, in reality it might happen that people must be authenticated under various states such as when they completed physiological activities (exercise). At the same time breathing pattern variations might occur in a significant manner after physiological activities as breathing is regulated by the brain and a complex interactions between various chemicals in the blood and in the air we breathe [7]. Ignoring such variations could reduce identification accuracy under realistic identity authentication scenarios.

In this research we investigated the feasibility of extracting features from radar captured breathing patterns from both post physiological activity and sedentary conditions. From our analysis of extracted respiratory features we found that, after short exertion, breath ratio decreases and exhale area and depth increases which illustrates that during sedentary recovery (after walking up stairs) the body ensures that more oxygen is absorbed into blood by means of a relatively slow exhalation. While this results in a broader range of vital signs parameters for an individual, the unique respiratory pattern or aerobic dynamics can help provide an additional parameter for recognizing individuals accurately.

II. Experimental Setup

A 2.4-GHz quadrature Doppler radar system was used for the experiment. The measuring system included a signal generator and the following off-the-shelf coaxial components: transmit and receive antennas (Antenna Specialist ASPPT2988), two 0° power splitters (MiniCircuits ZFC-2-2500), one 90° power splitter (MiniCircuits ZX10Q-2-25-S+), and two mixers (Mini-Circuits ZFM-4212). The retrieved signal from human subject is split and fed into two mixers. The local oscillator is connected to a quadrature power divider, providing in phase and quadrature version of the signal. The post processing is performed in MATLAB platform. Fig. 1 below illustrates the experimental setup for this experiment.

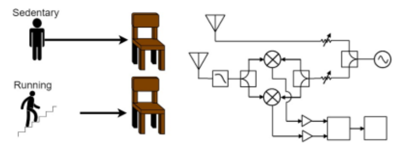

Fig. 1. Experimental setup for Radar captured respiratory pattern.

III. Feature Extraction

In this experiment, we collected data set from ten participants for about four weeks. Fig. 2 below illustrates different respiratory features of radar captured respiration pattern. The extracted features are described below.

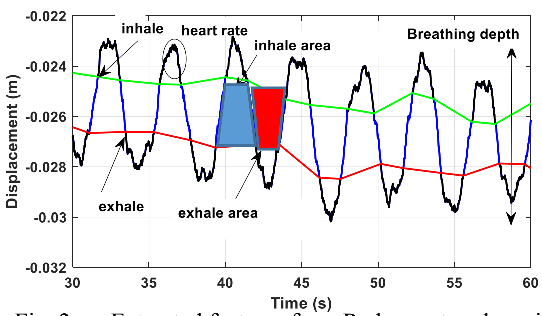

Fig. 2. Extracted features from Radar captured respiration. Each breathing cycle contains inhale, pause and exhale episode.

1) Breathing/Heart Rate: Breathing rate can be found by counting the number of breathing cycle in a given amount of time. Generally we take the Fast Fourier Transform (FFT) of the recorded signal to find the breathing rate [8]. For extracting heart rate we filtered respiration signal using Butterworth band pass filter within .8-2 Hz and then performing FFT [8]. 2) Inhale/exhale speed, average distances and standard deviation of peaks: From the peak search process we can find maximum/ minimum peaks and their time indexes of radar captured signal. From the information of peaks positions and time indexes we can find inhale/exhale rate, average distances, and standard deviation of the peaks [6]. 3) Breathing Depth: Breathing depth can be calculated by taking into account of the total displacement from minimum peak to maximum peak. Average depth is taken into calculated as one of the respiratory features. 4) Spectral Entropy: Spectral entropy is calculated by taking square of the amplitude of the radar captured signal and by normalizing the number of samples. Spectral entropy represents the breathing energy of the signal. 5) Dynamic Segmentation: Prior research [6] demonstrated the efficacy of this technique. The idea of this technique is that segmenting the 1 minute breathing cycle episode with 30%-70% amplitude and calculating the average area ratio of the inhale and exhale segment. This features (Breath ratio, R=inhale area trapezium/exhale area trapezium) gives us an idea how fast people initiates the next cycle of breathing [6]. Table-I below summarizes the extracted respiratory features for five different participants.

IV. Results

After capturing the respiration signal we filtered the signal segment for 60 seconds using FIR filter of the order of 1000. The sampling frequency of the data acquisition (DAQ) was 100 Hz. Finally FFT is employed on arc-tangent demodulated signal to find the breathing/heart rate. Fig. 3 illustrates the breathing rate .25 Hz when subject's measurement was taken during normal conditions. Fig.4 represents the breathing rate of five participants at sedentary and after short exertion. After analyzing five participants breathing pattern we found that, when people finish any short physiological activities their breathing/heart rate increase occurs a bit as just after short exertions and then they got chance to take rest (seated position) for radar measurement. For sedentary conditions, breath ratio is a unique features for identifying people [6] but after short exertion, breath ratio changes abruptly due to change in exhale area and there is also overlapping breath ratio for different subjects. However, we found that, their exhale area increases almost more than 1.4 times and breathing depth approximately more than 1.2 times than sedentary condition. We believe this is due to aerobic capacity or oxygen flow pattern, which means after

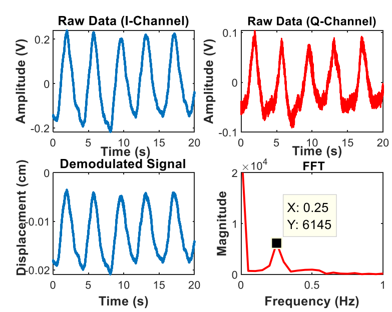

Fig. 3. Radar captured raw data channel signal (a) In-phase (I) channel signal (b) quadrature phase (Q) signal (c) arc-tangent demodulated signal for finding maximum chest displacement (d) FFT of the signal where peak of the signal illustrates the breathing rate of .25 Hz.

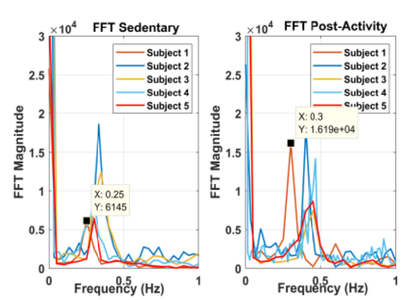

Fig. 4. FFT magnitude of Radar Captured signal. It illustrates that breathing rate change occurs after exertions.

finishing a short exertion subjects tend to take a long time to exhale which increases exhale area and breathing depth. It also indicates that the subject bodies try to make sure that more oxygen is absorbed into blood. Table-I below illustrates the summary of the extracted respiratory features. Fig. 5 represents the increase in breathing depth and exhale area of participants after short exertions. Further investigation is required to understand better how breathing dynamics changes when people come from long exertion (Gym workout) which remains as future work. We also integrated SVM classifier with radar system in our previous work [1]. In order to test the performance of our integrated classifier a total of 50 sets of data each having 60s of data were used for five different participants. Fig. 6 below illustrates the confusion matrix for identifying people for having mixed respiratory features (sedentary and exercise). The overall classification accuracy is almost 92% while it is 98.55% for sedentary. Some misclassification is occurred due to overlapping of some of the respiratory features after physiological activities, yet including short exertion in training was sufficient to maintain a significantly high success rate.

V. CONCLUSION

The feasibility of extracting respiratory features from a physiological radar monitoring system to track different respiratory patterns after physiological activities was tested for the purpose of subject identification. Aerobic dynamics related unique features (exhale area and depth) change in pattern in a consistent manner for individuals and thus help with recognition of people even after short exertion. Thus while identification errors increase with the increase in overlap of sedentary classifiers, “learning” the manner in which activity affects an individual can offset this error to maintain a high efficacy rate of identification.

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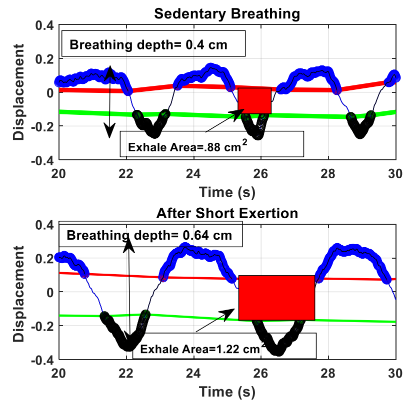

Fig. 5. Dynamic segmented (10 second) radar captured two different respiratory patterns for one participant. Breathing depth and exhale area increases after short exertions.

Confusion Matrix for Testing Dataset

9 18.0%	0 0.0%	0 0.0%	1 2.0%	0 0.0%	10 90% 10.0%
0 0.0%	10 20.0%	0 0.0%	0 0.0%	0 0.0%	10 100% 0.0%
0 0.0%	0 0.0%	8 16.0%	0 0.0%	2 0.0%	10 80.0% 20.0%
0 0.0%	0 0.0%	0 0.0%	9 18.0%	1 4.0%	10 90% 10.0%
0 0.0%	0 0.0%	0 0.0%	0 0.0%	10 20.0%	10 100% 0.0%
9 100% 0%	10 100% 0.0%	8 100% 0.0%	10 90% 10.0%	13 76.92% 23.08%	50 92.00% 8.0%
Sub-1	**Sub-2**	**Sub-3**	**Sub-4**	**Sub-5**	**Overall**

True class

Fig. 6. The diagonal position of the matrix represents the number of times subjects classified accurately.

TABLE I
SUMMARY OF RESPIRATORY FEATURE EXTRACTION FROM RADAR CAPTURED RESPIRATION

Features	**Subject 1**		**Subject 2**		**Subject 3**		**Subject 4**		**Subject 5**	
	Normal	**Walk**	**Normal**	**Walk**	**Normal**	**Walk**	**Normal**	**Walk**	**Normal**	**Walk**
Breathing Rate (Hz)	.33	.35	.4	.45	.25	.32	.35	.45	.25	.35
Heart Rate (Hz)	1.21	1.21	1.3	1.32	1.17	1.17	1.23	1.28	1.17	1.21
Breathing depth (m)	.019	.024	.019	.032	.015	.027	.022	.031	.024	.0312
Inhale/exhale ratio	1.10	.82	1.20	.92	1.60	1.10	1.72	0.94	1.40	1.30
Exhale Area (cm^2)	.88	1.22	.91	1.66	.74	1.15	.98	1.44	.72	1.50
Spectral Entropy (W/Hz)	.49	.59	.48	.65	.39	.69	.42	.52	.65	.69

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