Non-contact Measurement of Respiratory Function and Deduction of Tidal Volume

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Abstract— **This paper further the investigation of Doppler radar feasibility in measuring the flow in and out due to inhalation and exhalation under different conditions of breathing activities. Three different experiment conditions were designed to investigate the feasibility and consistency of Doppler radar which includes the combination of the states of normal breathing, deep breathing and apnoea state were demonstrated. The obtained Doppler radar signals were correlated and compared with the gold standard medical device, spirometer, yielding a good correlations between both devices. We also demonstrated the calibration of the Doppler radar signal can be performed in a simple manner in order to have a good agreements with the spirometer readings. The measurement of the flow in and out during the breathing activities can be measured accurately under different dynamics of breathing as long as the calibration is performed correctly.**

I. INTRODUCTION

The used of Doppler radar as a non-contact techniques for detecting and measuring human physiological functions such as breathing and heartbeat has been received significant attention compared to the conventional methods such as respiration belt and ECG [1]. Some of the research on the used of non-contact systems for certain vital human signs monitoring and detection has been reported in a number of papers for instance [2], [3], [4], [5], [6], [7], [8]. Additional on this, in [9], Lee et al demonstrated that Doppler radar is capable in capturing different type of breathing patterns which includes normal breathing, fast breathing, as well as different rate of inhale and exhale provided accurately as long as the issues of noise(motions artefact and etcetera) are addressed. Having said this, there are still rooms for improvement in using Doppler radar as an assistive technology in human vital's sign detection and measurements especially on the isolation of motion artefacts and the desired bio-signals.

Further to this, capability of Doppler Radar in obtaining the respiratory tidal volume [10] has been demonstrated using the known relationship between chest wall movement and tidal volume. In other word, continuous measurement of volume in and out along with other respiration parameters such as breathing rate, respiratory effort energy, respiration patterns and etcetera could potentially be used to assess certain breathing disorders especially it could be done in a non-contact approach. As mentioned in [11], variation in breath-by breath volume and pattern distribution changes depending on the clinical condition and pathophysiology which can be related to either restrictive or obstructive lung diseases. This draws the importance of having the measurement for tidal volume.

In this paper, we extended the work [10] in capturing the flow in and out during inspiration and exhalation for three different scenarios as discussed in section III. The rest of this paper is organized as follows: Section II discusses the theoretical approach of Doppler radar in measuring the breathing activities, Section III describes the experiment mechanism for the data collection and Section IV describes the signal processing algorithms used in dealing with the Doppler radar signals. Section V discusses on the results gained and a concluding remarks in the section VI.

II. THEORETICAL REVIEW

Physiological detection and measurement systems were designed based on the concept of Doppler effect where it occurs when there is change in frequency from the reflected radio wave off a moving object. In a continuous wave (CW) system, a continuous wave is transmitted towards the object where the reflected signal will be modulated due to the motion of the object. From this, the change of the frequency or phase can be derived from the received signal. Using a continuous wave (CW) transmitted signal from the radar defined by

$$T(t) = cos(\omega_0 t + \phi(t)), \quad (1)$$

where $T(t)$ is the transmitted signal, and ϕ is the arbitrary phase shift or the phase noise of the signal source. If $T_x(t)$ is reflected by target at a nominal distance of d_0, where time varying displacement of $x(t)$ is due to the movement of abdomen during respiration activities, the received signal at the receiver end can be approximated as

$$R(t) \approx cos(2\pi ft - \frac{4\pi d_0}{\lambda} - \frac{4\pi x(t)}{\lambda} + \phi(t - \frac{2d_0}{c})). \quad (2)$$

In a direct conversion system architecture, the received signals will be mixed with local oscillator (LO) and low pass filtered to yield the baseband output where in a quadrature receiver, the baseband signal will be split into two forms which are in phase and quadrature phase signals denoted by $I_B(t)$ and $Q_B(t)$ correspondingly. The phase different

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between this two signals will be $\frac{\pi}{2}$ and the representation of each signals are denoted as

$$I_B(t) = cos(\theta + \frac{4\pi x(t)}{\lambda} + \Delta\phi(t)), \tag{3}$$

$$Q_B(t) = sin(\theta + \frac{4\pi x(t)}{\lambda} + \Delta\phi(t)). \tag{4}$$

III. Experiment Mechanism

A 2.4 GHz Doppler radar module [12] was used in this experiment. The radar module was attached to two panel antenna (a transmitter and a receiver) and transmitting 2.4 GHz continuous wave at 0 dBm(1mW). For data acquisition part, the radar module was attached to a National Instrument data acquisition system (NI-DAQ: USB 6009) where the received signals is then further processed using MATLAB. The experiment was performed with a subject (normal clothing) seated at 0.8 m from the antenna where few set of experiments were performed to evaluate the flow in and out during inspiration and expiration using both the radar system and the spirometry (MLT1000L respiratory flow-head attached to the Powerlab sampled at 1000 Hz) as a reference.

For this purpose, a few different experiment conditions were designed to investigate the feasibility and consistency of Doppler radar on top of the works [10] under different breathing scenarios in obtaining the flow in and out corresponding to the spirometer readings. In this experiment, the subject was asked to:

1) Breathe deeply, pause, and continue to breathe deeply
2) Breathe normally followed by deep breaths
3) Breathe deeply followed by normal breathing

IV. Signal Processing

The received signal was acquired using National Instrument Data Acquisition module (NI-DAQ) and being sampled at 1000 Hz. At initial stage, the raw signals were further processed to have zero mean and filtered using a SG (Savitzky-Golay polynomial least squares) filter to smooth the signal while preserving the steep changes [7].

Typically, the amount of air inspired or expired during regular breathing is known as tidal volume where it is a measurement of the amount of air flowing into and out of the lungs [13]. The linear relationship between lung and volume during regular breathing has been previously documented (see, for example, [14], [10]) and since the output of the Doppler radar is proportional to the abdomen/chest wall movement the amount of air flow either in or out can be possibly derived in a similar way. Therefore, calibration was first performed in order to obtain the most reliable chest displacement measurement as follows:

1) Computation of Fast Fourier Transform(FFT) for radar and spirometer signals
2) Computation of the maximum value for both signals
3) Finding the corresponding ratio from the (2)
4) Regeneration of new signal for radar using the calculated ratio by multiplying the ratio with the radar signal.

Once obtained then we could use the known relationship between displacement of chest(signals from Doppler radar) and tidal volume to estimate the inhalation and exhalation flow rates. A general flow of the whole process is as shown in the Figure 1.

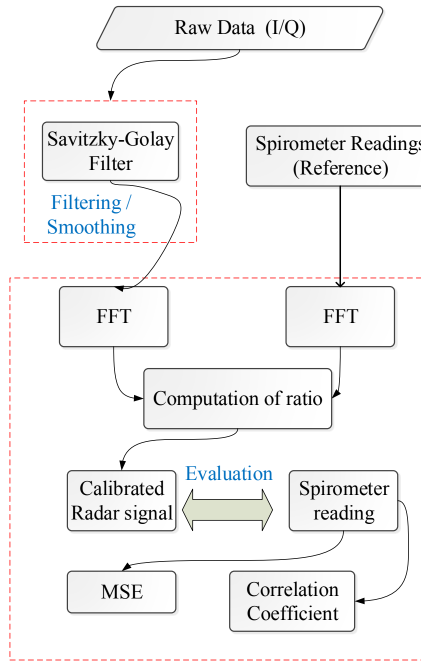

Fig. 1. Overall Process Flow

V. Results and Discussion

The in-phase (I) signals were chosen as the radar signal in this experiments as it is the closest to the optimum point [15]. The results were as shown in Figure 2, 3 and 4 respectively for each condition. From the results, the shape of the Doppler radar signal is similar to the spirometer readings but with an amplitude difference - without calibration. After calibration, the Doppler radar signals is almost identical to the spirometer readings. Assuming that the shifting of Doppler Radar is caused by the movement of the chest/belly during respiration, a linear relationship between the changed of flow has been derived based on the Doppler signal. We also see that the Doppler signal was sensitive enough to detect the differences in the breathing patterns. However, a calibration period of approximately 30 seconds is required and can be automated.

In all experiments, computation of mean square error (MSE) and correlation coefficients was performed between Doppler Radar signals and spirometer. Results show consistently high linear correlations between the Doppler radar and spirometer. From this experiments, we can actually see there is a possibility of Doppler radar in detecting different type of changes in breathing state as shown in all the results, for instance, normal breaths,deep breaths, and apnoea. This could leads to a different research interests where the feasibility of Doppler radar in capturing different types of breathing patterns, analysis on the respiration efforts energy,

TABLE I

COEFFICIENT COMPARISON ON DOPPLER RADAR SIGNAL WITH SPIROMETER

	Comparison	MSE	Correlation Coefficient
Experiment 1	Non- Calibrate Radar Signal with Spirometer	0.5867	0.9664
	Calibrated Radar Signal with Spirometer	0.1064	0.9664
Experiment 2	Non- Calibrate Radar Signal with Spirometer	1.2306	0.9551
	Calibrated Radar Signal with Spirometer	0.1939	0.9551
Experiment 3	Non- Calibrate Radar Signal with Spirometer	0.5023	0.9799
	Calibrated Radar Signal with Spirometer	0.0739	0.9799

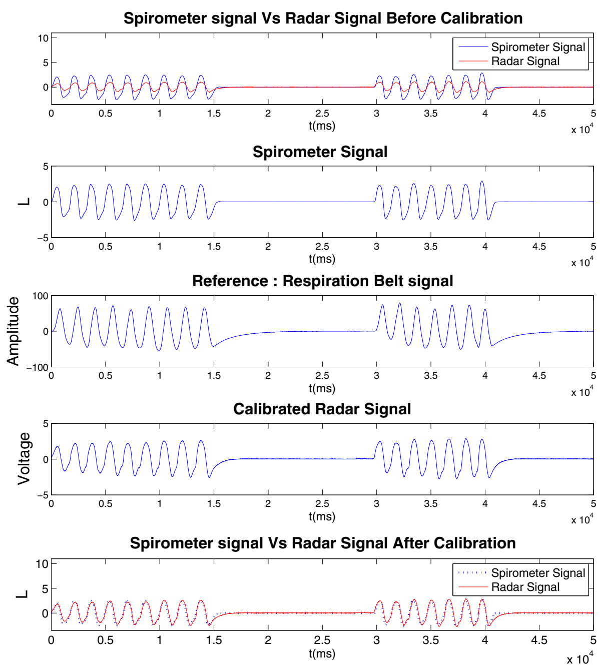

Fig. 2. Experiment 1: Deep Breaths followed by apnoea

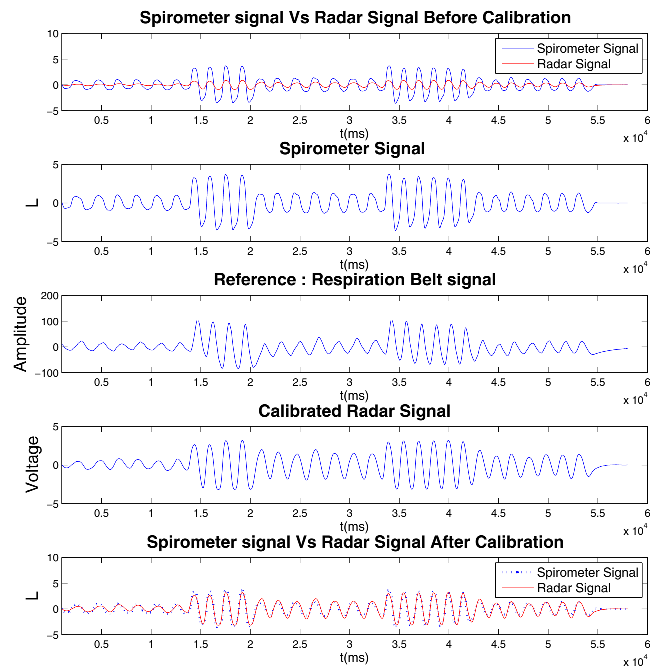

Fig. 3. Experiment 2: Normal Breaths followed by Deep Breaths

respiration rates and other respiration function that could be used for early diagnosis by deriving the relationship between the data obtained from Doppler radar to a certain respiration conditions, for instance, dyspnea, bradypnea, Cheyne-Stokes respiration and etcetera which could be beneficial due to its non-contact characteristic.

VI. CONCLUSION

In this paper, we demonstrated that consistency of Doppler radar signal in capturing the change of flows caused by the inhale and exhale process under different conditions such as deep breathing, normal and apnoea states as long as calibration is performed correctly. From the results obtained, we can concludes that, detection of changed in flow due to breathing activities can be measured reliably using Doppler radar as long as the issues of noise(motion artefacts and etcetera) is addressed. Additional on that, the results also shows that the robustness of Doppler radar in capturing accurate changes of conditions during breathing activities as mentioned previously. Thus, the potential of using Doppler Radar in detection and measurement of respiration function could be one of the essential device in replacement of the conventional method of using spirometer as it offers the comfortability and it can be performed in a non-contact method. The key work in the future would be in isolating the motion artefacts from the desired bio-signals in order to obtained absolute measurement due to respiration activities from the Doppler radar as well as extending the works to clinical trial on different range of patients. Additional on this, study on the position of the sensor in relative to the subject will be carried out to investigate the relationship between Doppler radar measurement and the tidal volume.

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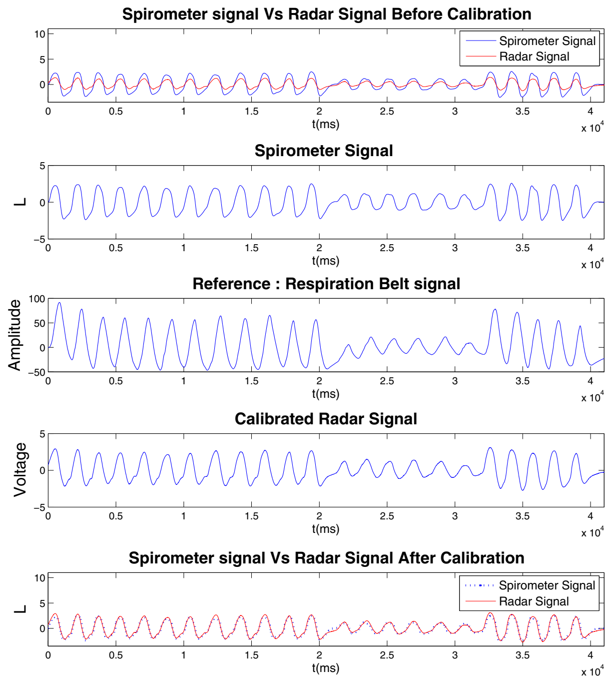

Fig. 4. Experiment 3: Deep Breaths followed by Normal Breaths

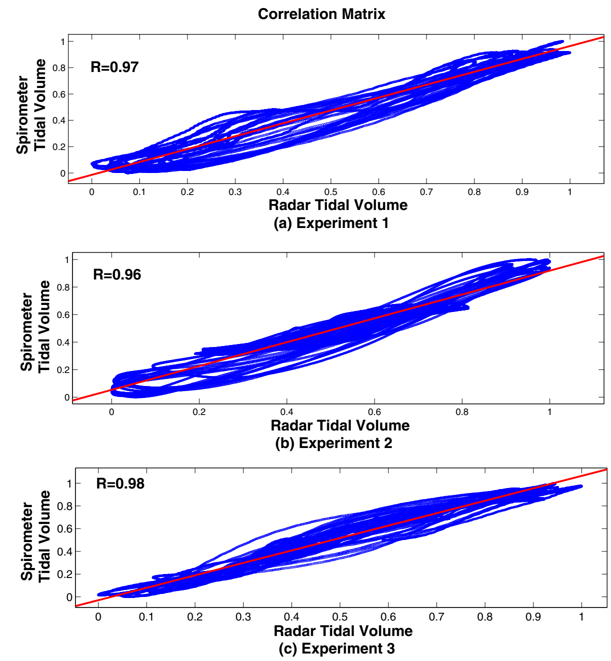

Fig. 5. Pearson's Correlation Plot between Radar signal and Spirometer signal

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