IDENTIFICATION OF DIFFERENT RESPIRATORY RATE BY A PIEZO POLYMER BASED NASAL SENSOR

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Abstract— In this paper, we present a new nasal sensor system developed using Polyvinylidene fluoride (PVDF) piezo polymer in cantilever configuration and its applicability for measuring human Respiration Rate (RR). Two identical PVDF nasal sensors are mounted on a headphone such that they are located below Right Nostril (RN) and Left Nostril (LN), in such a way that the nasal airflow during inspiration and expiration impinge on sensors. Due to nasal airflow, piezoelectric natured PVDF nasal sensors generate corresponding voltage signals. The RR is the number of breaths per minute (bpm). The RR was determined from the filtered respiratory signals, by computing a power spectral density (PSD) spectrum using Welch method of averaged periodograms. The developed PVDF nasal sensors were capable of identifying different RR corresponding to normal (18.5±1.5 bpm), tachypnea (34.5±4 bpm), and bradypnea (10.5±2.2 bpm) similar to 'Gold standard' Respiratory Inductance Plethysmograph (RIP) method and Nasal Prongs (NP).

Keywords: Respiration rate, breathing type, Polyvinylidene fluoride (PVDF), Respiratory Inductance Plethysmograph, Nasal Prongs.

I. INTRODUCTION

Respiratory Rate (RR) is a very important physiological parameter to be monitored in people both in healthy and critical condition, as it gives valuable information regarding their respiratory system performance [1]. The RR is defined as the number of breaths per minute [2]. A typical RR at resting is 12 and its corresponding frequency is 0.2 Hz [2]. During recovery from surgical anesthesia, a μ-opioid agonists used for pain control can slow down RR leading to bradypnea (RR<12) or even apnea (cessation of respiration for an indeterminate period) [3], while airway obstructions like asthma, emphysema and COPD will increase RR causing tachypnea (RR > 30) [4]. Hence RR measurement becomes clinically very important. The methods commonly used for measuring RR are visual observation, impedance pneumography, acoustic sensing, fiber optic sensing, Respiratory Inductance Plethysmograph (RIP) and nasal prongs (NP) [5]. However, due to very sensitive patients' movements and high cost, these methods find limited use in the clinical settings [6].

Polyvinylidenefluoride (PVDF) is a piezoelectric polymer that generates an electrical charge when it is mechanically deformed [7]. Earlier, Siivola examined the use of PVDF to record the body movements caused by the respiration and cardiac action in lying position [8]. Choi and Jiang developed a belt sensor with PVDF for measuring respiratory cycle [9].

In our present study, PVDF nasal sensor, RIP and NP were used to measure the RR of healthy human beings at rest. The aim here was to evaluate a new PVDF nasal sensor for identifying different RR compared to 'Gold standard' RIP and NP methods.

II. METHODS AND MATERIALS

PVDF NASAL SENSOR

PVDF film (Precision Acoustics, UK) is taken in the cantilever configuration to form a PVDF nasal sensor [10]. The length, width and thickness of the PVDF cantilever were optimized to 10mm×5mm×28μm. Two such identical nasal sensors were mounted on either side of headphone such that one PVDF nasal sensor is located below Right Nostril (RN) and the other below Left Nostril (LN), such that the nasal airflow during inspiration and expiration impinge on sensors. Since PVDF has piezoelectric property (polarization produced by mechanical forces), it gives corresponding voltage signal when nasal airflow impinge on it. The PVDF nasal sensors measures respiration from RN and LN, separately and simultaneously.

Respiratory inductance plethysmograph (RIP)

Respiratory inductive plethysmography (Respi-trace^{TM}) measures the changes in thoracic and abdominal cross-sectional area to provide an indirect measure of respiration [11]. It consists of two flexible sinusoidal wires embedded separately in stretchy fabric bands; one wrapped around the chest and the other around the abdomen .The inductance of each band changes upon rib cage and abdominal displacements and generates a voltage signal proportional to its inductance. The electrical sum of the ribcage and abdominal signals provides the total thoracoabdominal displacement.

Nasal Pronges (NP)

Assessment of nasal airflow is carried out by recording pressure at the nostrils [12]. To achieve this, conventional

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nasal prongs, used for oxygen therapy, were connected to a pressure transducer. The rationale of the method is that the airflow turbulences at the nostrils induce a pressure that is directly related to the magnitude of nasal airflow. Thus respiratory curve can be traced using NP.

Measurement set-up

The placement of PVDF nasal sensors, RIP and NP are shown in figure 1. Initially, NP is placed inside the nostril and its other end was connected to the pressure transducer. Further, the two PVDF nasal sensors were placed below left and right nostrils (approximately at a distance of 5mm). After placing NP and PVDF nasal sensors, two inductance bands were wrapped around the chest and abdomen of the subject.

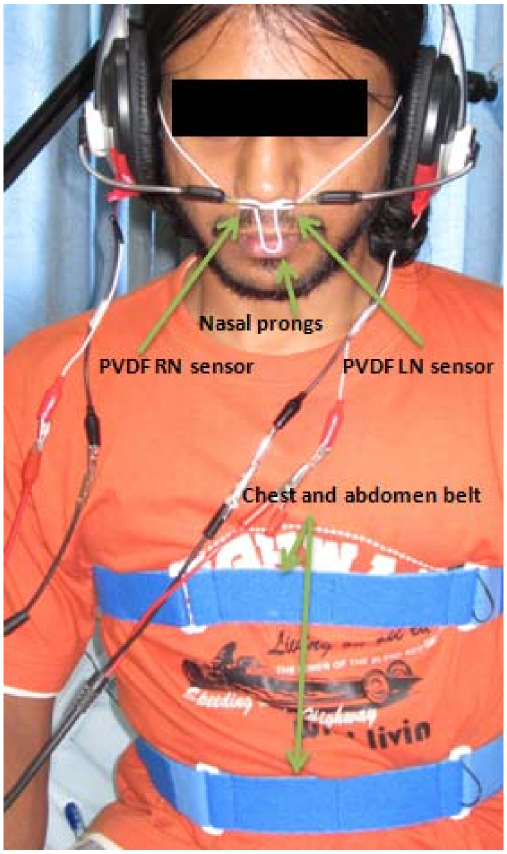
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Figure 1: Subject wearing the PVDF nasal sensor, Chest & abdomen belts and NP for RR measurement.

The output signals measured using PVDF nasal sensor, RIP and NP sensors were amplified with a two-stage amplifier. The amplifier was realized with a trans-impedance amplifier followed by a voltage amplifier. Tl072 (Texas Instruments) was used in both stages. An analog third order low pass filter was added to the circuit, between the amplifier stages with the cut-off frequency of 5Hz. The filtered and amplified signals were fed to data acquisition card [Labview DAQ card] for recording and storing in the computer for further analysis. Initial 30 seconds data was discarded in order to reduce the effects caused due to wearing of the sensors on the subject's face and body. Once the signal became artifact free, the respiratory signals for each subject were simultaneously recorded using the PVDF nasal sensor, RIP and NP for 60 seconds and stored in a computer with a sampling rate of 100 S/sec.

We measured RR using PVDF nasal sensor, RIP and NP in a relaxed sitting position of 10 healthy male subjects (age ranged from 22-56 years). During data/respiration signal recording, all subjects performed the different breathing types as per the experimental protocol **(**shown in Fig. 2**)**. These different breathing types are voluntarily simulated to analyze, in order to examine, whether our designed nasal sensor will be able to detect different RR, similar to RIP and NP device. The different breathing types performed include normal breathing for about 15s, fast breathing for about 15s (tachypnea), slow breathing for about 15s (bradypnea) and again normal breathing for about 15 s in sequence.

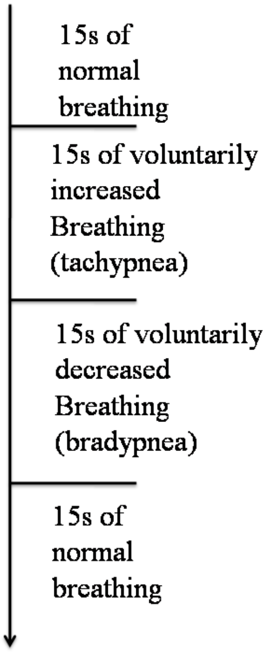


Figure 2: Performed experimental breathing protocol for ten adult subjects (while sitting).

Data analysis

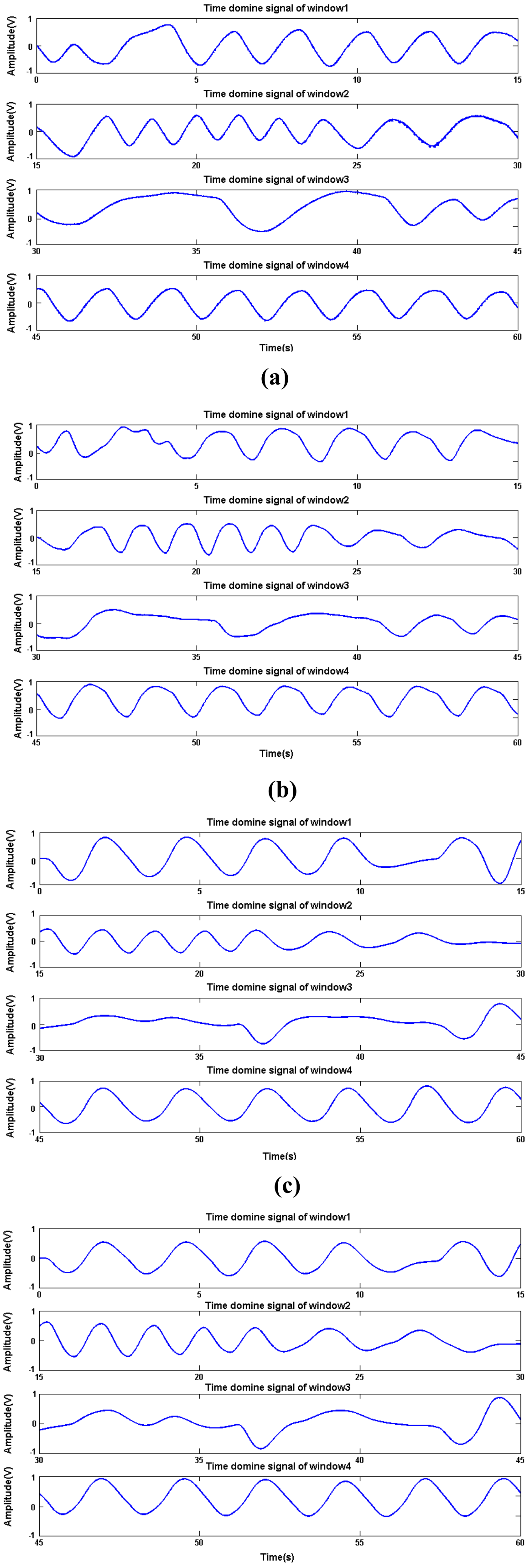
The recorded respiratory data was analyzed with Matlab® software. To determine the RR, the signals were first filtered with Butterworth third order lowpass filter. The cutoff frequency of lowpass filter was 2 Hz. The filtered 60 sec respiratory signals obtained from PVDF nasal sensors, RIP and NP were divided into four different windows corresponding to 4 different breathing types. Each window consisted of respiratory signals of 15 sec. Window 1 consisted of 0-15 sec of normal breathing, window 2 consisted of 15-30 sec of fast breathing (tachypnea), window 3 consisted of 30-45 sec of slow breathing (bradypnea) and window 4 consisted of 45-60 sec of normal breathing. The respiration rates were determined from all the four window filtered signals, by computing a power spectral density (PSD) spectrum with Welch method of averaged periodograms [13]. The peak at the calculated PSD spectrum corresponds to the frequency of average respiration rate.

III. RESULTS

The filtered time domine signals of the RIP, NP, PVDF right and left nasal sensors are shown in figure 3 (a) - (d) respectively, and their corresponding PSD spectrum are also shown in figure 4 (a)-(d) respectively, for one of the subjects. Window 1 and 4 corresponds to normal breathing type and their PSD peaks are at 0.33Hz and 0.35 Hz, respectively. Window 2 corresponds to tachypnea and its PSD peak is at 0.66Hz. Window 3 corresponds to bradypnea and its PSD peak is at 0.18 Hz. The PSD peaks (principle peaks) of PVDF right and left nasal sensors almost match with the RIP and NP PSD peaks for all types of breathing. Table 1 shows the RIP, NP and PVDF nasal sensors average RR obtained with PSD for different breathing types. The RR measured by PVDF nasal sensors for all different breathings are closer to the RR measured by reference RIP and NP methods. The results clearly shows that the designed PVDF nasal sensor identifies different RR similar to 'Gold standard' RIP method and NP. Real-time respiratory signals were obtained using these three methods and all three methods differentiated between different breathing types appreciably well. During data collection, one important thing observed was that few subjects were not comfortable with using NP and RIP as these caused irritation/inconvenience to their nose and body while wearing. This kind of problem was not faced while using PVDF nasal sensor as there was no contact between the subject nose and sensor.

Breathing types	Measuring method		Average RR
Window 1 (Normal)	PVDF	RN	18.5±1.5
		LN	18.5±1.5
	RIP		18.5±1.5
	NP		18.25±1.5
Window 2 (Tachypnea)	PVDF	RN	34.5±4
		LN	34.5±4
	RIP		34.75±5
	NP		34.5±5
Window 3 (Bradypnea)	PVDF	RN	10.5±2.2
		LN	10.5±2.2
	RIP		10.5±2
	NP		10.25±2
Window 4 (Normal)	PVDF	RN	19±1.5
		LN	19±1.5
	RIP		18.75±1.5
	NP		18.75±1.5

Table I: RR measured using PVDF, RIP and NP during different breathing types.



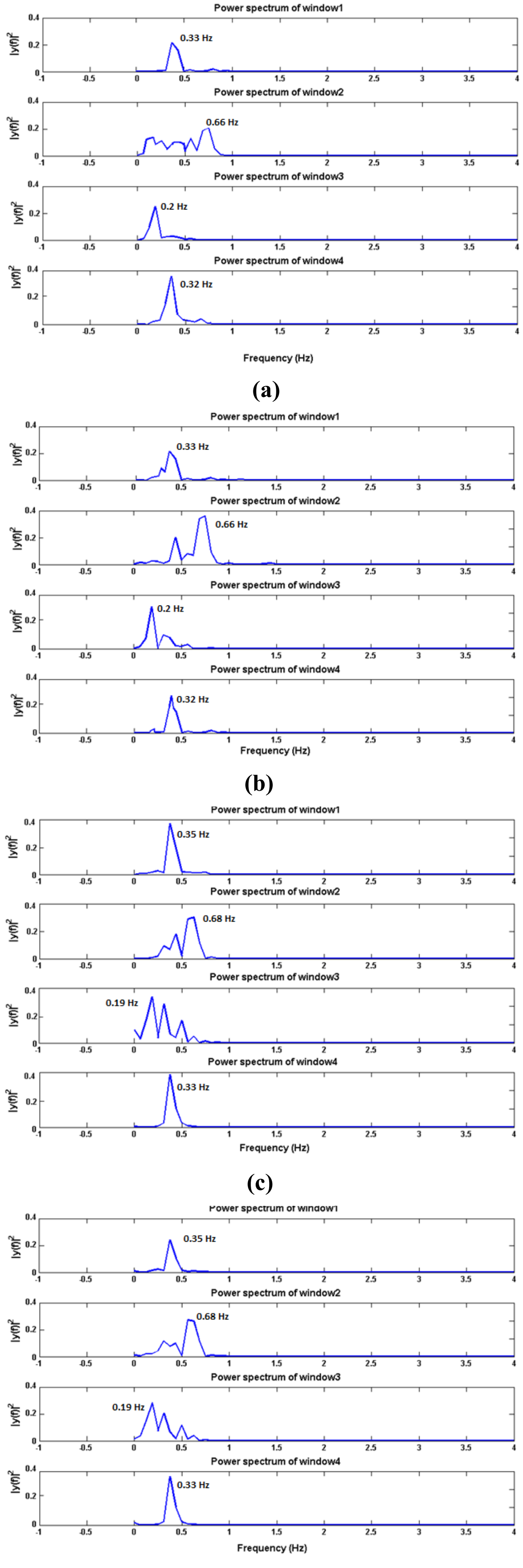
(a)

(b)

(c)

(d)

Figure 3: Time domine signals of respiratory signals measured using **(a)** RIP **(b)** NP **(c)** PVDF RN sensor **(d)** PVDF LN sensor



(d)

Figure 4: PSD spectrum of respiratory signals measured using **(a)** RIP **(b)** NP **(c)** PVDF RN sensor **(d)** PVDF LN sensor.

IV. Conclusion

The respiration rates were measured for different breathing types using PVDF nasal sensors, RIP and NP. The respiration rates measured by PVDF nasal sensors correlated well with the values calculated from the reference RIP and NP methods for all breathing types. The results clearly indicate that the designed PVDF nasal sensor is capable of identifying different RR corresponding to normal, tachypnea and bradypnea breathing types. Hence the presently developed PVDF nasal sensor system can be used in routine clinical setup for RR monitoring.

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