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A Wearable Bioimpedance Chest Patch for IoHT-Connected Respiration Monitoring

Chunkai Qiu and Mehmet Rasit Yuce

***Abstract*— This paper presents a wearable sensor patch with real-time respiration monitoring by measuring the change in thoracic impedance resulting from breathing. A bioimpedance (BioZ) sensor with two sensing electrodes is employed to measure the chest impedance. In addition, a medical-grade infrared temperature sensor is utilized to detect body temperature. The recorded data is transmitted via a Bluetooth module to a computer for online data computation and waveform visualization. The breath-by-breath breathing rate is calculated using the time difference between two BioZ signal peaks, and the results are validated against a commercial respiration monitoring belt. Experimental tests have been conducted on five subjects in both static (i.e., sitting, supine, sleeping on the left side, sleeping on the right side, and standing) and dynamic (i.e., walking) conditions. The experiment measurements show that the BioZ sensor patch can be used to monitor the breathing rate accurately in static conditions with a low mean absolute error (MAE) of 0.71 breath-per-minute (bpm) and can detect breathing rate effectively in a dynamic environment as well. The results suggest the feasibility of using the proposed approach for respiration monitoring in daily life.**

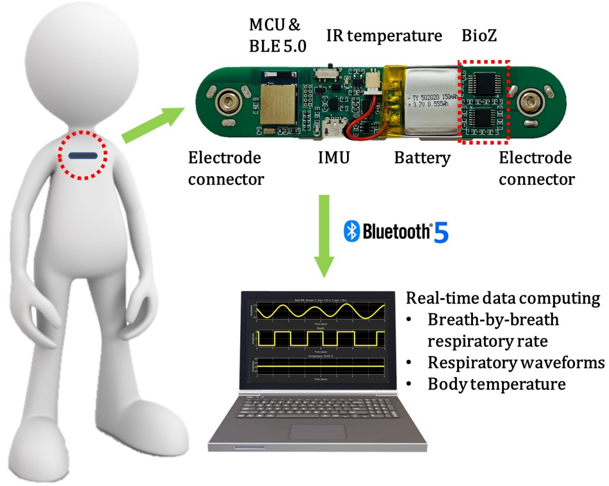

Fig. 1. The system overview of the proposed BioZ patch for real-time respiratory rate and body temperature monitoring.

I. INTRODUCTION

The emergence of the Internet of Health Things (IoHT) promotes the transformation of healthcare from treatment to prevention [1], [2]. People are no longer satisfied with the traditional mode of clinic diagnosis when they are sick. Instead, they want to know their health conditions at any time. Wearable devices that can realize real-time, dynamic, and continuous physiological parameters monitoring provide a promising solution for future higher-level healthcare [3], [4]. Respiratory rate, one of the four main vital signs for detecting medical diseases, is the number of times a person breathes per minute. The abnormal respiratory rate could be a sign of health issues, such as lung diseases, sleep apnea, chronic obstructive pulmonary disease (COPD), and asthma. The early detection of these diseases relies on continuous long-term monitoring.

At present, various approaches of wearable respiration monitoring have been proposed, including the respiratory inductance plethysmography (RIP) method [5], [6], the pressure sensor method [7], [8], the electrocardiography (ECG) derived respiration method [9], and the photoplethysmography (PPG) derived method [10], [11]. Besides, several studies have investigated the feasibility of detecting breathing using movement sensors, such as tri-axial accelerometers or Inertial Measurement Units (IMU) [12], [13]. However, the sensors are sensitive to motion artifacts, which could affect the accuracy of the measurement. Another promising technique used for respiration measurement is the bioimpedance (BioZ) method [14]. During inspiration, the increase in the chest gas volume and the expansion of conductance paths lead to an increment in the electrical impedance [15]. Hence, respiratory activities can be sensed by a BioZ sensor.

Here, a BioZ sensor based wearable chest patch for real-time breath-by-breath respiratory monitoring is introduced. The patch detects the respiration pattern and the respiration rate by measuring body impedance changes in the thoracic associated with breathing. The sensor is designed to be worn on the chest with a pair of monitoring electrodes. The acquired data can be transmitted with Bluetooth technology to process the signals online to display the real-time respiratory waveform and calculate breath-by-breath breathing rate. The system has been evaluated on five subjects under both static and dynamic (i.e., walking) circumstances and validated against a reference commercial respiration transducer.

II. METHODS

A. Hardware Design

A wearable biomedical device should have excellent wearability that is small, lightweight, comfortable, and easily attachable. In this work, a wireless body-worn chest patch, which can continuously measure breathing rate, respiratory waveform, and body temperature, is designed and proposed, as shown in Fig. 1. The size of the device is 10.5 cm × 2 cm,

Chunkai Qiu and Mehmet Rasit Yuce are with the Department of Electrical and Computer Systems Engineering, Monash University, Melbourne, VIC 3800, Australia.
Email: Mehmet.Yuce@monash.edu

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TABLE I

SUMMARISE OF EXPERIMENTAL PROTOCOLS.

	Posture	Breathing Pattern	bpm	Cycles	Duration
Test 1	Sitting for all phases	Phase 1: Inhale 1s – Exhale 1s	30	30	1 min
		Phase 2: Inhale 1s – Exhale 1s – Hold 1s	20	30	1.5 mins
		Phase 3: Inhale 2s – Exhale 2s – Hold 2s	10	30	3 mins
		Phase 4: Hold the breath	–	–	0.5 mins
Test 2	Supine Sleeping on the left side Sleeping on the right side Standing	Normal breath	–	–	3 mins for each posture
Test 3	Walking	Inhale 1s – Exhale 1s – Hold 1s	20	60	3 mins

it can fit comfortably on the chest. The chest patch consists of a BioZ circuit, an IR temperature sensor, an IMU for body posture and movement detection, a microcontroller unit (MCU) with a built-in Bluetooth module for data transmission, a rechargeable lithium-ion polymer (LiPo) battery, and two snap connectors for disposable monitoring electrodes.

BioZ Sensor: The high precision impedance converter AD5933 from Analog Devices® is utilized to monitor the respiration pattern by detecting the variations in body impedance due to thorax deformation related to breathing movement. The output peak-to-peak excitation voltage is configured to 440 mV with a frequency of 64 kHz. The data is read by the MCU with the I^2C interface.

MCU and Bluetooth Module: The Bluetooth module MDBT50Q from Raytac, designed based on the Nordic nRF52840 SoC, is used in this work as the data transmission unit. The module is a Bluetooth 5 transceiver with an integrated 64 MHz ARM Cortex M4F processor. It can read the digital signals from the sensors and then transmit the acquired data to a computer via Bluetooth.

Power: The device is powered by a rechargeable LiPo battery with a capacity of 150 mAh at 3.7 V, and a charge management IC MCP73831 is employed to control the battery charging process. The device is capable of operating continuously for 4 hours on a fully charged battery, and the operation time can be extended under the intermittent operation mode.

B. Experimental Protocols

Experimental testing was conducted on five young male adult subjects. The proposed device was attached to the participants' chest and a commercial piezo-electric respiration transducer (Pneumotrace II™) worn on the thoracic was used as the reference. Three experimental tests have been studied. The protocols for data collection are presented in Table I. The subjects were motionless in Test 1 and Test 2, and Test 3 was conducted to examine the practicability of the system under motion condition. The experimental procedures were approved by the Monash University Human Research Ethics Committee (MUHREC).

Test 1: The purpose of this test is to evaluate the range and accuracy of the patch in breathing rate detection. The subject sat in an ergonomic chair during the test and breathed in accordance with a pre-recorded breathing pattern video. The subject breathed at the rate of 30 breath-per-minute (bpm), 20 bpm, and 10 bpm, respectively. Each pattern contained 30 cycles, resulting in the time length of 1 minute, 1.5 minutes, and 3 minutes, respectively. After that, the subject was asked to hold his breath for 30 seconds. Therefore, the total duration of this test is 6 minutes.

Test 2: This test aims to explore the feasibility of monitoring breathing rates under different body postures. Every subject was informed to breathe normally for 3 minutes in each body position, including supine, sleeping on both the left and right sides of the body, and standing.

Test 3: This test investigates the capability of detecting breathing rate under motion condition, such as walking. The subject was instructed to walk on a treadmill at a speed of 2.5 km/h while following a pre-recorded breathing pattern video to breathe at the rate of 20 bpm.

C. Data Analysis

Both data obtained from the proposed sensor patch and the reference device were sampled at 200 Hz and were transmitted to a computer through Bluetooth for online data computing. All data processing was carried out using Matlab software (R2020b). Fig. 2 illustrates the block diagram of the signal processing processes. The BioZ signal was processed online to obtain the real-time breathing rate and the respiration waveform. The Pneumotrace II™ (reference) signal was processed online for waveform visualization and processed offline to obtain the reference respiration rate. Therefore, we can compare the online processed respiration rate with the offline processed reference to evaluate the accuracy of the proposed system.

In online processing, Matlab DSP System Toolbox™ was utilized for data filtering. The raw signals were smoothed using a moving average filter with a sliding window of 1 second. Then the signals were filtered by a fourth-order low-pass Chebyshev Type II filter with stopband edge frequency 1.5 Hz, followed by a second-order high-pass Butterworth filter with cut-off frequency 0.15 Hz to detrend the waveforms. The same filter parameters were applied in offline processing. Fig. 3 depicts a sample of online and offline filtered waveforms following Test 1 Phase 2 breathing pattern, in which 20 breaths can be identified in both waveforms. The breath-by-breath breathing rate is calculated from the time difference between two respiratory peaks, as illustrated

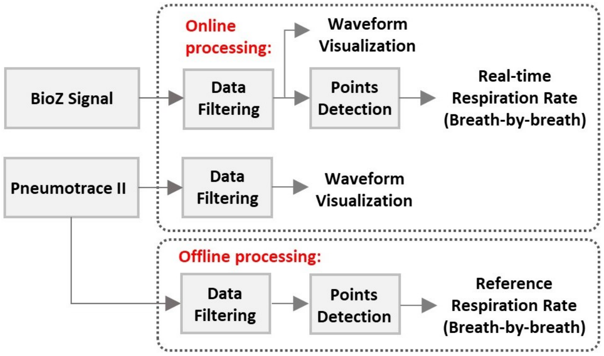

Fig. 2. The flowchart of signal processing.

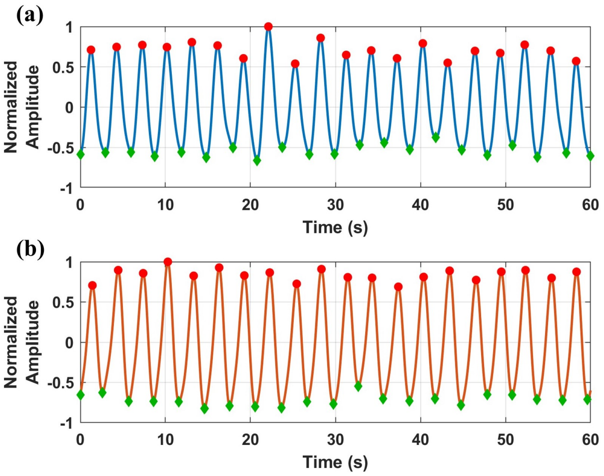

Fig. 3. Comparison of the filtered respiratory waveforms: (a) the proposed BioZ device and (b) Pneumotrace II™ respiration transducer (reference). Feature points (local minimum and maximum) are labeled.

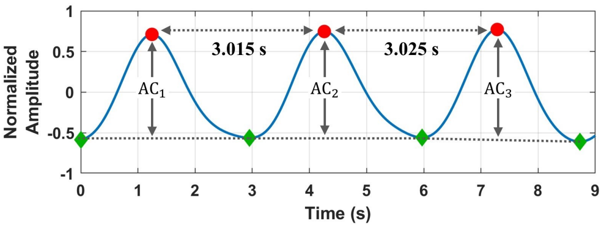

Fig. 4. The breath-by-breath breathing rate is calculated from the time interval between two respiratory waveform peaks. The amplitude of each cycle is determined as well.

in Fig. 4. Besides, the amplitude of each cycle is computed. If the amplitude is above the threshold, it implies a valid respiratory cycle has been detected.

III. RESULTS AND DISCUSSION

Fig. 5 shows the respiration waveforms and breathing rate trend of subject-1 (S1) during the experimental Test 1. The subject was required to perform 30 breathing cycles at three different breathing rates (i.e., 30 bpm, 20 bpm, and 10 bpm) respectively. Besides, the subject was challenged to hold his breath for 30 seconds at the end. The results indicate that the BioZ sensor patch can detect a wide range of breathing rates as well as the breath-holding pattern accurately. The mean absolute error (MAE) between the online computed breathing rate and the reference rate is 0.9 bpm in this case.

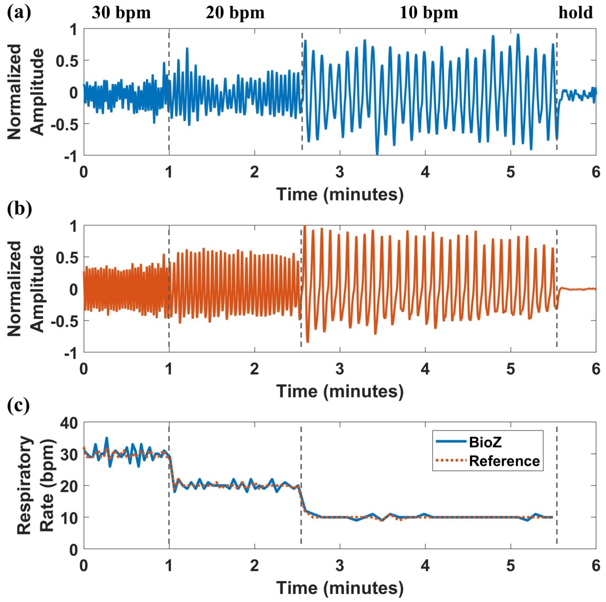

Fig. 5. Respiratory waveforms of subject-1 during experiment Test 1: (a) the BioZ signal, (b) the reference signal, and (c) the real-time breath-by-breath respiratory rate derived from the BioZ patch and the reference device.

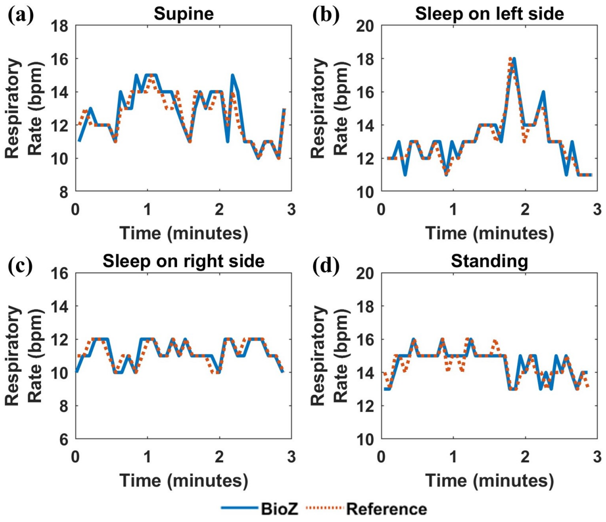

Fig. 6. The comparison of respiratory rate from the BioZ and the reference during experiment Test 2: (a) supine, (b) sleep on the left side, (c) sleep on the right side, and (d) standing. The data is from Subject-2.

Test 2 is performed to evaluate the accuracy of the system in detecting breath in sleeping and standing situations. The respiratory rate plot of subject-2 (S2) during Test 2 is depicted in Fig. 6. The measurements were conducted under supine, sleeping on the left side, sleeping on the right side, and standing postures. The subject breathed normally during the experiment. The waveforms in Fig. 6 demonstrate that the proposed system measurements are highly agreed with the reference with a MAE of 0.41 bpm in this example. Table II summarizes the MAE between the real-time online computed breathing rate by the proposed system and the reference in

TABLE II

MAE (BPM) BETWEEN THE ONLINE CALCULATED BREATHING RATE AND THE REFERENCE IN STATIC CONDITIONS.

	S1	**S2**	**S3**	**S4**	**S5**	**Average**
Test 1	0.90	0.64	1.34	0.91	0.81	0.92
Test 2	0.55	0.33	0.24	0.78	0.53	0.49

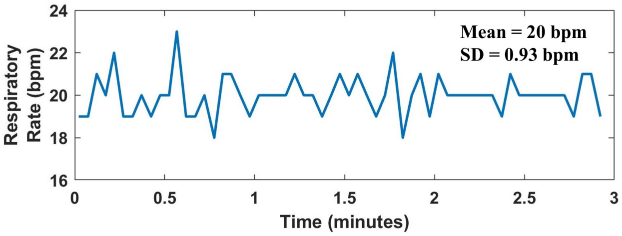

Fig. 7. Respiratory rate plot of subject-3 during experiment Test 3.

TABLE III

MEAN AND SD (BPM) OF TEST 3 RESULTS FOR ALL SUBJECTS.

	S1	**S2**	**S3**	**S4**	**S5**
Mean	20.02	19.98	20.00	20.07	20.07
SD	1.37	0.97	0.93	1.67	0.61

Test 1 and Test 2. The average MAE for Test 1 is 0.92 bpm and for Test 2 is 0.49 bpm. Hence, the overall average MAE for static testing is 0.71 bpm. The low MAE confirms that the proposed BioZ system can monitor respiration in static conditions accurately.

Test 1 and Test 2 evaluated the stationary performance of the system, while Test 3 focused on dynamic performance. In Test 3, the subject was requested to walk on a treadmill with a speed of 2.5 km/h. Since the reference device cannot provide reliable measurements under the dynamic condition, the subject is required to breathe according to a video that displays the breathing pattern with the rate of 20 bpm. The measurements from subject-3 (S3) as an example is illustrated in Fig. 7. It should be noted that body motions and the response delay to follow the video on each breathing cycle may result in the variation of breath-by-breath breathing rate. Despite these effects, the system is able to detect the breaths effectively with the mean breathing rate of 20 bpm and a standard deviation (SD) of 0.93 bpm in this sample. The mean and SD of the online measured breathing rate by the proposed system for all subjects during Test 3 are summarized in Table III.

IV. CONCLUSION AND FUTURE WORK

A wearable real-time respiration monitoring patch based on a BioZ sensor to be worn on the chest is presented in this paper. This sensor patch is small-sized and lightweight that can be attached to the chest with two disposable electrode pads without causing the subjects to suffer discomfort. The device integrates a Bluetooth module for wireless communication, which can be adopted in IoHT applications that enable respiration measurement anywhere anytime. Performance has been evaluated on five subjects with different postures (i.e., sitting, supine, sleeping on the left side, sleeping on the right side, and standing) and in the walking activity. Experiment results demonstrate that the proposed system is able to monitor respiration in both static and dynamic conditions effectively and accurately, which suggests the device is suitable for use during daily living activities.

In the future, the device will be tested on more subjects, especially females. In addition, several activities such as twisting and squatting will be used to evaluate performance. Furthermore, respiration rate computation relies on the Matlab program on a computer at this stage. Programming on the embedded MCU for real-time breathing rate computation is critical for real-world outdoor activity monitoring.

REFERENCES

[1] H. Habibzadeh, K. Dinesh, O. Rajabi Shishvan, A. Boggio-Dandry, G. Sharma, and T. Soyata, "A survey of Healthcare Internet of Things (HIoT): A clinical perspective," *IEEE Internet of Things Journal*, vol. 7, no. 1, pp. 53–71, 2020.

[2] S. M. R. Islam, D. Kwak, M. H. Kabir, M. Hossain, and K. Kwak, "The Internet of Things for health care: A comprehensive survey," *IEEE Access*, vol. 3, pp. 678–708, 2015.

[3] C. A. da Costa, C. F. Pasluosta, B. Eskofier, D. B. da Silva, and R. da Rosa Righi, "Internet of Health Things: Toward intelligent vital signs monitoring in hospital wards," *Artificial Intelligence in Medicine*, vol. 89, pp. 61 – 69, 2018.

[4] J. J. P. C. Rodrigues, D. B. De Rezende Segundo, H. A. Junqueira, M. H. Sabino, R. M. Prince, J. Al-Muhtadi, and V. H. C. De Albuquerque, "Enabling technologies for the Internet of Health Things," *IEEE Access*, vol. 6, pp. 13 129–13 141, 2018.

[5] T. Rahman, R. Page, C. Page, J.-R. Bonnefoy, T. Cox, and T. H. Shaffer, "pneuRIPTM: A novel respiratory inductance plethysmography monitor," *Journal of Medical Devices*, vol. 11, no. 1, 2017.

[6] R. I. Ramos-Garcia, M. H. Imtiaz, E. Sazonov, and S. T. Tiffany, "Evaluation of RIP sensor calibration stability for daily estimation of lung volume," in *2017 Eleventh International Conference on Sensing Technology (ICST)*, 2017, pp. 1–5.

[7] S. W. Park, P. S. Das, A. Chhetry, and J. Y. Park, "A flexible capacitive pressure sensor for wearable respiration monitoring system," *IEEE Sensors Journal*, vol. 17, no. 20, pp. 6558–6564, 2017.

[8] S. D. Min, Y. Yun, and H. Shin, "Simplified structural textile respiration sensor based on capacitive pressure sensing method," *IEEE Sensors Journal*, vol. 14, no. 9, pp. 3245–3251, 2014.

[9] Jia-Wei Jhuang and Hsi-Pin Ma, "A patch-sized wearable ECG/respiration recording platform with DSP capability," in *2015 17th International Conference on E-health Networking, Application Services (HealthCom)*, 2015, pp. 298–304.

[10] K. Nakajima, T. Tamura, and H. Miike, "Monitoring of heart and respiratory rates by photoplethysmography using a digital filtering technique," *Medical Engineering & Physics*, vol. 18, no. 5, pp. 365–372, 1996.

[11] T. Wu, J. Redouté, and M. R. Yuce, "A wearable wireless medical sensor network system towards Internet-of-Patients," in *2018 IEEE SENSORS*, 2018, pp. 1–3.

[12] A. Cesareo, Y. Previtali, E. Biffi, and A. Aliverti, "Assessment of breathing parameters using an inertial measurement unit (IMU)-based system," *Sensors*, vol. 19, no. 1, 2019.

[13] J. Skoric, Y. D'Mello, E. Aboulezz, S. Hakim, N. Clairmonte, M. Lortie, and D. V. Plant, "Relationship of the respiration waveform to a chest worn inertial sensor," in *2020 42nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2020, pp. 2732–2735.

[14] D. Blanco-Almazán, W. Groenendaal, F. Catthoor, and R. Jané, "Wearable bioimpedance measurement for respiratory monitoring during inspiratory loading," *IEEE Access*, vol. 7, pp. 89 487–89 496, 2019.

[15] C. Massaroni, A. Nicolò, D. Lo Presti, M. Sacchetti, S. Silvestri, and E. Schena, "Contact-based methods for measuring respiratory rate," *Sensors*, vol. 19, no. 4, p. 908, 2019.