

Wearable respiratory rate sensor technology for diagnosis of sleep apnea

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Abstract—Sleep apnea is a disease that occurs during sleep, which affects the daily life of patients due to the obstruction of the upper respiratory tract and decreases oxygen level in blood and it may even lead to patient death in the later stage. Monitoring the patients regularly has absolute importance to prevent patient disorders caused by sleep apnea. Wearable sensor technologies and patient tracking systems provide diagnosis, treatment, and monitoring of patients, and procure better health services in medical fields. In addition to decreasing the workload of health institutions, remote patient monitoring systems can serve continuous monitoring and determine variable symptoms of the patients. In this paper, we propose a patient monitoring system, which will be used for diagnosis and monitoring of sleep apnea by tracking the respiratory rate of patients with wearable sensor technology. The respiratory rate is detected using either an accelerometer sensor to be placed on the patients' abdomen or a temperature sensor to be placed on their noses. The proposed system offers an increase in the versatility of patient monitoring systems and offers an alternative new technology in sleep apnea diagnosis.

Keywords—sleep apnea; respiratory rate monitoring; wearable sensor technology

I. INTRODUCTION

Wearable sensor technology has made progress in healthcare and medicine over the past 50 years [1]. This technology provides opportunities for patients to control their health status at-home settings. Patient monitoring systems are seen as important services in today's healthcare systems where hospitals and healthcare services are insufficient [2]. These systems can be adapted to numerous health disorders such as diabetes [3], heart attacks [4], Parkinson's [5], Alzheimer's [6], etc.

Sleep apnea is a recurring condition in which complete or partial upper respiratory tract obstructions for at least 10 seconds take place during sleep [7]. Apneas are classified as Central Sleep Apnea, Obstructive Sleep Apnea, and Mixed Sleep Apnea [8], [9]. All types of apneas exhibit a lack of proper breathing.

Respiratory obstructions caused by sleep apnea reduces the oxygen saturation level in blood [10]. Aging, high body-mass index, gender, hypertension, and diabetes mellitus are known to be risk factors of sleep apnea [11]. Loud snoring, daytime sleepiness, and exhaustion are the main symptoms of sleep apnea [12].

Suspicion of having sleep apnea is generally caused by personal complaints and feedbacks from their acquaintances. A person who lives alone or cannot receive such feedbacks may suffer from sleep apnea without being aware of his/her condition. Once suspicious, the patient must be aware of the possible damages caused by sleep apnea and should attempt to get clinically diagnosed in an early stage of the condition. In the later stages of sleep apnea, the patient may have many abnormalities. These abnormalities could cause severe damages such as stroke, headaches, and depression. Studies prove that having sleep apnea is an important factor in deaths caused by cardiovascular diseases [13].

The clinical diagnostic standard of sleep apnea is nocturnal polysomnography [14], [15]. Polysomnography is mostly done in sleep laboratories, hospitals, or at sleep centers. Despite being accurate, this technique is costly and time-consuming [16]. Studies show that in the U.K the average sleep apnea patient waits around 14 months to get a doctor's appointment for polysomnography in a sleep laboratory whereas this waiting time is slightly over a year in the U.S [17]. Flexible capacitive sensors [20], mobile health technologies [21], electrocardiogram (ECG) signals-based patient monitoring systems [22] were also used for sleep apnea detection. Moreover, detection algorithms, such as wavelet transform and entropy-based features of ECG signals, and as well as deep learning based algorithms [23, 24] were utilized for sleep apnea. However, these methods are not suitable for home use, and require clinical and scientific expertise to operate.

In this study, we present a patient monitoring system to measure respiratory rate changes and to detect breathing cycle abnormalities for diagnosis and monitoring of sleep apnea. Since each type of sleep apneas cause respiratory impairment, the device is expected to report every case of sleep apnea. The system is designed for measuring diaphragm motion and breath temperature during sleep and continuously collecting the resulting data. The proposed system has a user-friendly, non-invasive, smart, and wearable medical device which is using information and wearable sensor technologies. The data gathered will be sent to a server and stored in a database. Later,

the data can be viewable in a web interface designed accessible to doctors so that the condition of a patient can be monitored remotely at home settings [18]. Moreover, this system can be integrated into a real-time communication system for online consultation of sleep apnea patients [19].

II. EXPERIMENTAL METHODS

A. Proposed System

The system components are shown in Fig. 1. The sensor that was used to measure diaphragm/thorax movement during breathing is MPU6050 (TDK InvenSense, U.S.A). MPU6050 is an electrical component comprised of a 3-axis gyroscope and a 3-axis accelerometer. MPU6050 was placed on the patient's diaphragm. A reference human model was presented in Fig. 2 with the corresponding axes of the device. The data gathered from the patient's diaphragm/thorax motion were used to determine the respiratory rate and breathing cycle abnormalities.

The temperature sensor in the proposed system is MLX90615 (Melexis, Belgium). It is a small, low-cost infrared temperature sensor that can be easily placed under the patient's nostrils by using a polymer-based clip to attach the sensor to the patient's nasal bone. The temperature data were measured by this sensor and it was analyzed according to the temperature difference between inhaled and exhaled breath [25] to check if the patient keeps breathing.

Arduino Mega Microcontroller Unit (MCU) (Arduino, Italy) was utilized to collect data from sensors. The collected data was transferred to the server using the ESP 8266 Wi-Fi module (Espressif Systems, China). This Wi-Fi module helps to develop the Internet of Things (IoT) applications that transfer data to the internet using the TCP/IP stack protocol.

B. Breathing Pattern Measurements

In overnight polysomnography studies, it was seen that patients go through sleep apnea for 15-20 seconds, 5-10 times an hour [26]. In this project, to ensure the accuracy of the breathing cycle analysis, we used a 3-axis accelerometer and gyroscope that can tolerate the movement of patients during sleep.

Since the over-inflation of the diaphragm is not associated with sleep apnea, there is no need to set a maximum elevation

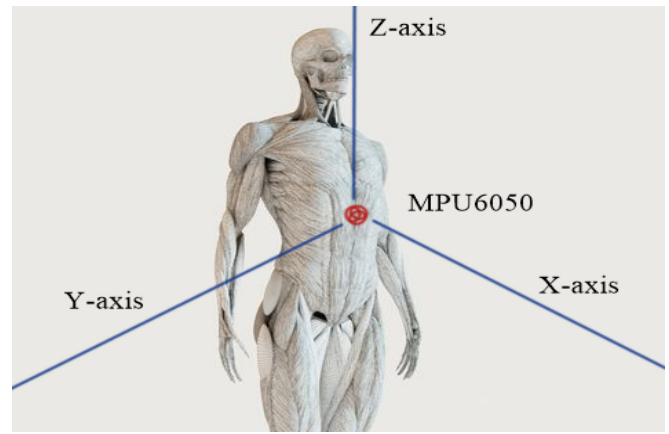


Fig. 2 Reference Human Model.

point for sleep apnea analysis. The only important point is to reveal the breathing pattern from the movement of the diaphragm. Also, an infrared thermometer is placed under the patient's nostrils to enhance the analysis of the breathing cycle. However, this data alone may be misleading sometimes, since a lot of people suffer from nasal obstructions and some people inhale from their mouths during sleep. Nonetheless, we believe that analyzing the accelerometer data with temperature data can lead to a trustworthy breathing cycle analysis.

III. RESULTS AND DISCUSSION

We conducted the breathing measurement while in lying position and we mimicked the sleep apnea by holding the breath for about 15 s. Changes in acceleration and angular velocity in different axes were presented in Fig. 3 and 4. The black lines in the graphs are the spline curves, which are used to reveal the breathing cycle. A total of 8 breathing cycles can be seen on the graphs; holding breath duration about 15 s can be observed as a stagnated area. Interestingly, in all axes, the cyclic pattern of breathing can be identified on accelerometer data. However, the angular velocity in the x-axis is the only one that cannot identify the breathing cycle.

The readings from the infrared thermometer during breathing were shown in Fig. 5. As expected, we observed that the exhaled breath temperature was always warmer than the ambient temperature, and the inhaled breath temperature was closer to the ambient temperature. By detecting these temperature changes, the breathing cycle can be revealed easily. Again, for the holding breath case, a stagnant area in the temperature closed to the ambient temperature can be observed. By using this temperature data, we can gather supportive data about the breathing cycle with the diaphragm motion data to increase the accuracy of the system.

The presented system can be used to eliminate possible damages caused by sleep apnea. For example, an external alarm unit can be connected to the Arduino Mega MCU to create a wake-up protocol if the apnea seizure is detected. If the patient will not wake up and turn off the alarm, a notification can be sent to the patient's doctor.

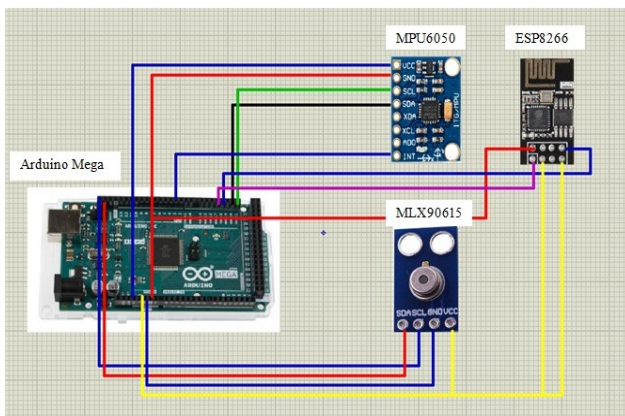


Fig. 1. Diagram of the proposed system.

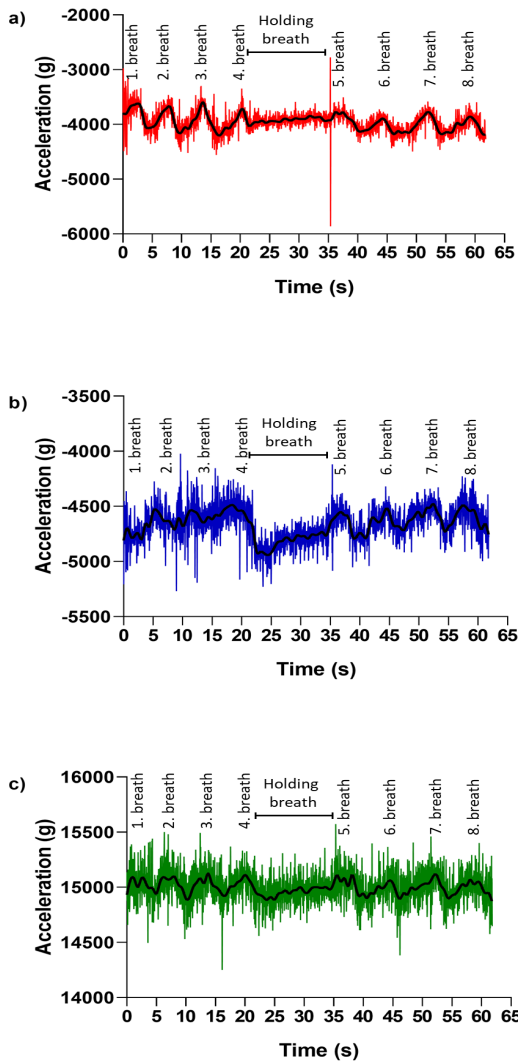


Fig. 3. Acceleration on a) x-axis, b) y-axis and c) z-axis during breathing.

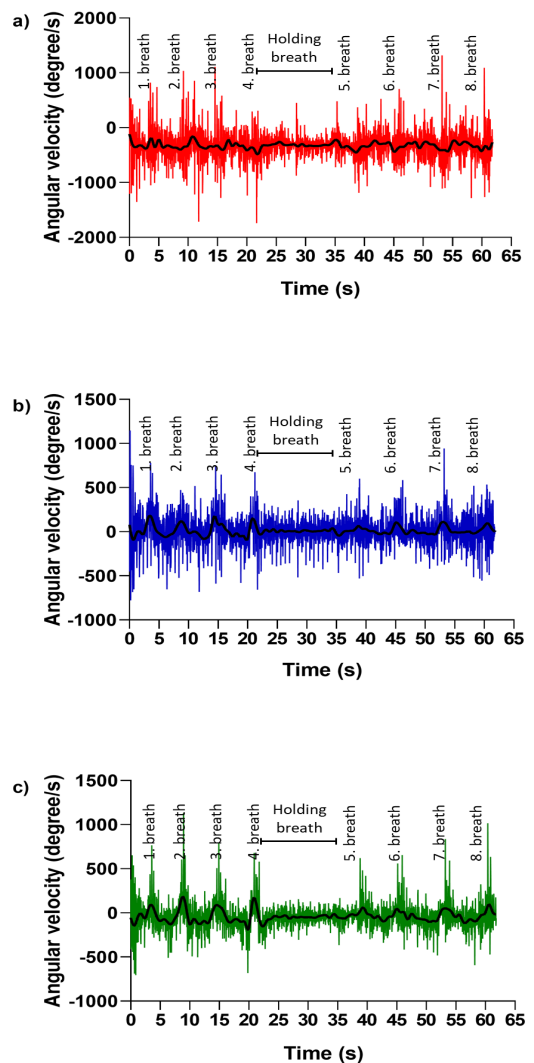


Fig. 4. Angular velocity on a) x-axis, b) y-axis and c) z-axis during breathing.

IV. CONCLUSION

In this study, we introduced a wearable patient monitoring system to analyze the breathing cycle and abnormalities for monitoring sleep apnea. We showed that analyzing diaphragm motion and breathing temperature using MPU6050 and MLX90615 could reveal breathing data and capture breathing impairments. Having a simplistic design, the device doesn't require any trained operator or a clinic. Since the device is aimed to be used at home, long waiting times associated with any stage of polysomnography can be eliminated while procuring home comfort. We foresee that this low-cost system (<60\$) would play an important role in increasing the accessibility of sleep apnea monitoring devices. We believe that increasing the accessibility of sleep apnea monitoring devices will increase population-level awareness for sleep apnea. We expect the system to shorten the time needed for the diagnosis of sleep apnea and to lower the long-term costs associated with this condition.

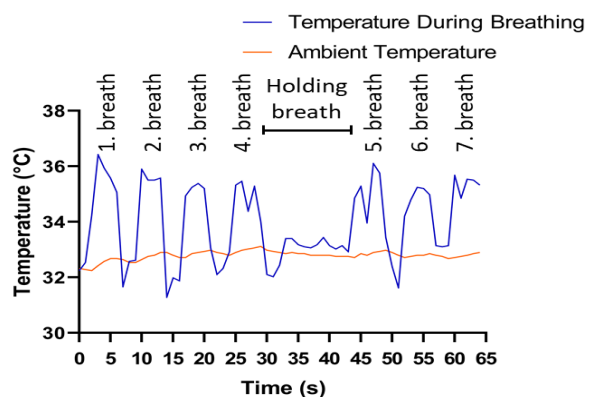


Fig. 5 Temperature during breathing.

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