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Development of Respiration Measurement Methods Using Wearable Gyroscope and Acceleration Sensors

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To diagnose respiratory diseases, it is essential to quantify the respiratory rate and respiratory movements. Moreover, the assessment of respiratory movements is a valuable tool for the evaluation of autonomic nervous system function, including the assessment of stress load. The present techniques for measuring respiration encompass the thermistor method, inductance method, and electrical impedance method. However, the thermistor and inductance methods present certain difficulties in terms of sensor attachment, and they place a significant burden on the subject. Furthermore, the electrical impedance method is susceptible to the effects of body movements and other factors. Conversely, considerable research is being conducted on the use of IoT in the development of wearable healthcare devices, which employ gyroscope and acceleration sensors. In this study, we attempted to measure respiratory movements by attaching a 6-axis sensor (comprising a 3-axis gyroscope sensor and a 3-axis acceleration sensor) to the chest. As a result, it was demonstrated that respiratory movements can be accurately measured even when the 6-axis sensor is attached to clothing.

1. Introduction

The number of deaths from respiratory diseases is increasing on an annual basis. Chronic obstructive pulmonary disease (COPD) represents the third most common cause of death on a global scale, with 3.23 million deaths in 2019, as reported by the World Health Organization.[1] The assessment of respiratory movements, including the measurement of respiratory rate and the analysis of respiratory waveforms, is a valuable tool in the diagnosis of respiratory diseases such as COPD. Moreover, the assessment of respiratory movements, including respiratory rate and respiratory waveform, is not only a crucial element in the diagnosis of respiratory diseases but also serves as a valuable tool for evaluating the function of the autonomic nervous system, particularly in the context of stress assessment.[2,3] There are several methods for measuring respiration, including the thermistor method, inductance method, and electrical impedance method.[4] However, the thermistor and inductance methods are both relatively complex to use

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and place a significant burden on the subject, and they are not sufficiently accurate. The electrical impedance method is less obtrusive for the subject, but it is easily affected by the subject's movements. Accordingly, the development of a high-precision measurement method that is both user-friendly and portable, with minimal burden on the subject in terms of wearing sensors, is a necessity. Concomitantly, investigation of IoT-enabled wearable healthcare devices utilizing gyroscope sensors and acceleration sensors is underway.(5–7) Moreover, a previous study by Naemura *et al.* demonstrated that the movements of the chest associated with respiration can be quantified using a gyroscope sensor.(8) The objective of this study was to investigate a breathing measurement method that can be applied to wearable healthcare devices using a 6-axis sensor (3-axis gyroscope and 3-axis accelerometer) for measurements in daily life.

2. Data, Materials, and Methods

The measurements of respiratory movements using a gyroscope sensor and an acceleration sensor were performed as follows, after obtaining approval from the Research Ethics Committee of Aino University (approval number: Aino2018-005). The subjects were five healthy adult males (age: 21–23 years, height: 165–180 cm, weight: 55–70 kg), and we fully explained the purpose of this study to them before the experiment and obtained their consent to participate in the experiment. After the experiment, we informed them that we would report the results of this experiment according to their wishes, and we obtained their written consent to report the results of the experiment.

As shown in Fig. 1, the measurement system consists of a measurement unit with a gyroscope sensor and an acceleration sensor, a 6-axis sensor [GY521 (MPU5060), SYNACORP], an Arduino Uno R3 microcontroller board made by Arduino Holding, and a general-purpose personal computer. The digital data from the 6-axis sensor was read out via an I^{2}C connection

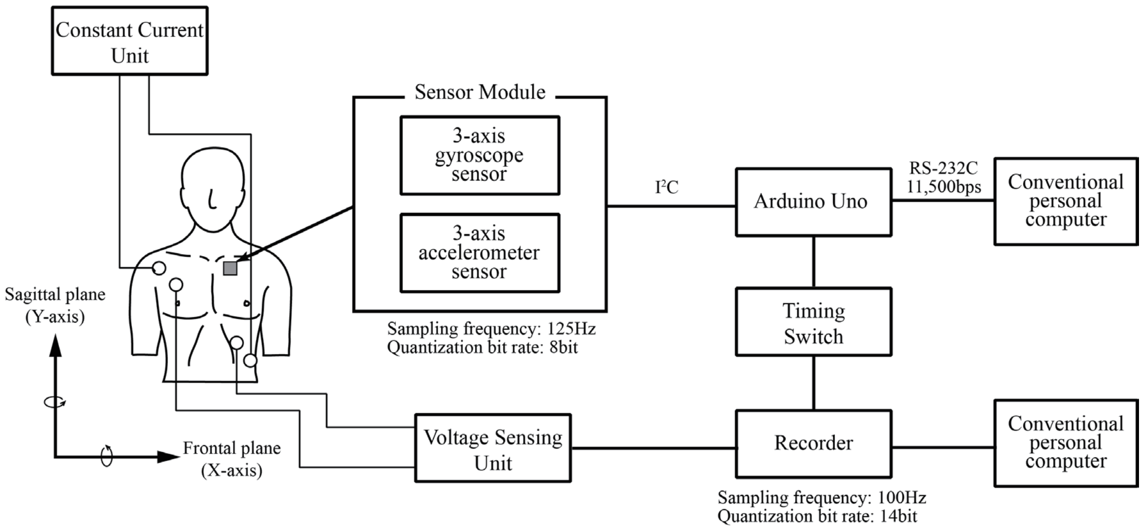


Fig. 1. Experimental setup used in this study.

with a sampling frequency of 125 Hz and 8-bit quantization. The Arduino IDE was used as the development environment. To calculate the variation, the output of the gyroscope sensor and the output of the acceleration sensor were entered into the Kalman filter processing program running on the Arduino. The Kalman filter used was the Kalman filter library (Kristian Lausz us, TKJ Electronics) from the Arduino library list.[9]

The 6-axis sensor was mounted so that the frontal part was the *X*-axis and the sagittal plane was the *Y*-axis. The data in the *Z*-axis direction was not used in this study, because the main respiratory movements are not in this direction. The section for measuring electrical impedance consists of an impedance respirometer (low-pass cutoff frequency: 0.16 Hz, high-pass cutoff frequency: 5.3 Hz) consisting of a constant current source, a voltage detection unit and an amplifier, and a general-purpose personal computer. The analog output of the impedance respirometer was converted to digital using an AD converter with a sampling frequency of 100 Hz and 14-bit quantization.

The experiment was conducted indoors while the subject was seated in a resting state with a 6-axis sensor attached to the surface of their clothing using adhesive tape. The 6-axis sensor was attached to the area near the collarbone as shown in Fig. 1.[10] In addition, measurements were taken while walking, using only the gyroscope and accelerometer measurement section, considering measurements in everyday life.

3. Results and Discussion

Figure 2 shows an example of impedance changes during breathing in a seated resting condition and the output results of the 6-axis sensor. Subject A whose results are shown in Fig. 2(a) is a male, 22 years old, 180 cm tall, and weighs 65 kg. Subject B whose results are shown in Fig. 2(b) is a male, 22 years old, 170 cm tall, and weighs 60 kg. The upper graph shows the waveform obtained using the electrical impedance method and the waveforms in the *X*-axis and

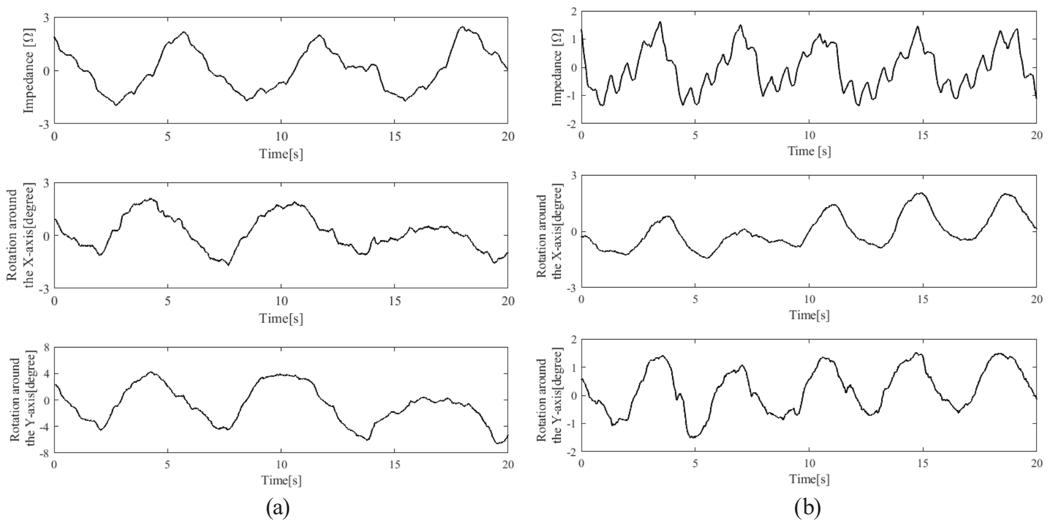


Fig. 2. Examples of the impedance changes during breathing at rest and the output results of the 6-axis sensor. (a) Subject A and (b) Subject B.

Y-axis directions of the 6-axis sensor. Although there were individual differences in amplitude, both the output waveform of the 6-axis sensor showed similar changes with time to the waveform obtained by the electrical impedance method. Therefore, it is suggested that it is possible to measure respiratory movements using a 6-axis sensor.

Figure 3 also shows the *X*- and *Y*-axis waveforms of the 6-axis sensor output and the results of frequency analysis. The subject whose results are shown in Fig. 3 is a male, 21 years old, 170 cm tall, and weighs 65 kg. Figure 3(a) shows an example of the results of 20 s measurements while sitting at rest. The upper graph shows the *X*-axis output of the 6-axis sensor, and the lower graph shows the *Y*-axis output of the 6-axis sensor. The measurement results showed that the amplitude changes more on the *X*-axis than on the *Y*-axis, and there is a phase difference between the *X*-axis and the *Y*-axis. The difference in waveform amplitude is considered to be caused by the fact that the movements of the chest during breathing are greater in the frontal plane than in the sagittal plane. In addition, the phase difference between the X- and Y- axes is considered to be caused by the fact that the movements of the chest during breathing occurs first in the frontal plane, then in the sagittal plane. Figure 3(b) shows the results of the frequency analysis of the data obtained during the seated resting condition in Fig. 3(a). The upper graph shows the *X*-axis output from the 6-axis sensor, and the lower graph shows the *Y*-axis output from the 6-axis sensor. In Fig. 3(b), both axes show a peak at around 0.25 Hz at rest, and the *X*-axis shows a higher power spectral density (PSD) value than the *Y*-axis. The peak at around 0.25 Hz corresponds to the subject's breathing rate of 16 times per min. In addition, the comparison of the PSD values confirmed that the movements of the chest were greater in the frontal plane than in the sagittal plane.

Figure 4 also shows the results of frequency analysis of the *X*-axis and *Y*-axis waveforms of the 6-axis sensor output in an experiment that considered measurements in everyday life. The subject whose results are shown in Fig. 4 is the same person as the subject whose results are shown in Fig. 3. Figure 4(a) shows an example of the results for 20 s measurements while walking, and Fig. 4(b) shows the results of the frequency analysis. In Fig. 4(b), both axes show peaks at around 0.25 and 1.4 Hz when the subject was walking, and the *Y*-axis also shows a peak at around 0.7 Hz. The peak at 0.25 Hz corresponds to the subject's breathing rate (approximately

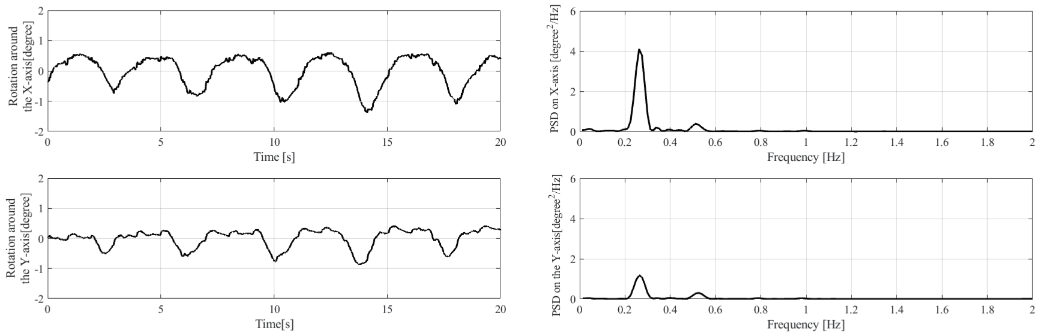
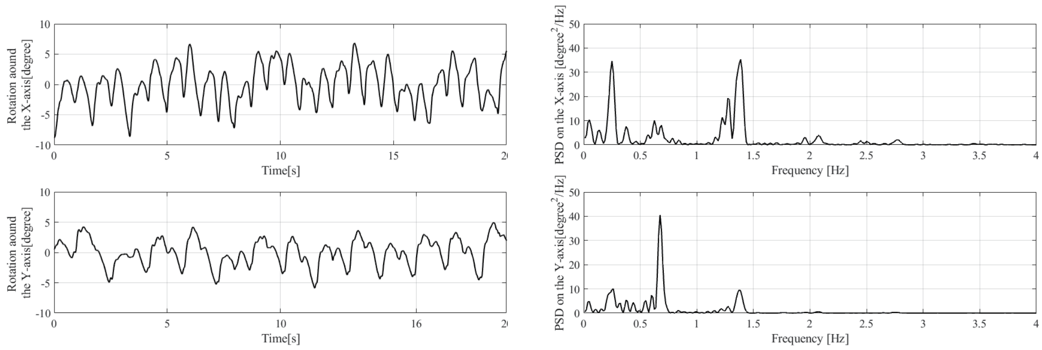


Fig. 3. (a) Output of the sensor at rest and (b) frequency analysis results of sensor output at rest.



(a) (b)

Fig. 4. (a) Output of the sensor at rest and (b) frequency analysis results of sensor output at rest.

16 times per min), and the peak at 1.4 Hz corresponds to the number of steps per second. The peak at around 0.7 Hz on the *Y*-axis is thought to be caused by the movements of the thorax in the sagittal plane due to the movements of the left shoulder that occurred during walking. The above results suggest that it is possible to measure the number of breaths even during walking.

4. Conclusions

It was confirmed that it is possible to measure the movements of the chest associated with breathing by attaching a 6-axis sensor to clothing and estimating the output by frequency analysis. Therefore, it was suggested that it is possible to measure the respiratory rate and respiratory movements using a 6-axis sensor. In the future, it is planned to investigate measurements in environments simulating everyday life and the wireless transmission of sensors.

Acknowledgments

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