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Implementation of a Wearable Sensor for Breathing Monitoring

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Abstract. Advancements in electronic textiles and flexible electronics have significantly enhanced tools for monitoring and improving quality of life. Among these innovations, resistive fabric has emerged as a valuable component in biomedical engineering due to its sensitivity to deformation. This work presents the development and evaluation of a wearable sensor utilizing conductive textile as a piezoresistive material for respiratory monitoring. The sensor, embedded in a chest band, measures breathing patterns by detecting voltage peaks associated with inhalation and exhalation. We detail the characterization of the conductive fabric, including resistance measurements and signal conditioning. To validate the performance of the textile-based sensor, we compared its readings with those from an inertial sensor (MPU6050). Both sensors were interfaced with Arduino and Simulink to enable parallel measurement of acceleration and voltage responses. Results demonstrate the effectiveness of the conductive textile sensor in capturing accurate respiratory signals, offering a practical and comfortable solution for continuous breathing pattern analysis.

Keywords. Smart textile, conductive fabric, impedance, resistance, respiratory monitoring, mcu6050.

1 Introduction

In the last decade, technological growth has enabled advancements in the development of e-textiles and flexible electronics. Among these developments, conductive fabric stands out and has been of interest to various researchers. For instance, Bernhart, S., Harbour, E., Kranzinger, S. et al., in their work titled “Wearable chest sensor for stride and respiration detection during running,” published in *Sports Engineering*, propose analyzing the respiratory patterns of athletes through the creation of a wearable respiratory sensor that competes in the market [1].

Similarly, Roudjane, M., Bellemare-Rousseau, S., Khalil, M., Gorgutsa, S., Miled, A., and Messaddeq, Y., in their work “A Portable Wireless Communication Platform Based on a Multi-Material Fiber Sensor for Real-Time Breath Detection” published in *Sensors*, monitor respiration in real-time using a different geometry in their conductive fabric [2].

On the other hand, MEMS inertial sensors can monitor very tiny movements, such as the chest movements induced by respiration or the heartbeat [3]. Some research works have been reported respiratory parameters using IMUs. For instance, P. Janik et al. presented a wearable sensor for monitoring breathing and the heart rate using a single inertial sensor [4]. Additionally, S. Beck et al. in [5] presented a novel method to calculate the angle between the quaternions of two IMUs to estimate the breathing rate. By positioning one IMU on the abdomen and the other on the thorax. R. De Fazio et al in [3] reported a device employed a differential inertial approach, placing two IMUs on the chest to detect the chest movements and back, acting as a reference.

Thus, the main objective of this work is to develop a wearable sensor for analyzing eupneic respiratory patterns, incorporating a different geometry for the conductive fabric in a chest band and, at the same time, using an MPU6050 to compare and ensure the accuracy of the readings obtained.

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2 Materials and Methods

The respiratory pattern of an individual is based on the analysis of the expansion and contraction movements of the thoracic cage during inhalation and exhalation, respectively. These movements can be translated into electrical signals by incorporating a wearable sensor capable of recording and processing the impedance changes in the material for analysis [6].

The generated signals allow for the analysis of individuals' breathing behavior, making it possible to track and detect respiratory abnormalities influenced by various factors through signal analysis [7].

2.1 Conductive Fabric

The breathing sensor consists of a piezoresistive sensing band that changes its electrical resistance when stretched or released, connected to an electronic conditioning and acquisition system.

The piezoresistive sensing band was fabricated with an elastic band, including a custom piezoresistive strain sensor based on conductive fabric. The dimensions for the sensor were 10 cm long and 2 cm wide of a piece of conductive fabric, as is shown in Figure 1.

2.2 Sensor Characterization

The impedance and resistance measurements were determined using a LCR meter Hioki 3536. through the "LCR Meter Sample Application" software the data were plotted, the connection diagram is shown in Figure 2.

By placing the wearable sensor around the thoracic cage, an AC voltage with 1V and a frequency sweep from 100Hz to 100 KHz were applied to determine the resistance for the sensor when it is in rest and when is stretched.

Through the .csv files generated by the "LCR Meter Sample Application" software, it is possible to numerically and graphically analyze the sensor's behavior in terms of Rdc resistance.

Impedance and Resistance Measurement: Impedance and resistance measurements of the conductive fabric sensor were conducted using the LCR meter Hioki 3536. The connection diagram for this setup is illustrated in Figure 2.

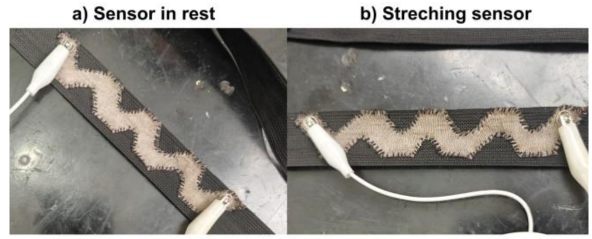
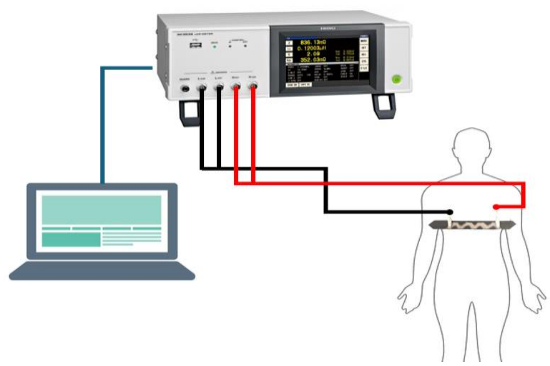


Fig. 1. Prototype of the respiration sensor based on conductive fabric and elastic band, (a) sensor in rest, (b) stretching sensor



(a)

(b)

Fig. 2. (a) LCR meter connection diagram, (b) connected sensor for its characterization

The data acquisition was facilitated through the "LCR Meter Sample Application" software, which allowed to analyze and plot the measurement focusing on direct current (Rdc) resistance for the sensor.

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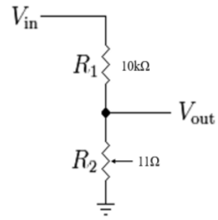

Fig. 3. Voltage divider for the conductive fabric

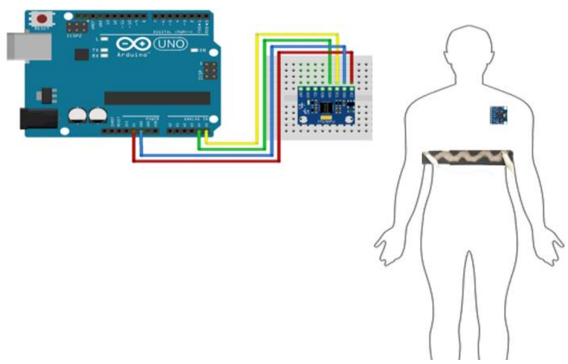

Fig. 4. Signal conditioning scheme for the chest band

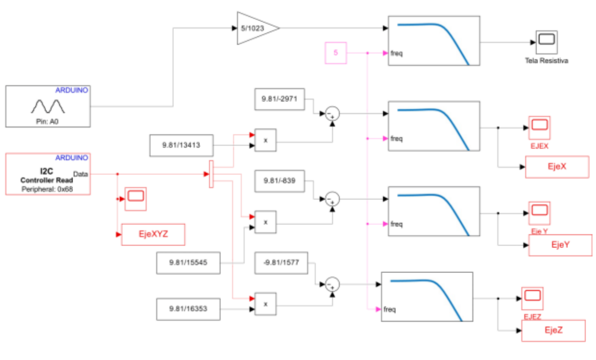

Fig. 5. Block diagram in Simulink [8] using for processing signal

The wearable sensor was positioned around the thoracic cage to simulate real-world application conditions. An alternating current (AC) voltage of 1V was applied to the sensor. The frequency of the AC voltage was swept from 100 Hz to 100 kHz to assess the sensor's response over a broad range of frequencies.

Resistance measurements were recorded for two conditions:

Rest State: The sensor was in its relaxed, un-stretched position.

Stretched State: The sensor was elongated to mimic the deformation experienced during breathing.

2.3 Signal Conditioning and Processing

Considering the resistive characteristics of the sensor used with the chest band, it is necessary to convert the resistance into voltage variations using a voltage divider, as is shown in Figure 3.

In the voltage divider shown in the Figure 3, the variable resistance "R2" is given by the conductive fabric, while the output voltage is connected to the "A0" analog input of the microcontroller board.

Additionally, after characterization of the conductive fabric, the MPU6050 sensor is placed on the chest band, while communication is established between the microcontroller, specifically Arduino, as shown in Figure 4.

By communicating the sensors with the Arduino, data generated from monitoring respiratory patterns, particularly eupnea, is collected and plotted, where the resistive fabric deforms, simultaneously with the movements and using the MPU6050 is possible to record the data of respiration for the comparisons.

The signal conditioning system is integrated with a Simulink through a block diagram that enables data collection and filtering, as shown in Figure 5 [8].

3 Results

The behavior of resistive fabric in the chest band produced the following graphs for each state of the band at rest:

a. The resistance values obtained in the frequency sweep from 100Hz to 100KHz in the fabric at rest are shown in Figure 6.
b. The resistance values obtained in the frequency sweep from 100Hz to 100KHz in the stretch mode are shown in Figure 7. The difference on resistance value from rest to stretch mode was 4 ohms approximately.

The tests were performed on a healthy adult at rest, placing the monitoring band around the

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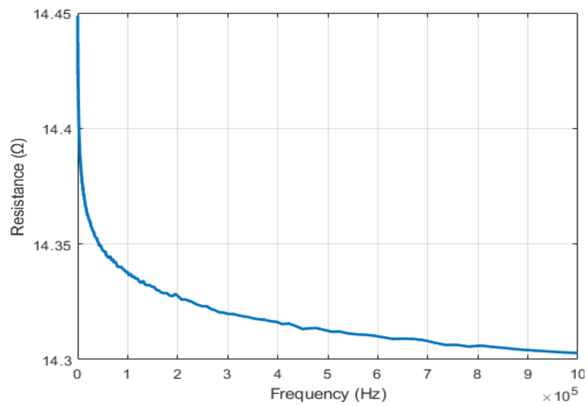

Fig. 6. Resistance vs frequency for the chest band at rest.

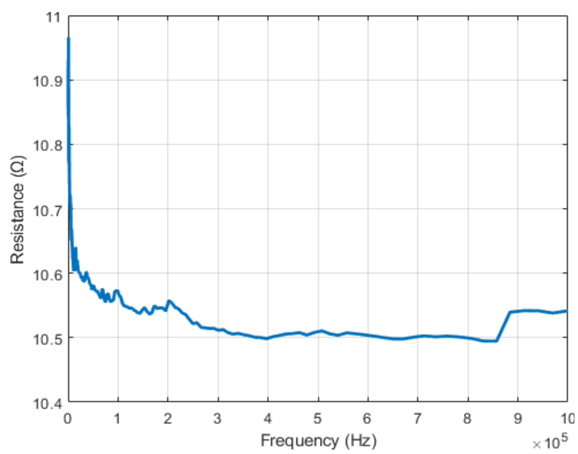

Fig. 7. Resistance vs frequency for the chest band in the stretched mode

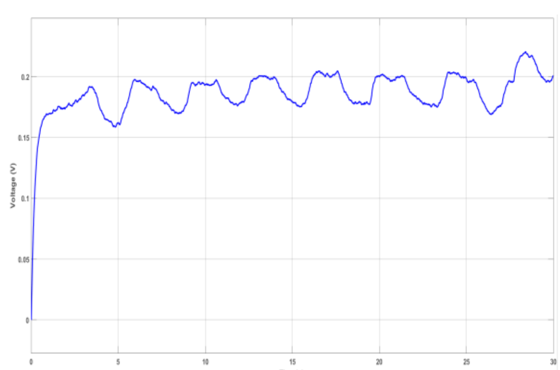

Fig. 8. Response of the piezoresistive fabric

thoracic cage while positioning the accelerometer on the chest. The resulting signals were obtained in intervals of 30-seconds, as shown in the following graphs.

Figure 8 allows for the counting of eight voltage peaks within 30 seconds, produced by the deformation of the conductive fabric due to the movements of the thoracic cage during the breathing process.

Figure 9, which corresponds to the X-axis of the accelerometer, shows the respiratory pattern concerning the force of gravity, where the graph shown is similar to the one generated by the resistive fabric, with a slight displacement.

Figure 10 shows the resulting signal from the movements recorded on the Y-axis by the accelerometer, with a slight disturbance at the beginning. It is important to note that, depending on the position of the MCU6050, the reference axes can vary.

Finally, the Z-axis readings are shown in Figure 11, which are similar to the previous figures but with less noise. It is worth noting that the readings are affected by the position of the sensor and the tests for the subject.

4 Analysis

After developing a piezoresistive wearable sensor for monitoring breathing using a deformation-sensitive conductive fabric and complementing it with an MPU6050 accelerometer to improve reading accuracy, tests were conducted on a healthy adult, where the sensor detected normal respiratory patterns with high sensitivity. The analysis using the Hioki 3536 LCR meter, which allowed for the characterization of the conductive fabric's resistance and impedance, showed clear variations between resting and stretching modes.

The regular respiratory rate changes with age, with 12 to 20 respirations per minute for a resting adult, our system is capable to monitor these values, during the measurements the rate was 16 respiration per minute.

The use of Simulink facilitated data collection and filtering, although some noise was observed in the piezoresistive fabric signals, affecting the precision compared to the accelerometer. This approach is similar to recent studies on wearable

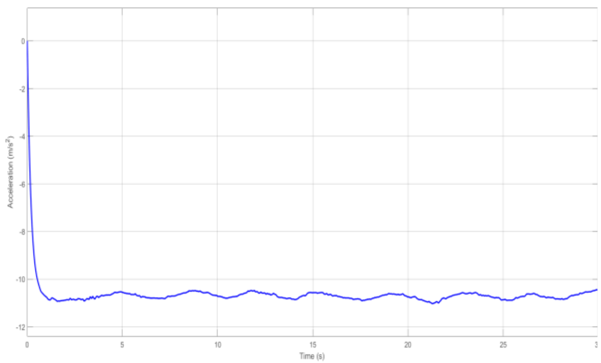

Fig. 9. Response of the MCU6050 on the X-axis.

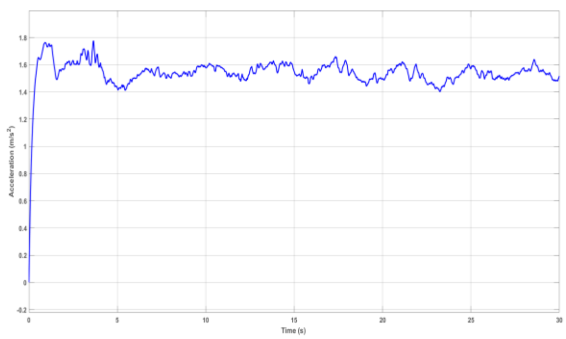

Fig. 10. Response of the MCU6050 on the Y-axis

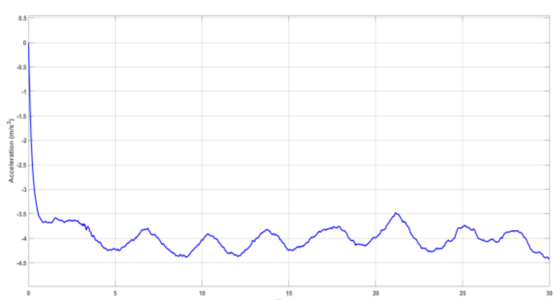

Fig. 11. Response of the inertial sensor MCU6050 on the Z-axis for breathing movements

sensors, such as those by Bernhart et al [1] and Roudjane et al. [2]., which also used conductive materials and real-time detection technologies to monitor breathing.

The proposed system stands out for its precision and potential in biomedical applications, although improvements are still needed in handling noise in the signals. This type of wearable sensor holds great potential in health monitoring, offering low-cost, high-efficiency solutions.

5 Conclusions

The development of this wearable system for respiratory monitoring highlights advancements in the use of conductive textiles and their potential for biomedical applications.

The implementation of the MPU6050 accelerometer effectively complements the analysis of respiratory patterns if it is used for detecting respiratory abnormalities.

However, the presence of noise in the piezoresistive fabric readings is an aspect to improve in future work, possibly through refining the signal conditioning circuit design or better isolating the sources of noise.

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References

1. **Bernhart, S., Harbour, E., Kranzinger, S. (2023).** Wearable chest sensor for stride and respiration detection during running. Sports Eng, Vol. 26, No. 19. DOI: 10.1007/s12283-023-00410-y.
2. **Roudjane, M., Simon, B.R., Mazen, K., Stepan, G., Amine, M., Younes, M. (2018).** A Portable Wireless Communication Platform Based on a Multi-Material Fiber Sensor for Real Time Breath Detection. Sensors, Vol. 18, No. 4, pp. 973. DOI: 10.3390/s18040973.
3. **De Fazio, R., Greco, M.R., De Vittorio, M., Visconti, P. (2022).** A Differential Inertial Wearable Device for Breathing Parameter Detection: Hardware and Firmware Development, Experimental Characterization. Sensors, Vol. 22, No. 24, pp. 9953. DOI: 10.3390/s22249953.

4. **Janik, P., Janik, M.A., Pielka, M. (2022).** Monitoring Breathing and Heart Rate Using Episodic Broadcast Data Transmission. Sensors, Vol. 22, No. 16, pp. 6019. DOI: 10.3390/s22166019**.**
5. **Beck, S., Laufer, B., Krueger-Ziolek, S., Moeller, K. (2020).** Measurement of respiratory rate with inertial measurement units. Current Directions in Biomedical Engineering, Vol. 6, No. 3, pp. 237–240. DOI: 10.1515/cdbme-2020-3060.
6. **Valle-Lopera, D.A., Castaño-Franco, A.F., Gallego-Londoño, J., Hernández-Valdivieso, A. M. (2017).** Fabricación y pruebas de sensores piezorresistivos para la medición de presión por contacto. Revista Facultad de Ingeniería Universidad de Antioquia, Vol. 82, pp. 47–52. DOI: 10.17533/udea.redin.n82a06.
7. **Guyton, H. (2019).** Patrones respiratorios normales y anormales. Tratado de Fisiología Médica.
8. **Filiberto, C.G., Mora, I.R., De la Cruz, I.V., Méndez, F., Roberto, A.L. (2020)**. Interfaz Arduino-Simulink para la medición en paralelo de dos sensores MPU6050. Memorias del XXVI Congreso Internacional Anual de la (SOMIM).

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