



Design and Development of Flex Sensor-Based Respiratory Rate Monitoring System Using Node MCU ESP32

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Abstract. Flex sensors are used to measure a patient's breathing status such as Eupnea, Bradypnea, and Tachypnea, providing respiratory rate data. The main objective of this capstone is to design and develop a device that accurately measures respiratory rate, thereby improving patient care assessment. The system utilized a flex sensor that can accurately detect the expansion and contraction of the chest and abdomen during breathing. This sensor is then used to calculate the respiratory rate, which is displayed in real-time on both the OLED screen and the web server. The OLED screen provides offline monitoring, allowing the respiratory rate and status to be easily viewed in real-time. On the other hand, the web server provides a more comprehensive view of the respiratory rate data, including a graphical representation of the start and end of each breath. The system has demonstrated an accuracy rate of 90.18% in eupnea and 91.03% in tachypnea, with a total accuracy of 93.73%, which is considered very satisfactory. The belt is more efficient when placed on the abdomen compared to the chest, which had an accuracy rate of 91.44% and 89.13%, and an overall efficiency rate of 90.29% and is interpreted as very satisfactory. This Flex Sensor-Based Respiratory Rate Monitoring System provides a reliable method for measuring respiratory rate, allowing medical personnel to obtain accurate baseline data for assessing a patient's respiratory function. The high accuracy rate aids in informed decision-making, enhancing patient care practices and leading to better health outcomes.

Keywords: Flex Sensor; Respiratory Rate; Breathing Status; Eupnea; Tachypnea; Bradypnea.





INTRODUCTION

Respiratory rate (RR) is identified as a vital sign that can provide strong information about a patient's condition (Honda et al., 2022). Among the vital signs, changes in respiratory rate hold a greater significance for patients at risk; respiratory rate is the best indicator for identifying health deterioration (Tiboni et al., 2021). However, despite its clinical importance, studies investigate the accuracy of measurement which brought into question the reliability of recorded respiratory rate to identify a patient's health declination.

Many solutions and devices for health monitoring have been introduced in the market (Amperawan et al., 2022). These monitoring tools consist mainly of wearable sensors. Strain sensors such as the Flex sensor are the most suitable to use for monitoring a patient's respiratory rate as this is small, lightweight, and can be embedded into a fabric, which is expected to be much more comfortable to wear by the subject (Balasubramaniyam et al., 2019). Furthermore, such sensors can also be integrated with the Internet of Things (IoT) using a microcontroller. The Node MCU ESP32 microcontroller can establish wireless transmission and processing of data to be sent to the user's devices, allowing it to be viewed in the developed mobile application or website, and continuously monitored by the staff.

METHODOLOGY

The conceptual framework in Figure 1 consists of Input, Process, and Output. The system is powered by a lithium battery and uses a charging module to protect the battery from overcharging, over-discharging, and over-current. This extends the battery's lifespan and ensures safety.

The input stage involves detecting the abdominal expansion and contraction that correspond to the respiratory rate. A voltage divider is combined with a





differential amplifier to refine the signal and prepare it for display by the Node MCU ESP32 microcontroller. This microcontroller also converts the analog signal to digital for data interpretation. There are two monitoring options available. First, an OLED screen is attached to the system's box, which displays respiratory rate and status offline. This screen ensures usability despite potential connectivity issues. Second, a web server is developed and accessible only by medical staff. This server holds all the patients' records while also providing a graphical representation of the start and end of breathing.

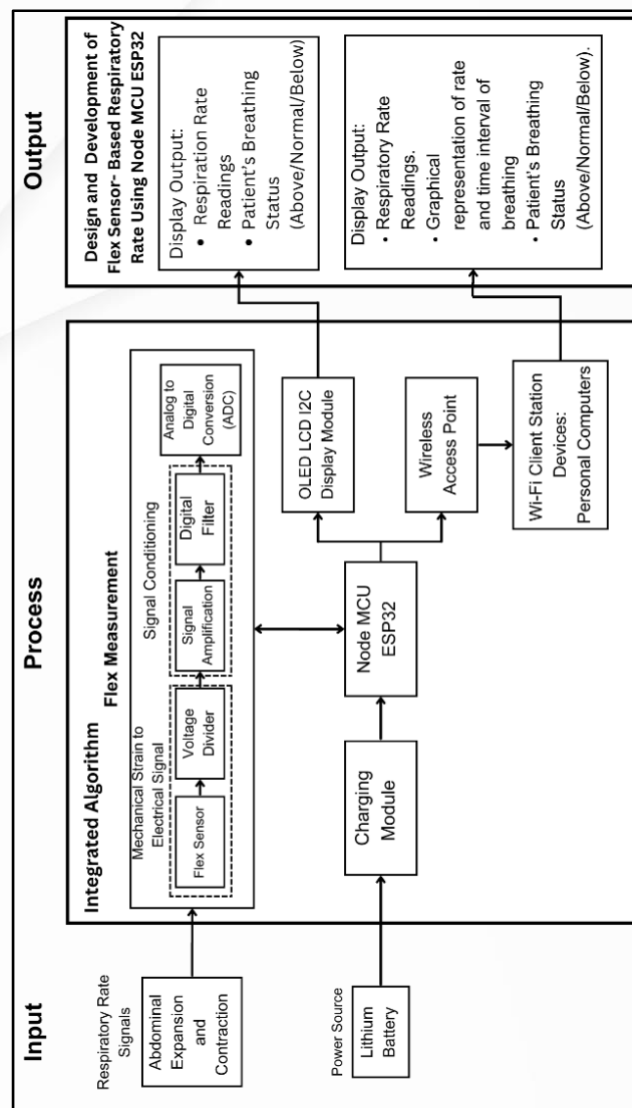


Figure 1. Conceptual Framework





Figure 2 depicts the block diagram of the overall system. This project utilized a Flex sensor that has a baseline resistance of 10 k-Ohm at a bend angle of 0 degrees and 32.6k ohms at a bend angle of 180 degrees. The sensor is attached to a belt worn on the abdomen to detect movements that are accompanied with breathing. The system includes a Differential Amplifier circuit driven by an Im358 Op-amp that amplifies and filters the collected data. The Node MCU ESP32 converts the analog input of the sensor into digital input and prepares it for display on the OLED screen. The processed data is stored in the system's database and can be viewed on the web server if the belt and the user's computer device are connected to the same wireless access point. Figure 2 shows the block diagram of the entire system.

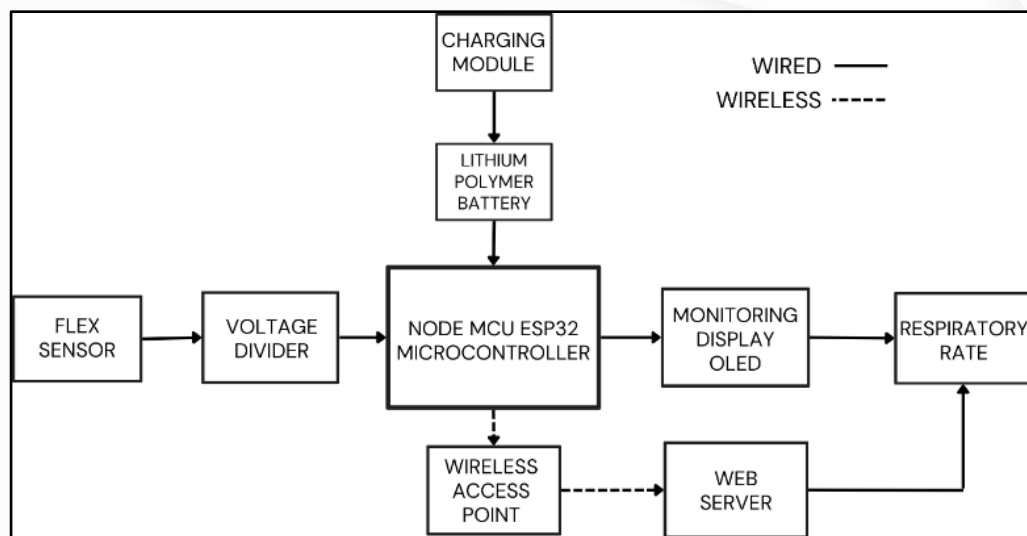


Figure 2. Entire Respiratory Rate Monitoring System Block Diagram

Figure 3 illustrates the flowchart of the monitoring system when it is in the offline state. When the power button is pressed, the system starts to measure the patient's respiratory rate. The system detects the movement of the





abdomen and displays the rate and status of the patient on the OLED after the 60-second measurement.

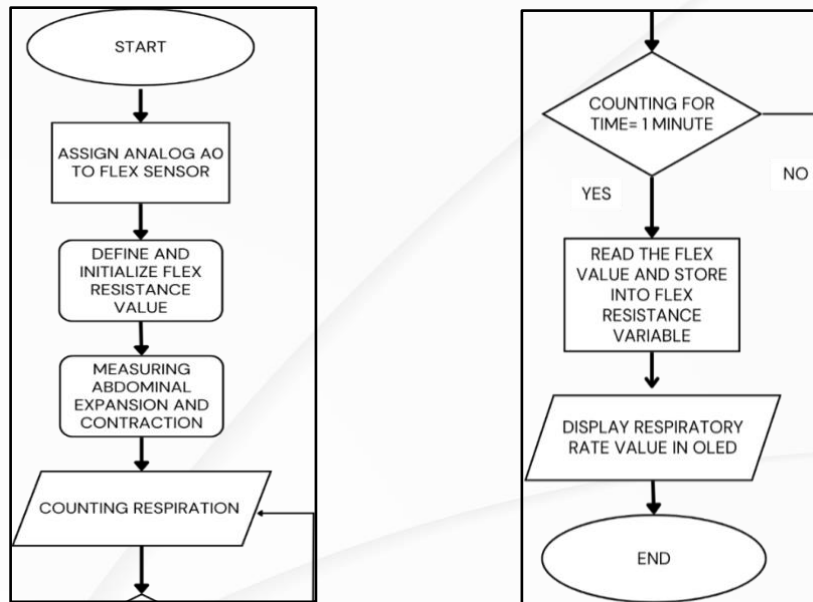


Figure 3. Flex Sensor to OLED Flowchart

Figure 4 shows the flowchart of the entire system in online mode. The system first attempts to connect to the local IP address and then starts counting the respiratory rate within a minute. After a minute, the system displays the respiratory rate and status on OLED and the web server, along with a graph and patient information.

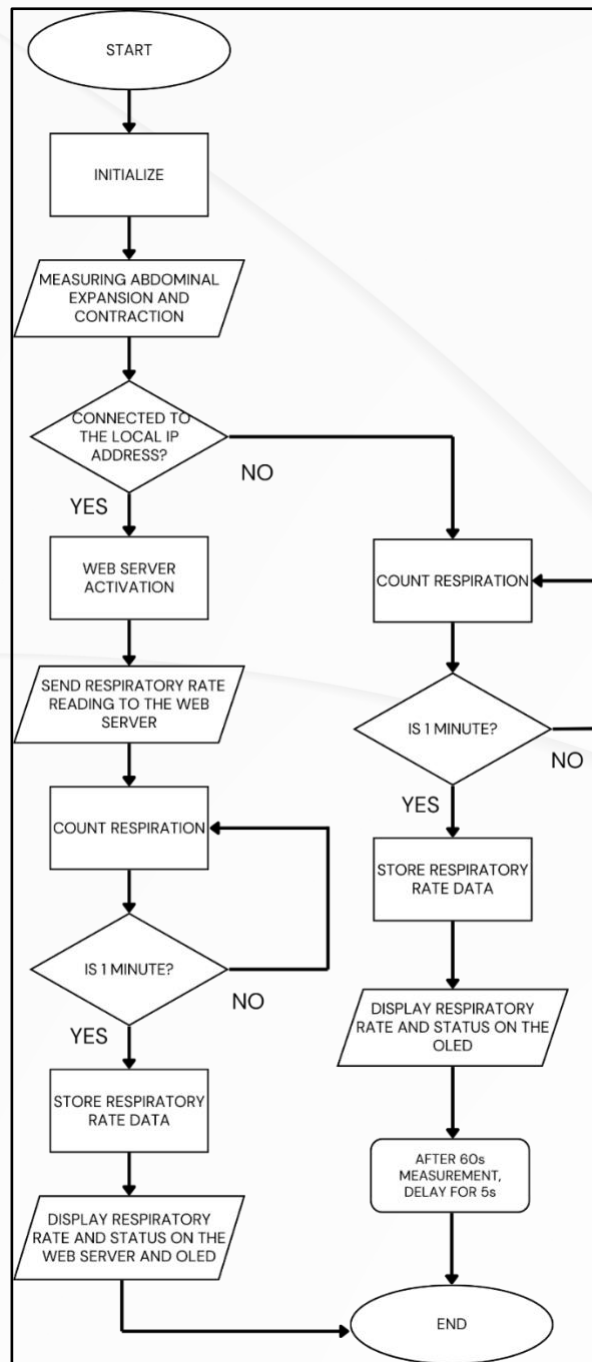


Figure 4. Entire Respiratory Rate Monitoring System Flowchart





Analog Circuit

The circuit consists of two main parts, namely the Voltage Divider and the Differential Amplifier shown in Figures 5 and 6 respectively. The main purpose of this circuit is to amplify the signal and filter out noise from the flex sensor.

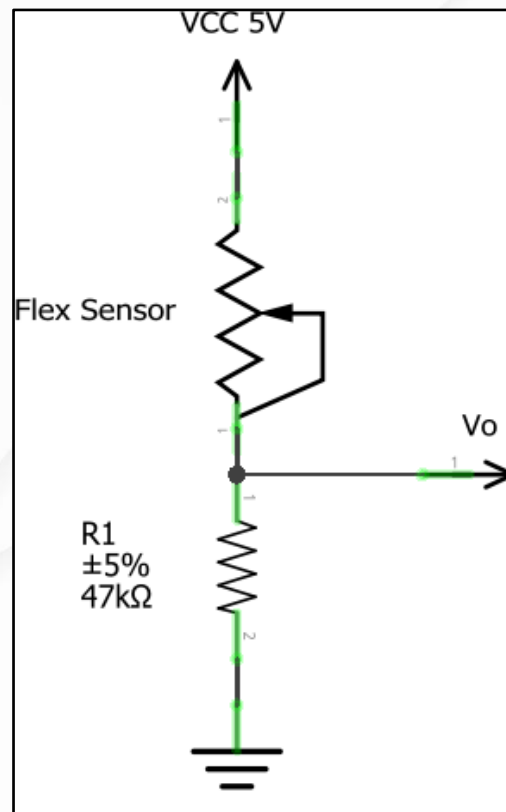


Figure 5. Voltage Divider

The circuitry of the voltage divider used in building the system is illustrated in Figure 5. The flex sensor changes its resistance when it is bent. As illustrated in the schematic diagram, a voltage divider circuit is used in conjunction with a differential amplifier in order to measure changes in resistance value. In addition to that, the flex sensor is connected to a 47k ohms resistor for the demonstration.

The formula for a two-resistor voltage divider circuit is used to calculate the voltage divider in this circuit, and this is as follows:



$$V_{out} = V_{in} \frac{R_1}{R_{FLEX} \times R_1}$$

In the given formula, R1 is the resistor connected to the ground, and RFLEX is the resistance of the flex sensor. While, Vin represents the voltage input, Vout is the voltage output, and this can be calculated using Ohm's Law.

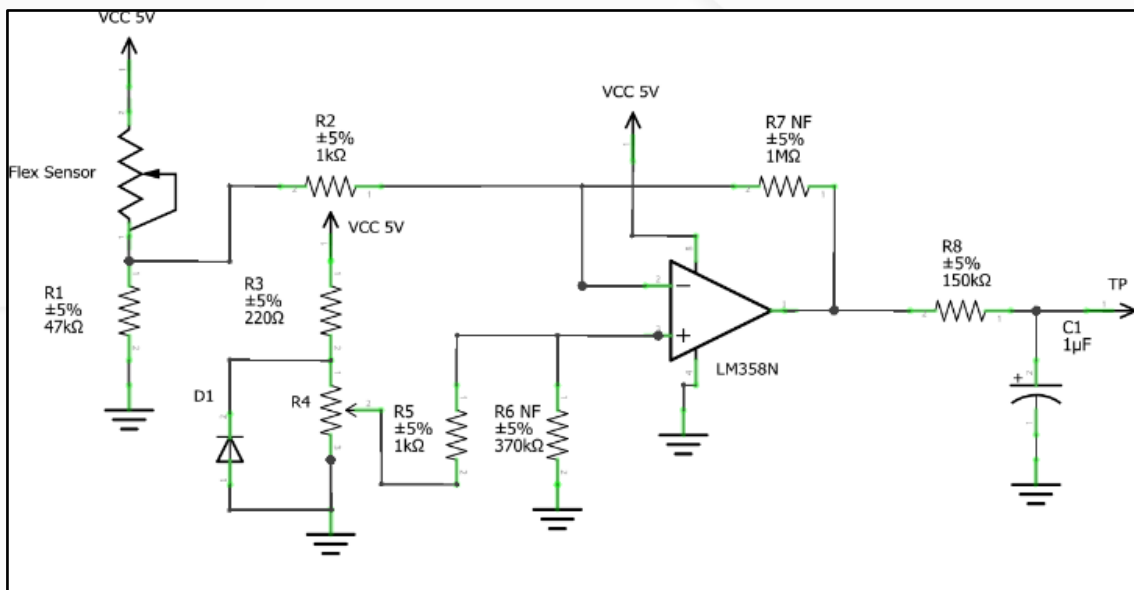


Figure 6. Differential Amplifier Circuit

The differential amplifier is designed to eliminate noise and gain voltage output. The formula for this is to get the difference value of Vin non-inverting with Vin inverting; this functions to gain the difference in value from the input voltage. The voltage gain was calculated based on inverting the op-amp amplifier:

$$A_v = -\frac{R_F}{R_{in}}$$

Where Av is the gain for the circuit output RF is the feedback resistor and Rin is the input resistor.



This capstone used Descriptive applied research to develop and obtain respiratory rate data from existing automation and manual/visual observation of respiratory rate. Provided below is the Prototyping Design Model which shows the prototyping techniques employed for this capstone project.

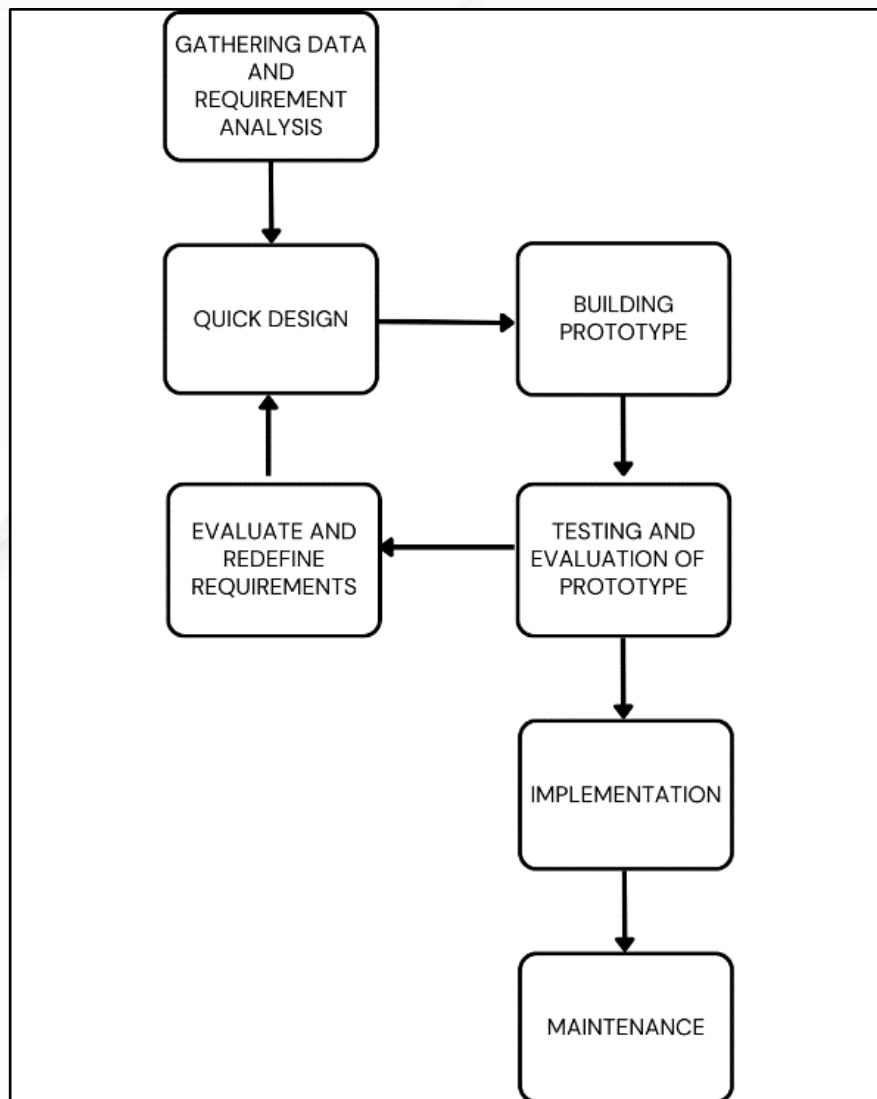


Figure 7. Prototyping Model



RESULTS

A. Functionality Test

I. Flex Measurement

a. Mechanical Strain to Electrical Signal

Table 1.
The Resistance of a Flex Sensor Base on the Bend Angle

Bend Angle (measured in degrees)	Resistance (measured in ohms)
0	10k
45	15k
90	18.4 k
145	26.3k
180	32.6k

Table 2.
The Voltage Output with 3.3 Voltage Input and 47k Ohms Voltage Divider

Bend Angle	Voltage Output
0	1.71 V
45	1.20V
90	0.95 V
145	0.86 V
180	0.68 V

b. Signal Conditioning

Table 3.
The Voltage Output After Passing Through Differential Amplifier

Bend Angle	Voltage Output
0	0 V
45	1.64 V





90	1.90 V
145	1.98 V
180	2.0

Tables 1 and 2 present the resistances of the flex sensor at different bending angles, and the voltage output changes when a 3.3-volt input is applied, along with a voltage divider. The results reveal that the voltage decreases as the angle of the bend increases, which corresponds to the changes in the resistance value of the flex sensor. The increase in output voltage displayed in Table 3 reflects the amplifier's gain and design, which shows the difference between the voltage from the voltage divider and a constant reference voltage. When the bend angle increases, the resistance of the flex sensor typically increases, leading to a decrease in voltage at the voltage divider output. However, the differential amplifier amplifies this voltage difference, resulting in an apparent increase in output voltage.

B. Accuracy Test

This capstone project included 20 trials, with most of them conducted at the university. However, the 3 trials involved were a family member and relative of the proponents who have been clinically diagnosed with hypertension and asthma. The following trials were randomly selected, and 5 of them were repeated twice on different parts of the body, namely, the abdomen and chest, to test the efficiency of the belt.

I. Trials Result – Eupnea

Table 4 shows the accuracy of the flex sensor-based respiratory rate belt to monitor for normal breathing (eupnea). The reference value for normal breathing is 16 breaths per minute (bpm). Based on the measured value and the reference value, the respiratory rate belt achieved an accuracy percentage of 90.18% and a verbal interpretation of "Very Satisfactory",





indicating that the belt performed accurately and reliably in monitoring for normal breathing

Table 4.
Flex Sensor-Based Respiratory Rate Readings (in abdomen) - Eupnea

Trials	Eupnea Reference: 16 breaths per minute, bpm
1	15 bpm
2	15 bpm
3	15 bpm
4	17 bpm
5	14 bpm
6	16 bpm
7	14 bpm
8	15 bpm
9	12 bpm
10	17 bpm
11	13 bpm
12	14 bpm
13	17 bpm
14	18 bpm
Total	212 bpm
Mean	15 bpm
Percent Error (%)	9.82%
Accuracy (%)	90.18%
Verbal Interpretation	Very Satisfactory

II. Trials Result – Tachypnea

Table 5 presents the accuracy of the flex sensor-based respiratory rate belt to monitor for tachypnea. The reference value used in the capstone project was 26 breaths per minute (bpm). The results show that the respiratory





rate belt had an accuracy percentage of 91.03% in detecting tachypnea, and provided a verbal interpretation of "Very Satisfactory". This means that the belt is a reliable and accurate tool for monitoring tachypnea.

Table 5.
Flex Sensor-Based Respiratory Rate Readings (in abdomen) – Tachypnea

Trials	Flex Sensor-Based Respiratory Rate – Tachypnea Reference: 26 breaths per minute, bpm
1	24 bpm
2	24 bpm
3	25 bpm
4	27 bpm
5	21 bpm
6	23 bpm
Total	144 bpm
Mean	24 bpm
Percent Error (%)	8.97%
Accuracy (%)	91.03%

III. Summary of Accuracy Test

The results of the accuracy test for different breathing statuses are summarized in Table 6, which shows a total accuracy percentage of 93.73% and a verbal interpretation of "Very Satisfactory."

Table 6.
Summary of Accuracy Test for Eupnea, Tachypnea, and Bradypnea

Summary of Accuracy Test	
Eupnea	90.18%
Tachypnea	91.03%
Bradypnea	100%





Total Accuracy	93.73%
Verbal Interpretation	Very Satisfactory

C. Efficiency Test

I. Comparison Testing

a. Manually Assessed Respiratory Rate vs. Flex Sensor Based Respiratory Rate Belt (in the abdomen)

Table 7 and Table 8 present a comparison between the accuracy of respiratory rate measurement by a flex sensor-based respiratory rate belt placed on the abdomen and the manual assessment done by a nurse. The belt and manual count resulted in a percent error of 8.56% and 9.62%, respectively. Using the following data, the accuracy of the belt and manual count resulted in 91.44% and 90.38%, respectively.

Table 7.
 Flex Sensor-Based Respiratory Rate Belt in Abdomen

Trials	Respiratory Rate in Abdomen
	Reference Value: 16 bpm (for Eupnea) and 26 bpm (for Tachypnea)
1	14 bpm
2	17 bpm
3	18 bpm
4	24 bpm
5	25 bpm
Total	98 bpm
Mean	20 bpm
Percent Error (%)	8.56%
Accuracy (%)	91.44%
Verbal Interpretation	Very Satisfactory





Table 8.
Manually Assessed Respiratory Rate

Trials	Manual Respiratory Rate
	Reference Value: 16 bpm (for Eupnea) and 26 bpm (for Tachypnea)
1	15 bpm
2	17 bpm
3	18 bpm
4	22 bpm
5	24 bpm
Total	96 bpm
Mean	19 bpm
Percent Error (%)	9.62%
Accuracy (%)	90.38%
Verbal Interpretation	Very Satisfactory

b. Manually Assessed Respiratory Rate vs. Flex Sensor-Based Respiratory Rate Belt (in chest)

Tables 9 and 10 present the comparison between the respiratory rate measured by a flex sensor-based respiratory rate belt placed in chest and the manual assessment done by a nurse. This test resulted in an equal percent error of 10.87% and a percent accuracy of 89.13%.

Table 9.
Flex Sensor-Based Respiratory Rate Belt in Chest

Trials	Respiratory Rate in Chest Reference Value: 16 bpm (for Eupnea) and 26 bpm (for Tachypnea)
1	13 bpm
2	17 bpm
3	17 bpm
4	23 bpm





5	23 bpm
Total	93 bpm
Mean	19 bpm
Percent Error (%)	10.87%
Accuracy (%)	89.13%
Verbal Interpretation	Very Satisfactory

Table 10.
Manually Assessed Respiratory Rate

Trials	Manual Respiratory Rate Reference Value: 16 bpm (for Eupnea) and 26 bpm (for Tachypnea)
1	15 bpm
2	17 bpm
3	19 bpm
4	22 bpm
5	24 bpm
Total	97 bpm
Mean	19 bpm
Percent Error (%)	10.87%
Accuracy (%)	89.13%
Verbal Interpretation	Very Satisfactory

II. Summary of Efficient Test

The flex sensor-based respiratory rate monitoring system can accurately measure respiratory rates when placed on either the abdomen or chest area of the patient demonstrated in Table 8. However, the device was more consistent and efficient when placed on the abdomen which resulted in an overall average of 90.29% and a verbal interpretation of “Very Satisfactory”.





a. Web Server Trials in Graphical Form – Abdomen and Chest Measurement

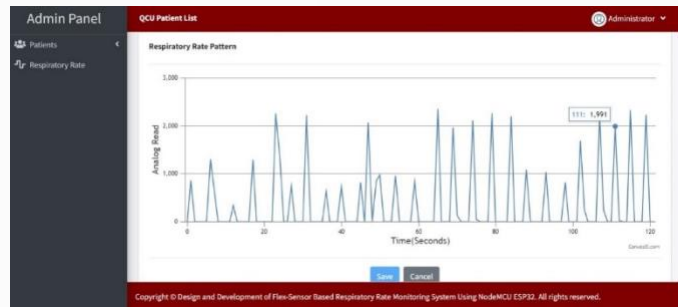


Figure 8. Trial 1 of Efficiency Test (Eupnea: 14,13 bpm).

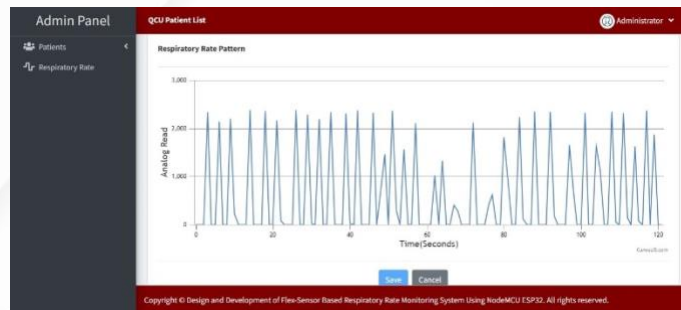


Figure 9. Trial 2 of Efficiency Test (Eupnea: 17,17 bpm).

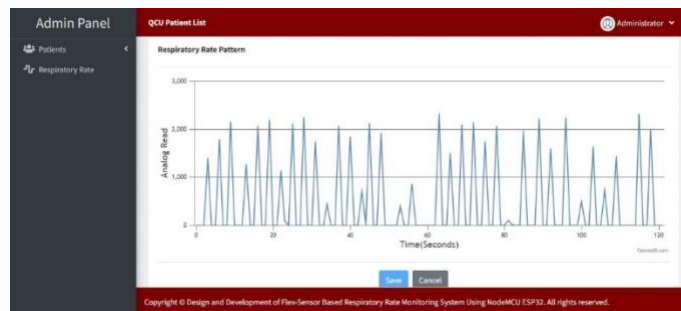


Figure 10. Trial 3 of Efficiency Test (Eupnea: 18,17 bpm).

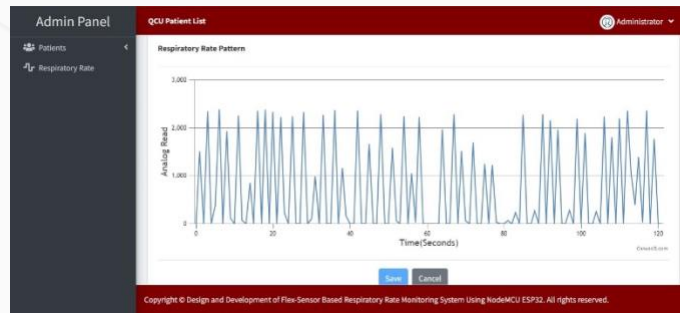


Figure 11. Trial 4 of Efficiency Test (Tachypnea: 24,23 bpm).

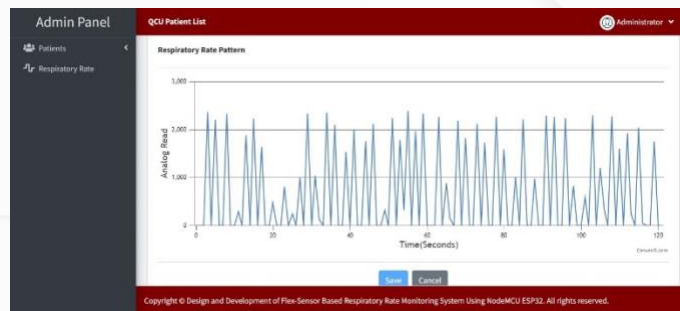


Figure 12. Trial 5 of Efficiency Test (Tachypnea: 25,23 bpm).

The web server used in the capstone project successfully stored and presented patient information. Furthermore, it was able to display the graphical representations showing breathing patterns. This feature aimed to offer additional insights, particularly to medical professionals, enhancing patient assessments.

Table 11.
Summary of Efficiency Test in Abdomen and Chest

Summary of Efficiency Test	
Flex Sensor-Based Respiratory Rate Belt in Abdomen	91.44%
Flex Sensor-Based Respiratory Rate Belt in Chest	89.13%
Total Accuracy	90.29%
Verbal Interpretation	Very Satisfactory





CONCLUSIONS

The proponents successfully developed a respiratory rate monitoring system based on flex sensors. The sensor can effectively detect changes in respiratory rate through the expansion and contraction of the abdomen or chest during breathing.

The system demonstrated an overall accuracy of 93.73%, making it a reliable device for measuring respiratory rates and distinguishing between three breathing statuses. The researchers found that the device was more accurate when worn at the abdomen, achieving a 91.44% accuracy, compared to the chest, which achieved an 89.13% accuracy. This emphasizes the efficiency of the belt placed on the abdomen in providing accurate and reliable respiratory rate and status.

The system allows two viewing methods: through the OLED screen and the developed web server. The OLED monitor provides offline monitoring, allowing the measured respiratory rate and status to be easily viewed in real time. On the other hand, the web server provides a more comprehensive view of the results, including the patient information and a graphical representation of the start and end of breath. All this information is displayed and stored via the web server, ensuring comprehensive data management and security.

This capstone project used flex sensors because other strain gauge sensors were not available in the market. Future researchers are encouraged to explore other sensors that could be used to read respiratory rates. Incorporating other sensors will help provide a more thorough assessment of the user's physical state.

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Conflict of Interest: The researchers affirm that no conflicts of interest are associated with this research's publication, providing the integrity and impartiality of the study's findings.

Ethical Statement: All subjects gave their informed consent for inclusion in the study before participating.

