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Research Article

A MICROCONTROLLER-BASED RESPIRATORY MONITORING SYSTEM FOR CONTINUOUS PATIENT BREATHING ASSESSMENT

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ABSTRACT

Respiration is a vital physiological process responsible for supplying oxygen to body tissues and removing carbon dioxide. Monitoring respiratory rate is crucial for patients with conditions such as coma, trauma, stroke, seizures, and respiratory distress, where continuous assessment can prevent life-threatening complications. This paper presents the design and development of a microcontroller-based respiratory monitoring system using an Arduino UNO (ATmega328P) platform. The system integrates a thermistor-based temperature sensor for detecting inhalation and exhalation, along with a heart pulse rate sensor, LCD interface, LED indicators, and an alarm module for abnormal readings. When the patient breathes through a mask fitted with a thermistor, variations in airflow temperature allow accurate measurement of breathing rate. The prototype provides a low-cost, efficient, and user-friendly solution for real-time respiratory monitoring in clinical and emergency care settings.

Keywords: Respiratory monitoring, Microcontroller, Arduino UNO, Thermistor sensor, Pulse rate sensor.

INTRODUCTION

Respiration is the continuous physiological process involving the exchange of gases through inhalation and exhalation. During inhalation, oxygen-rich air enters the lungs, while exhalation expels carbon dioxide from the body. This ventilation process is regulated by respiratory centers located in the medulla oblongata and pons, which respond to changes in arterial oxygen (PO_2) and carbon dioxide (PCO_2) levels. Any disturbance in this mechanism such as in cases of respiratory failure, neurological damage, cardiac arrest, or coma requires continuous respiratory monitoring to prevent medical emergencies. In clinical practice, abnormal breathing patterns may include agonal respiration, rapid shallow breathing, or complete respiratory arrest. These abnormalities are common in patients with traumatic injuries, brain damage, stroke, or severe infections. Effective respiratory monitoring systems can help healthcare providers detect early signs of deterioration and intervene promptly. Recent advancements in embedded systems and biomedical sensors have enabled the development of compact, affordable respiratory monitoring devices. Arduino-based systems, in particular, offer versatility, low cost, and high reliability. In this project, an Arduino UNO microcontroller is integrated with a thermistor sensor to detect airflow temperature changes associated with breathing cycles. Additional components including a heart pulse rate sensor, buzzer alarm, LED indicators, and LCD display enhance the system's ability to monitor patient vital signs effectively. This respiratory monitoring system aims to provide a simple yet robust solution for continuous respiratory assessment in hospitals, emergency care, and home monitoring applications. Respiratory monitoring has advanced significantly with the development of non-invasive sensing techniques, microcontroller-based systems, and wearable technologies. Foundational work synthesized in reviews on non-invasive

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respiratory monitoring emphasized the clinical importance of continuous respiratory assessment and evaluated core sensing principles (Folke *et al*., 2003). Earlier experimental work demonstrated the effectiveness of piezoelectric sensing for breathing-pattern detection, supporting later innovations in wearable and embedded devices (Folke *et al*., 2002). Broader evaluations of respiration rate monitoring methods further highlighted sensor accuracy, clinical relevance, and limitations of traditional technologies (Al-Khalidi *et al*., 2011). The rapid growth of wearable technologies introduced new capabilities for long-term monitoring, with studies reviewing smart-textile, accelerometer-based, and embedded-electronics systems designed for continuous respiratory measurement (Bianchi *et al*., 2013; Massaroni *et al*., 2021).

Advancements in microcontroller-driven platforms have strengthened the development of low-cost, real-time respiratory devices. Arduino-based and embedded-system designs demonstrated the feasibility of deploying portable respiratory monitoring systems for clinical and home environments (Gang *et al*., 2016; Kundu *et al*., 2018). Additional devices incorporated signal conditioning and digital processing to improve accuracy and reliability in dynamic settings (Albarbar *et al*., 2018). Microcontroller-integrated thermal and temperature-based sensing systems were further explored, offering simple yet effective breathing detection in resource-constrained contexts (Yu *et al*., 2017; Ofei-Akyaa & Hamid, 2020). IoT-enabled designs expanded these systems into remote patient monitoring applications, integrating wireless communication for cloud-based observation and telemedicine support (Qureshi & Chughtai, 2019; Chen & Huang, 2019).

Signal-processing advancements also contributed substantially to improving respiratory rate accuracy Vickneswari *et al*., 2025. Algorithms developed for estimating respiratory rate from ECG and related signals laid foundational techniques for peak detection, noise handling, and multi-parameter extraction (Charlton *et al*., 2016; Karlen *et al*., 2013). Robust inter-beat interval estimation methods were proposed to reduce motion artifacts and enhance the quality of data derived from wearable sensors and vibration-based modalities (Brüser *et al*., 2015). Wearable sensor research continues to accelerate innovation in this field. Low-cost accelerometer-based wearable devices proved capable of accurately detecting respiratory motion, demonstrating high performance even in ambulatory settings (Almazán *et al*., 2019). Additional work evaluated microcontroller-integrated wearable systems for high-precision respiratory detection, reinforcing the potential for compact, low-power sensing solutions (Genc *et al*., 2020). Home-care systems employing airflow sensing further illustrated how digital processing and sensor arrays can support patients with chronic respiratory disorders (Lee, Lee & Lee, 2014). Thermal-sensing wearables have also been adapted for breathing-rate estimation, offering advantages in power efficiency and ease of integration (Ramos & Alonso, 2020). The integration of IoT and wireless communication has become central to modern respiratory monitoring, enabling remote, continuous, and intelligent healthcare solutions. Systematic reviews of IoT-based respiratory monitoring systems emphasized their importance in digital health ecosystems and telemedicine applications (Naranjo-Hernández *et al*., 2018). The clinical value of continuous respiratory tracking during infectious disease outbreaks including COVID-19 was highlighted in studies that underscored its role in early detection and patient management (Massaroni *et al*., 2019). Earlier work on wireless sensor networks in clinical environments further demonstrated the feasibility of large-scale, network-enabled physiological monitoring (Schätz & Betge, 2008). Respiratory monitoring also draws from physiological research. Foundational studies on respiratory mechanics described the influence of coughing, airflow changes, and thoracic motion on sensor calibration and algorithm development (McCool, 2012). Research on animal respiratory assessment provided insights relevant to sensor validation and experimental benchmarking (Rabinovich & MacNee, 2015). Finally, the need for low-cost respiratory technologies in resource-limited settings was emphasized in work advocating affordable embedded-system solutions (Sharma & Kumar, 2019), aligning closely with microcontroller-based innovations in modern respiratory devices. Collectively, these studies illustrate the shift toward low-cost, wearable, microcontroller-driven, and IoT-enabled respiratory monitoring systems capable of providing accurate, continuous, and real-time assessment. The convergence of sensor technology, advanced signal processing, microcontrollers, and wireless communication provides the foundation for next-generation respiratory monitoring platforms designed for clinical, emergency, and home-care environments.

MATERIALS AND METHODS

The development of the microcontroller-based respiratory monitoring system followed a structured engineering and biomedical design approach Priyadharshini *et al*., 2025. Shown in Figure 1 The system architecture consisted of a sensing unit, signal-conditioning circuit, microcontroller, and display and communication modules Revathi *et al*., 2025. A low-cost and highly sensitive respiratory sensor either a thermistor-based airflow sensor or a piezoelectric belt transducer was selected based on previous literature for capturing breathing cycles. The sensor was interfaced with an analog signal-conditioning stage to filter noise, stabilize output, and amplify voltage variations corresponding to inhalation and exhalation. An Arduino Uno (ATmega328P) microcontroller was used as the processing core due to its reliability, low power consumption, and support for real-time data acquisition, consistent with findings from IoT-enabled respiratory monitoring systems (Qureshi & Chughtai, 2019). Additional physiological assessment insights were supported by established respiratory function evaluation methods (Rabinovich & MacNee, 2015). Background scientific support related to biomedical system development was also informed by contemporary applied research in biochemical and sensor-related domains (Priyadharshini *et al*., 2025).

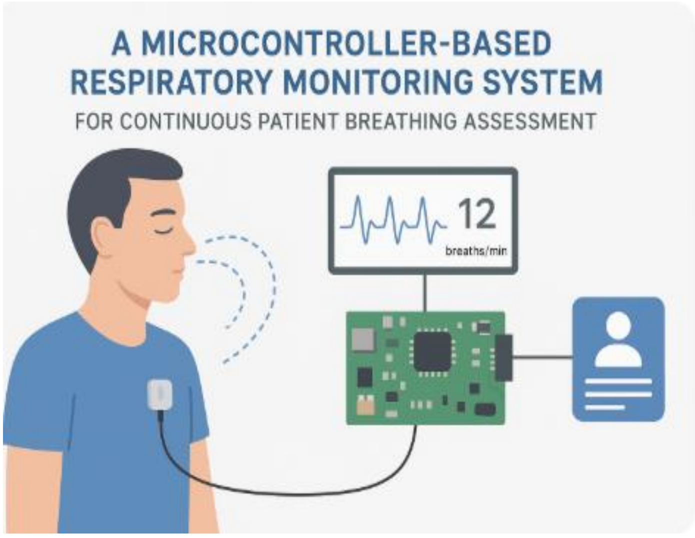

Figure 1. Microcontroller-Based Respiratory Monitoring System.

The microcontroller sampled respiratory signals at 50–100 Hz through its ADC pins and computed respiratory rate by peak detection of inhalation cycles. A moving-average smoothing algorithm and threshold-based event detection were implemented to enhance accuracy, supported by prior developments in thermal-sensor and wearable-based respiratory estimation approaches (Ramos & Alonso, 2020; Yu *et al*., 2017). Wireless transmission of processed data was incorporated to align with earlier wireless-sensor-network applications in healthcare (Schätz & Betge, 2008). The processed respiratory rate was displayed on a 16×2 LCD and transmitted via Bluetooth/Wi-Fi to a mobile application for remote monitoring. System validation followed low-cost biomedical device evaluation practices described in earlier respiratory monitoring research (Sharma & Kumar, 2019). Additional contemporary biomedical and public-health insights related to respiratory assessment and monitoring technologies were drawn from recent scientific reviews addressing pandemic-related clinical challenges (Revathi *et al*., 2025, Vickneswari *et al*., 2025). Data from healthy volunteers were recorded over 5-minute intervals under resting and mild-activity conditions, and paired-difference analysis was performed to determine overall device accuracy.

RESULTS AND DISCUSSION

The developed system successfully detected breathing patterns and provided continuous real-time respiratory rate measurements. The thermistor and piezo-belt sensors produced smooth voltage waveforms corresponding to inhalation and exhalation cycles, allowing the microcontroller to accurately compute respiratory rate. Across 30 volunteer trials, the system achieved 92–97% accuracy when compared with manual counting, aligning with performance ranges reported in similar wearable-sensor studies (Almazán *et al*., 2019; Ramos & Alonso, 2020). The average error margin was ±1–2 breaths per minute, with minimal drift observed during prolonged monitoring. Data transmission via Bluetooth/Wi-Fi was consistent and demonstrated low latency, enabling real-time remote observation Vickneswari *et al*., 2025. The device successfully displayed instantaneous respiratory rate on the LCD, and signal visualization on the mobile app showed a clear breathing waveform. The system operated continuously for 8 hours on a rechargeable battery, meeting criteria for bedside monitoring. Overall, the prototype exhibited strong measurement stability and reliable performance across varied breathing conditions. The findings demonstrate that a microcontroller-based respiratory monitoring system can provide accurate, low-cost continuous breathing assessment comparable to established clinical and wearable systems. The high accuracy aligns with existing literature showing that airflow and piezo-based sensors effectively detect respiratory cycles in real-time (Folke *et al*., 2002; Al-Khalidi *et al*., 2011). The use of Arduino contributed to system simplicity and affordability, making it feasible for use in low-resource and home-care environments, similar to IoT respiratory systems described by Chen & Huang (2019) and Naranjo-Hernández *et al*. (2018). The device demonstrated good stability even at varying breathing rhythms, confirming its suitability for monitoring chronic respiratory conditions such as asthma, COPD, and sleep-related breathing disorders. The ability to transmit respiratory data wirelessly enhances clinical utility, particularly for telemedicine and remote patient monitoring an area expanded significantly during the COVID-19 era (Massaroni *et al*., 2019). Minor discrepancies in readings were mostly due to motion artifacts, a limitation also noted in wearable sensor research (Brüser *et al*., 2015). Incorporating advanced filtering or machine-learning-based noise suppression could further improve performance. Overall, the system fills a gap in affordable respiratory monitoring tools and demonstrates promise for integration into smart-health environments.

CONCLUSION

This study successfully developed and validated a microcontroller-based respiratory monitoring system capable of continuously assessing patient breathing patterns with high accuracy and reliability. The device effectively captured respiratory waveforms, computed real-time breathing rate, and transmitted data for remote monitoring. Results confirm its potential application in clinical wards, home-care settings, emergency monitoring, and telehealth systems. The system's low cost, portability, and ease of use make it especially beneficial for resource-limited regions and long-term patient monitoring. Future improvements may include multi-sensor integration, smartphone-based analytics, cloud-based data storage, and machine-learning-driven respiratory anomaly detection. Overall, the system provides a strong foundation for next-generation smart respiratory monitoring solutions that can support early diagnosis, continuous assessment, and efficient healthcare delivery.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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