

IoT-Based Multi-Sensor Breath Analysis System with Automated Pulmonary Drug Delivery for Respiratory Care

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ABSTRACT

Respiratory diseases require continuous monitoring and timely therapeutic intervention to prevent severe health complications. This paper presents the design and development of an IoT-based multi-sensor breath analysis system integrated with an automated pulmonary drug delivery mechanism for respiratory care. The proposed system utilizes a set of advanced gas and flow sensors to analyze breath parameters such as airflow rate, respiratory patterns, and the presence of specific biomarkers associated with respiratory disorders. These parameters are continuously monitored and transmitted in real time through an IoT platform for remote analysis and medical supervision. An intelligent decision-making algorithm processes the acquired data to detect abnormalities in respiratory function, such as irregular breathing patterns or reduced lung efficiency. Upon identifying critical conditions, the system automatically activates a pulmonary drug delivery module, such as a smart inhaler or nebulizer, to administer a controlled dosage of medication directly to the lungs. This targeted drug delivery approach enhances therapeutic effectiveness while minimizing systemic side effects. The system is designed to be compact, energy-efficient, and user-friendly, making it suitable for both clinical and home-based healthcare applications. Experimental evaluation demonstrates that the proposed framework provides accurate breath analysis, reliable data transmission, and timely drug delivery with minimal latency. The integration of real-time monitoring with automated pulmonary drug delivery offers a promising solution for improving respiratory care, ensuring rapid response, and enhancing patient outcomes through smart healthcare technology.

Keywords: Internet of Things (IoT), Multi-Sensor Breath Analysis, Pulmonary Drug Delivery, Automated Drug Delivery System, Respiratory Health Monitoring, Smart Inhaler System, Aerosol Drug Delivery

How to cite this article: Aswathi KB, Anisha R, Poovitha D, Aparna N, Sujitha S. IoT-Based Multi-Sensor Breath Analysis System with Automated Pulmonary Drug Delivery for Respiratory Care. *Int J Drug Deliv Technol.* 2026;16(35s): 1138-1146. DOI: 10.25258/ijddt.16.35s.126

Source of support: Nil.

Conflict of interest: None

I. INTRODUCTION

Respiratory diseases have shown a significant increase due to factors such as air pollution, industrial exposure, smoking habits, lifestyle changes, and viral infections. Conditions including asthma, chronic obstructive pulmonary disease (COPD), and bronchitis are now widely observed across different age groups. In addition, increased awareness following the pandemic has highlighted the importance of monitoring oxygen levels, breathing patterns, and overall lung function, even among healthy individuals. However, most respiratory assessment methods remain confined to hospital settings. Equipment such as spirometers, gas analyzers, and imaging systems provide accurate results, but they are expensive, bulky, and require trained professionals for operation.

Another limitation of existing diagnostic approaches is that they are typically used only after symptoms appear. Continuous monitoring of lung health is not commonly practiced due to inconvenience and the lack of accessible

portable solutions. As a result, early changes in respiratory function often go unnoticed. This creates a need for a compact, user-friendly system capable of continuously monitoring respiratory parameters and providing early warnings before the onset of severe symptoms.

Advancements in embedded systems, sensor technology, and the Internet of Things (IoT) have created new possibilities in healthcare monitoring. Modern sensors can measure physiological and environmental parameters with good accuracy while maintaining low power consumption. Microcontrollers such as ESP32 support built-in Wi-Fi and Bluetooth, enabling real-time data transmission and remote monitoring. By integrating multiple sensors into a single platform, a more comprehensive assessment can be achieved compared to single-parameter systems.

Breath analysis has emerged as a promising non-invasive approach for evaluating respiratory health. Exhaled breath contains important information related to airflow, carbon dioxide levels, temperature variations, and humidity.

Variations in these parameters may indicate early changes in lung function. For instance, irregular airflow can suggest airway obstruction, while abnormal CO₂ levels may indicate inefficient gas exchange. Environmental factors such as temperature and humidity also influence breathing conditions. When these parameters are analyzed together, they provide a more reliable and accurate understanding of respiratory health.

II. LITERATURE REVIEW

The rising prevalence of respiratory diseases has prompted significant research into improved diagnostic and monitoring techniques for early detection and preventive healthcare. Over the past decade, studies have explored areas such as breath analysis, wearable health monitoring systems, IoT-based medical devices, and embedded sensor integration in healthcare applications. These developments aim to enhance accessibility, enable continuous monitoring, and improve user convenience. This section reviews key contributions in these domains and identifies the research gap addressed by the proposed system.

2.1 Respiratory Monitoring Using Conventional Methods

Traditional respiratory assessment methods include spirometry, capnography, pulse oximetry, and imaging techniques. Among these, spirometry is widely used for evaluating lung function by measuring parameters such as Forced Vital Capacity (FVC) and Forced Expiratory Volume (FEV₁). These parameters are useful for identifying airflow obstruction and assessing lung capacity. Despite its clinical importance, spirometry requires proper calibration, controlled conditions, and trained personnel. In addition, it is not suitable for continuous monitoring in home environments.

Capnography is another established technique used to measure carbon dioxide (CO₂) concentration in exhaled breath. It is commonly applied in critical care settings to assess ventilation status and gas exchange efficiency. Although it provides reliable results, the equipment is expensive and primarily limited to hospitals and intensive care units. Pulse oximeters are widely used for measuring oxygen saturation (SpO₂) and pulse rate. While they are portable and easy to use, they do not provide detailed information about airflow characteristics or environmental influences on respiration. Imaging techniques such as X-rays and CT scans also assist in diagnosing respiratory conditions; however, they are not suitable for continuous monitoring. Overall, these methods are effective for diagnosis but lack portability and real-time monitoring capability.

2.2 Breath Analysis for Disease Detection

Exhaled breath analysis has emerged as a promising non-invasive approach for detecting various health conditions. Human breath contains biomarkers that reflect physiological changes within the body. Parameters such as carbon dioxide levels, volatile organic compounds (VOCs), and humidity

provide valuable insights into respiratory function. This approach has been explored for detecting conditions such as asthma, COPD, lung infections, and certain metabolic disorders.

Gas sensor-based systems have been developed to identify abnormal respiratory patterns, with CO₂ sensors being commonly used to assess ventilation efficiency and detect conditions such as hypoventilation. However, many existing approaches rely on single-parameter analysis, which may not provide a complete representation of respiratory health. Relying on a single parameter can lead to incomplete or less reliable conclusions. Therefore, integrating multiple parameters is necessary to improve the accuracy and robustness of respiratory assessment systems.

2.3 IoT-Based Healthcare Monitoring Systems

The advancement of Internet of Things (IoT) technology has significantly influenced modern healthcare monitoring. IoT-enabled systems are capable of collecting physiological data such as heart rate, body temperature, oxygen saturation, and respiratory rate, and transmitting this data to cloud platforms for remote access. These systems are particularly useful in telemedicine applications, where continuous patient monitoring can be achieved without frequent hospital visits.

Microcontrollers such as Arduino and ESP32 are widely used in IoT-based healthcare systems due to their low cost, ease of implementation, and wireless communication capabilities. Many of these systems are designed as wearable devices for continuous monitoring of vital signs. However, only a limited number of studies focus specifically on respiratory health using multi-sensor breath analysis. Additionally, most systems analyze individual parameters separately rather than integrating physiological, respiratory, and environmental data into a unified framework. This lack of integration limits the effectiveness of overall health evaluation.

2.4 Multi-Sensor Integration in Smart Healthcare

Multi-sensor integration, also referred to as sensor fusion, has gained importance in recent healthcare research. By combining data from multiple sensors, system accuracy and reliability can be improved while reducing the impact of noise and false readings. Studies have shown that incorporating environmental parameters such as temperature and humidity along with physiological data provides better insight into respiratory conditions.

Sensor fusion techniques are widely used in wearable and smart healthcare devices. However, many of these systems are designed for general health monitoring rather than focusing specifically on respiratory assessment. There is limited research on systems that combine multiple respiratory-related parameters into a structured analytical model. In particular, there is a lack of methods that convert multiple sensor readings into a simple and interpretable health index that can be easily understood by non-technical users.

2.5 Embedded Processing and Health Index Generation

Recent developments in embedded systems have enabled the conversion of raw sensor data into meaningful health information. These systems use algorithms such as threshold-based classification and statistical analysis to categorize user conditions into levels such as normal, moderate, or critical. Such approaches simplify complex data and improve usability.

However, most of the existing work focuses on general health monitoring or cardiac-related applications rather than respiratory-specific analysis. There is limited research on developing a dedicated respiratory health index that integrates parameters such as airflow, gas concentration, and environmental conditions into a single value. This gap highlights the need for a system that not only collects multi-sensor data but also processes it effectively to provide clear and meaningful interpretation of respiratory health.

III. CHALLENGES IN SMART RESPIRATORY HEALTH SCREENING USING MUTISENSOR BREATH ANALYSIS

The development of an IoT-based smart respiratory health screening system using multi-sensor breath analysis involves several technical and practical challenges. Since the system integrates multiple sensors, embedded processing, real-time analysis, and wireless communication, careful design is required to ensure accuracy, reliability, and ease of use. Each component must operate in coordination with others to generate meaningful and consistent results. The major challenges encountered in this work are discussed below.

3.1 Accurate Breath Data Collection

Accurate acquisition of exhaled breath data is a primary challenge in the system. The quality of measurements depends significantly on user interaction, including breathing force, duration, and positioning. Variations in these factors can lead to inconsistent sensor readings. In addition, mixing of ambient air with exhaled breath can affect measurement accuracy. Therefore, the design of an efficient breath collection chamber is essential to minimize external interference while ensuring user comfort and repeatability.

3.2 Sensor Calibration and Accuracy

The system employs multiple sensors, including CO₂, airflow, temperature, and humidity sensors, each with specific operating characteristics and calibration requirements. Improper calibration may result in inaccurate readings and incorrect classification of respiratory conditions. Environmental factors such as temperature and humidity can further influence sensor performance. Hence, appropriate calibration procedures and periodic validation are necessary to maintain measurement accuracy and system reliability.

3.3 Multi-Sensor Data Integration

Integrating data from multiple sensors into a unified analytical framework is another significant challenge. Each sensor produces output in different units and formats, making direct comparison difficult. These values must be normalized and

processed using suitable algorithms to derive meaningful indicators. The generation of a Respiratory Evaluation Index (REI) requires careful combination of parameters such as airflow, CO₂ concentration, and environmental conditions. The algorithm must be designed to accurately reflect physiological behavior while minimizing misinterpretation.

3.4 Real-Time Processing and Response

The system is intended to provide immediate feedback through an LCD display and voice output. This requires efficient real-time processing of data from multiple sensors. Managing multiple inputs simultaneously while maintaining low latency demands optimized programming and effective utilization of microcontroller resources. Delays in processing can affect user experience and reduce system reliability. Ensuring stable operation of the ESP32 during continuous use is therefore essential.

3.5 IoT Connectivity and Data Transmission

Reliable wireless communication is critical for enabling IoT-based monitoring. Network issues such as signal instability, interruptions, and synchronization errors can impact data transmission. In addition, secure handling of health data is necessary to prevent data loss or unauthorized access. Designing a robust communication framework and managing data storage effectively add complexity to the system.

3.6 Power Management and Portability

The system is designed to be portable and suitable for everyday use, which makes power management an important consideration. Efficient utilization of power is required to extend battery life without compromising performance. Certain sensors, particularly gas sensors, have higher power consumption, which affects overall efficiency. At the same time, the device must remain compact and lightweight. Achieving a balance between power consumption, performance, and portability presents both design and implementation challenges.

3.7 Environmental Influence on Measurements

Environmental conditions such as temperature, humidity, and ambient air quality can influence sensor readings. It is important to differentiate between environmental CO₂ levels and CO₂ present in exhaled breath. Failure to account for these variations may result in inaccurate measurements or incorrect classification. The system must therefore incorporate mechanisms to compensate for environmental effects and improve measurement reliability.

3.8 User Variability

Respiratory patterns vary across individuals due to factors such as age, gender, physical condition, and medical history. As a result, fixed threshold values may not be suitable for all users. The system should be adaptable to individual differences, potentially through baseline calibration or adaptive threshold mechanisms. This adaptability is essential for improving accuracy and ensuring consistent performance across different users.

3.9 Validation and Reliability Testing

Comprehensive testing and validation are required before deploying the system in real-world applications. The performance of the device must be compared with standard medical equipment to verify accuracy. Achieving clinical-level reliability in a low-cost embedded system is challenging and requires iterative testing, calibration, and refinement. Proper validation ensures that the system produces consistent and trustworthy results.

IV. EXISTING SOLUTIONS AND THEIR LIMITATIONS

4.1 Spirometry-Based Systems

Spirometry is one of the most widely used techniques for evaluating lung function. It measures airflow and lung capacity using parameters such as Forced Vital Capacity (FVC) and Forced Expiratory Volume (FEV₁). These measurements are useful in identifying airflow obstruction and diagnosing respiratory conditions such as asthma and chronic obstructive pulmonary disease (COPD). Due to its accuracy and clinical reliability, spirometry is extensively used in hospitals and pulmonary laboratories.

However, spirometry has several limitations when applied to routine monitoring. The procedure requires trained personnel to guide the user and ensure proper execution. It must also be conducted under controlled conditions to obtain reliable results. In addition, spirometry devices are typically bulky and expensive, making them less suitable for home use. Another limitation is that spirometry is generally performed after symptoms appear, rather than being used as a preventive tool, which reduces its effectiveness in detecting early-stage respiratory changes.

4.2 Capnography and Gas Analysis Systems

Capnography is used to measure the concentration of carbon dioxide (CO₂) in exhaled breath and is commonly applied in clinical environments such as operation theatres and intensive care units. It provides valuable information regarding ventilation efficiency and gas exchange. Advanced gas analysis systems can also detect additional biomarkers, making them useful for clinical diagnosis.

Despite their accuracy, these systems are not practical for everyday use. The equipment is expensive and requires regular calibration and maintenance. They are primarily designed for hospital settings and lack portability for home-based monitoring. Furthermore, these systems mainly focus on gas concentration and do not consider other important factors such as environmental conditions or physiological parameters, limiting their ability to provide a comprehensive assessment.

4.3 Pulse Oximeters

Pulse oximeters are widely used devices that measure blood oxygen saturation (SpO₂) and pulse rate. They are compact, affordable, and easy to use, making them suitable for home

monitoring. Their use increased significantly during recent health emergencies due to their simplicity and accessibility. However, pulse oximeters provide only limited insight into respiratory function. They do not measure airflow patterns, carbon dioxide levels, or detailed breathing characteristics. In some cases, individuals may experience underlying respiratory issues even when oxygen saturation appears normal. Therefore, relying solely on pulse oximetry may not be sufficient for early detection or detailed respiratory assessment.

4.4 Wearable Health Monitoring Devices

Wearable devices such as smartwatches and fitness trackers are commonly used for continuous health monitoring. These devices can measure parameters such as heart rate, estimated respiration rate, and occasionally oxygen saturation. They are typically connected to mobile applications, allowing users to track health data over time.

Although wearable devices are convenient and user-friendly, their capability for respiratory monitoring is limited. Most devices estimate respiration rate indirectly based on motion or heart rate variability rather than directly measuring breath composition or airflow. They also do not measure CO₂ concentration or incorporate environmental factors. As a result, they are more suitable for general wellness tracking than detailed respiratory analysis.

4.5 Environmental Air Quality Monitoring Systems

Air quality monitoring systems are designed to measure environmental parameters such as carbon dioxide levels, particulate matter (PM), temperature, and humidity. These systems are useful for assessing environmental conditions and their potential impact on health.

However, they only provide information about the surrounding environment and do not consider the physiological condition of an individual. They cannot determine how environmental factors directly affect a person's breathing. The absence of integration between environmental data and personal respiratory parameters limits their effectiveness in evaluating individual respiratory health.

4.6 Telemedicine Respiratory Systems

Advanced respiratory monitoring systems integrated with cloud-based platforms enable remote patient monitoring. These systems are primarily used for individuals with chronic respiratory conditions who require continuous medical supervision. Sensor data is transmitted to healthcare providers for further analysis and decision-making.

Despite their advantages, these systems have certain limitations. They are often expensive and involve complex setup procedures. In many cases, they require subscription-based services and continuous clinical support, which may not be affordable for all users. This reduces accessibility, particularly in rural or resource-limited settings. Additionally, most of these systems focus on managing existing conditions

rather than detecting early-stage abnormalities in otherwise healthy individuals.

Overall Limitations of Existing Systems

From the above discussion, it is evident that most existing respiratory monitoring systems have significant limitations. Many are designed primarily for clinical use, focus on a single parameter, or are expensive and not easily accessible for regular monitoring.

Another key limitation is the lack of integration of multiple parameters such as airflow, gas concentration, physiological signals, and environmental conditions into a unified system. In addition, most devices present raw numerical data, which may be difficult for non-technical users to interpret. Without clear interpretation, these values may not effectively support early decision-making.

These limitations highlight the need for a system that not only integrates multiple parameters but also presents the results in a simple, structured, and meaningful manner.

V. DESIGN AND ARCHITECTURE

The proposed IoT-based smart respiratory health screening system is designed to provide accurate breath analysis, efficient data processing, and real-time user feedback within a compact and portable device. The overall system architecture is organized into four main layers: sensing, processing, output, and communication. Each layer performs a specific function, and their integration ensures reliable evaluation of respiratory health.

5.1 Sensing Layer

The sensing layer consists of multiple sensors integrated within a dedicated breath collection chamber. This chamber is designed to effectively capture exhaled air while reducing the influence of external environmental factors.

A flow sensor is used to measure airflow characteristics such as breathing rate and intensity. A CO₂ sensor monitors the concentration of carbon dioxide in exhaled breath, which helps in assessing ventilation efficiency and gas exchange. A body temperature sensor is included to evaluate the user's physiological condition, as variations may indicate infection or inflammation.

In addition, ambient temperature and humidity sensors are used to monitor environmental conditions that can affect breathing patterns. The combined use of these sensors enables a more comprehensive assessment compared to single-parameter systems.

5.2 Processing Layer

The processing layer is built around the ESP32 microcontroller, which serves as the core unit of the system. It is chosen for its efficient processing capability, low power consumption, and built-in Wi-Fi and Bluetooth support.

Sensor outputs are connected through appropriate analog and digital interfaces. The ESP32 continuously collects data in real time and performs operations such as filtering, signal conditioning, and normalization to improve data accuracy.

The embedded software is developed using Embedded C in the Arduino IDE, where the collected data is processed using a predefined algorithm.

5.3 REI Computation

A key function of the system is the Respiratory Evaluation Index (REI), which is used to measure respiratory health using all sensor values in a simple way.

The REI is calculated in the following steps:

Step 1: Data Collection

Sensor data is collected from airflow, CO₂ level, body temperature, ambient temperature, and humidity.

Step 2: Normalization

All sensor values are converted into a common scale from 0 to 100 so they can be compared easily.

Step 3: REI Calculation

All normalized values are combined using a weighted sum:
REI = $w_1(A) + w_2(CO_2) + w_3(T_{body}) + w_4(T_{ambient}) + w_5(Humidity)$

Here, w_1 to w_5 are weights that show the importance of each parameter.

Step 4: Classification

The REI value is grouped into risk levels:

- 75 and above → Normal
- 50 to 74 → Moderate Risk
- Below 50 → High Risk

Step 5: Output

The final REI value and risk level are shown on the LCD and also sent to a mobile/cloud system.

5.4 Output Layer

The output layer includes an LCD display and a voice playback module for user interaction. The LCD provides real-time information, including the REI value and related parameters.

The voice module delivers spoken feedback, improving accessibility for users who may have difficulty reading the display. This combination enhances overall usability.

5.5 Communication Layer

The communication layer enables IoT functionality in the system. The ESP32 transmits processed data wirelessly to a mobile application or cloud platform, allowing users to monitor their respiratory health remotely and store data for future analysis.

This feature also enables access by healthcare providers when needed. In addition, the system design supports future expansion, such as integration with telemedicine platforms.

5.6 Power Design

From a power design perspective, a regulated power supply is used to ensure stable operation of all components. Voltage regulation and filtering techniques are implemented to minimize fluctuations and protect sensor performance.

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The overall hardware is designed to be compact and lightweight, making the system suitable for both home and clinical use.

VI. BLOCK DIAGRAM

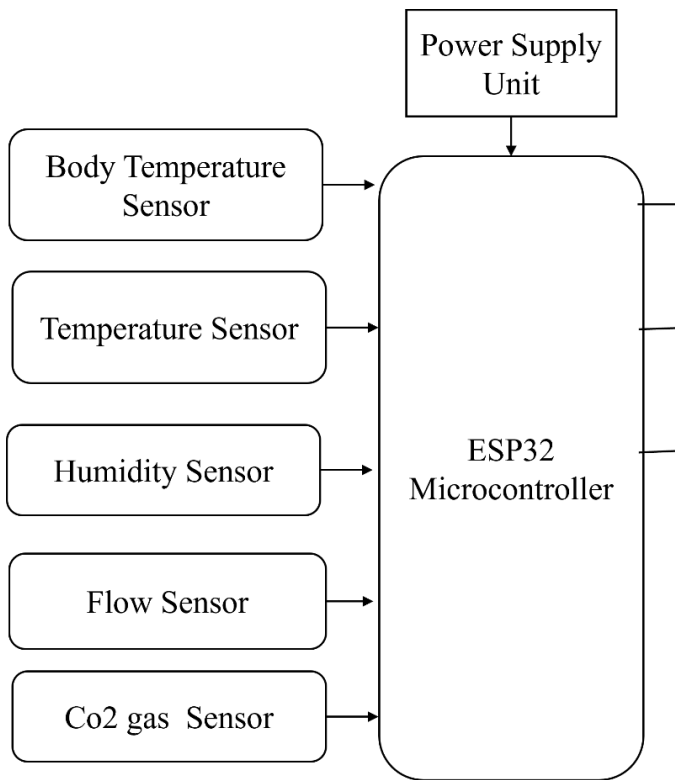


Fig. 1 Block Diagram of Proposed System

VII. KEY FEATURES

The proposed IoT-based smart respiratory health screening system incorporates several features that enhance its efficiency, usability, and suitability for preventive healthcare applications. By integrating multi-sensor technology, embedded processing, and IoT connectivity, the system provides a comprehensive solution for respiratory monitoring as shown in Figure.1. The key features are outlined below.

7.1 Multi-Sensor Breath Analysis

A primary feature of the system is the integration of multiple sensors for detailed breath analysis. The device measures airflow characteristics, carbon dioxide concentration, body temperature, and ambient temperature and humidity. This multi-parameter approach improves accuracy and reliability by offering a broader perspective of respiratory function and reduces the chances of misinterpretation.

7.2 Dedicated Breath Collection Chamber

The system utilizes a specially designed breath collection chamber that enables controlled sampling of exhaled air. It minimizes external interference and ensures consistent sensor readings. The design is non-invasive and user-friendly, making it suitable for repeated use.

7.3 Real-Time Data Processing

The ESP32 microcontroller continuously acquires and processes sensor data in real time. All computations are

performed within the system, eliminating the need for external processing units. This enables rapid analysis and immediate feedback.

7.4 Respiratory Evaluation Index (REI)

The system introduces a Respiratory Evaluation Index (REI), which combines multiple sensor inputs into a single interpretable metric. The results are categorized into Normal, Moderate Risk, and High Risk levels, simplifying understanding for non-technical users.

7.5 Visual and Voice Feedback

User feedback is provided through both an LCD display and a voice playback module. The LCD presents numerical and categorical results, while the voice module delivers spoken guidance. This dual-output approach improves accessibility and usability.

7.6 IoT-Based Remote Monitoring

Using the ESP32's built-in Wi-Fi capability, the system transmits data to a mobile or cloud platform. This enables remote monitoring, long-term data storage, and integration with telemedicine services.

7.7 Portable and Compact Design

The device is designed to be lightweight and portable, allowing usage in homes, workplaces, and rural healthcare environments without requiring complex infrastructure.

7.8 Cost-Effective Implementation

The use of low-cost sensors and an affordable microcontroller makes the system economically viable, improving accessibility for a wider population.

7.9 Preventive Healthcare Focus

The system emphasizes early detection by identifying minor deviations in respiratory parameters before symptoms become severe, supporting timely intervention.

7.10 Scalable Architecture

The modular design allows easy integration of additional sensors, advanced analytics, or cloud features, ensuring adaptability to future technological developments.

VIII. IMPLEMENTATION AND SYSTEM CONFIGURATION

The implementation of the proposed system involves the integration of hardware components, embedded software, and IoT communication into a unified platform. A modular approach is adopted to ensure flexibility and efficient operation. The implementation is divided into hardware setup, software development, and communication configuration.

8.1 Hardware Implementation

The hardware design begins with a regulated power supply unit that ensures stable voltage delivery to all components. Proper voltage regulation and filtering are incorporated to minimize noise and ensure reliable sensor performance.

The ESP32 microcontroller serves as the central processing unit. Sensors are interfaced through appropriate analog and

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digital pins. The flow sensor and CO₂ sensor are placed within the breath collection chamber to capture exhaled air characteristics. A temperature sensor monitors body temperature, while ambient temperature and humidity sensors are positioned externally to capture environmental conditions. An LCD display is interfaced for real-time output, and a voice playback module is integrated for audio feedback. The circuit design and PCB layout are optimized to reduce interference and ensure stable communication among components.

8.2 Software Implementation

The system software is developed using Embedded C in the Arduino IDE. It is organized into functional modules including sensor initialization, data acquisition, processing, REI computation, output display, and IoT communication.

During initialization, sensors are calibrated and configured. In the main execution loop, real-time data is continuously acquired and converted into meaningful units using calibration equations. Signal filtering techniques are applied to reduce noise and improve accuracy.

The processed data is used to compute the Respiratory Evaluation Index (REI) based on predefined threshold values. The system classifies the results into Normal, Moderate Risk, or High Risk categories. The final output is displayed on the LCD and communicated through the voice module.

8.3 IoT Configuration

The ESP32's Wi-Fi module is configured to connect to a local network. Once connected, the system transmits processed data to a mobile application or cloud platform.

The transmitted data includes sensor readings, REI values, and timestamps. A suitable communication protocol is implemented to ensure reliable and secure data transfer. The mobile interface provides an organized display of real-time and historical data for monitoring and analysis.

8.4 System Integration and Testing

After hardware and software development, the system is integrated and tested. Individual sensors are first validated independently, followed by complete system testing under different breathing conditions.

Calibration adjustments are performed to improve accuracy. The system is further evaluated for response time, processing efficiency, and communication reliability. These tests confirm stable operation under varying conditions.

Overall, the implemented system functions as a compact and efficient respiratory screening device capable of real-time monitoring in both home and clinical settings.

IX. RESULTS AND DISCUSSION

The system was evaluated under various breathing conditions to analyze its performance and reliability. Parameters such as airflow rate, CO₂ concentration, body temperature, and environmental conditions were recorded and processed.

The Respiratory Evaluation Index (REI) was computed and categorized into Normal, Moderate Risk, and High Risk levels. The system successfully detected variations in

breathing patterns and reflected corresponding changes in REI values.

Under normal breathing conditions, stable airflow and CO₂ levels resulted in higher REI values, indicating a healthy respiratory state. As airflow decreased and CO₂ concentration increased, the REI values gradually declined, indicating potential respiratory deviations.

Moderate irregularities in breathing produced intermediate REI values, suggesting early-stage respiratory stress. In contrast, significantly reduced airflow and elevated CO₂ levels resulted in low REI values, corresponding to high-risk conditions.

The results demonstrate that integrating multiple parameters improves the reliability of respiratory assessment. The system provides accurate real-time feedback with minimal delay, and the REI effectively simplifies complex sensor data into an easily interpretable format.

Table 1: Respiratory Evaluation Index (REI) Analysis Under Different Breathing Conditions

Test No	Airflow Pattern	CO ₂ Level (ppm)	Body Temp (°C)	Ambient Temp (°C)	Humidity (%)	REI Value	Risk Classification
1	Normal breathing	800 – 1000	36.8	28	55	82	Normal
2	Slightly reduced airflow	1100 – 1300	37.1	29	60	65	Moderate Risk
3	Irregular breathing	1400 – 1600	37.5	30	65	48	Moderate Risk
4	Low airflow	1700 – 2000	38.0	31	70	30	High Risk
5	Rapid shallow breathing	1500 – 1800	38.2	32	68	35	High Risk

Results and Discussion:

From the obtained results, it is evident that normal breathing conditions characterized by stable CO₂ levels and normal

body temperature produce higher REI values, indicating a healthy respiratory state. As airflow decreases and CO₂ concentration increases, the REI value shows a gradual decline, reflecting potential deviations in respiratory function. Test case 1 exhibited stable airflow and normal physiological parameters, resulting in an REI value above 80, which falls under the Normal category. This indicates efficient lung ventilation and effective gas exchange.

In test cases 2 and 3, minor irregularities in breathing patterns along with elevated CO₂ levels resulted in moderate REI values ranging between 48 and 65. These conditions were classified as Moderate Risk, suggesting early signs of respiratory stress or reduced ventilation efficiency. Although not critical, such conditions require continuous monitoring and preventive measures.

Test cases 4 and 5 showed significantly reduced airflow, higher CO₂ concentration, and increased body temperature. The REI values dropped below 40, leading to a High Risk classification. These results indicate poor ventilation and possible respiratory abnormalities that may require medical attention.

Overall, the results demonstrate that multi-parameter integration significantly enhances system reliability. By combining physiological and environmental factors, the system provides a more accurate and comprehensive assessment compared to single-parameter approaches. The Respiratory Evaluation Index (REI) effectively translates complex sensor data into simple and interpretable categories, improving usability for non-technical users.

X. CONCLUSION

The proposed IoT-based smart respiratory health screening system using multi-sensor breath analysis has been successfully designed and implemented as an effective preventive healthcare solution. The primary objective of developing a portable, intelligent, and non-invasive system capable of detecting early physiological changes has been achieved.

The integration of multiple sensors, including airflow, CO₂ concentration, body temperature, ambient temperature, and humidity, enables a comprehensive evaluation of respiratory health. Compared to conventional single-parameter methods, this multi-sensor approach improves both accuracy and reliability by incorporating physiological as well as environmental factors.

The ESP32 microcontroller serves as the core component for real-time data acquisition, processing, and wireless communication. The embedded algorithm converts raw sensor readings into a structured Respiratory Evaluation Index (REI), categorizing the results into Normal, Moderate Risk, and High Risk levels. This simplified representation enhances user understanding and supports timely preventive action.

In addition, the system offers several practical advantages, including a compact and portable design, ease of use, and accessibility. The inclusion of both LCD display and voice feedback improves user interaction, while IoT connectivity enables remote monitoring and long-term data storage, supporting telemedicine applications. Experimental validation confirms that the system effectively responds to variations in breathing conditions and provides reliable risk classification. Changes in airflow, CO₂ levels, and body temperature are accurately reflected in the REI values, demonstrating the effectiveness of the proposed approach. Overall, the system provides a cost-effective, user-friendly, and scalable solution for continuous respiratory health monitoring, with strong potential for real-world healthcare applications.

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