RESEARCH PAPER

Development of a Portable Differential Pressure Spirometer Integrated with PMS5003 Air Quality Monitoring

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ABSTRACT

Air quality significantly affects respiratory health. Fine particulate matter can irritate the lungs and reduce breathing capacity, while prolonged inhalation of polluted air contributes to the development of chronic respiratory conditions. Therefore, monitoring both lung function and air quality is important for early detection of respiratory problems. This study presents a portable monitoring device based on an ESP32 microcontroller. A differential pressure sensor measures airflow to estimate spirometry parameters such as Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV_1), while a PMS5003 sensor monitors particulate matter (PM1.0, PM2.5, PM10). Experimental results demonstrated consistent and reliable measurement performance, with FVC values ranging from 3.0–4.4 L and FEV_1 values from 2.3–3.5 L.

Keywords: Respiratory health, Air quality monitoring, Spirometry, ESP32, Particulate matter, Wireless communication

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1. Introduction

Respiratory disorders are a significant public health issue that affect human well-being and place considerable pressure on healthcare systems [4]. Lung function is highly sensitive to environmental conditions, particularly air pollution. Inhalation of fine particles, including PM1.0, PM2.5, and PM10, has been associated with measurable declines in pulmonary function indices such as FVC and FEV_1[1][20]. Continuous monitoring and early detection of respiratory impairment and air pollution exposure are essential for preventive healthcare [2]. Traditional clinical spirometry systems are often expensive, non-portable, and limited to healthcare facilities. Similarly, air quality monitoring solutions are typically separate, hindering real-time correlation between environmental exposure and individual health status. This underscores the need for an integrated, portable, and cost-effective system. In this work, we present a compact monitoring system developed using the ESP32 microcontroller to measure both lung function and ambient air quality simultaneously. A differential pressure sensor is used to estimate key spirometry parameters, including FVC and FEV_1, similar to recent efforts to create accessible spirometers for home monitoring [3]. A PMS5003 sensor measures particulate matter levels (PM1.0, PM2.5, PM10). Sensor data are processed by the ESP32 and transmitted wirelessly via Bluetooth or Wi-Fi to a mobile or web application for real-time visualization and storage. The system is designed to be portable, low-cost, and easy to use, making it suitable for both home and clinical environments. By integrating respiratory assessment with environmental monitoring, this approach helps identify respiratory risks early and supports preventive healthcare strategies [5][6].

2. Literature Review

Air pollution is now widely understood to have a strong impact on lung health. [1] explains that long-term exposure to polluted urban air can lead to serious respiratory diseases. In a similar way,[2] shows that even short-term exposure to pollutants can affect lung function and cause inflammation, even in healthy people. A study in [3] further highlights that combining portable spirometry with personal air quality sensors can give a clearer picture of how pollution affects individuals. Researchers have also focused on making respiratory monitoring more accessible. [4] introduced a low-cost spirometer that can be used at home, making regular lung testing easier. At the same time, [5] emphasizes that personalized air quality monitoring can help people better manage conditions like asthma. On the technology side [6] developed an ESP32-based system for real-time air quality monitoring, making pollution tracking more practical and affordable. Similarly, [7] showed that airflow-based sensors can effectively measure lung parameters.

Supporting all these findings, [8] confirmed that fine particles like PM2.5 directly reduce breathing efficiency. Overall, these studies clearly show that both air quality and lung function are important for respiratory health. However, most existing solutions treat them separately. This creates a clear need for a simple, portable, and cost-effective system that can monitor both together, which is the main idea behind this paper. Table 2.1 shows the comparison between the existing studies and the proposed system.

Table 2.1 Comparison Table

Parameter	Our System	Ferreira Nunes et al. (2024)	Alyami et al. (2025)	Mahetaliya et al. (2024)
Core Technology	ESP32 + MPS20N0040D + PMS5003	Venturi-based spirometer	Clinical spirometry + Air quality network data	ESP32 + Multiple gas sensors
Spirometry Parameters	FVC, FEV_1	FVC, FEV_1	FVC, FEV_1	Not included
PM Monitoring	PM1.0, PM2.5, PM10	Not included	PM2.5, NO_2	PM2.5 included
Portability	High (portable device)	High (home use)	Low (clinical setting)	High (portable system)
Target Application	Personal health tracking	Home respiratory monitoring	Epidemiological research	Indoor air quality control
Real-time Capability	Yes	Yes	No	Yes
Data Transmission	Wi-Fi enabled	Data acquisition circuit	Not specified	Wi-Fi enabled
Validation Status	System demonstration	Clinical validation	Large-scale study	Experimental validation

3. Methodology

3.1 System Architecture

The developed device is a compact embedded platform that enables simultaneous measurement of respiratory parameters and surrounding air quality. It consists of four main modules: air quality sensing, lung function sensing, data processing and communication, and user interface visualization. The air quality module uses the PMS5003 particulate matter sensor to measure PM1.0, PM2.5, and PM10 concentrations, which are widely recognized indicators of respiratory risk and environmental pollution exposure [1][4]. The lung function module is based on a differential pressure or airflow sensor integrated with a custom airflow channel and mouthpiece to function as a spirometer. This module captures respiratory parameters such as Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV_1), which are clinically important indicators for assessing pulmonary health [2]. Respiratory airflow is measured with a differential pressure sensor connected to a Venturi-type flow channel, exploiting the Bernoulli principle to relate pressure drop to flow, as in another Venturi-based spirometer.[11]

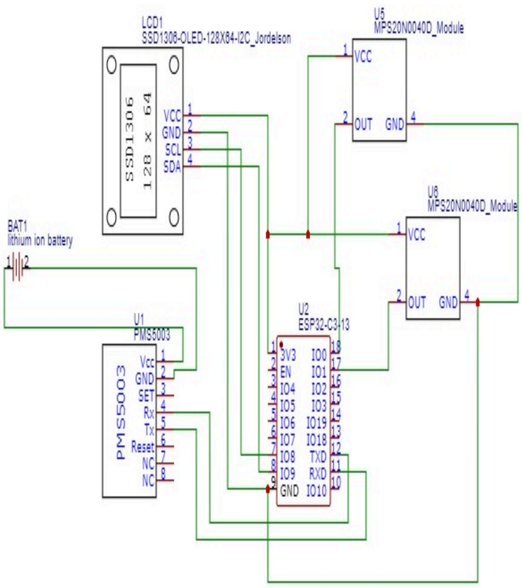

Fig .3.1.1 Circuit Diagram of the System

The system is designed using an ESP32 microcontroller as the core processing unit, integrating two MPS20N0040D pressure sensors to measure airflow for lung function analysis and a PMS5003 sensor to monitor air quality parameters such as PM1.0, PM2.5, and PM10. The collected data is processed in real time by the ESP32 and displayed on an SSD1306 OLED display using the I2C interface, providing continuous updates of both respiratory and environmental conditions. All components are properly interfaced to ensure efficient communication and operation. The system is powered by a lithium-ion battery, making it portable and suitable for continuous monitoring applications. Fig. 3.1.1 illustrates the complete circuit diagram of the proposed system.

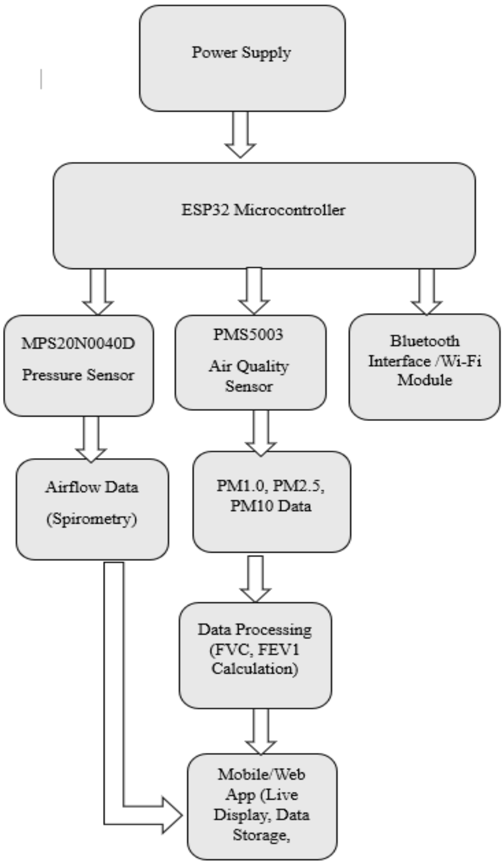

Fig 3.1.2 Block Diagram of Portable Spirometer

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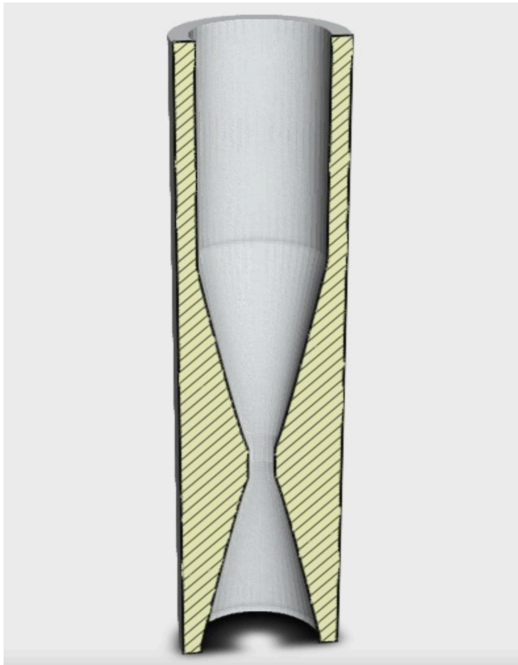

Fig 3.1.3 Venturi-based Flow Nozzle

The Venturi tube employed for airflow and pressure measurement was designed with an overall axial length of 13 cm. The outer diameter of the tube was maintained at 2.9 cm, while the throat section was designed with an inner diameter of 2.3 cm to create a measurable pressure differential based on Bernoulli's principle. The wall thickness of the tube was fixed at 0.3 cm to ensure structural stability during human respiratory airflow measurements. The tube geometry consisted of three main sections: an inlet straight section, a converging section, and a diverging section. The inlet straight section was designed with a length of 4.56 cm, followed by a converging section of 3.97 cm leading to the throat region. The diverging section had a length of 4.17 cm, allowing smooth pressure recovery at the outlet.

3.2 Hardware Development

3.2.1 Air Quality Sensor Integration

The PMS5003 particulate matter sensor is interfaced with the ESP32 microcontroller. The sensor continuously outputs concentration values for PM1.0, PM2.5, and PM10 by employing optical laser scattering to detect airborne particles [5]. The ESP32 continuously receives digital data frames from the sensor and extracts relevant particulate concentration values. To improve measurement stability, firmware-level signal conditioning techniques such as moving average filtering and outlier rejection are implemented. Sensor stabilization time of approximately 5–10 minutes is allowed before recording measurements to ensure reliable readings, as recommended in previous air quality monitoring studies

[6]. In our paper PM2.5 is primarily used in decision-making due to its strong impact on lung function.

3.2.2 Lung Function Sensor Integration

The lung function sensing module uses a pressure sensor connected to a custom-designed airflow channel and mouthpiece. When the user performs forced exhalation, airflow passing through the channel generates a measurable pressure difference proportional to the flow rate. Flow rate is calculated from the measured pressure difference using established fluid dynamic relationships, and lung volume is obtained by integrating flow over time [2], [7]. The ESP32 samples airflow data at a frequency of 50–100 Hz to accurately capture the dynamic flow–time curve.

Fig 3.3 Prototype of the Portable Differential Pressure Spirometer

Signal processing techniques such as low-pass filtering, baseline correction, and peak detection are applied to extract spirometry parameters, including FVC and FEV_1. Calibration of the spirometer is performed using reference measurements or known flow conditions to ensure measurement accuracy.[11]

3.3 Firmware and Algorithm Development

Embedded firmware is developed on the ESP32 platform to enable synchronized acquisition and processing of air quality and lung function data. Sensor readings are time-stamped to allow correlation between environmental exposure and respiratory performance. Data are stored locally and transmitted wirelessly via Wi-Fi / Bluetooth to the application interface. Algorithms are implemented to compute spirometry parameters from the flow–time curve. Forced Vital Capacity (FVC) is calculated as the total volume of air exhaled during a forced expiratory maneuver, obtained by integrating the airflow signal over the entire exhalation period. Forced Expiratory Volume in one second (FEV_1) is derived by integrating the airflow signal over the first one-second interval of the maneuver. These parameters are compared against standard clinical reference values to identify abnormal lung function conditions. Wireless communication protocols enable real-time data transmission, supporting remote monitoring applications. The ESP32 platform is well-suited for IoT-based healthcare systems due to its computational efficiency and integrated connectivity features [3], [8].

3.4 Mobile / Web Application Development

A cross-platform mobile application is developed to interface with the ESP32-based monitoring system via Wi-Fi for real-time data acquisition. The app displays respiratory parameters (FVC, FEV_1) and air quality data (PM1.0, PM2.5, PM10) in a simple user interface. An integrated GPS module captures the user's live location and visualizes it on a map. The emergency feature allows users to store a contact number; upon pressing the SOS button, the app automatically initiates a call and sends the user's location via message. Additionally, an intelligent alert system classifies conditions into levels such as Optimal, Clinical alert, Resilient, Sensitive, Impacted and hazardous based on lung health and air quality. When unsafe conditions are detected, the app provides immediate guidance (e.g., "move to a safer location within 2 minutes"), enabling proactive protection. Thus, the application enables real-time monitoring, adaptive alerts, location tracking, and rapid emergency response in a single platform.

3.5 Experimental Protocol

The system is evaluated under real-world environmental conditions to assess performance and investigate the relationship between air quality and lung function. Adult participants aged 18–40 years perform spirometry maneuvers consisting of maximum inhalation followed by forced exhalation. Each test is repeated three times, and the best measurement is selected according to standard spirometry guidelines.

Air quality parameters are recorded continuously during the experiment. Lung function measurements are time-stamped and correlated with concurrent environmental conditions. This approach enables assessment of both immediate and short-term effects of air pollution exposure on respiratory performance, as supported by previous studies linking particulate exposure to reduced lung function [1], [4].

3.6 Data Analysis

The dataset includes 15 subjects (P1–P15) with PM2.5 and FEV_1/FVC measurements. PM2.5 values range from 26 to 58 μg/m³, showing different pollution exposure levels. FEV_1/FVC values range from 67% to 84%, indicating variation in lung function. A slight decrease in lung function is observed as PM2.5 increases. Subjects with higher PM2.5 (P4, P5, P7) show moderate or reduced lung performance. Subjects with lower PM2.5 (P3, P9) show better lung function. However, this trend is not consistent across all subjects. Some individuals maintain normal lung function even in poor air quality. This indicates that individual health factors also influence lung performance. Overall, combining air quality and lung data provides a better health assessment.

3.7 Evaluation Metrics

System performance is evaluated based on the following metrics:

- Measurement accuracy
- Sensor response time
- Data transmission reliability
- Wireless connectivity stability
- Spirometry parameter accuracy (FVC, FEV_1)
- User interface responsiveness

These metrics ensure the system meets requirements for reliable real-time respiratory and environmental monitoring.

4. Results & Discussion

Table 4.1 presents the collected data from 15 subjects (P1–P15), including PM2.5 concentration, lung function (FEV_1/FVC %), air quality category, lung status, system status, and interpretation.

The PM2.5 values range from 26 to 58 μg/m³, indicating environmental exposure from moderate to hazardous levels, while the FEV_1/FVC ratio ranges from 67% to 84%, reflecting varying respiratory performance among individuals. A clear inverse correlation is observed between PM2.5 concentration and lung function. As PM2.5 levels increase, the FEV_1/FVC ratio decreases, indicating reduced pulmonary efficiency.

This trend is consistent with findings reported in multiple studies, where exposure to particulate matter is associated with declines in key spirometric parameters such as FEV_1 and FVC. Importantly, this effect is more pronounced in individuals with compromised or weaker lung conditions. Subjects exposed to higher PM2.5 levels (e.g., P4, P5, P7) show reduced lung function and fall under “Straining” or “Hazardous” system categories, indicating that polluted environments significantly worsen respiratory performance in vulnerable individuals. In contrast, subjects with lower exposure (e.g., P3, P9) maintain higher FEV_1/FVC ratios and are categorized as “Resilient,” suggesting stronger lung capacity and better tolerance to environmental stress. This observation aligns with existing research, which shows that individuals with pre-existing respiratory conditions or reduced lung capacity experience greater functional decline when exposed to particulate matter. Thus, air pollution does not affect all individuals equally but has a more severe impact on those with already compromised respiratory systems. While the overall negative correlation is evident, some variability exists due to individual physiological differences.

Along with the correlation results, the overall behavior of the system under different conditions shows its practical usefulness. The use of categories such as “Resilient,” “Sensitive,” and “Impacted” makes the output easier to understand compared to only showing numerical values. This helps even non-medical users quickly interpret their condition.

Table 4.1 PM Concentration and Lung Function Data

Person	$PM_{2.5}$	FEV_1/FVC (%)	Air Quality	Lung Status	System Status	Interpretation
P1	30	78	Moderate	Mild	Watch	Early Impact
P2	44	70	Poor	Low	Impacted	Pollution Damage
P3	26	82	Moderate	Normal	Resilient	Strong Lungs
P4	50	70	Hazardous	Mild	Straining	Reduced Capacity
P5	58	75	Hazardous	Mild	Hazardous	Risk Condition
P6	39	80	Poor	Normal	Compensating	Functional Stability
P7	53	84	Hazardous	Normal	Hazardous	Unsafe Condition
P8	40	69	Poor	Low	Impacted	Pollution Damage
P9	28	82	Moderate	Normal	Resilient	Strong Lungs
P10	29	68	Moderate	Low	Sensitive	Pollution Sensitive
P11	26	75	Moderate	Mild	Watch	Mild Restriction
P12	41	76	Poor	Mild	Straining	Reduced Capacity
P13	45	83	Poor	Normal	Compensating	Functional Stability
P14	44	67	poor	Low	Impacted	Pollution damage
P15	32	71	Moderate	Mild	Watch	Slight Reduction

It is also noticeable that not all individuals respond in the same way to similar pollution levels. Some subjects maintain stable lung function even under moderate exposure, while others show a decline. This highlights the importance of considering both environmental conditions and individual differences when assessing respiratory health.

Another important aspect is the real-time monitoring capability of the system. Instead of relying on a single reading, users can observe trends over time. This makes the system more useful for early detection and preventive care, as gradual changes can be identified more easily.

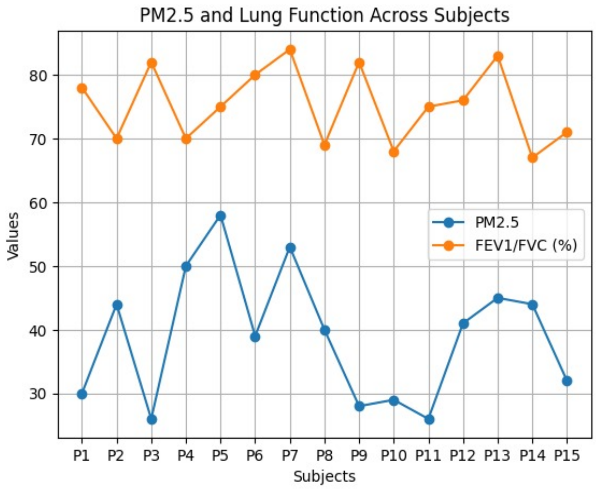

Fig 4.1 PM2.5 and Lung Function Across Subjects

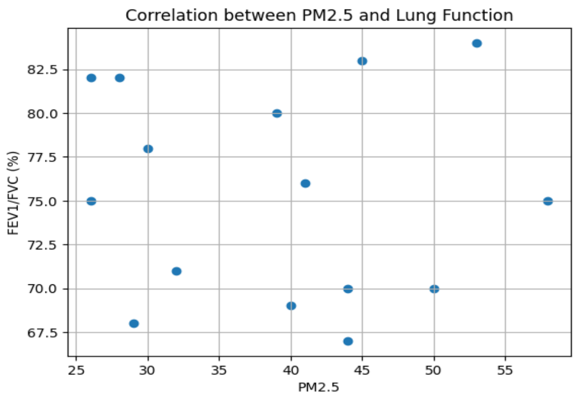

Fig 4.2 Correlation between PM2.5 and Lung Function

However, the combined analysis through system status classification effectively captures both environmental exposure and individual susceptibility, providing a comprehensive assessment of respiratory health

Limitations: This study has a few limitations that should be considered. The number of subjects involved is relatively small, so the results may not represent a wider population. Also, spirometry readings depend on user effort during exhalation, which can cause slight variations in the results. Environmental factors like temperature and humidity were not included in this study, which may have a minor effect on sensor performance. Future work can focus on testing with a larger group and improving measurement consistency.

5. Conclusion

The analysis confirms a negative relationship between PM2.5 exposure and lung function, where increased pollution levels lead to reduced respiratory performance. The impact is significantly higher in individuals with weaker or compromised lungs, highlighting their greater vulnerability to air pollution. While some variation exists due to individual differences, the overall findings emphasize that air quality alone cannot fully represent respiratory health. Therefore, integrating environmental and physiological parameters provides a more accurate and reliable assessment of lung health.

6. Future Enhancements

The proposed system can be further enhanced by incorporating several advanced features to improve performance and usability. It can include adaptive baseline profiling, where the system learns each user's normal respiratory parameters such as Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV_1), enabling personalized monitoring and early detection of small deviations. Real-time risk scoring can be introduced by combining lung function data with environmental parameters like particulate matter to generate a simple and intuitive risk indicator. The system can also provide smart predictive alerts by analyzing trends such as increasing pollution levels and decreasing airflow, helping users take preventive action at an early stage. Further improvements can include integrating additional sensors such as temperature, humidity, CO_2, and volatile organic compounds (VOC) to offer a more comprehensive assessment of environmental and health conditions. Wearable integration can allow synchronization with smart devices to correlate respiratory data with heart rate, physical activity, and sleep patterns. Voice-guided spirometry can assist users in performing correct breathing maneuvers, improving measurement accuracy and consistency. Offline edge processing using the ESP32 can enable the system to function without internet connectivity while ensuring faster response and better data privacy. Battery optimization techniques such as low-power modes and efficient sensor management can improve portability. In addition, cloud-based analytics combined with machine learning can be used for long-term monitoring and prediction of potential respiratory risks, making the system more suitable for real-world healthcare applications.

Conflicts of Interest

The authors confirm that there are no competing interests or financial affiliations that could have influenced the outcomes or interpretation of this work.

Author Contributions

Conceptualization, Asuntha A and Devadharshan R.S.; Methodology, Devadharshan R.S.; software, Devadharshan R.S.; validation, Asuntha A, Devadharshan R.S., Vinothini V, and Harshavarthini S; investigation, Devadharshan R.S.; writing original draft preparation, Devadharshan R.S.; writing review & editing, Asuntha A; Supervision, Asuntha A.

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