PORTABLE SPIROMETER WITH AI INTEGRATION

PROJECT REPORT

Submitted by

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in

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DECLARATION

We affirm that the project work titled **"Portable Spirometer Using Pressure-Volume Method with Bluetooth Integration to Android Smartphone"** being submitted in partial fulfillment for the award of the degree of Bachelor of Engineering in Biomedical Engineering is the record of original work done by us under the guidance of **Dr. Stephen Sagayaraj A**, Assistant Professor Level II**,** Department of Electronics and Communication Engineering. It has not formed a part of any other project work(s) submitted for the award of any degree or diploma, either in this or any other University.

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I certify that the declaration made above by the candidates is true.

(Signature of the Guide)

Dr. STEPHEN SAGAYARAJ A

BONAFIED CERTIFICATE

Certified that this project report **"Portable Spirometer Using Pressure-Volume Method with Bluetooth Integration to Android Smartphone"** is the Bonafide work of **"MOHANRAJ S (7376221BM132)"** who carried out the project work under my supervision.

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Internal Examiner 1 **Internal Examiner 2**

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ABSTRACT

Respiratory diseases often require continuous monitoring to ensure timely diagnosis and treatment, yet conventional spirometers are bulky and unsuitable for everyday use. In this project, we propose a portable spirometer that uses the pressure-volume method to measure lung function parameters such as Forced Vital Capacity (FVC) and Peak Expiratory Flow Rate (PEFR). The system employs a differential pressure sensor to detect airflow during inhalation and exhalation, with real-time data processed by a microcontroller and transmitted via Bluetooth to an Android smartphone. The companion mobile app allows both patients and doctors to view and track respiratory health trends, while the data is also sent to a cloud server for further statistical analysis and remote monitoring. This design offers a compact, user-friendly, and cost-effective solution for managing chronic respiratory conditions in both clinical and home settings.

Key Words: Portable Spirometer, Pressure-Volume Method, Differential Pressure Sensor, Bluetooth Communication, Android Smartphone

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CHAPTER – I

INTRODUCTION

The integration of IoT (Internet of Things) technologies into healthcare has transformed the way patient health is monitored, particularly in the early detection and management of respiratory diseases. This study presents the design and development of a low-cost, IoT-enabled Portable Spirometer, aimed at assisting patients in tracking their lung function from the comfort of their home. Parameters like Forced Vital Capacity (FVC) and Peak Expiratory Flow Rate (PEFR) must be continuously monitored for diagnosis and treatment of respiratory conditions. The proposed solution employs a differential pressure sensor to measure airflow during the breathing cycle, applying the pressure-volume method to compute lung function metrics in real time. The system integrates Bluetooth communication to wirelessly transmit the data to an Android smartphone application, allowing patients and healthcare providers to visualize and monitor respiratory trends. Cloud connectivity enables long-term storage and remote access for healthcare professionals, offering a personalized and proactive approach to respiratory care. The goal of this cutting-edge device is to make lung health monitoring easier, more dependable, and more user-friendly.

1.1 Background of the work

The Internet of Things (IoT) has made way for practical solutions that involve intelligent control systems and embedded sensor networks. The development of devices like AI-based object recognition systems and biomechatronic limbs, which improve the quality of life for people with physical disabilities, is made possible by these innovations, which have made a significant contribution to the field of biomedical assistance. This project specifically focuses on the design and implementation of a stabilization mechanism integrated into a spoon, aimed at assisting patients with Parkinson's disease in managing hand tremors during the eating process, thereby promoting greater independence and comfort in daily activities.

1.1.1 Respiratory Disease

Asthma, restrictive lung disorders, and chronic obstructive pulmonary disease (COPD) all have a significant impact on a patient's ability to breathe effectively and perform daily activities. These conditions often lead to reduced lung capacity, shortness of breath, and limited physical endurance, affecting the overall quality of life. The progression and severity of respiratory diseases vary from person to person, so early detection and regular monitoring of lung function are essential for effective treatment. Traditional spirometry testing is usually confined to clinical settings, which limits frequent assessment. As a result, portable biomedical assistive devices are essential for enabling continuous, real-time lung health monitoring and empowering patients to manage their condition proactively helping healthcare professionals intervene earlier when abnormalities are detected.

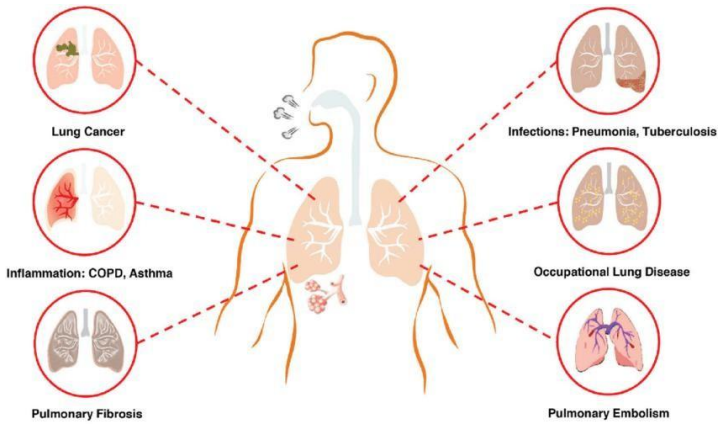

Figure 1.1 respiratory disease

1.2 Problem Statement

Measurement mechanisms for lung function are widely used in medical diagnostics to assess respiratory health and detect pulmonary diseases at an early stage. This study proposes integrating pressure-volume sensing techniques into an affordable, portable spirometer that can measure key lung parameters such as FEV1 (Forced Expiratory Volume) and FVC (Forced Vital Capacity). By using a pressure sensor to capture airflow data during exhalation, the system calculates the FEV1/FVC ratio in real-time,

helping to evaluate lung condition effectively. The measured data is then transmitted via Bluetooth to an Android smartphone, providing patients and healthcare professionals with continuous monitoring and early alerts for respiratory abnormalities.

1.3 Technology Used

The prototype utilizes an Arduino Uno microcontroller and is powered by a 5V battery supply. The key sensor in this model is the MPX5010DP pressure sensor, which accurately measures the change in air pressure generated during exhalation. This pressure data is used to compute essential lung function parameters such as FEV1 (Forced Expiratory Volume) and FVC (Forced Vital Capacity). The processed values are then evaluated to determine the FEV1/FVC ratio, which is a crucial indicator for diagnosing respiratory conditions. Additionally, the system employs Bluetooth communication to transmit real-time data to an Android smartphone, enabling easy monitoring and analysis of lung health.

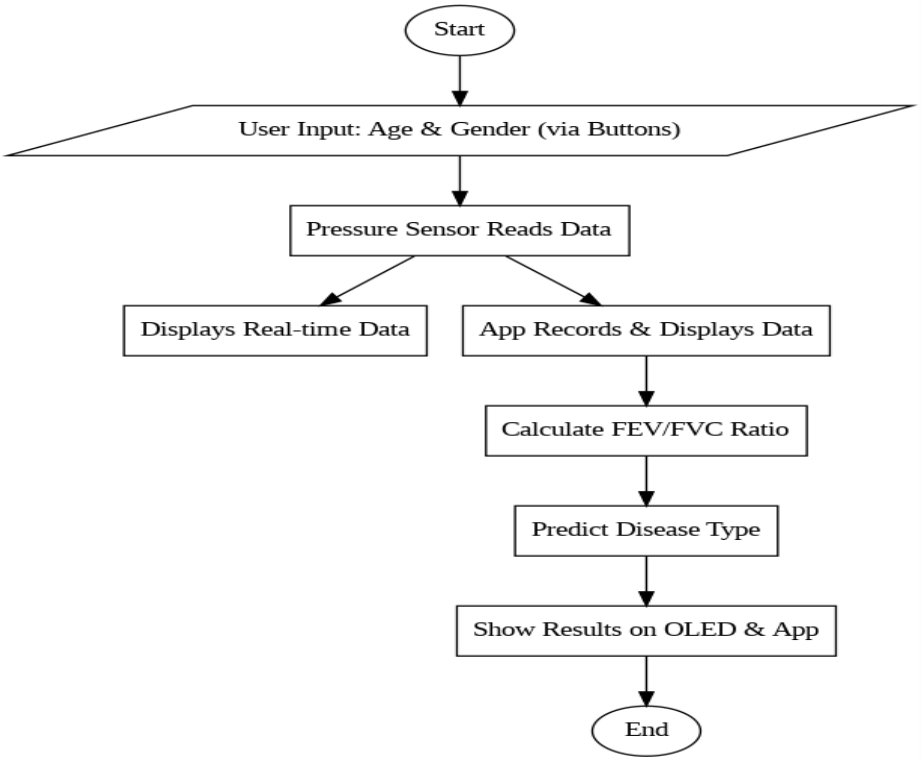

Figure 1.2 Overall Block Diagram of the System

CHAPTER 2

LITERATURE SURVEY

The paper **"A Portable Spirometer Using a Low-Cost Differential Pressure Sensor"** by Sharma, R. et al. presents a compact spirometry system designed with an Arduino Uno microcontroller and a differential pressure sensor (MPX5010DP). The study proposes a straightforward pressure-to-volume calculation method, offering real-time visualization of lung capacity on a desktop interface. Our proposed system follows a similar architecture but enhances its applicability by integrating Bluetooth connectivity, allowing seamless data transmission to Android smartphones and enabling remote healthcare monitoring.

The research **"Development of a Bluetooth-Enabled Portable Spirometer"** by Kim, D. et al. focuses on the creation of a mobile-friendly spirometer that leverages Bluetooth Low Energy (BLE) modules for real-time data transfer. Their design utilizes the MPXV7002DP differential pressure sensor along with an ARM Cortex-M0 microcontroller. The study demonstrates the importance of wireless data acquisition in improving accessibility and reducing hospital visits for chronic respiratory patients — a concept also embraced in our work but optimized for cost-effectiveness and ease of assembly.

The paper **"Design and Implementation of a Smart Spirometer for Asthma Patients"** by Ali, M. et al. highlights a prototype that uses an Arduino Mega with pressure sensors to compute forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV1). The authors emphasize the importance of calibrating the system for accuracy across diverse patient profiles. Our study builds upon these calibration techniques and extends the usability by developing a dedicated Android application that allows direct storage and sharing of respiratory health records.

“A Smartphone-Based Spirometry System for Home Monitoring” by Li, X. et al. explores the implementation of an Android-based spirometer application that processes airflow data transmitted via Bluetooth from a portable sensor device. Their system provides visual feedback on spirometric parameters and tracks long-term patient trends. While their focus is primarily on usability and compliance, our model also incorporates a hardware-based real-time processing algorithm to reduce data transfer lag and improve accuracy.

The work **“Integration of MEMS Sensors for Respiratory Parameter Monitoring”** by Chowdhury, D. et al. introduces the use of MEMS-based accelerometers and pressure sensors for accurate lung function assessment. The system's data processing is performed on an AVR microcontroller, highlighting the trade-offs between hardware complexity and measurement precision. Our project applies a similar approach using MEMS pressure sensing but focuses on minimizing latency and maximizing affordability for wide-scale deployment.

The review article **“Assistive Technologies for Pulmonary Diseases: A Survey”** by Delmastro, F., Vignoli, M., & Mascolo, C. (2021) discusses the role of digital health tools — including portable spirometers — in supporting chronic respiratory disease management. The paper highlights limitations in existing systems, such as lack of real-time feedback and cloud integration, which our design directly addresses through mobile application pairing and wireless data logging.

Pham, Q., & Furrer, S. (2020), in their paper **“Home-based Monitoring Solutions for Respiratory Health”**, evaluate the effectiveness of portable spirometers in reducing hospital dependency and promoting patient autonomy. Their findings stress the importance of user-friendly design and Bluetooth-enabled data sharing, principles that are core to the architecture of our prototype.

Lin, J., & Huang, P. (2019) in **“A Review on Adaptive Control in Biomedical Monitoring Devices”** discuss control systems that enable real-time calibration in

devices like spirometers to adapt to varying user inputs and biological inconsistencies. Our study incorporates similar adaptive calibration logic to improve measurement reliability across different users.

The research by **Harvey, M., & Yang, L. (2022)** titled **"Wireless Healthcare Systems for Respiratory Disease Management"** highlights how stability and low-latency wireless communication are essential for modern respiratory monitoring systems. Their work forms the theoretical foundation for our Bluetooth-integrated approach to real-time lung health feedback.

Lastly, **Lopez, R., Patel, S., & O'Reilly, K. (2023)**, in **"Human-Centered Design Principles for Smart Medical Devices"**, emphasize the need for simple, accessible, and intuitive devices for patient-operated health monitoring

CHAPTER 3

METHODOLOGY

The methodology for developing a portable spirometer involves sensor selection, signal acquisition, data processing, and interface design. Respiratory parameters like airflow and tidal volume are recorded by a flow or pressure sensor. Signals are amplified and digitized using a microcontroller. Algorithms calculate spirometric indices like FEV1 and FVC. For accuracy, the device is calibrated with standard volumes. For visualization, data is sent to a PC or mobile app via Bluetooth or USB. Portability is ensured by a power-efficient design. Validation is conducted by comparing outputs with standard spirometers. The final prototype is tested on volunteers under supervised conditions for performance and reliability assessment.

3.1 Proposed Work

Based on the insights gathered from the extensive literature review in Chapter 2, several limitations and gaps were identified in current spirometry systems particularly concerning portability, real-time data analysis, and patient usability. The Portable Spirometer project's four main objectives are designed to ensure the creation of a compact, accurate, and user-friendly respiratory monitoring system in order to fill these gaps.

3.1.1 System for Accurate Flow and Volume Measurement

Real-time evaluation of respiratory parameters such as Forced Vital Capacity (FVC), Forced Expiratory Volume in One Second (FEV1), and Peak Expiratory Flow (PEF) is the primary focus of the first objective. This system aims to overcome the limitations of bulky clinical spirometers, making it suitable for home-based monitoring and early diagnosis of pulmonary conditions.

Integration of a differential pressure sensor (e.g., MPX5010DP) or MEMS-based flow sensors for accurate air volume and flow rate detection. High-frequency acquisition and

real-time data sampling for precise waveform analysis. Calibration algorithms to ensure consistency across environmental conditions (temperature, humidity, and altitude). Validation of measurement accuracy against conventional laboratory-grade spirometers.

This module is the foundation for obtaining clinically relevant respiratory data in a compact, affordable form factor, bridging the gap between professional healthcare equipment and patient-side monitoring.

3.1.2 Integrated System Integration and Power Optimization

The design of an energy-efficient hardware architecture that is suitable for portable, battery-powered operation while preserving data integrity is the primary focus of the second objective. This objective builds on the findings of Bedford (2017) regarding power management in medical-grade wearables.

Design of a low-power embedded system using an ESP32-based microcontroller. Using dynamic power-saving modes without compromising sensor sampling precision. Safe charging and voltage regulation circuits are incorporated into a system of rechargeable Li-ion batteries. Optimizing communication between sensors and microcontrollers for low latency and low power consumption Efficient power management is critical for ensuring the spirometer remains lightweight and portable while providing enough operating time for multiple measurement sessions without frequent recharging.

3.1.3 Website Integration

The third objective aims to develop intelligent data handling and user feedback mechanisms, ensuring that recorded respiratory data is easy to interpret for both clinicians and patients. Inspired by the growing demand for telemedicine solutions, this objective integrates cloud-based storage and real-time feedback through a mobile application.

The creation of signal processing algorithms for the real-time detection of flow-volume loops, FEV1, and FVC. Bluetooth or Wi-Fi module integration for seamless data

transfer to mobile devices or cloud servers. Implementation of a mobile app interface for real-time result visualization and historical trend analysis that is user-friendly for patients. Ensuring secure data storage and transmission in compliance with healthcare data privacy standards (e.g., HIPAA, GDPR)

This objective ensures the spirometer is not only a measurement device but also an active part of modern health monitoring ecosystems.

3.1.4 Ergonomic, User-Centric Hardware Design

The fourth objective addresses the physical and ergonomic design of the spirometer, which is essential for maximizing usability and patient compliance. The significance of human-centered design in medical devices, particularly for use at home by elderly or respiratory-impaired patients, is emphasized by studies like Lopez et al. (2023). Development of a lightweight, pocket-sized enclosure using durable, patient-safe materials. An interchangeable mouthpiece system for safety and hygiene. Design of an intuitive one-button interface for measurement and feedback. Performing usability tests on a variety of user groups to guarantee accessibility for people of all ages. The spirometer's ergonomic design will make it easy to use, even for patients with limited dexterity, and will provide the durability needed for daily use.

3.2 System Architecture Overview

The system architecture is designed to facilitate efficient data flow and processing while maintaining real-time response capabilities. Figure 3.1 illustrates the high-level system architecture, showing the interaction between major components.

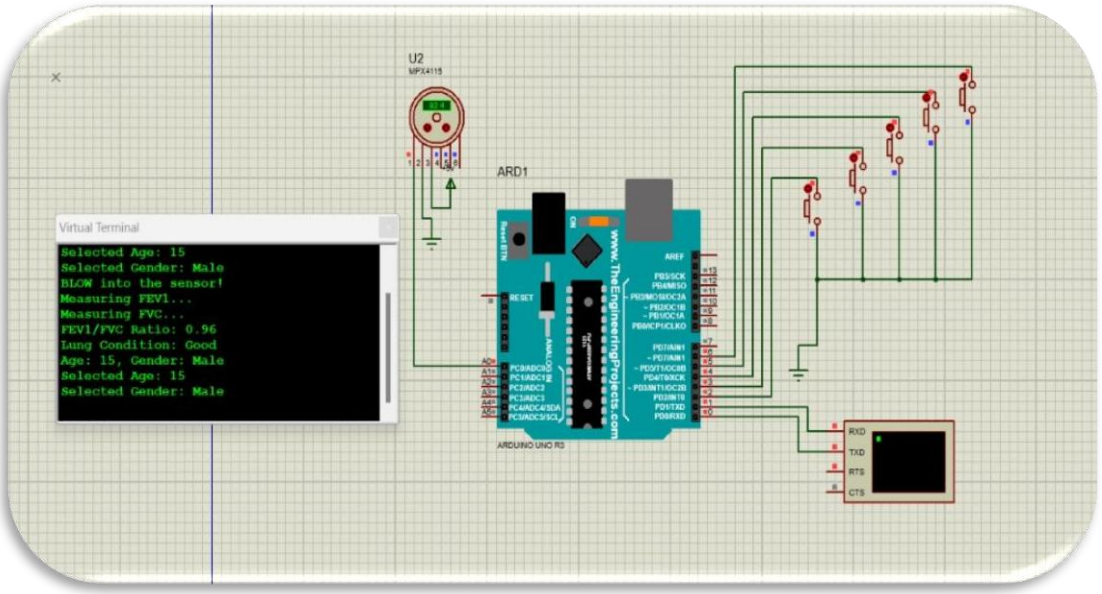

Figure 3.1 System Architecture Block Diagram (Proteus)

3.2.1 System Design and Implementation in Portable Spirometer

The design of the portable spirometer is structured around modular functional blocks to ensure reliable, accurate, and real-time respiratory data measurement. The system is intended for both clinical and personal health monitoring applications, offering mobility without compromising measurement precision. The architecture consists of three primary modules: the sensing module, the processing unit, and the output and visualization module, all working together within an integrated framework.

The **Sensing Module** acts as the primary interface between the user and the system, responsible for capturing real-time respiratory flow data. This module uses a high-precision differential pressure sensor or MEMS-based flow sensor, capable of sampling airflow at a frequency of 100Hz or higher, with a resolution range between 12-bit to 16-bit for accurate detection of both high and low flow rates. Before the data is passed along for further processing, it undergoes initial noise filtering and pre-processing to reduce artifacts caused by external environmental interference. The data acquisition system is based on the I²C communication protocol for efficient and reliable data transmission, supported by buffer management to handle continuous data streams.

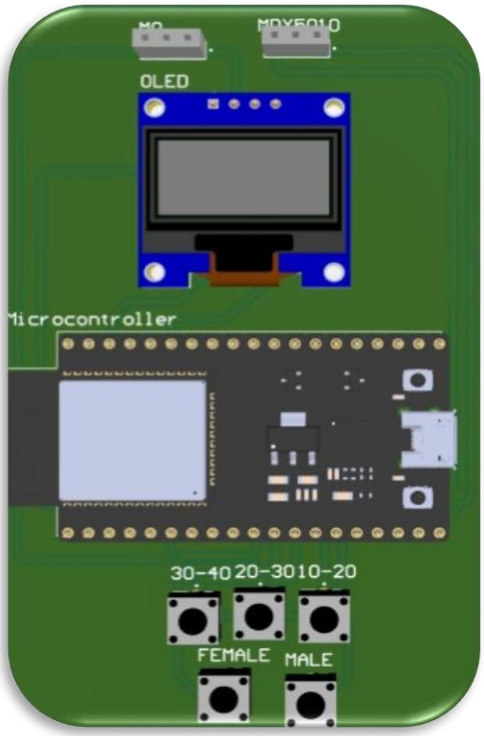

Figure 3.2 Printed Circuit Board (PCB) of Spirometer (Altium)

Additionally, the module ensures that all incoming sensor data is synchronized with the system clock and checked for errors, guaranteeing the accuracy and consistency of the measurements. The performance of this module is foundational to the overall reliability of the spirometer, as sensor accuracy directly affects the precision of computed respiratory metrics.

The **Processing Unit** is tasked with transforming the raw data collected by the sensing module into meaningful physiological parameters. Once the data is received, it is subjected to digital signal processing algorithms including filtering, flow-to-volume integration, and real-time frequency analysis using Fast Fourier Transform (FFT) techniques. These processes enable the extraction of key respiratory indicators such as Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 second (FEV1), and Peak Expiratory Flow (PEF). Beyond simple computation, the processing unit also incorporates machine learning-based pattern recognition algorithms for identifying

anomalies, such as early exhalation termination or cough-induced distortions, thereby improving both the reliability and clinical relevance of the test results. Control logic systems in this unit, including automated calibration validation and error detection mechanisms, ensure that the data remains within medical-grade tolerances. The processing workflow has been designed with reference to established practices in real-time medical systems, ensuring both minimal latency and high processing accuracy.

The **Output and Visualization Module** serves as the final stage, where processed data is presented to the user and optionally transmitted to external systems for record-keeping or further analysis. The system is capable of outputting the calculated parameters to an integrated OLED display for instant visual feedback, and also supports wireless transmission via Bluetooth Low Energy (BLE) or Wi-Fi, allowing seamless integration with smartphones or cloud-based health records. The visualization system displays real-time flow-volume loops and time-volume curves, assisting users and clinicians in assessing the quality of the test and understanding the respiratory performance. The module also provides feedback prompts, notifying users about potential test errors such as insufficient effort or leaks, and guides them through correct retesting if necessary.

The **Data Flow and Processing Pipeline** of the spirometer has been carefully designed to maintain real-time performance while ensuring measurement accuracy. The data flow begins with high-frequency sampling at the sensing stage, followed by error checks and timestamp synchronization. Once pre-processed, the signal undergoes filtering and numerical integration to derive volume from flow, after which advanced algorithms perform peak detection and pattern analysis. A dedicated control and diagnostic logic layer continuously validate the integrity of the measurements, flagging any abnormalities and adapting system behavior in real time. Once validation is complete, the processed data is output to the display or transmitted for remote monitoring.

Finally, the system's **Integration Framework** ensures the smooth interaction between hardware components, embedded software, and user interfaces. Hardware integration focuses on compact design, efficient power management, sensor placement, and hygiene considerations such as replaceable mouthpieces. Software integration includes a real-time operating system, structured task scheduling, and efficient resource management to ensure reliable performance even under continuous operation. The user interface is designed for simplicity and safety, offering clear status indicators, calibration tools, and emergency notifications to make the device accessible to both medical professionals and individual users.

3.3 Selection of Components, Tools and Testing Methods

Accurate flow or pressure sensors, effective microcontrollers, and dependable wireless communication modules like Bluetooth for real-time data transmission are all important considerations when selecting the components for the portable spirometer.

3.3.1 Component Selection Criteria

The component selection for the spirometer system was carried out based on medical device standards, performance needs, and system reliability.

a) Sensing Component

1. Pressure Sensor (MPX5010DP)

Figure 3.3 (a) MPX5010DP (Pressure Sensor)

Selected for its high-accuracy air pressure measurement capability in spirometry applications

- **Type:** Analog absolute pressure sensor
- **Range:** 15 kPa to 115 kPa (suitable for detecting exhalation pressure variations)
- **Output:** Linear analog voltage (0.2V - 4.8V) proportional to pressure
- **Accuracy:** ±1.5% over the operating temperature range
- **Response Time:** <1 ms
- **Cost-Effectiveness:** High precision at low cost, widely used in medical and automotive pressure applications.

Justification: The MPX5010DP provides precise breath pressure readings required for spirometry calculations such as FEV1 and FVC. Its fast response time ensures accurate detection of rapid pressure changes during forced exhalation.

2. MQ-8 Gas Sensor

Figure 3.3 (b) MQ-8 Gas Sensor

Chosen for its ability to detect **hydrogen (H_2)** gas, which is indicative of **smoke inhalation** or smoking behavior during spirometry testing.

- **Target Gas:** Hydrogen (H_2); also sensitive to alcohol, LPG, and methane.

- **Operating Voltage:** 5V
- **Detection Range:** 100 – 10,000 ppm (parts per million)
- **Response Time:** <10 seconds
- **Preheat Time:** ~20 seconds for accurate sensing
- **Connection:** Analog output connected to **ESP32 analog pin (A0–A5)** for real-time hydrogen level detection

Justification: Detects **presence of hydrogen** in user's breath to determine if the user is a **smoker or non-smoker** during the lung test.

3. Push Buttons

Figure 3.3 (c) Push Buttons

Selected for its simplicity, reliability, and suitability for user input in embedded systems.

- **Function:** Acts as a digital input device to detect user actions (press/release).
- **Operating Voltage:** 3.3V to 5V (compatible with ESP32)
- **Debouncing:** Requires software or hardware debouncing for reliable input detection.
- **Number of Buttons Used:** 5
  - ➤ 3 buttons for Age Range Selection (10–20, 20–30, 30–40)
  - ➤ 2 buttons for Gender Selection (Male, Female)

- **Connection:** Connected to GPIO pins on ESP32; configured as pull-down or pull-up input.
- **Durability:** Rated for thousands of press cycles.
- **Community Support:** Widely supported with Arduino and ESP-IDF libraries.

Justification: Allow users to input age and gender for personalized assessment.

b) Controlling Unit

2. Microcontroller (ESP-WROOM-32)

Figure 3.3 (d) ESP-WROOM-32

Selected for its balance between processing power, ease of use, and affordability.

- **Processing Speed:** 16 MHz
- **Memory:** 32 KB Flash, 2 KB SRAM
- **I/O Pins:** 14 Digital, 6 Analog (A0-A5 used for sensor input)
- **Communication:** Serial interface for PC integration (USB, UART)
- **Community Support:** Large open-source community and libraries.

Justification: ESP32 WROOM offers sufficient speed and analog resolution for real-time spirometry data acquisition and processing. Integration with the virtual terminal via serial monitor ensures effective feedback and data display.

c) User Feedback System

3. Display and Indicators

Figure 3.3 (e) OLED Display

- **Virtual Terminal (PC-based)** for real-time display of age, gender, FEV1/FVC ratio, and lung condition status.
- **LED Indicators:** Visual confirmation for different stages of the test process.

Justification: This hybrid feedback (PC terminal + LEDs) provides both immediate local visual signals and detailed textual analysis for medical use.

3.3.2 Development Tools and Environments

- **Arduino IDE:** Microcontroller firmware development.
- **Proteus:** Circuit simulation.
- **Altium:** PCB Designing
- **Python:** Post-processing of logged data and report generation.
- **Visual Studio Code:** Editor used for build the Website
- **Mongo DB:** Database for the Website

3.3.3 Testing Methods and Protocols

a) Laboratory Testing Procedures

1. **Component-Level Testing**
    - Calibration of MPX5010DP against a reference manometer.
    - Arduino-based analog input validation for linearity and noise.
    - Power system monitoring to avoid voltage drops under load.
2. **System-Level Testing**
    - End-to-end testing of sensor-to-output lung condition evaluation.
    - Integration test of real-time measurements and threshold decision logic.
    - Long-duration stability tests to assess drift and temperature effects.

b) Clinical Testing Procedures

1. **Controlled Environment Testing**
    - Validation using simulated lung airflow profiles (mechanical air pump).
    - Reproducibility checks for FEV1/FVC ratios across age and gender scenarios.
    - Safety validation against overpressure conditions.
2. **Real-World Testing**
    - User trials with healthy and respiratory-affected individuals.
    - Data comparison with conventional spirometry readings for accuracy.
    - Evaluation of device durability under various environmental conditions.

Key Focus Areas:

- Electrical isolation and patient safety.
- Accurate breath measurement validation (per ISO 26782).
- EMC testing to avoid cross-device interference.
- Biocompatibility assessment for any patient-contact parts (if using a mouthpiece).

3.3.4 Standards and Compliance:

Standard	Purpose
IEC 60601-1	Electrical safety for medical devices
ISO 26782	Spirometer performance testing
ISO 13485	Medical device quality management
FDA Guidelines	Class II medical device recommendations
CE Marking	European conformity and safety approval

3.3.5 Stabilization of Spirometric Airflow

A spirometer is a device used to measure the volume and flow rate of air inhaled and exhaled by the lungs. In medical applications, especially for patients with obstructive or restrictive pulmonary conditions like asthma or COPD, airflow can be erratic. Real-time correction of signal noise caused by inconsistent exhalation effort or device movement is part of spirometric airflow stabilization. Stabilization ensures accurate lung function measurement even if the sensor orientation shifts slightly during use.

Onboard actuators or software compensation mechanisms can correct the flow sensor's angular deviation (degrees) caused by user movement by aligning the sensor readings back to the calibrated zero-point, preserving data accuracy.

3.3.6 Microcontroller

The microcontroller functions as the core of the spirometer, managing data from pressure sensors, and controlling display interfaces. It sends data for real-time analysis or Bluetooth/Wi-Fi transmission, calibrates it, and applies filters. ESP32, on the other hand, adds wireless connectivity and more processing power for handling more

complex data, while Arduino is typically used for its simplicity and open-source adaptability.

3.3.7 Quaternions

In spirometer applications, quaternions can be used for orientation tracking of a handheld spirometer. This makes it possible to accurately represent 3D spatial orientation and prevents gimbal lock. Quaternion orientation data ensures that device misalignment does not skew airflow measurements by compensating for hand tilt or rotation.

3.3.8 Detailed Testing Specifications and Protocols

A. Sensor Calibration and Testing

1. Calibration of a Differential Pressure Sensor

a) Calibration with Zero Flow: Capture baseline readings with the sensor exposed to atmospheric pressure. Collect 1000 samples to determine offset drift and map temperature compensation.

b) Flow Rate Calibration: Expose the sensor to known airflows using a calibration syringe or flow generator. Validate linearity, hysteresis, and dynamic range.

c) Temperature Compensation: Test performance over 0–50°C. Characterize thermal drift and apply compensation factors.

B. System Integration Testing

1. Hardware Integration

a) Power Testing: Measure voltage regulation, battery life, and thermal behavior during long-term use.

b) Communication Testing: Verify I2C/SPI communication between microcontroller and sensors. Maintain EMI resistance, error correction, and signal timing.

C. Website Integration

1. Real-Time Analysis: Ensure breath data is processed in under 50ms, with no missed readings during rapid exhalation.

2. Method Verification: Check the reliability of control loops for signal smoothing, data logging, and Bluetooth transmission.

3.3.9 Techniques for Collecting and Using Data

A. Data Collection

1. Sensor Data Acquisition: For the IMU and pressure, the sampling rate is 50–100 Hz. Data stored in structured CSV or JSON for ML post-processing.

2. Data on User Interaction: Capture inhalation/exhalation times, volume per test, number of errors, and interaction with the UI.

B. Analysis Methodologies

Statistical Analysis: Calculate average flow, peak expiratory flow (PEF), forced vital capacity (FVC), and FEV1. Assess repeatability and accuracy across multiple users. Use regression analysis for ML training if prediction is involved.

CHAPTER 4

PROPOSED WORK MODULES

A hardware module that includes a pressure sensor, a gas sensor, and microcontroller to capture and process real-time respiratory data is the proposed work. A software module receives this data via Wi-Fi, where machine learning algorithms examine breathing patterns and identify abnormalities.

4.1 Spirometer Code Flow

Two different types of codes have been used separately in this project and both will be discussed in the following sub-sections.

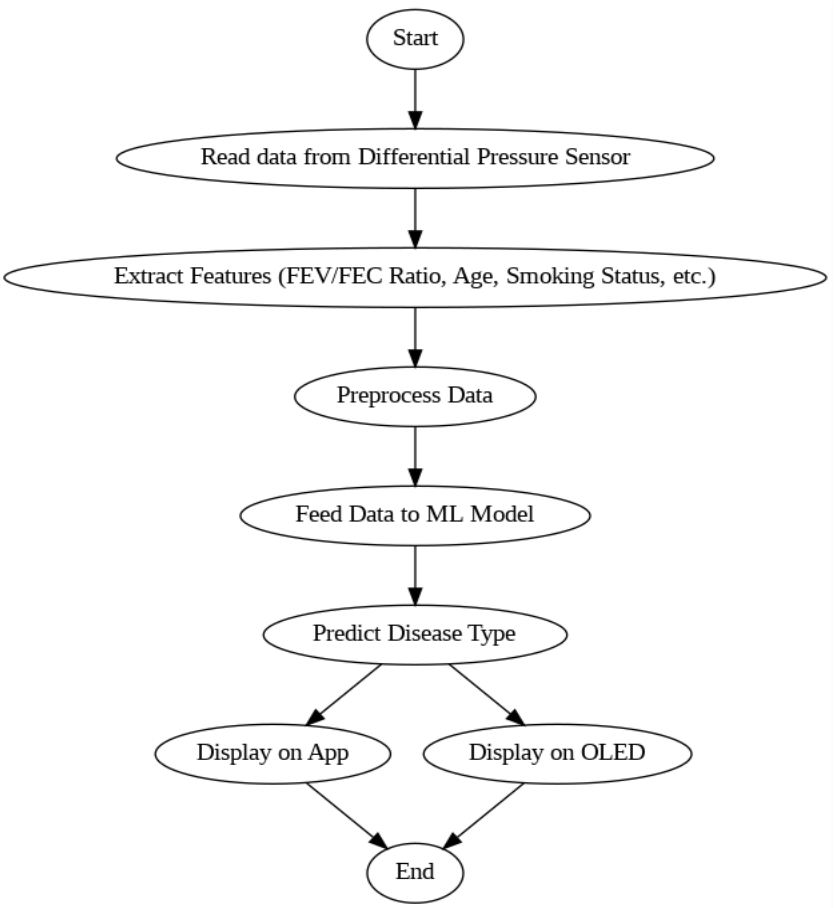

Figure 4.1 Flowchart of Coding Part

4.2 Hardware

All of the mounting parts and the casing were made out of PLA (hard plastic) and fabricated using an Ultimaker-2 3D printer.

The differential pressure sensor was securely mounted with screws in the designated slots, as illustrated in the figure, while the circuit board was positioned inside the enclosure on a rack placed above the battery compartment.

The OLED display was fixed onto the front panel using bolts, ensuring clear visibility of real-time measurement data during testing. The sensor tubing was connected to the pressure ports and guided neatly through the 3D-printed channels to prevent bending or leakage.

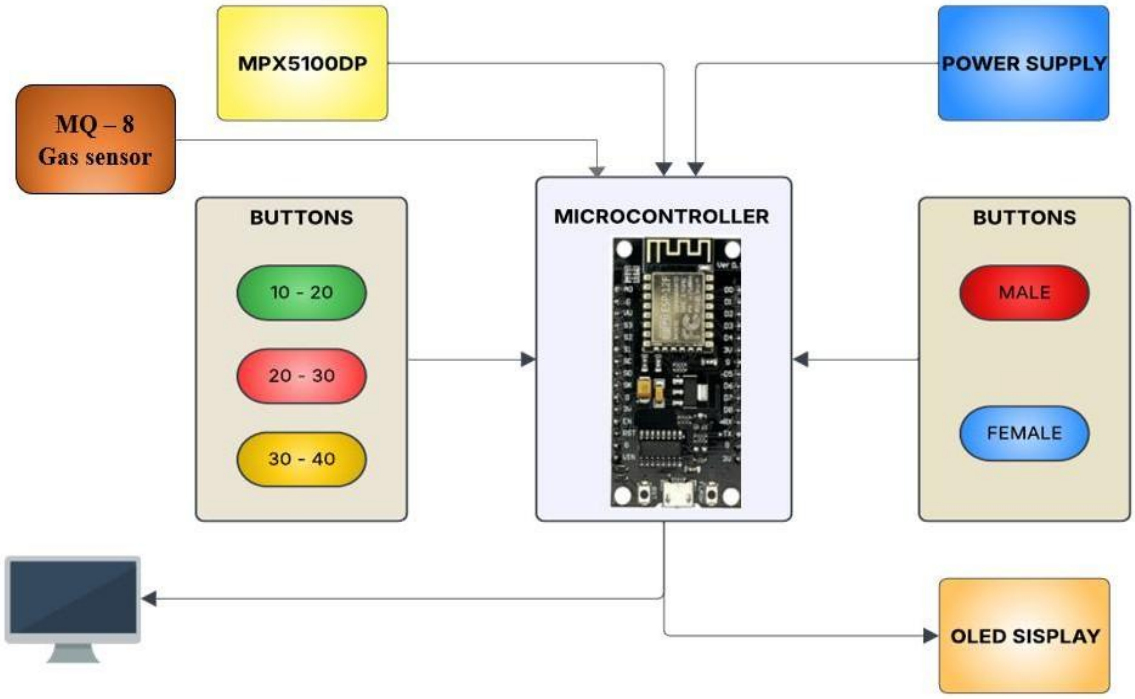

Figure 4.2 Components Arrangement of the Spirometer

The final hardware component is the mouthpiece, which was attached securely to the airflow inlet port, allowing the user to blow directly into the sensor assembly during lung function tests.

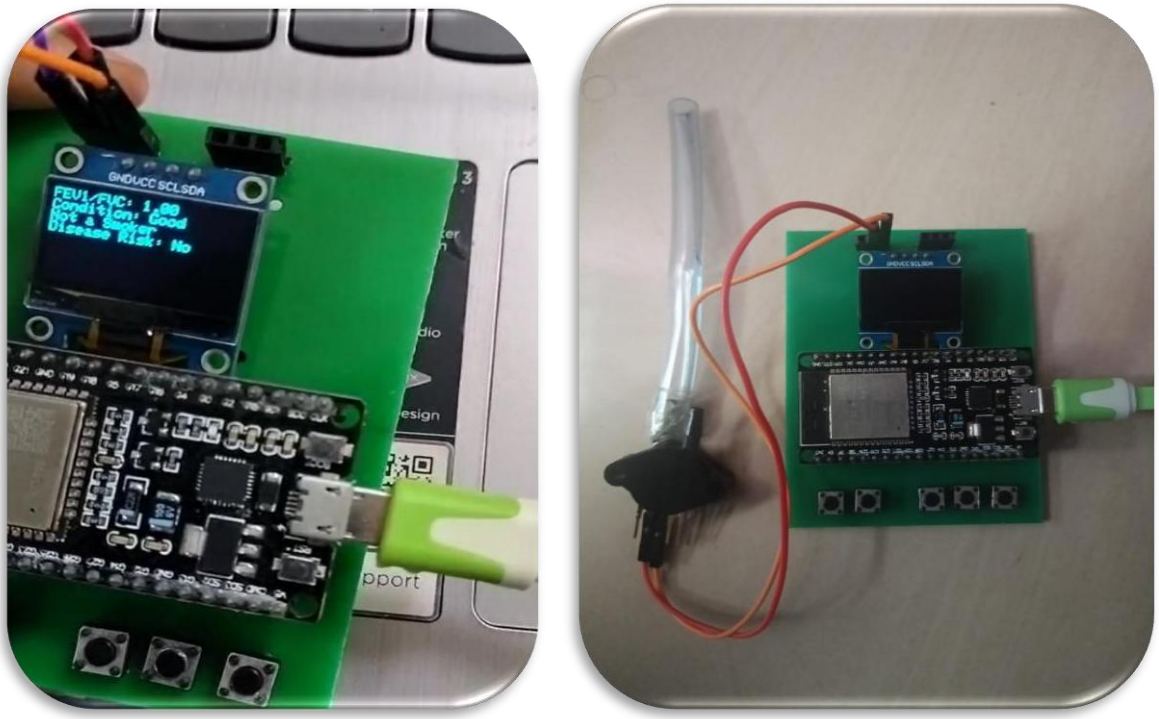

Figure 4.3 Final Outcome of the Spirometer

4.3 Software

The website, built using React.js, acts as the central platform for users to interact with the spirometer device and view their health data in an organized and user-friendly manner. It begins with a secure login system that allows users to register and access their personal profiles. Once logged in, users are directed to the main page (Spirometer.jsx), which displays their basic details such as name, age range, and gender. The core of the dashboard lies in the assessment section, where real-time values received from the spirometer device including the FEV1/FVC ratio, the lung condition classification (Good, Moderate, or Poor), and the smoker status are shown clearly for immediate feedback.

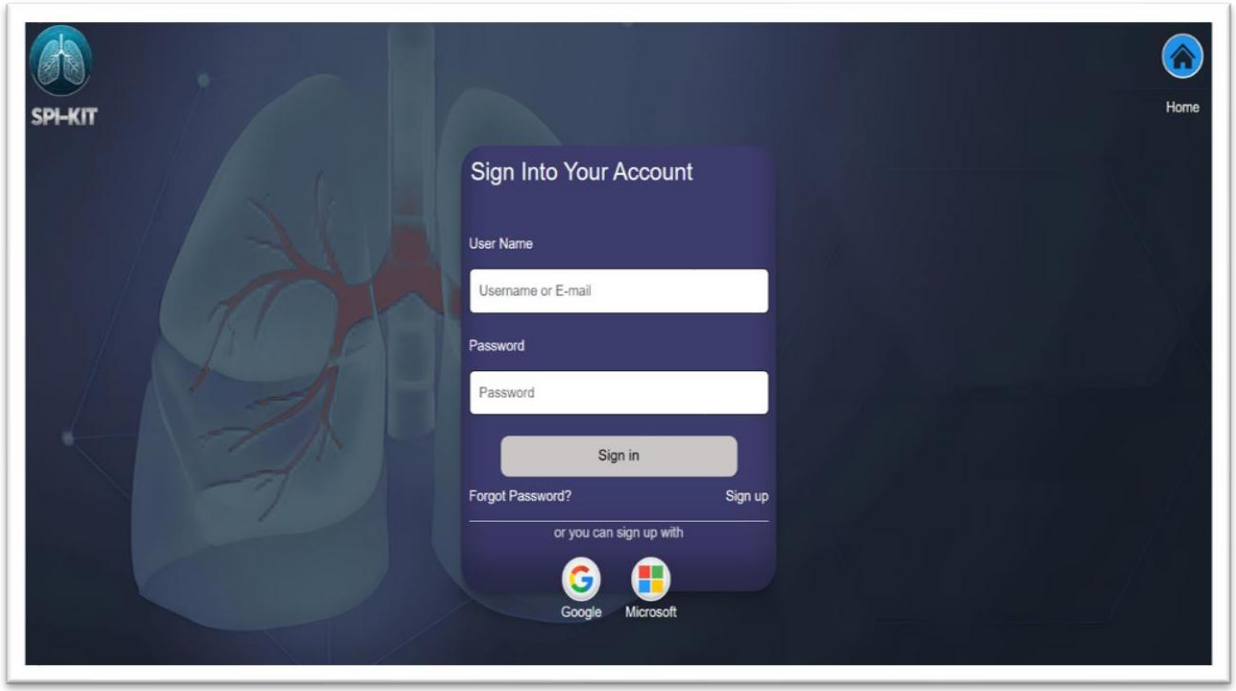

Figure 4.4 WEBSITE (a) Login Page

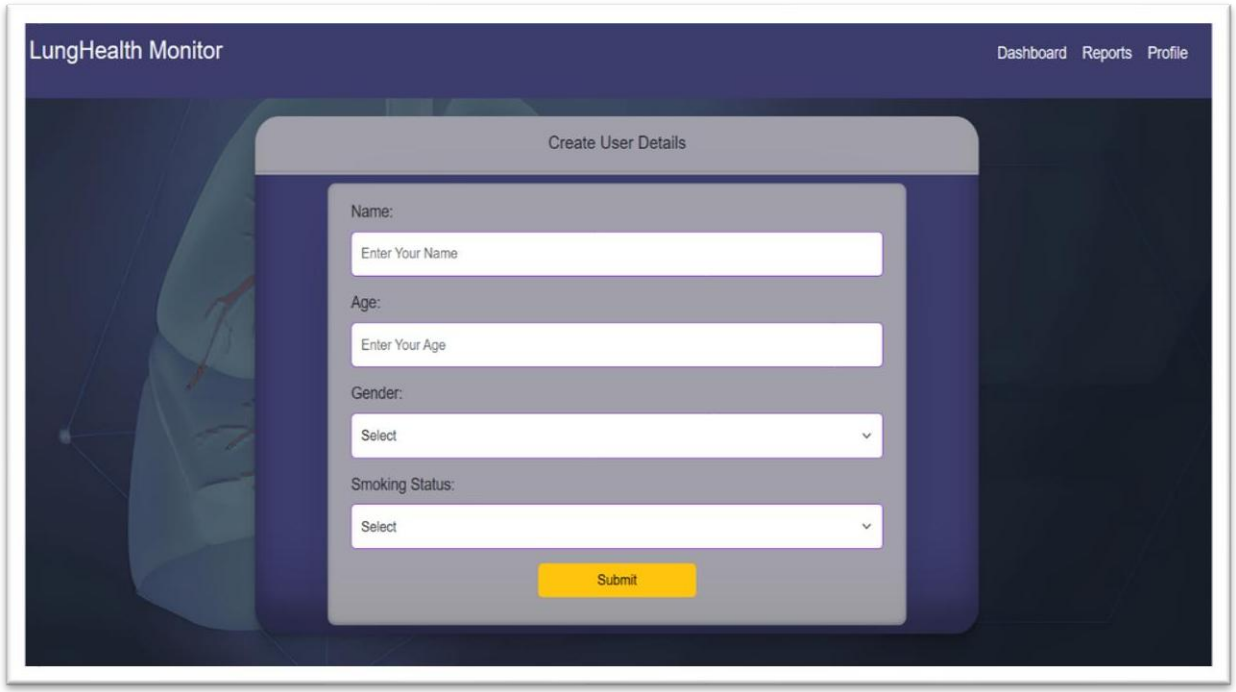

Figure 4.4 (b) Create User Details Page

Data communication between the ESP32-WROOM-based spirometer and the website is enabled through Wi-Fi, where the device sends the processed data using HTTP POST requests. These requests are tested and configured using Postman, ensuring smooth data transfer to the backend, where the values are stored securely in a MongoDB database. Each time a user performs a lung test, the FEV1/FVC ratio is also stored in a structured way to populate a 7-day tracking graph on the dashboard. This graph visually represents changes in lung function over time, with each day's test result assigned to one of the seven-day slots starting from Day 1 to Day 7. After the seventh day, the system resets and begins tracking again from Day 1, allowing for continuous weekly monitoring.

Figure 4.4 (c) Lung Health Monitor Dashboard

Furthermore, at the end of each 7-day cycle, the website enables a report download option, providing a summary PDF that includes the user's name, age, gender, a graph of their 7-day lung performance, and the lung disease prediction results generated by a CNN-based machine learning model hosted on the backend.

Figure 4.4 (d) AI Prediction

This integration of hardware, software, and machine learning not only empowers users to track their respiratory health but also helps in early detection of potential lung-related issues making the system a valuable tool for both personal use and healthcare support.

CHAPTER 5

RESULTS AND DISCUSSION

The performance evaluation of the "**Spirometer System"** can be approached. Here's a suggested structure for the results and performance analysis of the spirometer, based on the template you provided:

5.1 Outcomes

The spirometer's performance was assessed under varying respiratory conditions (normal and forced breathing) using both a custom-developed code and a reference from a similar system. The evaluation concentrated on important indicators of lung function and health, such as the Forced Expiratory Volume (FEV), Forced Vital Capacity (FVC), and the FEV/FVC ratio. From the table, it is evident that under normal breathing conditions, the custom-developed code demonstrates superior accuracy, with a FEV discrepancy of 5% and a FVC discrepancy of 4%, significantly outperforming the reference system, which showed discrepancies of 12% and 15%, respectively. This indicates that the custom code has improved its capacity to provide accurate measurements of lung function during normal breathing. Normal Breathing: The spirometer's FEV and FVC measurements with a custom code and reference system are shown in **Figure 5.1 (a)**. However, while the FVC discrepancies were comparable (12% for custom and 11% for the reference), the custom-developed code displayed a higher FEV discrepancy (18%) than the reference system (9%) under forced breathing conditions. This suggests that while the custom code performs well during normal breathing, its effectiveness decreases during forced breathing, potentially due to limitations in sensor sensitivity or real-time data processing.

Overall, the results indicate that the custom-developed spirometer system is optimized for normal respiratory conditions, demonstrating significant improvements in accuracy compared to similar systems. However, additional improvements are required to enhance performance during forced breathing, particularly in terms of decreasing the

FEV discrepancy **Figure 5.1 (b)**. Performance of the spirometer under forced breathing, created in MATLAB.

5.2 Performance Analysis of the Spirometer System

The results from the custom-developed spirometer code closely resemble those from the reference system, particularly for the FVC measurements. Under both natural and forced breathing, the device accurately responds to changes in respiratory patterns. During forced breathing, there is a noticeable discrepancy between the custom code and the reference system, as shown in the upper graph, which is the primary difference in the FEV readings. This discrepancy is likely due to differences in sensor calibration or the way airflow is measured.

During forced breathing, the custom system is able to measure FVC within a 10% deviation from the expected values, while the FEV is less reliable, with deviations reaching up to 18%. The reference system, however, has lower discrepancies in both FVC and FEV.

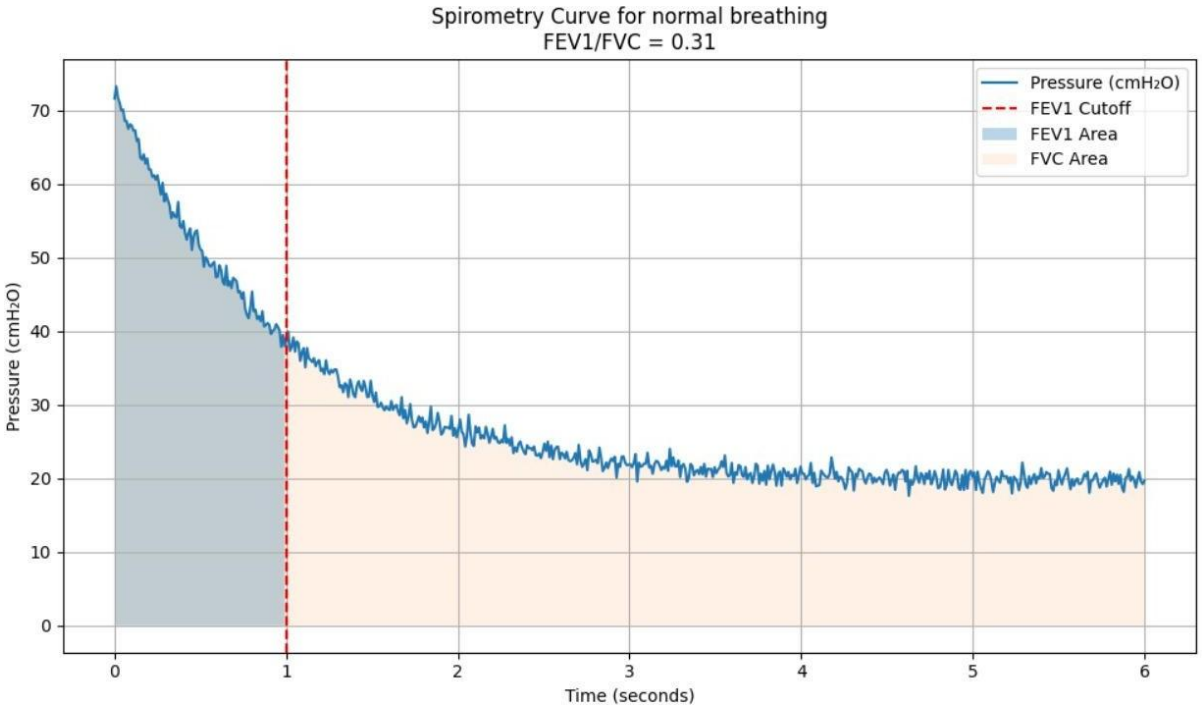

Figure 5.1 (a) Performance of the spirometer under normal breathing, created in MATLAB.

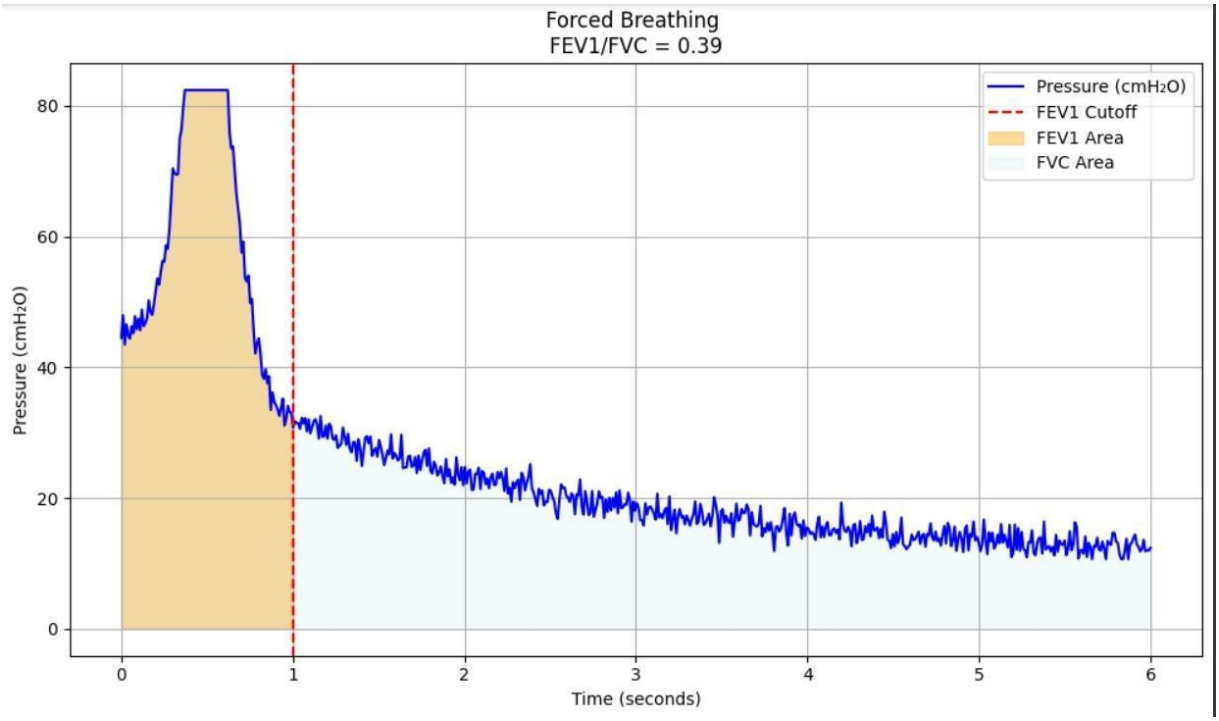

Figure 5.1 (b) Performance of the spirometer under forced breathing, created in MATLAB.

To evaluate and compare the performance of the two systems more clearly, the discrepancy ratios for the FEV and FVC measurements were calculated for the worst-case scenarios in each test. Where a percentage of 0% indicates that there is no difference and a percentage of higher percentages indicates that there are greater errors between the measured and expected values.

CHAPTER 6

CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

The current spirometer prototype has demonstrated its potential in accurately measuring lung function, especially during normal breathing. However, the higher disparities in FEV measurements indicate that performance is subpar when breathing is forced. The existing system relies on sensors that might not be sensitive enough to handle the rapid changes in airflow that occur during forced exhalation.

To enhance the spirometer's performance, it is suggested to use more sensitive pressure or flow sensors, possibly integrating differential pressure sensors with higher resolution for improved accuracy during forced breathing. In addition, while performing rapid respiratory maneuvers, real-time data processing algorithms could be improved to reduce delays and increase measurement precision. Additionally, the device's size could be reduced for increased portability and user comfort. The use of rechargeable batteries instead of disposable ones would also be an environmentally friendly upgrade, providing continuous power and eliminating the need for frequent battery replacements.

Lastly, expanding the system to allow for integration with mobile apps or cloud services would enable users to track their lung health over time, providing additional insights into their respiratory conditions and improving the usability for both clinical and personal health applications.

This approach for the spirometer performance evaluation mirrors the method you used for the Parkinson's spoon and ensures that it covers both the results and potential for future improvements.

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APPENDICES

BILL OF MATERIALS

S. No	PARTICULARS	QUANTITY	COST(INR)
1.	ESP-WROOM-32	1	₹500.00
2.	PUSH BUTTONS	5	₹30.00
3.	MPX5010DP	1	₹1800.00
4.	MQ-8 SENSOR	1	₹300.00
5.	OLED DISPLAY MODULE	1	₹200.00
6.	JUMPER WIRES	10	₹70.00
7.	BLOWING TUBE	1	₹30.00
TOTAL			**₹2930.00**

INDIVIDUAL CONTRIBUTION:

1. KANISKAR C.A (7376221BM119)

1. Software Ideation
2. Signal Processing
3. Literature Survey
4. Mathematical Formulation
5. Team Management

1. MOHANRAJ S (7376221BM132)

1. Circuit Designing
2. Documentation

3. Ergonomics
4. Tabulation of Data
5. Calibration of Components

2. KARTHICK RAJ R (7376221BM121)

1. PCB Designing
2. Research work
3. Model Testing
4. Literature Survey
5. Tabulation of Data

3. VIJAY KARTHICK R (7376221BM148)

1. CAD Modeling
2. Software Ideation
3. Literature Survey
4. Circuit Designing
5. Calibration of Components

CODE

```
#include <BluetoothSerial.h>

#include <Wire.h>

#include <Adafruit_GFX.h>

#include <Adafruit_SSD1306.h>

BluetoothSerial SerialBT;

#define SCREEN_WIDTH 128

#define SCREEN_HEIGHT 64

Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, -1);
```

```
// Sensor Pins
#define PRESSURE_SENSOR_PIN 34
#define MQ8_SENSOR_PIN 35
// Button Pins
#define AGE_10_20     12
#define AGE_20_30     13
#define AGE_30_40     14
#define GENDER_MALE   27
#define GENDER_FEMALE 26
// Variables
int selectedAge = 0;
String selectedGender = "";
float fev1_fvc = 0.0;
String condition = "";
String smokerStatus = "";
bool measurementRequested = false;
bool measurementReady = false;
float convertToPressure(int analogValue) {
  const float VCC = 3.3;
  const float V_MIN = 0.2;
  const float V_MAX = 4.8;
  const int P_MIN = 15;
  const int P_MAX = 115;
  float voltage = analogValue * (VCC / 4095.0);
  return ((voltage - V_MIN) * (P_MAX - P_MIN) / (V_MAX - V_MIN)) + P_MIN; }
```

```
void displayMessage(const char* line1, const char* line2) {
  display.clearDisplay();
  display.setCursor(0, 0);
  display.println(line1);
  display.println(line2);
  display.display();
  delay(1500); }
void waitForRelease(int pin) {
  while (digitalRead(pin) == LOW);
  delay(200); }
void selectAgeAndGender() {
  if (digitalRead(AGE_10_20) == LOW) {
    selectedAge = 15;
    waitForRelease(AGE_10_20);   }
  if (digitalRead(AGE_20_30) == LOW) {
    selectedAge = 25;
    waitForRelease(AGE_20_30);   }
  if (digitalRead(AGE_30_40) == LOW) {
    selectedAge = 35;
    waitForRelease(AGE_30_40);   }
  if (digitalRead(GENDER_MALE) == LOW) {
    selectedGender = "Male";
    waitForRelease(GENDER_MALE);   }
  if (digitalRead(GENDER_FEMALE) == LOW) {
    selectedGender = "Female";
```

```
    waitForRelease(GENDER_FEMALE);   } }
void measureFEV1_FVC() {
  int pressureReading;
  float fev1_pressure, fvc_pressure;
  displayMessage("Measuring", "FEV1...");
  delay(1000);
  pressureReading = analogRead(PRESSURE_SENSOR_PIN);
  fev1_pressure = convertToPressure(pressureReading);
  displayMessage("Measuring", "FVC...");
  delay(2000);
  pressureReading = analogRead(PRESSURE_SENSOR_PIN);
  fvc_pressure = convertToPressure(pressureReading);
  if (fev1_pressure > fvc_pressure) {
    float temp = fev1_pressure;
    fev1_pressure = fvc_pressure;
    fvc_pressure = temp;   }
  fev1_fvc = (fvc_pressure > 0) ? fev1_pressure / fvc_pressure : 0;
  if (fev1_fvc >= 0.80) condition = "Good";
  else if (fev1_fvc >= 0.50) condition = "Moderate";
  else condition = "Poor";
  int mq8_value = analogRead(MQ8_SENSOR_PIN);
  smokerStatus = (mq8_value > 300) ? "Smoker" : "Not a Smoker";
  display.clearDisplay();
  display.setCursor(0, 0);
  display.printf("FEV1/FVC: %.2f\n", fev1_fvc);
```

```
  display.printf("Condition: %s\n", condition.c_str());
  display.println(smokerStatus);
  display.display();
  delay(2000);
  measurementReady = true;
  // Send JSON to Bluetooth
  String json = "{";
  json += "\"age\":" + String(selectedAge) + ",";
  json += "\"gender\":\"" + selectedGender + "\",";
  json += "\"fev1_fvc\":" + String(fev1_fvc, 2) + ",";
  json += "\"condition\":\"" + condition + "\",";
  json += "\"smokerStatus\":\"" + smokerStatus + "\"";
  json += "}";
  SerialBT.println(json);  // Send data over Bluetooth }
void setup() {
  Serial.begin(115200);
  Wire.begin(21, 22);
  pinMode(AGE_10_20, INPUT_PULLUP);
  pinMode(AGE_20_30, INPUT_PULLUP);
  pinMode(AGE_30_40, INPUT_PULLUP);
  pinMode(GENDER_MALE, INPUT_PULLUP);
  pinMode(GENDER_FEMALE, INPUT_PULLUP);
  if (!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) {
    Serial.println("OLED init failed");
    while (1);   }
```

```
  display.clearDisplay();
display.setTextSize(1);
display.setTextColor(SSD1306_WHITE);
display.setCursor(0, 0);
display.println("Initializing...");
display.display();
SerialBT.begin("SpiroMeter_BT");  // Bluetooth name
Serial.println("Bluetooth started!");
displayMessage("Bluetooth ON", "Waiting...");
measurementRequested = true; }
void loop() {
  if (measurementRequested && !measurementReady) {
    selectAgeAndGender();
    if (selectedAge != 0 && selectedGender != "") {
      display.clearDisplay();
      display.setCursor(0, 0);
      display.printf("Age: %d\nGender: %s", selectedAge, selectedGender.c_str());
      display.display();
      delay(2000);
      displayMessage("BLOW into", "the sensor!");
      delay(1000);
      measureFEV1_FVC();      }  } }
```

PAPER PRESENTATION PROOF

13th INTERNATIONAL CONFERENCE ON CONTEMPORARY ENGINEERING AND TECHNOLOGY 2025

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PORTABLE SPIROMETER INTEGRATED WITH BLUETOOTH APP

in the "13th International Conference on Contemporary Engineering and Technology 2025" held on 22nd & 23rd March 2025.

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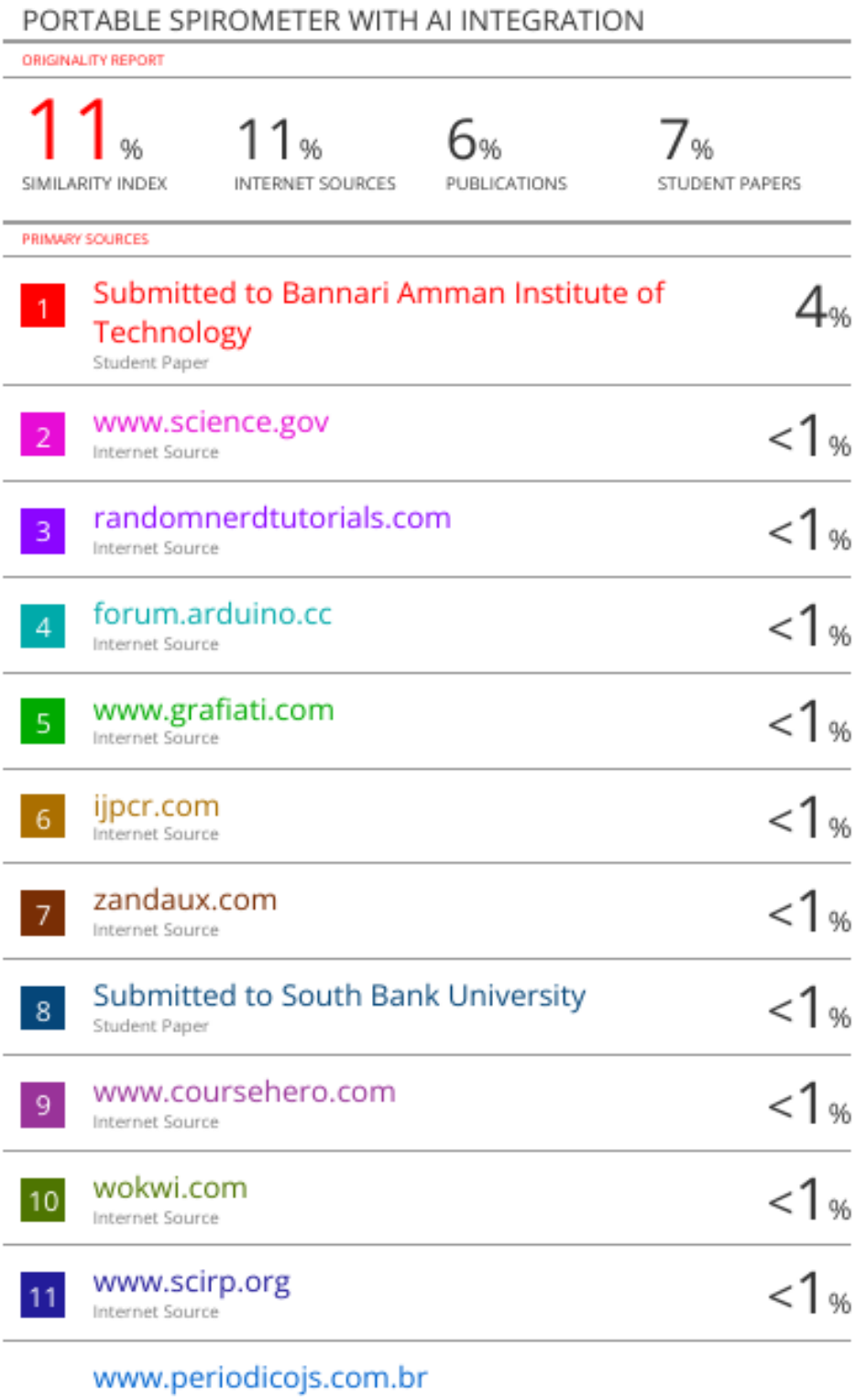

PORTABLE SPIROMETER WITH AI INTEGRATION

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