IR-based Low-cost Portable Turbine Spirometer

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***Abstract*—The escalating costs of medical instruments have led to a growing need for affordable alternatives. This research project focuses on developing a low-cost spirometer using readily available materials to measure lung volumes and flow rates accurately.**

Spirometry plays a crucial role in assessing lung function by measuring airflow and pressure. It enables the evaluation of airway pressures, flows, volumes, compliance, and resistance. The spirometer records the volume of exhaled air as numerical data, which can be analysed to assess the mechanical characteristics of the lungs. The flow rate is determined using rotational velocity, and the integration of the flow rate over time provides the volume of gas passing through the tube. Our model incorporates a single, lightweight IR sensor to measure these parameters.

While spirometry is essential for diagnosing various pulmonary diseases such as COPD, its current cost limits its accessibility. This study aims to develop a comprehensive spirometer equipped with essential sensors, including a flow meter, and programmable through an Arduino UNO Rev3 Microcontroller. We aim to create a functional and user-friendly spirometer that fulfils all the necessary requirements.

Keywords: Spirometer, Flow rate, Lung Volume, Low-cost, COPD (Chronic Obstructive Pulmonary Disease)

I. Introduction

Between the years 129 and 200 A.D., early endeavours were made to measure lung capacities. Claudius Galen, a Roman physician and philosopher, conducted one of the first volumetric experiments on human breathing. The respiratory system, responsible for vital functions such as oxygen distribution and carbon dioxide elimination, plays a critical role in the body.

In the field of medicine, the primary focus is on disease prevention and early treatment. However, this mission should not come at an exorbitant cost. According to the American Association for Respiratory Care (AARC), more than 500 million individuals have been diagnosed with COPD, making it the fourth leading cause of death globally. Unfortunately, many patients with this diagnosis reside in developing nations where the high cost of spirometric equipment hinders healthcare practitioners from acquiring it.

Lung and respiratory diseases are widespread health concerns that impact a significant number of individuals globally. These conditions arise from a variety of factors, including smoking, infections, and genetic predisposition. The lungs play a vital role in delivering oxygen to the body and eliminating carbon dioxide, making them susceptible to various disorders. Understanding the signs and symptoms associated with different lung and respiratory conditions is crucial for early detection and effective management.

Within the lungs, a complex network of bronchioles extends into alveolar ducts and sacs, ultimately leading to the alveoli, which are small vesicles lined with a delicate layer of mucus. The respiratory system plays a vital role in safeguarding the cells of the human body by removing carbon dioxide, a byproduct of the oxidation process, and delivering the essential oxygen needed for their functioning.

Spirometry plays a crucial role in identifying asymptomatic patients who may be at risk of developing chronic conditions such as COPD. In our study, we have adopted a sustainable approach by utilising plastic bottles to design our spirometer. This approach aligns with the ideology of promoting sustainability while providing an affordable solution for healthcare practitioners in resource-limited settings.

A spirogram is a diagnostic test used to assess lung function. It measures various parameters related to airflow, lung volumes, and lung capacities. The test involves the patient inhaling and exhaling into a spirometer, which records the volume and flow rate of air. Spirometry provides valuable information about respiratory health and can aid in the diagnosis and monitoring of conditions such as chronic obstructive pulmonary disease (COPD), asthma, and other lung disorders. By analysing spirometric data, healthcare professionals can evaluate lung function, identify abnormalities, and make informed treatment decisions.

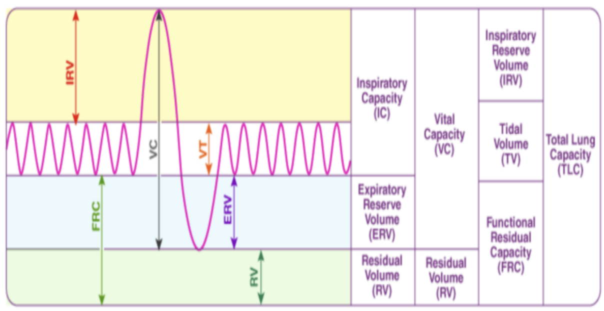

Fig 1. A typical Spirogram illustrating the different lung volumes and capacities.

The most popular pulmonary function test is spirometry, which involves a series of evaluations of the respiratory systems under controlled conditions. By monitoring the volumes of air mobilised by respiratory movements and ventilatory fluxes, spirometry aims to regulate the ventilatory function. Normal values in healthy individuals aged 20-60 vary from 4.5 to 3.5L, and for healthy females, it ranges from 3.25 to 2.5L.

A. Motivation

The rotational speed of the turbine can be used to determine the flow rate. By integrating the flow rate over a specific time period, the volume of gas passing through the pipe can be calculated. Additionally, conducting the experiment at different time intervals allows us to assess various lung volumes and capacities.

II. Literature Review

A notable study conducted by Cheung et al. [6] investigated the use of three-dimensional electrical impedance tomography to assess spirometric lung impedance. This approach offers a comprehensive evaluation of lung parameters, providing valuable insights.

Another significant contribution, presented by Sridevi et al. [7], introduced a cost-effective spirometer specifically designed for the detection of COPD. The authors demonstrated that this affordable solution accurately measures lung volumes and capacities, making it accessible in resource-limited settings and enabling early COPD detection.

Furthermore, Adiono et al. [8] developed a portable device capable of monitoring vital signs, including spirometric parameters. The authors showcased the utility of this device within the context of the Covid-19 pandemic.

III. Methodology

Our model focuses on the utilisation of IR sensors in turbine-based spirometers to accurately measure and analyse parameters related to lung volume and capacities. By incorporating IR sensors into our spirometer design, we aim to provide a reliable and efficient method for assessing respiratory function.

In our experimental setup, the spirometer features a vertically positioned turbine that serves as the primary mechanism for measuring airflow. As an individual blows air into the spirometer, the airflow creates a rotational motion within the turbine. This rotating airflow is a direct result of the exhaled breath, and it allows us to capture and quantify the volume of expelled air.

To determine the flow direction and rate, we have integrated a pair of optical sensors into our spirometer design. These sensors function by accurately counting the number of rotations of the turbine. By analysing the rotational data provided by the optical sensors, we can precisely measure the flow rate of the expelled air.

Once we have collected the data on rotational speed and flow rate, we calculate the volume by integrating the flow rate over a specific time interval, enabling us to accurately determine the volume of gas that passes through the spirometer.

Specifications of *Arduino* UNO Rev3 Microcontroller*: Operating voltage: +5V (Recommended), Input Voltage: +7V to +12V, In/Out Voltage (Limit): + 6V to +20V PWM, Digital I/O Pins: 6, Analog Input Pins: 6, Digital I/O pins: 14 [6 pins to provide PWM output] DC Current per I/O pin: 20 mA.*

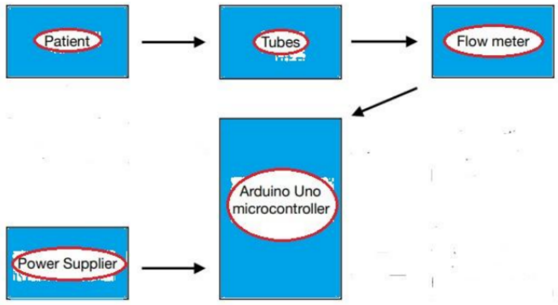

Fig 2. Circuit layout

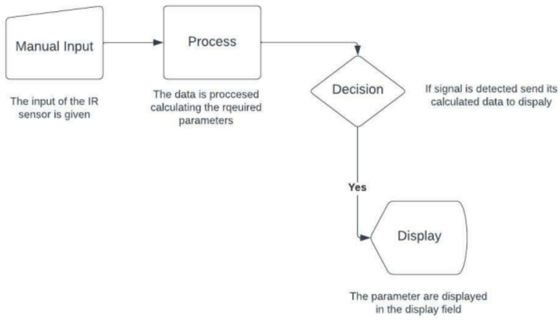

Fig 3. Block diagram

Component specifications:

- IR sensor module for sensing the tip of the fan.
- Arduino UNO Rev3 Microcontroller for the interface.
- 9V Battery power supply.

The IR sensor module has excellent adaptability to ambient light and consists of infrared-emitting tubes and a receiver tube. It emits a specific frequency when detecting obstacles and processes the reflected frequency to generate a digital signal. The sensor's detection distance can be adjusted using a potentiometer knob. It has minimal interference, easy installation, and is versatile for various applications like line tracking and obstacle avoidance. The effective distance range is 2-10 cm, and it operates within a voltage range of 3.3V-5V.

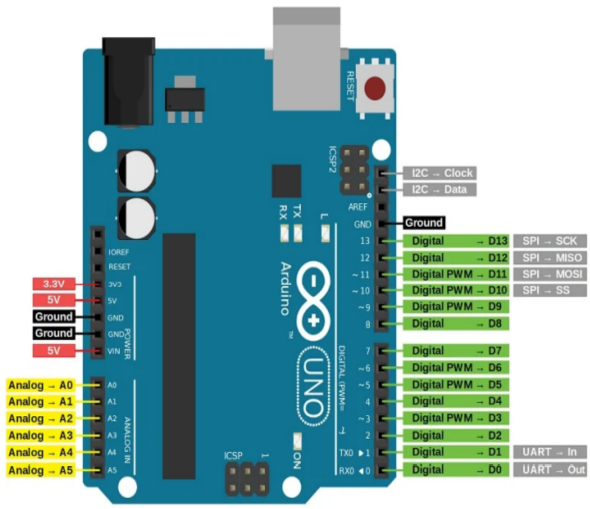

Fig 4. Arduino UNO Rev3

IV. Results and Discussion

We employed an IR sensor to measure the required parameters in our spirometer. The sensor detects the blades of the rotor used in our apparatus. Our design emphasises simplicity and environmental friendliness, aligning with our goal of creating an affordable and portable spirometer. The rotor blades were crafted from recycled plastic bottles.

The flow rate is calculated based on the velocity of the airflow. Integration of the flow rate yields the subject's volume. Healthy young women typically exhibit flow rates between 150 and 200 L/min, with values decreasing with age for both males and females. Peak Expiratory Flow Rate (PEFR) represents the maximum flow rate achieved during a Forced Vital Capacity (FVC) maneuver, with healthy individuals often surpassing 600 L/min. Males have an average tidal volume of 38.9 mL, while females have an average tidal volume of 46 mL.

As the subject exhales into the apparatus, the airflow spins the turbine, and the IR sensor measures the time interval between successive blades to determine the airspeed. By integrating the results, we derive the subject's lung volume, providing the necessary parameters for flow rate and volume measurements. These measurements aid in identifying subjects with COPD, allowing for appropriate guidance based on the spirometer's findings.

Lung volume is obtained by integrating sample flow rate inputs, which are detected by an IR sensor. This information provides insights into individual lung capacities and volumes, facilitating the diagnosis of COPD in subjects.

V. Conclusion

The objective of the project was to develop a spirometer that is affordable and user-friendly for measuring lung volumes. Our approach involved incorporating sustainability and eco-friendly considerations into the design of the spirometer. By implementing a rotating turbine that is operated by the user, we were able to effectively measure both volume and flow rate, providing valuable information about lung capacities.

The implementation of our portable turbine spirometer enables accurate assessment of lung parameters, which is particularly beneficial for the early detection of conditions such as COPD. Additionally, the model’s compact size and low maintenance cost makes it highly portable and accessible to individuals from various backgrounds, ensuring that it is affordable and usable for a wide range of users.

A. Future scope of work

Spirometry can show airflow restrictions, but it cannot identify the cause. The functionality can be expanded to measure various other parameters.

By integrating oximetry and capnometry functions, the spirometer becomes more versatile, allowing for simultaneous measurement of oxygen, carbon dioxide, and volume parameters, thereby reducing diagnosis time and costs while enhancing diagnostic efficiency.

Future research can explore miniaturisation to make the spirometer more portable without compromising functionality. Wireless connectivity and smartphone applications could enable real-time data monitoring and analysis. Artificial intelligence techniques can also be utilised for advanced data interpretation and personalised respiratory care.

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References

[1] Abdulaziz Aladib, Zaid Hayek, Omar Kharsa “Spirometer” Published Online-2018 http://docs.neu.edu.tr/library/6682401378.pdf

[2] Seakale Chandrakar, “Design and development Of Low Cost Spirometer With PC Interface” Published Online - June 2014 https://raiith.iith.ac.in/127/1/EE12M1032.pdf

[3] Jeremy Glynn, Jeremy Schaefer, Andrew Dias, Andrew Bremer, “Low Cost Spirometer” Published Online- May 8 2009 https://bmedesign.engr.wisc.edu/projects/s09/spirometer/file/view/344d117e-e497-4b4c-9c5d-2a98f5322293/final_report.pdf

[4] AARC (American Association for Respiratory Care) http://www.aarc.org/headlines/08/11/copd_month/

[5] Spirometry https://byjus.com/biology/spirogram-diagram/

[6] P. T. Cheung, F. Zouari, A. Touboul, V. Sin, E. C. Wong and R. W. Chan, "3D EIT Enables Global and Regional Spirometric Lung Function Assessment," TENCON 2022 - 2022 IEEE Region 10 Conference (TENCON), Hong Kong, Hong Kong, 2022, pp. 1-6, doi: 10.1109/TENCON55691.2022.9978086.

[7] P. Sridevi, P. Kundu, T. Islam, C. Shahnaz and S. A. Fattah, "A Low-cost Venturi Tube Spirometer for the Diagnosis of COPD," TENCON 2018 - 2018 IEEE Region 10 Conference, Jeju, Korea (South), 2018, pp. 0723-0726, doi: 10.1109/TENCON.2018.8650092.

[8] T. Adiono et al., "Respinos: A Portable Device for Remote Vital Signs Monitoring of COVID-19 Patients," in IEEE Transactions on Biomedical Circuits and Systems, vol. 16, no. 5, pp. 947-961, Oct. 2022, doi: 10.1109/TBCAS.2022.3204632.