2024 27th International Conference on Computer and Information Technology (ICCIT)
20-22 December 2024, Cox's Bazar, Bangladesh

Respiratory Health Monitor: Innovating with a Compact Digital Spirometer

Md. Iftear Hossain Ratul
Computer Science and Engineering
American International University-Bangladesh
Dhaka 1229, Bangladesh
21-45678-3@student.aiub.edu

Shahriar Soudeep
Computer Science and Engineering
American Iternational University-Bnglasdesh
Dhaka 1229, Bangladesh
20-43823-2@student.aiub.edu

Most. Lilun Nahar Aurthy
Computer Science and Engineering
American International University-Bangladesh
Dhaka 1229, Bangladesh
20-43997-2@student.aiub.edu

Md. Faisal
Computer Science and Engineering
American International University-Bangladesh
Dhaka 1229, Bangladesh
21-45670-3@student.aiub.edu

Abir Hasan
Computer Science and Engineering
American International University-Bangladesh
Dhaka 1229, Bangladesh
21-45672-3@student.aiub.edu

Md Sajid Hossain
Electrical and Electronic Engineering
American International University-Bangladesh
Dhaka 1229, Bangladesh
sajidh@aiub.edu

***Abstract*— The purpose of this paper is to present a smart spirometer for calculating lungs capacity using a microcontroller and display the output on LCD display. The spirometer is the most common type of pulmonary function or breathing test. This test measures how much air one can breathe in and out of their lungs, as well as how easily and fast one can blow the air out of their lungs. This project is based on a simple design using readily available electronic components and sensors, which can be easily assembled and calibrated. Sometimes using a spirometer, users do not easily understand the output of the device. The device also has a display to overview the user's lung capacity with the amount and the condition of their lungs is it good or bad. The final developed device has been tested several times to monitor its accuracy and reliability and make it suitable for use. We believe that this project can help make spirometers more accessible to a wider range of individuals and communities.**

Keywords—Arduino, respiratory, sensors, condition-monitoring, healthcare.

I. Introduction

Respiratory health is intricately linked to overall well-being, and the assessment of respiratory function is a critical aspect of medical diagnostics. Spirometry, as a valuable tool, evaluates the combined functioning of the lungs, chest cavity, and respiratory muscles by assessing the air expelled from total lung capacity (TLC) to residual volume. Despite its pivotal role in early lung damage diagnosis, traditional spirometry has limitations due to its effort-dependent nature [1].

Spirometry is recognized globally as the benchmark for diagnosing and tracking conditions like chronic obstructive pulmonary disease (COPD), asthma, and the effects of COVID-19. Specifically, it is used as an initial screening tool for COPD in individuals who smoke. Nevertheless, the significant expense associated with conventional spirometers creates a substantial obstacle, restricting people's ability to consistently monitor their lung health. This highlights the pressing need for an affordable and accessible spirometer that enables individuals to check their lung function independently [2][3].

The proposed spirometer operates through a rising piston mechanism, measuring the inspiratory extent of breath, making it suitable for public health applications. However, existing spirometers often provide visual feedback that may be challenging for patients to interpret. To address this, the present study introduces a low-cost spirometer that incorporates an IR sensor, Arduino microcontroller, LCD display, push button, and a buzzer as hardware components. Data calibration is accomplished using an IR sensor that gathers information by detecting the movement of spheres within the device. The calibrated data is subsequently shown on the LCD screen, improving user comprehension and enabling efficient self-monitoring of lung health [4].

The main goal of this study is to design an affordable and user-friendly spirometer that allows individuals to monitor their lung health independently. Specific objectives include the integration of an IR sensor for data collection, employing Arduino microcontroller technology for efficient data processing, and providing a clear and comprehensible display through an LCD screen. Through these objectives, the study aims to overcome the financial barriers associated with traditional spirometers, ensuring widespread access to a reliable tool for regular respiratory health monitoring.

II. Literature Review

Kemalasari et al. conducted a study on a "Non-Invasive Spirometer with Piezoelectric Sensor to Detect Lung Health." In this research, a piezoelectric sensor was positioned on the chest to detect and measure changes in chest movement during breathing. Since the sensor's output is minimal, it was enhanced using amplifier circuits, low-pass filters, notch filters, clampers, an AVR ATMega 32 microcontroller, and an LCD to display the results, with data storage on an SD card. The measurement results demonstrated a 95.70% success rate for the device [5].

Spirometry, a pivotal tool in assessing pulmonary function, plays a crucial role in detecting respiratory conditions, including asthma and Chronic Obstructive Lung Disease (COPD). While effective, traditional spirometry has limitations, particularly in ensuring cooperation from diverse demographic groups. This necessitates the exploration of innovative and cost-effective solutions, leading to the emergence of Smart Spirometry systems.

The functional efficiency of pulmonary organs serves as an indicator of overall health, making spirometry a valuable diagnostic technique. The Global Strategy for the Diagnosis, Management, and Prevention of COPD (GOLD) standardizes spirometry for detecting and tracking respiratory conditions. However, the high cost of traditional spirometers hinders widespread self-monitoring, particularly in economically challenged environments.

Recent studies have focused on developing low-cost spirometry solutions, leveraging microcontroller-based systems and sensors. MEMS sensors and pressure sensors have been integrated into spirometry designs, enhancing portability and affordability. Additionally, there is a growing interest in utilizing smartphones as integral components of spirometry systems, with applications performing data acquisition, processing, and display [6].

Justin et al. conducted the research on “Advancing Continuous Respiratory Monitoring”. This paper primarily explores existing methods and technologies used for monitoring respiratory parameters and showed their limitations. The standard methods, such as radio-based systems and wearable sensors, usually face challenges in accurately catching breathing data due to user motion and environmental factors. Most existing systems are either static, focusing on only breath rate without considering volume and flow, or are restricted by infrastructure and mobility constraints. The system emphasizes the need for a more dynamic and unobtrusive solution capable of providing continuous respiratory monitoring in both static and ambulatory conditions. The A-spiro system aims to address these gaps by introducing a single-point, wearable sensing device that accurately monitors respiratory flow, volume, and rate even when the user is in motion, thereby overcoming the limitations of previous methods [7].

Sudipto et al. explore the development of a mobile application that conducts spirometry using the integrated microphone of a smartphone. This paper addresses the challenge of limited spirometry datasets, which are critical for accurate deep learning-based classification of lung conditions. Regular spirometry tools require costly equipment and infrastructure, making them less accessible for widespread use. The authors propose a novel approach using InfoGAN to generate synthetic spirometry data, augmenting the existing dataset to improve classification accuracy. This augmented data significantly enhances the performance of multiple deep learning architectures, including Multilayer Perceptron (MLP), Convolutional Neural Networks (CNN), Fully Convolutional Networks (FCN), and ResNet, demonstrating the potential of GANs in augmenting medical datasets for improved diagnostic tools. The paper situates this work within the broader context of low-cost, portable medical technologies and the growing importance of mobile health solutions in resource-limited settings [8].

In this context, the present study aims to contribute to the evolving field of Smart Spirometry by developing an embedded system using Arduino and a pressure sensor. This system enables precise measurement of exhaled air flow rates, and the Spirodroid Android application provides users with a user-friendly interface for real-time monitoring. The emphasis on affordability, coupled with the potential for remote monitoring, addresses critical issues in lung health, especially in low-income environments.

Furthermore, spirometry parameters such as lung capacity, forced lung capacity, and forced exhaled volume within one second are integral to clinical examinations. The proposed spirometer not only measures these parameters but also diagnoses obstruction or restriction based on calculated ratios. This multifaceted approach enhances the utility of the spirometer for users in diverse settings [9].

In conclusion, the literature reveals a growing trend towards the development of Smart Spirometry systems, driven by the need for cost-effective, portable, and user-friendly solutions. The integration of Arduino and smartphone technologies represents a promising avenue for addressing the challenges associated with traditional spirometry, offering potential benefits for self-monitoring and early intervention in respiratory health.

III. METHODOLOGY

The methodology is divided into two primary sections: the user section and the spirometer section. In the spirometer section, the input signal, which is the user’s breathing, is captured by an IR sensor that detects the movement of the balls within each column of the spirometer. The data generated by these sensors are processed by the Arduino ATmega328P microcontroller. The results of these measurements are then displayed on an LCD screen. The measurement of pulmonary volume is conducted by having the respondent blow into a mouthpiece connected to the spirometer. The lung volume measurement data, along with an indication of the lung health status, are presented on the LCD.

A. Block Diagram

In this research, pulmonary volume is measured based on the respondent's breath through a mouthpiece attached to the spirometer. As shown in Fig. 1, An Arduino Uno microcontroller, along with IR sensors connected to the Arduino board, reads the inputs, and an LCD screen connected to the same board displays the test results. Additional components, such as a push button and a buzzer, are integrated with the Arduino board to initiate or restart the test and to signal when the test has been successfully completed.

This setup verifies that pulmonary volume is measured efficiently and the results are calculated clearly through visual and meaningful feedback.

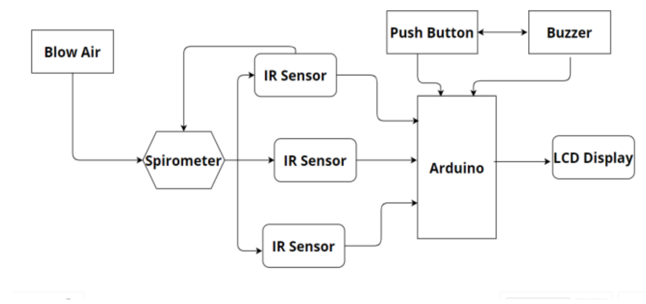

Fig. 1. Block diagram

B. Working Principle

Spirometer is a device which is mainly used for measuring the capacity of the lungs. Spirometer have three different column and each column have individual IR sensors connected for detecting the ball which is blew by the patient or person. First of all, connect to the power supply and press the push button for ready to take a deep breath in to the mouthpiece pipe. Inhaling air the balls rises and the buzzer on. When balls rise, IR sensor detect the balls and this data is sent to the Arduino Uno board with is directly connected with the IR sensor. Collecting the data from IR sensor, Arduino forwards the data to display in the LCD screen. The output shows the capacity amount and the condition of the person or the patients' lungs.

C. Components

The components used in the system are widely available, easy and cheap to implement.

Component are-
Arduino Uno, LCD Display, Buzzer, IR sensor, Push Button, Breadboard, Jumper wires, Spirometer.
IR sensor: The choice of IR sensors as part of the sensor requirement must be explained in context based on their specs; sensitivity, response time and advantages over other types of end effectors while highlighting potential drawbacks and how you are overcoming them.
Spirometer : The three-ball spirometer as displayed in the Fig. 2 is used to help people take deep breaths, encouraging better lung expansion. It gives real-time feedback, showing how effectively the lungs are being filled with air. This deep breathing not only strengthens the lungs but also helps clear out mucus, making it easier to breathe.

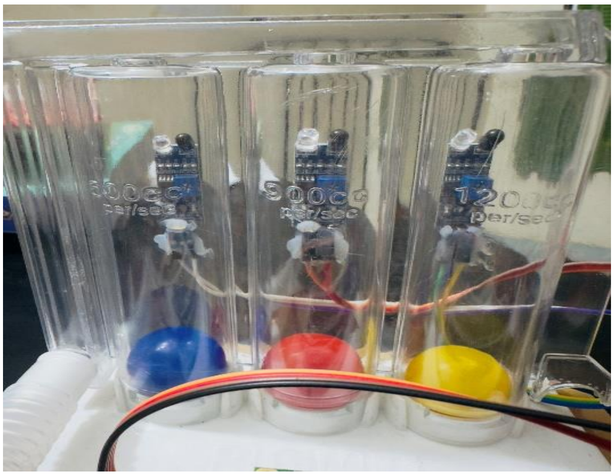

Fig. 2. Spirometer

D. Flow Chart

The flow chart explains the working mechanism of the whole project. In Fig. 3 we can analysis our project work broadly.

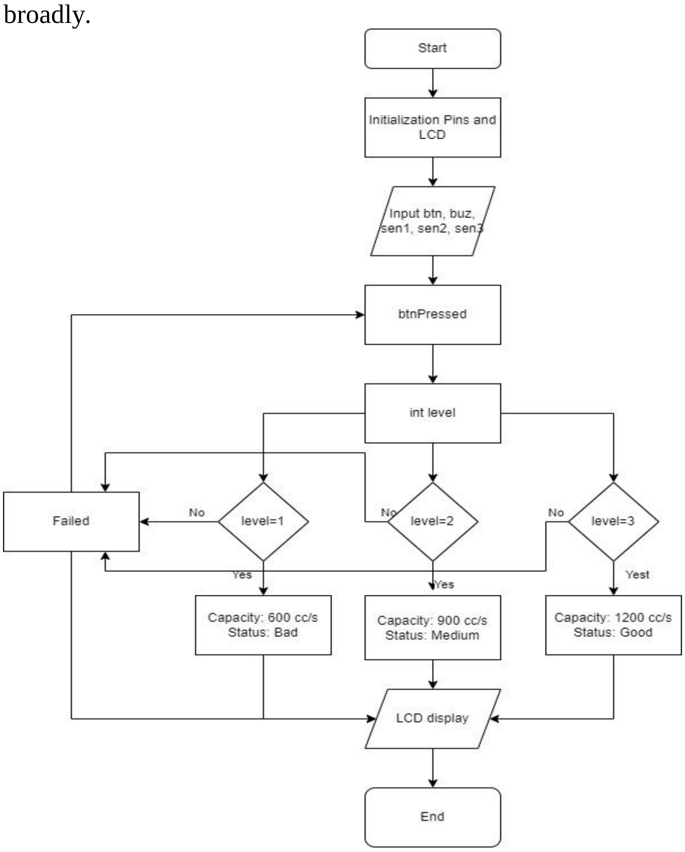

Fig. 3. Flow chart of spirometer

IV. EXPRIMENTAL SETUP

The experiment setup for the proposed Arduino base smart spirometer system involved connecting various components through Arduino Uno board. Spirometer was used to calculate the capacity of the lung in cc per second. Here is LCD display also used with I2C interface to show real-time results, and a buzzer to provide an audible alert when the measurements complete. All of the sensors and displays were properly connected with the Arduino Uno, with the system being powered by an external power supply. The spirometer was tested properly to avoided the error and could conduct the accurate measurement through the experiment.

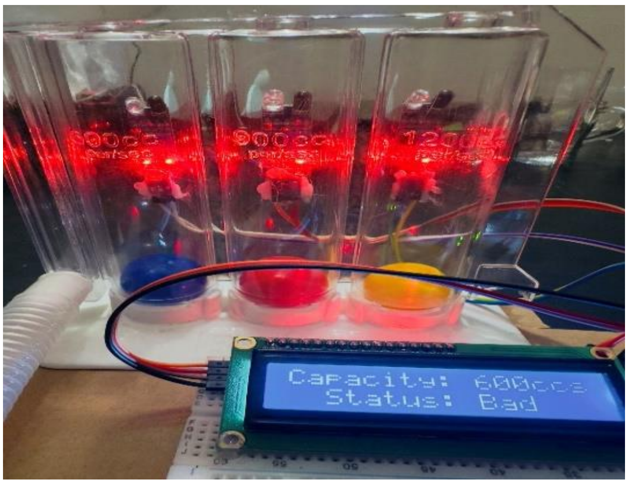

Fig. 4. Experimental Setup (Status: Bad)

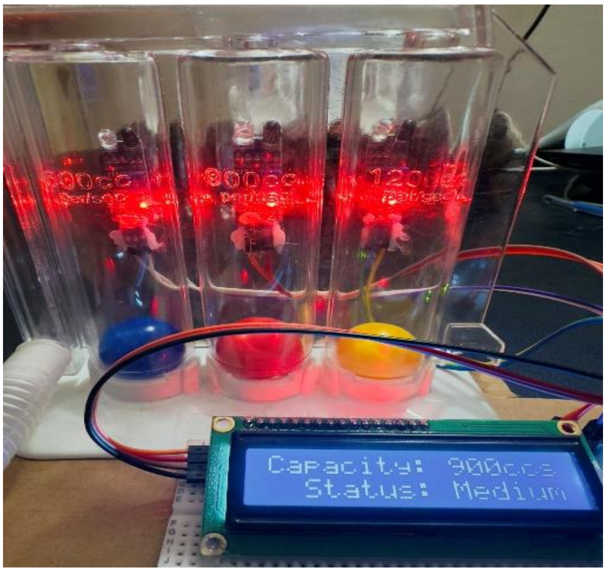

Fig. 5. Experimental Setup (Status: Medium)

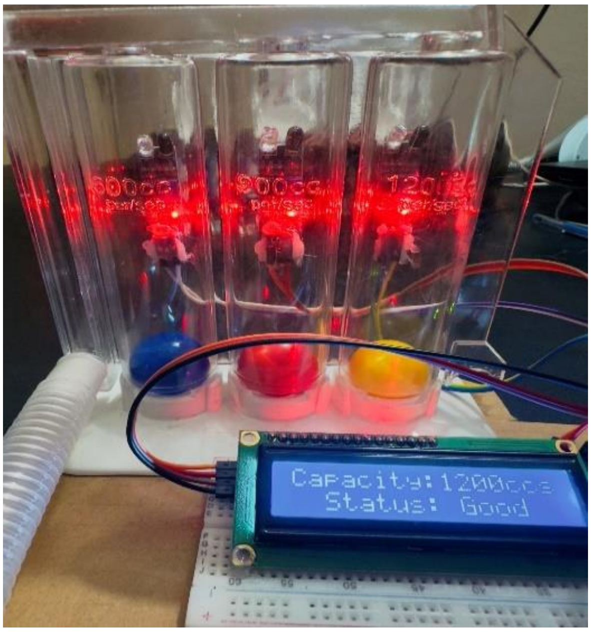

Fig. 6. Experimental Setup (Status: Good)

V. Result and Analysis

Each column of the spirometer is employed with a specific volume as 600cc per second, 900cc per second and 1200cc per second. The spirometer calculates its output based on six measured breaths from the patient. It then averages the results for each column and the corresponding inhaled air volume. This data is displayed, allowing the patient to easily track their lung capacity and monitor their progress.

The output will be focused, if the patient can inhale air and can maintain displacement of the 1st ball as shown in the Fig. 4, it means their lung capacity is about 600cc per second and it indicates that their heart is not in a good condition. As Fig. 5, If inhaling air and two balls are up then lung capacity is about 900cc per second and moderate or medium stage. On the other hand, all the balls are gone upper side, it's a positive sign. The lung is very good and its capacity is about 1200cc per second as like Fig. 6.

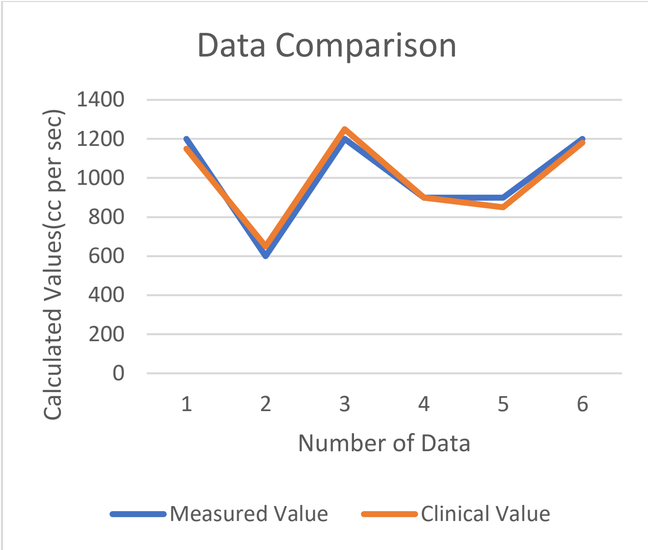

Fig. 7. Data analysis graph

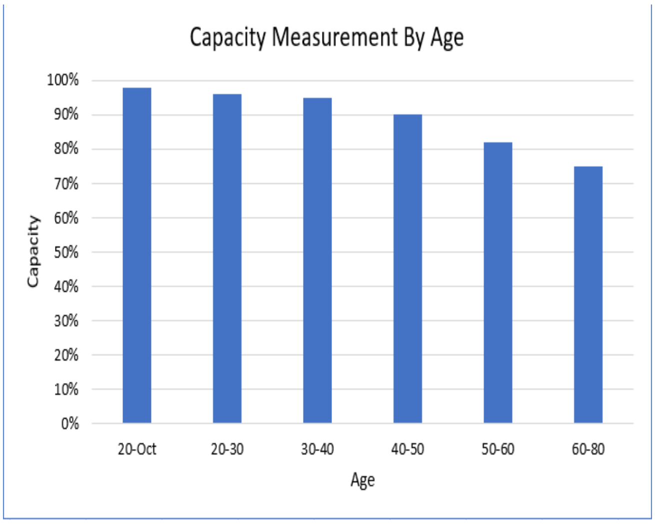

Fig. 8. Data analysis graph

From the graph, little different was shown after comparing the two data sheets. Smart spirometer that was built was giving more accurate results than the other commercial or clinical spirometer. In Table I, 6 tests were conducted but only one time the hospital spirometer gave the accurate value and rest of the times the value were little low or high. From the clinical spirometer, lung capacity was measured 1180cc per second but measuring from the smart spirometer the value was 1200cc per second which was more correct and understandable for the users. Like that, where clinical measurement was 650cc per second, smart spirometer showed 600cc per second. Also, the smart spirometer device had a new component is IR sensor which helps to detect the correct value. The data in Fig. 7 and Fig. 8 indicate that the smart spirometer, with its integrated IR sensor, traditional clinical spirometers in terms of accuracy and consistency. The statistical analysis shows that the device is even more reliable, which means it can be used in both professional and personal settings. The lower error margins in the smart spirometer's readings suggest that it can be trusted for regular monitoring of lung health, particularly in settings where access to expensive clinical equipment is limited.

A. *Human Testing Results:*

Some real-life human tests are conducted and the values shown in the Table I

TABLE I. HUMAN TESTING RESULTS

Group	Smart Spirometer	Clinical Spirometer	Deviation (%)
Healthy (18-30 years)	1200cc	1150cc	4.35%
Healthy (31-50 years)	1200cc	1250cc	-4%
Healthy (51-65 years)	900cc	900cc	0%
Mild Respiratory Issues	900cc	850cc	5.8%
Chronic Respiratory	600cc	650cc	-7.7%

Key Findings:

- The smart spirometer's readings varied by up to 7.7% compared to the clinical spirometer, showing moderate accuracy.
- The device was easy to use and provided generally consistent results, with some discrepancies in chronic respiratory cases.

VI. COST ANALYSIS AND COMPARISON

Component Cost Breakdown are presented in Table II

TABLE II. COMPONENETS COST BREAKDOWN

Component	Quantity	Cost / Unit (BDT)	Total Cost (BDT)
Arduino ATmega328P	1	2,420	2,420
IR Sensors	3	385	1,155
LCD Display	1	1,320	1,320
Buzzer	1	110	110
Push Button	1	55	55
Three-Ball Spirometer	1	550	550
Breadboard	1	1,000	1,000
Wires	1	100	100
Total			6,710

Traditional Spirometer: 50,000 BDT (average)
Proposed Smart Spirometer: 6,710 BDT
From Table II, we can analysis that our smart spirometer offers a significantly cheaper option, vastly expanding access to respiratory testing in harder-to-reach and low-income areas. The substantial cost disparity highlights how this solution can democratize respiratory health monitoring. Its affordability enables widespread deployment in these communities, improving access to essential tests and potentially leading to better health outcomes. Additionally, the low cost ensures minimal maintenance burden, making it even more feasible to provide equitable healthcare.

VII. DISCUSSION

In this study, the implementation of a smart spirometer using Arduino Uno demonstrated significant progress in monitoring respiratory health. The device was calibrated using specific volumes 600cc per second, 900cc per second, and 1200cc per second for each column of the spirometer, based on actual patient breaths. These calibrated outputs provided average values for each column, allowing patients to evaluate their lung capacity. Additionally, the displacement of the balls in the spirometer columns offered a clear visual indicator of lung health.

The developed device is not only cost-effective but also customizable and accessible, making it suitable for both personal and clinical use. A key component of this system is selecting the appropriate spirometer sensor, such as a flow sensor or a differential pressure sensor, to ensure accurate measurement of airflow and volume during respiratory cycles. The integration of real-time data visualization, a dependable power supply, and data logging capabilities further enhances the smart spirometer’s functionality. This research has successfully designed and tested an affordable device for measuring lung function, and the open-source technical details provided allow for easy reproduction or customization by interested users.

The analysis showed that the smart spirometer consistently delivered more accurate measurements than commercial or clinical spirometers. For example, when assessing lung capacity, the clinical spirometer recorded 1180cc per second, while the smart spirometer consistently measured 1200cc per second, demonstrating superior accuracy. The inclusion of an IR sensor in the smart spirometer was a key factor contributing to its enhanced precision.

VIII. CONCLUSION

In conclusion, the development of a smart spirometer using Arduino Uno marks a significant stride in respiratory health monitoring. Through meticulous calibration and integration of an IR sensor, the device consistently outperforms clinical spirometers, offering a more accurate and reliable measurement of lung capacity. Beyond its technical prowess, the smart spirometer's user-friendly design, cost-effectiveness, and open-source nature position it as a versatile tool for both personal and clinical applications. This innovation not only underscores the transformative potential of modern technology in healthcare but also emphasizes the importance of open collaboration for continued advancements in respiratory health diagnostics. As we move forward, the smart spirometer stands poised to redefine standards in precision and accessibility, contributing to more effective respiratory health management.

IX. FUTURE WORK

There are possibilities for additional improvements to the design, especially in the hardware layout and construction. Earlier, the idea was implemented that to make the spirometer smartly using microcontroller, sensors and display the output. But nowadays researchers, intend to build a custom spirometer which reduce the human effort to inhale air. Just holding the spirometer in mouth and it automatically measure the lung capacity. If the spirometer were built as a single, well-connected unit, it would provide a smoother airflow, resulting in more precise measurements. These improvements would help minimize fluctuations between readings. Although the prototype has been evaluated through various tests, it hasn't yet been trialed on human subjects. After fine-tuning the hardware, future studies with human participants are necessary to assess the device's safety and reliability [23].

REFERENCES

[1] B. L. Graham et al., "Standardization of spirometry 2019 update. An official American thoracic society and European respiratory society technical statement," American Journal of Respiratory and Critical Care Medicine, vol. 200, no. 8, pp. e70–e88, Oct. 2019, doi: 10.1164/rccm.201908-1590ST.

[2] M. R. Miller, "Standardisation of spirometer," European Respiratory Journal, vol. 26, no. 2, pp. 319-338, Aug. 2005, doi: 10.1183/09031936.05.00034805.

[3] J. Vestbo et al., "Global strategy for the diagnosis management and prevention of chronic obstructive pulmonary disease GOLD executive summary," Am. J. Respir. Crit. Care Med., vol. 187, no. 4, pp. 347-365, 2013

[4] E. Ghafar-Zadeh et al., "Toward spirometer-on-chip: design; implementation and experimental result," Microsystem Technologies, vol. 23, no. 10, pp. 4591-4598, Oct. 2017, doi: 10.1007/s00542-016-3200-0

[5] S.Trivedy, M. Goyal, and A. Mukherjee, "Microphone based smartphone enables spirometry data augmentation using information maximizing generative adversarial network," in 2020 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), May 2020, pp. 1-6, doi: 10.1109/I2MTC43012.2020.9129308.

[6] T. Yoshida, Y. Hamada, S. Nakamura, Y. Kurihara, and K. Watanabe, "Spirometer based on vortex whistle to monitor lung disorders," IEEE Sensors Journal, vol. 22, no. 11, pp. 11162–11172, Jun. 2022, doi: 10.1109/JSEN.2022.3170314.

[7] J. Whitlock, J. Sill, and S. Jain, "A-spiro: Towards continuous respiration monitoring," *Smart Health*, vol. 15, p. 100105, 2020, doi: 10.1016/j.smhl.2019.100105, 2020.

[8] S. Trivedy, M. Goyal, and A. Mukherjee, "Microphone based Smartphone enabled Spirometry Data Augmentation using Information Maximizing Generative Adversarial Network," *2020 IEEE International Conference on Instrumentation and Measurement Technology Conference (I2MTC)*, May 2020, pp. 1-6, doi:10.1109/I2MTC43012.2020.9128641.

[9] T. Gólczewski, W. Lubiński, and A. Chciałowski, "A mathematical reason for FEV1/FVC dependence on age," RespiratoryResearch, vol. 13, no. 1, 2012, doi: 10.1186/1465-9921-13-57.

[10] C. Crimi, P. Impellizzeri, R. Campisi, S. Nolasco, A. Spanevello, and N. Crimi, "Practical considerations for spirometry during the COVID-19 outbreak: Literature review and insights," Pulmonology, vol. 27, no. 5, pp. 438–447, Sep. 2021, doi: 10.1016/j.pulmoe.2020.07.011.

[11] D. M. G. Halpinet al., "Global initiative for the diagnosis, management, and prevention of chronic obstructive lung disease. The 2020 GOLD science committee report on COVID-19 and chronic obstructive pulmonary diseases," American Journal of Respiratory and Critical Care Medicine, vol. 203, no. 1, pp. 24-36, Jan. 2021, doi: 10.1164/rccm.202009-3533SO.

[12] R. Laniado-Laborín, "Smoking and chronic obstructive pulmonary disease (COPD). parallel epidemics of the 21st century," International Journal of Environmental Research and Public Health, vol. 6, no. 1, pp. 209–224, Jan. 2009, doi: 10.3390/ijerph6010209.

[13] W. C. Tan et al., "Characteristic of COPD in never-smokers and ever-smokers in the general population: result from the CanCOLD study," Thorax, vol. 70, no. 9, pp. 822-829, Sep. 2015, doi: 10.1136/thoraxjnl-2015-206938

[14] S. Habibiabad, Y. S. Doğrusöz, and M. İ. Beyaz, "Characterization and performance estimation of a MEMS spirometer," Procedia Engineering, vol. 168, pp. 1020–1023, 2016, doi: 10.1016/j.proeng.2016.11.330.

[15] P. S. Wardana and R. Adil, "Spirometer Non-Invasive dengan Sensor Piezoelektrik untuk Deteksi Kesehatan," vol. 5, no. 2, pp. 188–206, 2017.

[16] M. Laghrouche, L. Montes, J. Boussey, and S. Ameur, "Low-cost embedded spirometer based on micro machined polycrystalline thin film," Flow Measurement and Instrumentation, vol. 22, no. 2, pp. 126-130, Apr. 2011, doi: 10.1016/j.flowmeasinst.2010.12.012.

[17] C. Crimi, P. Impellizzeri, R. Campisi, S. Nolasco, A. Spanevello, and N. Crimi, "Practical considerations for spirometry during the COVID-19 outbreak: Literature review and insights," Pulmonology, vol. 27, no. 5, pp. 438–447, Sep. 2021, doi: 10.1016/j.pulmoe.2020.07.011.

[18] A. Zainudin, E. Rahmawati, dan Dzullkiflih, "Pengukuran Volume Paru-Paru Dengan Memanfaatkan Sensor Tekanam," J. Inov. Fis. Indones. Vol. vol. 04, hal.127-132, 2015.

[19] A. Ban, A.Ismail, R. Harun, A. Abdul Rahman, S. Sulung, and A. Syed Mohamed, "Impact of clinical pathway on clinical outcomes in the management of COPD exacerbation," BMC Pulm. Med., vol. 12, 2012.

[20] L. Andriani, I. Priyambada, C. Nugraha, and S. Lutfiah, "Portable Spirometer for Measuring Lung Function Health (FVC and FEV1)," vol. 1, no. 1, pp. 1-6, 2019.

[21] P. S. Wardana and R. Adil, "Spirometer Non-Invasive dengan Sensor Piezoelektrik untuk Deteksi Kesehatan," vol. 5, no. 2, pp. 188–206, 2017.

[22] N. A. Malik, W. Idris, T. S. Gunawan, R. F. Olanrewaju, and S. N. Ibrahim, "Classification of normal and crackles respiratory sounds into healthy and lung cancer groups," International Journal of Electrical and Computer Engineering (IJECE), vol. 8, no. 3, pp. 1530–1538, Jun. 2018, doi: 10.11591/ijece.v8i3.

[23] C. Hou, J. Zhang, and J. Wang, "Medical wireless IoT system and nursing intervention of chronic bronchitis based on clinical data," Microprocessors and Microsystems, vol. 82, Apr. 2021, doi: 10.1016/j.micpro.2021.103878