

Development of a Real-Time Spirometry Diagnostic Device for Pulmonary Function Assessment Using Flow Sensor and Android Display

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ABSTRACT

Accurate and convenient measurement of lung function is an important requirement in medical diagnosis. This research was previous research by changing the pressure sensor to develop a flow meter sensor and using an Android display on an Android server. The spirometer tool was developed using an ESP32 microcontroller and a flow meter sensor, the measurement results of which are displayed in real-time on the Nextion LCD and Android server. The measured data includes FVC and FEV1 parameters, with hotspots used to connect the device to the server. Measurements using this tool show the highest error of 0.36% in the FVC parameter and 0.86% in the FEV1 parameter. The lowest error was recorded at 0.01% for FVC and 0.13% for FEV1. Real-time measurement results can be viewed via the Nextion LCD and also accessed via Android devices. The patient's lung volume can be measured accurately and visualized in graphical form. The use of a flow meter sensor connected to an ESP32 microcontroller has proven effective for detecting changes in air flow during patient breathing. The measurement results are stable with a very small error rate. Integration with Android servers makes it easy to monitor results digitally and in real-time. Overall, this device offers a practical and efficient solution for the diagnosis of pulmonary conditions. It can be concluded that the flow meter sensor used in this spirometer can measure lung volume accurately with a very small error rate. This tool can be an effective alternative for real-time and easily accessible FVC and FEV1 measurements.

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1. INTRODUCTION

The respiratory system is one of the essential systems in the human body and plays a critical role in maintaining adequate gas exchange [1], [2], [3]. Respiratory function can be evaluated through pulmonary function tests, one of the most commonly used methods being spirometry. Therefore, Unlike respiratory rate monitoring, which primarily measures the number of respiratory cycles per minute, spirometry provides quantitative measurements of respiratory airflow and lung volumes during forced or normal breathing maneuvers [4], [5], [6]. Respiratory rate assessment and monitoring is essential for patients with chronic diseases, athletes, and individuals undergoing rehabilitation, so monitoring respiratory signals is necessary to identify the causes and health impacts that occur [7], [8], [9], [10]. Thus, it is important to ensure proper implementation of spirometry in order to reduce the risk of delayed treatment and prevent fatal misdiagnosis for patients [11], [12].

Respiratory disorders remain an important health concern worldwide [13],[14], [15], [16]. Respiratory rate is an important parameter in Covid-19 examination [17], [18]. COPD, for example, is a major chronic

respiratory disease associated with persistent airflow limitation and symptoms such as shortness of breath, wheezing, and chronic coughing [19] [20]. Obstructive sleep apnea (OSA) is another respiratory disorder characterized by repeated upper-airway obstruction during sleep, which can lead to intermittent hypoxia and increase the risk of cardiovascular and cerebrovascular complications [21], [22], [23], [24]. This condition is a lung disorder characterized by inflammation and narrowing of the airways, resulting in shortness of breath, wheezing, and attacks that can be life-threatening [25], [26], [27], [28]. These conditions highlight the importance of accurate pulmonary function assessment to support early detection, monitoring, and clinical decision-making [29], [30]. therefore, spirometry is required when quantitative assessment of lung function is needed [31], [32].

A spirometer is a medical device used to measure the volume and flow of air inhaled and exhaled by a subject [33], [34]. Spirometry is the most common method used by pulmonologists to evaluate lung function in patients with COPD, asthma, and monitor obese patients. Spirometer calibration needs to be done regularly because the results are very important for medical diagnosis [35], [36], [37], [38]. Apart from that, there is also a need for specific spirometry reference values to improve the detection and management of lung disorders [39], [40]. Improving the quality and reliability of spirometry tests is important for early detection and management of lung conditions in the work environment. An understanding of the factors that influence testing and training for technicians can improve outcomes and effectiveness in respiratory health management [41], [42].

Conventional spirometry systems may involve relatively bulky instrumentation and limited mobility. This limitation can make pulmonary function assessment less convenient when measurements are required outside conventional clinical settings. The development of portable spirometry systems therefore provides an opportunity to improve the flexibility and accessibility of pulmonary function testing. accurate without invasive procedures [43], [44], [45]. The sensor measures air flow with Bernoulli's Law, which states that an increase in flow velocity causes a decrease in pressure. This allows the sensor to provide accurate data on flow velocity and is important for optimizing design as well as measurement accuracy [46]. Remote spirometer monitoring is effective and well accepted, making it an important component in the management of lung disease [47]. The wireless module allows direct data transmission, making the spirometer more portable and integrated with medical systems [48]. Android-based mobile applications increase the efficiency of communication between patients and doctors. With this app, patients can monitor their health conditions independently, potentially improving treatment outcomes [49], [50], [51]. Although home spirometry offers flexibility, results are often less consistent than in-clinic measurements. Therefore, monitoring and evaluating pulmonary function test results is still necessary so that the resulting spirometry data is more accurate [52], [53], [54]. For its use in clinical practice, adjustments in data interpretation are essential so that results from home spirometry can be more appropriately used in medical decision making [55].

In early 2021, Jung-Yoon Kim and his team developed a respiratory monitoring system that uses channel status information from commercially available Wi-Fi devices. In this study, they successfully extracted respiratory parameters from Wi-Fi signals and estimated relative tidal volume. However, this study did not provide data display via Android devices [56].

Despite advances in portable and wireless respiratory monitoring technologies, there remains a need for a spirometry device that integrates airflow measurement, real-time data visualization, and wireless connectivity within a compact and portable system. More accurate portable spirometers with real-time monitoring and data display on the Android platform are needed to address these issues. This study aims to address this gap by developing a portable spirometer that replaces traditional pressure sensors with flow sensors, improving measurement accuracy. The device will be equipped with real-time data display on the Nextion LCD platform and use bluetooth connection to Android devices, offering a more reliable and accessible solution for monitoring lung function. This innovation is expected to improve the management and diagnosis of respiratory conditions, as well as overcome the limitations of existing spirometry devices

2. METHOD

This research focuses on the development of a spirometer for measuring pulmonary function based on respiratory airflow during forced expiration. The main spirometric parameters measured are Forced Vital Capacity (FVC) and Forced Expiratory Volume in the first second (FEV1). FVC is calculated as the total volume of air exhaled during a forced expiratory maneuver, which is obtained by integrating the measured airflow over the duration of expiration. Meanwhile, FEV1 is calculated as the cumulative volume of air exhaled during the first one second of the forced expiration. The values and graphics will be display on the nextion LCD and Android Display.

2.1 Materials

2.2.1. Flow Rate Sensor

Flowmeter serves as the main tool for measuring gas. This tool detects the amount of air flow that passes through its sensor. Thus, we can know the volume of air flowing accurately [57].

2.2.2. ESP32

The ESP32 microcontroller, with Bluetooth and WiFi features, provides a flexible and economical solution for educational purposes [58]. The ESP32 microcontroller is capable of collecting and processing data from sensors to activate the system automatically [59]. This device has been shown to be capable of consistently sampling sensors at high speeds with excellent stability [60], [61].

2.2.3. LCD Nxtion

Nxtion LCD is a TFT display that is quite widely used because of its convenience. This display supports serial communication, so it is easy to connect to various devices. In addition, Nxtion LCD has a display editor that makes it easy for users to design the interface. These features make it suitable for projects that require practical control and display.

2.2 Diagram Block

A diagram block functions to provide a comprehensive overview of the structure and workflow of a device by displaying the main components and their functional relationships. **Fig.1** shows the block diagram for this device



Figure. 1. The Diagram Block of Real-Time Lung Function Measurement with Flow Meter and Android Display

This study involves the use of a funnel for respondents to blow air. Then the flow rate sensor will detect the analog signal received and will be forwarded to the ESP 32 in the form of a digital signal. This sensor functions to convert analog data into digital data, which will then be converted into volume units using the Bernoulli equation. The ESP32 microcontroller will transmit data to the Nxtion LCD via the TX and RX pins. The results of lung volume measurements will be stored in the form of values and graphs. The values will then be converted into graphs manually. Then, the results will be sent by the ESP32 to the Android device in the form of values and graphs.

2.3 Flowchart

A flowchart functions to visually represent the sequence of steps or processes in the creation of a device. It provides a structured guide for the development and maintenance of the device. **Fig. 2** will display the flowchart for this device.

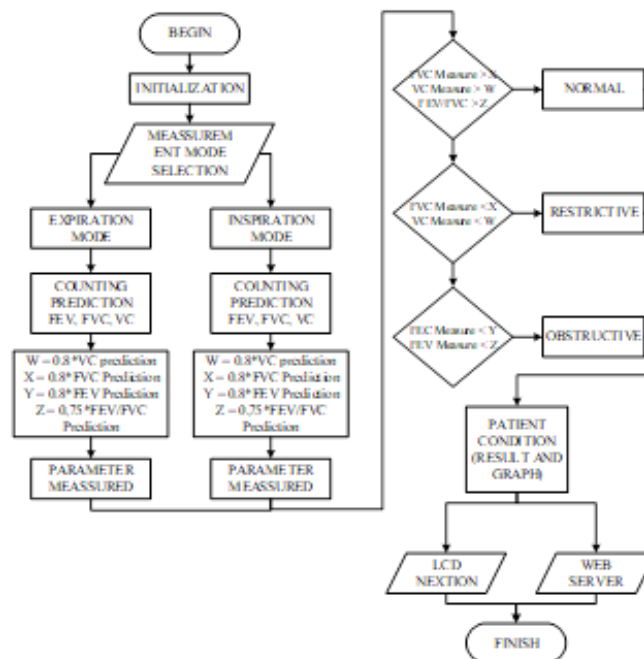


Figure. 2. Flowchart of Real-Time Lung Function Measurement with Flow Meter and Android Display

On this flowchart when the tool is turned on, the system will initialize. Then the user is asked to enter the patient's personal data and the program will calculate the predicted value. To determine the parameters to be measured, the user is asked to press a button to take measurements which will then be processed by ESP32. The processed data will be displayed on the LCD as well as Android via wireless by ESP32

2.4 Spirometer Hardware Circuit

Can be seen in the circuit above, the circuit above is powered by a lithium battery with a current of 2000 mAh with a voltage of 3.7V. This battery can be recharged using a charger module. When the circuit is on, the battery will flow through all circuits and the flow sensor can read the air flow. After the air flow is read by the flow, the output is in the form of an ADC and will be received by the ESP 32. the results will be displayed via the nextion LCD and also sent via the internet by the ESP32 to be displayed on the android application.

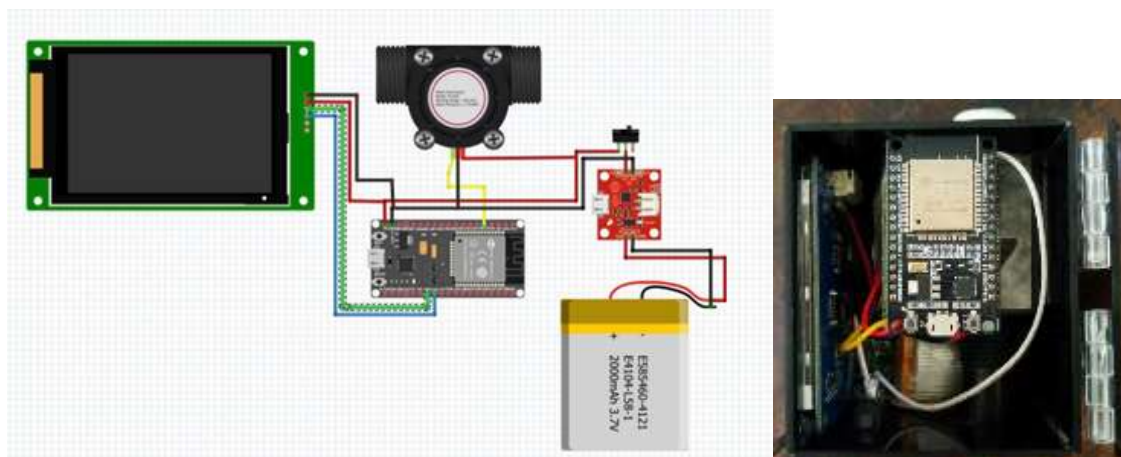


Figure . 3. Wiring Diagram and module of Real-Time Lung Function Measurement tool with Flow Meter and Android Display

2.5 Data Collection

This study uses 2 criteria, namely the measurement of the age between. The measurement is carried out for ages over 20 years. And the measurement is carried out for height 150-172 cm. The measurement is carried out using the expiration and inspiration method.

3. RESULTS AND DISCUSSION

3.1. Result

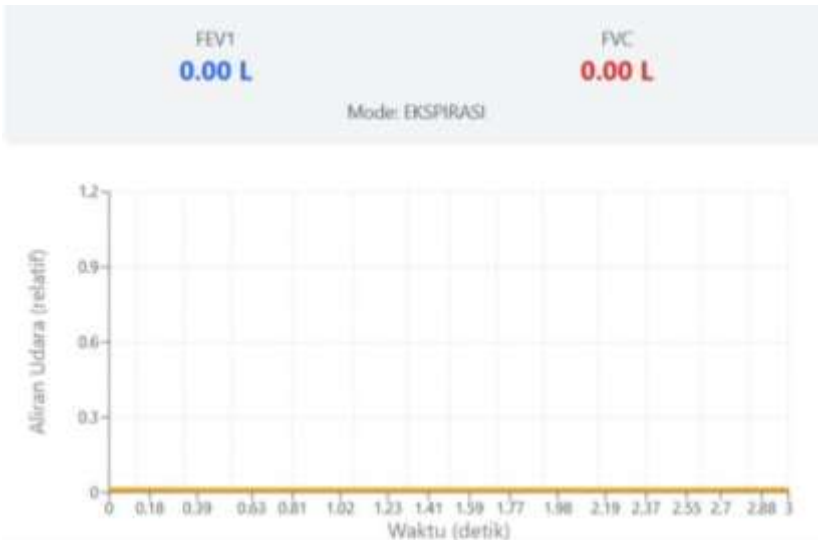
The developed spirometer was tested into two measurement modes, namely expiration and inspiration, to observe the response of the flow sensor and resulting spirometric parameters. The measured parameters were Forced Expiratory Volume in the first second (FEV1) and Forced Vital Capacity (FVC). During the expiration measurement, the subject was instructed to perform a forced expiratory maneuver by exhaling as forcefully as possible through the spirometer. During the inspiration measurement, the subject was instructed to inhale through the device. The measurement results were processed by the microcontroller and displayed numerically and graphically on the Nextion LCD and Android application.

The results obtained from the tested subject are presented in Table 1. In the expiration mode, the system recorded an FEV1 value of 0.53 L and an FVC value of 0.87 L. In the inspiration mode, the recorded values were 0.57 L for FEV1 and 0.70 L for FVC. These results demonstrate that the developed system was able to acquire airflow-related data and generate FEV1 and FVC values in both measurement modes.

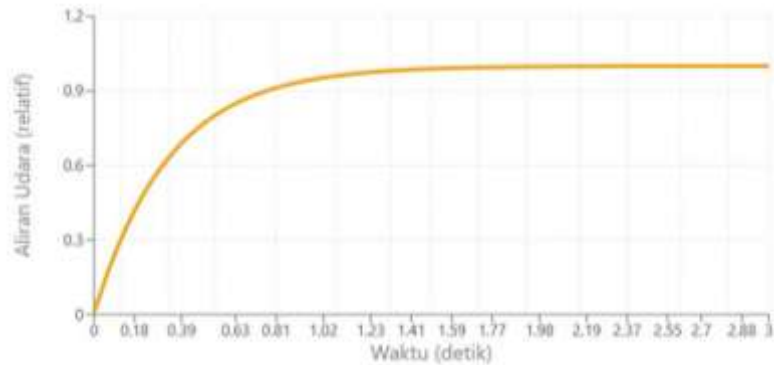
However, the results in Table 1 should be interpreted as an initial functional evaluation of the developed device rather than as evidence of measurement accuracy. The measured values cannot be classified as accurate or inaccurate solely from the values obtained from the developed spirometer because no reference values or measurements from a standard clinical spirometer are presented in this study. In addition, FEV1 and FVC are primarily determined from forced expiratory maneuvers; therefore, the inspiration-mode results should be considered as airflow measurement data and should not be interpreted as equivalent to standard FEV1 and FVC measurements obtained during forced expiration.

To establish the measurement accuracy and reliability of the developed spirometer, further testing is required using an appropriate reference standard, such as a calibrated clinical spirometer or a validated airflow calibration system. The evaluation should involve multiple subjects and repeated measurements, followed by quantitative comparison between the developed device and the reference instrument. Such evaluation can provide objective measures of measurement error, agreement, and repeatability.

Table 1. Initial measurement Results of the Developed Spirometer in Expiration and Inspiration Mode

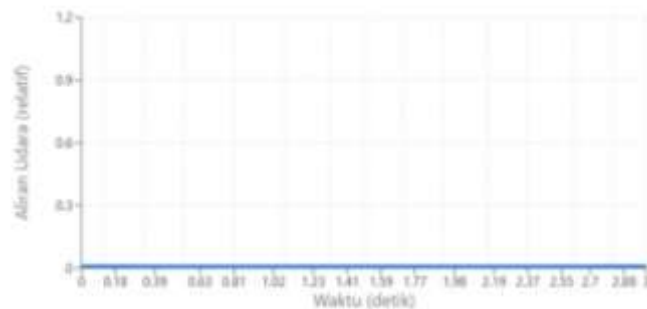
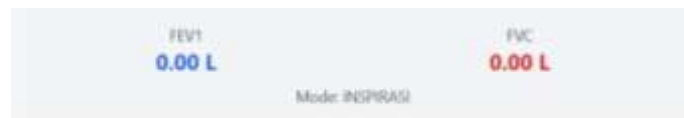
Mode	Result	
	Value (L)	Picture
Expiration		
Deaflut state	FEV1:0 FVC:0	

Measurement result
FEV1:0.53
FVC:0.87

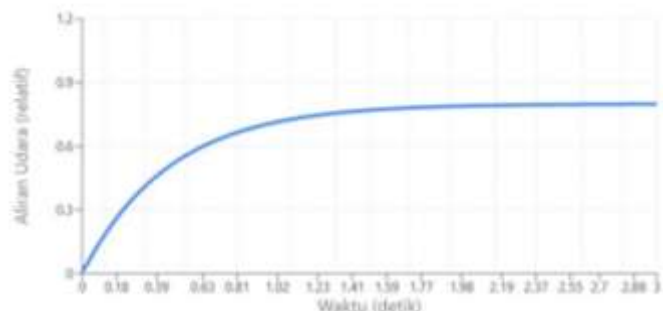


Inspiration

Measurement result
FEV1:0
FVC:0



Measurement result
FEV1:0.57
FVC:0.7



3.2. Discussion

In this study, a spirometer equipped with a WiFi system and a flow meter sensor showed that FEV1 and FVC measurements varied depending on the measurement mode. When using the inspiration mode, the results were less than optimal because many respondents felt uncomfortable when trying to inhale as hard as possible. On the other hand, the expiration mode provided more accurate results because patients could exhale maximally, so that airflow and lung capacity measurements became more reliable. The integration of the flow meter sensor with ESP32 and the real-time display on Android improved the accuracy and usability of the device, making the measurement data more detailed and easily accessible.

Previous studies, such as Jung-Yoon Kim's study, created a Tidal Volume Monitoring System, which already used a WIFI channel. In contrast, this study's approach combines a WIFI channel and a flow sensor, which offers real-time data display and storage on an Android server [56]. The monitor in Jung-Yoon Kim's study, while effective, lacked the capability for remote monitoring or real-time data access, which this study's approach successfully addresses. The addition of these capabilities is a significant improvement over previous devices, which offer more direct and detailed patient feedback.

One important weakness of this study is the potential discomfort experienced by respondents during the inspiratory mode, which may have led to suboptimal measurement results. Furthermore, although the device effectively integrates a WIFI channel for data display and storage, the accuracy of the flow sensor and the microcontroller calibration could be further improved. This study also lacks a comprehensive comparison with a wider range of spirometry devices, which could provide a more robust evaluation of its performance compared to existing technologies.

The findings of this study highlight the benefits of integrating WIFI channel technology into spirometry to improve measurement accuracy and real-time data access. The use of an Android-based flow sensor and display system offers improved usability and data management, which may lead to more effective lung function monitoring in clinical settings. The real-time display and storage capabilities may facilitate better patient management and rapid intervention, contributing to advances in respiratory care and potentially setting a new standard for future spirometry devices.

4. CONCLUSION

This study aims to develop and evaluate a portable spirometer equipped with a flow sensor and an Android for displaying spirometric measurement result. The developed device is designed to measure respiratory airflow and calculate the Forced Expiratory Volume in the first second (FEV1) and Forced Vital Capacity (FVC) parameters. The measurement results are displayed numerically and graphically on the Nextion LCD and Android application, providing real-time visualization of the acquired spirometric data. The results indicate that the developed system is capable of displaying FEV1 and FVC measurements on both the local display and Android device. The Android application functions as a wireless display platform that receives and presents measurement data transmitted from the spirometer; it does not determine or validate the measurement accuracy. This technology has several advantages, such as the ability to connect to the network for real-time data access and it transmits measurement data to the Android application via a wireless connection send results to medical personnel. However, the present is limited to the development and technical evaluation of the device and does not assess clinical workflow integration, longitudinal patient monitoring, or clinical decision making. In the future, research needs to focus on improving sensor calibration, involving more patient samples, and integrating more in-depth data analysis to optimize device performance both in the clinic and for remote use.

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