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Smart Mini Spirometer Monitoring System Based on ESP32 and MQTT Communication Protocol

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Abstract Effective management of respiratory health greatly depends on ongoing observation, but standard spirometers frequently do not provide remote access. To overcome this challenge, this study introduces an intelligent mini spirometer system that allows for live remote tracking through an online dashboard. Lung health monitoring is very important. This can be used to detect lung disease in its early stages. The parameters used to detect lung health are lung function parameters, especially Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV1). This study aims to design a smart mini spirometer that can calculate the parameters of FVC and FEV1. The tools and materials used are the pressure sensor, MPX5010DP, venturi pipe, ESP32, 0.96-inch OLED, laptop, Arduino IDE, Message Queuing Telemetry Transport (MQTT) protocol, Web dashboard, and WiFi Internet. The results obtained successfully created a Smart Mini Spirometer Monitoring System. The test outcomes show that the system reaches a performance accuracy of 97. 5% in comparison to a standard volume measurement of 3. 78 liters. In the end, the created prototype offers a dependable and accurate method for monitoring breathing remotely in real-time through an online dashboard.

Keywords: Esp32, Forced Expiratory Volume in one (FEV(1)), Forced Vital Capacity (FVC), MQTT, Spirometer.
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INTRODUCTION

Respiratory health is a crucial factor in supporting human life. The vital organs of the lungs are the site of exchange of oxygen gas from the environment with carbon dioxide produced by the body's metabolism. Impaired lung function can indicate serious respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD)[1]. The three leading causes of death in Indonesia are cardiovascular disease, cancer, and non-infectious lung disease [2]. Therefore, regular monitoring of respiratory health is crucial for early disease detection [3].

Lung health monitoring uses a clinical spirometer. Hospital-based spirometers are bulky, expensive, and require professional staff. Because of these limitations, they are less effective for daily monitoring [4]. A portable, highly accurate, and precise instrument is therefore needed for monitoring without distance constraints.

Real-time monitoring based on the Internet of Things (IoT) has undergone development. The use of IoT in the medical field has been widely studied. The Internet of Things (IoT) opens opportunities to create portable, affordable, and efficient lung health devices that can be connected to the internet (connected health). One of the ESP32 microcontroller devices, supporting IoT hardware, continues to be developed. The ESP32 is efficient because it has dual-core architecture and integrated Wi-Fi and Bluetooth modules with low power consumption [5].

IoT implementation can use several communication protocols, including Hypertext Transfer Protocol Secure (HTTPS), Constrained Application Protocol (CoAP), WebSocket protocol, and Message Queuing Telemetry Transport (MQTT) protocol. MQTT, compared to these protocols, has the following advantages: it is able to provide efficient, reliable, bandwidth-saving, and efficient communication [6][7].

Research on IoT-based mini spirometers continues to be developed and widely studied. The method of measuring spirometer signals can use an IR sensor. The spirometer signal output on the movement of the ball-shaped air tube detects the movement of the ball, and the data results are processed using the NODE MCU ESP 8266 and displayed in a .NET Core-based web application. The measurement results for the spirometer column volume have a certain volume, namely 600 cc, 300 cc, and 300 cc, with a total capacity of 1200 cc [8]. The spirometer research was developed, not based on IoT. Using an MPX5500DP pressure sensor with an ATmega328 microcontroller. The results obtained have an accuracy of 99.14% for an inspiratory capacity of 85.51% [9]. The creation of a spirometer that employs a venturi tube has been explored for a capacity of 2 liters. This research made use of an MPX5010DP pressure sensor combined with an ESP32 microcontroller, but it did not include features for wireless IoT monitoring. However, previous research has not been IoT-based with an MAPE result of 1.53% [10]. Other research has also used the MPX5010dp sensor with an Arduino Uno microcontroller to create a spirometer measuring instrument. In this study, the relationship between respiratory volume and the resulting voltage was studied. This study was not IoT-based [11]. Other research on spirometers has been studied using the MPX5700DP series piezoresistive transducer with a sensitivity level of 6.4 mV/kPa. A previous study utilized a venturi tube integrated with an Arduino Uno platform [12]. However, unlike that standalone system, the current research transitions to an ESP32-based architecture to enable IoT-driven data transmission. The research on the spirometer measuring instrument was conducted to detect fitness. This detection instrument utilizes a standard spirometer based on Arduino Uno, and the instrument was calibrated [13]. The design of the Spirometer is based on ESP 32 with the MAX30102 sensor. Kodular software, which incorporates a MySQL The results obtained from this research indicate an error value of 8.78% for FVC, 14% for FEV1, and a FEV1/FVC ratio of 4.6% [14].

Previous research has shown that the design of IoT-based spirometers has not been widely studied. Therefore, this study aims to design an IoT-based spirometer and evaluate the performance of the spirometer system. Instead of relying on standalone hardware or protocols, this study emphasizes the synergistic combination of an ESP32 architecture, an MPX5010DP differential pressure sensor, and MQTT telemetry. This integrated approach is specifically designed to mitigate the limitations of traditional, expensive, and non-portable spirometers, resulting in a clinically relevant, low-cost mini-spirometer system. This study also uses the Node Red web dashboard, which has not been widely used in spirometer design research.

METHOD

This research used the following tools and materials: ESP32 DevKit V1, MPX5010DP sensor, venturi tube (spirometry tube), small silicone tubing, 0.96" I2C OLED, jumper cables, breadboard, laptop, Arduino IDE, 5V USB power bank, and 10k ohm resistor. This research developed an IoT-based spirometer. This system uses a venturi tube to exhale air from the mouth. A pressure difference occurs in the tube, which is detected by the MPX5010DP sensor. The signal is converted into an electrical signal, which is then processed by the ESP 32 microcontroller, with the resulting data being concurrently projected onto a local OLED screen and a remote web-based dashboard powered by a Node-RED software architecture stack.

The venturi tube was designed with an inlet diameter of 20 mm and a throat diameter of 10 mm (**Figure 1**). This ratio is optimal to avoid excessive resistance when exhaling [15]. The sensor port is connected to two tapping points located on the inlet side ($+\boldsymbol{P1}$) and the throat side ($+\boldsymbol{P2}$). The pressure sensor used is the MPX5010DP. This sensor has been widely used for spirometers because the measured pressure corresponds to human respiratory pressure, around 0-10 kPa, with this device's high sensitivity (450 mV/kPa) [16]. Powered by a 5V supply line connected to its V_{cc} and Ground pins, the MPX5010DP sensor produces a 5V analog output. To ensure compatibility with the 3.3V maximum tolerance of the ESP32 microcontroller and prevent overvoltage damage, this analog signal is routed through an intermediate voltage divider that acts as a signal-conditioning interface before reaching the ADC pin.

The OLED module is connected to the I2C (SDA and SCL). The ESP is then powered, and the program is entered into the Arduino IDE. The ESP32 is interfaced with the MQTT protocol on the web dashboard. The venturi tube is then blown, and the output is displayed on the OLED. The LED will light up when the value reaches its maximum. The circuit can be clearly seen in **Figure 2**. The data is then sent to the web dashboard, where it is sent and saved in CSV format. Data is collected by measuring it, with each measurement repeated three times.

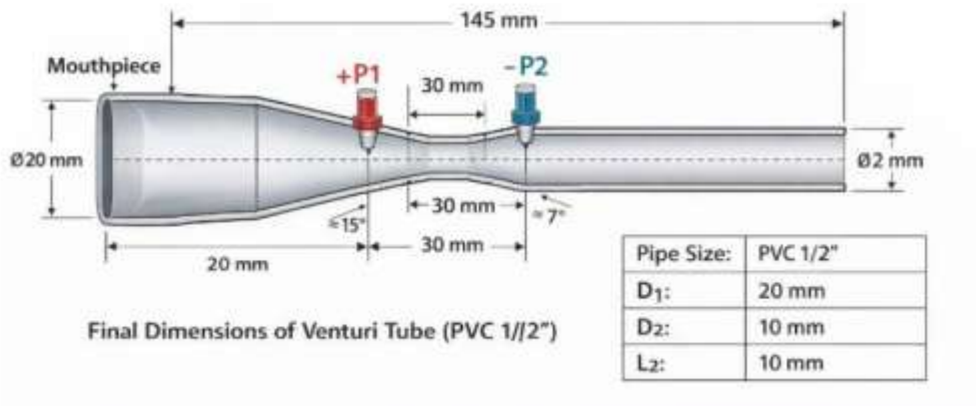


Figure 1. Mechanical design and dimensions of venturi pipe

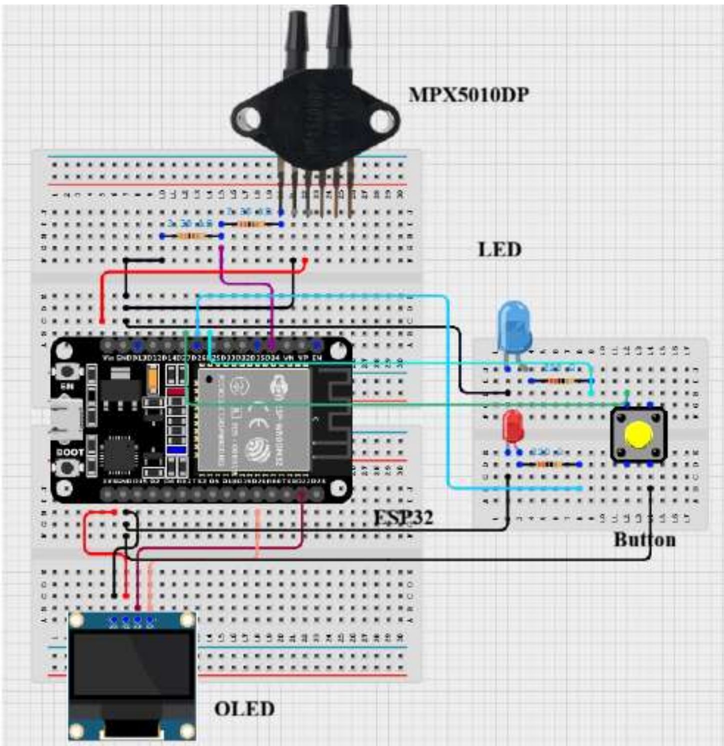


Figure 2. Spirometer system electronic circuit

The difference in voltage levels between the MPX5010DP sensor output and the ESP 32 requires a voltage divider circuit with resistors R1 = 2.2 kΩ and R2 = 3.3 kΩ. This circuit reduces the voltage to 3 V. The OLED displays data connected to I2C on GPIO 21 (SDA) and GPIO 22 (SCL), and two indicator LEDs on GPIO 2 and GPIO 15, equipped with 220 Ω resistors, serve as visual indicators of the device's readiness status and recording process.

The venturi tube complies with Bernoulli's Law and the Continuity Equation in fluid dynamics. To measure respiratory airflow, a venturi tube is used, which has a different cross-sectional area between the inlet (Ψη) and throat (Ψη). Based on Bernoulli's law of conservation of mechanical energy in fluids, the relationship between pressure (η) and flow velocity (η) at these two points is formulated as follows:

$$P1+12\rho v12+\rho gh1=P2+12\rho v12+\rho gh2 \quad (1)$$

Since the pipe is placed in a horizontal position, the height is assumed to be the same ($h1=h2$), so the potential component can be ignored. Next, the continuity equation is applied which states that the incoming flow rate ($\boldsymbol{Q}$) is equal to the outgoing flow rate:

$$Q=A1v1=A2v2 \rightarrow v1=A2\boldsymbol{A1}v2 \quad (2)$$

By substituting equation (2) into equation (1) to eliminate the variable $v1$, the equation for the flow velocity at the venturi neck ($v2$) is obtained:

$$v_2 = \sqrt{\frac{2(P_1 - P_2)}{\rho\left(1 - \frac{A_2}{A_1}\right)^2}} \cdots$$

Since $Q=A2v2$, the volumetric air flow rate ($\boldsymbol{Q}$) can be calculated using equation (5), where the equation has taken into account the diameter ratio ($\beta=\boldsymbol{D2/D1}$) and the discharge coefficient ($\boldsymbol{Cd}$) to correct fluid friction to obtain equation (5). The software contained in the microcontroller is programmed to perform data acquisition, physical conversion, and network communication. The data processing process begins by converting the digital value from the Analog-to-Digital Converter (ADC) into an electrical voltage. Next, the output voltage ($Vout$) is converted into a differential pressure value ($\boldsymbol{\Delta P}$) in kPa units. Where ($\boldsymbol{\Delta P}$) is the pressure difference ($\boldsymbol{P2-P1}$) read by the MPX5010DP sensor. The sensor voltage output value is converted to kPa units using a linear transfer function [13].

$$P = \frac{\frac{V_{out}}{V_S} - 0.04}{0.09} + Error_{koreksi} \quad (4)$$

Once the pressure value ($\boldsymbol{P}$) is obtained, the airflow rate or Flow-Rate ($\boldsymbol{Q}$) is calculated by applying the Bernoulli equation. This differential pressure measurement method has been proven valid for digital spirometry with a clinically acceptable level of accuracy if properly calibrated [17].

$$Q = C_d \cdot A_2 \cdot \sqrt{\frac{2\Delta P}{\rho \cdot (1 - \beta^4)}} \quad (5)$$

In equation (5), ρ is the air density ($1.225 kg/m3$), $A2$ is the cross-sectional area of the throat, and β is the diameter ratio ($\boldsymbol{D2/D1}$). Cd is the discharge coefficient obtained through the tool calibration process. Finally, the total air volume (V), such as Forced Vital Capacity (FVC), is calculated by integrating the flow rate (Q) against time (t) during the expiratory period ($t0$ to tn), which can be calculated using the following equation

$$V = \int_{t_0}^{t_n} Q(t)dt \approx \sum_{i=0}^{n} Q_i \cdot \Delta t \quad (6)$$

Communication Protocol Implementation (MQTT)

This system uses the MQTT (Message Queuing Telemetry Transport) communication protocol for wireless data transmission. MQTT was chosen because it has very little data packet overhead and low latency, making it superior to the HTTP protocol for real-time health monitoring applications on networks with limited bandwidth [18]. The ESP32 publishes data to a specific topic, which is then received (subscribed to) by the Web Dashboard interface.

Calibration and Testing of Tools

Data validity can be determined in two stages, namely calibration testing and functional verification testing. The first stage is zero-offset calibration on the MPX5010DP sensor. This is done by taking the average sensor voltage reading when there is no air flow ($\boldsymbol{Q}=\mathbf{0}$) for 5 seconds, then the offset value is stored in the ESP32 EEPROM memory to be a reduction in the actual reading value [19]. Next, accuracy testing is carried out by comparing the measurement results of the mini spirometer prototype against a standard measuring instrument (Gold Standard) or using a 3 Liter Calibration Syringe as a fixed volume reference. The test involved a number of healthy volunteers with an age range of 20–25 years. Each subject was asked to perform a standard FVC (Forced Vital Capacity) maneuver: inhale as deeply as possible, then exhale forcefully and quickly into a venturi tube until the lungs are empty. The FVC and FEV1 parameter data measured by the prototype ($\boldsymbol{Vukur}$) were compared with the reference value ($\boldsymbol{Vstandar}$). The accuracy level of the tool was evaluated using the Relative Error (%) and Mean Absolute Percentage Error (MAPE) parameters calculated using the equation.

$$Error(\%) = \left|\frac{V_{standar} - V_{ukur}}{V_{standar}}\right| \times 100\% \quad (7)$$

In addition to measurement accuracy, the test also includes a Latency test of the MQTT communication system, namely, measuring the time difference between data sent by the ESP32 until the data appears on the user interface dashboard, to ensure the system meets real-time monitoring standards.

RESULTS AND DISCUSSION

The built spirometer system

An IoT-based digital spirometer system has been successfully implemented using an ESP32 microcontroller as the main processing unit and an MPX5010DP sensor as the pressure transducer. Hardware integration included the installation of a custom venturi tube with a 20 mm inlet diameter and a 10 mm throat, as well as a signal conditioning circuit (voltage divider) to match the 5 V sensor output to the 3.3 V ESP32 ADC input. The implemented device is shown in **Figures 3 and 4**.

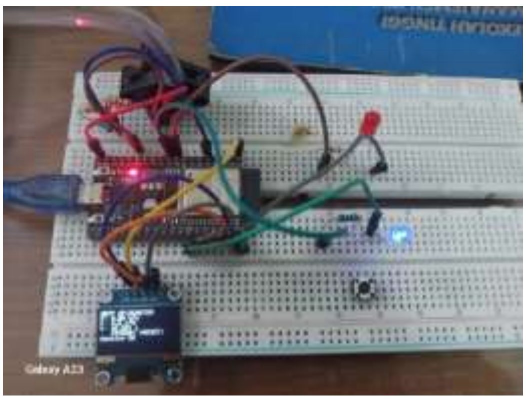


Figure 3. ESP32 based digital spirometer hardware on standby

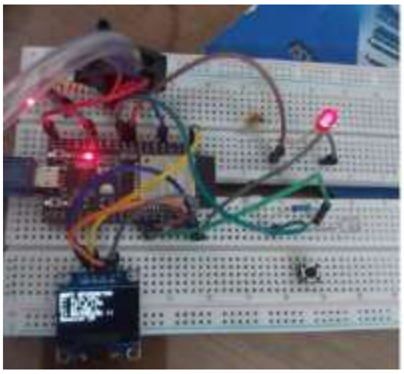
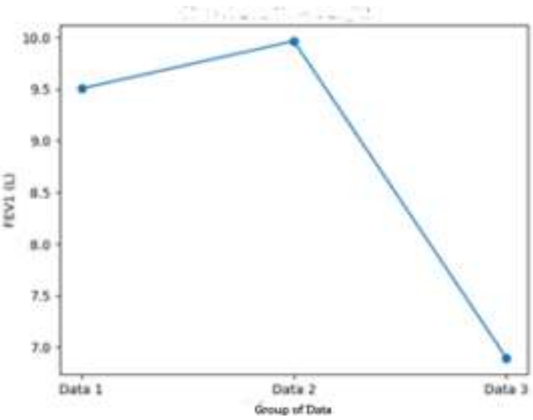


Figure 4. ESP32 based digital spirometer hardware during expiration

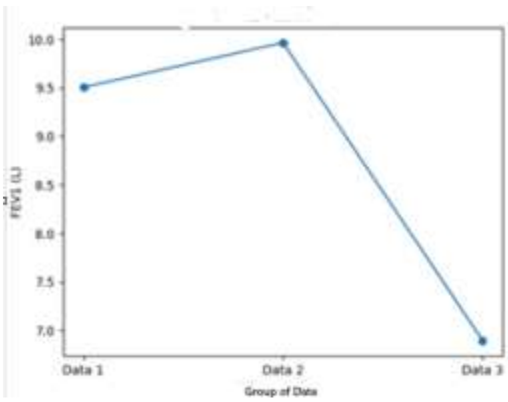
Functional testing demonstrated stable operation of the device. LED indicators provide visual feedback during data acquisition (Red LED) and standby (Blue LED), facilitating user interaction without the need for complex external displays.

Airflow Profile Analysis

The characteristics of airflow during forced expiration were analyzed using a graph of the relationship between differential pressure (kPa) and time (seconds). Based on the FVC maneuver test, the graph profile obtained is shown in **Figure 5**.



a.



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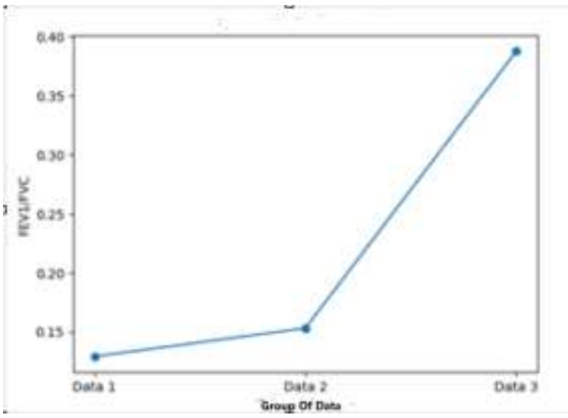

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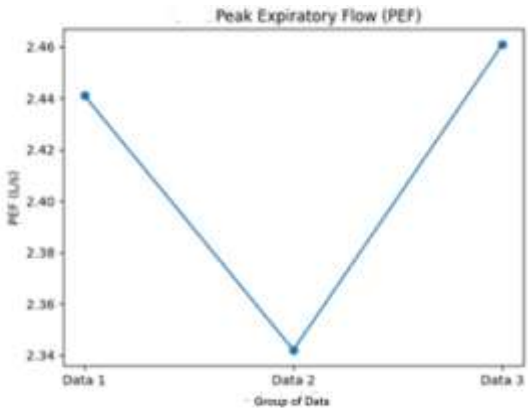

d.

Figure 5. a. First measurement of FEV1, b. Second measurenment c. Rasio FEV1 with PEF d. Measurenment of PEF

Figure 5 shows a pattern consistent with human respiratory physiology, where a significant pressure spike occurs at the beginning of expiration (0 to 0.5 seconds), representing Peak Expiratory Flow (PEF). After reaching the peak, the pressure decreases exponentially as the volume of air in the lungs decreases. The MPX5010DP sensor has been shown to capture the dynamics of these pressure changes responsively without significant noise. Measurement Accuracy Validation

Quantitative validation was conducted to determine the accuracy of the device in measuring Forced Vital Capacity (FVC). Testing was conducted three times by comparing the volume measured by the device (FVC) to the standard reference value (FVC) of 3.78 liters. The test results are summarized in **Table 1**.

Tabel 1 Spirometer Measurement Results and Error Calculations

Repetition	Value of Reference (L)	Value of Measurenment (L)	Delta (L)	Error
1	3.78	3.65	0.13	3.4%
2	3.78	3.72	0.06	1.5%
3	3.78	3.68	0.10	2.6%
Mean	3.78	3.68	0.09	2.5%

Based on the data in **Table 1**, the device demonstrated good measurement consistency with low deviation between trials. The relative error calculation yielded an average error of 2.5%. This value indicates excellent performance, considering that the tolerance standards for medical spirometry devices according to the American Thoracic Society (ATS) allow variability of up to ±3% or 0.05 L. This low error rate (below 5%) proves that the use of the MPX5010DP sensor with a measuring range of 0-10 kPa is very effective in increasing the resolution of data readings compared to sensors with a wide range (such as the MPX5500DP/MPX5700DP) used in previous studies.

IoT System Implementation

In addition to accuracy, the success of wireless data transmission was also tested. The system successfully sent data packets containing pressure, flow rate, and cumulative volume values to the MQTT broker in real-time. In connectivity testing, respiratory parameter data could be displayed on the monitoring dashboard with minimal latency, proving that the ESP32 is capable of handling ADC data acquisition and Wi-Fi communication simultaneously without disrupting the sensor data sampling process.

Figure 6. Real-time display of respiratory parameter data on the IoT Dashboard interface

Figure 6 shows the system successfully displaying the measurement data visualization wirelessly. The dashboard acts as a subscriber, receiving JSON data packets from the ESP32 microcontroller via the MQTT protocol. The interface displays graphs and numerical values for crucial parameters, such as actual pressure, flow rate, and cumulative volume, which are updated in real-time during the breathing maneuver. This successful data display demonstrates the integrity of the communication system, as there was no packet loss during transmission from the hardware to the monitoring platform, thus supporting effective tele-monitoring.

CONCLUSION

This research has successfully developed a low-cost, IoT-based portable spirometer system using the MPX5010DP pressure sensor and ESP32 microcontroller. Based on the test results, In preliminary controlled testing, the sensor array demonstrated a baseline relative error of 2.5% for the FVC parameter against standard references under optimized airflow conditions. However, full clinical accuracy validation remains subject to further refinement of the numerical integration algorithm within the software architecture to eliminate data anomalies and ensure absolute data consistency across all monitoring platforms The selection of the MPX5010DP sensor proved effective in increasing the sensitivity of low-pressure respiratory signal readings. In addition, the integration of the MQTT protocol successfully facilitated real-time remote monitoring via a web dashboard without significant data transmission constraints. This system has the potential to be an alternative affordable medical device to support telemedicine services. Further research can be developed by adding artificial intelligence features for automatic early detection of lung disease.

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REFERENCES

[1] J. B. West and A. M. Luks, West's Respiratory Physiology: The Essentials, 11th ed. Philadelphia, PA: Wolters Kluwer, 2021.

[2] O. D. Asmara et al., “Lung Cancer in Indonesia,” J. Thorac. Oncol., vol. 18, no. 9, pp. 1134–1145, 2023, doi: 10.1016/j.jtho.2023.06.010.R. T. Wang, “Title of Chapter,” in *Classic Physiques*, edited by R. B. Hamil (Publisher Name, Publisher City, 1999), pp. 212–213.

[3] M. N. Islam, I. H. Sarker, T. Iqbal, A. S. M. Hoque, P. K. Das, and M. K. Ali, "Internet of Things (IoT) enabled health monitoring system: A comprehensive survey," Wireless Personal Communications, vol. 119, no. 1, pp. 623–647, 2021..

[4] A. Banik, M. A. A. Walid, and M. A. Amin, "Design and implementation of a low-cost portable spirometer for home-based respiratory health monitoring," in 2021 IEEE International Conference on Biomedical Engineering, Computer and Information Technology for Health (BECITHCON), Dhaka, Bangladesh, 2021, pp. 15–19.

[5] P. M. N. D. P. Silva, V. N. G. J. Soares, and J. M. L. P. Caldeira, "Performance analysis of ESP32 microcontroller in a WBAN scenario for healthcare applications," Sensors, vol. 22, no. 3, p. 1176, Feb. 2022.

[6] Petrescu, E. Niculae, V. Vulturescu, A. Dimitrescu, and L. M. Ungureanu, “Transport and Application Layer Protocols for IoT : Comprehensive Review,” Technol. 2025, vol. 13, p. 583, 2025.

[7] S. Tyagi, A. Tanwar, S. K. Gupta, and D. Kumar, "Performance analysis of MQTT and HTTP protocols in IoT-based health monitoring system," in 2022 10th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), Noida, India, 2022, pp. 1–5.

[8] A. Keerthana, A. Loganayagi, M. Praveena, M. Swetha, and R. Radhiga, “Iot Based Electronic Incentive Spirometer,” Int. J. Eng. Res. Appl., vol. 11, no. 7, pp. 59–63, 2021, doi: DO1:10.9790/9622-1107045963.

[9] F. F. D Juliandri, Erliawati, F. A Yudithia, “Development of a Portable Spirometer with MPX550DP air Presure Sensor and ATmega328 Microcontroler.” Journal Appropriate Technology for Agriculture, Environment and development (JATAED), 2024. [Online]. Available: https://doi.org//10.62671/jataed.vl

[10] J. Wallace et al., “A frugal arduino-based spirometer for low-resource settings : design , development and validation of a preliminary prototype,” Front. Bioenegineering Biotechnol., no. January, pp. 1–15, 2026, doi: 10.3389/fbioe.2025.1664127.

[11] Hasanain Aziz Abed, “Design and Implementation od Digital Spirometer Using Arduino.” American Journal of Engineering Mechanics and Architecture, pp. 2993–2637, 2025. [Online]. Available: www.grnjournal.

[12] N. A Maharania, A. Muida*, “Rancang Bangun Alat Pengukur Volume Paru-paru Berbasis Sensor Tekanan Gas MPX5700DP dan Arduino Uno,” Prisma Fisika., vol. 7, no. 3, 2019.

[13] L. N. Purwanto, M.Sigit, Y. Hernawan, “Rancang Bangun Alat Pendeteksi Kebugaran Paru-Paru Pada Personil TNI (Spirometer) Berbasis Arduino Uno,” J. Tek. Elektro dan Komput., vol. 6, no. No.1, pp. 3–4, 2019.

[14] M. N. W. and H. S. Luthfiyah, R. E. Yuwana, H. G. Ariswati, “esign and Development of an IOT-based Pulmonary Function Monitoring Device of FVC and FEV1 for Children with Bronchial.”

Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics, pp. 34–42, 2024.

[15] A. Banik, M. A. A. Walid, and M. A. Amin, "Design and implementation of a low-cost portable spirometer for home-based respiratory health monitoring," in 2021 IEEE International Conference on Biomedical Engineering, Computer and Information Technology for Health (BECITHCON), Dhaka, Bangladesh, 2021, pp. 15–19.(Sitasi untuk: Desain pipa dan metode low-cost spirometry).

[16] T. P. F. Nguyen and M. Garcia, "A frugal arduino-based spirometer for low-resource settings: design, development and validation of a preliminary prototype using MPX5010DP," Frontiers in Bioengineering and Biotechnology, vol. 12, p. 1664127, 2024

[17] F. Joyce and S. J. K. J, "IoT based smart spirometer for remote health monitoring using ESP32," in 2023 7th International Conference on Intelligent Computing and Control Systems (ICICCS), Madurai, India, 2023, pp. 1102–1107.

[18] S. Tyagi, A. Tanwar, S. K. Gupta, and D. Kumar, "Performance analysis of MQTT and HTTP protocols in IoT-based health monitoring system," in 2022 10th International Conference on Reliability, Infocom Technologies and Optimization (ICRITO), Noida, India, 2022, pp. 1–5.

[19] A. G. Budiarto, "Implementasi Filter Kalman pada Sensor Tekanan Udara untuk Meningkatkan Akurasi Spirometer Digital," Jurnal Fisika dan Aplikasinya, vol. 18, no. 2, pp. 55-61, 2023.