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MODIFICATION OF ULTRASONIC NEBULIZER WITH AIR FLOW RATE CONTROL AND ANDROID-BASED THERAPY DURATION MONITORING

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ABSTRACT An ultrasonic nebulizer is a medical device designed to convert liquid medication into a fine mist for inhalation therapy. Conventional nebulizers, however, often lack an automatic shut-off feature when the water chamber is empty or the therapy duration ends, which can cause discomfort and potential risks for patients. This study focuses on modifying the ultrasonic nebulizer by integrating an automatic shut-off mechanism and an Android-based monitoring system to enhance safety, comfort, and effectiveness during therapy. The modification employs an ESP32 microcontroller to detect water levels in the chamber and monitor therapy duration. When the water level reaches a minimum threshold or the preset time expires, the device automatically shuts down. Additionally, a real-time monitoring feature was developed through an Android application, allowing users to set therapy durations from 5 to 20 minutes in 5-minute intervals and observe usage directly via a mobile device. Performance testing demonstrated high accuracy. Stopwatch measurements showed a therapy duration accuracy of 99.93% on the device and 99% via the application. Flow rate testing with a mass flow sensor resulted in accuracies of 94.20% (low), 96.64% (medium), and 98.15% (high). Furthermore, Bluetooth connectivity was reliable up to 8 meters. These results confirm that the modified nebulizer improves safety, convenience, and real-time monitoring for patients.

INDEX TERMS Ultrasonic nebulizer, Therapy duration monitoring, Bluetooth, ESP32, Inhalation therapy

I. INTRODUCTION

A nebulizer is a medical device used to convert liquid medication into a fine mist, making it easier for patients—especially those with respiratory diseases such as asthma and bronchitis—to inhale [1], [2]. Asthma is a respiratory disorder of the bronchi characterized by reversible periodic bronchospasms (prolonged contraction of the bronchial airways), which cause airway narrowing due to edema, making breathing difficult. Patients may experience respiratory symptoms such as infections that lead to increased sputum production [3], [4]. A nebulizer is beneficial for patients with respiratory problems such as cough, mucus buildup in the lungs or chest, phlegm due to colds or nasal congestion, and for improving airflow in the respiratory tract [5]. The compressor nebulizer is the most commonly used type. This type employs a compressor to convert liquid medication into aerosol. It is widely used because it is practical, inexpensive, and compatible with various inhaled drugs, including those for COPD [6], [7].

In 2021, Iranpak et al. conducted a study on an IoT-based patient monitoring system. Their system was capable of recording and classifying patients vital signs in real time using sensors, internet connectivity, and cloud storage. With the support of machine learning algorithms (particularly LSTM), data collected from sensors such as body temperature, heart rate, and blood pressure could be processed to automatically detect patient conditions and provide early notifications to medical personnel [8], [9].

In 2022, Richardson Peter developed an ultrasonic nebulizer equipped with a timer and fan selection based on a microcontroller. The device used a piezoelectric element to generate aerosol and an Arduino Nano as the microcontroller. However, the device lacked an automatic shut-off when the timer ended, had no measurement of medication capacity for infants, children, and adults, and could not provide real-time remote therapy monitoring through mobile devices [10], [11].

In 2021, Bainur Rahman and Abdul Firman designed a portable ultrasonic nebulizer model controlled by an Arduino Nano. The device featured four timer options for nebulization duration. Nevertheless, it had no fan speed adjustment and the battery voltage was unstable [12].

Based on these studies, the author decided to redesign the ultrasonic nebulizer by adding timer settings, blower settings, and a water-level detection feature using a float sensor. In addition, the device can monitor inhalation therapy duration online via a mobile gadget. The development of an ultrasonic nebulizer with automatic control and IoT-based time monitoring is essential to improve patient safety and comfort during therapy. With these features, the nebulizer can automatically stop when the therapy time ends or the water chamber runs empty, while also enabling real-time monitoring via mobile devices. This is expected to extend the device's lifespan, minimize damage, and enhance both the effectiveness and comfort of inhalation therapy. Moreover, this innovation distinguishes the present work from other ultrasonic nebulizer designs.

II. RESEARCH METHOD

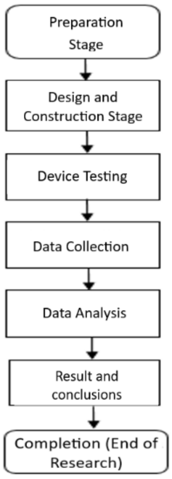

FIGURE 1. **Research method consisting of several stages: preparation, design and construction of the device, device testing, data collection, data analysis, and formulation of results and conclusions until the research is completed.**

Based on Fig. 1, this is the research method of this study. In this study, the hardware used includes an ESP32 microcontroller, ESP32 is a microcontroller that has many functions but consumes low power, and its board is already equipped with integrated Wi-Fi and Bluetooth Low Energy (BLE) [13], a water level sensor (float), The float in an ultrasonic nebulizer plays a very important role in ensuring the device operates optimally and safely. The main function of the float is to maintain the water level in the container at the proper height [14].

A blower (fan), The fan is an important component in an ultrasonic nebulizer, functioning to direct the drug vapor produced by the ultrasonic transducer toward the patient's respiratory tract [15], the L298N motor driver is one of the most widely used DC motor driver modules in electronics, functioning to control both the speed and the direction of DC motor rotation [16], [17].

A piezoelectric component as an aerosol generator [18], a buzzer is often used as an indicator that a process has been completed or that an error has occurred in a device (alarm) [19]. A power supply, It is a circuit that functions to supply voltage to circuits requiring a 12 Volt DC power source [20], the LCD (Liquid Crystal Display) integrated with Arduino is commonly employed to display information, including inhalation therapy time and blower (fan) speed settings [21], [22], and a android application, In this study, the author used the MIT App Inventor platform to develop a nebulization time monitoring application that can be accessed on Android devices [9].

The software consists of Arduino IDE for programming the ESP32 and an Android application to monitor and control the therapy time. A control program was developed on the ESP32 to manage the timer, detect water levels, and control the blower. Furthermore, the Android application was integrated to display therapy duration in real time via Bluetooth connection.

A. BLOCK DIAGRAM

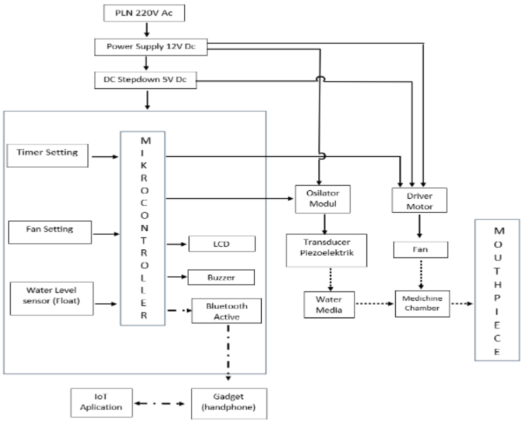

FIGURE 2. **Block diagram of the modified ultrasonic nebulizer system equipped with an ESP32 microcontroller, timer setting, fan setting, water level sensor, Bluetooth module, and Android-based IoT application for real-time monitoring.**

From Fig. 2, we can see that The 220V AC input voltage enters the power supply circuit with an output of 12V DC, which provides power to the motor driver and the oscillator module. The output of the power supply is then stepped down through a DC step-down converter to 5V DC, which distributes voltage to each block as required, including supplying the motor driver. The microcontroller functions as the brain of the control system, receiving input from the timer setting button, fan speed setting, and the water level sensor (float). The microcontroller is also connected to an LCD for displaying information, a buzzer as an alarm, and a Bluetooth module that links it to the IoT application on a mobile device for remote control. Control signals from the microcontroller are sent to the oscillator module, which activates the piezoelectric transducer to generate ultrasonic vibrations that convert liquid medication into aerosol through the water medium. At the same time, signals are also sent to the motor driver to control the fan, which pushes the aerosol into the medicine chamber and subsequently to the mouthpiece for patient inhalation

B. FLOWCHART

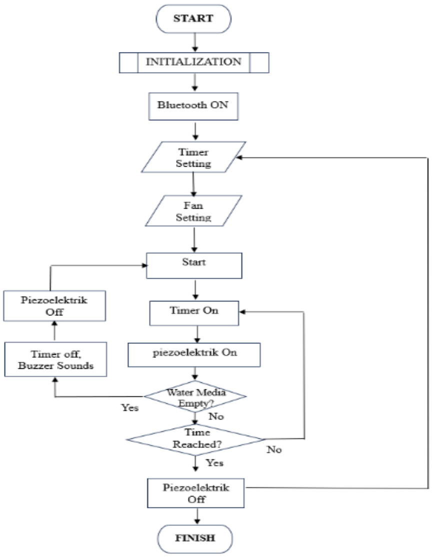

FIGURE 3. **Flowchart of the working principle of the modified ultrasonic nebulizer system, illustrating the initialization process, Bluetooth activation, timer and fan settings, nebulization process control, water level monitoring, and automatic shut-off when the set time is reached or the water medium is empty.**

From Fig. 3, this is flowchart for the device. The operation of the ultrasonic nebulizer begins by filling the water chamber until the water level sensor (float) reaches the maximum limit. When the device is switched on, the system initializes, displaying information on the LCD, and automatically activates the ESP32 Bluetooth connection, which can be paired with an Android device. Users can set the therapy duration (5, 10, 15, or 20 minutes) and fan speed (low, medium, or high) through the available settings as shown in Fig. 4.

After pressing the *start/stop* button, the timer begins counting down while the piezoelectric circuit generates ultrasonic vibrations to produce aerosol. If the water level falls below the minimum threshold, the system automatically stops, activates the buzzer, and pauses the nebulization until water is refilled. Once the set time is reached, both the timer and piezoelectric circuit stop, completing the nebulization process.

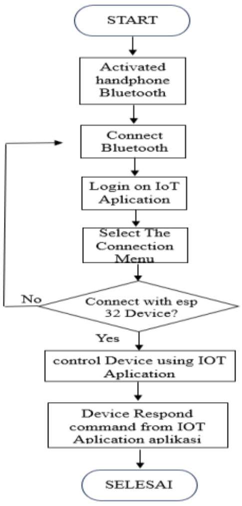

FIGURE 4. **Flowchart of the Bluetooth connectivity process between the ultrasonic nebulizer and the IoT application, illustrating device pairing, application login, connection setup, and real-time control of the nebulizer through mobile devices.**

C. HARDWARE DESIGN

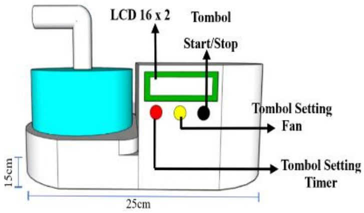

FIGURE 5. **Front view of the modified ultrasonic nebulizer, showing the 16x2 LCD display, Start/Stop button, Fan Setting button, Timer Setting button, and the medicine chamber with mouthpiece.**

From Fig. 5, this front view of the ultrasonic nebulizer shows its main components: a 16x2 LCD display for system information, a Start/Stop button above the LCD, and two control buttons below for fan speed (yellow) and timer setting (black). On the left side is the water and medicine chamber with the mouthpiece on top. The device measures approximately 25 cm × 15 cm, making it compact and user-friendly.

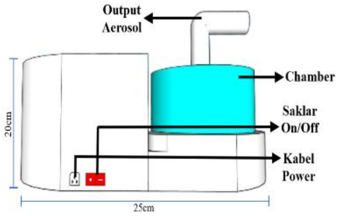

FIGURE 6. **Rear view of the ultrasonic nebulizer, showing the main body structure, chamber placement, and power input components.**

From Fig. 6, this is the rear view of the ultrasonic nebulizer highlights several key components. At the top, there is the aerosol output, which delivers the generated mist to the patient. Below it, the medicine chamber is located, where the liquid medication and water medium are placed. On the right side of the device, there is an On/Off switch used to power the device, and a power cable connection at the lower part for supplying electrical input. The overall dimensions of the device are approximately 25 cm in length and 20 cm in height, making it compact and practical for use.

D. SOFTWARE DESIGN

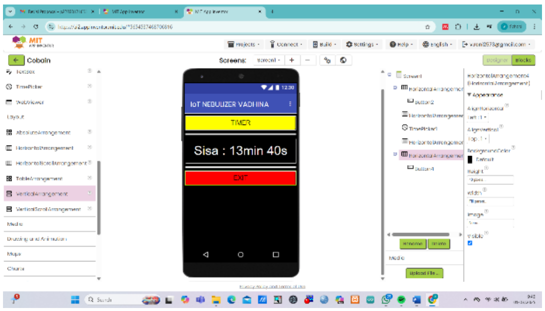

FIGURE 7. **Display design of the Android-based IoT nebulizer application created using MIT App Inventor, showing the timer function, remaining therapy duration, and exit option for real-time monitoring.**

From Fig. 7, In the software design of this device, the MIT App Inventor website was used to develop an Android application tailored to the objectives of this study, namely to monitor nebulization time. The application interface was designed through the MIT App Inventor platform showing the timer function, remaining therapy duration, and exit option for real-time monitoring. With this application, it is expected that information can be displayed to the user in real time.

E. DATA COLLECTION TECHNIQUE

1) Airflow Rate Measurement

The airflow rate (LPM) at the output of the ultrasonic nebulizer was measured to determine the performance of the fan using a mass flow analyzer. According to the Ministry of Health of Indonesia guidelines, the standard airflow range for ultrasonic nebulizers is 0.5–2 LPM. Each test was conducted with a 1 minute rest interval between measurements.

2) Time Accuracy Testing

Time accuracy was tested on both the ultrasonic nebulizer and the IoT Nebulizer application using a stopwatch. The measurement was conducted in seconds, with a 5-minute rest interval between tests.

3) Connectivity Distance Measurement between Device and IoT

The connectivity distance between the nebulizer and an Android device was tested in meters to determine the maximum Bluetooth range of the ESP32 module, using a measuring tape.

4) Drug Solution Testing over Time

The output of the ultrasonic nebulizer was tested in milliliters per second (ml/s) to measure the time required for the medication to run out, using a syringe and stopwatch. The solution used was NaCl 0.9%, with a 1-minute rest interval between tests. Table 3.5 presents the results of drug depletion time at each flowrate setting.

III. RESULT AND DISCUSSION

A. PHYSICAL FORM OF THE DEVICE

FIGURE 8. **front view of the Design of the Vortex Mixer. equipped with an LCD display for information, an On/Off button for operation, and a power cable as the power source.**

From Fig. 8, this is the front part of an ultrasonic nebulizer prototype. It has a 16x2 LCD screen and three buttons: a timer button, a fan speed adjustment button, and a start nebulization button. There is also an on/off switch and a power cable. The device dimensions are length (L) 26 cm, width (W) 14 cm, and height (H) 16 cm, with a container diameter of 14 cm.

B. APLICATION INTERFACE

The Fig. 9 shows the user interface design of the IoT Ultrasonic Nebulizer, which provides several essential control features for operating the device. At the top, the interface includes a Bluetooth connection button that allows the nebulizer to connect wirelessly with a smartphone or other devices. Below it, two separate control buttons are available: one for adjusting the fan and another for setting the operating time. The central green button functions as a start/stop control, enabling users to activate or deactivate the nebulizer with ease. A digital timer is displayed prominently to show the remaining operating time, while an exit button at the bottom allows users to close the application. This design emphasizes simplicity and usability, making it easier for users to manage the nebulizer functions efficiently.

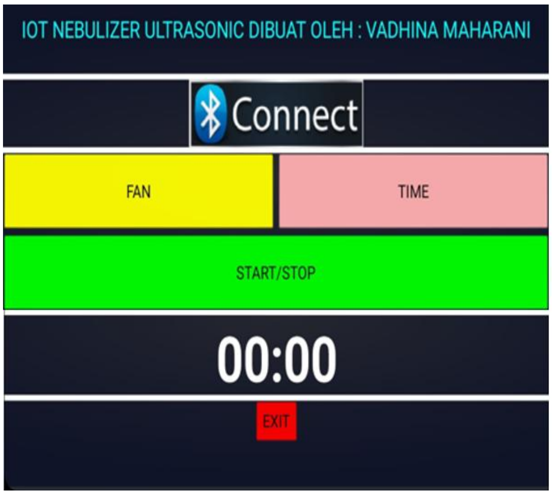

FIGURE 9. User interface display of the IoT Ultrasonic Nebulizer application, featuring Bluetooth connection, fan and timer control, start/stop functionality, countdown timer, and exit option.

B. TESTING AND DATA ANALYSIS

Testing and data analysis were carried out to evaluate the performance and reliability of the modified ultrasonic nebulizer. The testing process consisted of functionality testing.

Based on the results in table 1, we can conclude that the functional tests and performance evaluations, it can be concluded that the ultrasonic nebulizer device operates properly. All components, including the control buttons (on/off, timer, fan, and start/stop), the piezoelectric transducer, fan, buzzer, LCD display, as well as the Bluetooth connection and IoT application, work according to their intended functions. The testing also demonstrated high accuracy in the timer, airflow rate, and medication delivery settings. These results confirm that the device not only functions as designed but is also reliable for effective use in inhalation therapy.

TABLE I
TESTING DEVICE SECTION

No	Device Section	Test Results (Works or Not)
1	Switch On/Off	Works
2	Timer Button	Works
3	Fan Button	Works
4	Start/Stop Button	Works
5	Transducer Piezoelektrik	Works
6	Fan	Works
7	Bluetooth	Works
8	Buzzer	Works
9	LCD Display	Works
10	IoT Nebulizer Aplication	Works

Following the testing, there are data analysis which consist flowrate measurement, timer accuracy testing, Bluetooth connectivity testing, and liquid medication consumption testing. Each stage was conducted using appropriate measuring instruments to ensure the accuracy of the results.

1) Flowrate measurement

TABLE II
FLOWRATE MEASUREMENT TESTING

Measurement	Low (0,5 LPM)	Medium (1,25 LPM)	High (2 LPM)
1	0,64	1,39	1,92
2	0,43	1,3	1,83
3	0,57	1,23	2,04
4	0,52	1,29	2,02
5	0,4	1,22	1,94
6	0,58	1,21	1,89
7	0,53	1,42	2,02
8	0,62	1,32	1,95
9	0,51	1,28	2,04
10	0,58	1,26	1,98
Average	0,534	1,292	1,963
Acuracy%	94,20%	96,64%	98,15%

Based on the results in Table 2, The flowrate measurement results demonstrate that the device performs reliably across different operating levels. At the low setting (0.5 LPM), the average measured flowrate was 0.534 LPM, yielding an accuracy of 94.20%. For the medium setting (1.25 LPM), the average recorded value reached 1.292 LPM with an accuracy of 96.64%. Meanwhile, at the high setting (2 LPM), the average measurement was 1.963 LPM, resulting in the highest accuracy of 98.15%. These findings indicate that the device operates with good precision, with overall accuracy values consistently above 90%.

2) Timer accuracy testing

TABLE III
TIMER ACCURACY TESTING

Measurement	Setting timer			
	5 Minute	10 Minute	15 Minute	20 Minute
1	301	600	900	1200
2	300	599	900	1200
3	301	600	900	1201
4	300	601	901	1201
5	300	600	900	1201
6	299	600	900	1200
7	300	600	900	1201
8	300	601	900	1200
9	301	600	900	1200
10	300	600	901	1200
Average	300,2	600,1	900,2	1200,4
Accuracy%	99,93%	99,98%	99,98%	99,97%

Based on Table 3, The timer accuracy testing results show that the system is capable of providing highly precise timing performance across different settings. At a 5-minute setting, the average measured time was 300.2 seconds with an accuracy of 99.93%. For the 10-minute setting, the average result was 600.1 seconds, corresponding to an accuracy of 99.98%. Similarly, at the 15-minute setting, the system recorded an average of 900.2 seconds with an accuracy of 99.98%, while at the 20-minute setting, the average value was 1200.4 seconds with an accuracy of 99.97%. These results indicate that the timer operates with exceptional reliability, with all accuracy values consistently above 99.9%.

3) Bluetooth connectivity testing

The Bluetooth connectivity distance testing was carried out to evaluate the effective range of the device's wireless communication. The results show that the device maintained a stable connection from a distance of 1 meter up to 8 meters without any disconnection. This indicates that the Bluetooth module, based on the ESP32, is capable of delivering reliable communication within the tested range under normal conditions without significant interference or obstacles. The Bluetooth connectivity distance testing was carried out to evaluate the effective range of the device's wireless communication. The results show that the device maintained a stable connection from a distance of 1 meter up to 8 meters without any disconnection. This indicates that the Bluetooth module, based on the ESP32, is capable of delivering reliable communication within the tested range under normal conditions without significant interference interference or obstacles.

4) Liquid medication consumption testing

TABLE IV
LIQUID MEDICATION CONSUMPTION TESTING

Liquid medication volume (6 ml)						
Fan Speed	consumption test (s)					Average drug discharge (ml/s)
	1	2	3	4	5	
Low	154	105	110	141	110	0,05 ml/s
Medium	79	67	92	69	66	0,08 ml/s
high	44	85	84	54	72	0,12 ml/s

Based on tTable 4, The table shows the results of liquid medication consumption testing at different fan speeds. At low speed, the discharge rate is 0.05 ml/s, while at medium speed it increases to 0.08 ml/s, and at high speed it reaches 0.12 ml/s. These results indicate that higher fan speeds lead to faster medication discharge, showing a direct relationship between airflow and the rate of liquid consumption.

IV. CONCLUSION.

Based on the design process and data collection of the developed ultrasonic nebulizer equipped with an airflow control feature and Android-based time monitoring, several conclusions can be drawn. The modification of the ultrasonic nebulizer with airflow control and Android-based monitoring was successfully implemented and functioned properly according to the performance tests. Timer testing using a stopwatch showed a high level of accuracy, with 99.93% for the 5-minute setting, 99.98% for both the 10-minute and 15-minute settings, and 99.96% for the 20-minute setting. Flowrate testing with a mass flow sensor also demonstrated reliable accuracy, reaching 94.20% for low fan speed, 96.64% for medium, and 98.15% for high.

Bluetooth connectivity tests indicated stable performance at distances of 1–8 meters, although connection issues began to appear at 9 meters. Furthermore, timer synchronization between the nebulizer device and the Android application was highly accurate, with a maximum difference of only 0.02%. In addition, liquid consumption tests showed that at low fan speed the device delivered an average flow rate of 0.05 ml/s, at medium speed 0.08 ml/s, and at high speed 0.11 ml/s, resulting in a total drug delivery rate ranging from 3 mL/min up to 6.6 mL/min. These results confirm that the developed ultrasonic nebulizer operates effectively and meets the intended design specifications.

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