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Design and Development Smart Inhaler System

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ABSTRACT

The prevalence of respiratory diseases, such as asthma and Chronic Obstructive Pulmonary Disease (COPD), continues to increase worldwide, posing significant challenges for patients and healthcare systems. Monitoring remaining doses and inhaler dose notifications are becoming increasingly scarce, becoming a major concern for asthma patients. Therefore, the Smart Inhaler is designed to provide a real-time shrinking dose counter display and notifications via devices for refilling inhaler doses. This Smart Inhaler consists of a 3.7V power supply and Force Resistive Sensor used as input, display on OLED notifications as output, and ESP32 as a processor to connect to the Internet. The Smart Inhaler uses an IoT application as a counter that connects the inhaler to devices such as smartphones. Force Resistive Sensor is used to determine the dose taken by the user, and calculations are subtracted until the inhaler dose is depleted. Notifications are sent to the device when the Smart Inhaler reaches a low dose count, starting from 50,30 to 10 doses, to remind patients to replace the inhaler. This Smart Inhaler can be enhanced with a more practical design on the top of the metal canister to facilitate inhaler dose calculation by the Force Resistive Sensor.

Keywords: Smart Inhaler, Respiratory Diseases, Medication Adherence, Inhalation Technique, Sensor Technology.

ABSTRAK

Kelaziman penyakit penafasan, seperti asma dan penyakit pulmonari obstruktif kronik (COPD), terus meningkat diseluruh dunia, menimbulkan cabaran penting bagi pesakit dan sistem penjagaan kesihatan. Pemantauan baki dos dan notifikasi dos penyedut semakin berkurangan menjadi aspek utama pemasalahan bagi pesakit asma. Justeru itu, Smart Inhaler direkabentuk dengan menyediakan paparan kaunter dos masa nyata menyusut dan pemberitahuan melalui peranti bagi pengisian semula dos penyedut. Smart Inhaler ini, terdiri daripada *Force Resistive Sensor* dan bekalan kuasa 3.7V digunakan sebagai input, paparan pada notifikasi Oled sebagai output, dan ESP32 sebagai pemproses untuk menyambung ke Internet. Smart Inhaler menggunakan aplikasi IOT sebagai kaunter yang menyambungkan penyedut dengan peranti seperti telefon pintar. *Force Resistive Sensor* digunakan untuk menentukan dos yang diambil oleh pengguna dan kiraan dikurangkan sehingga dos penyedut habis. Notifikasi dihantar ke peranti apabila Smart Inhaler mencapai jumlah dos yang kurang mulai kiraan 50, 30 sehingga 10 dos bagi mengingatkan pesakit agar menukar penyedut baru. Smart Inhaler ini boleh diperbaharui dengan rekabentuk yang lebih praktikal pada bahagian atas *Metal Canister* untuk memudahkan pengiraan dose penyedut oleh *Force Resistive Sensor.*

Kata kunci: Penyedut Pintar, Penyakit Pernafasan, Pematuhan Pengambilan Ubat, Teknik Penghirupan, Teknologi Sensor.

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I. INTRODUCTION

Asthma is a chronic respiratory condition affecting over 300 million individuals worldwide, with increasing incidence in both industrialized and developing countries. It is characterized by airway inflammation and hyperresponsiveness, requiring long-term management using inhaled medications as the mainstay of therapy. Inhalers, such as pressurized metered-dose inhalers (pMDIs) and dry powder inhalers (DPIs), are widely prescribed due to their portability and rapid drug delivery mechanism [1]. Despite their efficacy, real-world outcomes often fall short due to poor patient adherence and incorrect inhaler techniques, which can severely impact treatment success [2].

Over the years, researchers have extensively studied the causes of improper inhaler usage and explored potential interventions. Studies have shown that up to 80% of patients use their inhalers incorrectly, leading to reduced medication deposition and suboptimal asthma control [3]. A local study in Malaysia revealed that only 4.3% of patients demonstrated correct inhaler use, with frequent errors related to inhalation timing, breath coordination, and device orientation [4]. Researchers have proposed a range of solutions to mitigate these issues, including patient education programs, simplified device regimens, and pharmacist-driven monitoring [5]. Meanwhile, advancements in technology have led to the development of electronic inhaler monitoring devices (EIMDs) capable of recording actuation events and tracking dose usage [6]. More recently, smart inhalers equipped with sensors, microcontrollers, and wireless connectivity have emerged, offering real-time feedback, adherence tracking, and personalized asthma management tools [7], [8].

Despite these advancements, many existing smart inhalers are either commercially restricted, lack open-source adaptability, or are limited in functionality particularly in their ability to detect technique errors in real time or notify users of low dose counts automatically. Some systems also rely on rigid architectures or proprietary software, making them less suitable for integration with cost-effective IoT platforms or community healthcare applications [6], [7], [5]. Moreover, limited work has been done on developing affordable smart inhaler prototypes using open-source microcontrollers such as ESP32 combined with custom sensor integration and cloud-based alert systems [9], [10].

To address these gaps, this paper presents the design and development of a Smart Inhaler System using a force-sensitive resistor (FSR), ESP32 microcontroller, OLED display, and Telegram-based mobile notification interface. The system aims to detect actuation force during inhaler usage, decrement and display remaining dose counts, and send real-time alerts to users as the medication approaches depletion. The prototype combines embedded hardware with open-source programming and affordable sensor integration to enhance asthma self-management, particularly in resource-constrained settings.

II. LITERATURE REVIEW

Metered Asthma remains one of the most prevalent chronic respiratory diseases worldwide, and inhaler therapy is considered a cornerstone of its management. However, the effectiveness of inhalers is highly dependent on patient adherence and correct usage techniques, which continue to pose significant challenges.

1. Challenges in Inhaler Usage and Adherence

Early literature has long established that the success of inhaler therapy depends on proper device selection and patient technique. A report by the Drug and Therapeutics Bulletin [1] emphasized that incorrect inhaler use, such as poor coordination, shallow inhalation, or incorrect device positioning leads to suboptimal drug delivery, with only 7–20% of medication reaching the lungs in real-world scenarios. This issue persists today. Scichilone [3] reinforced that no single inhaler suits all patients, and selection should be tailored based on individual capability and preference to maximize asthma control.In Malaysia, a local study revealed that only 4.3% of patients demonstrated correct inhaler technique, with multiple errors identified among pMDI and DPI users [4]. These findings highlight the pressing need for systematic monitoring and patient support beyond conventional training and follow-up.

2. Evolution of Inhaler-Based Monitoring Devices

The transition from traditional to smart inhalers has been progressive. Kikidis et al. [6] provided a comprehensive review of early electronic inhaler monitoring systems dating back to the 1980s, such as the Nebulizer Chronology and Smart Mist. Over the decades, innovations have added sensors, memory modules, and connectivity to improve patient monitoring, forming the foundation for modern inhaler-based monitoring devices (IBMDs). These systems not only track inhalation events but also detect technique errors using airflow, acoustic, and motion sensors.

3. Development of Smart Inhaler Technologies

More recently, smart inhalers have integrated Internet of Things (IoT) functionality, offering real-time data transmission and feedback loops. Owunyesiga [7] discussed engineering considerations in smart inhaler systems, including the incorporation of inertial sensors and microcontrollers to support cloud-based analytics. Zhang and Kumar [8] elaborated on the implementation of wireless communication (Bluetooth/Wi-Fi), cloud storage, and app-based user interfaces to provide personalized asthma management and early intervention alerts.

Further integration of smart inhalers with electronic health records (EHR) and predictive analytics holds promise for precision medicine approaches. Zhang and Ali [5] emphasized the critical role of pharmacists in educating patients about smart inhaler usage and interpreting the data for improved treatment planning.

4. Embedded Systems and Sensor Integration

Embedded system design is a key element in smart inhaler development. Lei [9] designed an ESP32-based system with pressure and motion sensors to detect actuation events, using finite-state machines and object-oriented programming to process inhalation data. The system also transmitted usage reports to healthcare providers via Bluetooth, addressing both techniques tracking and data accessibility.

Parallel advancements in sensor design have enabled more compact, responsive, and cost-effective monitoring solutions. Watschke et al. [10] proposed a novel resistive sensor fabricated via additive manufacturing using TPU and conductive PLA. This flexible sensor offered high sensitivity under compressive forces and could be customized for different detection thresholds—an approach well-suited for inhaler actuation monitoring.

5. Impact of Inhaler Device Complexity on Outcomes

Device complexity also influences patient adherence. A study by Dhand et al. [2] found that patients using multiple types of inhalers (e.g., pMDI and DPI) were more prone to technique errors, leading to reduced treatment efficacy and increased healthcare costs. The authors recommended minimizing regimen complexity and standardizing inhaler types, a goal that smart inhalers with built-in guidance and reminders can effectively support.

The reviewed literature reveals a clear trajectory from recognizing limitations in inhaler use to the emergence of smart inhaler systems that leverage embedded electronics, IoT, and advanced sensing to enhance asthma management. Despite technological progress, challenges remain in user education, system integration, and long-term clinical validation.

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However, the cumulative evidence supports the development of comprehensive smart inhaler solutions that improve both medication adherence and technique, ultimately advancing patient outcomes. Smart Inhaler to display the remaining doses.

III. METHODOLOGY

The kind of research that is being done is the creation of a genuine project, which is the manufacturing of a smart inhaler. Three stages comprise the project's design and development: design block diagram and schematic circuit, design and product fabrication, and testing process.

1. Design Block Diagram and Schematic Circuit

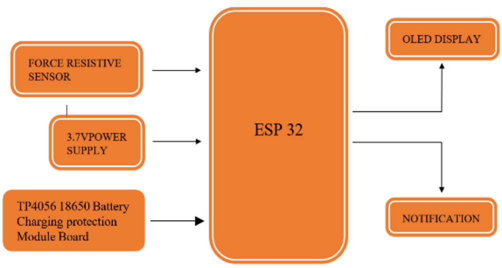

Figure 1. Block Diagram

Figure 1 shows the block diagram for Smart Inhaler. Block diagram indicates the implementation of input, output and processing system for Smart Inhaler. Force sensor and 3.7v battery are used as input for circuit operation. Input is processed and controlled by ESP 32 microcontroller. ESP 32 will process the input and send data to output which is OLED display and Telegram notification.

The schematic circuit for this project is shown in Figure 2. ESP32 is the primary microcontroller used. The circuit includes one force resistive sensor, OLED display, battery charging module, 3.7v battery, 10k and 100k resistors that are interconnected and controlled by a microcontroller.

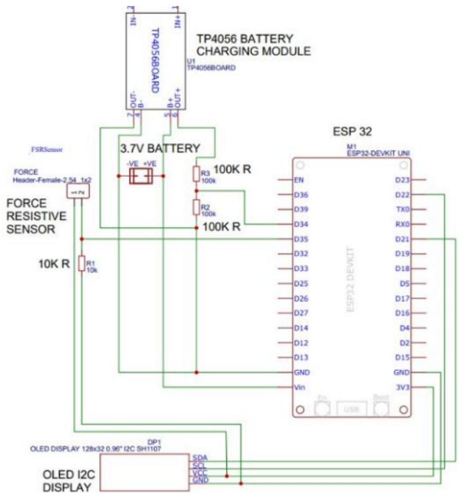

Figure 2. Schematic Circuit

The circuit operation, starting from 3.7v battery will supply the whole circuit. Battery charging module to4056 will show the battery life and act as charger Force Resistive Sensors are connected with fixed value resistor (10kΩ) to create a voltage divider and to create a variable voltage output, which can be read by a microcontroller's ADC input. When the force resistive sensor detects a force that goes higher than 37 N, microcontroller stores the data and OLED display will appear the remaining dose and battery percentage.

2. Development and Fabrication

The development and fabrication of the Smart Inhaler casing were carried out using **TinkerCAD**, a browser-based 3D modeling platform suitable for rapid prototyping

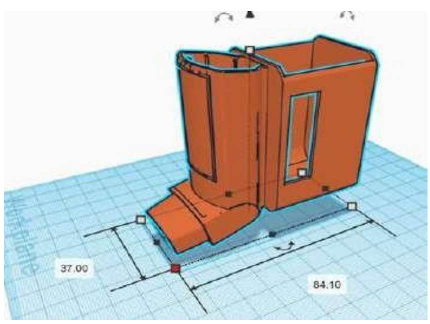

Figure 3. Smart Inhaler Designing

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Figure 3, shows the casing was custom-designed to accommodate key hardware components including the force-sensitive resistor (FSR), ESP32 microcontroller, OLED display, and power module. The model incorporates ergonomic contours to align with standard inhaler shapes, ensuring both functionality and user familiarity.

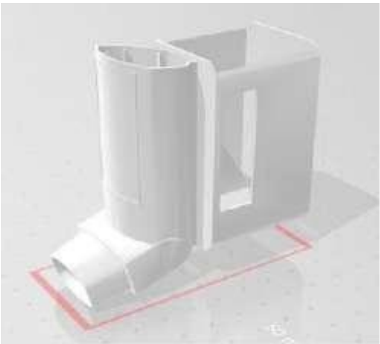

Figure 4. Completed Smart Inhaler Body Casing Display in 3D Modelling.

The 3D rendering in Figure 4 illustrates the completed digital model, which was then exported for 3D printing. The casing was fabricated using PLA filament material, providing sufficient structural rigidity while maintaining light weight and cost-effectiveness.

Figure 5. Front View of Smart Inhaler Model

Figure 5 shows the front view of the assembled Smart Inhaler prototype, featuring the integrated conventional inhaler and a visible OLED display interface.

Figure 6. Product on Right Side View

Figure 7. Left View of Smart Inhaler Model

Figure 6 provides the right-side view, highlighting the external rechargeable battery pack and enclosure cut-out for sensor access. Meanwhile, the left-side view depicted in Figure 7 offers a clearer profile of the assembled body with smooth edges and dimensional integrity achieved via 3D printing.

3. Testing Process

To guarantee that the generated product can operate correctly and meet the study's objectives, testing of the system is required. There are 3 method of testing methods have been done such as Pressure testing, notification testing, and OLED display testing. The testing instrument used is a checklist form.

a. Pressure testing

Figure 8. Dose Amount Reduced Using Pressure Testing

Pressure testing methods are proceed, for testing the suitable pressure value to reduce the count of Smart Inhaler, shows in Figure 8. The pressure detection test confirmed the FSR sensor's responsiveness to inhaler actuation.

b. Notification Testing

Figure 9. Notification Appears When The Inhaler Dose Reaches A Specific Amount.

Figure 9 shows a notification testing method for testing the effectiveness of ESP 32 as a microcontroller. The notification test validated that the system reliably sent alerts when the dose count dropped to the warning threshold. This microcontroller was connected to the internet and telegram application.

c. OLED display testing

Figure 10. The Amount Of Remaining Dose And Percentage Of Battery Is Display In OLED.

Additionally, the OLED display test demonstrated accurate and consistent visual updates of remaining doses and battery level. Figure 10 shows the OLED display testing which tests the connection between force resistive sensors, 3.7v battery, and OLED display. The test is to ensure that the OLED display will display updated current dose value when force resistive sensor is pressed and when battery level is increased and decreased. Final integration tests confirmed that all modules sensing, processing, display, and communication functioned cohesively to deliver a user-friendly and reliable smart inhaler solution.

IV. DATA ANALYSIS

There are presents, several findings from the functionality test of smart inhaler system can conduct. To evaluate the functionality of the Smart Inhaler System, a series of controlled tests were conducted to assess sensor responsiveness, dose tracking accuracy, and notification reliability.

Table 1: Sensor Testing Results.

Test	Result
Force Resistive Sensor	Success

Table 1 shows the force resistive sensors functionality can be operated successfully to function according to their respective roles.

Table 2: Pressure Force Testing Result

Force	Result
>37 N	Dose counter reduced and display at OLED display
<37 N	No action

Table 2 shows, the result of detecting the force applied on the sensor based on the force difference indicated.

As presented in Table 1 and Table 2, the system successfully detected pressure inputs exceeding 37 N, which was the predefined actuation threshold. When activated, the system appropriately decremented the dose count and displayed the updated value on the OLED screen. Conversely, for forces below the threshold, the system performed no action, confirming the effectiveness of the input filter logic implemented in the microcontroller. Program starting, when force resistive sensor accept input value higher than 37 N, as shows in Figure 11. Then Smart Inhaler's dose amount will be reduced by 1 and display on OLED display.

Figure 11: Dose Displayed At OLED Display When Pressure Applied >37N

Table 3: Telegram Notification Testing

Remaining amount of inhaler	Result
50	Notification sent "WARNING! Inhaler LOW: 50 left"
30	Notification sent "WARNING! Inhaler LOW: 30 left"
10	Notification sent "WARNING! Inhaler LOW: 10 left"

Notification logic was tested by simulating different remaining dose levels. The system was programmed to transmit warning messages to the user when the remaining dose count reached 50, 30, and 10 units, respectively. Table 3 shows, the testing result of notification appears based on the remaining number of doses specify. The result appear in Telegram messages such as "WARNING! Inhaler LOW: 30 left" were successfully triggered and received in real time.

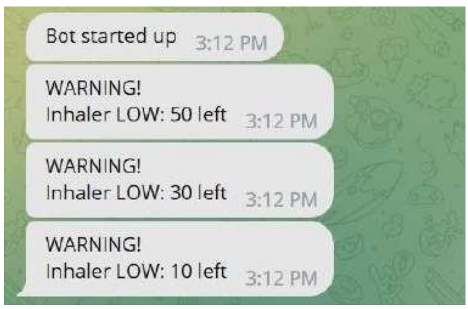

Figure 12: Result Notification On Telegram Application

Due to the system's integration of BotFather's generated coding and IDBot's ID used by the Telegram application, warning notification will be sent via Telegram. The notification received as depicted in Figure 12 will depend on the programming done in the Arduino IDE.

V. CONCLUSION

The design and development of the smart inhaler system represents a significant advancement in the management of respiratory diseases such as asthma and COPD (Chronic Obstructive Pulmonary Disease). This project successfully achieved all three design objectives. A working prototype was built around an ESP32 microcontroller and a force-sensitive resistor (FSR) to function as a reliable dose counter. It provides immediate feedback on dose usage by updating the remaining count on the OLED display after each actuation. The device also implements timely refill reminders via a Telegram notification interface, alerting users at predefined dose thresholds. These features mirror the cap abilities of emerging smart inhaler technologies, which not only track inhaler usage but also offer real-time feedback and personalized alerts to users.

Testing and evaluation of the 3D-printed prototype confirmed the system's effectiveness. The FSR-based sensor consistently detected inhaler actuations when the applied pressure exceeded ~37 N, a value within the typical range of forces required to operate commercial inhaler. Each valid actuation event triggered a correct decrement of the dose count, and the updated count was immediately reflected on the OLED screen. Furthermore, the Telegram notification mechanism performed as intended, issuing automated warnings when the remaining dose count reached 50, 30, and 10, thereby prompting the user to plan for refills. This demonstrates that the system can reliably provide the intended dose reduction feedback and refill notifications in real time, helping users remain aware of their medication status. Such capabilities are expected to support better adherence to inhaled therapy, as smart inhaler interventions in clinical studies have been associated with improved medication adherence and even reductions in exacerbation rates

However, for future recommendation, smart inhaler will implement IOT cloud to store dose count as a backup with the addition of cloud, remaining dose can be stored and retrieved if there any malfunction occurs. Dose Inhaler can resume counting from the last count before the malfunction without resetting it. Besides that, Smart Inhaler also can enhance with a more practical design on the top of the metal canister to facilitate inhaler dose calculation by the Force Resistive Sensor.

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