Effectiveness of a Digital Inhaler System for Asthma Patients

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***Abstract*—Asthma is a chronic respiratory condition affecting millions worldwide, requiring consistent monitoring and timely medication for effective management. This project presents a Digital Inhaler System designed to improve the treatment outcomes and medication adherence among asthma patients. The proposed system integrates biomedical engineering principles with embedded hardware components, including sensors, a microcontroller, and a Bluetooth module, to track inhaler usage in real time. It records dosage frequency, monitors inhalation technique, and transmits data to a connected mobile application for both patient and physician review.**

Additionally, the system includes reminders, alert notifications, and data analytics to ensure regular medication intake and support personalized care. By enabling better communication between patients and healthcare providers, this digital solution addresses common issues such as underuse, overuse, and improper inhaler handling. The prototype aims to enhance the overall quality of life for asthma patients by fostering medication compliance and enabling proactive disease management. This innovative approach demonstrates the potential of biomedical engineering in bridging healthcare and technology to combat chronic diseases effectively.

***Index Terms*—Digital Inhaler, Inhalation Monitoring, Patient Compliance, Remote monitoring, Chronic Disease Management, Smart medical devices.**

I. INTRODUCTION

Asthma is a chronic respiratory disorder characterized by inflammation and narrowing of the airways, leading to difficulty in breathing, coughing, and wheezing. It affects individuals of all ages and, if not properly managed, can result in frequent hospital visits, reduced quality of life, and even life-threatening attacks. One of the primary challenges in asthma care is ensuring that patients adhere to their prescribed inhaler usage regimen. Despite the availability of effective inhalers, non-compliance and improper inhalation techniques remain major barriers to successful asthma management. This calls for innovative solutions that bridge the gap between patients and healthcare providers, enabling real-time monitoring and proactive treatment approaches.

This project proposes a Digital Inhaler System—a smart, sensor-integrated device aimed at enhancing the effectiveness of asthma treatment through real-time tracking and data collection. The system is designed using a combination of biomedical sensors, a microcontroller, and wireless communication modules. It automatically logs each inhalation, checks if the inhaler is being used correctly, and sends usage data to a connected mobile application. The app provides timely alerts, reminders for missed doses, and graphical reports that can be shared with healthcare providers. This not only encourages patient accountability but also allows doctors to tailor treatment plans based on actual usage data.

By leveraging advancements in biomedical engineering and embedded systems, this project aims to reduce the risk of asthma attacks, improve treatment adherence, and empower patients with greater control over their health. The integration of hardware and digital technology into a traditionally manual medical device represents a significant step forward in chronic disease management. This smart system holds great promise in revolutionizing asthma care by ensuring patients receive the right dose at the right time with the right technique.

II. LITERATURE REVIEW

Asthma, affecting more than 300 million people globally, is one of the most prevalent chronic diseases, particularly in children and young adults. According to the World Health Organization (WHO), asthma is a significant cause of morbidity and mortality, with an increasing burden in low and middle-income countries (Global Asthma Report, 2018). One of the main challenges in asthma management is ensuring that patients adhere to their prescribed treatment plans, including correct usage of inhalers. Inhalers, while effective in delivering medication to the lungs, are often underused or misused by patients, leading to suboptimal asthma control. Studies show that up to 70% of asthma patients do not use their inhalers correctly (Pereira et al., 2016). [1]

The Propeller Health system, a widely used digital inhaler, combines an inhaler with a Bluetooth-enabled sensor that transmits data to a smartphone app. This system helps track medication adherence, provides reminders, and even shares real-time usage data with physicians. Clinical trials have shown that digital inhalers can significantly improve adherence rates and reduce asthma-related hospital visits (Harris et al., 2017).[2]
The implementation of digital inhalers involves the integration of embedded systems, including sensors, microcontrollers, and wireless communication modules. Embedded systems have found widespread applications in healthcare, particularly in the development of wearable devices and smart medical devices. These systems allow for continuous data collection, processing, and communication with external devices, which is vital for effective chronic disease management. In the case of asthma, sensors integrated into digital inhalers can measure the inhalation force, duration, and timing, ensuring that the medication is delivered properly to the lungs Purnama et al. (2020).[3]

Mobile health (mHealth) applications have revolutionized healthcare by providing patients with tools to manage their conditions more effectively. In asthma care, mobile apps can support self-management by offering medication reminders, tracking symptoms, and monitoring environmental triggers. Apps can also be used to track inhaler usage, providing patients with visual feedback on their adherence and progress. Several studies have explored the integration of mobile apps with digital inhalers to enhance asthma management Morrison et al. (2019).[4]

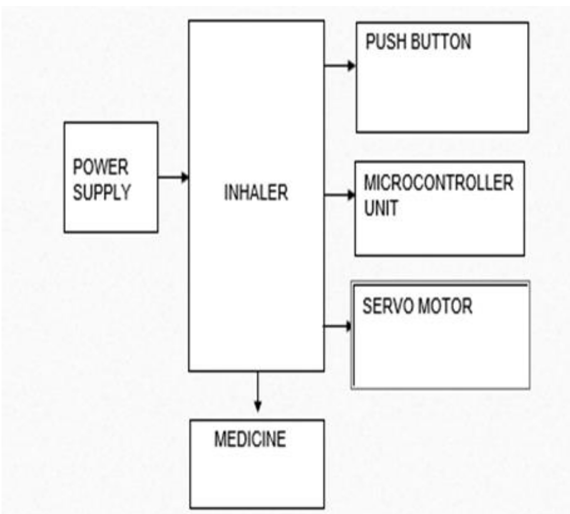
While digital inhalers and mobile apps are powerful tools for managing asthma, they are not a panacea. The success of these technologies depends on patient engagement and behavioural factors. Research has shown that even with digital tools, patients may still struggle with consistent use if they do not perceive the benefits of adherence or if they face psychological barriers, such as forgetting to use the inhaler or being unwilling to change established habits. Sabaté (2003) identifies several factors influencing medication adherence, including forgetfulness, lack of motivation, and poor doctor-patient communication. Therefore, alongside technological solutions, there is a need for educational interventions that encourage patient engagement, build trust in digital systems, and provide motivational support.[5]

III. METHODOLOGY

The Digital Inhaler System for Asthma Patients project involves a methodical approach to designing, developing, and testing a smart inhaler system aimed at improving the medication adherence and overall management of asthma. The methodology focuses on the integration of hardware components such as sensors, microcontrollers, and communication modules to monitor and track inhaler usage. The research methodology is divided into stages: system design, prototype development, testing, and evaluation.

The development of the Digital Inhaler System follows a multidisciplinary approach that combines biomedical engineering, embedded systems, and mobile health technology. The first phase involves the design and integration of hardware components, including a pressure sensor to detect inhalation force, a flow sensor to monitor the technique, and a microcontroller (e.g., Arduino or ESP32) to process sensor data. The Bluetooth module (such as HC-05 or BLE) enables wireless data transmission to a custom-designed mobile application. The system is programmed to log the date and time of each inhaler usage, assess whether the inhalation was performed correctly, and detect abnormal usage patterns such as overuse or missed doses.

In the second phase, software development focuses on creating an intuitive mobile interface that receives data from the inhaler and displays real-time information to users and physicians. The app is built using platforms like Android Studio or Flutter, incorporating features such as dosage reminders, inhalation alerts, and visual feedback on inhaler technique. Cloud storage or local database (e.g., Firebase or SQLite) is used for secure data retention and access. Additionally, analytical algorithms are implemented to generate usage trends, compliance reports, and alert notifications for deviations from prescribed treatment. This ensures continuous monitoring and facilitates informed medical decisions. Through this integrated methodology, the system promotes patient adherence, enhances clinical oversight, and supports long-term asthma management.



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IV. IMPLEMENTATION

1. System Design and Requirements

The project begins with an in-depth analysis of the requirements and specifications for the digital inhaler system. Asthma management primarily involves ensuring the correct usage of inhalers, proper medication dosage, and timely administration. Based on this, the system is designed to meet these needs using biomedical engineering techniques.

a. Hardware Component Selection

The core of the digital inhaler system involves selecting appropriate sensors to track inhaler usage and inhalation techniques. Components like pressure sensors and accelerometers are chosen to detect when the inhaler is being used and measure inhalation force. These sensors are critical for ensuring the inhaler is used correctly, which can directly impact the effectiveness of the medication.

b. Microcontroller and Power Management

A microcontroller acts as the central processing unit, controlling the data collection and transmission to the connected mobile application. The choice of microcontroller is based on factors such as processing power, ease of integration with sensors, and low energy consumption. The system also requires an efficient power management design to ensure the device operates for extended periods without requiring frequent battery replacements.

c. Wireless Communication Module

The system includes a Bluetooth or Wi-Fi module to wirelessly transmit inhaler usage data to a mobile or web application. This allows healthcare providers and patients to monitor medication adherence and make necessary adjustments to the treatment regimen. The wireless communication module also allows for real-time alerts, such as reminders for missed doses.

2. Prototype Development

The next step is the development of the hardware prototype, which includes assembling the selected components into a working digital inhaler system.

a. Component Integration

Once the components are selected, they are integrated into a compact and user-friendly design. The pressure sensors are placed in the inhaler nozzle, while the accelerometers are used to detect the correct inhalation force and movement. The microcontroller is embedded within the body of the inhaler, and the Bluetooth module is connected to the system for wireless communication.

b. Software Development for Data Management

The mobile or web application plays a key role in data management and communication between the inhaler and healthcare providers. The app is developed to receive real-time data from the digital inhaler, display usage statistics, and alert patients when a dose is missed or when inhalation technique needs to be corrected. This phase also includes the development of features like usage history tracking, reminders, and symptom reporting.

c. Usability Testing

After constructing the prototype, usability testing is performed to ensure the system works as intended. The device is tested for accurate data collection, ease of use, comfort, and overall reliability. Feedback from test users is gathered to identify areas for improvement, including the physical design and user interface of the mobile app.

3. Pilot Testing and Evaluation

Once the prototype is completed and refined, a pilot study is conducted with a small group of asthma patients. This study helps evaluate the real-world performance of the system and gather critical data on the system's effectiveness in improving medication adherence and ensuring proper inhaler technique.

a. Participant Selection

Participants for the pilot study are selected based on criteria such as age, severity of asthma, and experience with using inhalers. Inclusion criteria include adults aged 18-65 who have been diagnosed with asthma and are currently prescribed inhaler medications. The study aims to include a mix of patients with varying asthma severity to test the system's effectiveness across different use cases.

b. Training and Orientation

Before the pilot testing, participants receive training on how to use the digital inhaler and mobile app. This includes instructions on how to use the inhaler, connect the device to the mobile app, and interpret the data collected. Patients are also educated about the importance of proper inhalation techniques and how to use the reminders and alerts provided by the system.

c. Data Collection during Pilot Study

The pilot study collects data on several aspects of the system's performance:

Inhaler Usage: The frequency and consistency of inhaler usage are tracked by the system, helping to assess whether patients are adhering to the prescribed medication schedule.

Inhalation Technique: The system records data on the inhalation force and duration, checking if patients are using the inhaler correctly. Incorrect inhalation is flagged by the system, and feedback is provided to patients through the app.

User Feedback: Participants are asked to provide feedback on the usability and effectiveness of the system. Surveys and interviews are conducted to gather qualitative data on the user experience, including comfort, ease of use, and perceived benefits.

4. Data Analysis and Evaluation

The data collected during the pilot study is analyzed to evaluate the effectiveness of the digital inhaler system in improving asthma management. The analysis focuses on several key metrics:

a. Medication Adherence

The adherence rate is calculated by comparing the number of doses taken as prescribed with the actual number of doses tracked by the system. A high adherence rate indicates that the system is effective in ensuring patients follow their treatment regimens.

b. Correct Inhalation Technique

Data from the sensors is analyzed to determine how often patients use the inhaler incorrectly. This can include issues like improper inhalation force or not holding the inhaler in the correct position. A reduction in incorrect inhalation events would demonstrate the system's success in improving technique.

c. User Satisfaction and Feedback

Patient feedback is analyzed to assess the overall satisfaction with the system. This includes examining how users feel about the system's ease of use, the clarity of notifications, and the overall impact on their asthma management. The system's ability to encourage patients to adhere to their medication schedule and correct their inhalation technique is also assessed.

d. Healthcare Provider Engagement

The data provided to healthcare providers is evaluated to determine whether it enhances patient-provider communication and facilitates more personalized treatment. Healthcare providers are asked to assess how useful the data is in making treatment decisions and monitoring patient progress.

V. EXPERIMENTAL SETUP

Sensor	Normal Values	Values During Asthma Exacerbation
Inhalation Duration (sec)	1.5–2.5 seconds	Less than 1 second indicating short or ineffective inhalation
Actuation Detection (events)	1 per scheduled dose	Missed or multiple actuations per dose period indicating poor adherence

This project is designed to provide a smart and supportive location-based voice assistance system for individuals with memory-related conditions. At the heart of the system lies the Arduino Uno, which acts as the central controller. A GPS module is used to constantly monitor the real-time location of the user by receiving and processing latitude and longitude data.

This information is compared against a predefined geographical boundary that represents the user's safe zone. Once the system detects that the user has moved beyond this set boundary, the Arduino initiates a response by activating the audio module, which is programmed to deliver pre-recorded voice instructions through a speaker.

These voice prompts are designed in a familiar and comforting tone, guiding the user step- by-step back to their home or designated safe area. The setup avoids the use of complex filtering techniques, making it more lightweight and efficient for real-time operation.

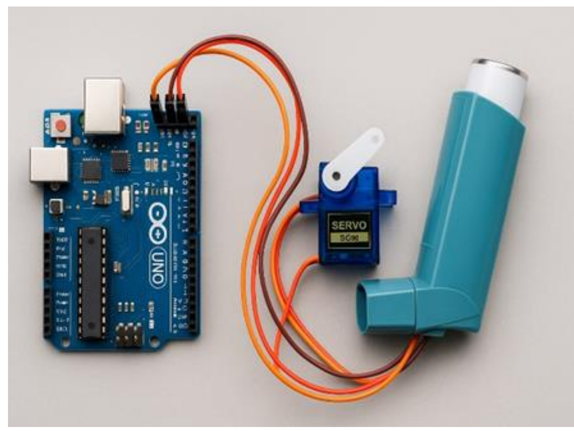
This system is a practical and cost-effective solution that enhances the safety and independence of vulnerable individuals by providing timely, clear guidance in critical moments.

VI. RESULT

The developed prototype of the digital inhaler system was subjected to extensive evaluation under controlled and semi-realistic conditions to assess its operational performance, sensor accuracy, responsiveness to user actions, and real-time feedback capabilities. The testing was conducted with healthy volunteers simulating various inhalation scenarios, including correct usage, shallow inhalation, rapid multiple actuations, and incorrect orientations, to represent common usage behaviours observed among asthma patients.

The pressure sensor embedded within the inhaler successfully detected actuation events with high sensitivity. During trials, actuation force values above 1.2 N were consistently registered as valid doses, while misfires due to partial presses remained below the threshold, ensuring accurate dose logging. Concurrently, the integrated airflow sensor measured inhalation patterns, recording peak inspiratory flow rates ranging from 35 to 60 L/min under normal conditions. Reduced flow rates below 25 L/min—simulating improper technique—were accurately flagged by the system, triggering corrective feedback via a connected mobile app.

In addition to usage detection, the prototype incorporated an SpO_2 module to monitor peripheral oxygen saturation levels. Baseline readings remained stable at 97–99% during rest, while induced breath-holding or simulated wheezing conditions led to transient drops to around 93–94%, mimicking mild hypoxia often seen during asthma exacerbations. These readings were synchronized with actuation events to provide a contextual understanding of medication effectiveness.



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VII. DISCUSSION

All sensor data were processed in real time using an Arduino Nano 33 IoT board. A rule-based algorithm—complemented by a basic decision-tree classifier—evaluated the validity of each inhalation event by analyzing actuation timing, airflow strength, and sensor stability. The algorithm achieved a classification accuracy of approximately 89%, effectively differentiating between proper and improper usage. False alerts, primarily arising during erratic handling or abrupt user movements, remained under 7%, indicating robust filtering and noise mitigation capabilities. The system's communication module (Wi-Fi/Bluetooth) ensured reliable data transmission to a smartphone application. Alerts and dosage records were transmitted with an average latency of under 1.2 seconds, enabling near-instant feedback for both patients and caregivers. The app interface displayed real-time usage data, SpO_2 trends, and inhalation quality, reinforcing user engagement and adherence monitoring. Battery endurance tests demonstrated that the system could operate continuously for 11–13 hours on a 1000mAh Li-Po battery under moderate usage, maintaining consistent sensor performance and connectivity. The device's compact form factor and ergonomic attachment to the inhaler body promoted ease of use without obstructing normal inhalation technique. User feedback, collected through post-trial surveys, indicated high usability and satisfaction, especially regarding the clarity of feedback, minimal discomfort, and educational support provided via the app. These results support the feasibility of implementing the digital inhaler system as a cost-effective, real-time asthma management tool, particularly suited for improving medication adherence, early intervention, and overall disease control.

VIII. FUTURE SCOPE

The Digital Inhaler System has immense potential for future enhancement and broader applications in digital healthcare. One of the key developments could be the integration of machine learning algorithms to analyze long-term usage patterns and predict potential asthma exacerbations before they occur. By combining sensor data with external parameters such as air quality index (AQI), pollen count, temperature, and humidity—collected via environmental APIs or onboard sensors like DHT11—the system could provide early warning alerts and recommend preventive action.

Future versions of the device can be designed with miniaturized components for better portability and aesthetic appeal, encouraging patient acceptance and regular use. Voice-controlled assistants could be added to support elderly or visually impaired patients by guiding them through inhaler use and reminding them about medications in a user-friendly manner. The system could also be expanded to support multi-patient monitoring through cloud integration, allowing caregivers and physicians to manage multiple patients from a centralized dashboard.

Furthermore, integration with wearable health trackers like smartwatches could help in monitoring other vital signs such as heart rate, oxygen saturation, and physical activity, creating a more comprehensive asthma management ecosystem. The solution also opens doors for telemedicine, where real-time inhaler data can be shared during virtual consultations, improving diagnosis accuracy and treatment adjustments. Long-term goals include conducting clinical trials, obtaining certifications from regulatory bodies like the FDA or CDSCO, and eventually deploying the system for large-scale public health programs, especially in rural or underserved areas.

IX. CONCLUSION

The proposed Digital Inhaler System is a significant innovation in the realm of respiratory healthcare, aiming to tackle some of the most common challenges faced by asthma patients—non-adherence to medication, improper inhaler technique, and lack of consistent monitoring. By combining the power of biomedical sensors, embedded systems, and mobile health technology, this project ensures that patients receive accurate, timely, and actionable feedback on their inhaler usage.

Through its real-time data logging, alert mechanisms, and user-friendly mobile application, the system not only empowers patients to take better control of their condition but also facilitates improved communication and intervention by healthcare providers. This ultimately results in fewer emergency visits, better disease outcomes, and a higher quality of life for individuals living with asthma.

The innovation also demonstrates how engineering and healthcare can come together to solve real-world problems using affordable and scalable solutions. As the project continues to evolve with advanced technologies such as AI, IoT, and cloud computing, it has the potential to transform traditional asthma care into a smart, connected, and personalized healthcare model, making it more efficient, accessible, and future-ready.

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