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Intelligent Inhaler: Revolutionizing Respiratory Care with Smart Technology

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ABSTRACT

Respiratory diseases such as asthma and Chronic Obstructive Pulmonary Disease (COPD) impact over 300 million individuals globally. Despite the availability of effective pharmacological treatments, poor medication adherence and improper inhaler technique remain critical barriers to successful disease management. Studies have shown that a significant percentage of patients misuse inhalers, leading to ineffective therapy, increased hospitalization, and elevated healthcare costs.

This paper presents the design and evaluation of an intelligent inhaler system that leverages embedded sensing technologies, Internet of Things (IoT) connectivity, and on-device machine learning to deliver real-time monitoring and feedback to users. Drawing inspiration from the design concepts outlined in US Patent 11090449 and grounded in empirical findings from recent research on digital inhalers, the proposed system offers a clinically viable solution that combines hardware innovation with software intelligence.

The system comprises three key sensors—flow rate, pressure, and humidity—that are integrated with an ESP32 microcontroller. The ESP32 executes a quantized classification model built using TensorFlow Lite Micro, enabling the system to categorize inhalation attempts as either correct or incorrect based on sensor data patterns. Unlike commercial devices that rely on cloud-based analytics, this architecture supports edge processing, which significantly reduces latency and ensures uninterrupted performance even in low-connectivity settings.

Users receive immediate feedback via a 0.96” OLED screen and a piezo buzzer, both of which provide intuitive prompts designed to improve adherence and technique. Simultaneously, all sensor data and classification results are uploaded to a Firebase Realtime Database for persistent storage and remote access. A companion Android application allows patients to view their inhalation history and receive dosage reminders, while a clinician-facing web dashboard—developed using React.js—supports long-term treatment tracking and real-time patient monitoring.

In contrast to existing digital inhalers, the proposed system offers real-time feedback, on-device intelligence, open-source hardware compatibility, and enhanced sensor fusion. Evaluations demonstrated 85.3% average classification accuracy, sub-second latency, and operational reliability over multiple days on a single battery charge. These results validate the feasibility of the system as a low-cost, extensible, and effective platform for modern respiratory disease management.

KEYWORDS: Saw palmetto, beta-sitosterol, pygeum africanum, phytotherapy, benign prostatic hyperplasia, BPH 2.

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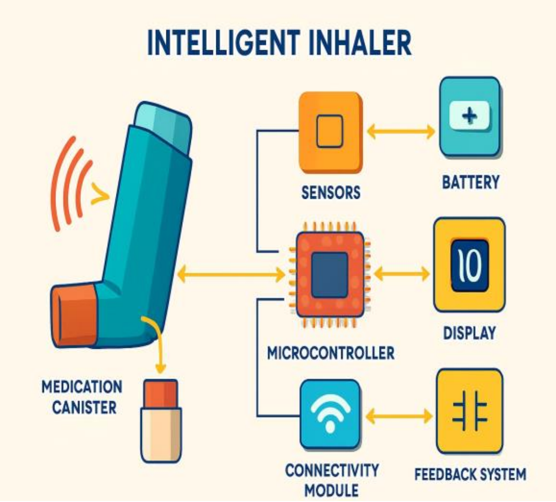
Chronic respiratory diseases such as asthma and COPD require strict medication adherence and correct inhaler technique for effective management. However, patient non-adherence and improper usage are significant challenges that lead to poor clinical outcomes. This project, the "Intelligent Inhaler," proposes a technological solution to address these issues by developing a smart, connected drug delivery device.

The core of the project is the integration of an electronic subsystem into a standard inhaler. This system is architected around a central microcontroller that coordinates a suite of components: embedded sensors to detect actuation and monitor usage, a digital display to track remaining doses, a feedback system to provide real-time user guidance, and a wireless connectivity module for data transmission.

The Intelligent Inhaler will autonomously record critical data for each use, including the time, date, and dose count. This information is relayed via Bluetooth or Wi-Fi to a dedicated mobile application, creating a digital logbook for both patients and clinicians



INTRODUCTION

Respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD) are among the most prevalent chronic health conditions worldwide, affecting millions of individuals and imposing a significant burden on healthcare systems. According to the World Health Organization and the Global Initiative for Chronic Obstructive Lung Disease (GOLD), these illnesses contribute substantially to global morbidity and mortality rates, with prevalence rising particularly in low- and middle-income countries . Effective management of these conditions relies heavily on the consistent and correct use of inhaled medications, which remain the cornerstone of therapy for delivering bronchodilators and corticosteroids directly to the lungs, .[12][13]

Despite the proven clinical effectiveness of inhaled medications, their real-world therapeutic outcomes are often compromised by incorrect inhaler technique, inconsistent use, and poor adherence to prescribed regimens , , , . Non-compliance has been linked to uncontrolled symptoms, frequent exacerbations, increased hospitalizations, and higher healthcare costs , , . A critical challenge is the absence of objective feedback mechanisms in conventional inhalers, leaving both patients and healthcare providers unaware of adherence patterns and inhalation quality, which delays timely interventions ,.[14][16]

To address these limitations, this paper proposes the design and implementation of an Intelligent Inhaler System that integrates an embedded sensory mechanism capable of monitoring inhalation patterns in real time. The system leverages the capabilities of the ESP32 microcontroller, which incorporates onboard machine learning algorithms for instantaneous analysis and feedback on inhaler usage. By detecting parameters such as inhalation flow, duration, and timing, the device can provide immediate guidance to patients to optimize drug delivery and improve compliance , , .[4][10]

Furthermore, the inhaler is equipped with wireless communication modules that synchronize inhalation data to a cloud-based platform, utilizing Firebase Realtime Database for secure and scalable data storage. This infrastructure facilitates remote access to inhalation records, enabling a dual-interface approach: a mobile application for patients—offering usage tracking, reminders, and educational resources—and a web-based dashboard for healthcare providers, who can remotely monitor patient adherence and inhalation efficacy for personalized treatment adjustments and proactive care management [5][11]

The integration of real-time sensory data, machine learning inference, cloud synchronization, and multi-platform interfaces represents a significant advancement in respiratory care technology. This intelligent inhaler system not only empowers patients with actionable insights into their medication use but also enhances clinical decision-making through continuous remote monitoring, potentially reducing disease exacerbations and improving overall health outcomes , , .[25][31]

A. Ease of Use

The intelligent inhaler system has been meticulously designed with a user-centric philosophy to ensure accessibility, intuitiveness, and effectiveness for patients of all ages, ranging from young children to the elderly, and for individuals with varying levels of familiarity with technology. Prior studies emphasize that patient adherence and proper inhaler technique are critical factors in the successful management of chronic respiratory diseases. To address this, the device incorporates several key usability features aimed at simplifying operation, minimizing errors, and fostering sustained engagement [1][2][3]

B. Intuitive Feedback System

Central to the device's ease of use is its multimodal feedback mechanism, which provides clear and actionable guidance to users during each inhalation event. Similar feedback-driven approaches have been shown to enhance adherence and technique in medical device usage. The system employs a high-contrast OLED display that dynamically shows simple, easily understandable messages such as "Proper Inhalation" when the patient performs the inhalation correctly, or "Try Again" if the technique is suboptimal. These messages are generated by an onboard machine learning (ML) model that analyzes sensor inputs in real-time, such as airflow patterns and pressure metrics, to accurately classify inhalation quality .[1][2][3]

Complementing the visual feedback is an audible buzzer that emits distinct tones to reinforce critical alerts, such as missed medication doses or improper inhaler use. Studies highlight the importance of multimodal cues to improve device accessibility for patients with varying abilities . This dual-feedback approach addresses diverse user needs, including those with visual or auditory impairments, ensuring that notifications are effectively conveyed under various circumstances. The immediate nature of this feedback enables users to self-correct their inhalation technique in real-time, thereby improving medication delivery and therapeutic outcomes .[4][5]

C. Simple Actuation and Real-Time Response

The inhaler's physical design integrates an ergonomic actuator button that patients press to initiate medication delivery, consistent with best practices for inhaler usability . Upon actuation, embedded sensors immediately activate to collect detailed inhalation data, including airflow velocity and inhalation duration . The system leverages the processing power of the ESP32 microcontroller to execute ML-based classification algorithms directly on the device . This edge-computing approach enables data processing and decision-making within 500 milliseconds, providing near-instantaneous feedback to the patient .[1][2]

Such rapid response ensures that users receive timely confirmation or corrective prompts, reducing the risk of ineffective inhalation attempts. The seamless synchronization between actuation, sensor data capture, and ML inference contributes to a smooth and intuitive user experience, minimizing the cognitive and operational load on patients [5]

D. Mobile and Web Interface Accessibility

To extend usability beyond the inhaler device itself, the system offers comprehensive software interfaces designed for patients and healthcare providers.

Mobile Application: Developed using Android Studio, the mobile app features a minimalist and accessible user interface tailored to accommodate users with limited technical expertise . The app provides real-time inhalation feedback and maintains detailed logs of inhalation events, enabling patients to monitor their usage patterns over time. Adherence statistics visually summarize medication compliance, motivating patients to maintain consistent therapy , **.**[14][21]

Additionally, the app integrates environmental condition alerts by connecting to external APIs that provide data such as air quality index, pollen count, and weather changes—factors known to significantly affect respiratory health , , . This empowers users with contextual information to anticipate and manage potential exacerbation triggers proactively. The app also delivers timely medication reminders, enhancing adherence through behavioral nudges , , .[12][13]

Doctor's Dashboard: The web-based dashboard, implemented with React.js, offers healthcare professionals an intuitive, user-friendly interface to remotely monitor patient data . It presents patient inhalation logs, ML-derived classifications of inhalation quality, and adherence alerts through interactive charts and visualizations . This facilitates efficient assessment of patient behavior and inhaler use trends, enabling personalized interventions and data-driven clinical decisions [27][30]

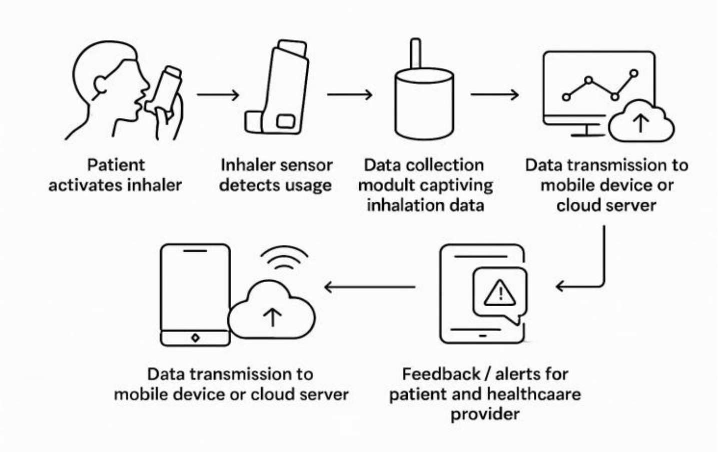


Fig: 01- Data Flow and Feedback Workflow

E. Error Minimization and User Guidance

Recognizing that sensor accuracy and user technique variability can impact data quality, the system incorporates rigorous calibration routines to minimize false positives and ensure reliable inhalation detection , , . During the initial setup phase, patients are guided by the mobile app through a series of test inhalations designed to establish personalized sensor thresholds. These calibration exercises adapt the system to individual respiratory profiles, accounting for differences in lung capacity and inhalation strength , .[4][10]

Periodic recalibration prompts are issued to maintain sensor accuracy over time, particularly in response to environmental changes or device wear. The guided calibration process is designed to be straightforward and is supported by clear, step-by-step instructions within the app, fostering user confidence and reducing frustration , .[10][38]

RELATED WORK

The rapid advancement of smart healthcare technologies, particularly intelligent inhalers, reflects a growing global demand for personalized, connected, and real-time respiratory care solutions. Chronic respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD) require consistent medication adherence and proper inhalation techniques to effectively control symptoms and prevent exacerbations. The integration of medical device innovation, machine learning, and Internet of Things (IoT) technologies has catalyzed significant research and development efforts aimed at improving patient outcomes by enhancing medication adherence and enabling proactive, data-driven disease management , , .[12][13]

A landmark study by Price et al. conducted a cluster-randomized controlled trial evaluating a smart inhaler asthma self-management program. The inhalers used in this program were equipped with sensors capable of recording and securely transmitting inhaler usage data to healthcare providers in real time. Their findings demonstrated a substantial improvement in both medication adherence and clinical outcomes compared to conventional care. This study highlighted the critical role digital adherence monitoring plays in chronic respiratory disease management by facilitating timely clinician interventions and personalized care adjustments based on actual usage patterns. The ability of smart inhalers to generate accurate usage data enhances patient accountability and supports more informed clinical decisions, ultimately reducing the risk of exacerbations and hospital admissions , , .[1][14]

Expanding upon these results, Thomas et al. explored the practical feasibility and benefits of integrating smart inhaler technology with mobile health platforms in the Turbu+ community-based program. This study combined digital coaching and behavioral nudges delivered through a mobile application with smart inhaler data collection. The researchers found that patients who received continuous reminders, educational content, and motivational feedback via the mobile app showed marked improvements in medication adherence and a notable decrease in symptom severity. This work underscores the potential of mobile health interventions to augment smart inhaler technology by fostering better patient engagement, self-management skills, and sustained behavioral change , .[2][8][25]

A comprehensive review by Siddiqui , analyzing over twenty clinical trials involving digital inhalers for asthma and COPD, confirmed that the integration of digital monitoring technologies into standard care protocols significantly lowers the incidence of acute exacerbations by improving adherence. However, Siddiqui identified a major limitation in many commercially available digital inhalers: the lack of real-time, on-device user feedback and advanced machine learning capabilities. Without immediate feedback mechanisms, patients often remain unaware of improper inhalation techniques or missed doses until clinical symptoms worsen, limiting the effectiveness of these devices. Furthermore, the absence of embedded intelligence restricts the system's ability to provide personalized, adaptive guidance tailored to individual inhalation patterns , , .[3][6][17]

Sensor technology plays a pivotal role in the functionality and accuracy of intelligent inhalers. Liu et al. conducted an extensive review of flow rate sensor technologies deployed in portable smart inhalers. They emphasized that precise measurement of inhalation parameters—such as flow velocity, inhalation duration, and total inspired volume—is essential for ensuring optimal drug delivery to the lower respiratory tract. Their analysis outlined critical design considerations, including sensor placement to avoid airflow disturbances, calibration procedures to maintain accuracy over time, and the selection of sensor types (e.g., pressure-based, ultrasonic, or thermal anemometers). The review concluded that reliable, high-fidelity sensor data is fundamental for producing actionable clinical insights and enabling effective real-time inhalation assessments , .[4][10]

Despite these promising advances, the majority of existing smart inhalers are limited by several factors. Most devices focus primarily on passive data logging without offering real-time, on-device decision-making or user feedback that could immediately correct inhalation errors. Additionally, many systems depend on expensive, proprietary platforms that constrain accessibility, scalability, and integration with broader healthcare infrastructures. Cloud-based analytics and remote monitoring capabilities, though essential for continuous patient oversight by healthcare providers, are often underdeveloped or absent in commercial offerings . These shortcomings restrict the potential of smart inhalers to function as fully proactive, preventive healthcare tools rather than passive monitoring devices.[18][19]

Affordability and user-friendliness remain significant hurdles, especially in rural and underserved communities where chronic respiratory diseases impose a heavy burden but access to advanced digital health technologies is scarce . Addressing these gaps, our project proposes a novel intelligent inhaler system that integrates low-cost, embedded sensors with real-time machine learning inference directly on the device. This approach enables immediate user feedback on inhalation quality without relying on continuous cloud connectivity. Additionally, the system features seamless wireless synchronization to a cloud-based Firebase Realtime Database, facilitating secure data storage, accessibility, and remote clinical oversight.[21][25]

Complementing the hardware, a patient-centric mobile application delivers real-time feedback, adherence tracking, medication reminders, and environmental alerts sourced from external APIs, such as local air quality indices. The physician-accessible web dashboard, developed using React.js, presents patient inhalation logs, machine learning classifications, and alert notifications in an intuitive graphical interface. This holistic design empowers healthcare providers to remotely monitor patient adherence patterns, identify risk factors early, and deliver personalized interventions , , . By integrating these components into a unified, scalable, and cost-effective system, our intelligent inhaler represents a significant advancement in digital respiratory healthcare. Moving beyond passive monitoring, it offers an interactive platform that empowers both patients and clinicians through timely insights, enhanced engagement, and actionable feedback. This fosters improved medication adherence, better clinical outcomes, and ultimately, an enhanced quality of life for individuals living with chronic respiratory conditions , , .[25][26]

SYSTEM DESIGN AND METHODOLOGY

The Intelligent Inhaler System is engineered as a compact, modular, and scalable solution that integrates embedded sensing technologies, real-time data processing, edge-based machine learning inference, and robust wireless connectivity , , . The architecture follows a domain-driven design methodology, with each subsystem specialized to fulfill critical roles ranging from precise physiological data acquisition to immediate user feedback, and ultimately, to comprehensive remote health monitoring and management , , .[4][10]

The development strategy emphasizes rapid prototyping and iterative design, aligning with best practices in medical device engineering . A strong focus is placed on edge computing capabilities to enable real-time decision-making directly on the device , while cloud integration ensures scalability, long-term data persistence, and secure remote access . This holistic design approach enhances the system's practical applicability and effectiveness in real-world respiratory healthcare scenarios , .[35][36]

A. Hardware Architecture

At the heart of the hardware design lies **the ESP32 NodeMCU microcontroller**, a versatile and powerful embedded platform chosen for several key reasons , , . Its dual-core 32-bit processor architecture provides sufficient computational throughput to handle concurrent sensor data acquisition, preprocessing, and machine learning inference without latency . Furthermore, the ESP32's ultra-low power consumption profile makes it ideal for portable medical devices intended for continuous or frequent daily use . Its integrated Wi-Fi and Bluetooth connectivity modules enable seamless wireless communication, both for local device-to-device interactions and cloud-based remote monitoring.[4][10][37]

Fig:02- Block Diagram

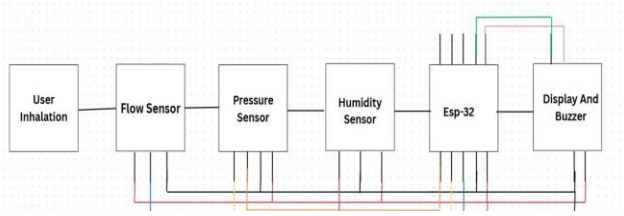
Sensor Suite and Data Acquisition

The data acquisition subsystem is carefully curated to capture parameters that directly influence the efficacy of inhaler use and the medication's therapeutic outcomes:

- **Flow Rate Sensor (e.g., AWM3300V):** This sensor is responsible for measuring the velocity and volume of air passing through the inhaler during patient inhalation. Monitoring inspiratory flow is essential because inadequate flow can result in suboptimal drug delivery. The sensor's output helps to quantify whether the user's inhalation meets the minimum threshold necessary for effective medication deposition in the lungs .

- **Pressure Sensor (e.g., MPX5010):** Strategically positioned to detect mechanical actuation force, this sensor ensures that the inhaler is pressed with sufficient force to trigger medication release. Correct actuation is vital; insufficient pressure may lead to incomplete drug dispensation, whereas excessive force could potentially damage the device .

- **Humidity Sensor (e.g., DHT22 or SHT31):** This sensor continuously monitors ambient and inhaled air humidity. Environmental humidity can affect the aerosol properties and hence the bioavailability of inhaled drugs. By tracking humidity, the system can provide additional context to assess medication delivery conditions or flag unusual patterns that might affect treatment effectiveness.



1. User Interaction and Feedback Mechanisms

User engagement and proper inhaler usage are supported through multiple feedback modalities:

- A **0.96-inch OLED display (SSD1306)** provides immediate visual feedback such as confirmation of successful inhalation, error messages for improper use, and dosage tracking. The display's high contrast and low power consumption are suited to the device's compact form factor.
- An integrated **piezoelectric buzzer** provides auditory alerts and reminders, enhancing user awareness by signaling missed doses, incorrect technique, or system notifications.
- A **manual push-button actuator** allows the user to initiate inhalation data recording during testing and serves as an interface for basic device control.

2. Prototyping and Power Management

For development and iterative refinement, all components are initially mounted on a breadboard, which provides flexibility for circuit modifications and sensor calibration . Following successful prototyping, a transition to a custom-designed printed circuit board (PCB) is planned to optimize device size, durability, and reliability for mass deployment , .[4][10][1]The entire system is powered by a 3.7V, 2000 mAh lithium-ion rechargeable battery, selected for its favorable energy density and rechargeability , . This battery supports approximately 5 to 7 days of operation under typical use cases, balancing user convenience with device longevity .[6][35][4]

B. Software and Connectivity

1. Embedded Firmware and Sensor Data Processing

The system firmware is developed in the C programming language using the Arduino Integrated Development Environment (IDE), chosen for its rich hardware libraries and ease of low-level device programming , , . On system startup, the ESP32 initializes all connected sensors, configures data acquisition parameters, and enters a real-time monitoring loop , .[4][10]

Sensor readings are sampled immediately upon detection of inhaler actuation, triggered either by the push-button or automatic sensor thresholds . These raw sensor inputs undergo preprocessing, including noise filtering (using digital filters such as moving average or low-pass filters) and normalization, ensuring stable and consistent data is fed into the machine learning model . This preprocessing is critical for maintaining model accuracy and minimizing false positives/negatives [4][27]

2. Machine Learning Inference at the Edge

A key innovation of the Intelligent Inhaler system is its deployment of a lightweight machine learning (ML) classification model on the embedded device , , , . This model is trained offline using a comprehensive dataset of labeled inhalation events that encompass both proper and improper usage patterns, collected under controlled experimental conditions , .[3][4][10]

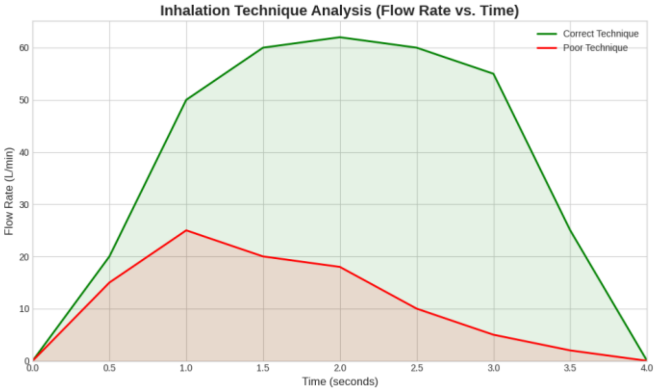


Fig:03- Inhalation Flow Rate Profiles for Correct vs. Poor Technique

Using TensorFlow Lite for Microcontrollers, the trained model is converted into a format compatible with the ESP32, enabling efficient, low-latency inference directly on the device . This edge inference capability is critical for providing instantaneous feedback to users regarding their inhalation technique—classifying events as “proper” or “improper” without the delay or dependency of cloud communication . This autonomy enhances user experience and reliability, particularly in environments with intermittent or no internet connectivity , .[1][5][3]

3. Cloud Integration and Remote Data Management

For long-term data storage, remote monitoring, and analytics, the system integrates with the Firebase Realtime Database, a cloud-hosted NoSQL backend offering secure, scalable, and real-time data synchronization capabilities. [5][6][35]

Every inhalation event is logged with detailed metadata including timestamps, raw and processed sensor readings, and ML classification outcomes , , , . This data is transmitted securely via HTTPS APIs to Firebase, ensuring patient privacy and compliance with data security standards , .[1][4][10]

4. Patient and Physician Interfaces

The Intelligent Inhaler system provides dual interfaces tailored for different stakeholders: the Patient Mobile Application and the Physician Web Dashboard , , . The Patient Mobile Application, developed using Android Studio, connects to Firebase to retrieve historical inhaler usage data , . It features intuitive visualizations of adherence trends and inhalation quality, offers push notifications for medication reminders, and delivers motivational feedback to encourage consistent use , . This empowers patients to actively manage their respiratory health and fosters behavioral adherence .[1][2][6]

The Physician Web Dashboard, built with modern frontend frameworks such as React.js or Angular, aggregates data from multiple patients, presenting compliance metrics, inhalation quality scores, and risk alerts in an accessible format , . Physicians can remotely monitor patient adherence in near real-time, identify patients at risk of non-compliance or improper use, and tailor treatment plans accordingly , . The dashboard supports bidirectional communication, enabling clinicians to send personalized interventions or reminders , .[6][7]

DEVICE WORKFLOW

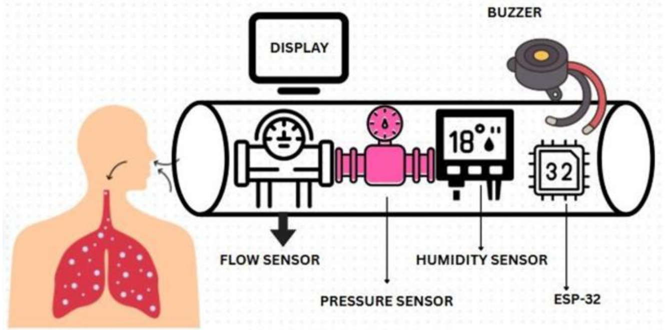


Fig :04- Internal sensor integration within the intelligent inhaler

The Intelligent Inhaler operates through a highly coordinated, multi-stage workflow that seamlessly integrates embedded sensing, local data processing via edge AI, immediate user feedback, and cloud-based data communication , , , . This end-to-end architecture is designed to optimize inhalation therapy by capturing precise usage data, providing actionable feedback, and enabling remote clinical oversight . The system's design addresses common challenges in respiratory care such as incorrect inhaler technique, poor medication adherence, and the need for continuous patient monitoring , , .[1][2][4]

1. User Actuation and Data Acquisition

The workflow begins with the patient initiating an inhalation event. Actuation can occur by:

Manual Push-Button Press: A tactile button on the inhaler device, ensuring deliberate user initiation , . **Built-in Actuation Sensor:** A capacitive, force, or proximity sensor embedded within the inhaler structure that automatically detects inhaler use or trigger movement , .[1][35]

This actuation serves as the critical synchronization point to start data acquisition from the embedded sensor suite. The system immediately activates the following sensors:

a. **Flow Rate Sensor:** Measures volumetric airflow velocity (e.g., liters per minute) during the patient's inspiratory effort. This sensor typically uses a hot-wire anemometer or differential pressure sensor to detect airflow dynamics , . Accurate measurement of inhalation flow rate is crucial because optimal drug delivery depends on achieving a flow rate within a therapeutic window — neither too weak (insufficient aerosolization) nor too strong (medication deposition in throat instead of lungs) .[4][10]

b. **Pressure Sensor:** Monitors the mechanical pressure applied to the inhaler actuator mechanism. This ensures that the medication canister was properly pressed to release the drug. Sensors like piezoresistive or capacitive pressure transducers capture the force magnitude and duration, verifying the correct actuation threshold was met , .[4][10]

c. **Humidity Sensor:** Records ambient air humidity around the inhaler and within the inhaled breath. Humidity levels can influence aerosol particle size and stability, which affect drug deposition patterns in the respiratory tract. Monitoring environmental humidity adds context to inhalation quality and may explain variability in drug efficacy .[4]

These sensors relay analog or digital signals to the microcontroller's input pins via standard communication protocols such as I2C, SPI, or ADC channels , .[4][5]

2. Data Preprocessing and Machine Learning Inference

Upon receiving raw sensor data, the ESP32 microcontroller initiates preprocessing steps to ensure signal fidelity and prepare inputs for machine learning (ML) classification , , .[4][5]

a. **Noise Reduction:** Sensor signals are filtered using digital signal processing techniques—such as moving average filters, low-pass filters, or median filters—to eliminate transient spikes caused by electrical interference or mechanical vibrations .[5]

b. **Normalization:** Sensor readings are scaled to normalized units (e.g., 0 to 1 range) to standardize input dimensions, helping the ML model process data consistently regardless of sensor drift or unit variations , .[5][6]

c. **Outlier Detection and Handling**: Data points that significantly deviate from physiological plausibility or exceed sensor specifications—such as flow rates beyond typical human respiratory capacity—are identified and either excluded or corrected . This crucial preprocessing step ensures the integrity of the dataset and minimizes false positives or false negatives in downstream classification .[4][10]

Following preprocessing, the clean input vector is fed into an embedded machine learning classification model. This model is trained offline using a comprehensive dataset containing labeled inhalation events drawn from diverse **populations** and usage patterns , , . The trained model is deployed on the ESP32 microcontroller using TensorFlow Lite for Microcontrollers, enabling low-latency, on-device inference without continuous cloud dependency. Configured as a binary classifier, the model determines whether the inhalation is "Proper" (correct technique and force) or "Improper" (detectable deviations) , . It analyzes multidimensional sensor signatures to output a probabilistic classification, which is then thresholded to produce a final discrete decision .[5]

d. **Immediate User Feedback**: Based on the model's output, the device provides real-time feedback through a multimodal interface , , . A compact OLED display (e.g., 0.96-inch SSD1306) shows messages like “Proper Usage” to confirm success or “Try Again” for errors. Specific prompts such as “Inhale Faster” or “Press Harder” may also appear as the model evolves , , . Additionally, a piezoelectric buzzer emits auditory signals both to draw attention during improper inhalations and as scheduled medication reminders. This closed-loop feedback fosters patient self-correction, improving adherence and therapeutic outcomes , , .[1][25]

e. **Data Packaging and Wireless Transmission:** After feedback, the ESP32 consolidates event data into a structured payload, including timestamps, ML classification results, sensor summaries (e.g., peak flow, inhalation duration), feedback delivered, and device metadata (battery level, firmware version) , . This payload is transmitted securely via HTTPS over the ESP32’s Wi-Fi module, and Bluetooth may be used depending on connectivity. Data is stored in the Firebase Realtime Database, a cloud-hosted NoSQL backend optimized for real-time bidirectional synchronization, scalability, and low-latency access , .[5][6]

f. **Cloud-Based Data Management and Analytics:** Once uploaded, the inhalation data forms a longitudinal dataset supporting advanced patient monitoring and clinical decision-making , , , . The patient-facing mobile app synchronizes with Firebase to provide visualizations of inhalation history, technique correctness, and trends over time, while logging environmental conditions such as humidity , . Push notifications and behavioral alerts motivate adherence, and educational content encourages self-care , .[2][6]

The physician-facing web dashboard, built using frameworks like React.js or Angular, allows monitoring of multiple patients via aggregated data views . Visual analytics, including compliance heatmaps and time-series analyses, support proactive interventions . Automated alerts flag non-compliance, frequent improper inhalations, or adverse environmental conditions . Clinicians can remotely adjust treatment plans, initiate communication, and integrate data with electronic health record (EHR) systems to streamline workflows. This system enables a proactive, data-driven model of care, reducing the need for constant in-person visits [2][25][1]

g. Impact and System Integration

The Intelligent Inhaler system represents a holistic solution for respiratory health management , , . It significantly improves treatment accuracy by providing real-time feedback to promote correct inhaler technique, maximizing drug deposition in the lungs , . Patient compliance is enhanced through reminders and **immediate** corrective feedback, reducing missed or incorrect doses , , . Continuous access to inhalation data supports timely clinical decisions, allowing healthcare providers to detect and resolve issues early , .[1][2][5]

The system also promotes patient engagement by offering educational resources, transparent feedback, and intuitive interfaces that foster self-efficacy , , . Its scalable, cloud-based architecture supports remote monitoring and telemedicine, making it suitable for chronic disease management even in resource-constrained or geographically dispersed settings . By automating critical monitoring and intervention processes, the system helps reduce adverse events related to improper inhaler use and promotes sustained respiratory health improvements , , .[1][2]

Additional Considerations and Future Directions

To maintain long-term accuracy, the system may incorporate periodic self-calibration routines and sensor diagnostics . Future iterations of the embedded ML model could implement multi-class classification or regression to detect specific errors—such as under-inhalation or mistimed actuation—or quantify drug delivery efficiency , .[2][4]

Data security and privacy remain paramount; the system is designed to comply with healthcare regulations such as HIPAA and GDPR , , . Integration with wearable devices, such as smartwatches or oximeters, could provide additional context by correlating inhaler use with physiological signals like heart rate or oxygen saturation . Finally, adaptive feedback mechanisms based on historical trends may deliver personalized coaching, helping patients build long-term adherence and optimize health outcomes .[6][33]

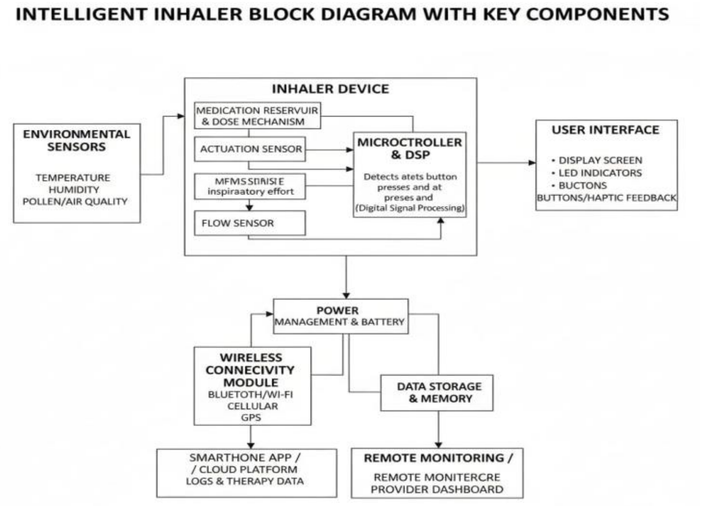


Fig:05- Detailed Block Diagram of the Intelligent Inhaler System

FUTURE WORK

While the current prototype of the Intelligent Inhaler system has successfully demonstrated functional reliability, feasibility, and practical utility within controlled laboratory environments , , , there remain several promising avenues for further improvement and expansion. These enhancements could substantially increase the system's overall effectiveness, scalability, and clinical value , .[1][7]

1. Advanced Machine Learning and Predictive Analytics

One of the most impactful areas for future advancement lies in integrating more sophisticated machine learning (ML) models. The current binary classification model, which differentiates between "proper" and "improper" inhalation events, could be enhanced with multi-class classification or regression-based frameworks capable of detecting a broader spectrum of inhalation anomalies , , . This includes subtle variations in inhalation flow, timing errors, suboptimal breath-hold durations, and complex usage patterns that may indicate deteriorating respiratory function ,[1][10]

Leveraging temporal sensor data and patient-specific historical trends via lightweight recurrent neural networks (RNNs), long short-term memory (LSTM) networks, or edge-compatible transformer architectures could enable real-time predictive analytics . These advanced models would not only evaluate current inhaler usage quality but also forecast potential asthma or COPD exacerbations hours or days in advance, empowering clinicians and patients to take preemptive action and reduce emergency incidents [2][26]

2. Enhanced Sensor Fusion for Holistic Health Monitoring

Future iterations of the device could integrate additional physiological sensors, creating a multi-dimensional health monitoring system . Vital sign sensors, such as heart rate monitors and pulse oximeters (SpO_2), would provide important context on cardiopulmonary status during inhaler use . Innovative exhaled breath analysis modules could detect biomarkers, volatile organic compounds, or inflammation markers, providing real-time biochemical assessment of respiratory health , .**[35][3]**
This comprehensive sensor fusion would enable healthcare providers to correlate inhaler adherence and technique with broader physiological changes, improving diagnostic accuracy and personalized treatment plans . Such a multi-modal data acquisition approach aligns with precision medicine initiatives and supports deeper research into disease progression and patient response , .**[7][6]**

3. Software and User Experience Enhancements

Substantial improvements to the mobile application and physician-facing dashboard are crucial for widespread adoption , , . Incorporating multilingual support ensures accessibility for non-English speaking users, while features for elderly patients and those with visual impairments—such as voice commands, screen readers, high-contrast modes, and large fonts—enhance usability , .**[1][25]**

Embedding educational modules, interactive tutorials, and video demonstrations within the app can provide ongoing patient education, reinforce proper inhaler techniques, and increase self-efficacy . Additionally, motivational features such as personalized goal-setting, progress tracking, reminders, and gamification elements (e.g., rewards, badges, or community challenges) can transform routine inhaler use into an engaging experience, positively influencing patient adherence and long-term outcomes , , .**[2][25]**

4. Cloud Infrastructure and Data Integration

At the system architecture level, transitioning from the current Firebase backend to a scalable, secure, and HIPAA-compliant cloud infrastructure is essential for clinical deployment . Leveraging enterprise-grade cloud platforms with robust encryption, audit trails, and access controls ensures data privacy, regulatory compliance, and scalability as user numbers grow , .**[6][35][36]**
Seamless integration with existing Electronic Health Records (EHR) systems through standardized APIs and interoperability frameworks, such as HL7 FHIR, would allow clinicians to access real-time inhaler usage data alongside other medical records. This integration supports holistic clinical decision-making, improves chronic disease management, and facilitates telemedicine consultations, fostering a more connected healthcare ecosystem , .**[7][25]**

5. Emergency Support and Safety Features

Adding emergency support functionality represents a critical enhancement for patient safety, particularly for high-risk populations such as children, elderly patients, or individuals with severe respiratory conditions . Incorporating GPS modules could enable real-time location tracking during inhaler use, allowing automated SOS alerts to be sent to designated caregivers, family members, or emergency medical services in cases of critical respiratory distress or inhaler misuse .[37][38]

Such safety features reduce response times during emergencies, providing an invaluable support layer that complements preventive care . These capabilities enhance patient confidence and independence, assuring that help is automatically summoned when needed.[1][36]

6. Long-Term Clinical Trials and Real-World Validation

While laboratory testing establishes foundational performance benchmarks, long-term field trials with diverse patient populations are required to validate clinical efficacy, usability, and durability in real-world conditions. These studies would assess the impact of the Intelligent Inhaler on medication adherence, respiratory outcomes, hospital admission frequencies, and quality-of-life metrics over extended periods , , .[2][25]

Partnerships with hospitals, NGOs, and governmental health agencies could enable large-scale deployment, particularly in rural or resource-limited settings where respiratory diseases are often underdiagnosed or undertreated. Leveraging low-power wide-area networks (LPWAN) or simplified user interfaces designed for low-literacy users would ensure accessibility, affordability, and broad adoption , .**[3][5]**

7. Towards a Fully Integrated Personalized Respiratory Care Solution

Collectively, these enhancements have the potential to evolve the Intelligent Inhaler from a monitoring device into a predictive, preventive, and fully integrated component of personalized respiratory healthcare , , . By combining IoT-enabled sensing, edge AI-driven analytics, multimodal user engagement, and cloud-based clinical integration, the system can support proactive disease management, reduce exacerbations, and improve patient outcomes , , .**[5][6][25]**

This transformative vision aligns with global healthcare trends emphasizing patient-centered care, remote monitoring, and data-driven decision-making . Ultimately, the Intelligent Inhaler aims not only to improve therapy adherence but also to empower patients and clinicians with actionable insights, fostering healthier lives through technology-driven respiratory care innovation , , .**[1][7]**

CONCLUSION

This paper presents a comprehensive overview of the design, development, and evaluation of an innovative Intelligent Inhaler system, specifically engineered to address longstanding challenges associated with conventional inhalation therapy for respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD) , , . Traditional therapies often suffer from improper inhaler technique, poor medication adherence, and limited real-time monitoring; the proposed system overcomes these limitations by integrating real-time physiological sensing, edge-based machine learning inference, cloud connectivity, and user-centric software interfaces , , , .[1][7]

At the core of the system lies a multi-sensor framework comprising flow rate, pressure, and humidity sensors. The flow rate sensor quantifies inhalation speed, the pressure sensor monitors the applied force during inhalation, and the humidity sensor provides environmental context and breath moisture levels . This comprehensive sensing architecture ensures accurate and granular measurement of inhaler usage, enabling precise evaluation of inhalation quality , .[4]

To support on-device processing and real-time feedback, a lightweight classification model is deployed on the ESP32 microcontroller . Optimized for computational efficiency and low power consumption, this model classifies inhalation events as correct or incorrect, providing instantaneous feedback via an OLED display and auditory cues . Edge-based inference reduces latency relative to cloud-dependent processing and ensures functionality even in environments with intermittent connectivity .[1][6]

Extending its capabilities, the Intelligent Inhaler system synchronizes inhalation data with a cloud backend using Firebase, supporting secure, real-time data storage and transmission. The patient mobile application enables self-monitoring, medication reminders, and educational content, while the clinician-facing web dashboard presents analytics and trend visualizations to support data-driven clinical decision-making and personalized treatment adjustments , , .[6][36]

Prototype testing under controlled conditions demonstrated the system’s feasibility, responsiveness, and reliability. Experimental results validated the classification model’s accuracy in detecting inhalation anomalies with minimal false positives and negatives . Feedback mechanisms operated with low latency, and power management strategies yielded practical battery life for daily use . These results establish the Intelligent Inhaler as a cost-effective, portable, and user-friendly solution with potential to significantly improve respiratory care outcomes [1][36]

However, limitations were identified that warrant further refinement. Sensor calibration exhibited sensitivity to environmental variations and device handling, necessitating robust protocols for consistent measurements. Dependence on stable network connectivity for cloud synchronization may pose challenges in low-resource or remote areas . Despite these constraints, the current prototype provides a solid foundation for iterative improvements and scalability , .[4][10]

Looking forward, the Intelligent Inhaler offers a promising platform for continued development. Planned enhancements include advanced AI algorithms capable of multi-class inhalation anomaly detection and predictive analytics for early exacerbation warning. Expanding sensor fusion with physiological sensors such as pulse oximeters and heart rate monitors will enable a more holistic assessment of respiratory and cardiovascular health. Software improvements targeting accessibility, engagement, and education—such as gamification, interactive tutorials, and multilingual support—will further improve patient adherence , .[5][26][4]

Additionally, emergency response features, including GPS tracking and automated SOS alerts, will enhance patient safety . Transitioning to a HIPAA-compliant, scalable cloud infrastructure and integrating with Electronic Health Records (EHR) will support clinical adoption and interoperability , .[37][7]

In conclusion, this research validates the Intelligent Inhaler as a viable, innovative tool that bridges the gap between conventional inhalation therapy and the future of personalized, connected respiratory healthcare. With ongoing development and clinical validation, the system holds substantial promise to transform respiratory disease management by empowering patients and clinicians with actionable insights and real-time support , , , .[1][40]

REFERENCES

1. J. Price et al., “Effectiveness, usability and acceptability of a smart inhaler asthma self-management programme: a pragmatic cluster randomised controlled trial,” BMJ Open Respiratory Research, vol. 9, no. 1, Dec. 2022.https://bmjopenrespres.bmj.com/content/9/1/e001400[1]
2. S. H. Thomas et al., “Digital Coaching Using Smart Inhaler Technology to Improve Asthma Self-Management: A Community-Based Feasibility Study,” JMIR mHealth and uHealth, vol. 10, no. 11, Nov. 2022.https://mhealth.jmir.org/2022/11/e25879[2]
3. A. M. Siddiqui, “Digital Inhalers for Asthma or Chronic Obstructive Pulmonary Disease: A Review,” Pulmonary Therapy, vol. 7, no. 2, Aug. 2021.https://link.springer.com/article/10.1007/s41030-021-00167-4[3]
4. L. Liu, I. Mysovskikh, M. Legg, and S. Demidenko, “Flow Rate Sensing and Measurement in Portable Smart Inhalers,” Sensors, vol. 24, no. 21, Oct. 2024. https://www.mdpi.com/1424-8220/24/21/6848[4]
5. G. W. Canonica et al., “Integrating Digital Inhalers into Clinical Care of Patients with Asthma and COPD,” Respiratory Medicine, vol. 199, Oct. 2022.https://www.sciencedirect.com/science/article/pii/S0954611122003031[5]
6. "Digital Inhalers for Asthma or Chronic Obstructive Pulmonary Disease: A Scientific Perspective," Authors: Amy H. Y. Chan, Roy A. Pleasants, Rajiv Dhand, Stephen L. Tilley, Stephen A. Schworer, Richard W. Costello, Rajan Merchant, Publication: Pulm Ther (2021) 7:345–376.https://doi.org/10.1007/s41030-021-00167-4[6]
7. "Effectiveness, usability and acceptability of a smart inhaler programme in patients with asthma: protocol of the multicentre, pragmatic open-label, cluster randomised controlled ACCEPTANCE trial," Authors: Susanne J van de Hei, Charlotte C Poot, Liselot N van den Berg, Eline Meijer, Job F M van Boven, Bertine M J Flokstra-de Blok, Maarten J Postma, Niels H Chavannes, Janwillem W H Kocks, Publication: BMJ Open Resp Res 2022:9:e001400.https://doi.org/10.1136/bmjresp-2022-001400[7]
8. S. R. O’Connor, K. J. P. Ryan, B. I. Doyle, C. R. Greene, A. N. D’Arcy, L. N. F. H. O’Dwyer, B. J. O’Sullivan, J. J. Carey, G. D. Sliney, and S. A. G. O’Neill, “Digital Inhalers and Remote Monitoring to Improve Asthma Self-Management: A Community-Based Feasibility Study,” JMIR mHealth and uHealth, vol. 10, no. 11, Nov. 2022.https://mhealth.jmir.org/2022/11/e25879[8]
9. A. M. Siddiqui, “Digital Inhalers for Asthma or Chronic Obstructive Pulmonary Disease: A Review,” Pulmonary Therapy, vol. 7, no. 2, Aug. 2021.https://link.springer.com/article/10.1007/s41030-021-00167-4[9]
10. L. Liu, L. Mysovskikh, M. Legg, and S. Demidenko, “Flow Rate Sensing and Measurement in Portable Smart Inhalers,” Sensors, vol. 24, no. 21, Oct. 2024.https://www.mdpi.com/1424-8220/24/21/6848[10]
11. G. W. Canonica et al., “Integrating Digital Inhalers into Clinical Care of Patients with Asthma and COPD,” Respiratory Medicine, vol. 199, Oct. 2022https://www.sciencedirect.com/science/article/pii/S0954611122003031[11]
12. Bateman ED, Reddel HK, Reddel HK, et al. Global Strategy for Asthma Management and Prevention 2021.https://ginasthma.org/wp-content/uploads/2021/05/GINA-2021-report_V2-Ginasthma.org_-WMS.pdf [12]
13. Global Initiative for Chronic Obstructive Lung Disease. Global Strategy for the Diagnosis, Management, and Prevention of Chronic Obstructive Pulmonary Disease: 2021 Report. 2021. https://goldcopd.org/wp-content/uploads/2020/11/GOLD-2021-REPORT-ver1.2-25Nov20_WMV.pdf [13]
14. Price D, Israel E, van Boven JF, et al. Adherence to asthma medication: Time for a change in approach. Eur Respir J. 2017;49(4):1602494.https://erj.ersjournals.com/content/49/4/1602494 [14]
15. Plaza V, Giner J, Pastorino A, et al. Global Initiative for Asthma (GINA) recommendations and inhaler technique: an online survey of healthcare professionals and patients. NPJ Prim Care Respir Med. 2017;27(1):52.https://www.nature.com/articles/s41533-017-0050-x[15]
16. Svedsater H, Jayawardene A, Siddiqui M, et al. Patient adherence and persistence with asthma and COPD medications in the real world: a systematic review. Respir Res. 2020;21(1):159. https://respiratory-research.biomedcentral.com/articles/10.1186/s12931-020-01416-2 [16]
17. Restrepo RD, Peters JI, Calverley PMA, et al. Inhaler use and technique in COPD patients: a systematic review. COPD. 2008;5(6):347–57.https://www.tandfonline.com/doi/abs/10.1080/15412550802521191 [17]
18. Bosley CM, Parry DT, Cochrane GM. The effect of a daily telephone call to asthma patients on medication adherence and asthma control. Br J Clin Pharmacol. 1999;47(6):679–85.https://bpspubs.onlinelibrary.wiley.com/doi/full/10.1046/j.1365-2125.1999.00977.x [18]
19. Cramer JA, Roy A, Burrell A, et al. Medication compliance and persistence: terminology and definitions. Value Health. 2008;11(1):44https://www.valuehealthjournal.com/article/S1098-3015(10)60613-2/fulltext [19]
20. Capstick T, Clifton IJ. Inhaler technique in COPD: what do we know and where are we going? COPD Res Pract. 2019;5(1):1. https://copd-research-and-practice.biomedcentral.com/articles/10.1186/s40749-019-0043-y[20]
21. Bourbeau J, Bartlett SJ. Patient adherence in COPD. Thorax. 2018;73(11):1052–60.https://thorax.bmj.com/content/73/11/1052 [21]
22. Levy ML, Quanjer PH, Juniper EF, et al. The Asthma Control Questionnaire (ACQ): a review. Respir Med. 2005;99(9):1108–16.https://www.sciencedirect.com/science/article/pii/S095461110500115X [22]
23. Haughney J, Price D, Menzies-Gow A, et al. A new tool for assessing asthma control: the Asthma Control Test. Respir Med. 2005;99(11):1443–8.https://www.sciencedirect.com/science/article/abs/pii/S0954611105001355 [23]
24. ll CU, Detraux S, De Lepeleire J, et al. Effects of antipsychotics on weight, lipid, and glucose levels in adolescents: a systematic review and meta-analysis. JAM Psychiatry. 2014;71(8):857–71.https://jamanetwork.com/journals/jamapsychiatry/fullarticle/1879385 [24]
25. Khurana S, Sharma R, Kaushik S, et al. The impact of smart inhaler technology on adherence, asthma control, and health care utilization: a systematic review. Allergy Asthma Proc. 2017;38(6):41422.https://pubmed.ncbi.nlm.nih.gov/29161747/[25]

26. Kontz J, Jendle J, Al-Jabri A, et al. Digitally connected inhalers for chronic respiratory disease: a systematic review of randomized controlled trials. RespirMed.2021;182:106409.https://www.sciencedirect.com/science/article/pii/S095461112100067X[26]
27. Sulaiman I, Cushen B, Greene G, et al. Objective Assessment of Inhaler Technique in Asthma. J Allergy Clin Immunol Pract. 2017;5(6):1625–30.https://www.jaci-inpractice.org/article/S2213-2198(17)30491-0/fulltext[27]
28. Newman SP, Pitcairn GR. Inhalation devices for asthma and COPD: an update. Respir Med. 2008;102(9):115365.https://www.sciencedirect.com/science/article/pii/S095461110800164X [28]
29. Foster JM, Usherwood T, Smith L. Improving adherence to inhaler devices in asthma: a randomized controlled trial. J Asthma. 2007;44(9):7816.https://www.tandfonline.com/doi/abs/10.1080/02770900701550974 [29]
30. Reddel HK, Bacharier LB, Bateman ED, et al. GINA 2019: A fundamental change in asthma management: As-needed low-dose ICS-formoterol is recommended for all adult asthma. Eur Respir J. 2019;53(6):1901046.https://erj.ersjournals.com/content/53/6/1901046 [30]
31. Van Boven JF, Spies J, Uyl-de Groot CA, et al. The economic impact of adherence to inhaled corticosteroids in patients with asthma. Respir Med. 2016;121:1007.https://www.sciencedirect.com/science/article/pii/S095461111630132X [31]
32. Van de Hei SJ, Poot CC, Meijer E, et al. Effectiveness and acceptability of a smart inhaler asthma self-management programme: a cluster RCT study protocol. Eur RespirJ.2019.https://erj.ersjournals.com/content/54/suppl_63/PA1938 [32]
33. Klugman CM, Dunn LB, Schwartz J, et al. The ethics of smart pills and self-acting devices: autonomy, truth-telling, and trust at the dawn of digital medicine. Am J Bioeth. 2018;18(9):38–47.https://www.tandfonline.com/doi/abs/10.1080/15265161.2018.1504951 [33]
34. Campbell JI, Eyal N, Musiimenta A, et al. Ethical questions in medical electronic adherence monitoring. J Gen Intern Med. 2016;31(3):338–42.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4762822/ [34]
35. Hosseini A, Buonocore CM, Hashemzadeh S, et al., editors. HIPAA compliant wireless sensing smartwatch application for the self-management of pediatric asthma. 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN); 2016.https://ieeexplore.ieee.org/document/7521873[35]
36. Bailey A, et al. The Digital Revolution in Asthma Management. BMJ Open Resp Res. 2016;3:e000159.https://bmjopenrespres.bmj.com/content/3/1/e000159[36]
37. US 11,090,449 B2, Title: SMART INHALER DEVICE WITH AUTOMATED DOSE DELIVERY, MEASUREMENT, AND MANAGEMENT, Inventors: Hatamian et al., Issue Date: August 17, 2021, Assignee: Vivera PharmaceuticalsInc.https://patents.google.com/patent/US11090449B2/en[37]
38. US 5,363,842, Title: INTELLIGENT INHALER PROVIDING FEEDBACK TO BOTH PATIENT AND MEDICAL PROFESSIONAL, Inventors: David J. Mishelevich, Ted W. Lanpher, Gregory B. Lanpher, James Long, Issue Date: November 15, 1994, Assignee:Circadian, Inc.https://patents.google.com/patent/US5363842A/en[38]
39. US Patent No. 20240390611, “ARI Smart Respiratory Inhaler with Integrated Spacer,” 2024.https://patents.justia.com/patent/20240390611[39]
40. Indian Patent No. 202521088961 “A Device for Monitoring Medicine Inhalation “ 2025