SMART PILL BOTTLE with CAREGIVER ALERTS

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Abstract: Medication non-adherence and unauthorized access to prescription drugs continue to be two of the critical challenges that plague modern healthcare, often resulting in inefficient treatment, adverse drug events, and avoidable hospitalizations. This work proposes an IoT-enabled Smart Pill Bottle for controlled and timely medication intake in a monitored environment. This system includes embedded sensors, an ESP32-based control unit, and cloud connectivity, enabling real-time authentication of medication access and dose consumption verification. Sensor-based event detection, combined with automated reminders and notifications to caregivers, will permit continuous adherence monitoring and immediate response to missed or delayed doses. Tamper-detection mechanisms further recognize unauthorized access attempts and secure safety for controlled and high-risk medications. Cloud-synchronized logs and adherence analytics will present valid, timestamped data to caregivers and healthcare professionals to facilitate proactive intervention and evidence-based clinical decisions. The proposed solution provides significant improvement in medication safety while improving accountability and enhancing remote healthcare monitoring for elderly and chronically ill patients.

Keywords: IoT Healthcare, Medication Adherence, Cloud-Based Monitoring, Medicine Dispenser.

I.   INTRODUCTION

Non-adherence to medication and uncontrolled access to prescribed drugs, especially controlled substances, present significant clinical risks by allowing dose deviations, reducing therapeutic efficacy, and leading to opportunities for drug diversion. Conventional pill containers offer no schedule enforcement, no access authentication, and no objective intake verification, leading to unmonitored consumption patterns and seriously compromising patient safety. To address these limitations, this work proposes an IoT-enabled Smart Pill Bottle that enables secure, time-gated, and sensor-verified medication dispensing. The proposed architecture is modular and includes four tightly integrated subsystems: i) an embedded hardware unit built around the ESP32 microcontroller, which integrates ultrasonic proximity sensing, tamper-event detection, and real-time edge processing; ii) a patient-side application for schedule retrieval and proactive reminder delivery; iii) a caregiver monitoring dashboard for adherence supervision and anomaly awareness; and iv) a clinician interface enabling prescription programming and analytical review of long-term adherence behaviour. The continuously operating embedded unit monitors legitimate pill-removal events and transmits timestamped adherence data to a cloud backend over Wi-Fi. Conversely, any missed dose, delayed interaction, or unauthorized access attempt instantly triggers caregiver notifications. All system-level events (lid activations, sensor-validated dispensing actions, tamper anomalies) are recorded in a secure Firebase database, enabling traceable audit trails and longitudinal adherence analytics. Based on continuous sensing, cloud-synchronized logging, and automated multi-party alerting, the proposed system establishes a technically sound framework for medication schedule enforcement, misuse detection, and data-driven telehealth monitoring.

II.   OBJECTIVES

To design an IoT-enabled Smart Pill Bottle that can automatically track, using sensor-based detection, medication intake; it generates real-time alerts and keeps logs of doses taken or missed, thus managing adherence more effectively.

This system will be developed to ensure secure remote access through mobile and web applications, which will enable caregivers or clinicians to check medication history, be notified instantly, and manage user authentications using email-based login.

To provide reliable support for patients by timely reminding them, using visual, audio, and wearable-device alerts, about adhering to their medication routines in a safe, consistent, and supervised manner.

III. LITREATURE SURVEY

Medication adherence monitoring has evolved from simple reminder devices to sophisticated cyber-physical systems that integrate embedded sensing, cloud synchronization, and automated supervisory control. The available literature shows considerable progress in the design of IoT-based medication compliance tools; however, earlier systems have architectural fragmentation, limited sensing granularity, and inadequate multi-stakeholder support. This section critically discusses the works referenced and places the proposed system in relation to existing state-of-the-art deployments.

Early research in smart medication devices relied mostly on event-driven reminder architectures. Silvana et al. [1] designed a smart pill box that implemented reminder triggers, box-opening authentication, and basic confirmation functions. Their design presented the first thoughts on event logging and notification of a remote caregiver, creating a baseline for tracking adherence. However, this architecture used only lid-opening as a proxy for medication intake, without sensor-level discrimination of physical pill removal. Their model was therefore susceptible to false-positive confirmations, and it did not provide any fine-grained interaction sensing, tamper detection, or secure cloud-linked data persistence.

IoMT-based frameworks have been explored with wide interest for telemedicine and remote physiological monitoring. Vidhya et al. [2] have highlighted the role of IoMT nodes in ensuring continuous data acquisition from distributed sensors and sending out structured information to cloud infrastructures. Their work validated the necessity for always-on cloud connectivity, bi-directional data synchronization, and notification pathways on real- time events. While the proposed solution contributed in shaping the cloud–device communication stack, it operated at a coarse granularity and lacked embedded-intelligence mechanisms for verifying micro-interactions associated with pill-access events.

More advanced, dispensing-centric architectures emerged with AIRMED by Kevin et al. [3], which implemented ultrasonic sensing to validate the pill dispensing events alongside a remotely configurable medication schedule. AIRMED successfully showed that ultrasonic range sensing can serve as a non-contact displacement measurement modality for detecting pill extraction in a much more reliable way compared to simple mechanical triggers. This design was still a bulk dispenser rather than a bottle-centric solution and relied on a more centralized mechanical dispensing unit. Moreover, it lacked optimization in low-power edge processing and real-time cloud synchronization essential for home-based and battery-driven use scenarios.

Recent research has demonstrated new sensing modalities for verifying adherence. Seckin et al. [4] described MedDock, which leveraged a textile-based capacitive contact sensor built into a 3D-printed structure to enable high-resolution detection of pill interactions. This work validated the feasibility of integrating soft material sensors for fine-grain pickup detection. However, MedDock was not designed for continuous cloud-connected operation and omitted multi-tier alert escalation and tamper anomaly analytics, limiting its suitability for clinical use.

IV. EXISTING SYSTEM AND PROBLEM DEFINITION

A. Existing Work:

Most of the currently available smart pill bottles are limited in functionality, often consisting only of time-based reminders, LEDs, and logging of lid-opening events. These systems do not verify actual pill removal, lack real-time sensing modules, and don't detect unauthorized access or tampering. Current products are single-medicine containers, making them unsuitable for patients with multiple prescriptions. The commercial solutions are expensive and do not provide cloud-synchronized adherence tracking, multiuser access for the caregivers/clinicians, or sensor-validated confirmation of taking medication. Therefore, existing systems serve as simple reminder tools rather than reliable, data-driven medication monitoring platforms.

B. Problem Definition:

Current pill bottle systems have several major limitations. They lack sensor-based verification and, thus, are only able to confirm the bottle was opened and cannot confirm actual pill consumption. They provide no detection against tampering or unauthorized access and, therefore, cannot be employed with controlled or sensitive medications. They do not support adherence tracking in real-time nor logging on the cloud for longer-term monitoring. They usually can accommodate only one type of medication and are often too expensive for patients managing more than one prescription. Moreover, these systems do not track refills or maintain medication schedules, which thus causes skipped doses and irregular intake

patterns. Therefore, this calls for a cost-effective, IoT-enabled sensor-verified Smart Pill Bottle that is capable of enforcing dosage schedules, authenticating medication intake, detecting tampering, and supporting real-time adherence visibility for caregivers and clinicians.

C. Problem Analysis:

Non-adherence and uncontrolled access have been the major concerns in home-based medication management. Patients often miss doses due to forgetfulness, cognitive decline, or lack of reminders, while unauthorized access—especially to restricted medications—may lead to diversion or misuse. Traditional pill containers offer no mechanism for event validation, secure access, or remote supervision, resulting in unmonitored consumption and safety risks. Without a system capable of continuous sensing, cloud synchronization, and automated caregiver alerts, deviations in medication behaviour go undetected, leading to treatment failure, increased complications, and preventable clinical emergencies. A smart, sensor-equipped, tamper-aware IoT architecture is therefore needed for safe, reliable, and accountable medication handling.

V. PROPOSED SYSTEM

The proposed system, The Smart Pill Bottle with Caregiver Alerts, is an IoT-based medication management device for assisting patients in maintaining accurate medication adherence and facilitating caregivers' and healthcare professionals' real-time monitoring and alerts. It integrates embedded hardware with cloud connectivity and mobile application interfaces for tracking, intelligent reminders, and access to medicines in a secure and authenticated mode.

This system presents an economical solution, which is under ₹1500, and can house multiple medicines with the help of four storage compartments. The added feature is that it removes the requirement for separate storage containers. In addition to automated reminders and overdose/missed-dose detection, the system provides tamper and authentication alerts by logging each opening event, thus preventing unauthorized access or theft of medicines. It consists basically of five major components:

A. Smart Pill Box/Bottle

This smart pill box is controlled by a microcontroller and contains four compartments for storing and providing up to four types of medicines. Opening events, such as removal of pills and the timing of access, are detected by sensors to precisely track intake behaviour. In case of non-access of the box at the scheduled time, a real-time alert signal is sent to the mobile applications of both the patient and the caretaker through the cloud. Each event of opening is recorded as an authenticated activity to verify it and avoid misuse or double dosing. The system can trigger an alert in case the opening time does not correspond to the predefined medicine schedule.

B. Patient's Mobile Application

The patient application shows prescription schedules and sends personalized push notifications to ensure timely intake. The app continues with reminder alerts until the system verifies successful dose consumption. The user can see prescription history, dosage instructions, and medical information. Each and every time the pill box opens, the event gets recorded and is reflected inside the app for transparency and accountability.

C. Caretaker's Mobile Application

The caretaker app enables remote supervision of medication adherence. In addition, caregivers receive real-time alerts in the case of a missed or delayed scheduled dose, or unauthorized access. Caretakers can also book doctor appointments based on availability and update the pill schedule once prescriptions are assigned. The caretaker is responsible for slotting medications in the pill box and receives immediate notifications of every interaction with the box, ensuring authentication and patient safety.

VI. SYSTEM DESIGN

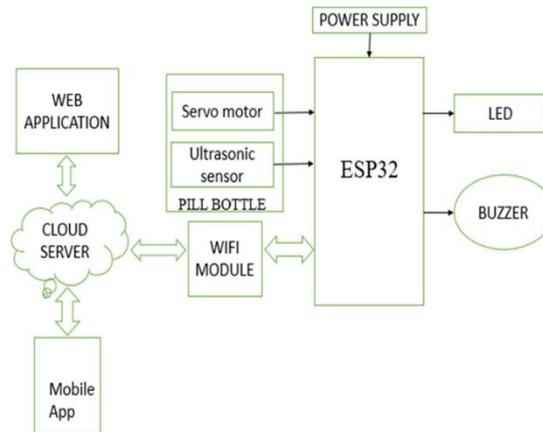### A. Block Diagram of Smart Medicine Box

Fig. 1 Block diagram

A block diagram representing the complete system architecture of the Smart Pill Bottle with Caregiver Alerts has been designed. The proposed system revolves around the ESP32-based pill bottle, which has all the necessary electronic modules, including an ultrasonic sensor, a servo motor, LED indicators, a buzzer, and a Wi-Fi communication unit. In addition to the embedded hardware, the system involves two major user interfaces: a mobile application and a web application. These interfaces provide means for patients, caregivers, and healthcare providers to remotely access medication schedules, alerts, and adherence logs in real time. The cloud server serves as the main communication hub for synchronization between the smart pill box and all connected applications so that continuous, reliable, and accurate monitoring of medication is possible.
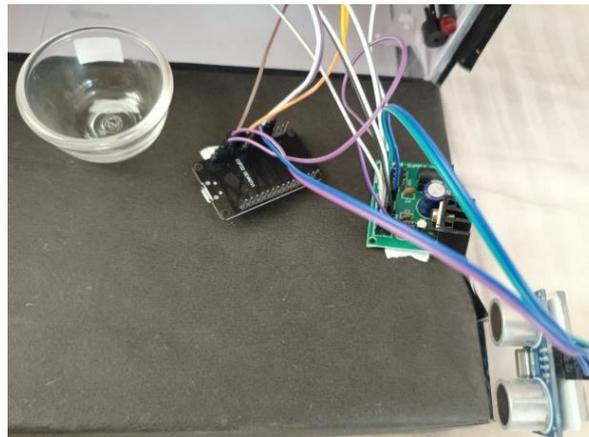
B. Block Discription:

Fig. 2 Hardware Implementation

A. Power Supply:
The power supply provides all system elements, including the ESP32 microcontroller, ultrasonic sensor, servo motor, LED, and buzzer, with the DC voltage they need. It ensures stable and continuous power so that sensing, processing, and communication operations function reliably throughout the medication schedule.

B. ESP32 Microcontroller:
The ESP32 acts as the central processing unit for the smart pill bottle. It reads data from the ultrasonic sensor, keeps track of the medication timer, and activates reminders accordingly; it operates the servo motor in opening and closing the bottle lid and relays all events of medication to the cloud via its in-built Wi-Fi. It also sends logs like dose taken or missed.

C. Ultrasonic Sensor:

The ultrasonic sensor detects the opening of the pill bottle or the removal of a pill. It measures changes in distance inside the bottle and sends this information to the ESP32. The microcontroller uses this input to confirm medication intake and send an alert if the bottle is not accessed at the scheduled time.

D. Servo Motor:

The servo motor acts to control the bottle lid mechanically. At the time of scheduled medication, ESP32 instructs the servo to unlock or open the cap for access to the pills. After taking the dose, or after a set period of time, the servo re-locks the lid again to avoid unauthorized or accidental access.

E. LED Indicator:

The LED thus acts as a visual alert element, lighting up or blinking at the time of drug intake or when a dose is missed. This ensures that the reminder is caught even when it falls within an environment devoid of any sound.

F. Buzzer:

The buzzer provides an audible alert to the user during medication time. It beeps to alert the patient that there is a dose due. The buzzer works with the LED to facilitate clear, accessible reminders.

G. Wi-Fi Module (ESP32 In-built):

The Wi-Fi module integrated into the ESP32 sends real-time medication logs to the cloud. It allows the pill bottle to connect to the internet and ensures that every dose taken or missed is updated instantly for remote monitoring.

H. Cloud Server:

All medication schedules and adherence data are stored on the cloud server. Whenever there is an event detection—such as pill removal or missed dose—the ESP32 uploads the information to the cloud. Digital logs maintained on the server can be accessed remotely.

I. Mobile/Web Application:

The mobile app and web app serve as user interfaces for patients, caregivers, and healthcare providers. They show, in real time, notifications, medication schedules, and adherence history. Caregivers can instantly track dose-taking activity and are alerted when a dose is missed.

VII.   RESULTS AND DISCUSSION

The Smart Pill Bottle solution has been successfully developed and applied under real-time operating environments. The hardware solution worked properly in the environment, while the images of the final product have been included for demonstration. Upon successful entry of the intake time for medications in the application interfaces of both the website and the smartphone app, the ESP32 remote control turned the servo motor in the Smart Pill Bottle for controlled distribution of medications while simultaneously displaying the visual alert signal through the LEDs as well as the auditory signal through the buzzer for the users to heed to or comply with all along. Intake of medications has been confirmed through the ultrasonic sensor for successful recording in the application interface. Removal of medications has been approved in the Smart Pill Bottle solution only when there has been actual successful intake of medications from users for reliable recording in the interface of the application interface. Missed intake of medications has led to instant alert notification for the caregivers of patients for timely attention in the Smart Pill Bottle solution while modification of medicine names, quantities, as well as intake timing, has been possible in both the website interface as well.
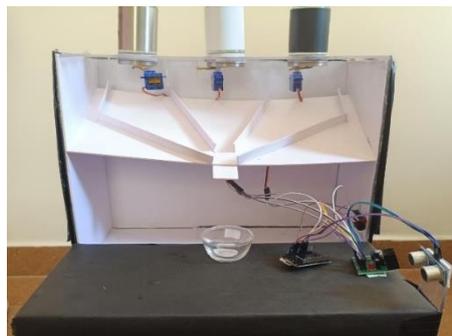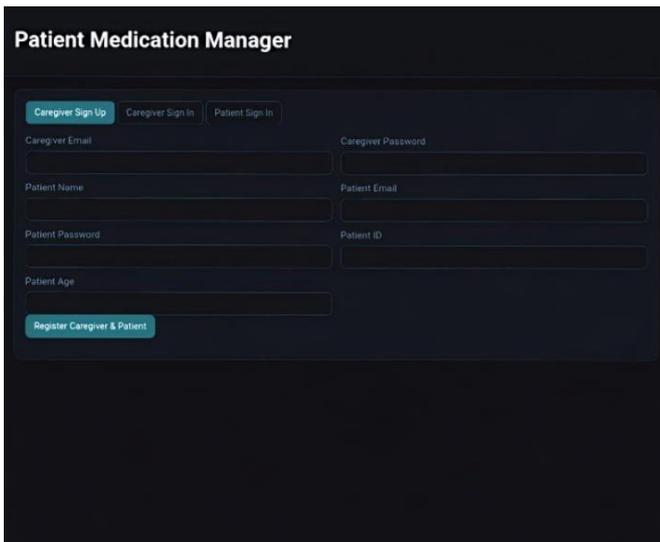

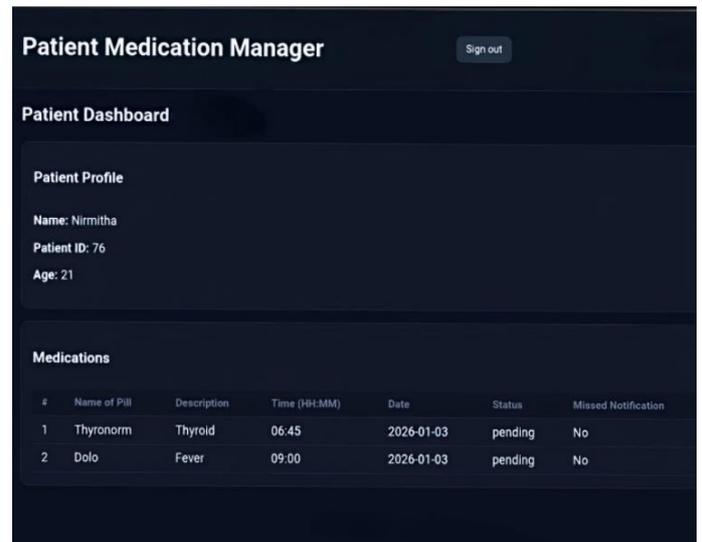Fig. 3 Hardware Implementation

Fig. 4 Login dashboard
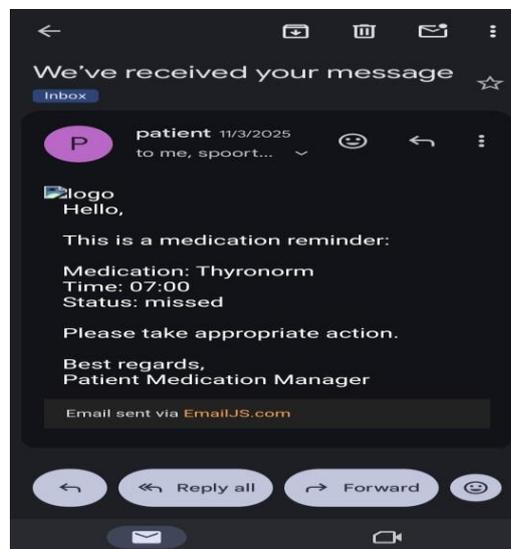

Fig. 5 Main dashboard

Fig. 6. Missed Notification alert via Mail

VII.   CONCLUSION AND FUTURE WORK

A. Conclusion

This project addresses the recurring challenges that patients face in sticking to prescribed medication schedules. The Smart Pill Box would facilitate real-time reminders, dose logging, secure access, and monitoring support to both patients and caretakers. Having a microcontroller-based design ensures reliable and user-friendly operation with minimal complexity and significant functional benefits. The solution ensures correct dosage intake at the appropriate time, reducing medical errors and associated mortality rates. Moreover, this authentication system restricts unauthorized access, helping to reduce illegal misuse of prescribed drugs.

B. Future Work

In the future, face-detection-based access control can be integrated to strengthen the system, which allows the pill bottle to authenticate the authorized user before unlocking. This would keep children or unauthorized people from accessing medication and would greatly increase security. The system can be connected to a wearable device that will enable smartwatches or fitness bands to receive vibration alerts and reminders and notifications in real time on the user's wrist. It ensures that no dosage reminder is ever missed because the user is away from the phone. Additionally, this allows for

faster updates for caregivers. These will make the Smart Pill Bottle much more intelligent, safer, and user-adaptive to overcome limitations in the currently proposed design and provide reliable service within a medication-management ecosystem.

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