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PillBot — Smart IoT Medication Adherence System

Prof. Santhosh H S
Assistant Professor
Dept. of ECE
K S School of Engineering and Management
Bengaluru, India
santhoshhs@kssem.edu.in

Megharaj Danapla
Student
Dept. of ECE
K S School of Engineering and Management
Bengaluru, India
megharajd@kssem.edu.in

Nabeel Fouzaan
Student
Dept. of ECE
K S School of Engineering and Management
Bengaluru, India
nabeelm@kseem.edu.in

M Jashnavi
Student
Dept. of ECE
K S School of Engineering and Management
Bengaluru, India
Jashnavim@kseem.edu.in

Varun Kumar C S
Student
Dept. of ECE
K S School of Engineering and Management
Bengaluru, India
varuncs@kseem.edu.in

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***Abstract*—Medication non-adherence remains a persistent global health bottleneck, contributing to nearly 50% of treatment failures and elevating preventable hospitalizations. Conventional smart dispensers often lack robust multi-patient access control, fail to verify physical drug release, or rely on loose-pill architectures prone to cross-contamination and mechanical jamming. This paper presents PillBot, an automated, multi-profile Internet of Things (IoT) medication adherence system designed for multi-patient domestic healthcare. The electromechanical framework utilizes four independent circular medicine trays, each partitioned into seven distinct compartments. Tray positioning and rotational indexing are driven by 28BYJ-48 5V stepper motors via ULN2003 drivers, calibrated with A3144 Hall-effect sensors and neodymium magnets to eliminate positional drift. The processing pipeline is governed by dual ESP32 microcontrollers, incorporating an integrated 3.5-inch 480×320 LVGL-driven touchscreen display for intuitive on-device scheduling alongside a battery-backed DS3231 Real-Time Clock (RTC) module to maintain offline scheduling integrity. Biometric security is enforced via an R307 optical fingerprint scanner, restricting medicine access strictly to authorized patient profiles. To prevent dispensing errors, released medication passes through a guided funnel assembly into a collection cup, where physical delivery is validated via dual-stage verification combining an optical IR break-beam sensor and an HX711-interfaced load cell. Multimodal alarms incorporate a MAX98357A I2S Class-D amplifier driving a 5W speaker alongside an active buzzer, while onboard Wi-Fi connectivity dispatches automated alerts to remote caregivers in the event of missed doses. Experimental testing confirms that PillBot provides a dependable, secure, and verifiable hardware-software solution for domestic medication management.**

Keywords—Internet of Things, medication adherence, biometric authentication, ESP32, automated dispenser, stepper motor, Hall-effect sensor, healthcare technology.

I. INTRODUCTION

The persistent challenge of medication non-adherence represents a critical systemic bottleneck in global healthcare, contributing to nearly 50% of treatment failures and a marked increase in preventable hospitalizations annually. This issue is particularly acute for patients managing chronic conditions and elderly individuals navigating complex multi-drug schedules. In domestic settings, safe administration is often compromised because only the patient knows their specific schedule, while partially used blister packs make pills difficult to identify by shape or color alone, preventing family members from assisting safely without risking dosage errors.

A review of smart healthcare literature reveals significant functional and mechanical limitations in existing solutions. Many dispensers rely on loose, spherical pill mechanisms that suffer from mechanical jamming, tablet degradation, and cross-contamination. Moreover, security remains inadequate; devices lacking biometric access control risk unauthorized tampering or accidental ingestion by children. Existing systems also frequently lack robust closed-loop dispensing verification, failing to confirm whether a tablet was actually released, while remote caregiver connectivity remains missing.

To resolve these challenges, this paper presents PillBot, an automated, multi-profile IoT medication adherence system engineered for domestic healthcare. PillBot replaces prone loose-pill mechanisms with an electromechanical carousel architecture comprising four independent circular medicine trays, each featuring seven partitioned compartments. Actuated by dedicated 28BYJ-48 5V stepper motors via ULN2003 drivers, each tray incorporates A3144 Hall-effect sensors and neodymium magnets to achieve closed-loop rotational homing and compartment alignment. The central control architecture utilizes dual ESP32 microcontrollers, pairing an integrated 3.5-inch 480×320 LVGL-driven touchscreen display for dynamic on-device scheduling with a secondary ESP32 core. Scheduling integrity is maintained offline using a battery-backed DS3231 Real-Time Clock (RTC) module.

User authentication is secured via an R307 optical fingerprint sensor, ensuring that access is granted strictly to registered patient profiles. Upon authorization, pills are dispensed through a funnel assembly into a collection cup, where an optical IR break-beam sensor and an HX711-interfaced 1 kg load cell execute dual-stage physical drop and weight verification. Multimodal reminders are delivered locally through a high-fidelity MAX98357A I2S Class-D amplifier driving a 5W speaker alongside an active buzzer.



II. LITERATURE REVIEW

In [1], Abiruth S *et al*. (2026) address the critical challenges of medication non-adherence and insufficient health monitoring in geriatric care, the MediTrack framework integrates an automated smart pillbox with real-time physiological sensing and predictive analytics. Built around an ESP32 microcontroller, the system captures vital signs, including heart rate, blood oxygen (), and body temperature using MAX30102 and DS18B20 sensors. Data is transmitted via the MQTT protocol to a MongoDB Atlas cloud database and a Flutter-based mobile application, which provides caregivers with real-time alerts and comprehensive weekly reports. To enhance its proactive capabilities, MediTrack employs machine learning algorithms—including Logistic Regression, Random Forest, and Gated Recurrent Unit (GRU) neural networks—to identify health anomalies and forecast adherence patterns with 88.90% accuracy. Practical evaluations demonstrate the system's technical efficacy, achieving a 98.5% pill detection accuracy via internal infrared (IR) sensors and facilitating a 25% reduction in missed doses, thereby offering a robust, integrated solution for chronic disease management.

In [2], Raja Waqas *et al*. (2026) examined the efficacy of AI-enabled and digitally augmented systems—such as smart pillboxes, electronic monitors, and personalized reminder platforms—in managing medication adherence for chronic diseases, The authors analyzed seven studies, including randomized controlled trials and observational cohorts, focusing on populations with conditions like diabetes, hypertension, and HIV, the review highlights a mixture of clinical outcomes; while some interventions, such as real-time electronic monitoring and SMS-integrated systems, demonstrated adherence gains of up to 17–22%, other findings were inconsistent. Notably, the large-scale REMIND clinical trial involving over 2,700 cardiovascular patients failed to show a statistically significant improvement in adherence compared to usual care, from a quality improvement perspective, the authors argue that these technologies enhance patient safety and engagement by enabling real-time monitoring and proactive clinical intervention, However, they ultimately conclude that the current evidence base is constrained by small sample sizes, high heterogeneity, and a moderate risk of bias, necessitating more robust, large-scale research to confirm long-term clinical and system-level benefits.

In [3], Dr. Kasthuri Natarajan *et al.* (2026) presents an IoT-integrated framework designed to tackle the chronic issues of medication non-adherence and administration errors. Moving away from traditional, manual solutions like standard pillboxes, the study proposes a comprehensive system that synchronizes automated medication dispensers with wearable sensors and cloud-based analytics to provide real-time oversight of patient health. The technical architecture is built around a central dispensing unit—developed using a Raspberry Pi microcontroller—which is responsible for managing dosage schedules. This is paired with wearable devices that continuously monitor physiological metrics, including heart rate, blood pressure, and body temperature. All gathered data is transmitted to a cloud platform (such as AWS or Azure), where it is processed to provide immediate feedback to both patients and clinicians through a dedicated mobile application.

In [4], Priyanka R *et al*. (2026) presents "Medibot," an AI-enabled, IoT-based automated pill dispenser designed to improve medication adherence for elderly and chronically ill patients. The system integrates a mobile application for scheduling and remote monitoring, while employing voice recognition and autonomous navigation to reach patients with mobility or cognitive impairments. Unlike traditional dispensers, Medibot features a built-in water dispensing unit and a 2D barcode scanner that uses OCR technology to verify expiration dates. Security is maintained through facial recognition to prevent unauthorized access, and real-time alerts are sent to caregivers for missed doses or low medication inventory. Additionally, the system utilizes a machine learning risk assessment model to predict drug degradation based on environmental factors like temperature and humidity. This integrated hardware-software framework aims to reduce medication errors and enhance patient autonomy while easing the burden on healthcare providers.

In [5], Rahmatia Azizatunnisa and Muhammad Thesa Ghozali (2025) explore the transformative role of the Internet of Medical Things (IoMT) in addressing the global challenge of medication non-adherence among geriatric populations. Through a narrative review of evidence synthesized from Scopus, PubMed, and the Cochrane Library, the study evaluates how intelligent pill dispensers mitigate common barriers such as cognitive decline, polypharmacy, and physical impairments. The research highlights that these devices—equipped with real-time reminders, automated tracking, and direct caregiver interfacing—significantly reduce missed doses while increasing satisfaction for both patients and their support networks. Beyond simple reminders, the authors detail how integration with Electronic Health Records (EHR) and cloud platforms facilitates a collaborative care model. However, the paper also identifies critical roadblocks to widespread adoption, specifically highlighting data privacy risks (GDPR compliance), high upfront costs, and limited internet connectivity in rural or low-resource settings. Ultimately, the study advocates for the future integration of artificial intelligence (AI) to provide predictive adherence modelling and personalized interventions to further optimize elderly healthcare.

In [6], R Sivaguru and P Revathi (2025) outline the development of a Smart IoT-Based Medication Adherence System (SMAS) designed for continuous patient oversight. The framework integrates IoT-enabled pill containers that log dosage events via embedded sensors with wearable devices that track physiological metrics such as heart rate, blood pressure, and glucose levels. Central to the system is a mobile application that syncs this data to a cloud platform, where machine learning algorithms analyze patient behavior and vital signs to identify health trends or potential risks. Beyond the technical architecture, the research emphasizes the role of real-time alerting mechanisms that notify both caregivers and healthcare providers of missed doses or



health anomalies. The authors conclude that while such systems can drastically reduce hospital readmissions and healthcare costs, their practical deployment faces hurdles regarding cross-platform interoperability, patient motivation, and the necessity of maintaining rigorous data privacy standards in line with HIPAA and GDPR regulations.

In [7], S. Sujiya *et al*. (2025) introduces a novel approach to medication adherence by developing an IoT-based implantable AI pill designed to overcome the inaccuracies of traditional monitoring methods like smart bottles or patient self-reporting, recognizing that external sensors only track when a container is opened rather than actual ingestion or physiological response, the researchers proposed an intra-gastrointestinal infrastructure. This system utilizes a capsule equipped with miniaturized sensors, communication modules, and machine learning computations that monitor the patient from within the gastrointestinal tract. The device functions by recording real-time physiological data—specifically pH levels and temperature—as it moves through the body. This data is transmitted wirelessly to a cloud-based platform where AI algorithms analyse consumption trends, detect anomalies, and provide personalized feedback to both patients and healthcare providers, By shifting the focus from indirect proxies of adherence to direct physiological measurements, the system aims to move healthcare from a reactive to a proactive management model.

In [8], Nadia Dahmania, Suja A. Alex (2024), introduces a novel IoT-based Medication Adherence System designed to address the persistent problem of non-adherence among patients with chronic conditions like diabetes and heart disease. The authors propose a technical framework that utilizes an ingestible sensor embedded directly within the medication, which activates upon contact with gastric acid to transmit real-time data. The system architecture is built around a PIC18F46K22 microcontroller acting as a gateway, which receives information from a ZigBee transmitter and relays it through an ESP8266 Wi-Fi module to the Thingspeak IoT platform. This setup allows for the collection of longitudinal data, including precise timestamps of medication intake, which can be viewed by patients, caregivers, and doctors via a custom-developed Android application. To protect sensitive health information, the researchers implemented AES encryption for secure data transmission. Beyond the hardware implementation, the study advocates for a holistic approach to chronic disease management that combines technological intervention with patient education and behavioural modifications. While highlighting the potential for "digital pills" to revolutionize patient care and reduce hospital re-admissions, the authors also provide a critical look at current barriers, such as the increased cost of sensor-integrated medication, data privacy concerns, and the need for designs that support non-oral administration routes.

In [9], Vinay Peddisetti *et al*. (2024) illustrate the integrated IoT-based ecosystem designed to improve medication adherence through a smart pill dispenser, a sensor-equipped cup, and a mobile application. A standout feature is the consumption verification system, which uses an Inertial Measurement Unit (IMU) and ultrasonic sensors in the cup to confirm that a patient has actually taken their medication. The prototype also incorporates an RFID-based fail-safe mechanism to prevent dispensing errors and utilizes Bluetooth Low Energy (BLE) for energy-efficient connectivity. Evaluation of the system demonstrated 100% accuracy in both the dispensing mechanism and consumption tracking, highlighting its potential for high-precision remote patient monitoring.

In [10], P, Balaji *et al*. (2024) explained the pervasive global challenge of medication non-adherence, Balaji et al. developed the Intelligent Medication Compliance System (IMAC), a sophisticated IoT-based framework centered on an ESP32 microcontroller. A distinctive capability of the IMAC system is its integrated design that manages both solid and liquid medications within a single unit, surpassing the limitations of many existing dispensers that are restricted to solid forms. The architecture leverages the MQTT (Message Queuing Telemetry Transport) protocol for lightweight, encrypted communication between the hardware and the MedSync mobile application, which delivers real-time notifications to patients and enables remote monitoring by healthcare providers. To enhance proactive care, the system utilizes K-Nearest Neighbor (KNN) clustering algorithms to analyze historical adherence data and patient demographics, allowing it to predict potential compliance risks and identify groupings of similar dose times. The hardware setup incorporates infrared (IR) sensors and servo motors to ensure precise dispensing and robust consumption verification, while the use of ESP32 deep sleep modes ensures energy-efficient operation for long-term clinical use. Empirical results from the study demonstrated high levels of patient satisfaction and a measurable improvement in adherence rates, establishing the system as an effective, human-centered solution for managing chronic disease regimens.

In [11], Luigi Gargioni *et al*. (2024) conducted a comprehensive systematic review using the PRISMA methodology, analyzing 56 relevant papers published between 2013 and 2023 to evaluate automated medication dispensers through a socio-technical, human-centered lens,,. Their analysis categorized existing solutions based on their maturity—ranging from preliminary design studies to commercial products—and detailed their technical architectures involving various microcontrollers, sensors, and communication protocols. The review deeply explored interaction modalities, highlighting a shift toward mobile-mediated control while noting that advanced paradigms like natural language processing and understanding remain significantly underutilized for cognitively or visually impaired users, A significant contribution of the study is its assessment of user involvement, identifying that while most systems currently require manual recharging by patients or caregivers, there is a growing need for professional integration via pharmacies or prepackaged medication pouches to ensure safety and accuracy,. The authors identified several critical research gaps, specifically the lack of standardized adherence definitions and limited feedback from healthcare professionals, alongside technical



challenges regarding system scalability, cybersecurity, and the complex integration of these devices into broader Internet of Things (IoT) ecosystems, Conclusively, the study advocates for a modular, API-driven architectural approach to ensure interoperability and safety, providing a strategic roadmap for designing flexible therapy management systems that prioritize long-term user acceptance and clinical efficacy,,.

In [12], P. Dayananda and Amrutha (2024) examined the SPEC 2.0, it is an IoT-based smart pill dispenser designed to improve medication adherence through automated distribution and remote monitoring. Built with a Renesas microcontroller and integrated with a dedicated Android application, the system allows users to schedule pill cycles and receive real-time SMS alerts. A key technical feature is its over-dosage prevention mechanism, which uses an IR obstacle sensor to detect unconsumed pills and automatically move them into a secure secondary container after 10 seconds. Performance evaluations show that the prototype achieves 90% accuracy, marking a 5% improvement over existing smart dispensing systems.

[13] Suja A. Alex *et al*. (2024) proposed an Internet of Things (IoT)-based framework designed to address the persistent challenge of medication non-adherence, the research highlights a critical gap in healthcare where, despite accurate diagnoses, over 50% of patients fail to follow their prescribed medication regimens. The authors identify two primary drivers for this non-compliance: a general lack of patient education and an inherent fear regarding the long-term side effects of chronic drug consumption. To mitigate these issues, the system leverages IoT technology to provide smart monitoring of a patient's adherence, ensuring that chronic conditions such as diabetes or heart disease are managed more effectively through regular consumption, By integrating real-time monitoring, the research aims to realize the full therapeutic potential of pharmacological treatments that are often undermined by irregular patient behavior. This work situates itself within the evolving field of digital health, alongside other advancements like electronic pill technology and capsule endoscopy, to improve long-term health outcomes through better compliance.

[14] S.V. Priya *et al*. (2024) address the persistent challenge of medication non-adherence by proposing an IoT-integrated smart medicine box that combines physical storage with digital monitoring. The hardware design utilizes 21 distinct compartments for medicine organization, supplemented by voice recognition technology to facilitate natural user interaction. Central to the system's functionality is a companion Android-based mobile application that acts as a control interface for programming medication schedules, delivering reminders, and tracking patient adherence in real-time. By bridging the gap between hardware storage and mobile connectivity, the research seeks to mitigate common barriers such as forgetfulness and the complexity of multi-drug regimens. This integrated solution was presented at the 2024 International Conference on Advances in Computing, Communication and Materials to demonstrate how technological intervention can improve health outcomes for elderly patients.

III. COMPARISON OF THE TECHNIQUES

Table 1: Comparison Table

Author Name	Methodology	Results	Gaps	Year
Abiruth S *et al.*	MediTrack framework using ESP32, pulse oximeter, and machine learning	Achieved 98.5% pill detection accuracy, 88.90% adherence prediction accuracy.	Many strong predictive models operate offline without real-time integration	2026
Waqas *et al.*	digitally augmented medication adherence interventions for chronic diseases	improvements in adherence were reported in several interventions.	Heterogeneity in outcome measures, and risk of bias	2026
Kasthuri Natarajan *et al.*	Fully integrated system including medication dispensers, wearable sensors.	Demonstrated 30% reduction in missed doses, 20% increase in engagement.	high sensitivity of healthcare data to potential cyberattacks	2026
Priyanka R *et al.*	Medibot robot featuring voice recognition, navigation.	Provides unique features like automated water dispensing.	Current prototype is limited to solid medications.	2026
Rahmatia Azizatunnisa *et al.*	IoMT-enabled dispensers: A brief literature review	Reported high adherence rates, reduced missed doses,	poor internet quality in rural areas, data privacy concerns, and financial barriers.	2025
Nadia Dahmani *et al.*	IoT system leveraging ingestible Proteus sensors and wearable patches to track	High accuracy in detecting intake events.	restricted to oral medications; cost increases associated with sensor.	2024



IV. METHODOLOGY

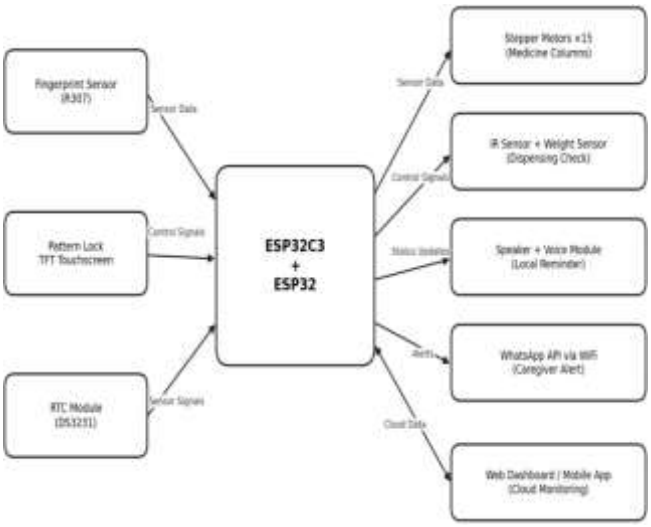
The operational methodology of PillBot follows a multi-stage, closed-loop electromechanical process orchestrated by an integrated dual-ESP32 microcontroller architecture, powered by a regulated 5V 5A switch-mode power supply (SMPS) with inline fuse protection and decoupling capacitors (1000 µF, 470 µF, and 0.1 µF) to eliminate transient noise during motor operation. System timekeeping is continuously governed by a high-precision DS3231 Real-Time Clock (RTC) module backed by a coin-cell battery, ensuring accurate scheduling windows and persistent timestamps independently of cloud synchronization or network dropouts. When a scheduled time arrives, multimodal audiovisual reminders are initiated: the primary ESP32 drives an active 5V buzzer alongside an I2S MAX98357A Class-D audio amplifier coupled to a 5W 4Ω full-range speaker for clear voice prompts, while the 3.5-inch 480×320 LVGL-rendered touchscreen interface displays the active patient profile and invites authentication.

Patient security is enforced through an optical R307 fingerprint sensor. Once the biometric signature matches an enrolled identity profile, the ESP32 looks up the patient's prescription record and triggers the dispensing routine. Actuation signals are dispatched to ULN2003 driver boards to energize the assigned 28BYJ-48 5V unipolar stepper motor. The motor indexes one of the four circular medicine carousels, each divided into seven distinct compartments. Precise mechanical alignment and rotational zero-homing are maintained via A3144 Hall-effect sensors triggered by neodymium magnets embedded on each tray assembly, systematically eliminating angular drift and step-loss across repeated cycles.

As the tray rotates to the discharge port, the tablet falls by gravity through a guided chute assembly into the medicine collection cup. Closed-loop delivery confirmation relies on a dual-stage sensing mechanism: an optical IR break-beam sensor immediately registers the dynamic transit of the pill, while an HX711 24-bit ADC amplifier reading a 1 kg single-point load cell records the steady-state mass delta in the collection cup. If both sensor thresholds are verified, the intake event is timestamped, stored in local non-volatile memory, and transmitted over Wi-Fi to a cloud dashboard. Conversely, if biometric validation fails or the dual sensors detect no pill drop within a preset timeout, the system logs a missed-dose exception, sounds a secondary warning, and immediately dispatches an automated alert to designated remote caregivers to enable timely clinical intervention. Furthermore, the companion web dashboard updates in real time, enabling remote healthcare practitioners to evaluate longitudinal adherence trends and adjust medication regimens dynamically. To prevent accidental double-dosing or overdosing, the controller locks out further dispensing cycles for that specific slot until the subsequent scheduled timeframe arrives. A dedicated maintenance and refill mode can be accessed via the touchscreen, allowing authorized caregivers to restock the 7-compartment trays under secure biometric override.

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Block Diagram:



Flow Chart:







V. RESULT

Experimental evaluation of the PillBot prototype validated its electromechanical precision, biometric security, and closed-loop dispensing verification across multiple trials. The 28BYJ-48 stepper motor drive system, coordinated via ULN2003 drivers and indexed with A3144 Hall-effect sensors and neodymium magnets, achieved consistent homing calibration and accurate 7-compartment tray positioning without mechanical stalls or positional drift. Biometric access control using the R307 optical fingerprint scanner effectively restricted medication release solely to enrolled patient profiles, preventing accidental or unauthorized access. During scheduled intervals triggered by the DS3231 real-time clock, the dual-stage verification framework—combining the optical IR break-beam sensor and the HX711-interfaced load cell—confirmed pill drop events and weight displacement in real time. For unverified intakes or missed dose timeouts, the system initiated automated alerts over Wi-Fi, reliably informing caregivers for timely intervention. Overall, the hardware-software integration demonstrated dependable operational uptime, zero mechanical jamming, and robust adherence tracking for multi-patient domestic healthcare management.



VI. CONCLUSION

The development of PillBot demonstrates an effective, hardware-validated solution to the critical challenge of medication non-adherence in domestic environments. By moving away from prone loose-pill mechanisms and passive reminder systems, the platform successfully combines electromechanical precision, biometric access control, and closed-loop dispensing verification into a cohesive architecture. The coordinated dual-ESP32 architecture, backed by a DS3231 real-time clock, guarantees reliable offline scheduling while operating four independent 7-compartment circular trays via 28BYJ-48 stepper motors. Incorporating A3144 Hall-effect sensors and neodymium magnets ensures zero positional drift and precise alignment during operation. Furthermore, patient safety is reinforced through R307 optical fingerprint authentication, preventing unauthorized access, while the integration of an optical IR break-beam sensor and an HX711-interfaced load cell provides verifiable, dual-stage physical drop confirmation.

By closing the loop with multimodal audiovisual alerts and real-time caregiver notifications over Wi-Fi, PillBot provides an essential safety net that prevents missed doses and mitigates the risk of preventable hospitalizations. The system establishes an affordable, scalable, and tamper-resistant framework tailored to the complexities of polypharmacy and multi-patient households. Future work will focus on expanding the platform's capabilities by integrating machine learning models for predictive adherence tracking, incorporating automated inventory reordering via cloud APIs, and exploring cellular fallback options to ensure continuous connectivity in low-resource settings. Overall, PillBot marks a significant step forward in connected digital health, delivering a secure, verifiable, and human-centered foundation for automated medication management.

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