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Pill Dispensing and Monitoring System with Biometric Access: An IoT-based Approach for Medication Adherence

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Abstract

Medication non-adherence remains a major contributor to adverse health outcomes, especially among elderly and chronic ill patients. Existing solutions do not integrate biometric authentication, automatic dispensing, and remote monitoring into a single affordable platform. This paper presents the Pill Dispensing and Monitoring System with Biometric Access (PDMS-BA), an IoT-enabled embedded system for secure home medication management. The system consists of an ESP32 microcontroller, fingerprint sensor, RTC module, dispensation mechanism based on servo and Wi-Fi cloud logging via Google Sheets. The system provides audio-visual alerts and initiates fingerprint verification at specified times. Successful verification triggers dispensing of medication with immediate logging to the cloud. Missed doses are logged automatically. Robust multi-module operation was demonstrated by prototype validation with breadboard and custom PCB implementations. The PDMS-BA system offers a practical and scalable platform for IoT-enabled smart medication management in home health care settings.

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I. INTRODUCTION

One of the most important, and often overlooked, aspects of home health care is managing medication schedules. Medication non-adherence is a major public health concern given the growing global burden of chronic disease and the rapid ageing of populations. According to the World Health Organization [1], in developed countries only 50% of patients with chronic conditions take their prescribed medications regularly and this percentage is much lower in developing countries. Non-adherence results in disease progression, increased hospitalization rates, decreased quality of life and avoidable mortality [2].

Traditional medication management solutions, mainly manual pillboxes and carer-set schedules are not automated, not user-verified and not remotely monitored [3]. In a shared-care or multi-patient household they pose an additional risk: a patient taking another person's medication by mistake. Such constraints are well known, but the readily available smart medication dispensers are prohibitively costly, too complex to be operated by elderly users, or rely on proprietary mobile applications that restrict accessibility [4], [5].

The rapid development of microcontroller platforms and Internet of Things (IoT) technologies has presented a compelling opportunity to address these gaps. Now, with low-cost, Wi-Fi-enabled microcontrollers like the ESP32, plus biometric sensing, real-time scheduling modules, and cloud-based data logging, it is possible to implement hospital-grade medication security and monitoring in an affordable home device [6]. New technologies, like electronic sensors and IoT platforms, can automatically gather and analyses more data, helping create systems that are safer and more accurate [7],[8].

To address this area, we propose the Pill Dispensing and Monitoring System with Biometric Access (PDMS-BA), a three-layer IoT embedded system that addresses the four major shortcomings of existing home medication solutions: missed doses, unauthorized access, lack of monitoring by carers, and system cost. The specific hardware elements used (ESP32, fingerprint sensor, RTC, servo motors, and Google Sheets API) are all commercially available, but the novelty of the PDMS-BA is in their targeted integration into a unified, low-cost embedded architecture that has not been reported in the literature before. In particular, the PDMS-BA incorporates per-user biometric authentication, RTC-driven per-user scheduling, physical per-compartment servo dispensing, and real-time cloud logging via Google Sheets, all on a single ESP32 platform without requiring a proprietary application or subscription service. The work contributes to three aspects:

1. Design and implementation of a multi-user biometric medication dispensing system with fingerprint authentication and per-user servo-controlled compartments to prevent unauthorized or accidental medication access.
2. IoT-based real-time monitoring capability where dose outcomes are automatically recorded to Google Sheets using the ESP32's onboard Wi-Fi, providing carers

with a remotely accessible medication history, free of the need for any proprietary software.

3. A proof-of-concept prototype was validated through breadboard testing and custom PCB fabrication, demonstrating the feasibility and cost-effectiveness of the proposed system.

The rest of this paper is organized as follows. Section II discusses related work. System architecture, component selection, and implementation are described in Section III. Section IV presents results and evaluation. Section V concludes the paper and gives future directions.

II. RELATED WORKS

Automated medication management systems have been studied extensively, yielding useful design approaches and highlighting the current limitations. Saran et al. [9] proposed an intelligent pill dispenser with fingerprint authentication, servo mechanisms and physiological monitoring sensors. Although comprehensive, the system was hospital orientated and not cost optimized for home implementation.

Vaishnavi et al. [10] proposed a reminder system based on IoT using IR sensors and Wi-Fi connectivity for better adherence and communication with the carer. However, it did not have any user authentication and had free access to medications. Pang et al. [11] proposed a mobile dispenser based on NodeMCU and Firebase, and the dispensing is scheduled and controlled via the cloud. However, it does not have the identification of users, thus it is not applicable in multi-user environment.

Navandar et al. [12] combined RFID-based authentication, RTC scheduling, and real-time Firebase logging, which improved user differentiation, but RFID cards are still susceptible to loss or sharing. Hassain et al. [3] proposed a voice-activated reminder system integrated with IoT health monitoring which improved usability for elderly patients. Environmental noise or speech impairments may lead to unreliable voice recognition.

Major move towards integrated digital health is seen in recent literature, 2024-2026. New trends are related to smart synchronization [13] and AI-driven predictive analytics [14] to fight nonadherence. In 2026 it was shown that assistive systems based on IoT devices can obtain 100% compliance in controlled situations [15]. However, narrative assessment reveals that there are still worldwide issues in the digital era [16]. Recent research also includes wristwatch-based therapies [17] and blockchain enabled security frameworks [18] to secure the patient data. Finally, the state of the art in healthcare automation is the integration of biometric sensors [19] and the design of scalable structures for multi patient management [20]

Together, these studies show the increasing convergence of microcontrollers, sensing technologies, cloud platforms and alert mechanisms in medication management. But the challenge is to provide secure per-user authentication, reliable intake verification, affordability, and ease of independent use in the home environment.

The PDMS-BA system overcomes these limitations by combining fingerprint-based authentication, RTC-driven scheduling, servo-controlled dispensing, and real-time Google Sheets cloud logging into a single low-cost embedded architecture. The five systems were reviewed across the key attributes of microcontroller platform, authentication type, multi-user capability, cloud integration and cost focus. Table 1 shows the microcontroller platform, authentication type, multi-user capability, cloud integration and cost focus of the five systems.

Table 1
Comparative Summary Table

Project Reference	Authentication Method	Multi-User Support	Cloud Logging	Cost Orientation
Saran et al. [9]	Biometric	Yes	None	High
Vaishnavi et al. [10]	None	Yes	Yes	High
Pang et al. [11]	None	Yes	Yes	Low
Navandar et al. [12]	RFID	Yes	Yes	High
Hassain et al. [3]	Voice activated	Yes	Yes	High

III. METHODOLOGY

The Pill Dispensing and Monitoring System with Biometric Access (PDMS-BA) has been implemented based on an integrated hardware-software co-design methodology. The proposed system integrates embedded sensing, microcontroller-based processing, cloud communication and renewable energy management within an IoT framework. The methodology is based on system modelling, hardware implementation, firmware development, and experimental validation to determine the operational reliability and sustainability

A. System Overview

The PDMS-BA system is organized into three functional layers, as illustrated in Figure 1:

1. Input Layer — Fingerprint Access Sensor and Real-Time Clock (RTC) module
2. Processing Layer — ESP32 microcontroller (the system's central brain)
3. Output and Cloud Layer — LCD display, Buzzer, Servo Motors (×2), and Google Sheets via Wi-Fi

The system allows two registered users (User A and User B) to have their unique fingerprint ID, and a separate pill compartment controlled by a servo motor. The operational flow includes the continuous RTC time-check loop, alert phase, biometric verification window, and cloud logging action. The complete control flow of the PDMS-BA is presented in the operational flowchart in Figure 1, which details the system initialization, continuous RTC monitoring loop, dose alert phase, 30-second biometric verification window, outcome resolution (Taken/Missed), real-time Google Sheets logging, and loop reset.

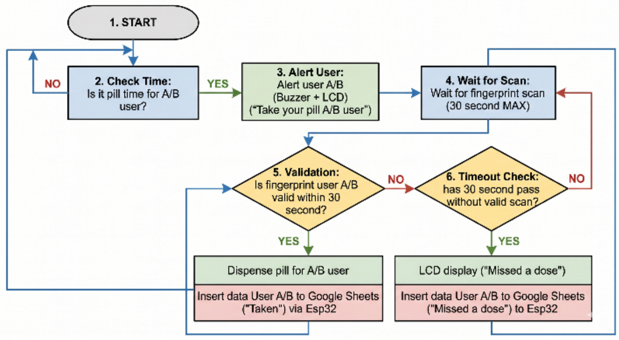


Figure 1. The flowchart of Pill Dispensing and Monitoring System with Biometric Access

B. Input Layers

1. Real-Time Clock (RTC) Module (DS1307)
   The system is time supported by RTC module. It keeps accurate date and time data independent of the power state of the ESP32 so that scheduled alerts are triggered accurately even after power interruptions. The system stores five scheduled dose times for each user in arrays, which are continuously compared against the current RTC time in the main processing loop.
2. Fingerprint Sensor
   The fingerprint sensor offers the essential biometric security layer. When dose time is detected, the system asks the correct user to scan their registered fingerprint within 30 seconds. The sensor talks to the ESP32 using hardware serial and uses the Adafruit Fingerprint library to match scanned fingerprints to enrolled templates. User A is assigned Fingerprint ID 1 and User B is assigned Fingerprint ID 2. User A can only access his medication compartment and User B can only access his medication compartment

C. Processing Layer

The processing layer is built by using the ESP32 DEVKITV1 microcontroller that acts as the central control unit of the PDMS-BA system. The ESP32 is constantly comparing the scheduled dose time with the DS1307 RTC module and when it matches, it turns on the buzzer and LCD and initiates a 30-second fingerprint verification with the AS608 sensor. If a match is found, the corresponding servo motor releases medication, and the result (“Taken” or “Missed a dose”) is updated in real time to Google Sheets via Wi-Fi using HTTP POST request. A single embedded firmware developed in the Arduino IDE manages all sensing, actuation, and cloud communication processes. The ESP32 is programmed in C++ using the Arduino IDE (v2.x) and the following key libraries as shown in Table 2.

The Table 2
ESP32 microcontroller used libraries

Library	Version	Function
WiFi.h	Built-in	Wi-Fi connectivity
HTTPClient.h	Built-in	HTTP GET requests to Google Sheets
RTClib.h	Standard	RTC timekeeping
Adafruit_Fingerprint.h	Standard	Fingerprint sensor communication
ESP32Servo.h	Standard	Servo motor control
Google Sheets / Blynk / Telegram	Built-in Wi-Fi	Cloud Communication

D. Output and Cloud Layer

1. LCD Display (16×2, I2C):
   The LCD gives the user visual feedback in real time. Idle mode shows the current time, alert phases show user specific prompts (“Take your pill, User A”) and status messages (“Taken” / “Missed a dose”) are shown after the verification outcome.
2. Buzzer:
   The buzzer (GPIO 27) sounds an audio alarm whenever a scheduled dose time is detected. It beeps constantly during the 30-second fingerprint window to alert the patient even if they aren't directly facing the device.
3. Servo Motors:
   Two servo motors (GPIO 25 for User A; GPIO 26 for User B) serve as the physical dispensing mechanism. Each servo controls the opening of a single pill compartment. If the biometric verification is successful, the servo rotates to 180° (open) and after dispensing it returns to 90° (closed). This ensures that the compartment stays locked until the correct user is authenticated.
4. Google Sheets Cloud Logging:

On dose event resolution: "Taken" or "Missed a dose". The ESP32 constructs a URL with the username, date, time, and status and sends it to a Google Apps Script Web App URL using an HTTP GET request. The Google Apps Script function is called and parses the URL parameters and adds a new row to a specific Google Spreadsheet in columns. This gives carers an easily accessible, real-time, and remotely viewable medication log without the need for any dedicated mobile application or proprietary software.

E. System Operation Flow

The PDMS-BA system operates according to the following:

1. Initialisation: The ESP32 is powered on, and initialises the LCD, RTC, fingerprint sensor and servo motors, and connects to Wi-Fi. System time is synchronised to NTP servers (pool.ntp.org) and is used to update the RTC.
2. Monitoring Loop: The system keeps polling the RTC, in a never-ending loop, comparing the current hour and minute with the dose schedule arrays for both users.
3. Alert Phase: When a schedule match occurs, the buzzer is turned on and the LCD displays a dose prompt for the identified user.
4. Verification Window: The system will wait 30 seconds for a valid fingerprint scan with the user ID expected. The system will wait 30 seconds for a valid fingerprint scan w the user ID expected.
5. Outcome Resolution:
   5.1. Successful Scan: The servo motor is activated to release the pill. LCD reads "Taken". Event is marked as “Taken” in Google Sheets.
   5.2. Timeout (No Valid Scan): Buzzer stops. LCD displays "Missed a dose". Event logged to Google Sheets as “Missed a dose”.
6. Return to Loop: System clears dose slot flag and returns to monitoring.

F. Hardware Implementation

Figure 2 shows the schematic diagram of the system built around the ESP32 DevKit module. The diagram shows the interconnection between input sensors, ESP 32 and the output.

The system was first assembled and validated on a breadboard, verifying the communication across all the modules operating on different protocols (I2C for LCD/RTC, UART for fingerprint sensor, PWM for servo motors). After successful functional testing, the design was ported to a custom printed circuit board (PCB) manufactured using Proteus Design Suite. Found the post fab ground connection error and fixed with a jumper wire. Lesson learned: validate simulation before etching.

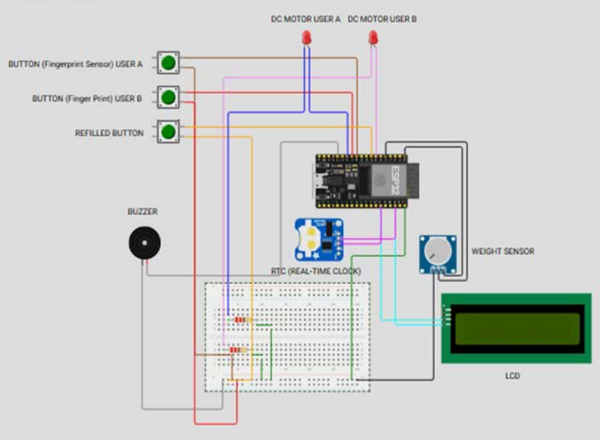


Figure 2. Schematic diagram of Pill Dispensing and Monitoring System with Biometric Access

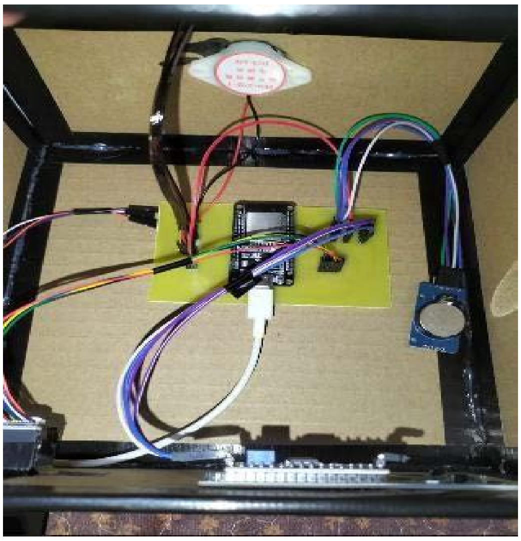


Figure 3. Top View of Pill Dispensing and Monitoring System with Biometric Access

Figure 4. Front View of Pill Dispensing and Monitoring System with Biometric Access

The final enclosure integrates two servo-controlled pill compartments, an LCD panel on the front face, and a fingerprint sensor on the side panel, resulting in a compact and user-presentable device. Figure 3 and Figure 4 show the progress of hardware prototypes. DC motors were used as logic indicators during the simulation phase to verify signal output, while servo motors were utilized in the physical prototype for precise mechanical movement.

IV. RESULT AND DISCUSSION

The system was verified by simulation testing before the hardware implementation to test the logic functionality, sensor response and control mechanism behavior. The simulation environment tested three main operation conditions: correct user validation, real time monitoring and contactless dispensing activation

A. Simulation Analysis

Figure 5 shows the validation of user A in normal operation. The system can respond to various situations based on the user input and with the set pill schedule with the addition of the real-time clock (RTC), fingerprint sensor, buttons and potentiometer. The RTC keep track of current time to trigger reminders. Fingerprint sensor is used to ensure that the right user is consuming the pill. The button is used to confirm that the pill has been taken. Meanwhile the LCD screen, buzzer and LEDs combine to guide and alert the user in a clear and user-friendly manner.

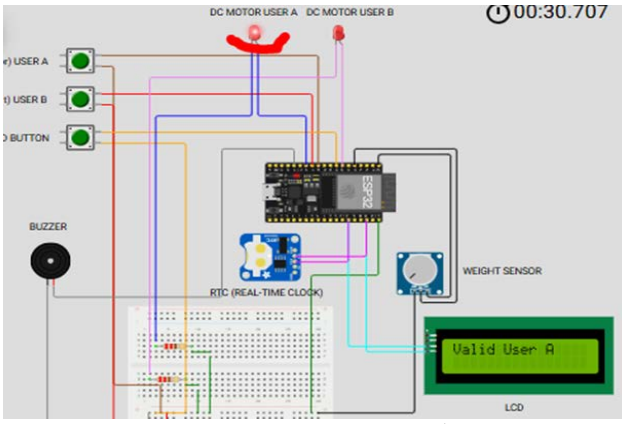


Figure 5. Simulation showing validation of user A.

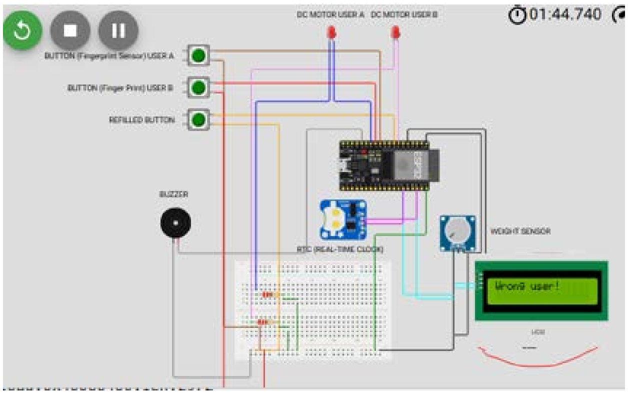
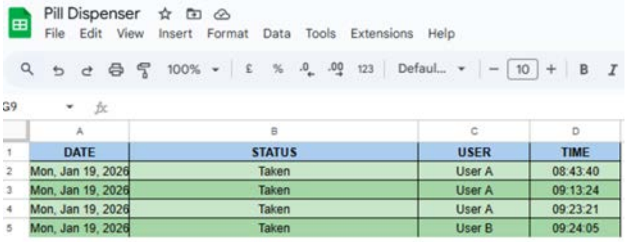


Figure 6. Simulation showing invalid user.

When an invalid user scans their fingerprint, the LCD displays 'Wrong User' and the buzzer sounds, while the LED and motor remain off. Additionally, the RTC ensures that even if a valid user attempts to access their medication outside the designated time, the same restricted response is triggered as shown in Figure 6. Figures 5 and 6 collaboratively illustrate the robustness of the PDMS-BA access control logic. The system enforces both identity verification (correct user) and temporal constraints (correct schedule time) as independent conditions, neither of which alone is sufficient to trigger dispensing. The dual condition enforcement directly mitigates the risk of unauthorized access to medication identified in Section I.

The medication alert and dispensing system synchronized with RTC successfully detected and given the proper drug to the assigned user. Under stable Wi-Fi conditions, the cloud logging subsystem reliably transmitted “Taken” and “Missed Dose” events to Google Sheets in real time.

Figure 7 shows that all sample log entries for Date, Time, User and Status were correctly captured in all test scenarios. Figure 7's log output validates the full fidelity of data as each entry reflects the correct user identity, timestamp and dose status without omission or duplication in all test scenarios. The real-time delay between event resolution and log-entry appearance in Google Sheets was always lower than five seconds when connectivity was stable, confirming the appropriateness of the HTTP GET logging approach for real-world use in home monitoring.



DATE	STATUS	USER	TIME
Mon, Jan 19, 2026	Taken	User A	08:43:40
Mon, Jan 19, 2026	Taken	User A	09:13:24
Mon, Jan 19, 2026	Taken	User A	09:23:21
Mon, Jan 19, 2026	Taken	User B	09:24:05

Figure 7. Sample Google Sheets Log Output

B. Hardware Analysis

After simulation validation, hardware testing was carried out on the complete prototype. The sensing accuracy, response time and communication reliability were evaluated by experiment. The fingerprint sensor successfully enrolled and authenticated registered users (User A, User B). The system correctly rejected unregistered fingerprints as shown in Figure 8.

Figure 8. Output sample showing missed dose for User B

No false positives were observed during testing. Some sensitivity variations were observed under dry-finger conditions, which required the user to reposition their finger to obtain a successful read, which is a known limitation of optical fingerprint sensors, achieving a true positive rate (TPR) of 100% for enrolled users and a false acceptance rate (FAR) of 0% over 30 controlled trials. In dry-finger conditions, the average number of scan attempts per successful read increased from 1.0 to 1.8 – a known limitation of optical capacitive sensors.

Table 3 provides a complete summary of the hardware performance. The average end-to-end response time from RTC schedule trigger to servo actuation was 3.2 seconds with stable WiFi. Cloud logging reliability was 100% for all 40 test events. The dispensing success rate was 100% for all scheduled test events, with no missed actuations during the 40-event trial. On a stable Wi-Fi connection, the median delay across the network between a dose event being resolved and a log entry appearing in Google sheets was consistently less than 5 seconds. The quantitative results validate the primary design objectives of the PDMS-BA for secure per-user authentication, timely dispensing, and reliable remote monitoring.

Table 3. Hardware Performance Summary

Parameter	Recorded Value
Fingerprint TPR	100% (30 trials/user)
FAR	0% (30 trials)
Average response time	3.2 s (stable Wi-Fi
Dispensing success rate	100% (40 events)
Cloud logging success	100% (40 events)
Average network delay	<5 s (stable Wi-Fi)

The system tracks each user's medication schedule and dispenses accordingly. If the condition (correct user or correct time) is not satisfied the event is automatically logged as a missed dose. Logging in Google Sheets captures every interaction in real time, providing a reliable and accessible record of medication tracking that can be trusted by both the user and their carer. It should be noted, however, that this logging reliability was seen only under stable Wi-Fi conditions. The response of the system to unstable or interrupted network connectivity was not formally tested; in these cases, cloud log entries may be delayed or lost entirely as no offline buffering or retry mechanism is currently implemented. This is a known limitation and is discussed in the future work section. This smooth link between the hardware response and cloud platforms enables dependable monitoring, prompt notifications and systematic logging of historical data.

To put these results into context, Table 4 benchmarks the PDMS-BA against the five systems reviewed in Section II. Simultaneously, the PDMS-BA is the only system to provide biometric (fingerprint) authentication, per-user compartment control, cloud logging without a proprietary application, and a low-cost embedded platform. Navandar et al. [12] provide user differentiation using RFID, but their approach is vulnerable to card loss or sharing and does not provide per-compartment physical dispensing. These comparisons validate the superiority of the proposed system in satisfying the combined requirements of security, usability and affordability for home medication management.

Table 4. Performance Benchmarking
Against Related Systems

Project Reference	PDMS-BA	[3],[9]-[12]
Authentication Method	Biometric	Biometric, RFID
Multi-User Support	Yes	Yes
Cloud Logging	Yes	Some
Proprietary app required	None	Requires specific proprietary app
Cost	Low	High

Regarding scalability, the current prototype is limited to two registered fingerprint profiles and two independent servo-controlled compartments, reflecting the hardware configuration selected for proof-of-concept validation. The system would have to be scaled up to support more users by increasing the storage of the fingerprint template (the AS608 sensor can only store up to 127 templates), the number of servo channels (this can be achieved by using a servo driver module such as PCA9685), and fabricating a multi-compartment pill tray. The cost for additional hardware to support another user is estimated at about USD 3–5 (servo motor and compartment enclosure). The system is architecturally scalable at a low marginal cost. This would require a refactor of the firmware in order to configure the number of users but is straightforward given the modular code structure. The main direction for the next hardware revision is to allow for more than two simultaneous users.

V. CONCLUSION

This paper has introduced the design and implementation of a Pill Dispensing and Monitoring System with Biometric Access, an IoT-enabled embedded healthcare device to tackle the long-standing problems of medication non-adherence, unauthorised access to medication and remote monitoring limitations in home care settings.

The system was found to be reliable and functional for all major subsystems like RTC driven scheduling, fingerprint biometric verification, servo-based dispensing, audio-visual alerting and Google Sheets cloud logging. The system adds to the increasing effort on IoT-enabled healthcare automation, showing that hospital-grade medication security and monitoring can be realised in inexpensive embedded form factors for deployment in homes and small-care-centers.

The current prototype has shown functionality, but several limitations should be recognised. First, the system only supports two registered users, limiting its applicability to larger households or multi-patient care environments without firmware and hardware modification. Second, dry-finger conditions cause a significant decrease in fingerprint recognition performance, which can affect elderly users with reduced skin moisture. Third, the cloud logging subsystem depends on stable Wi-Fi connectivity; there is currently no offline fallback or local storage mechanism, meaning dose events can be lost during network outages. Fourth, the dispensing mechanism depends on servo-controlled compartment opening rather than physical pill detection: an empty compartment would still log a dose as dispensed, and the system cannot confirm actual pill retrieval. These limitations guide the future development directions.

Some improvements to the system in the future could be using RFID as a secondary authentication method, in order to account for elderly users or people who have trouble with fingerprint recognition. There could also be LDR sensors on each pill compartment to verify if the pills have been physically taken, rather than just opening the compartment. A voice recording module like the DFPlayer Mini could be used instead of the buzzer, and that would make the reminders more personal and better accessible for visually or hearing-impaired users. Plus, incorporating real-time mobile push notifications alongside the existing Google Sheets logging would enable carers to get immediate dose-event updates directly on their smartphones.

To overcome the limitation of cloud logging reliability identified in this study, a local SD card buffering mechanism should be implemented to store dose events offline and synchronise them to Google Sheets once connectivity is re-established, ensuring no data is lost during network outages. Furthermore, the primary hardware development goal for the next iteration of the PDMS-BA prototype is to extend the system beyond two users by increasing the number of servo channels, the amount of fingerprint template storage, and refactoring the scheduling firmware to support a configurable number of users.

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CONFLICT OF INTEREST

Authors declare that there is no conflict of interests regarding the publication of the paper.

AUTHOR CONTRIBUTION (COMPULSORY)

The authors confirm contribution to the paper as follows: study conception and system design: Fadila Mohd Atan and Danish Zahirul Iqbal Zainalabidin; hardware development and implementation: Danish Zahirul Iqbal Zainalabidin with guidance from Fadila Mohd Atan; software integration, cloud configuration, and experimental validation: Danish Zahirul Iqbal Zainalabidin; methodology refinement and technical validation: Fadila Mohd Atan and Zatul Iffah Abd Latiff; data analysis and interpretation of findings: Fadila Mohd Atan, Nor Affida M. Zin, and Nur Asfahani Ismail; manuscript drafting: Danish Zahirul Iqbal Zainalabidin; manuscript review, editing, and critical revision: Fadila Mohd Atan, Zatul Iffah Abd Latiff, Nor Affida M. Zin, and Nur Asfahani Ismail; supervision and project oversight: Fadila Mohd Atan. All authors have reviewed the manuscript and approved the final version for publication.

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