Journal of Telecommunication, Electronic and Computer Engineering
ISSN: 2180 – 1843 e-ISSN: 2289-8131 Vol. 18 No. 2 (2026) 23-29
jtec.utem.edu.my
DOI: https://doi.org/10.54554/jtec.2026.18.02.004

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

Danish Zahirul Iqbal Zainalabidin, Fadila Mohd Atan*, Zatul Iffah Abd Latiff, Nor Affida M. Zin and Nur Asfahani Ismail
Faculty of Electrical Engineering, Univesiti Teknologi MARA (UiTM), Johor Branch, Pasir Gudang Campus, Masai, 81700 Johor, Malaysia.

Article Info

Article history:
Received Mar 6th, 2026
Revised May 6th, 2026
Accepted Jun 3rd, 2026
Published Jun 30th, 2026

Index Terms:
Medication
Biometric Access
Medication Adherence
Pill Dispenser

Abstract

Medication non-adherence remains a major contributor to adverse health outcomes, particularly among elderly individuals and patients with chronic diseases. Existing medication management solutions often lack the integration of biometric authentication, automated dispensing, and remote monitoring within a single affordable platform. This paper presents the Pill Dispensing and Monitoring System with Biometric Access (PDMS-BA), an Internet of Things (IoT)-enabled embedded system designed for secure home medication management. The proposed system integrates an ESP32 microcontroller, fingerprint sensor, Real-Time Clock (RTC) module, servo-based dispensing mechanism, and Google Sheets cloud logging via Wi-Fi. At scheduled medication times, the system provides audio-visual alerts and initiates fingerprint verification. Successful authentication triggers medication dispensing and immediate cloud logging, while missed doses are automatically recorded. The prototype was validated through both breadboard testing and custom printed circuit board (PCB) implementation, demonstrating reliable operation of the integrated hardware and software modules. The results confirm that the. Proposed PDMS-BA provides secure user authentication, timely medication dispensing, and reliable remote monitoring using a low-cost embedded platform. The proposed PDMS-BA system offers a practical, cost-effective, and scalable solution for IoT-enabled smart medication management in home healthcare environment.

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*Corresponding Author: fadila2533@uitm.edu.my

I. INTRODUCTION

One of the most important, and often overlooked, aspects of home healthcare is medication management. Medication non-adherence is a major public health concern due to 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 as directed, and this percentage is considerably lower in developing countries. Medication non-adherence results in disease progression, increased hospitalization rates, reduced quality of life, and avoidable mortality [2].

Traditional medication management solutions, including manual pillboxes and caregiver-managed schedules, lack automation, user verification, and remote monitoring capabilities [3]. In shared-care or multi-patient households, these systems pose an additional risk of patients accidently taking another person's medication. Although commercially available smart medication dispensers address some of these limitations, they are often prohibitively expensively, overly complex for elderly users, or dependent on proprietary mobile applications that restrict accessibility and flexibility [4], [5].

The rapid development of microcontroller platforms and Internet of Things (IoT) technologies has created new opportunities to address these gaps. Low-cost, Wi-Fi-enabled microcontrollers such as the ESP32, combined with biometric authentication, real-time scheduling modules, and cloud-based data logging, make it is possible to develop affordable home medication systems with advanced security and monitoring capabilities [6]. Furthermore, electronic sensors and IoT platforms enable automated data collection and analysis, improving the safety, reliability, and accuracy of medication management systems [7],[8].

To address these challenges, this paper proposes the Pill Dispensing and Monitoring System with Biometric Access (PDMS-BA), a three-layer IoT embedded system designed to overcome four major limitations of existing home medication solutions: missed medication doses, unauthorized access, limited caregiver monitoring and high system cost. Although the individual hardware components employed in this proposed system, namely the ESP32 microcontroller, fingerprint sensor, real-time clock (RTC), servo motors, and Google Sheets API, are commercially available, the novelty of the PDMS-BA lies in their integration into a unified, low-

cost embedded architecture that has not been previously reported in the literature. Specifically, the PDMS-BA combines per-user biometric authentication, RTC-based medication scheduling, servo-controlled compartment dispensing, and real-time cloud logging via Google Sheets on a single ESP32 platform without requiring proprietary mobile applications or subscription services.

The main contributions of this work are summarized as follows :

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. Development of an IoT-based real-time monitoring capability, in which medication dispensing events are automatically recorded to Google Sheets using the ESP32's onboard Wi-Fi, providing caregivers with remotely accessible medication records without requiring proprietary software.
3. Validation of a proof-of-concept prototype through breadboard testing and custom printed circuit board (PCB) fabrication, demonstrating the feasibility and cost-effectiveness of the proposed system.

The remainder of this paper is organized as follows. Section II reviews the related work. Section III describes the system architecture, hardware selection, and implementation. Section IV presents the experimental results and system evaluation. Finally, Section V concludes the paper and outlines future research directions.

II. RELATED WORKS

Automated medication management systems have been extensively studied, leading to the development of various design approaches while also highlighting existing limitations. Saran et al. [9] proposed an intelligent pill dispenser incorporating fingerprint authentication, servo mechanisms, and physiological monitoring sensors. Although comprehensive, the system was primarily designed for hospital environment and was not optimized as a cost-effective solution for home use.

Vaishnavi et al. [10] proposed an IoT-based medication reminder system using infrared (IR) sensors and Wi-Fi connectivity to improve medication adherence and communication with the caregivers. However, the system lacked user authentication, allowing unrestricted access to medications. Pang et al. [11] developed a cloud-based medication dispenser using a NodeMCU microcontroller and Firebase, where medication dispensing was scheduled and controlled remotely through the cloud. However, the system did not support user identification, making it unsuitable for multi-user environments.

Navandar et al. [12] integrated RFID-based authentication, RTC scheduling, and real-time Firebase logging, which improved user differentiation. However, RFID cards remain susceptible to loss, theft, or unauthorized sharing. Hassain et al. [3] proposed a voice-activated medication reminder system integrated with IoT-based health monitoring, which improved usability for elderly patients. However, environmental noise and speech impairments may reduce the reliability of voice recognition.

Recent studies published between 2024-2026 demonstrate a significant shift toward integrated digital healthcare solutions. Emerging trends include smart synchronization techniques [13] and artificial intelligence (AI)-driven predictive analytics [14] to improve medication adherence. In 2026, researchers demonstrated that IoT-based assistive systems could achieve 100% medical compliance under controlled conditions [15]. Nevertheless, narrative assessments indicate that medication adherence remains a global challenge despite advances in digital healthcare technologies[16]. Recent research also explored wristwatch-based therapeutic systems [17] and blockchain-enabled security frameworks [18] to enhance patient data security. Furthermore, current advances in healthcare automation focus on integrating biometric sensors [19] and developing scalable architectures for multi patient medication management [20].

Together, these studies show the increasing convergence of microcontrollers, sensing technologies, cloud platforms and intelligent alert mechanisms in medication management systems. However, significant challenges remain in providing secure per-user authentication, reliable medication intake verification, affordability, and ease of independent use within home environments.

The proposed Pill Dispensing and Monitoring System with Biometric Access (PDMS-BA) addresses these limitations by integrating fingerprint-based authentication, RTC-driven medication scheduling, servo-controlled dispensing, and real-time cloud logging through Google Sheets into a unified, low-cost embedded architecture. The five representative systems were compared based on key attributes, including the microcontroller platform, authentication method, multi-user capability, cloud integration and cost orientation. Table 1 summarizes this comparison.

Table 1
Comparative Summary of Existing Medication Dispensing Systems

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) was developed using an integrated hardware-software co-design methodology. The proposed system integrates embedded sensing, microcontroller-based processing, bio-metric authentication, and cloud communication within an IoT framework. The methodology comprises system modelling, hardware implementation, firmware development, and experimental validation to evaluate the operational reliability of the proposed system.

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, which serves as the central processing unit of the system.

3. Output and Cloud Layer: LCD display, buzzer, servo motors (×2), and Google Sheets cloud logging via Wi-Fi.

The system allows two registered users (User A and User B), each assigned a unique fingerprint ID and a dedicated pill compartment controlled by an individual servo motor. The operational flow consists of continuous RTC-based time monitoring, medication alert generation, biometric verification window, real-time logging action, and system reset. The complete control flow of the PDMS-BA is presented in Figure 1, which presents the system initialization, continuous RTC monitoring loop, medication alert phase, 30-second biometric verification window, outcome resolution ("Taken" or "Missed a Dose"), real-time Google Sheets logging, and return to the monitoring loop.

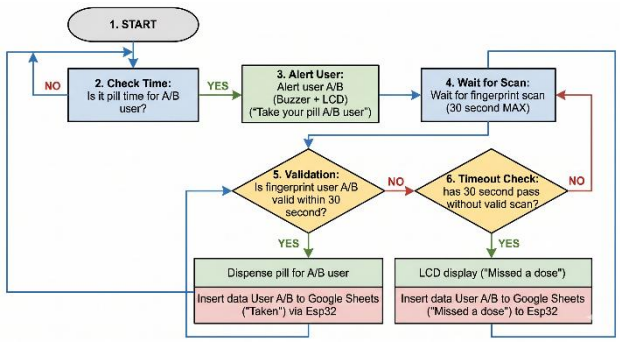


Figure 1. The flowchart of Pill Dispensing and Monitoring System with Biometric Access

B. Input Layers

1. Real-Time Clock (RTC) Module (DS1307)
   The system timing is maintained by a DS1307 Real-Time Clock (RTC) module. The RTC maintains accurate date and time information independently of the ESP32 power state, ensuring that scheduled medication alerts are triggered accurately even after power interruptions. The system stores five scheduled medication times for each user in separate arrays, which are continuously compared with the current RTC time during the main processing loop.
2. Fingerprint Sensor
   The fingerprint sensor provides the essential biometric security layer of the proposed system. When a scheduled medication time is reached, the system prompts the corresponding user to scan the registered fingerprint within a 30 second verification window. The sensor communicates with the ESP32 through a hardware serial interface and uses the Adafruit Fingerprint library to match scanned fingerprints against stored templates. User A is assigned Fingerprint ID 1 and User B is assigned Fingerprint ID 2. Each user is authorized to access only the assigned medication compartment.

C. Processing Layer

The processing layer is built around the ESP32 DEVKITV1 microcontroller, which serves as the central control unit of the PDMS-BA system. The ESP32 continuously compares the scheduled medication time with the current time obtained from the DS1307 RTC module. When a scheduled time is reached, the ESP32 activates the buzzer and LCD display while initiating a 30-second fingerprint verification process using the AS608 fingerprint sensor.

If fingerprint authentication is successful, the corresponding servo motor dispenses the medication, and the medication status ("Taken" or "Missed a Dose") is transmitted to Google Sheets in real-time via Wi-Fi using an HTTP GET request. A single embedded firmware developed using the Arduino IDE manages all sensing, authentication, dispensing, and cloud communication processes. The ESP32 microcontroller is written in C++ using Arduino IDE (Version 2.x) together with the key libraries listed in Table 2.

The Table 2
Libraries used in the ESP32 microcontroller

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 provides real-time visual feedback to the user. During normal operation, the display shows the current time. During medication alerts, it displays user-specific messages such as "Take your pill, User A." After verification, the LCD displays the medication status, either "Taken" or "Missed a Dose."
2. Buzzer:
   The buzzer (GPIO 27) generates an audible alarm whenever a scheduled medication time is reached. The alarms continues throughout the 30-second fingerprint verification window to ensure that users are notified they are not directly facing the device.
3. Servo Motors:
   Two servo motors are used as the physical dispensing mechanism, with GPIO 25 for User A and GPIO 26 for User B. Each servo controls a dedicated medication compartment. Following successful biometric authentication, the corresponding servo rotates to 180° to open the compartment and returns to 90° after dispensing, ensuring that the compartment remains locked until the authorized user is verified.
4. Google Sheets Cloud Logging:
   Upon completion of each medication event, the system determines whether the medication "Taken" or "Missed a Dose". The ESP32 constructs an HTTP GET request containing user's identity, date, time, and medication status, and sends it to a Google Apps Script Web App URL via Wi-Fi. The Google Apps Script processes the received parameters and automatically appends a new record to the designated Google Spreadsheet. This enables caregivers to remotely access real-time medication records through Google Sheets without requiring a dedicated mobile application or proprietary software.

E. System Operation Flow

The PDMS-BA system operates according to the following sequence:

1. Initialization: The ESP32 is powered on, and initializes the LCD, RTC, fingerprint sensor and servo motors before

establishing a Wi-Fi connection. System time is synchronized with NTP servers (pool.ntp.org) and subsequently written to the RTC.
2. Monitoring Loop: The system continuously polls the RTC and compares the current hour and minute with the predefined medication schedules for both users.
3. Alert Phase: When a scheduled medication time is detected, the buzzer is activated and the LCD displays a medication reminder for the corresponding user.
4. Verification Window: The system waits up to 30 seconds for the expected user to provide valid fingerprint scan.
5. Outcome Resolution:
   5.1. Successful Authentication: The corresponding servo motor dispenses the medication. The LCD displays "Taken" and the even is recorded in Google Sheets.
   5.2. Timeout (No Valid Authentication): The buzzer is deactivated, The LCD displays "Missed a dose," and the event is recorded in Google Sheets as a missed dose.
6. Return to Monitoring: The system clears the processed medication event and resumes continuous monitoring of the medication schedule.

F. Hardware Implementation

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

The system was first assembled and validated on a breadboard to verify communication among all hardware modules operating under different communication protocols, including I^2C for the LCD and RTC modules, UART for the fingerprint sensor and PWM for the servo motors. Following successful functional testing, the design was transferred to a custom printed circuit board (PCB) designed using the Proteus Design Suite. During PCB testing, a ground connection error that occurred during fabrication was identified and corrected using a jumper wire. This correction emphasizes the need for comprehensive design verification before PCB fabrication. Lesson learned: validate simulation before etching.

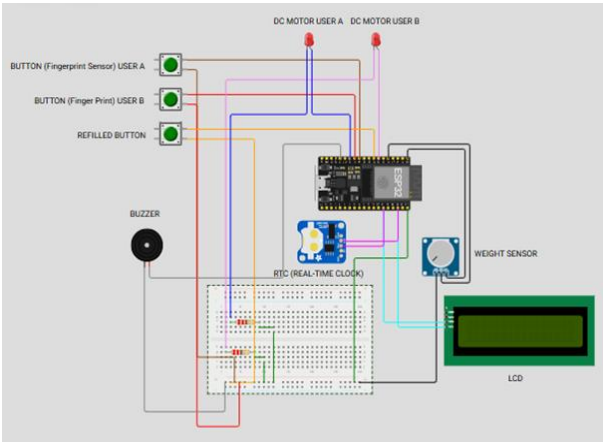


Figure 2. Schematic diagram of Pill Dispensing and Monitoring System with Biometric Access

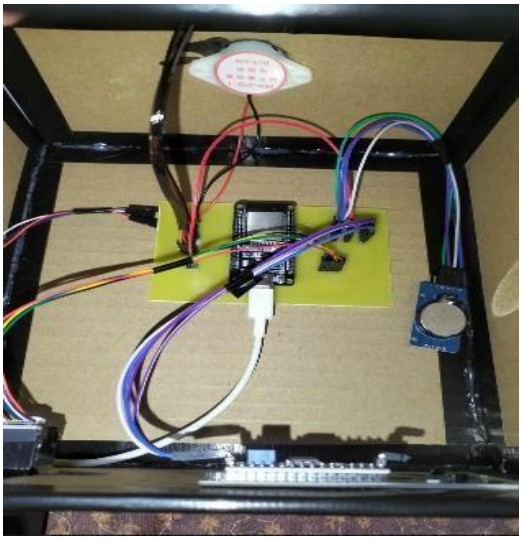


Figure 3. Top View of Pill Dispensing and Monitoring System with Biometric Access



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

The final prototype integrates two servo-controlled pill compartments, an LCD panel on the front panel, and a fingerprint sensor on the side panel, resulting in a compact and user-friendly device. Figure 3 and 4 show the fabricated hardware prototype. During the simulation stage, DC motors were used as output indicators to verify the control signals, while servo motors were utilized in the fabricated prototype to provide precise mechanical dispensing.

IV. RESULT AND DISCUSSION

The proposed system was verified through simulation testing prior to hardware implementation to evaluate the logic functionality, sensor response and dispensing mechanism. The simulation environment evaluated three main operation conditions: correct user authentication, real time medication monitoring and contactless dispensing activation

A. Simulation Analysis

Figure 5 shows the successful validation of user A during normal operation. The simulation demonstrates the system's ability to respond appropriately to user inputs based on the predefined medication schedule using the real-time clock (RTC), fingerprint sensor, buttons and potentiometer. The

RTC maintains the current time to trigger medication reminders. The fingerprint sensor ensures that only the authorized user access the medication. The button is used to confirm that the medication has been taken. Meanwhile the LCD display, buzzer and LEDs provide clear visual and audible feedback to guide and alert the user throughout the dispensing process.

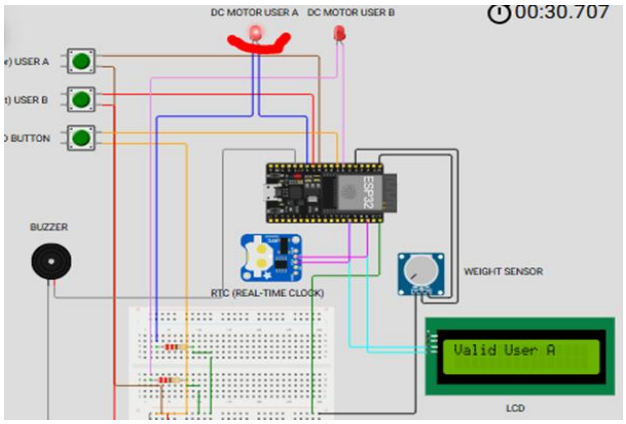


Figure 5. Simulation showing validation of user A.

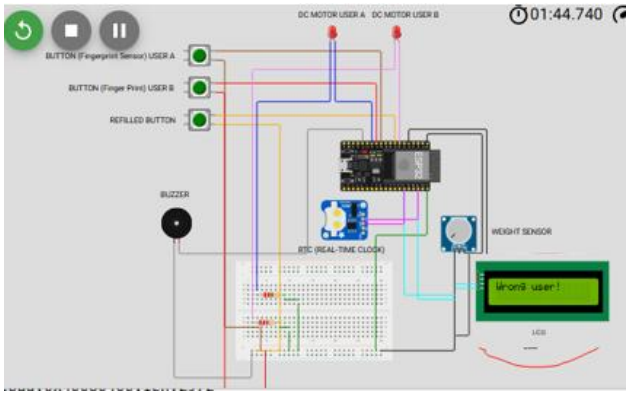
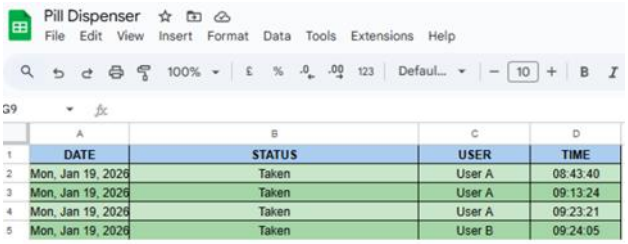


Figure 6. Simulation showing invalid user authentication.

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

The RTC-synchronized medication alert and dispensing system successfully detected scheduled medication times and dispensed the correct medication to the assigned user during the simulation. 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 the Date, Time, User and Status fields were correctly recorded for all test scenarios. The log output confirms the integrity of the recorded data, as each entry accurately reflects the corresponding user identity, timestamp, and medication status without omission or duplication. Furthermore, the delay between medication event resolution and its appearance in Google Sheets remained below five seconds under stable network conditions, demonstrating the suitability of the HTTP GET-based cloud logging approach for real-time home medication monitoring.


Pill Dispenser
File Edit View Insert Format Data Tools Extensions Help

	A	B	C	D
1	DATE	STATUS	USER	TIME
2	Mon, Jan 19, 2026	Taken	User A	08:43:40
3	Mon, Jan 19, 2026	Taken	User A	09:13:24
4	Mon, Jan 19, 2026	Taken	User A	09:23:21
5	Mon, Jan 19, 2026	Taken	User B	09:24:05

Figure 7. Sample Google Sheets Log Output

B. *Hardware Analysis*

Following successful simulation validation, hardware testing was conducted using the complete PDMS-BA prototype. The sensing accuracy, response time, dispensing performance, and cloud communication reliability were evaluated. The fingerprint sensor successfully enrolled and authenticated the registered users (User A and User B) while correctly rejecting unauthorized fingerprints as shown in Figure 8.



Figure 8. Output sample showing missed dose notification for User B

No false-positives authentication events were observed during testing. Under dry-finger conditions, minor sensitivity variations were observed, requiring users to reposition their fingers to achieve successful authentication. This behavior is a known limitation of optical fingerprint sensors. Nevertheless, the system achieved a True Positive Rate (TPR) of 100% for enrolled users and a False Acceptance Rate (FAR) of 0% over 30 controlled authentication trials. Under dry-finger conditions, the average number of scan attempts required for successful authentication increased from 1.0 to 1.8 attempts.

Table 3 summarizes the measured hardware performance. The average end-to-end response time from RTC schedule trigger to servo actuation was 3.2 seconds under stable WiFi conditions. Cloud logging achieved a 100% success rate across 40 medication events, while the dispensing mechanism also achieved a 100% dispensing success rate, with no missed servo actuations during the trial. In addition, the average network delay between medication event resolution and its appearance in Google Sheets remained below 5 seconds under stable network conditions. These Wi-Fi connection quantitative results demonstrate that the proposed PDMS-BA successfully achieves its primary design objectives of secure user authentication, timely medication 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 medication accordingly. If either condition (correct user or scheduled medication time) is not satisfied, the event is automatically logged as a "Missed Dose." Logging through Google Sheets captures every medication event in real time, providing caregivers with a reliable and accessible medication history record. It should be noted, however, that this logging reliability was observed only under stable Wi-Fi conditions. The system response under unstable or interrupted network connectivity was not formally evaluated. Under such conditions, cloud log entries may be delayed or lost entirely because the current implementation does not include an offline buffering or automatic retry mechanism. This limitation is discussed in the Future Work section. This seamless integration between the hardware platform and cloud loggings enables dependable monitoring, prompt notifications and systematic recording of medication history.

To place these results into context, Table 4 compares the PDMS-BA with the five systems reviewed in Section II. The PDMS-BA is the only system that combines fingerprint-based biometric authentication, per-user compartment control, cloud logging without requiring a proprietary application, and a low-cost embedded platform. Navandar et al. [12] provide user differentiation using RFID; however, their approach is susceptible to card loss or sharing and does not provide per-compartment medication dispensing. Overall, the comparison demonstrates that the proposed PDMS-BA effectively satisfies the combined requirements of security, usability, affordability, and remote medication monitoring for home healthcare 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 supports two registered fingerprint profiles and two independent servo-controlled medication compartments, reflecting the hardware configuration selected for proof-of-concept validation. The system can be expanded to support additional users by increasing the fingerprint template capacity (the AS608 sensor supports up to 127 templates), adding servo channels using a servo driver such as the PCA9685, and fabricating a multi-compartment pill tray. The additional hardware cost for each new user is approximately USD 3–5, primarily for the servo motor and compartment enclosure. Therefore, the proposed system is architecturally scalable at a relatively low incremental cost. Expanding the system would require modifications to the firmware to support additional users; however, this can be readily received because of the modular software architecture. Future hardware development will focus on extending the system to support more than two simultaneous users.

V. CONCLUSION

This paper has presented the design and implementation of the Pill Dispensing and Monitoring System with Biometric Access (PDMS-BA), an IoT-enabled embedded healthcare device developed to address the long-standing challenges of medication non-adherence, unauthorized medication access, and limited remote monitoring in home healthcare settings.

The proposed system was found to be reliable and functional across its major subsystems, including RTC-driven medication scheduling, fingerprint-based biometric authentication, servo-controlled dispensing, audio-visual alerting, and Google Sheets cloud logging. The proposed system contributes to the growing field of IoT-enabled healthcare automation by demonstrating that secure medication management and remote monitoring can be achieved using a low-cost embedded platform suitable for home and small-scale care centers.

Although the current prototype has successfully demonstrated its intended functionality, several limitations should be acknowledged. First, the system currently supports only two registered users, limiting its applicability to larger households or multi-patient care environments without firmware and hardware modifications. Second, dry-finger conditions reduce fingerprint recognition performance, which may affect elderly users or individuals with reduced skin moisture. Third, the cloud logging subsystem depends on stable Wi-Fi connectivity and currently does not provide an offline backup or local storage mechanism, which may result in lost medication records during network outages. Fourth, the dispensing mechanism depends on servo-controlled compartment opening rather than physical pill detection. Consequently, an empty compartment would still be recorded as a successful dispensing event, and the system cannot verify whether the medication has actually been retrieved. These limitations provide important directions for future development.

Future improvements may include incorporating RFID as a secondary authentication method to accommodate elderly users or individuals who experience difficulty with fingerprint recognition. In addition, light-dependent resistor (LDR) sensors may be integrated into each medication compartment to verify that the medication has been physically removed rather than simply opening the compartment. A voice playback module, such as the DFPlayer Mini, may also replace the buzzer to provide more personalized medication reminders and improve accessibility for visually or hearing-impaired users. Furthermore, integrating real-time mobile push notifications with the existing Google Sheets logging system would enable caregivers to receive immediate medication event updates directly on their smartphones.

To improve cloud logging reliability, a local SD card buffering mechanism should be implemented to temporarily store medication events during network outages and automatically synchronize the records with Google Sheets once connectivity is restored, thereby preventing data lost. Furthermore, the primary objective of the next hardware revision is to extend the PDMS-BA prototype beyond two

registered users by increasing the number of servo channels, expanding the fingerprint template capacity, and modifying the scheduling firmware to support a configurable number of users.

ACKNOWLEDGMENT

The authors sincerely thank Universiti Teknologi MARA (UiTM) for providing the facilities, technical resources, and academic support that made this project possible, and the Faculty of Electrical Engineering for their guidance throughout the system's development and evaluation.

CONFLICT OF INTEREST

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

AUTHOR CONTRIBUTION

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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