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Design and Development of an Automated Biometric-Authenticated Community Medication Dispensing System for Hypertensive and Diabetic Patients in Rural Primary Care

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***Abstract*—Sustained medication adherence is critical in the long-term management of hypertension and diabetes, yet many rural health units continue to rely on manual dispensing workflows and paper-based documentation that constrain efficiency, traceability, and continuity of care. This study aimed to design and develop an Automated Biometric-Authenticated Community Medication Dispensing System (ABACMeDS) to provide secure, scheduled, and accountable medication access for hypertensive and diabetic clients in a rural primary healthcare setting. A developmental research design guided systematic requirements analysis, system architecture formulation, hardware–software integration, prototype fabrication, and pilot validation. The completed system integrates facial recognition–based biometric authentication, a Raspberry Pi–driven embedded controller for localized edge processing, servo-actuated dispensing mechanisms, and a web-enabled transaction logging and inventory management module. Pilot implementation demonstrated reliable patient verification, controlled medication release aligned with stored prescription parameters, and real-time recording of dispensing transactions while maintaining operational stability under typical rural clinic conditions with intermittent connectivity and limited technical supervision. With a total material cost of ₱19,525.00, the prototype represents a financially feasible alternative to conventional hospital-based automated dispensing infrastructures. Through adapting established automation principles to decentralized healthcare environments, ABACMeDS strengthens medication governance, enhances documentation integrity, reduces administrative workload, supports structured dispensing intervals, and promotes responsible medication access. Future research should consequently evaluate longitudinal adherence outcomes, cross-site scalability, integration with electronic health information systems, and long-term sustainability across resource-constrained rural healthcare networks to determine the system's measurable impact on clinical outcomes, operational efficiency, and cost-effectiveness over time.**

***Index Terms*—Automated dispensing machine; Biometric verification; Facial recognition; Hypertension and diabetes; Rural health unit**

I. INTRODUCTION

Chronic non-communicable diseases (NCDs), such as hypertension and diabetes, have a significant impact on global health. In 2023, NCDs were responsible for approximately 74% of global deaths, with hypertension and diabetes being among the most common conditions necessitating long-term pharmacological management. Inconsistent medication adherence worsens clinical outcomes, leading to more hospitalizations and higher healthcare costs, especially in underserved and rural areas where access to healthcare is limited or irregular [1]. Despite advances in digital health technologies, medication adherence remains suboptimal, frequently falling below 50%, limiting effective disease control and prevention [2].

Automated medication dispensing technologies have primarily been studied in institutional healthcare settings, where their implementation has resulted in increased medication distribution efficiency, inventory management, and patient safety. A scoping review published in 2025 emphasizes the advantages of automated dispensing cabinets (ADCs), which streamline medication workflows, reduce medication errors, and boost operational efficiency by decentralizing dispensing near the point of care. These systems have been especially useful in settings with high prescription volumes and limited staffing resources [3].

According to recent research, automated medication dispensing systems can be successfully deployed in low-resource, community-based settings. A study conducted in Eswatini, for example, discovered that such systems improved access to antiretroviral therapy and NCD medications while also reducing dispensary congestion and wait times [4]. According to the study, gradually introducing medication classes and integrating them into routine clinical services improved the acceptability and use of these systems in real-world clinical workflows.

However, current literature focuses primarily on the feasibility and usability of these systems in institutional settings, while failing to address the engineering processes required to adapt them to rural community health environments. Most studies focus on implementation outcomes or user evaluations, rather than comprehensive designs that take into account local infrastructure limitations, user competencies, and specific community health needs [5].

This study aims to address these gaps by describing the design, and development of an Automated Biometric-Authenticated Community Medication Dispensing System (ABACMeDS) for hypertensive and diabetic (HPN/DM) patients the Municipality of Cantilan, Surigao del Sur. The study provides an overview of relevant technologies, engineering requirements, system architecture, fabrication challenges, and field deployment issues, with a focus on rural adaptation and biometrics integration. This paper describes the development process and provides a practical, evidence-based framework for deploying automated dispensing technology in resource-constrained environments.

II. RELATED WORK

Technological advancements continue to improve efficiency, accessibility, and service delivery in healthcare. This review examines research on automated and biometric-assisted community medication dispensing systems as a practical response to increasing patient demand and limited healthcare resources. For HPN/DM clients, consistent access to maintenance medicines is necessary for controlling their condition and avoiding complications. However, many rural health units (RHU) like in Cantilan, Surigao del Sur still rely on manual dispensing workflows, which lead to repeated client visits, crowding, and delays in documentation and service.

Medication continuity is necessary for effective chronic disease management, particularly among clients with hypertension and diabetes. Studies show that manual dispensing processes in primary care settings increase documentation time and elevate the risk of stock inaccuracies [6]. In RHU’s, these challenges often result in repeated visits by clients seeking maintenance refills, which contribute to crowding and delays in service delivery [7]. These workflow inefficiencies affect both the convenience of medication access for clients and the workload of healthcare staff.

Automated dispensing systems have been shown to reduce manual workload and support more consistent medication distribution practices. Automated dispensing solutions help standardize refill schedules, decrease patient waiting time, and improve documentation accuracy. These systems also enhance traceability, which supports ongoing monitoring and continuity of care [8]. In this study, the ABACMeDS integrates these principles into a barangay-level setting, where medication distribution is frequent and clinic congestion is commonly experienced.

Recent researches highlight the importance of automated drug dispensing systems in enhancing medication distribution and supporting adherence. As demonstrated in recent research, implementing an automated dispensing cabinet system in a surgical unit significantly improved drug distribution efficiency, reduced delays, and facilitated better stock management [9]. Similarly, automated dispensing not only reduced pharmacists' workload but also improved dispensing practices by minimizing the time spent on labeling and increasing accuracy [10]. In a similar vein, the perceptions and satisfaction of users in Al-Hasa hospitals, concluding that automated dispensing systems were well-received and contributed to increased patient safety and operational efficiency [11].

Local RHU often rely on handwritten logbooks and manual verification of medication release schedules, resulting in significant inefficiencies. Studies have shown that manual dispensing procedures slow service flow, increase waiting times, and lead to errors in documentation. For example, a study of rural primary care facilities in the Philippines found that geographic isolation, limited staff, and high patient volume contribute to delays in medication distribution [12]. Similarly, a study in the Philippines highlighted how staffing shortages and manual verification processes hindered efficient medication dispensing, with healthcare workers overwhelmed by administrative tasks [13]. Frequent repeat visits for the same service contribute to crowding and staff workload [14]. These findings emphasize the need for systems like ABACMeDS, which aim to reduce the burden of manual tasks and improve service delivery. These findings mirror existing conditions in Cantilan, where clients often return for free maintenance medicines before the recommended interval. ABACMeDS aims to reduce these repetitive visits by enforcing secure dispensing intervals and providing structured access.

In the Philippines, traditional paper-based recording methods, such as logbooks, are still widely used for documenting patient encounters and medication dispensing at the primary care and RHU level. This tradition is associated with data inconsistencies and risks of record loss, which has been identified as a barrier to reliable health information management and has motivated policy shifts toward electronic health records and interoperable health information systems [15].

The implementation of a biometric-based patient monitoring system in a local community clinic reported improved identity verification accuracy and reduced instances of duplicate service claims [16]. Similarly, a prototype dispensing cabinet for basic medicines in a rural barangay was found to help standardize release schedules when aligned with clear client records [17]. These local studies strengthen the relevance of applying a biometric dispensing model in community-based health services such as ABACMeDS.

III. METHODOLOGY

This study adopted a developmental research design to systematically design, construct, and preliminarily validate the ABACMeDS for deployment at the RHU of Cantilan, Surigao del Sur. Developmental research is particularly appropriate for healthcare engineering innovations, as it emphasizes iterative prototyping, contextual adaptation, and technical refinement rather than mere outcome measurement. The objective was to translate established principles in automated dispensing and biometric authentication into a cohesive, field-deployable system suited to rural primary healthcare conditions.

The methodological process unfolded in three interrelated stages: (1) requirements analysis and conceptual modeling, (2) system architecture design and hardware–software integration, and (3) prototype fabrication and functional validation. Each phase was guided by operational realities within the RHU, including infrastructure limitations, workflow constraints, and user diversity.

A. System Requirements and Conceptual Framework

The first phase focused on identifying operational requirements and defining core system modules. Observations of medication dispensing workflows at the RHU revealed recurring inefficiencies associated with manual identity verification, handwritten logs, and repetitive client visits for maintenance medications. These findings informed the development of a system capable of secure authentication, automated dispensing, and digital record management.

ABACMeDS was conceptualized around three primary functional components:

1) Biometric Authentication Module:

Facial recognition was selected as the principal verification mechanism due to its contactless nature and suitability for multi-user community settings. The module captures a facial image through an integrated camera and compares it with stored biometric templates. Only verified patients are granted dispensing access, thereby minimizing risks of misidentification or unauthorized retrieval.

2) Automated Dispensing Module:

A mechanically controlled dispensing subsystem releases prescribed maintenance medications according to pre-configured schedules and quantity limits. Automation reduces human intervention and enforces standardized dispensing intervals.

3) Transaction Logging and Audit Module:

Each dispensing event is recorded with patient identity, timestamp, and medication details. This structured log ensures traceability, enhances accountability, and supports inventory monitoring.

The overall conceptual integration of these modules is illustrated in Figure 1, which presents the functional relationship between authentication, dispensing control, and transaction recording.

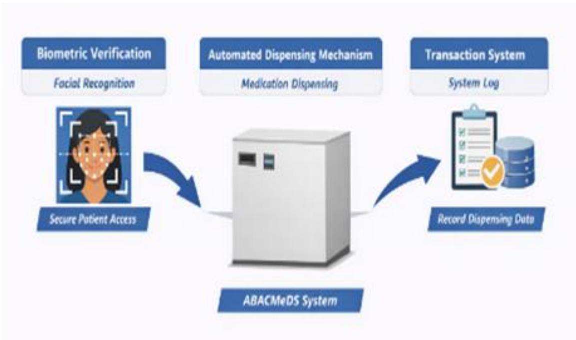

Fig 1: conceptual Design

B. System Architecture and Hardware Software Integration

Following conceptual definition, a modular system architecture was developed to separate user interaction, embedded processing, and administrative management layers. The system's architecture is shown in Figure 2.

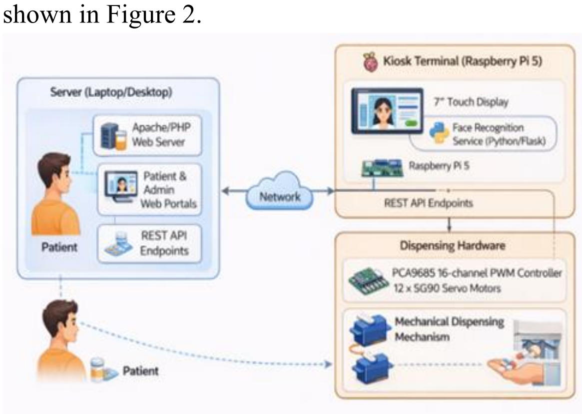

Fig 2: System Architecture

The architecture comprises two principal subsystems:

1) Kiosk Terminal Subsystem:

This user-facing unit integrates:

- A 7-inch touchscreen interface
- A Pi Camera Module for facial recognition
- A Raspberry Pi 5 (8 GB RAM) as the embedded controller
- A PCA9685 Pulse Width Modulation (PWM) driver
- SG90 servo motors for mechanical actuation

The Raspberry Pi performs local facial recognition processing and controls the dispensing mechanism. Edge processing ensures operational continuity even during intermittent internet connectivity, a critical consideration in rural healthcare environments. The PWM driver coordinates servo actuation, enabling controlled and sequential release of medication compartments.

2) Server and Management Subsystem:

The server hosts the web-based administrative portal and Application Programming Interface (API) endpoints. It manages patient records, prescription schedules, dispensing logs, and inventory data. Secure HTTP-based communication enables synchronization between the kiosk and centralized database while preserving modular independence. This architectural separation enhances scalability, maintainability, and operational resilience.

C. Operational Workflow

The procedural logic governing ABACMeDS operation is depicted in Figure 3, which outlines the system's stepwise workflow from authentication to dispensing completion.

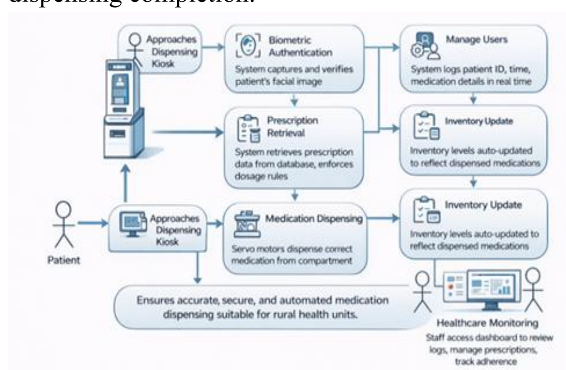

Fig 3: Process Flow

The workflow proceeds as follows:

1) The patient approaches the kiosk and initiates biometric authentication.

2) The system captures and processes a facial image, comparing it against stored templates.

3) Upon successful verification, the patient dashboard displays prescription eligibility.

4) The dispensing controller activates according to predefined medication schedules and dosage limits.

5) Medications are released sequentially if multiple prescriptions are assigned.

6) The transaction is logged in real time, recording identity, timestamp, and dispensed items.

7) The system resets to idle mode for the next user.
If authentication fails, dispensing access is denied and the event is recorded for security monitoring. This structured automation ensures dispensing accuracy, secure identity validation, and consistent inventory updates while reducing manual workload within the RHU.

D. Prototype Fabrication and Validation Procedures

After finalizing architectural specifications, a functional prototype was fabricated. Core hardware components were mounted within a protective enclosure to ensure durability and stability suitable for community healthcare deployment. Internal spatial adjustments were performed to optimize mechanical clearance among servo assemblies and to maintain organized cable routing.

Integration testing required iterative calibration of both biometric and mechanical subsystems. Facial recognition parameters were adjusted to accommodate indoor lighting variability typical of RHU facilities. Mechanical validation involved repeated actuation cycles to confirm dispensing accuracy, compartment alignment, and synchronization with digital logs.

System validation criteria included:
- Accurate biometric authentication prior to dispensing
- Reliable medication release per authorized command
- Real-time transaction recording
- Inventory synchronization between physical stock and database records

Through repeated testing and refinement, ABACMeDS achieved stable operational performance, demonstrating readiness for controlled field deployment.

IV. RESULTS AND DISCUSSION

This section presents the technical outcomes of the ABACMeDS development and situates them within the broader body of literature discussed earlier. Consistent with the concerns raised particularly medication non-adherence, workflow inefficiencies, and infrastructure limitations in rural health units, the results demonstrate how existing dispensing and biometric technologies were adapted into a cohesive, field-ready system. The discussion bridges empirical system performance with established research, ensuring alignment with contemporary developments in automated medication management.

A. Existing Technologies Relevant to the Development of ABACMeDS

The completed ABACMeDS prototype integrates three technological domains identified in prior studies: automated dispensing systems, smart medication adherence devices, and biometric authentication platforms [18], [19]. Each contributed distinct design principles that were localized for RHU Cantilan [20], [21].

1) Automated Medication Dispensing Systems (AMDS) in Hospital Settings

Automated Medication Dispensing Systems (AMDS) are widely implemented in tertiary hospitals to enhance medication safety, workflow efficiency, and inventory management [22], [23], [24]. These systems automate storage, retrieval, and tracking while integrating with electronic records for monitoring and reporting. A systematic review of automated dispensing cabinets (ADCs) found that their implementation reduces omitted and delayed doses while improving inventory control compared to manual systems [25], [26]. Similarly, hospital pharmacy evaluations reported significant reductions in dispensing errors following the integration of ADCs, barcode medication administration, and smart counters [27].

The results of the ABACMeDS pilot demonstrate that core AMDS principles, automation, traceability, and standardized dispensing intervals, can be translated to a rural primary care context. During prototype validation, mechanical dispensing accuracy was maintained across repeated cycles, and real-time logging ensured full traceability of each transaction.

Despite the benefits documented in institutional settings, AMDS adoption remains limited in rural facilities due to high acquisition costs and infrastructure demands. Traditional systems rely heavily on barcode verification and centralized electronic order entry, rather than biometric identity confirmation. Literature suggests that integrating facial recognition enhances secure access in decentralized environments where manual oversight is limited [28].

ABACMeDS adapts AMDS functionality by reducing architectural complexity while incorporating facial recognition as a primary authentication layer. This modification addresses identity security gaps that barcode-based systems may not fully resolve in community health contexts.

2) Smart Medication Dispensers for Home Use

Smart medication dispensers developed for home-based adherence have shown positive effects on scheduled medication intake, particularly through automated reminders and dose release mechanisms [21]. These systems improve adherence for patients with chronic conditions but are typically designed for single-user environments. As noted in prior research, most smart dispensers lack the capacity to serve multiple users within shared healthcare infrastructures [29].

ABACMeDS expands this concept from individual to community scale. The developed prototype supports multiple registered users, each authenticated through biometric verification before medication release. Unlike home dispensers, which prioritize reminder systems, ABACMeDS emphasizes access governance, dispensing control, and transaction traceability within a public health kiosk environment. The system thereby addresses a scalability limitation identified in adherence-focused smart dispenser research.

3) Biometric Authentication Technologies

Facial recognition technology has gained prominence in healthcare due to its contactless identification capability and high accuracy in patient verification [30]. Its integration into ABACMeDS demonstrated reliable authentication during controlled pilot testing, reducing reliance on manual identification and handwritten logs.

However, research consistently notes that facial recognition performance can be influenced by lighting variation and environmental inconsistency [31], [32]. During enclosure integration, calibration adjustments were required to optimize detection under indoor RHU lighting conditions. This experience aligns with documented environmental sensitivity in biometric systems.

Privacy and data protection considerations are also central to biometric deployment. Literature emphasizes the importance of safeguarding stored biometric data to ensure regulatory compliance and user acceptance [33]. Accordingly, ABACMeDS implements controlled database access and session-based authentication protocols to mitigate security risks.

4) Integration of Biometric Authentication with Automated Dispensing

Recent studies show that combining biometric authentication with automated dispensing significantly enhances patient safety by ensuring medication is released only to verified individuals [34]. Dual authentication models in institutional settings demonstrate improved dispensing accuracy and fraud prevention.

ABACMeDS operationalizes this integration within a rural community framework. Facial recognition serves as the primary gateway prior to mechanical actuation. During validation testing, dispensing commands were executed only after successful biometric confirmation, eliminating unauthorized retrieval attempts. This integration strengthens governance mechanisms in settings where manual supervision may be limited.

B. Development Process of ABACMeDS Based on Engineering Conditions

1) Technical Requirements

The design and implementation of ABACMeDS incorporate secure biometric access and automated medication management consistent with contemporary digital health technologies. The facial recognition module ensures that only registered clients access prescribed medications, aligning with recent dispensing innovations that utilize facial authentication to reduce incorrect retrievals [35]. Secure session handling and rapid verification mechanisms reflect broader digital health approaches that improve medication safety and minimize error rates [36].

The dispensing subsystem supports multi-medication management with prescription-based release controls. Automatic inventory updates synchronize physical stock with digital records, mirroring the efficiency and safety improvements reported in automated clinical systems [37]. The web-based management interface enables real-time prescription updates and audit trails, consistent with digital pharmacy frameworks emphasizing workflow transparency and oversight [38].

ABACMeDS utilizes a Raspberry Pi 5 (8 GB RAM) as an embedded controller, enabling local processing and reduced latency, an approach aligned with edge computing applications in healthcare [39]. Biometric capture through a Pi Camera Module and local recognition processing reflects low-cost, standalone implementations demonstrated in recent Raspberry Pi-based biometric systems [40]. Multi-channel actuation is managed via a PCA9685 PWM driver, consistent with established mechatronics designs for servo coordination [41].

A lightweight Flask-based service layer exposes device functions through HTTP endpoints, paralleling embedded instrumentation systems that integrate web-based control directly on edge devices [42]. Structured database storage and role-based access interfaces ensure auditability and supervision, as recommended in digital health architecture models [42], [39].

2) Material and Labor Costs

The finalized prototype required targeted hardware investment to ensure system reliability and biometric precision. Key components are presented in Figure 4, illustrating the integrated hardware configuration.

Fig 4: Hardware Components

The total material cost amounted to ₱19,525.00, detailed in Table I. The relatively modest cost demonstrates feasibility for rural deployment when compared to high-cost institutional AMDS infrastructure.

3) Fabrication and Installation

Fabrication prioritized durability and deployment readiness. As shown in Figure 5, a custom stainless-steel enclosure was constructed to protect internal components, while the medication canister utilized plywood for cost-effective structural support.

Table 1: Material and Labor Costs

Component	Unit Cost (₱)	Quantity	Subtotal (₱)
Raspberry Pi 5 + Set	12,000.00	1	12,000.00
PCA9685 Servo Driver	467.00	1	467.00
SG90 Servos	96.00	12	1,152.00
Buck Converter	480.00	1	480.00
12V Power Adapter	80.00	2	160.00
Pi Camera Module 3	2,409.00	1	2,409.00
7" Touch Display	2,237.00	1	2,237.00
Components (wires, etc.)	135.00	5	620.00

During installation, integration of biometric hardware within the enclosure required recalibration of recognition parameters.

Fig. 5: Stainless Steel Enclosure

Further optimization addressed lighting variability, consistent with embedded vision research emphasizing environmental tuning for performance stability [43]. Following full hardware–software integration, pilot testing verified dispensing reliability and authentication accuracy. The iterative refinement process aligns with broader IoT healthcare development trends emphasizing modular scalability and environment-aware calibration [44].

A. System Functions and Operational Performance

Biometric authentication improved secure access control, consistent with evidence that biometric methods enhance authentication reliability in IoT-enabled healthcare systems [45], [46]. Automated dispensing reduced manual handling, paralleling IoT-based medication dispensing implementations shown to minimize error rates [47].

Real-time transaction logging strengthened traceability and adherence monitoring, aligning with findings that IoT monitoring systems improve medication governance [48]. Operational workflow demonstrates structured authentication, dispensing, and logging sequences.

Biometric verification precedes dispensing activation, reducing reliance on manual checks and improving identity accuracy49 [49]. Automated actuation improves dispensing efficiency relative to manual systems [50]. Integrated logging and inventory tracking reflect digital pharmacy models that enhance traceability and stock control [51].

Ergonomic considerations, such as touchscreen positioning and simplified interface design, align with kiosk usability research emphasizing accessibility in public health environments [46]. Facial recognition calibration under varying lighting conditions reflects real-world deployment practices in embedded AI healthcare systems [52].

B. Barriers and Challenges Across the System Lifecycle

Development and deployment revealed challenges consistent with digital health implementation literature. Hardware sourcing delays and integration complexities required iterative adjustments. Environmental limitations such as intermittent power and unstable connectivity are recognized barriers in rural regions [53].

Additionally, digital literacy gaps and workflow adaptation challenges may hinder technology adoption if not supported through training and institutional alignment [53]. These findings underscore the necessity of comprehensive implementation strategies that incorporate technical support, modular scalability, and integration with broader health information systems.

V. CONCLUSION

This study presented the systematic design and development of the Automated Biometric-Authenticated Community Medication Dispensing System (ABACMeDS) as a context-sensitive solution to medication management challenges among hypertensive and diabetic (HPN/DM) clients in a rural health unit. Grounded in documented concerns regarding medication non-adherence, workflow inefficiencies, and documentation limitations in primary care settings, the system was engineered to integrate biometric authentication, automated dispensing, real-time transaction logging, and inventory synchronization within a modular and cost-conscious architecture.

The development and pilot validation of ABACMeDS demonstrate that secure facial recognition can be effectively combined with controlled mechanical dispensing to strengthen identity verification, enforce structured medication release schedules, and enhance traceability. The embedded edge-processing design supports operational continuity in environments with intermittent connectivity, while digital logging mechanisms replace paper-based documentation with structured, auditable records. Collectively, these features contribute to improved governance of medication distribution, reduced manual workload, and enhanced operational transparency in rural healthcare contexts.

Although technical feasibility has been established, long-term sustainability will depend on institutional readiness, user training, and integration with broader health information systems. Future research should therefore focus on longitudinal evaluation of medication adherence outcomes, scalability across multiple rural health units, and interoperability with electronic medical record platforms.

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