Intelligent Medication Management System

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Abstract

To address the widespread risk of medication non-adherence, this project introduces an IoT-based Medicine Reminder and Monitoring System designed for the elderly and those on strict regimens. The hardware is powered by an ESP32 microcontroller which coordinates a servo motor for automated dispensing, an OLED for visual status, and a buzzer coupled with a voice playback IC to provide clear, audible reminders for the patient to consume their medicine. Upon activation at a scheduled time, the device releases the required pills and immediately updates a digital inventory count, ensuring the physical supply remains synchronized with system records. On the software side, a Flask-based Python server facilitates communication between the device and a Flutter mobile application using REST APIs and a MySQL database. This allows caregivers to remotely manage schedules and receive instant notifications regarding patient compliance or low-stock alerts. By combining robust hardware, personalized voice prompts, and a seamless mobile interface, this system provides a cost-effective, scalable solution for improving patient safety and modernizing home healthcare.

Keywords: IoT-based Healthcare, Automated Medication Dispensing, Remote Patient Monitoring

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1. Introduction

In the contemporary healthcare landscape, the fusion of Internet of Things (IoT) technologies and intelligent systems has sparked a significant paradigm shift. Among the most critical hurdles in medical management is the consistency of medication adherence, particularly for the elderly managing chronic conditions. Factors such as cognitive decline and intricate dosing schedules often lead to patients inadvertently bypassing their routines, resulting in diminished treatment efficacy and increased hospitalizations. Conventional tools like basic alarms or manual organizers frequently fall short because they lack automated dispensing and real-time connectivity. To bridge this gap, the proposed Smart Medicine Reminder and Monitoring System offers a comprehensive ecosystem by synthesizing embedded hardware, robust backend architecture, and intuitive mobile interfaces. The system utilizes an ESP32 microcontroller to coordinate a servo motor for automated dispensing, while an OLED display and buzzer provide immediate status updates. To ensure the patient is effectively prompted, the system integrates a voice playback IC, delivering clear verbal instructions to consume the medicine at the exact scheduled time. This multi-sensory approach combining mechanical action, digitized inventory, and vocal reinforcement is supported by a Flask-based server and a Flutter mobile application, fostering a safer, more disciplined approach to patient care and remote caregiver oversight.

2. Literature review

The integration of IoT and automated systems has become a cornerstone in addressing medication non-adherence among elderly and chronic patients. This section reviews eight key studies relevant to smart medication dispensing and remote healthcare monitoring.

Siddiqha [1] developed an IoT-based real-time medicine reminder and dispenser specifically for elderly users. The system utilizes high-decibel buzzers, LCD interfaces, and cloud-based caregiver updates. The study emphasizes that for successful adoption, technical complexity must be replaced with a simple, one-touch interface to ensure ease of use for the target demographic.

Gargioni et al. [2] conducted a systematic review of pill and medication dispensers, identifying a critical "ingestion gap" where devices track dispensing but cannot confirm actual consumption. The authors advocate for intelligent verification methods and long-term evaluation metrics to overcome common mechanical limitations such as jamming and connectivity issues.

Peddisetti et al. [3] addressed the ingestion gap by synchronizing an IoT pill dispenser with a sensor-equipped "smart cup" to verify medication intake through fluid consumption. While this dual-device approach provides a holistic adherence profile, the research notes that it introduces higher system complexity, increased costs, and a heavy reliance on patient compliance.

Dayananda [4] proposed a smart pill expert system that prioritizes intuitive user interface (UI) design and intelligent backend logic. The study suggests that a user-centric software layer is essential to act as a digital assistant for elderly schedule management, effectively compensating for user confusion and ensuring dosage accuracy in IoT environments.

Sazid [5] explored the synergy between ESP-based hardware and a centralized web platform using REST APIs for remote management. While the system proved successful as a proof-of-concept for real-time monitoring and adherence logging, the author highlighted the need for advanced cybersecurity protocols and long-term clinical stress testing.

Faisal et al. [6] established an industry taxonomy by categorizing market-ready medication adherence products. Their survey identifies essential features—such as safety locks, connectivity, and notification systems—that serve as a vital guide for prioritizing core components in modern automated dispenser design.

Abhijith et al. [7] validated the use of the ESP32 microcontroller as a cost-effective and powerful hub for medical automation. By leveraging native Wi-Fi for seamless scheduling and caregiver alerts, the research provides a technical roadmap for time-based dispensing logic, though it notes a need for larger-scale validation in real-world domestic settings.

Murugan et al. [8] introduced an institutional hospital-grade automated drug dispenser utilizing RFID and GSM technologies for secure, high-volume distribution. While the system significantly reduces human error in clinical settings, the study highlights a trade-off between high-level institutional security and the affordability required for home-based consumer use.

In summary, the reviewed literature highlights a shift toward IoT-integrated solutions to bridge the gap between medication dispensing and actual patient adherence. However, challenges regarding system complexity, the "ingestion gap," and the balance between security and affordability persist, indicating a need for more streamlined, user-friendly, and verifiable dispensing technologies.

3. Objectives

This IoT-based automated medication management system centers on an ESP32-controlled hardware mechanism engineered to deliver precise dosages at strictly scheduled intervals while utilizing a multi-modal alert system synchronizing visual OLED displays, auditory buzzers, and voice playback modules to provide clear, spoken instructions that enhance accessibility for elderly users. This physical device is supported by a mobile platform that enables caregivers to remotely manage complex timetables and receive real-time notifications for synchronous oversight, ensuring immediate awareness of successful or neglected doses. By archiving every event in a comprehensive compliance log, the system allows healthcare providers to review long-term adherence patterns, while integrated inventory analytics trigger automated low-stock alerts to prevent treatment gaps. Ultimately, the project balances sophisticated data tracking with economic scalability, using cost-effective components and a simplified user interface to remain approachable for individuals with varying levels of technical literacy.

4. Methodology

The proposed IoT-Based Medicine Dispensing System is a sophisticated, IoT-enabled healthcare architecture engineered to automate pharmaceutical adherence and bolster patient safety. By synthesizing embedded hardware, a Python-based web server, and a cross-platform mobile interface, the project establishes a cohesive ecosystem for modern medication management.

The fundamental goal of this architecture is to transition from manual, error-prone dispensing to a fully automated, digitally logged process. Through the mobile application, a caregiver inputs essential parameters, including patient demographics, medication identifiers, precise dosage timestamps, and the initial inventory count. This data is transmitted via a Flask-based REST API to a centralized MySQL database for persistent storage.

On the hardware side, the ESP32 microcontroller maintains a persistent Wi-Fi connection to synchronize with the server. When the real-time clock aligns with a programmed schedule, the ESP32 triggers a multi-modal alert: activating a buzzer for auditory signalling, updating the OLED for visual instruction, and engaging a voice playback IC to deliver clear verbal reminders to the patient. Simultaneously, the system engages a servo motor to mechanically dispense the pill. Following the physical delivery, the system autonomously decrements the inventory count in the cloud and logs the event status. This closed-loop communication reinforced by vocal prompts ensures that caregivers receive immediate updates on compliance, while automated" low-stock" triggers prevent any interruption in the treatment regimen.

4.1. System Design

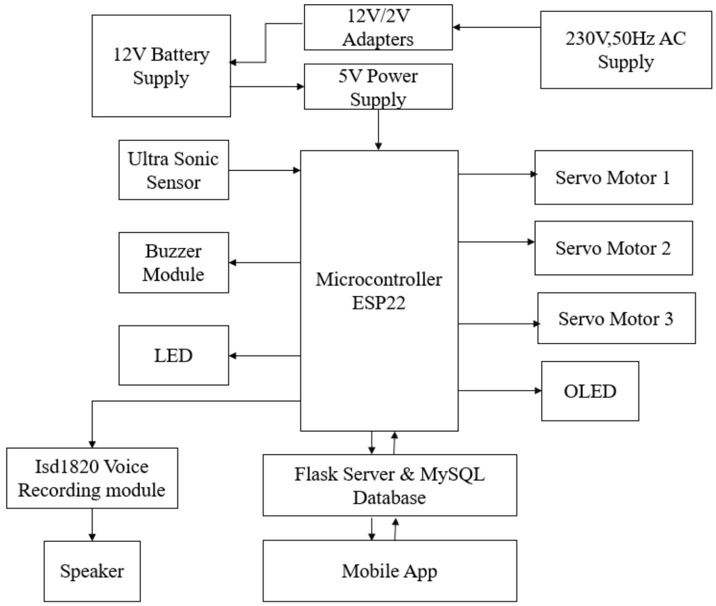

Figure 1: System Design

4.2. Hardware Layer

The hardware layer serves as the physical foundation of the system, comprising the integrated electronic circuitry and mechanical components essential for dispensing and signalling. At the core of this layer is the ESP32 microcontroller, which functions as the central logic execution unit. It interfaces directly with several peripheral modules, including the servo motor, auditory buzzer, OLED module, voice playback IC, status LEDs, and an ultrasonic sensor.

This layer is responsible for critical, real-time autonomous operations, including:

- **Temporal Synchronization:** Continuously comparing the local real-time clock (RTC) against the programmed medication timestamps retrieved from the cloud.
- **Multi-Modal Alerting:** Initiating the sequenced activation of the buzzer and visual indicators to engage the user.
- **Vocal Reinforcement:** Triggering the voice playback IC to broadcast pre-recorded verbal instructions, providing a clear and natural audio prompt that helps the elderly user identify exactly when to take their medicine.
- **Precision Dispensing:** Managing the pulse-width modulation (PWM) signals for the servo motor to execute controlled pill release.
- **Verification Sensing:** Utilizing the ultrasonic sensor to detect a change in distance when the medication is removed from the tray, thereby confirming the dispensing event through proximity-based verification.

By managing these low-level tasks, the hardware layer ensures that the physical objectives of the system are met with high accuracy and minimal latency.

4.3. Server Layer

Server Layer (Middleware and Data Management) The server layer acts as the intelligent bridge of the architecture, developed using the Flask web framework within a Python environment. This middleware facilitates the bidirectional communication between theESP32 hardware and the end-user mobile application via standardized RESTful APIs.

The server layer is tasked with the following administrative functions:

- **Data Persistence:** Organizing and storing complex medication schedules within a structured MySQL database. Inventory Analytics: Dynamically calculating and updating the remaining tablet count to prevent stock-outs.
- **Compliance Auditing**: Maintaining a chronological log of patient behavior, specifically categorizing events as" successful intake" or" missed dose."
- **API Orchestration:** Processing incoming JSON-formatted data packets from then ESP32 and routing the appropriate logic responses.
- **System Synchronization:** Ensuring that any change made on the mobile application is instantaneously reflected in the hardware's operational logic.

This layer is the" source of truth" for the system, ensuring that data remains consistent, secure, and accessible across all connected nodes.

4.4. Application Layer

Application layer represents the high-level interface of the system, featuring a cross-platform mobile application engineered using the Flutter framework and the Dart programming language. This layer is designed specifically for caregivers, providing a sophisticated yet intuitive dashboard for remote oversight and administrative control.

Through this interactive interface, users can perform several high-level tasks:

- **Identity Management:** Facilitating secure user registration and encrypted login protocols.
- **Patient Profiling:** Archiving and managing individual patient demographics and specific medical requirements.
- **Chronotherapeutic Configuration:** Defining specific pharmaceutical names, precise dosage timings, a recurring schedule. Inventory Initialization: Setting the baseline pill count and defining threshold limits for alerts.
- **Remote Surveillance:** Monitoring real-time adherence metrics and receiving automated push notifications for critical events, such as a missed dose or a low-stock warning.

Ultimately, the application layer transforms raw backend data into actionable insights, empowering caregivers with the tools necessary for effective remote patient super vision.

5. Conclusion

The IoT-Based Medicine Reminder and Monitoring System optimizes pharmacological adherence by integrating an ESP32 microcontroller, a Flask backend, and a Flutter mobile app. This architecture automates medication scheduling and dispensing while utilizing a multi-layered alert system—comprising visual OLED updates, auditory buzzers, and a voice playback IC for clear verbal instructions—to ensure elderly patients are prompted effectively. By maintaining real-time digital inventory and tracking dispensing events through a MySQL database, the system ensures proactive refill notifications and accurate record-keeping for seamless care.

Ultimately, this project bridges the gap between hardware automation and remote digital oversight to enhance patient safety. By providing caregivers with transparent compliance data and utilizing vocal reinforcement to reduce the risks of missed doses, the system offers a dependable, modern, and highly accessible approach to medication management.

6. Result and Discussion

The results of the IoT-Based Smart Medicine Reminder and Monitoring System with Voice Command demonstrate significant progress toward achieving the primary objective of improving medication adherence and enabling remote monitoring. The system successfully integrates embedded hardware, mobile application technology, and server-side processing to create a reliable platform for automated medicine reminders and monitoring.

Through implementation and testing, the hardware components such as the ESP32 microcontroller, servo motor, ultrasonic sensor, OLED display, buzzer, and LED indicators were effectively integrated to perform coordinated operations. The ESP32 acts as the central controller, managing communication between the server and the hardware modules. The servo motor mechanism successfully dispenses the medicine when the scheduled event is triggered. The ultra-sonic sensor detects whether the medicine has been taken by the patient, while the LED indicators identify the active medicine compartment. The OLED display provides clear information about the medicine name, helping the user identify the correct medication.

The backend system developed using Flask server architecture with a MySQL database successfully manages medication schedules, tablet counts, and patient compliance records. The ESP32 retrieves schedule information through REST API communication, enabling real-time synchronization between the hardware device and the server. During testing, the system demonstrated reliable communication and timely data exchange between the mobile application, server, and the hardware module.

The Flutter-based mobile application allows caregivers to configure medication schedules, set tablet counts, and monitor medication status remotely. The application successfully displays alerts when medicines are dispensed, missed, or when the tablet count reaches zero. The notification system ensures that caregivers remain informed about the patient's medication adherence in real time.

An additional enhancement in the system is the integration of voice command functionality, which improves accessibility and user interaction. Through voice commands, the patient can interact with the device to confirm medication intake or request system information. This feature is particularly beneficial for elderly users who may have difficulty interacting with mobile interfaces or physical buttons. The voice-based interaction increases the usability of the system and makes the medication management process more convenient.

Testing results indicate that the system operates with minimal delay in triggering reminders and dispensing medication. The synchronization between the mobile application, server, and hardware device ensures consistent performance and accurate tracking of medication events. The IR-based confirmation mechanism further enhances reliability by verifying whether the patient has taken the medicine.

Overall, the developed system demonstrates the feasibility of combining IoT technology, mobile applications, server-based databases, and voice-assisted interaction for intelligent medication management. The system provides an effective solution for monitoring medication adherence, reducing the risk of missed doses, and supporting caregivers in supervising patient treatment remotely. The results confirm that the proposed system can serve as a practical and scalable healthcare assistance tool for home-based patient monitoring.

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