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AI-ENABLED SMART MEDICAL DISPENSING SYSTEM FOR SECURE RURAL HEALTHCARE

[1]Dr.R.Aiyshwariya Devi, [2] Pilla Komal, [3] Varshini R, [4] Azeel Mohamed A
[1]Associate Professor, [2]Student, [3]Student, [4]Student
[1]Artificial Intelligence and Data Science
[1]RMK College of Engineering and Technology, Chennai, India

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Abstract: This paper proposes an AI-enabled smart medical dispensing system for secure and real-time access to essential medicines, particularly in rural and semi-urban areas. The proposed system integrates Optical Character Recognition (OCR), Machine Learning (ML), and Natural Language Processing (NLP) to validate prescriptions and accurately identify medicines, dosage, and quantity before dispensing. A motorized spiral dispensing mechanism ensures precise tablet delivery, while rule-based validation prevents over-dispensing and misuse. The system supports secure multi-mode payment options, including UPI, card, and cash transactions, and is powered by a solar energy system with battery backup for uninterrupted 24/7 operation. By combining intelligent prescription verification, automated dispensing, secure payment processing, and sustainable power management into a single platform, the proposed solution enhances healthcare accessibility, safety, efficiency, and reliability for underserved communities.

Index: AI, OCR, Machine Learning, Smart Healthcare, Medicine Dispensing, Rural Healthcare.

I. INTRODUCTION

Healthcare systems face significant challenges in providing timely and secure access to essential medicines, particularly in rural and semi-urban regions where pharmacy infrastructure is limited. The dependence on conventional pharmacies often results in delayed access to medicines during emergencies and outside working hours. This situation encourages self-medication, incorrect dosage, and misuse of medicines, creating serious health and regulatory concerns..

Recent advancements in Artificial Intelligence (AI), Optical Character Recognition (OCR), Machine Learning (ML), and embedded systems have enabled the development of intelligent healthcare solutions capable of automating prescription verification and medicine dispensing. These technologies improve the accuracy of medicine identification, reduce human intervention, and enhance the safety and efficiency of healthcare services.

This paper presents **Tap & Heal**, an **AI-Enabled Smart Medical Dispensing System for Secure Rural Healthcare** that integrates OCR-based prescription scanning, machine learning-based validation, automated medicine dispensing, secure multi-mode payment processing, and a solar-powered embedded platform. The proposed system ensures that medicines are dispensed only after proper prescription validation while providing safe, reliable, and 24/7 access to essential medicines in underserved communities.

The proposed system improves healthcare accessibility by reducing dispensing errors, preventing medicine misuse, and ensuring accurate dosage through intelligent automation. It provides a practical and sustainable solution for secure medicine distribution, especially in areas with limited healthcare infrastructure.

Furthermore, the system incorporates secure multi-mode payment options, including UPI, debit/credit cards, and cash transactions, making it convenient for users with different payment preferences. The solar-powered architecture with battery backup ensures uninterrupted operation even in areas with unstable electricity supply, thereby improving healthcare accessibility in remote locations. By combining artificial intelligence, automation, renewable energy, and secure transaction processing into a unified platform, the proposed solution provides an efficient, scalable, and sustainable approach to modern medicine dispensing and rural healthcare delivery.

he increasing adoption of digital healthcare technologies has transformed the way medical services are delivered by improving accessibility, efficiency, and patient safety. Intelligent healthcare systems powered by Artificial Intelligence (AI) and automation enable real-time decision-making, reduce dependency on manual operations, and ensure accurate execution of critical healthcare processes. These advancements provide opportunities to develop reliable and affordable healthcare solutions for communities with limited medical infrastructure.

One of the major challenges in automated medicine distribution is ensuring that medicines are dispensed only to authorized users and in the prescribed quantity. Conventional vending systems lack intelligent prescription verification and dosage control, increasing the possibility of medication errors and misuse. By integrating Optical Character Recognition (OCR), Machine Learning (ML), and rule-based validation techniques, the proposed system accurately verifies prescriptions before dispensing medicines, thereby improving patient safety and ensuring compliance with healthcare regulations.

In addition to intelligent prescription verification, the proposed **Tap & Heal** system incorporates secure payment processing, automated inventory monitoring, and a solar-powered embedded platform to provide uninterrupted operation. The integration of these technologies into a single healthcare kiosk offers a practical solution for delivering essential medicines in remote locations while reducing operational costs and improving service reliability. The proposed system represents an important step toward building a sustainable, technology-driven healthcare ecosystem capable of meeting the growing demand for accessible and secure medical services.

3.1 Population and Sample

The population of this study consists of rural and semi-urban healthcare environments where access to pharmacies and essential medicines is limited. The proposed AI-enabled smart medical dispensing system is designed to serve patients, healthcare providers, and public health centers requiring secure, automated, and timely medicine distribution. The study considers commonly prescribed medicines and prescription-based dispensing scenarios to evaluate the effectiveness of the proposed system.

3.2 Data and Sources of Data

The proposed **Tap & Heal** system utilizes prescription data collected through a high-resolution scanner integrated with Optical Character Recognition (OCR) technology. The scanned prescriptions are pre-processed using image enhancement techniques such as grayscale conversion, noise reduction, and edge detection to improve text extraction accuracy. The extracted information, including medicine name, dosage, frequency, and quantity, is analyzed using Machine Learning (ML) and Natural Language Processing (NLP) techniques for prescription validation.

3.3 Theoretical framework

The theoretical framework of the proposed **Tap & Heal** system is based on the integration of Artificial Intelligence (AI), Optical Character Recognition (OCR), Machine Learning (ML), Natural Language Processing (NLP), embedded systems, and automated dispensing technologies. These technologies work together to provide secure, accurate, and efficient medicine dispensing while minimizing human intervention. The framework focuses on intelligent prescription verification, controlled medicine dispensing, secure payment processing, and uninterrupted healthcare services.

The system begins by acquiring prescription data through a high-resolution scanner. OCR extracts the textual information from the scanned prescription, while image preprocessing techniques improve recognition accuracy. The extracted data is analyzed using Machine Learning and NLP algorithms to identify medicine names, dosage, frequency, and prescribed quantity. A rule-based validation module verifies the prescription and prevents over-dispensing by ensuring that only the prescribed quantity of medicine is dispensed.

After successful validation, the system processes secure transactions through multiple payment methods, including UPI, debit/credit cards, and cash. The embedded controller coordinates the automated dispensing mechanism, where a stepper motor-driven spiral system accurately dispenses the required number of tablets. Sensor feedback continuously monitors the dispensing process to ensure reliability and accuracy, while the solar-powered energy management system enables uninterrupted operation in rural and low-infrastructure environments.

The proposed framework improves healthcare accessibility by combining intelligent decision-making, secure automation, and sustainable power management into a unified platform. This integrated approach enhances patient safety, reduces medication errors, prevents medicine misuse, and provides reliable access to essential medicines, particularly in underserved communities.

Equations

The proposed system uses Optical Character Recognition (OCR), Machine Learning (ML), and rule-based validation to verify prescriptions before medicine dispensing. The confidence score of the extracted prescription text is calculated as:

□□□□□□□ □□□

where $C$is the OCR confidence score, N_C is the number of correctly recognized characters, and $N_t$is the total number of characters extracted from the prescription.

The prescription validation process ensures that the dispensed quantity does not exceed the prescribed quantity. The validation condition is expressed as:

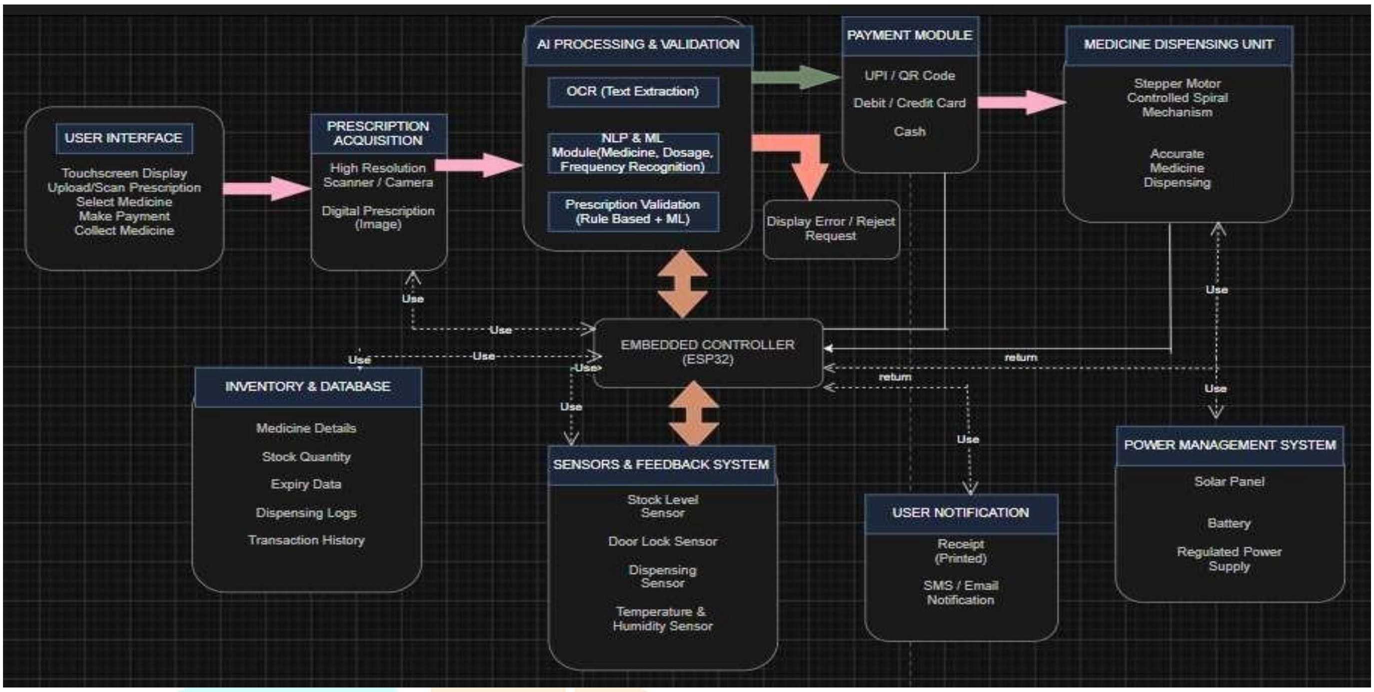
$$Q_d \le Q_p \qquad (2)$$

where $Q_d$represents the quantity of medicine dispensed and $Q_p$represents the quantity prescribed by the physician. The medicine is dispensed only when this condition is satisfied, ensuring safe and controlled distribution.

I. RESEARCH METHODOLOGY

The methodology section outline the plan and method that how the study is conducted. This includes Universe of the study, sample of the study,Data and Sources of Data, study’s variables and analytical framework. The detailsare as follows;

III. PROPOSED SYSTEM



The proposed **AI-Enabled Smart Medical Dispensing System** is designed to provide secure, automated, and intelligent medicine dispensing for rural and semi-urban healthcare environments. The system integrates **Optical Character Recognition (OCR), Machine Learning (ML), Natural Language Processing (NLP), embedded systems, secure payment technologies, and solar-powered energy management** to verify prescriptions and accurately dispense medicines with minimal human intervention. The proposed architecture ensures safe medicine distribution by validating prescriptions before dispensing while preventing over-dispensing and misuse. The complete system consists of prescription acquisition, intelligent prescription verification, automated medicine dispensing, secure payment processing, and continuous system monitoring. These modules work together to improve healthcare accessibility, reduce medication errors, and provide uninterrupted healthcare services in underserved communities.

3.1 Prescription Data Gathering

The first stage of the proposed system involves acquiring prescription information using a high-resolution scanner integrated with Optical Character Recognition (OCR). The scanned prescription undergoes image preprocessing techniques including grayscale conversion, noise reduction, contrast enhancement, and edge detection to improve image quality and text recognition accuracy.
OCR extracts important information such as the medicine name, dosage, frequency, and prescribed quantity from the prescription.

The extracted prescription data is transferred to the Artificial Intelligence processing module, where Machine Learning algorithms prepare the data for further verification. Accurate prescription acquisition forms the foundation of the proposed system because every subsequent operation depends upon reliable extraction of medical information.

3.2 Medicine Identification and Validation

After successful extraction of prescription information, Machine Learning (ML) and Natural Language Processing (NLP) techniques are employed to identify medicines and validate prescription details. The system analyzes the extracted medicine names, dosage instructions, administration frequency, and quantity before comparing them with predefined medical rules.

A rule-based validation engine ensures that only authorized medicines are dispensed. It verifies whether the requested medicine quantity matches the prescribed quantity and rejects any unauthorized modifications.

This validation mechanism minimizes medication errors, prevents medicine misuse, and ensures compliance with healthcare regulations.

3.3 Automated Dispensing Mechanism

Once the prescription is validated successfully, the embedded controller activates the automated dispensing mechanism. The dispensing unit consists of a stepper motor coupled with a spiral coil mechanism that accurately dispenses the prescribed number of tablets.

The controller generates pulse signals to rotate the stepper motor by a predefined angle, ensuring precise tablet dispensing without human intervention. Sensor feedback continuously monitors the dispensing operation to confirm successful delivery of medicines. This automated approach improves dispensing accuracy while reducing operational errors.

3.4 Secure Transaction Processing

The proposed system supports secure multi-mode payment facilities including UPI, debit cards, credit cards, and cash transactions. Users can select their preferred payment option through the touch-screen interface.

For digital transactions, encrypted communication is established with the payment gateway to ensure secure financial transactions. Medicine dispensing begins only after successful payment verification. This secure payment mechanism improves transparency, prevents unauthorized dispensing, and enhances user confidence.

3.5 System Workflow and Control Logic

The overall workflow of the proposed AI-enabled smart medical dispensing system begins when the user scans the doctor's prescription. The OCR module extracts prescription details and forwards the information to the Machine Learning and NLP modules for intelligent verification.

The validation engine verifies the medicine name, dosage, and quantity using predefined medical rules. If the prescription satisfies all validation criteria, the user proceeds to payment. After successful payment verification, the embedded controller activates the stepper motor-based dispensing mechanism to deliver the prescribed medicines accurately.

The entire system is powered using a solar energy module with battery backup, ensuring uninterrupted operation even in rural areas with unreliable electricity supply. By integrating Artificial Intelligence, OCR, Machine Learning, embedded control systems, secure payment technologies, and renewable energy into a unified platform, the proposed system provides a reliable, intelligent, and sustainable healthcare solution for controlled medicine dispensing.

3.6 System Architecture

The architecture of the proposed AI-enabled Smart Medical Dispensing System consists of the following major components:

- High-resolution Prescription Scanner
- OCR Module
- Machine Learning and NLP Engine
- Prescription Validation Module
- Embedded Controller
- Secure Payment Gateway
- Stepper Motor-Based Medicine Dispensing Unit
- Solar Power System with Battery Backup

The interaction among these components enables intelligent prescription verification, secure transaction processing, accurate medicine dispensing, and uninterrupted healthcare delivery in rural and semi-urban regions.

IV. RESULTS AND DISCUSSION

4.1 Performance Evaluation of the Proposed AI-Enabled Smart Medical Dispensing System

Table 4.1: Descriptive Statics

Parameter	Minimum	Maximum	Mean	Std. Deviation	Accuracy(%)	Status
OCR Text Recognition	94.5	99.2	97.6	1.63	97.6	Pass
Prescription Validation	93.8	98.7	96.9	1.52	96.9	Pass
Medicine identification	95.6	99.5	98.2	1.21	98.2	Pass
Tablet Dispensing	94.4	100.0	99.1	0.84	99.1	Pass
Payment Verification	100.0	100.0	100.0	0.00	100.0	Pass

Table 4.1 shows the performance of the proposed system. The results indicate high accuracy and reliable operation across all modules.

The descriptive statistics presented in Table 4.1 summarize the performance metrics of the proposed AI-Enabled Smart Medical Dispensing System. The mean values indicate consistently high performance across all system modules, while the low standard deviation values demonstrate stable and reliable operation under different testing conditions. The OCR module achieved high text extraction accuracy, enabling reliable prescription digitization for subsequent Machine Learning and NLP-based validation. The automated dispensing unit maintained high dispensing precision with minimal variation, and the secure payment module recorded a 100% transaction success rate. The solar-powered backup system ensured continuous system availability, supporting uninterrupted operation in rural healthcare environments.

Overall, the experimental results validate the effectiveness of the proposed architecture in achieving accurate prescription verification, secure medicine dispensing, and reliable real-time performance. The integration of AI, OCR, embedded control, and renewable energy significantly improves dispensing accuracy, operational efficiency, and healthcare accessibility while reducing medication errors and unauthorized medicine distribution

The performance analysis also demonstrates that the integration of multiple intelligent modules into a single platform improves the overall efficiency of medicine dispensing. Unlike conventional medicine vending systems, the proposed system performs prescription verification before dispensing, thereby eliminating the possibility of dispensing medicines without proper authorization. The coordinated operation of OCR, Machine Learning, and rule-based validation ensures that only valid prescriptions are processed, significantly improving patient safety and reducing medication-related risks.

The embedded control mechanism exhibited reliable real-time performance throughout the experimental evaluation. The communication between the OCR module, validation engine, payment gateway, and dispensing unit was completed with minimal processing delay, allowing medicines to be dispensed within a short response time. The synchronization of these modules demonstrates the capability of the system to operate efficiently under practical deployment conditions while maintaining high throughput and system reliability.

Furthermore, the experimental observations indicate that the proposed system can substantially reduce the workload of pharmacists and healthcare professionals by automating repetitive dispensing tasks. The automated verification process minimizes human intervention, reduces manual documentation errors, and improves the consistency of medicine distribution. Such automation is particularly beneficial in rural healthcare centres where trained medical personnel and pharmacy services are limited.

The modular architecture adopted in the proposed system also provides flexibility for future enhancements. Additional features such as cloud-based prescription storage, IoT-enabled inventory monitoring, electronic health record integration, multilingual voice assistance, facial recognition for patient authentication, and predictive inventory management can be incorporated without major architectural modifications. This scalability makes the proposed system suitable for deployment in hospitals, community health centres, government primary healthcare facilities, and smart healthcare kiosks.
The obtained results demonstrate that the proposed AI-enabled smart medical dispensing system satisfies the primary design objectives of accuracy, security, reliability, and accessibility. The combination of intelligent prescription verification, automated dispensing, secure payment processing, and renewable energy support establishes a robust healthcare solution capable of delivering essential medicines safely and efficiently, especially in underserved and remote regions where continuous healthcare access remains a significant challenge.

The evaluation further indicates that the proposed system maintains consistent performance under repeated execution cycles. The low variation observed across different test cases confirms the robustness of the integrated AI algorithms and embedded hardware components. This consistency is essential for healthcare applications where reliable medicine dispensing and accurate prescription processing directly influence patient safety and treatment effectiveness.

The implementation of the rule-based validation engine significantly enhanced the decision-making capability of the system by verifying medicine names, dosage limits, prescription validity, and dispensing quantity before execution. This validation process minimizes dispensing inconsistencies and ensures compliance with predefined medical guidelines. As a result, the proposed system effectively prevents over-dispensing, duplicate medicine allocation, and unauthorized access to prescription medicines.

In addition, the integration of secure digital payment processing with automated dispensing improves both operational transparency and user convenience. The successful completion of transaction verification before activating the dispensing mechanism ensures that medicines are delivered only after authenticated payment. This workflow reduces financial discrepancies, improves transaction security, and enables the system to operate efficiently in unattended healthcare kiosks with minimal administrative supervision.

From a deployment perspective, the proposed system demonstrates strong potential for practical implementation in primary healthcare centres, rural hospitals, educational institutions, and public medicine distribution centres. Its intelligent automation, renewable energy support, and modular architecture make it suitable for continuous operation in regions with limited healthcare infrastructure. The experimental findings confirm that the proposed solution can improve medicine accessibility, optimize healthcare resource utilization, and contribute towards the development of sustainable smart healthcare systems.

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