Development of Image Processing Technology in the Design of Smart Medicine Cabinets for Hospitals

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***Abstract*—In the context of increasing pressure on healthcare systems, the application of automation and artificial intelligence (AI) has become a key solution for optimizing healthcare delivery processes. This study proposes the design of a smart medicine cabinet system based on a microcontroller platform, such as STM32, integrated with IoT and AI technologies to automate medication dispensing. The system employs a camera and authentication algorithms, including facial recognition or PIN-based verification, in combination with image processing techniques to ensure that medication is delivered to the correct patient while also supporting the assessment of the patient's current condition. Through appropriate model training, the cabinet is expected to identify the patient's health status by analyzing visual features extracted from images, particularly skin-related characteristics. With a hardware architecture comprising servo motors for compartment control, an alarm speaker, and a display interface, the smart cabinet not only reminds patients to take their medication but also assists healthcare personnel in remotely managing treatment data via a mobile application. Experimental results indicate that the system operates stably, minimizes medication-related errors, reduces the distance between hospitals and patients, and is particularly beneficial for supporting elderly individuals and preventing cross-infection in hospital environments.**

Keywords-component; Smart medicine cabinet, artificial intelligence, facial recognition.

I. INTRODUCTION

Successive industrial revolutions—from steam-powered mechanization to the present era of cyber-physical systems—have driven transformative advances in efficiency, productivity, and occupational safety across nearly every sector of the global economy. The healthcare sector, although traditionally human-centered, has not remained outside this trend. In fact, the shock of the COVID-19 pandemic accelerated the adoption of technology in medicine at an unprecedented pace, creating the foundation for breakthroughs that are now permeating the entire continuum of healthcare delivery. According to the World Health Organization (WHO) by 2030, individuals aged 65 years and older are expected to account for approximately 17.5% of the global population [1]. This substantial demographic shift is placing significant pressure on healthcare systems for older adults, particularly in countries experiencing rapid population aging, such as Japan [9]. Meeting this rapidly growing demand has become a major challenge for many nations, and Vietnam is a representative example. In Vietnam alone, outpatient departments nationwide recorded more than 186 million visits in 2024 [2], a clear indication of rising public expectations and the increasing burden on hospital infrastructure. Overcrowding at central hospitals, which often receive hundreds of new cases each day, not only causes inconvenience and health risks for patients and increases pressure on healthcare staff, but may also lead to delayed treatment initiation and a higher probability of adverse clinical events throughout the course of therapy. Therefore, the design of automated medication dispensing and patient monitoring models is of critical importance in order to enhance service capacity and ensure continuity in the care process.

Artificial intelligence (AI) has become an important factor, not only in improving the efficiency of diagnosis and treatment, but also in optimizing operational processes and ensuring quality in hospitals. Beyond diagnostic applications, AI also underpins next-generation continuous patient monitoring systems, automated medication verification, inventory optimization, and intelligent drug dispensing workflows, thereby reducing preventable errors and freeing healthcare personnel to focus on higher-value direct care activities. In addition, AI can support continuous monitoring of patient condition throughout treatment, whether in hospitals or at home. This not only improves convenience for all stakeholders, but also ensures close and continuous connectivity between physicians and patients.

Building on this momentum, the present study addresses two persistent challenges in Vietnamese hospitals: reliable patient monitoring and error-free medication dispensing. Previous studies have proposed various smart medication dispensing devices capable of automatically delivering medicine to patients at pre-programmed times. However, existing IoT-based [3] medicine cabinets remain largely limited to mechanical dispensing based on barcodes or weight sensing and generally fail to account for the patient's current health condition. In contrast, the integration of AI-enabled camera-based diagnosis can establish a closed-loop workflow: patient authentication → image-based assessment of disease progression → medication dispensing [4] or timely medical alerting, thereby opening the way toward a comprehensive [5], secure solution for remote diagnosis and treatment [6] [7]. In this work, we propose a smart medicine cabinet system that integrates computer vision algorithms with secure authentication protocols to ensure that the right medication is delivered to the right patient at the correct dose and time. Designed with usability and modular scalability in mind, the cabinet maintains continuity of care by recording every transaction, immediately flagging abnormal signs, and enabling bidirectional communication with hospital information systems.

The system operates as an assistive device that helps prevent medication non-adherence, especially among elderly patients [8] [9]**.** In addition, through image data and the use of collected datasets, the system is capable of identifying and predicting the patient's current condition. It also provides monitoring services via a mobile-linked application, allowing patients to communicate more flexibly with physicians and family members. Beyond its evident clinical benefits—fewer adverse drug events, faster response times, and improved treatment adherence—this solution is expected to generate substantial economic and social benefits, including enhanced public trust in the healthcare system. Nevertheless, fully realizing its potential will require sustained investment in robust technical infrastructure, comprehensive training programs for healthcare personnel, strategic collaboration with technology providers, and continued research to expand system functionality while ensuring compliance with evolving legal frameworks for medical data security and patient safety.

The remainder of this paper is organized as follows. Section 2 presents the smart medicine cabinet design process. Section 3 describes the workflow for building the image-processing dataset. Section 4 presents the design results. Finally, Section 5 provides discussion and future research directions.

II. Proposed Method

A. Model of smart medicine cabinet

Figure 1 shows the medicine cabinet model designed in the study. The medicine cabinet is composed of 8 drawers, of which 7 main drawers contain medicines for patients, the remaining drawer is a reserve drawer. The reserve drawer will operate if one of the main drawers is broken. There is a camera placed in front of the medicine cabinet to perform facial recognition. Besides, there is a keyboard with 9 numeric keys for patients to enter the PIN code in case the facial recognition system fails. The medicine cabinet's display and sound system will notify when the medicine is dispensed successful

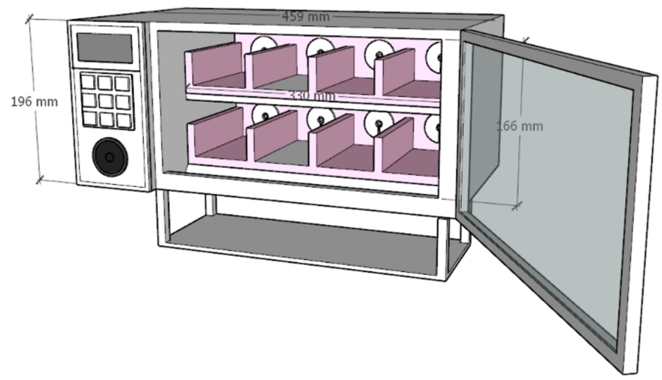

Figure 1. Smart Medicine Cabinet Model

B. Methodology and implementation process of the smart medicine cabinet

1) Hardware block diagram

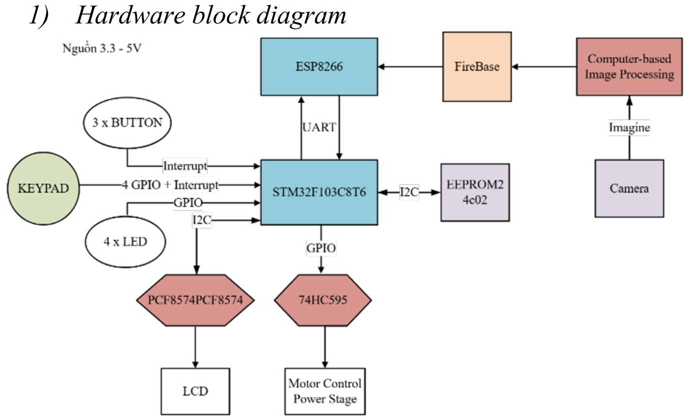

Figure 2. Hardware Block Diagram

The hardware components of the smart medicine cabinet include: an STM32 microcontroller serving as the central processing unit of the device; step-down voltage regulator ICs that supply power to all system modules; an ESP8266 module used to transmit data to the server; an LED indicator employed to signal the device's data-transmission status; and a camera used to capture images, with image processing performed on the computer, and the results sent to the server.

2) Actual hardware

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Physical cabinet realization is done with respect to fixing all the hardware components such as STM32 controller, ESP8266, keypad, power components, camera, as well as frame structure. The components are fixed as per the layout of the PCB, and the components are connected tightly for stable operation.

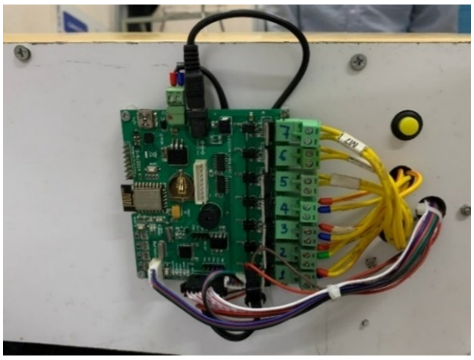

Figure 3. Actual Hardware

C. Software design – control algorithm

1) Functional models

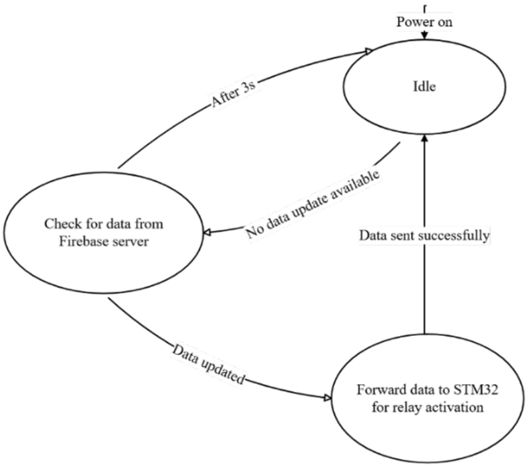

Figure 4. Finite-State Machine Diagram of STM32 in the Medicine Cabinet Controller

The operating system of the STM32 is structured through flexible states: from the Standby mode, waiting for commands, to processing button presses and keypad input (PIN entry). The system continuously updates the LCD screen to provide feedback to the user, while using UART to receive facial-recognition data from ESP8266/Firebase in order to decide whether to dispense medication. In addition, the LED Blink state is always maintained to monitor system stability and support timely debugging.

The ESP8266 operates based on the following main states: Idle State: No work is done. Firebase Data Check State: It is used to check for new facial recognition data on the server. Data Transmission State: Sends control signals to STM32 for triggering the relay system for dispensing medicine.

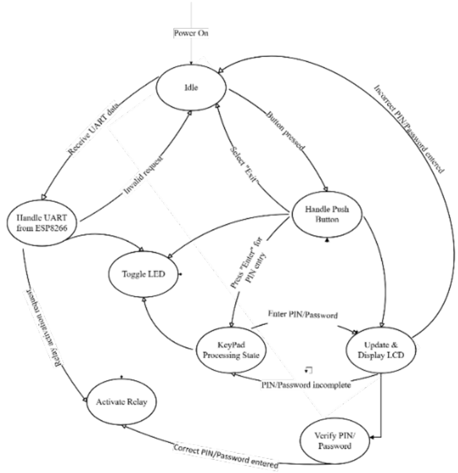

Figure 5. Finite-State Machine Diagram of ESP8266 in the Medicine Cabinet Controller

2) Flowchart algorithm

The algorithm is described by the flowchart in Figure 6 and operates using an interrupt-driven mechanism to optimize responsiveness. The system receives input from push buttons and data from Firebase via the ESP8266, and then controls the FETs to trigger medication dispensing. Flags such as, flag_button, flag_key, flag_rx_done help accurately manage the processing sequence. Although this approach has advantages such as a simple structure and easy customization, it still has limitations in terms of real-time performance and is prone to data synchronization errors when multiple events occur simultaneously.

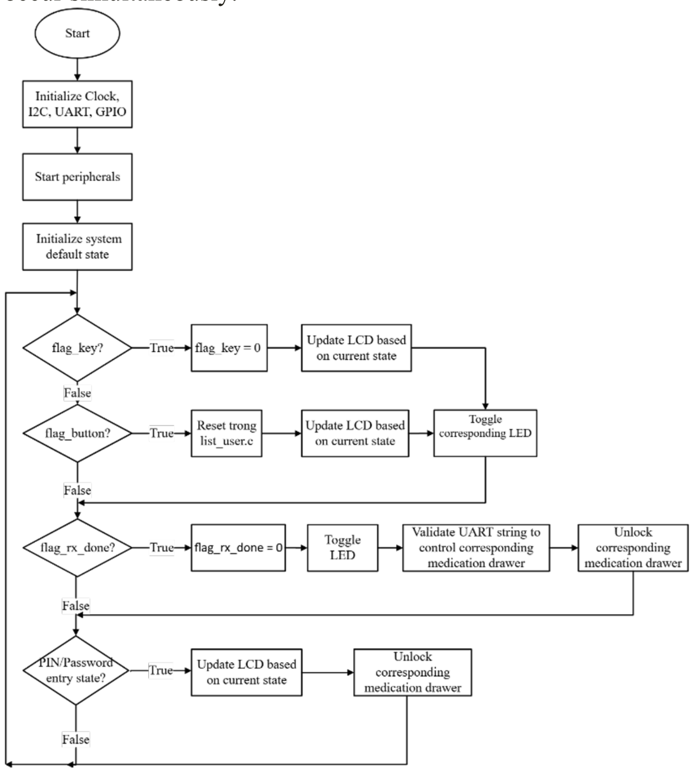

Figure 6. STM32 workflow

D. *Face-recognition module for automated medication dispensing*

1) *Design of the face-recognition module*

A fixed-focus HD camera is embedded in the cabinet door at eye level (≈45 cm from the user) to capture frontal facial images under controlled distance and illumination. The recognition workload is executed on a fan-less single-board computer (Intel J4125, 8 GB RAM) running Ubuntu 22.04 and Python 3.10. An ESP8266 Wi-Fi micro-controller forwards authentication results to an STM32F103 MCU, which in turn drives logic-level MOSFET relays that unlock the corresponding medication drawer. Optical isolation is provided on the UART line to protect the computer from relay-induced transients

In addition to building the automatic medication-dispensing workflow, this study also employs the Teachable Machine training model to recognize patient images. In order to detect and predict disease conditions manifested through skin pigmentation [10] [11] [12]. The disease data is collected from datasets on Kaggle to train the recognition model and improve its accuracy [13] [14] [15]. Although still limited, the medicine-cabinet system has proven effective in both automatically dispensing medication to the correct patient and providing timely diagnosis of their condition, thereby maximizing support for doctors during monitoring and examination.

2) *Face Recognition*

a) *Face Registration*

This process is performed first to store patient data, including entering the registrant's name, enabling the camera, and saving the identification image if the old face data is not available or invalid. To confirm that the face data is valid, perform the following preprocessing steps:

Step 1: Flip the image like a mirror and convert it to grayscale. Each webcam frame is flipped horizontally so the user sees it more comfortably when the front face is detected, while also converting to grayscale for detection using Haar Cascade

Step 2: Detect faces. The program uses the Haar Cascade detector to find faces in the image. If multiple faces are detected, the program selects the face with the largest index value below.

$$\text{faces} = \text{detectMultiScale}(\text{gray}, 1.3, 5) \quad (1)$$

Then, draw the detection frame, crop the face region, convert it to a feature vector, and save it on the PC. The registration image is only accepted if a face is detected and the faces value has been generated.

b) *Identity Recognition*

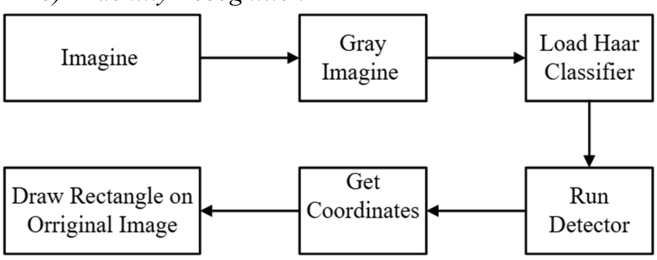

Figure 7. Face Recognition

Step 1: Launch the interface and ML model on the computer to prepare for the entire process as shown in Fig. 14

Step 2: Detect the face using Haar Cascade, resize the image to 128×128, then perform recognition using cosine distance:

$$d_i = 1 - \cos sim(x, y_i) = 1 - \frac{x.y_i}{\|x\|.\|y_i\|}; d_{min} < 0.6 \quad (2)$$

with confidence computed as:

$$\text{Confidence} = 1 - \frac{d_{min}}{2} \quad (3)$$

Step3**:** Segment the image using SLIC with parameters $n_{segments} = 5, \sigma = 5$, and feed each region into the skin-disease prediction model to improve accuracy

Step 4: Save the results, including the captured image for patient identification and disease signs, for future diagnostic purposes.

The face detection process, illustrated in Fig. 4, is implemented using the Python programming language and the OpenCV library [21]. Image acquisition and pre-processing are implemented with OpenCV 4.9.0. Facial bounding boxes are detected using the Histogram-of-Oriented-Gradients (HOG) cascade accelerated by a light-weight CNN supplied in the *dlib* package. Each detected face is converted into a 128-dimensional embedding by the *face_recognition* wrapper of the ResNet-34 facial network [21]. Persistent user data (ID, facial template, remaining dispense quota) are stored in a Firebase Realtime Database; network latency for a read–update–write transaction averages 35ms.

3) *Enrolment procedure*

During enrolment, the operator enters the patient's alphanumeric ID and instructs the patient to face the camera. A single frame is captured and accepted only if exactly one face is detected. The resulting embedding e_e is transmitted to the database and linked to an initial dispense-quota Q_0 assigned by clinical staff. Quality control rejects blurred images (variance of Laplacian < 100) or profiles exhibiting yaw > 20°.

4) *Verification and dispensing logic*

At run-time the camera streams 30 fps images; the pipeline selects one frame every 400ms and applies the same detection-embedding process to obtain the query vector $\mathbf{e}_\varphi$. The Euclidean distance $d = \|\mathbf{e}_\varphi - \mathbf{e}_e\|_2$ is computed against all registered templates. A match is declared when $d < 0.50$, a threshold derived from preliminary ROC analysis yielding 98.3% true-accept and 1.9% false-accept [8] at illumination levels of 200–800 lux.

Upon a positive match, the application retrieves the current quota Q from Firebase using an atomic transaction. If $Q > 0$, the quota is decremented, and an "AUTH_OK" packet containing the patient ID and drawer index is sent via UART (9600 bps) to the ESP8266. The micro-controller echoes the packet to the STM32, which energises the appropriate relay for 800ms, releasing the drawer latch. If $Q = 0$, the transaction aborts and the user interface display "No remaining doses" without actuating the hardware

5) *Failure handling*

If no face is detected for 5 s, a prompt instructs the patient to adjust position. Three consecutive mismatches trigger a 30-

s lockout to deter spoofing attempts. Power-loss recovery is guaranteed by non-volatile quota storage in Firebase and a watchdog timer on the STM32 that returns all relays to the locked state. Environmental robustness is improved by an automatic exposure algorithm and a near-infra-red LED ring that maintains recognition accuracy down to 20 lux.

III. EXPERIMENTAL RESULTS

Training results are presented in Figure 8,9. The accuracy on the training set increases rapidly and reaches nearly 100% after about epoch 5, then remains stable until the end of training. On the test set, accuracy fluctuates around 94%–96%, indicating that the model generalizes well.

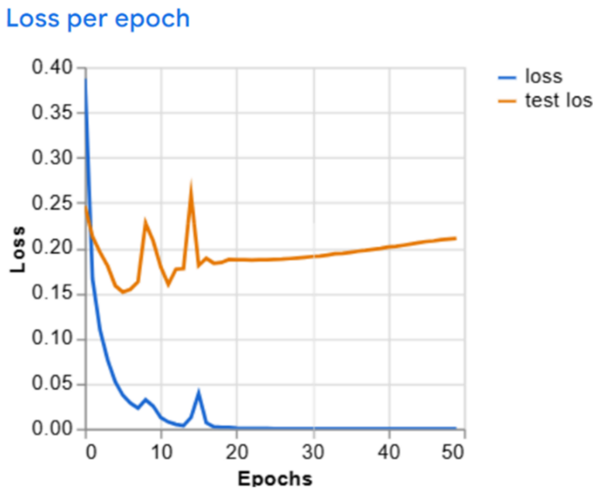

Figure 8. Loss per epoch

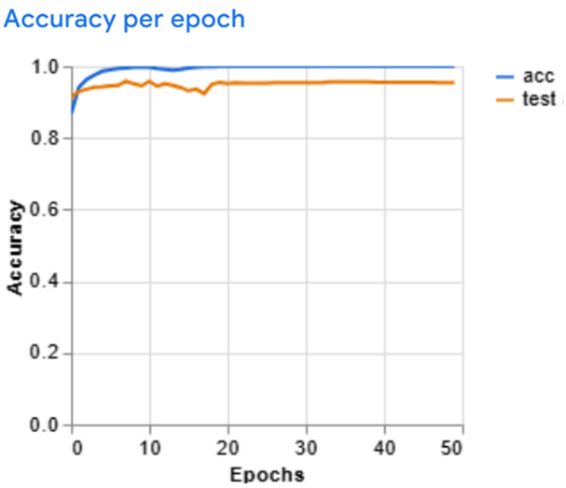

Figure 9. Accuracy per epoch

The loss on the training set drops sharply and approaches 0 after about 20 epochs. In contrast, the loss on the test set decreases to about 0.15, then oscillates slightly and gradually rises to around 0.21 in later epochs, showing that the model exhibits mild overfitting. Overall, the model achieves high accuracy, low loss, and reliable classification performance.

The system recognizes the patient and returns the patient's name, while the computer connects to the server to send a signal to the medicine cabinet via the ESP Wi-Fi module, so that medication is dispensed from the correct drawer. At the same time, the system logs the patient's name, the drawer from which medication is dispensed, and the disease type diagnosed by the model. This is an applied research with the result being a medicine cabinet model as shown in the Figure 7. The experimental process is carried out as follows:

The user inputs 1 through 8 as an identification. The input is verified for correctness and the system is connected with Firebase through Firebase Admin SDK with a.json credentials file. Once integrated, the system can read/write in real-time for user access as well as drug dispensing records. The GUI is implemented with Kivy with features such as: Web_cam: webcam perspective; self.button: Face verification button; self.verification_label: verification status; self.notification_label: usage notification. Widgets are arranged vertically with BoxLayout, while size_hint is used for proportional layout. Video is captured with cv2.VideoCapture(0) and is refreshed every 1/33 seconds with Clock.schedule_interval.

When the "Verify" button is clicked, the frame is captured and compared with saved encodings using theface_recognition library. When compared, the medication is dispensed. Otherwise, the user is prompted to reposition. Firebase integration tracks user usage count. On successful authentication, usage count goes down and gets updated in Firebase. When usage count is zero, usage gets blocked for further use until renewed, with their usage being capped fairly and under system control.

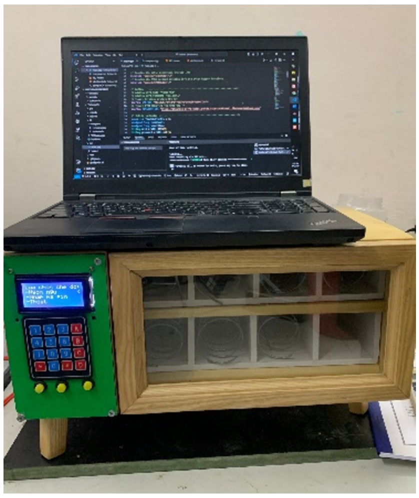

Figure 10. Realistic smart medicine cabinet model

Smart medicine cabinets can automatically dispense medicine to patients based on images processed by advanced technology. In case patients cannot directly go to the medicine cabinet to get medicine, they can ask someone else to get medicine by providing a PIN code. The smart medicine cabinet authenticates patients only through facial recognition, eliminating physical keys, cards or PINs that can be lost, shared or stolen. The image recognition results are up to 98.3% accurate. The actual results show that the medicine cabinet can automatically dispense medicine to staff with high reliability. This process reduces the manual workload involved in checking and dispensing medicine, giving medical staff more time to focus on patient care.

IV. Conclusion

This study successfully designed and prototyped a smart medicine cabinet to support the dispensing of medicine to patients. The smart medicine cabinet dispenses medicine through one of two mechanisms: (i) facial recognition; (ii) PIN code given to the patient. Applying this device in practice can save time and effort for medical staff, allowing them to focus on patient care. In addition, it also supports nurses and doctors in monitoring the patient's condition throughout the examination and treatment process, making the treatment procedure easier. With policies encouraging the application of advanced technologies such as artificial intelligence and image processing in the healthcare industry, the smart medicine cabinet model in the study will be a useful and highly practical solution.

Although the current system, with its minimalist design, is limited to dispensing pre-packaged medication doses for each patient and operates with minimal human intervention, several limitations remain to be addressed in future development stages. In future improved versions, the system could be further integrated with advanced technologies, such as a smartphone-linked virtual assistant with natural language processing capabilities to help answer patients' questions about prescriptions, provide proper medication instructions, and monitor and remind patients to take their medication at the correct dosage. In addition, adding a patient condition assessment function would bring significant benefits.

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