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Automated Medication Dispensing Device for Patients Using Face Recognition and QR Codes

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Abstract

The overcrowding of patients in hospitals has become a significant problem in many countries. To address this problem, the application of information technology, Internet of Things, and artificial intelligence is increasingly being integrated into major hospitals worldwide to support doctors and nurses in patient care and improve the quality of healthcare services. The study proposes an automated medication dispensing device designed to help nurses administer medication to patients. The device is built around a Raspberry Pi 4 embedded computer and utilizes face recognition technology and QR code scanning to verify patient identities, ensuring that medication is dispensed to the correct person. In addition, QR codes are used to authenticate information in medication packages, ensuring that the correct medication is provided to the patient. The device also has the ability to replenish medication supplies and notify nurses in cases where incorrect medication is administered.

Keywords: Automatic pill dispenser, face recognition, IoT device, QR code, Raspberry Pi.

1. Introduction

The overcrowding of patients remains a challenging issue for healthcare systems in hospitals around the world. Overcrowding in hospitals can threaten public health by compromising patient safety and reflects a lack of adequate inpatient capacity for critically ill patients. Overcrowding in hospitals can lead to prolonged inpatient treatment duration, resulting in higher treatment costs for patients and increased pressure on healthcare personnel, potentially leading to more severe outcomes, such as higher mortality rates among inpatients. Hospital overcrowding could become increasingly severe with the rapidly growing aging population worldwide. According to WHO [1], by 2030, people over 65 years of age will make up approximately 17.5% of the global population. This alarming increase puts significant pressure on healthcare care systems for the elderly, particularly in countries with a high aging population, such as Japan [2].

To address overcrowding, various applications of the Internet of Things (IoT), information technology, and artificial intelligence (AI) have been implemented in healthcare to support doctors and nurses and improve service quality. Remote health monitoring systems allow authorized medical professionals to access stored data from any IoT platform for patient diagnosis. The application of AI has increased significantly with its rapid advancement, optimizing patient flow and resource allocation in hospitals through descriptive research methods and secondary data collection, significantly improving waiting times, resource utilization, and patient outcomes. The Diagnostic Decision Support System (DDSS) assists physicians in making diagnostic decisions, reducing errors, and improving precision [3]. Typically, nurses and caregivers distribute medications, but the increase in the number of patients increases overcrowding and pressure on healthcare personnel. Excessive overcrowding can negatively affect patients, causing delays or errors in medication delivery.

Therefore, in this paper, we introduce a solution by proposing a device designed to support and potentially replace nurses in the medication distribution process. The study presents an automated medication dispensing system that integrates face recognition and QR code scanning technologies, using a camera with object detection capabilities. To ensure safe and accurate medication delivery, the device must comply with the principles of 'The 5 Rs for medication safety", as outlined in [4]. The key contributions of this research are as follows.

- Designing an automated medication dispensing system that leverages face recognition and QR code scanning / decoding through a camera for patient identification.

- Developing a double-check drug verification algorithm to guarantee the accuracy of the medication administered to patients.

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2. Related Work

There are several versions of the medication boxes available on the market. The simplest version of a smart pillbox, such as the product sold on eBay [5], features a round container that is capable of storing approximately 28 days of medication. This pillbox is equipped with a screen to display time and set medication schedules. It alerts the patient when it is time to take their medication. However, as a simple version, its functions are quite basic and not very user-friendly.

Studies [6-9], propose various designs for smart medication dispensing devices that can automatically provide medication to patients at scheduled times. Each design in these studies has some unique features. In [6], the device uses an Arduino microcontroller connected to an Real-Time Clock (RTC) module to provide date and time, a servo motor to open the box, a vibration motor to disperse the medication, and a GSM module to send notifications to family members of whether the patient has taken their medication. In [8], the authors add a temperature and humidity sensor to detect changes around the medication dispenser to determine if the patient has moved. The study [7] proposes a system that uses several interconnected ESP8266 microcontrollers to form a network of medication dispensers, monitored through IoT. The system allows real-time monitoring of the status of each dispenser using a Web page, which contains valuable data on how patients are treated. In the study [9], the authors applied voice control technology to the smart pillbox to make it easier for visually impaired and elderly patients to use. Although each of these studies introduces unique features, they are primarily designed for home use by individual patients. Consequently, most of these medication dispensing devices are only suitable for a single patient.

Studies [10, 11] have applied artificial intelligence (AI) technology, specifically face recognition, to accurately identify patients, ensuring that medication is administered to the correct person.

In general, these research efforts aim to simplify the process of medication administration, ensuring that patients receive their medications at the appropriate times. However, a significant issue arises in that there is no verification to ensure that the correct medication is administered to the patient. This error can potentially occur during the distribution process. Typically, this verification step is always performed in a hospital setting, where nurses or medical personnel administer medication to inpatients.

3. Proposed Method

3.1. Hardware Design

The automatic medication dispensing device is built around a Raspberry Pi 4 embedded computer and incorporates several key components, including a Picamera, an ultrasonic sensor, a Pal-Til HAT, a step motor with its controller board, an LCD display, a pillbox, jumper wires, and a breadboard. The system block diagram is illustrated in Fig. 1

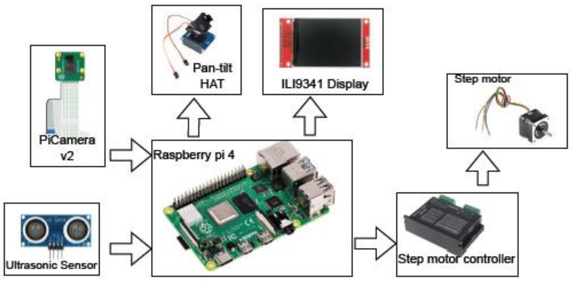

Fig. 1. Block diagram of the automatic medication dispensing device.

The Raspberry Pi 4 Model B is a powerful single-board computer with strong processing capabilities and high-speed network connectivity. It is responsible for processing signals from sensors and the camera, while also sending control signals to the motors and the display. The Raspberry Pi 4 Model B handles patient and medication authentication and controls the medicine dispenser.

The PiCamera V2 is a camera module designed for the Raspberry Pi. It is used to capture images of the patient or a QR code. These images are sent to the Raspberry Pi to identify and authenticate the patient, as well as to read medication information from the package.

The HC-SR04 is a popular ultrasonic sensor used to measure distance. It functions like a miniature sonar, determining the distance to an object by emitting ultrasonic waves and measuring the time it takes for the echo to reflect back. In this project, the sensor is used to detect the presence of a nearby patient.

The Pan-Tilt HAT is an expansion board for the Raspberry Pi. It allows a small camera or other sensors to be mounted and controlled along two axes: horizontal (Pan) and vertical (Tilt). In this project, the Pan-Tilt HAT provides flexible positioning, enabling the camera to seamlessly switch between identifying the patient and reading the medication's QR code.

A step motor is a brushless electric motor that converts electrical pulses into discrete, precise angular movements. Instead of rotating continuously like a conventional motor, a step motor's rotor turns and stops at specific angular positions called ”steps”. In this project, the step motor is used to rotate the medicine container, ensuring accurate dispensing of the correct medication.

The ILI9341 is a versatile LCD display module with a resolution of 240x320 pixels. It receives commands from microcontrollers via the SPI interface and converts them into signals to display in this project, the ILI9341 LCD is used to display medication information and notifications to the patient, ensuring they receive accurate and timely details.

3.2. System Workflow

The smart medication dispenser, integrated with a monitoring system, autonomously dispenses medication after verifying a patient's identity using face recognition technology. This approach has been successfully implemented in the dispensing device, as discussed in previous studies [10, 11]. Although the system operates efficiently in home environments, certain challenges may arise in healthcare settings such as hospitals.

One potential issue occurs when inpatients have head or eye injuries that require bandages that obscure parts of their face, potentially affecting recognition accuracy. To mitigate this, recognition models focusing on unobstructed facial regions can enhance the reliability of patient verification. Another challenge involves severely injured patients who are bedridden and unable to retrieve their medication independently, which requires the assistance of nurses or family members. In such cases, relying solely on face recognition may not be ideal.

To address these limitations, an alternative verification method should complement face recognition for patient identification. Our device integrates face recognition and QR code authentication via object detection technology, ensuring reliable identification even if face verification fails. Using object detection to recognize QR codes, the device leverages existing hardware, namely, the camera, eliminating the need for additional components and reducing costs.

The system operates through a series of interconnected components that manage the medication dispensing process efficiently. Its operation is divided into two main phases: dispensing medication to patients and reloading medication into the device. The complete process of the device is shown in Fig. 2. Each phase relies on identity verification through face recognition or QR code scanning, distinguishing between two types of IDs, the patient's ID and the nurse's ID.

Initially, the device reads values from the ultrasonic distance sensor to determine if someone is approaching. If the distance is less than 20 cm, the device assumes that a person is present. The sensor should be strategically placed to avoid interference from passersby. Once a user is detected, the system activates the camera to start capturing frames for user identification. The camera will be active for a countdown of approximately 2 minutes. If no valid identification is made within this time, the system will automatically turn off the camera and return to the distance sensor monitoring. This helps conserve hardware resources by preventing continuous camera operation. The user can choose to identify themselves using either face recognition or QR code scanning. If the identification is successful, the corresponding ID will be retrieved.

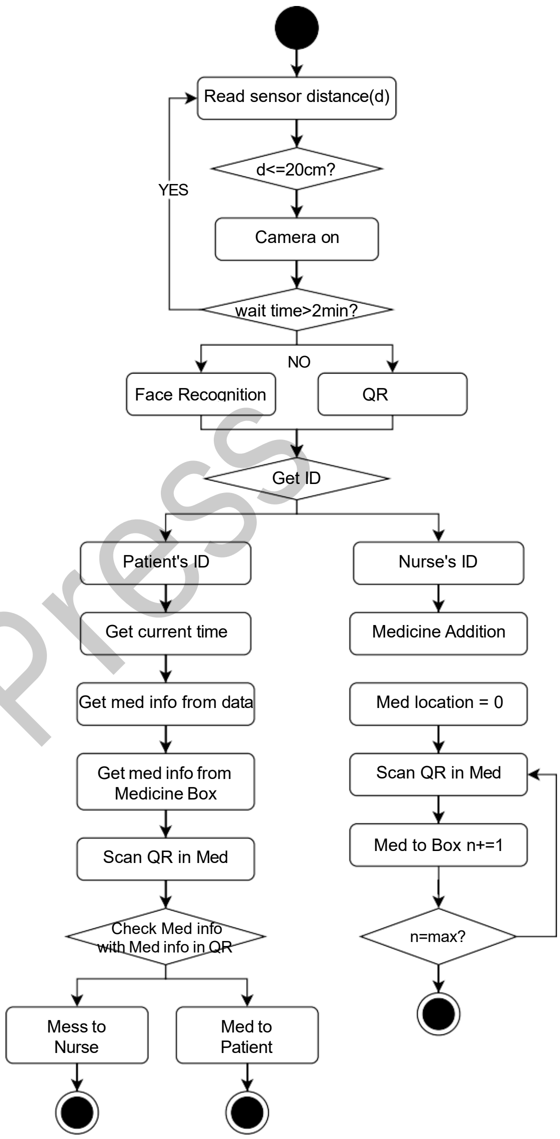

Fig. 2. Activity diagram of the medication dispensing system.

3.2.1. Patient verification process

The verification process guarantees that only authorized patients receive the prescribed medication. When a patient interacts with the dispensing device, their identity is initially verified using face recognition or QR code authentication. If the system confirms the identification as belonging to a patient, it proceeds with its core function: dispensing medication. After obtaining the patient's ID, the system utilizes the Raspberry Pi real-time clock to determine the correct dosage time, which is essential since dosage requirements can vary depending on the time of day. The operating algorithm of the device is described in Algorithm 1.

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Algorithm 1 Medication dispensing and verification process using QR code and camera.

Input: ID, T
Output: Medication dispensed
Read distance D from ultrasonic sensor
if $D < 20$ cm **then**
  Activate camera
  Start timer $T_{max} = 2$ min
  if User ID via face or QR **then**
    Determine time period: T P
    if $7 \leq T < 9$ **then**
      T = Morning
    else if $11 \leq T < 12$ **then**
      T = Noon
    else if $18 \leq T < 20$ **then**
      T = Evening
    end if
    Retrieve medication position P and info $M1$ using ID and T
    Activate step motor to dispense medication
    Scan QR code Q to get $M2$
    if $M1 = M2$ **then**
      Confirm medication
    else
      Alert P and N
    end if
  else
    Deactivate camera
    Return to distance sensing
  end if
end if

Upon retrieving the patient's ID and the corresponding time T, the system accesses the medication database within the device to collect the relevant details, including the prescribed drug $M1$ and its storage location P. Then it determines the drug position and activates the step motor to rotate the medication box accordingly. The medication package is placed for the camera to scan its QR code, extracting the drug information $M2$. The system then verifies whether $M1$ and $M2$ match. If they correspond, the patient receives the medication. However, if a discrepancy is detected - indicating that the drug dispensed does not match the prescription - the system immediately alerts the nurse to rectify the problem and ensure that the correct medication is provided.

3.2.2. Medication refill process for nurses

When the system identifies the ID as belonging to a nurse, it recognizes that the user is responsible for refilling the medication rather than receiving it as a patient. Upon verification, the device switches to refill mode, helping the nurse streamline the process. While the nurse manually replenishes the medication bags, the system facilitates operation, ensuring efficiency and accuracy. The workflow of the medication refill process is detailed in Algorithm 2.

Algorithm 2 Medication Refill Process.

$n \leftarrow 0$ // Initialize counter
Move box to P_0 // First position
while $n < N_{max}$ **do**
  if Slot P_n is empty **then**
    Request QR scan
    Update database with D_b
    Place medication in P_n
  end if
  $n \leftarrow n + 1$ // Increment counter
  Move to P_n
end while

In refill mode, the system initializes a counter n in 0 and positions the medication tray at the first slot. If the slot in position P_n is empty, the device prompts the nurse to scan the QR code on the medication to retrieve its details, which are then stored in the patient's database D_b. Once the medication is placed in the slot, the counter n increases by 1. If the slot already contains medication, the counter automatically increases by 1, and the tray advances to the next position. This cycle continues until n reaches the maximum slot capacity of the tray, N_{max}. The integration of QR code scanning streamlines the refill process by reducing the time required and ensuring accurate medication data entry. The data collected are then used in the drug dispensing function of the system for patients.

3.3. Patient Identification Using Face Recognition and QR Codes

3.3.1. Face recognition

Facial recognition is a biometric technology that uses image and pattern analysis to verify the identity of an individual. The core principle involves comparing a person's facial features against a pre-existing database for identification. This process consists of two primary components: training and identification, as illustrated in Fig. 3.

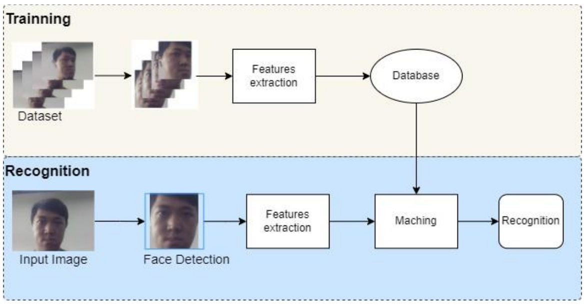


Fig. 3. Facial recognition-based patient identification process

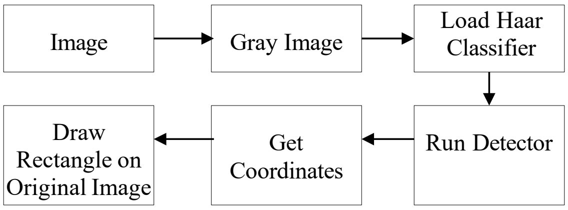


Fig. 4. Face detection process

Face detection is an essential step in the face recognition process, as it identifies the presence and location of a face within a given frame or image prior to facial identification. This approach is based on machine learning, where a cascade function is trained using a large set of positive and negative images to recognize objects in a picture. The face detection process, illustrated in Fig. 4, is implemented using the Python programming language and the OpenCV library.

The detected face is processed through a deep learning model to compute and encode it into a 128-dimensional vector. This vector is then compared with a pre-existing database created during the model training phase using a given face dataset. The comparison result will yield the name of the person being identified (if the database contains the trained data of the person).

3.3.2. QR code detection

Rather than relying on conventional barcode scanning modules for QR code recognition and decoding, this project employs an object detection model. This approach optimizes the hardware capabilities of the Picamera V2 module, effectively reducing overall product costs. The selected model, TensorFlow Lite 2, was chosen for its compact size, making it ideal for devices with limited resources such as the Raspberry Pi 4 while maintaining high accuracy in object detection. The model was trained using a dataset of 4,074 QR code images captured under various angles and lighting conditions, with the training process carried out on Google Colab.

Once trained, the model is used to detect and decode QR codes from images captured by Picamera, as illustrated in Fig. 5. Once the QR code is detected within the image, several pre-processing steps are performed before initiating the decoding phase, as described in Algorithm 3. The detected image I is first cropped to isolate the QR code region, producing an image denoted I_{bbox} . This image then undergoes perspective correction, generating I_{corr} . Subsequently, the image is resized into multiple versions with varying dimensions to enhance the decoding accuracy. Each version undergoes standard image processing techniques, including color inversion, grayscale conversion, sharpening, and thresholding to create a binary image. In addition, various K-size kernels are applied for blurring. Finally, each processed image is decoded separately. If decoding is successful, the extracted information is returned; otherwise, an empty value is provided. QR code decoding is performed using the open source library pyzbar [12].

Algorithm 3 QR code processing and decoding.

Input: I
Output: $QR\ decoded$
$BB \leftarrow$ BoundingBox(I)
$Q \leftarrow$ Quadrilateral(I)
$I_{bbox} \leftarrow$ Crop(I, BB)
$I_{quad} \leftarrow$ Crop(I, Q)
$I_{corr} \leftarrow$ CorrectPerspective(I_{quad})
$S \leftarrow \{1, 0.5, 2, 0.25, 3, 4\}$
for $s \in S$ **do**
  $I_{rescaled} \leftarrow$ Rescale(I_{corr}, s)
  $Iinv \leftarrow$ Invert($Irescaled$)
  $I_{gray} \leftarrow$ Grayscale(I_{inv})
  $I_{sharp} \leftarrow$ Sharpen(I_{gray})
  $I_{thresh} \leftarrow$ Threshold(I_{sharp})
  $K \leftarrow \{5 \times 5, 7 \times 7, 3 \times 3\}$
  for $k \in K$ **do**
    $Iblurred \leftarrow$ Blur($Ithresh$, k)
    $QR\ decoded \leftarrow$ DecodeQR($I_{blurred}$)
    if $QR\ decoded \neq \emptyset$ **then**
      return $QR\ decoded$
    end if
  end for
end for
return $\emptyset$

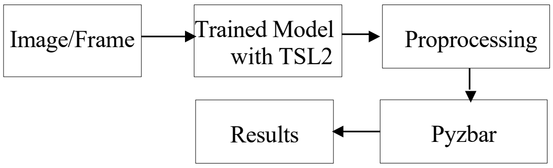


Fig. 5. QR code detection process.

3.4. Design of the Medication Dispensing Device

The medication dispensing device has a straightforward front window that exposes the medication package, allowing the camera to scan the QR code and retrieve the relevant information. Internally, the device consists of a circular compartment divided into multiple sections, each designated to store a customized medication package for a specific patient and scheduled for a particular time of day. Fig. 6 presents both the interior and exterior views of the medication box. The front panel includes a transparent window, allowing clear visibility of the medication packet and facilitating the recognition of QR codes by the camera. The image of the final automated medication dispensing machine manufactured is shown in Fig. 7

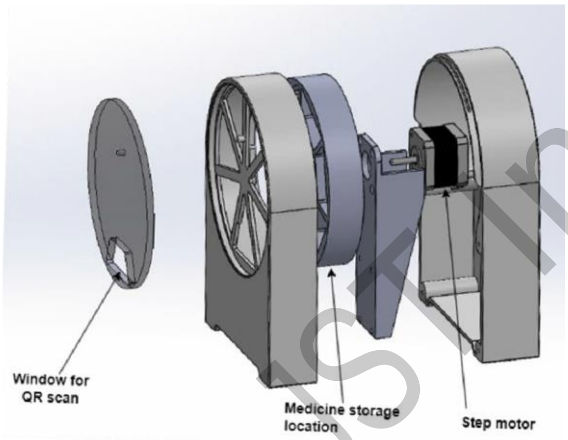


Fig. 6. 3D Structure of the medication dispensing device

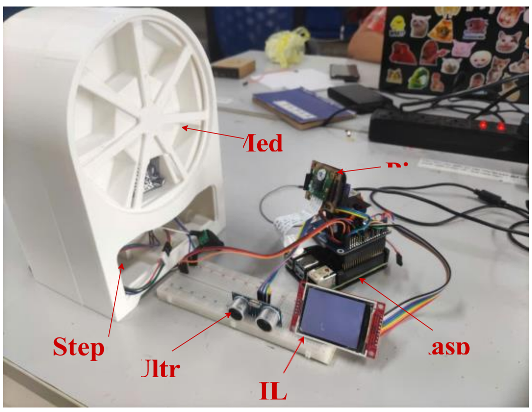


Fig. 7. Final product of the automated medication dispensing device

4. Results and Discussion

The operational scenarios of the medication dispensing device have been carried out and documented, covering key aspects such as analyzing patient medication data after identification, verifying the accuracy of the medication during a second confirmation, and addressing cases of incorrect verification.

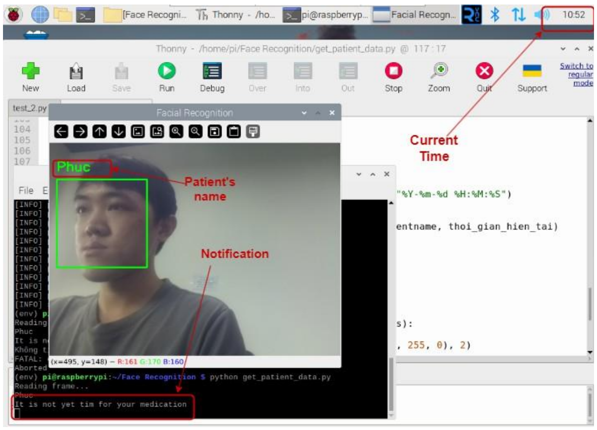
4.1. Patient Medication Dispensing Results

Following verification of the patient's identity, the system retrieves the validation results and uses the current time to identify the correct medication data for the patient. The experimental findings are presented in Fig. 8. In Fig. 8(b), the patient's identification time is 11:02, which falls within the allocated medication window from 11:00 to 12:00, designated as the midday dose period. Based on verification results and identification time, the system retrieves and displays relevant medication details, including the patient's name, ID, prescribed dosage, administration time, and the medication's storage location within the device. Existing studies [6-9] focus primarily on the basic designs of automated medication dispensing (AMD) devices but lack patient authentication capabilities. Research [10, 11] implements a basic face recognition model for patient identification and authentication; however, its effectiveness diminishes when patients wear masks or medical bandages, leading to recognition failures.

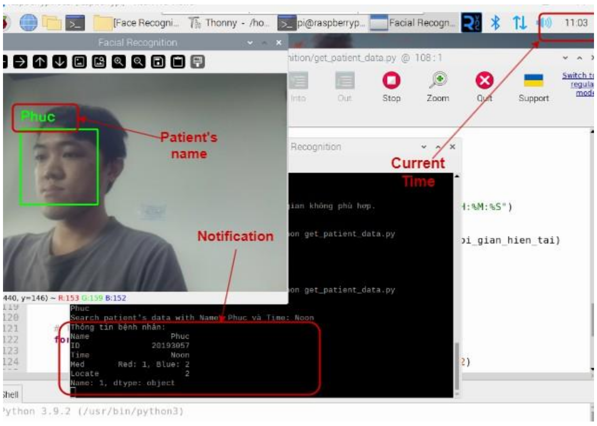
4.2. Verification of Prescription Medication Information

Once the patient's medication details and its storage location within the device are retrieved, the system activates the motor to position the medication packet in the box window, allowing the camera to scan and verify the information printed on the packet. The experimental results illustrate two primary scenarios for drug verification. The first scenario occurs when the patient's medication information matches correctly the data extracted from the QR code of the medication, as depicted in Fig. 9 (a). In the second scenario, the QR code verification reveals a mismatch between the medication packet and the patient's prescribed medication. Fig. 9 (b) shows a comparison of the two medications on the terminal screen, highlighting the discrepancies between the QR code data on the packet and the dosage required for the patient. In response, the system generates a warning message, advising the patient not to take the medication and to wait for a nurse's intervention.

Once prescription medication verification is successfully confirmed, the device alerts the patient through a notification on the LCD screen, prompting them to collect their medication. The message displayed is illustrated in Fig. 10.



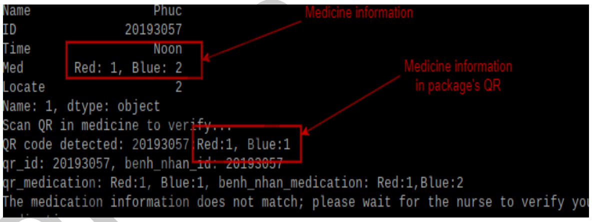
(a) Identification outside the scheduled time window



(b) Identification within the correct time window

Fig. 8. Results of patient identification

(a) Prescription medication match



(b) Prescription dedication mismatch

Fig. 9. Results of prescription medication information

Fig. 10. Patient notification for prescription medication verification.

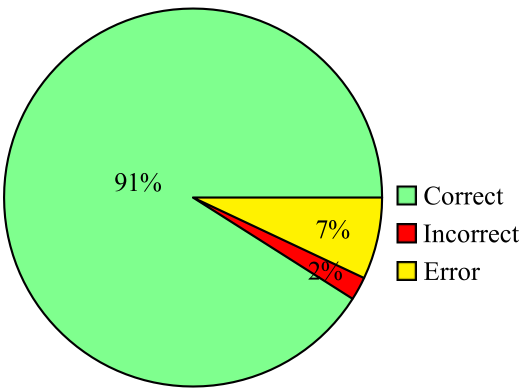


Fig. 11. Assessment of the automated medication dispensing device.

Once the prescription medication verification is incorrect, a notification will be sent immediately to the nurse through the application to address the problem with the medication administered to the patient.

We tested the device's operation over the course of one month, with approximately 200 trials conducted at different times of the day under consistent conditions. The results are displayed in the pie chart in Fig. 11. Experiment results show that around 91% of the trials resulted in accurate drug verification and correct drug dispensing to the patient. In 2% of the cases, the second drug verification was incorrect and the device sent a notification to the nurse. In practice, this error was mainly due to the process of the nurse loading the drugs into the medication box rather than to a malfunction of the device. Approximately 7% of the cases involved the detection of the QR code on the drug, but the code could not be decoded.

5. Conclusion and Future Work

The research explores an intelligent medication dispensing device intended for hospital use to assist or replace nurses in administering medication to patients. Using facial recognition and QR code scanning through object detection, identifies patients and confirms the accuracy of the medication. The system ensures appropriate and precise medicine delivery, with alerts sent to patients if discrepancies arise during verification.

Since this project is a prototype and operates in a limited time frame, the medication device currently has a basic design and size, presenting certain limitations that require future improvements. At this stage, the box is specifically designed to store pills-based medications, which makes it unsuitable for liquids or vials. Enhancing the device could involve integrating advanced technologies, such as a chat-bot with natural language processing capabilities to assist patients with inquiries about their medications and provide guidance on proper use. In addition, incorporating a medication sorting function would be beneficial. Although the current design relies on pre-packaged doses for the patient, an automated classification feature would enable the system to operate with minimal human intervention.

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