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Implementation and Design of a Smart Pharmacy Automation System Using Raspberry Pi

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ABSTRACT

Manual medication dispensing in pharmacies remains prone to human errors and is time-intensive, particularly under high patient loads, while existing commercial automation solutions are cost-prohibitive for small to medium-sized pharmacy settings. This paper presents the design and implementation of a cost-effective smart pharmacy automation system leveraging a Raspberry Pi 5 platform. The proposed system integrates a web camera for real-time image acquisition, a stepper motor-driven dispensing mechanism, and an HDMI display for visual feedback of identified medications. To enable accurate drug recognition, we employ the YOLOv8 deep learning object detection algorithm. A custom dataset comprising 1,500 images of ten distinct medication classes—with 150 samples per class, captured under varying illumination conditions (bright, normal, and low light) and three viewing angles—was constructed for model training and evaluation. The dataset was partitioned into 70% training, 20% validation, and 10% testing sets. Experimental results demonstrate that the YOLOv8-based model achieves exceptional performance, with an overall precision of 98%, precision and recall values approaching 1.0, and mAP50 and mAP50-95 scores of approximately 0.99, indicating high reliability for real-time deployment. The entire system, including both hardware and software, is able to accurately identify and dispense medications in an automatic manner with minimal delay. This affordable, on-site alternative to high-cost commercial systems presents an efficient and scalable solution to help decrease dispensing mistakes and enhance workflow in a pharmacy setting with limited resources.

Keywords: Computer vision in healthcare, Raspberry Pi, Recognition medication, Smart pharmacy automation, Python.

1. INTRODUCTION

The fast-growing embedded computing systems and artificial intelligence technologies have resulted in tremendous advancements in most healthcare applications, especially in

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pharmaceutical management and medication handling systems. The contemporary pharmacy setting involves proper medication identification, an effective storage system, and an effective dispensing system to minimize medication errors and enhance patient safety **(Larios Delgado et al., 2019; Ting et al., 2020)**. Conventional pharmacy processes tend to be manual, thus creating delays, adding to the workload and increasing the likelihood of human error when handling and distributing medications **(Chang et al., 2020)**. Based on this, smart pharmacy robots have gained prominence in research across healthcare engineering and medical informatics **(Al Washahi et al., 2023; Kuo et al., 2024).**

Current literature has investigated different technology methods to improve medication identification and automation in pharmacy. As an illustration, deep learning methods have been effectively used in drug identification tasks with high accuracy in identifying drug packages and pills when used in varying conditions **(Ting et al., 2020)**. On the same note, medication identification systems, which apply computer vision to detect drugs, have been created to aid pharmaceutical activities and facilitate medical personnel in checking the medication when filling out prescriptions **(Larios Delgado et al., 2019)**. Besides that, wearable and assistive technology like smart-glasses systems have been suggested to aid the visually impaired patients in identifying drug pills with deep-learning techniques and camera-based identification systems **(Chang et al., 2020).**

Another area that has been investigated as far as the integration of smart sensors and intelligent monitoring technologies is concerned is pharmaceutical environments. Medication identification platforms based on smart sensors have demonstrated good outcomes in enhancing the precision of the pharmaceutical classification systems and helping to minimize medication errors in healthcare institutions **(Kuo et al., 2024)**. Moreover, the Internet of Things (IoT) technologies have been implemented to develop interconnected pharmacy systems that could track the conditions in medication storage and offer automated notification systems **(Al Washahi et al., 2023)**. Raspberry Pi and RFID-based architecture of automated pharmacy monitoring systems have also shown their potential to improve pharmaceutical inventory management and medication tracking procedures **(Abdulkadhim et al., 2020).**

Simultaneously, the use of embedded systems like Raspberry Pi is gaining popularity as a means of building low-cost intelligent systems because of its flexibility, computing power, and simplicity of interfacing with sensors and other external devices. Various smart control and monitoring systems have been developed around Raspberry Pi in various engineering processes, which have proved to be reliable in real-time monitoring and automation processes **(Hu and Wang, 2022)**. In addition, automated picking and object handling systems through robotics and intelligent control systems have been unveiled with embedded controllers and microcontroller platforms **(Zijp et al., 2020; Ma et al., 2025)**. These advances signify that embedded computing platforms are capable of offering viable solutions to automation systems having real time process, as well as mechanical control.

Recently, object detection models of artificial intelligence and deep learning demonstrated impressive results in the visual recognition task. The YOLO (You Only Look Once) family of algorithms has emerged as one of the most popular real-time object detection frameworks as it exhibits great detection speed and high accuracy **(Wang and Liao, 2024)**. The application of YOLO-based detection models has been effectively utilized in various applications such as object recognition, currency detection and real time visual monitoring systems **(Fanzury and Hwang, 2025)**. Also, it has been proven that it is possible to implement deep learning models directly on embedded computers, allowing intelligent

processing in real-time, as well as on small-scale computing systems **(Vehkaoja and Hästbacka, 2021)**
Inspired by these advancements, this paper introduces the design and realization of an automated pharmacy system, an embedded computing platform, with pinpointed design and implementation objectives. The suggested system merges a Raspberry Pi 5 processor with a variety of hardware components such as a camera-based recognition system, a stepper motor-driven dispensing mechanism, a limit switch for drop confirmation, and an HDMI display interface. This research aims to create a low-cost intelligent pharmacy prototype that will be able to automate the medication identification and dispensing operations while maintaining a high level of operational accuracy and system flexibility.
Despite the significant progress in automated medication identification and robotic dispensing systems, most existing solutions remain fragmented, either focusing solely on visual recognition without physical dispensing capabilities, or relying on costly commercial robotic arms that are not affordable for small to medium-sized pharmacies. Moreover, there are few works which successfully combines real-time deep learning-based object detection with accurate motor control in a single low-cost embedded platform. To overcome these drawbacks, this work proposes to develop an efficient and compact all-in-one medication recognition system using the YOLOv8 model and an automatic stepper motor dispensing system based on the Raspberry Pi 5, which is cost-effective and easy to operate.
Its key contributions could be summarized as follows:

1. Design and development of a complete, low-cost smart pharmacy automation prototype system that integrates real-time visual medication recognition and an automated motor-driven dispenser in a single embedded Raspberry Pi 5 platform.
2. Development and optimization of a YOLOv8-based deep learning model specifically tailored for medication detection on resource-constrained edge devices, achieving high inference speed suitable for real-time pharmacy operations.
3. The creation of a custom dataset of images of medications with 1500 samples across 10 medication classes, taken under varying lighting conditions (bright, normal, and low light), and varying viewing angles, that can be used as a benchmark for future studies in this area.
4. Experimental results, showing 98% of detected images, precision and recall close to 1.0, and mAP50-95 around 0.99, proved the reliability of the proposed system for use in practical applications in small-to-medium-sized pharmacy environments.
5. Demonstration of a scalable, cost-effective architecture that offers a viable alternative to expensive commercial pharmacy automation systems, with clear potential for expansion to accommodate larger medication inventories and additional functionalities in future work.

2. MATERIALS AND METHODS

2.1 System overview

The smart pharmacy system proposed is an integrated embedded platform which is a combination of real -time medication recognition and automated dispensing. The system works based on three key functional steps which include image acquisition, processing and output generation.
The first step is to take pictures of drugs in front of the system, which is taken by a web camera. The images are then processed on a Raspberry Pi 5, which serves as the central

processor. Raspberry Pi along with other embedded platforms are highly used in intelligent automation systems because of their low cost and flexibility **(Zhou and Yuan, 2020; Hu and Wang, 2022).**
To identify medicine in real-time, a deep learning model that is based on YOLOv8 is used. Deep learning techniques have been proven to be extremely successful in object detection tasks related to healthcare **(Ting et al., 2020; Wang and Liao, 2024). (Khow et al., 2024)** demonstrated that the accuracy of object detection in complex environments can be greatly improved by the development of better models with YOLOv8. Furthermore, **(Mao et al., 2018; Vehkaoja and Hästbacka, 2021)** highlighted the applicability of real-time object detection frameworks to edge-based applications and embedded systems.
The system gives a visual representation by showing the identified medication as a picture on an HDMI-based touchscreen display, enabling real-time visualization of detected medication. Moreover, a stepper motor system is used to carry out automated dispensing processes. **Fig. 1** illustrates a complete workflow of the proposed smart pharmacy system.

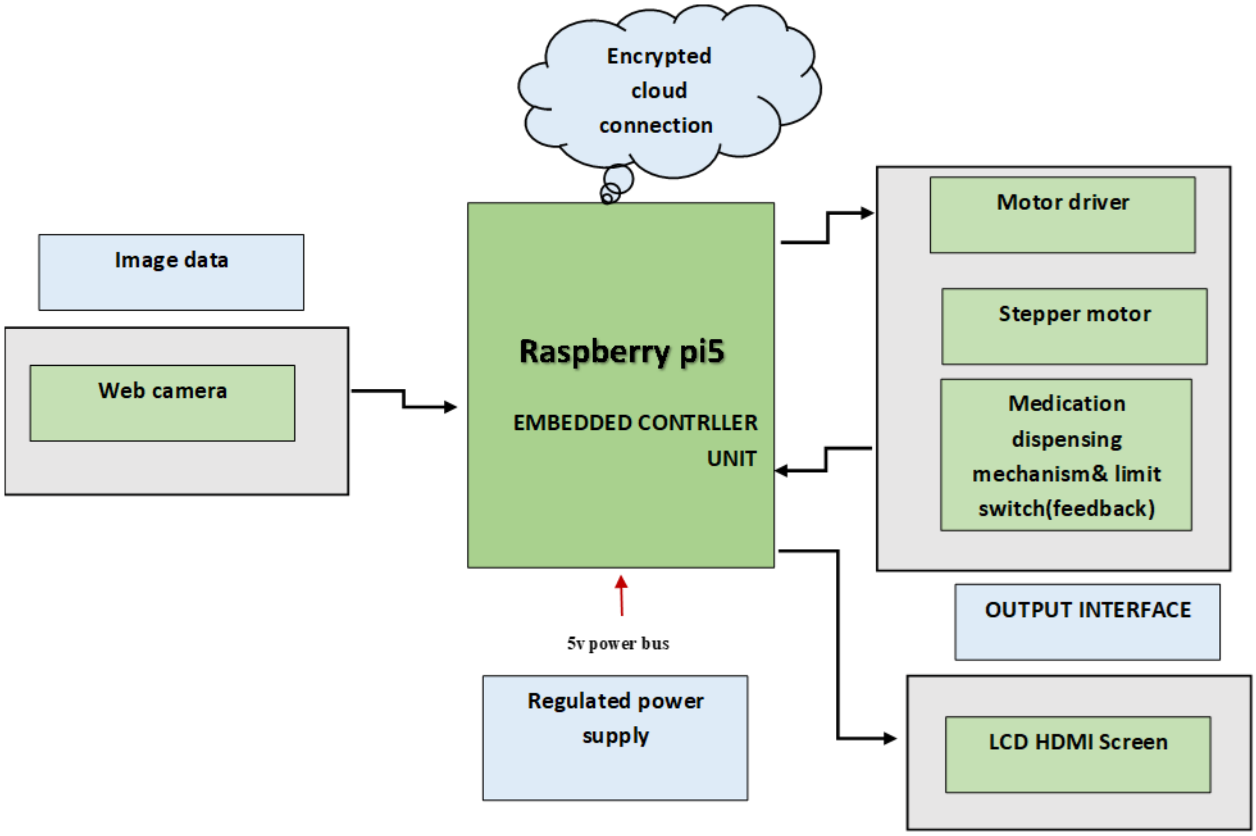

Figure 1. The workflow of the proposed smart pharmacy system

2.2 Hardware Components

The proposed system performs system actions and provides feedback to the user. It contains a stepper motor, a motor driver module, a medication dispensing mechanism, and an HDMI-based display to present the graphical output.
The stepper motor gives accurate control of the dispensing mechanism hence allowing accurate delivery of medications. Controlled object handling and positioning have been realized with similar motor-driven automation systems with robotic and intelligent picking systems **(Dhoke and Desai, 2017; Ma et al., 2025).**

The dispensing system is adopted through acrylic structural design that systematizes the drug compartments and allows the release of pharmaceutical products to be controlled. Automated drug dispensing machines have been reported to enhance efficiency of the operations and minimize human error in pharmacy settings **(Meshram et al., 2022; Cheng et al., 2025).**
The system uses a kind of display that is connected with an HDMI cable to show pictures and videos. This makes it possible for us to see the medication images that the system has found. These HDMI displays are better, than the LCD screens because they can show many different kinds of information. The system comes with a 7-inch capacitive HDMI touch screen which has a resolution of 1024 x 600 pixels. The display is configured with graphical output and touch interaction to enable the system to display the images of the detected medication in a clear and understandable way and increase the interaction with the user. The system is built with a plastic box to keep everything stable and organized and this box has special places to hold the medication.
Specifying the Raspberry Pi 5 technical details (Quad-core Cortex-A76 processor, 4GB RAM, Raspberry Pi OS "Debian-based", and Python 3.9 with PyTorch and OpenCV libraries)
The system component specifications are summarized in **Table 1**

Table 1. Hardware Components of the Proposed Smart Pharmacy System

Component	Description	Function
Raspberry Pi 5	Embedded computing platform	Central control and processing unit
Web Camera	Vision sensor	Captures medication images for detection
Stepper Motor	Electromechanical actuator	Controls dispensing mechanism
Motor Driver	Control interface	Drives the stepper motor
LCD HDMI	Output interface	Displays system status and results
RFID Module	Identification sensor	Identifies medication (optional)
Acrylic Structure	Mechanical frame	Organizes medication compartments
Power Supply (5V)	Electrical source	Provides system power

2.3 Software Implementation

The input layer will be in charge of getting the information from the real world and forwarding it to the processing unit. The main components of this layer in the proposed system include a web camera and optional identification modules, a stepper motor-driven dispensing mechanism, and a limit switch for drop confirmation. The camera takes real-time photographs of medications that are in the system compartments.
A deep learning-based object detection model is used to process these images to detect medicines accurately. Past research has revealed that drug recognition systems based on computer vision can greatly enhance recognition and lessen medication mistakes in a clinical setting **(Larios Delgado et al., 2019; Ting et al., 2020)**. Also, identification systems based on smart sensors have proved to be useful in improving the pharmaceutical verification processes **(Al-Hussaeni et al., 2023; Kuo et al., 2024).** Camera-based recognition has been applied in the healthcare sector as well, with wearable and assistive systems, which prove to be reliable in the real-time medication identification process **(Chang et al., 2020; Lee and Youm, 2021).**
The processing layer is implemented by the Raspberry Pi 5 embedded system as the main controller in the smart pharmacy system. It has a variety of functions, such as processing images, decision making and control signal generation. The system is based on the

Raspberry Pi OS and is written in Python, which offers a flexible system to add artificial intelligence and hardware control capabilities.
The suggested system will have a deep learning model of medication recognition in real time, which will use YOLO. YOLOv8 algorithms are not only known to be very fast in detecting objects in real-time but also very accurate **(Wang and Liao, 2024).** The latest developments of the YOLO architectures have enhanced the detection performance, thus suitable in an embedded application where quick and accurate inference is needed **(Fanzury and Hwang, 2025).**
Besides, running deep learning models on embedded systems has been proven to be a viable solution in order to perform intelligent processing in real-time without involving the use of other external computing capabilities **(Vehkaoja and Hästbacka, 2021)**. This will allow the proposed system to conduct effective on-device medication recognition.
Besides analyzing images, the Raspberry Pi controls the communication of the parts of the system and produces the control signals to the dispensing mechanism. Embedded control systems have been extensively used in automation systems, such as intelligent monitoring and robotic systems **(Ma et al., 2025)**. The training hyperparameters are listed in **Table 2**.

Table 2. Software Components of the Proposed System

Component	Description	Function
Raspberry Pi Imager	OS installation tool	Installs operating system
Raspberry Pi OS	Operating system	Runs system software
Python	Programming language	Implements system logic
Thony IDE	Development environment	Code development and debugging
YOLO Model	Deep learning algorithm	Medication detection
Dataset (Train/Test)	Image dataset	Model training and validation

2.4 Dataset

A custom dataset of medication images was collected to train and evaluate the YOLO-based recognition model. The dataset consists of ten medication classes that are commonly found in community pharmacies. In each of these classes, 150 images per class represent the total number of images for that medication, distributed across all lighting conditions and viewing angles. The pictures were captured in three lighting conditions (bright, normal, and low light) and three angles (front, 15° tilt left, 15° tilt right) to replicate the real-life pharmacy settings. This variety enhances the model robustness to illumination and orientation variations, in line with the best practices in deep learning to identify medication **(Larios Delgado et al., 2019; Ting et al., 2020).**
The data was divided into three subsets:
Training set: 70% of the images– used to update model weights.
Validation set: 20% of the images- used to tune hyperparameters and keep track of overfitting.
Test set: 10% of the images - not used in any way, except in final performance evaluation.
All images have been resized to a size of 640x640 pixels and annotated with the LabelImg tool that produces bounding boxes and class labels in YOLO format. The training set was augmented only with data augmentation techniques (random horizontal flip, ±10% brightness adjustment, and small rotations), which increased the effective training size and minimized overfitting. Other recent recognition systems based on YOLO have reported similar data preparation strategies **(Wang and Liao, 2024)**. **Fig. 2** shows that the

distribution of boxes is well-balanced and shows a suitable variety of sizes, which is helpful for the model to learn multiple patterns of shapes and sizes.

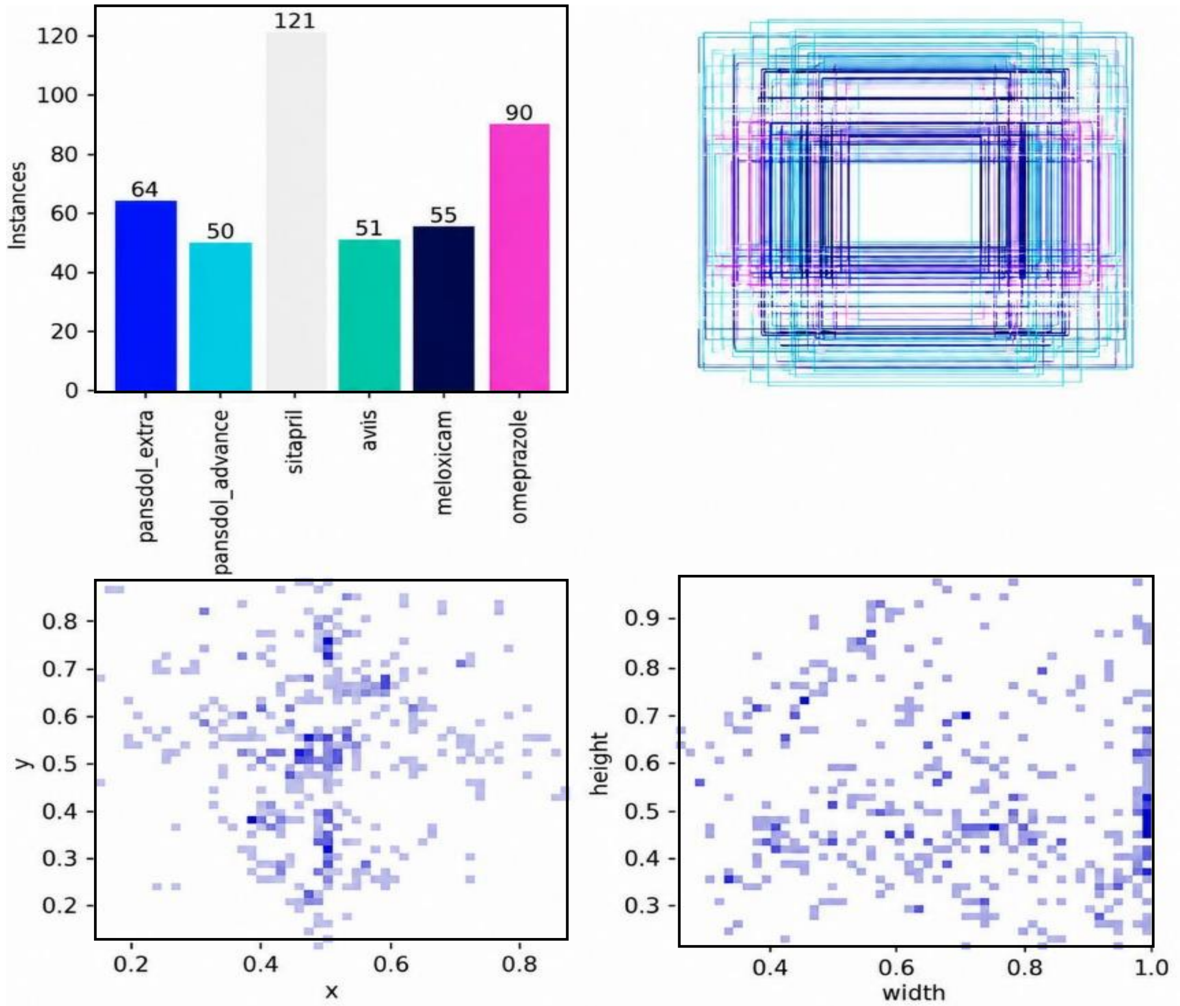

Figure 2. The dataset analysis.

2.5 YOLO-Based Medicine Location Model

The system that is proposed utilizes a YOLO (You Look Once) object detection model of real-time medication recognition. It is well known that YOLO can be used to detect objects with high accuracy and high speed, so it can be used in embedded healthcare applications **(Wang and Liao, 2024).**

Several important features of the algorithm meet the real-time and resource-limited requirements of the system, such as YOLOv8: First, YOLOv8 provides an optimum balance between detection accuracy and inference speed, significant Mean Average Precision (mAP) with fast inference speed, which is suitable for embedded platforms such as the Raspberry Pi 5 **(Wang and Liao, 2024).** Second, YOLOv8 introduces a new anchor-free detection head and a more efficient backbone network that improves the detection performance of small objects, like medicines packages, and reduces computational complexity when compared to its predecessors (YOLOv5 and YOLOv7) **(Fanzury and Hwang, 2025).** Thirdly, YOLOv8 offers native support for TensorRT and ONNX quantization, making it possible to deploy to ARM-based edge devices without compromising accuracy. These features make YOLOv8

well suited for online automation in a pharmacy, where responsiveness and high detection reliability are essential, and it was trained for 100 epochs.
The model takes input images taken by the camera and gives bounding boxes and class labels for images that have seen some medications. The difference in comparison to the traditional way of classifying images is that one can classify multiple images simultaneously using YOLO .
Recent developments in YOLO have led to even greater accuracy and speed in detection, enabling it to be deployed on resource-constrained embedded systems like Raspberry Pi5 **(Fanzury and Hwang, 2025)**.

2.6 Model Training and Evaluation of Performance

The suggested smart pharmacy system was tested through a detailed framework that incorporates model training, optimization, and real-world test of the system. The YOLOv8 (nano) was chosen because of the lightweight architecture and the ability to use it in embedded systems. With about 3.2 million parameters, the model requires around 8.4 GFLOPs per inference and can be successfully deployed on the Raspberry Pi 5, without depending on other clouds to assist with inference **(Lee and Youm, 2021; Sharma et al., 2025).**
The Ultralytics YOLO architecture under Python 3.11 on the Google Colab platform, which provides deep learning tasks with free access to a trained GPU, was used to train the model **(Abasa et al., 2025; Sharma et al., 2025)**. A custom dataset of ten medication classes was used, with data being collected under different light conditions and orientations. It was split into training (70%), validation (20%), and testing (10%) subsets, which is typical in the evaluation of deep learning models **(Cheng et al., 2025)**. To enhance generalization, data augmentation methods were used, including mosaic augmentation, horizontal flipping, HSV adjustment, and translation **(Dayananda and Upadhya, 2024).** The comparative analysis is presented in **Table 3**.

Table 3. YOLO model training settings

Parameter	Value
Epochs	100
Batch size	16
Learning rate	0.01 (cosine decay)
Optimizer	SGD (momentum = 0.937)
Image size	640 × 640
Data augmentation	Mosaic, flip, HSV, translation

The model was then optimized to be embedded on boards by converting it into TensorFlow Lite format and 8-bit integer quantization. This optimization cut the model size by more than 14 MB to 3.8 MB and reduced the inference time by over 1.2 seconds to 0.8 seconds per image, without sacrificing accuracy within 1% of the original model. The use of quantization methods has been popular in improving the performance of deep learning applications on embedded systems **(Dhoke and Desai, 2017; Ma et al., 2025).**
In order to confirm the system performance in a real-world application, an experimental setup was done in a controlled indoor setup with ambient lighting of about 300 lux. All the test samples utilized were 100 in number; each of the ten classes was represented by ten

medication units. The system was presented with each sample, which required to conduct real-time detection and automated dispensing. This test was designed to assess the end-to-end system performance, covering medication recognition, display and automated dispensing. The system was able to identify and dispense the samples of drugs successfully, even in real time, proving the system is reliable in a simulated environment of a pharmacy.

The assessment was based on various performance indicators. The accuracy of recognition was estimated as a percentage of correct classifications where the predicted label was equal to the ground truth with a confidence threshold of 0.85. Based on the confusion matrix produced by the test results, precision and recall were determined **(Wang and Liao, 2024)**. The rate of dispensing success was also determined as the percentage of tests where the correct medication was successfully delivered without mechanical failure, including jamming or multiple outputs. The system response time was calculated as the time interval between the image capture and the time when dispensing was completed, and was averaged across successful trials. The rate of false positives was also measured to determine the number of wrong detections.

Error analysis was done to find out the reasons for unsuccessful cases. These were environmental factors like dim lighting and covering of objects, and mechanical factors like misalignment of the motor. This analysis is fundamental in knowing the limitations of the systems and enhancing real-world reliability **(Zufi Shad et al., 2025).**

In addition, the results obtained were compared with available literature results on system performance, where necessary **(Larios Delgado et al., 2019; Ting et al., 2020; Cheng et al., 2025)**. The training and evaluation performance curves of the model are shown in **Fig. 3.** The loss curves indicate a steady decrease, indicating steady convergence, whereas precision, recall, and mAP measures indicate a steady improvement.

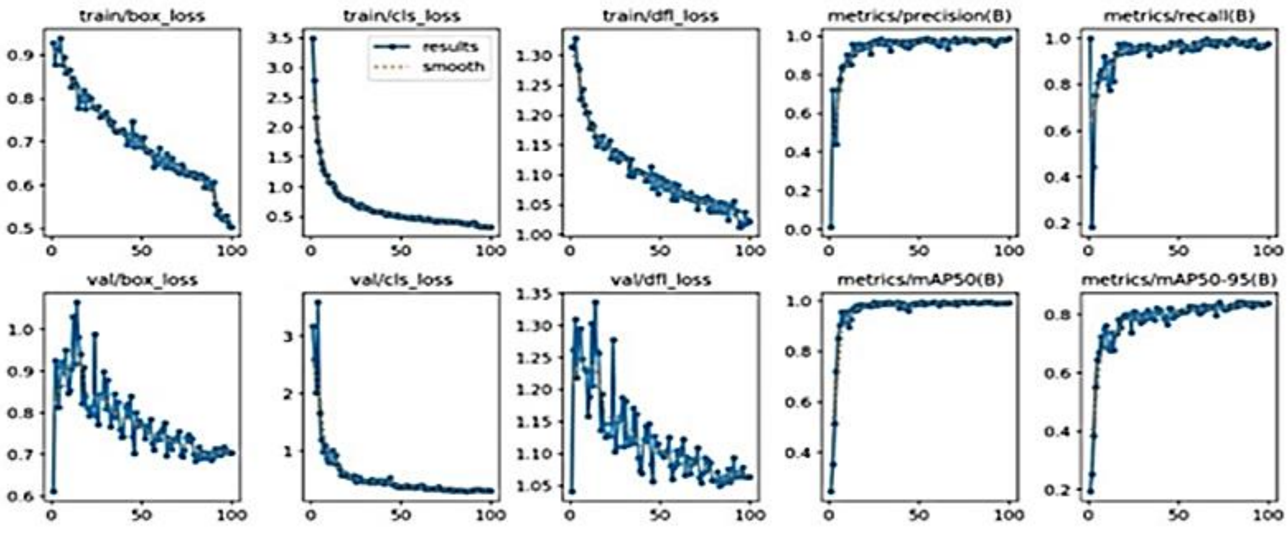

Figure3. YOLOv8 training output visualizations.

2.7 System Operation Workflow

The proposed architecture entails the incorporation of both hardware and software elements, which facilitates smooth functionality of the smart pharmacy system. The system workflow will start with taking medication images using the camera, and then processing

them with the YOLOv8 detection model. According to the recognition outputs, a system will produce relevant control signals to trigger the dispensing mechanism.
The convergence of the artificial intelligence, embedded systems and IoT technologies has been pointed out as a component in enhancing automation and medication safety in the pharmacy **(Al Washahi et al., 2023; Zufi Shad et al., 2025)**. Moreover, RFID technologies and embedded platform-based smart pharmacy monitoring systems have proven to provide great advancements in inventory tracking and management of pharmaceuticals **(Abdulkadhim et al., 2020).**
The proposed system is modular and thus can be later upgraded with cloud-based monitoring, smart inventory management, and predictive analytics of pharmaceuticals. These extensions are in line with the recent developments of AI-powered healthcare systems and intelligent pharmacy systems **(Ferreira and Carneiro, 2025; Sharma et al., 2025).**
This perception (vision), decision-making (AI model) and action (motor control) combination is a complete intelligent automation cycle. The same smart combination techniques have been effectively implemented in smart healthcare and automation systems **(Chang et al., 2020; Dayananda and Upadhya, 2024)**.
The dispensing sequence begins when the Raspberry Pi activates the stepper motor, which rotates a pusher arm to guide the medication from its storage slot into the chute. A limit switch at the chute end confirms the drop and sends feedback to the system, completing the cycle. The overall system design, including this mechanism **Fig. 4**. It shows a physical prototype of the smart pharmacy system showing dispensing units and a control interface**.**

Figure 4. Physical prototype of the smart pharmacy system.

3. RESULTS AND DISCUSSION

The performance of the proposed smart pharmacy system was tested according to the quantitative indicators and the real-life work of the system. The analysis is based on how well the YOLOv8 based medication detection model works and how well the system is integrated in general.

3.1 Detection Performance

The trained YOLOv8 model had shown good performance in the detection of ten types of medications in real-time situations. This model had a general precision of about 98%, which means that it has a powerful capacity to properly label the pharmaceutical products . Also, the precision and recall values have been noted to be near to 1.0, and have given mAP50 (B) and mAP50-95 of about 0.99. The overall precision of the model was around 98%. The system achieved an average inference speed of approximately 20 FPS on the Raspberry Pi 5 platform, confirming its suitability for real-time pharmacy dispensing operations.

The results demonstrate that the intelligent computer vision systems are capable of effectively assisting pharmaceutical identification and monitoring tasks in a real-time environment. **(Javaid et al., 2024)** discussed the rising significance of computer vision technologies in health care applications, and **(Chiu, 2024)** showed that embedded CNN-based medication verification systems have proven useful. Furthermore, **(Tavakoli et al., 2025)** found that deep learning object detection systems can greatly enhance the accuracy of pharmaceutical product recognition and warehouse management. These developments also contribute to the future vision of intelligent pharmacy systems that **(Aungst, 2025)** discusses. The metrics reported were acquired at the last training epoch. **Table 4** has a summary of the overall performance of the system.

Table 4. Performance Evaluation of the YOLO Model

Metric	Value
Accuracy	98%
Precision	0.99
Recall	0.98
mAP50 (B) and mAP50-95	0.99

3.2 Visual Detection Results

The system was tested in real-time conditions; the overall time between image capture and final dispensing was between 1.5 and 2.0 seconds. This real-time functionality can be used in normal workflow processes of pharmacies where a few seconds delay can be tolerated in exchange for higher accuracy and reduced manual labor. The medications detected are shown on the screen in the form of bounding boxes and labels, and the dispensing mechanism is triggered at the same time, which proves the efficient coordination of software and hardware elements. The results he got showed that the proposed system can provide reliable results in real-time environments of medication detection. **(Ting et al., 2020; Tan et al., 2021)** also showed their deep learning and YOLO based methods to be effective for pill/medicament identification with high accuracy. The real-time detection feature of the system is depicted in **Fig. 5,** where the YOLO model manages to recognize the medication and produce bounding boxes of the objects detected. The medication names identified are shown with the bounding boxes on the HDMI touch screen, and the user gets clear visual feedback.

3.3 System Performance Analysis

The combination of the detection model and the dispensing mechanism was proven to be valid. After the camera identifies the drug with the help of the YOLO model, the system makes two coordinated actions. The identified drug is shown on the HDMI touch screen inside the bounding boxes and labels of the classification, and it provides the user with visual feedback. At the same time, the embedded system produces control signals to move the stepper motor, allowing the dispensing of the respective medication in its respective compartment.

Figure 5. Real-time medication output displayed on the HDMI touch screen

The high accuracy of detection can be explained by:
1 .Diversity and quality of the training data.
2 .Effectiveness of the YOLO model in extracting features.
3 .The systematic process of training.

The system can also identify more than two medications in one frame, as shown in **Fig. 6**, which shows the strength of the detection model. These results are in agreement with earlier US experiments, which revealed the power of deep learning models in healthcare recognition tasks **(Hajizadeh et al., 2023; Hu and Wang, 2022; Sharma et al., 2025)**.

Figure 6. Multi-object medication detection with multiple drugs detected at once with the YOLO model.

This system is deployed as a prototype, to show how detection and actuation can be integrated into an embedded setting.

Although the system was very accurate, there are some limitations which can occur when:
1 .Poor lighting conditions
2 .Obstructed or obscured drugs.
3. Similar packaging designs

Nevertheless, the general system has great potential for being applied in real-world settings in smart pharmacies. Further advancements can incorporate the expansion of the dataset and introduction of more advanced deep learning models to improve the performance of detection. The results of this research align with the recent push for smart pharmaceutical systems and automated dispensing. **(Li et al., 2023)** highlighted that hospital intelligent pharmacy systems will be a key component of the future hospital infrastructure. The field of incorporating AI into pharmacy processes is gaining significance for enhancing medication safety and healthcare efficiency. **(Ogbuagu et al., 2023)** discussed the role of AI in enhancing patient-centered pharmacy care. As previously mentioned, AI-powered pharmacy systems can boost the efficiency of pharmaceutical processes, medication management, and intelligent healthcare services **(Khan et al., 2023; Rammal et al., 2024)**. To benchmark the performance of the proposed system, a comparison with recent related studies is presented in **Table 5** below.

Table 5. Comparison of the Proposed System with Previous Studies

Study	Platform / Method	Accuracy	Key Feature
(Ting et al., 2020)	CNN-based	~95%	Pill identification only
(Chang et al., 2020)	Smart glasses + DL	~92%	Assistive device
(Abdulkadhim et al., 2020)	Raspberry Pi + RFID	N/A	Inventory tracking
This Work	Raspberry Pi 5 + YOLOv8	98%	Real-time recognition + automated dispensing + drop feedback

Figure 7 represents the performance of the proposed YOLOv8-based system in real-time operation, where medication packages are in different orientations and almost hidden from the camera.

Figure 7. Detection performance for varying viewing angles and visibility of part of the object.

4. CONCLUSIONS

This paper describes the design and execution of a smart pharmacy automation system, using an embedded computer platform. The presented system will combine artificial intelligence, computer vision, and mechanical control into one architecture to facilitate the automated medication identification and dispensing operation. The system developed is based on a Raspberry Pi 5, which serves as a central controller, and a camera-based recognition module, a YOLOv8 deep learning model for real-time medication recognition. Moreover, a stepper motor-driven dispensing mechanism, a limit switch for the drop confirmation system and a graphical interactive screen are also included to provide the ability to act automatically and interact with users. The system shows the capability of utilizing end-to-end processing, including the image acquisition to the medicine recognition and ultimate output using the display interface. The experimental findings revealed that the proposed model had good detection precision of about 98%, precision and recall of nearly 1.0, and a good and consistent performance. The system was also tested on a sample of ten distinct types of medication and it was able to effectively identify and respond to the medication in real time under realistic operating environments. One of the main characteristics of the system is a 7-inch HDMI capacitive touch screen that allows visualization of the detected medications in real-time as images, not text. This increases the level of user interaction and increases the usability of the system, which is more applicable to real-life pharmacy applications. Though the system was tested on a sample of ten medication types, the suggested architecture is scalable and can be expanded to address a greater number of pharmaceutical products. Future research can aim at increasing the size of the dataset, incorporating the cloud-based monitoring systems, improving the model by introducing more sophisticated artificial intelligence approaches.
and improving the model to a more sophisticated deep learning-based system to make use of pharmaceutical-scale applications and comprehensive experimental comparison of YOLOv8 with other state-of-the-art detectors (e.g., YOLOv5, YOLOv7, SSD, and Faster R-CNN) on our dataset to further validate model selection. Summing up, the suggested system of the smart pharmacy is a cost-effective, scalable, and smart solution to the modern healthcare setting, which is suitable for real pharmacy deployment to enhance the medication management and efficiency of operations within the pharmacy systems.

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Credit Authorship Contribution Statement

Saja Sadiq Bakhit: performed the system design, implementation, collected the dataset, trained the YOLO model, and manuscript writing. Saleem Lateef: Supervision, methodology guidance, and manuscript review. Ali Al-Najy: Technical support, system validation, and assisted in manuscript editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تنفيذ وتصميم نظام أتمتة صيدلية ذكية باستخدام راسبيري باي

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الخلاصة

يظل صرف الأدوية يدويا في الصيدليات عرضة للأخطاء البشرية ويستغرق وقتا طويلا، خاصة تحت أعباء المرضى العالية، بينما حلول الأتمتة التجارية الحالية مكلفة جدا للصيدليات الصغيرة والمتوسطة. تقدم هذه الورقة تصميم وتنفيذ نظام أتمتة صيدليات ذكي فعال من حيث التكلفة يستفيد من منصة Raspberry Pi 5. يدمج النظام المقترح كاميرا ويب لالتقاط الصور في الوقت الحقيقي، وآلية توزيع مدفوعة بمحرك الخطوة، وشاشة HDMI لتغذية الراجعة البصرية للأدوية المحددة. لتمكين التعرف الدقيق على الأدوية، نستخدم خوارزمية YOLOv8 لاكتشاف الكائنات العميقة للتعلم العميق. تم إنشاء مجموعة بيانات مخصصة تضم 1500 صورة لعشر فئات أدوية مختلفة—مع 150 عينة لكل فئة، تم التقاطها تحت ظروف إضاءة مختلفة (إضاءة ساطعة، عادية، ومنخفضة الإضاءة وثلاث زوايا رؤية لها—لتدريب النماذج وتقييمها. تم تقسيم مجموعة البيانات إلى مجموعات تدريب بنسبة 70٪، و20٪ تحقق، و10٪ اختبار. تظهر النتائج التجريبية أن النموذج المبني على YOLOv8 يحقق أداء استثنائيا، بدقة إجمالية تبلغ 98٪، وقيم الدقة والاستدعاء تقترب من 1.0، ودرجات mAP50 وmAP50-95 تقارب 0.99، مما يشير إلى موثوقية عالية للنشر في الوقت الحقيقي. النظام بأكمله، بما في ذلك الأجهزة والبرمجيات، قادر على تحديد الأدوية وصرفها بدقة بطريقة تلقائية مع تأخير بسيط. يقدم هذا البديل الميسور التكلفة في الموقع للأنظمة التجارية عالية التكلفة حلا فعالا وقابلا للتوسع للمساعدة في تقليل أخطاء الصرف وتحسين سير العمل في بيئة صيدلية ذات موارد محدودة.

الكلمات المفتاحية: الرؤية الحاسوبية في الرعاية الصحية، راسبيري باي، التعرف على الأدوية، أتمتة الصيدليات الذكية، بايثون.