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A Novel Approach to QR Code Recognition: Leveraging Image Processing and PLC Integration

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ABSTRACT: *As societal progress accelerates and the enhancement of quality of life takes precedence, consumer demand for products with traceable origins has intensified. QR code scanning on packaging presents a swift method for verifying origin. However, printing imperfections can lead to unreadable, distorted, or blurred codes, impeding origin verification and detrimentally affecting customer satisfaction. This paper introduces an automated QR code recognition system employing LabVIEW image processing software and a PLC (Programmable Logic Controller) to address this challenge. The system encompasses both hardware and software components, with significant experiments conducted to validate its efficacy, yielding feasible results that demonstrate the applicability of the proposed system.*

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I. INTRODUCTION

In today's rapidly evolving society, scientific and technological advancements are increasingly impacting the manufacturing industry. These advancements offer numerous applications, but they also coincide with a continuous rise in labor costs, leading to higher product prices. As competition intensifies, the application of science and technology to reduce production costs becomes an inevitable necessity.

Fig. 1 QR code applications [1]

However, this focus on cost reduction needs to be balanced with evolving consumer demands. Rising living standards lead to stricter consumer expectations. Today's consumers demand clear and accurate information, particularly regarding product origin and source. Unfortunately, some Vietnamese manufacturing plants, while adopting QR codes on their products, lack a proper verification system. Their reliance on manual inspection, prone to human error, can result in incorrect or faulty QR codes. This ultimately hinders consumers' ability to access crucial origin information, potentially damaging the company's reputation and negatively impacting perceived product quality (see Fig. 1).

In light of these considerations, several solutions have emerged, with one garnering particular attention: the integration of a Programmable Logic Controller (PLC) with image processing technology for QR code recognition. This approach leverages the PLC's capabilities to create an automated and adaptable system. Meanwhile, image processing facilitates the identification of QR codes and the transmission of relevant signals to the PLC for further processing. This combined solution offers a reduction in labor requirements, enhanced system accuracy, and minimized error occurrences. This research project delves into the application of image processing technology within the LabVIEW software environment for QR code recognition [1-3]. Additionally, it explores the integration of a PLC to establish an automated system capable of accurately positioning products according to predefined parameters [4-10].

The core focus of this research lies in addressing two key challenges: (1) the utilization of image processing technology to recognize and verify QR codes against a reference code, providing accurate "pass" or "fail" signals in a timely and highly accurate manner; and (2) the design and development of an automated system for QR code sorting. The potential applications of this research extend to various business entities, including small and medium-sized enterprises.

II. DESIGN OF THE HARDWARE SYSTEM

In systems engineering and related fields, a system block is a graphical element used in block diagrams. These diagrams visually represent a system by breaking it down into its functional sub-components. Each block represents a subsystem or specific function within the larger system. Arrows connecting the blocks depict the flow of data or signals between them. This approach helps visualize complex systems and understand how different parts interact. The system's block diagram proposed in this study is shown in Fig. 2. The main blocks from the proposed system include the followings:

- Camera Module: This module serves as the "eyes" of the system, acquiring information from the surrounding environment by capturing images and converting them into digital signals. These signals are then transmitted to the computer for image processing.
- Image Processing Module (PC): The computer is responsible for processing and analyzing image data acquired from the camera module. After processing, the computer sends the data to the PLC via the OPC UA (Open Platform Communications Unified Architecture) protocol for further steps.
- PLC Module: The PLC plays a crucial role in controlling the system's actuators. Specifically, it controls the gripper robot cluster, receiving data from the computer through the OPC UA protocol. The PLC then decodes this data and generates control signals to move the product to the desired location.
- Gripper Robot Cluster: This cluster is the main actuator of the system. Upon receiving control signals from the PLC, the gripper robots pick up and move objects to designated locations.
- Power Supply Module: This module provides and stabilizes the power supply for the entire system's operation.

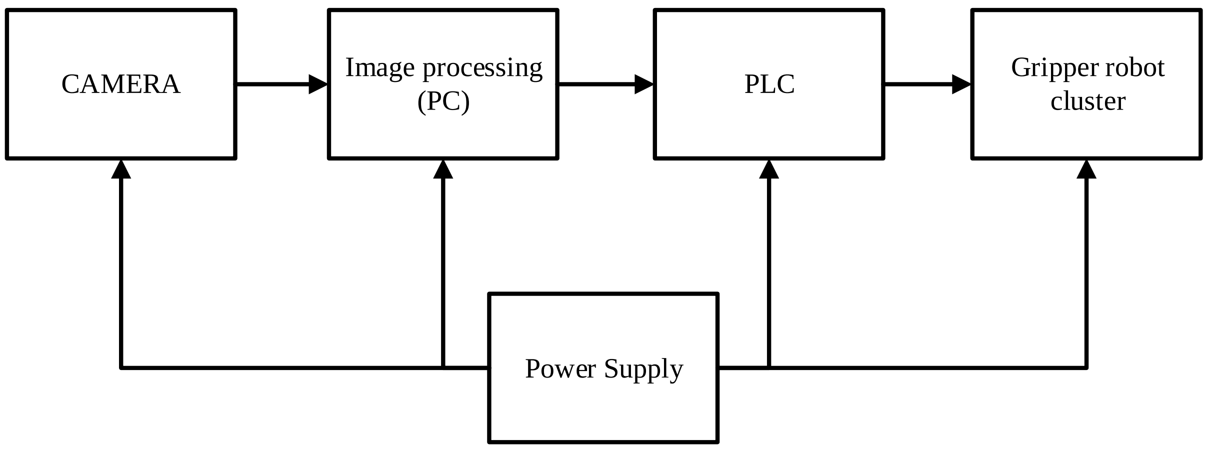

Fig. 2 Block diagram presenting the whole system

III. DESIGN OF THE CONTROL ALGORITHM

3.1. PLC

3.1.1 Structure and Operation of PLC:

Programmable Logic Controllers (PLCs) are specialized industrial computers designed for automation tasks within manufacturing processes. They excel at controlling, monitoring, and operating machinery and equipment based on user-defined logic derived from input and output signals. By leveraging PLCs, users can automate a wide range of industrial tasks, reducing the need for manual labor and minimizing the potential for human error.

The application of PLCs is widespread across various industries, with a particularly prominent role in production lines and conveyor systems. In these settings, PLCs act as the central orchestration units, overseeing and managing the entire production process. Offered in a variety of configurations, PLCs provide a crucial function in regulating and governing production operations. Their adaptability in programming allows users to tailor control programs to specific technological requirements, ultimately leading to optimized production efficiency.

A PLC system as illustrated in Fig. 3 comprises the following primary components:

- Memory: Consists of RAM and ROM, and can be supplemented with external memory such as

EPROM.

- Central Processing Unit (CPU): Executes calculations and processes control commands from the program.
- Input/Output (I/O) Module: The I/O module receives input signals from peripherals and controls output devices through output signals. When expanding the number of I/Os, additional I/O modules can be installed.
- PLC-Computer Connection Port: Connects to the computer through interfaces such as RS232, RS422, RS485.

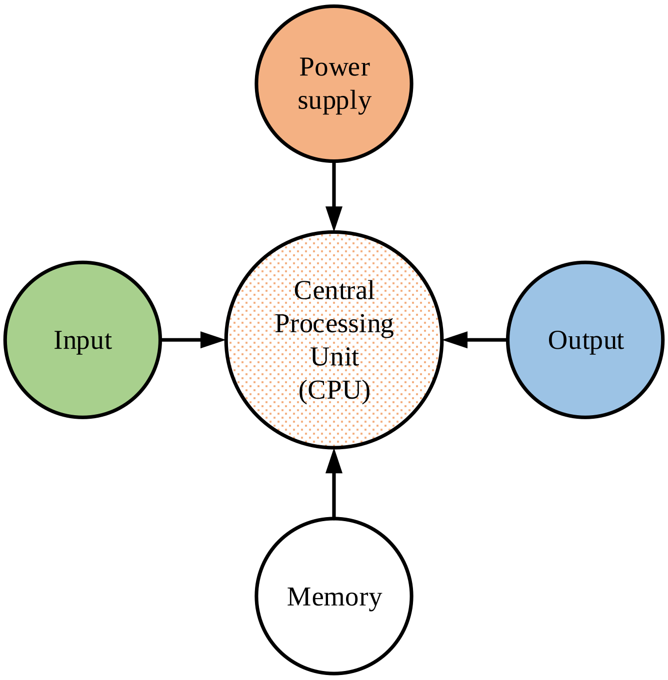

Fig. 3 The typical structure of a PLC

- Communication Port: Typically, PLCs incorporate a Modbus RTU communication port. They can also integrate other communication standards like Profibus, Profinet, CANopen, EtherCAT, etc.

The Central Processing Unit (CPU) acts as the PLC's brain, assuming primary responsibility for controlling all its operations. The processing speed of the CPU directly correlates to the control speed of the entire PLC system. The program logic, defining the desired control behavior, is stored within the PLC's Random Access Memory (RAM). Additionally, a backup battery safeguards the program from data loss during unexpected power outages.

The CPU executes a cyclical process known as program scanning. This process involves systematically checking and executing the program instructions in a predefined order. During each scan cycle, the CPU reads the state of each input signal. Based on the program logic and the retrieved input data, the CPU then triggers corresponding actions on the output signals. This continuous scanning process, occurring at high speeds, ensures the system's ability to maintain control over connected equipment with both continuity and accuracy.

3.1.2 PLC Algorithm flow chart in the System

Upon activation by a START button press, the PLC initiates the system operation. Subsequently, a product with a QR code is conveyed to a designated inspection location. Following image capture and subsequent analysis by LabVIEW, the processed data is transmitted back to the PLC for control decision-making. If the analysis determines a valid QR code, the gripper arm executes a pick-and-place operation, transferring the acceptable product to a designated "acceptable product" area. Conversely, for products with invalid QR codes, the gripper arm relocates them to the designated "unacceptable product" area. This iterative inspection and sorting process continues sequentially until all products have been evaluated and categorized (see Fig. 4).

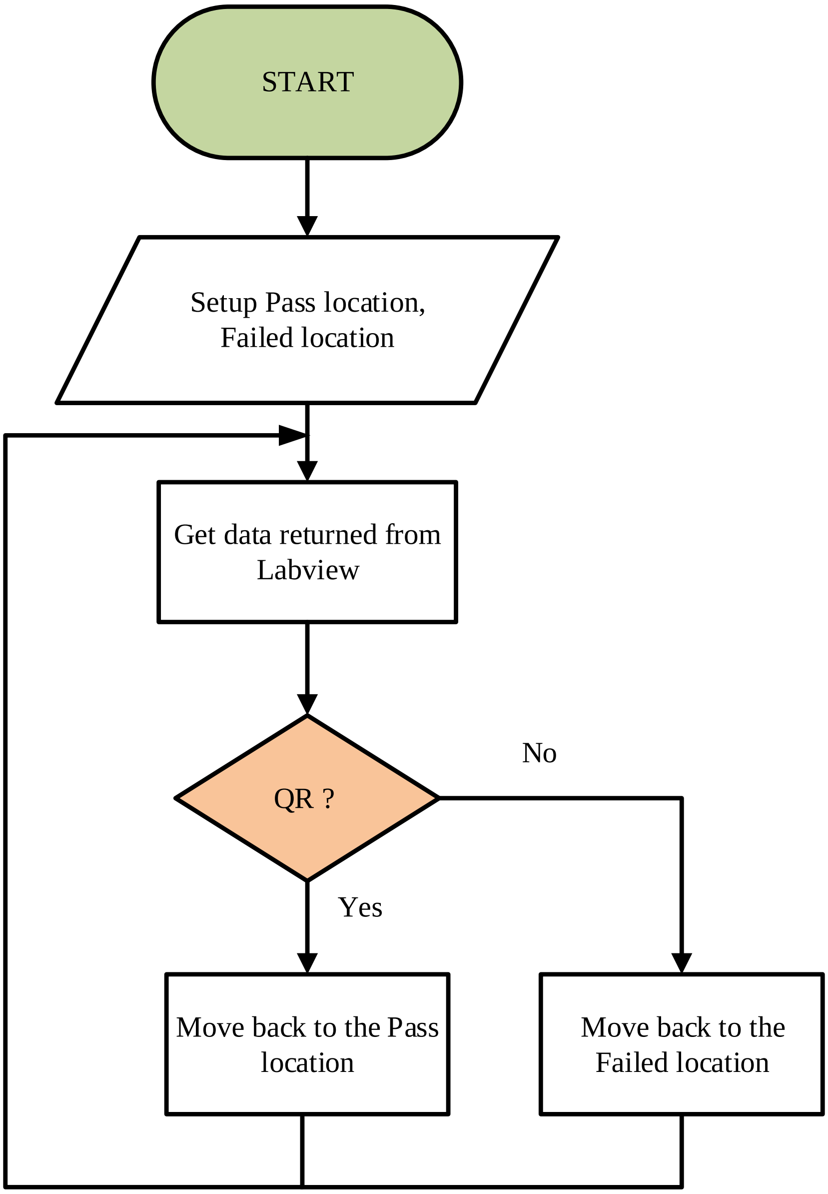

Fig. 4 The flow chart of PLC's algorithm proposed in this study

3.2 Image processing

The field of image processing bridges the gap between established scientific principles and the ever-evolving landscape of technological advancements. Although a relatively young discipline compared to its well-established scientific counterparts, image processing has emerged as a powerful tool with a multitude of practical applications, particularly in the realm of object recognition. This field harnesses the computational prowess of digital computers to analyze and manipulate image data through the implementation of one or more sophisticated algorithms.

At its core, image data can be conceptualized as a digitized representation of a real-world image. In essence, an image is comprised of a finite collection of discrete data points. Each individual data point encodes the specific color intensity at a corresponding location within a two-dimensional space. To effectively organize and process this data, it is typically arranged into a two-dimensional array structure. Each data point within this array is referred to as a pixel, forming the fundamental building block of digital images

3.2.1 The Basics of Image Processing

A diagram representing the basics of image processing plotted in Fig. 5 consists of the following

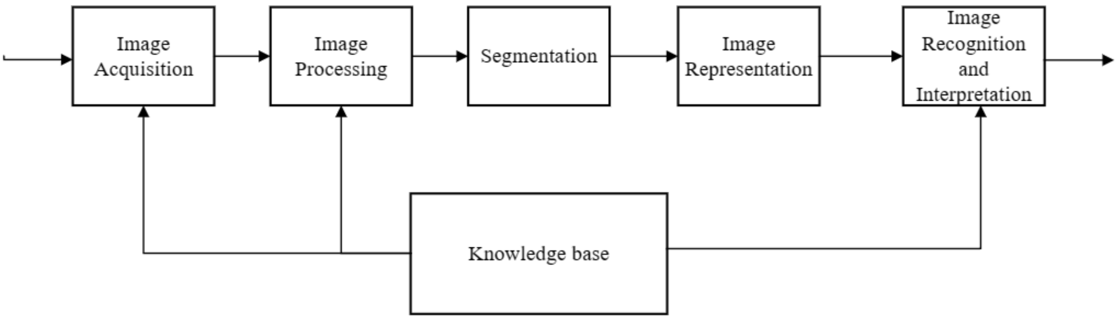

Fig. 5 Block diagram representing image processing steps

components:

- Image Acquisition: A camera is used to capture and provide image data (a standard CCIR camera with a 1/25 frequency, 25 lines per image). The quality of an acquired image depends on the capture device and the environment (lighting, scenery).
- Image Preprocessing: This involves noise filtering and contrast enhancement to improve image clarity and sharpness, as images can be affected by noise and low contrast.
- Segmentation: This involves dividing the image into distinct regions based on color or brightness levels.
- Image Representation: The output image after segmentation contains the pixels of the segmented region (the segmented image) along with codes that link to neighboring regions. This step enables the detection, recognition, and measurement of objects within the image.
- Image Recognition and Interpretation: This process typically involves comparison with previously learned (or stored) reference patterns. Interpretation involves making judgments based on the recognition. There are different ways to classify images. According to recognition theory, mathematical image models are classified into two basic types of image recognition:
  - Parameter-based recognition
  - Structure-based recognition
- Knowledge Base: Images are complex objects in terms of lines, brightness levels, pixel density, and are easily affected by noise from the sampling environment. The goal is to mimic the human process of image reception and processing. Thus, knowledge bases are leveraged.

3.2.2 Image Processing Algorithm

- Input: The image is captured using a camera.
- Color Conversion: The image color state is converted from natural color to grayscale.
- RGB to Grayscale Conversion: The image color is converted from RGB to grayscale using an equation: $Y = 0.299R + 0.587G + 0.114B$
- Each different RGB color value corresponds to a different grayscale value.
- Each pixel is converted to grayscale until the entire frame is complete.
- Search and Compare: This process consists of two main stages: Learning and Matching.
  - Learning: The algorithm extracts grayscale values from the sample image. The algorithm sets up and stores the information of the inspection image. The information from this stage is stored as the sample image.
  - Matching: The algorithm extracts grayscale values from the inspection image, then searches for similarities from the sample image. It then locates areas in the inspection image where the correlation is highest. This is the object.
- QR Code Reading: Each QR code is a combination of black dots and patterned squares on a white background that contains information such as URLs, time, production location, descriptions, and introductions to a specific product.
- Processing and Result: The encoded information from the QR code is presented for comparison with the standard sample.

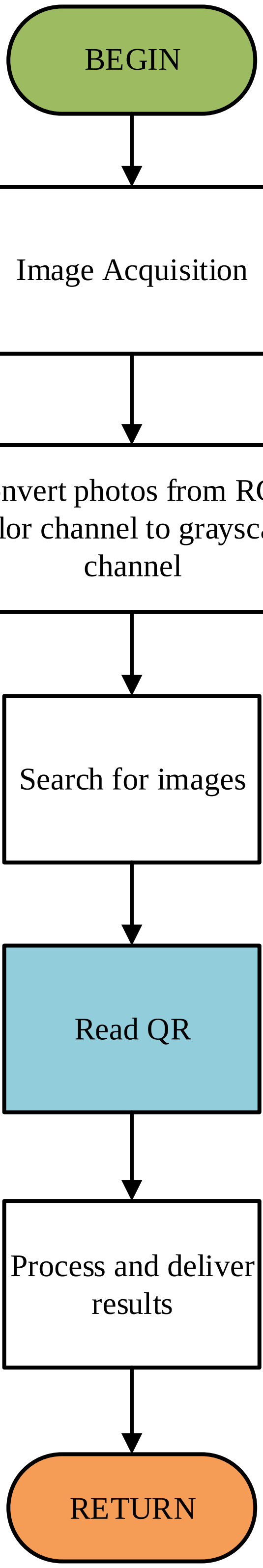

Fig. 6 QR image processing algorithm

IV. EXPERIMENT RESULTS

This section shows experiment results for the system designed earlier. System operation commences with the selection of a sample QR code from a designated computer directory. Following the selection of the target QR code for recognition, the appropriate camera address is configured. This configuration establishes a connection between the computer and the camera, enabling the flow of image data for processing. Subsequently, a system delay is meticulously adjusted to ensure optimal compatibility with the overall system operation.

During the inspection process, the camera scans each product. If the QR code on a product deviates from the pre-defined reference code (indicating a faulty code), the "Failed" indicator light illuminates. LabVIEW then transmits a corresponding signal to the PLC for further processing based on the failure condition. Conversely, if the scanned QR code matches the reference code (indicating a valid code), the "Pass" indicator light activates, and LabVIEW transmits a distinct signal to the PLC for processing based on the successful verification. The LapVIEW interface employed in this study is illustrated in Fig. 7.

Our research team employed Siemens' TIA Portal V16 software to design a dedicated WinCC control interface for the system. This interface provides functionalities for controlling the movement speed of individual axes within the gripper robot mechanism. Additionally, it offers real-time visualization and control capabilities for the positions of these axes (see Fig. 8).

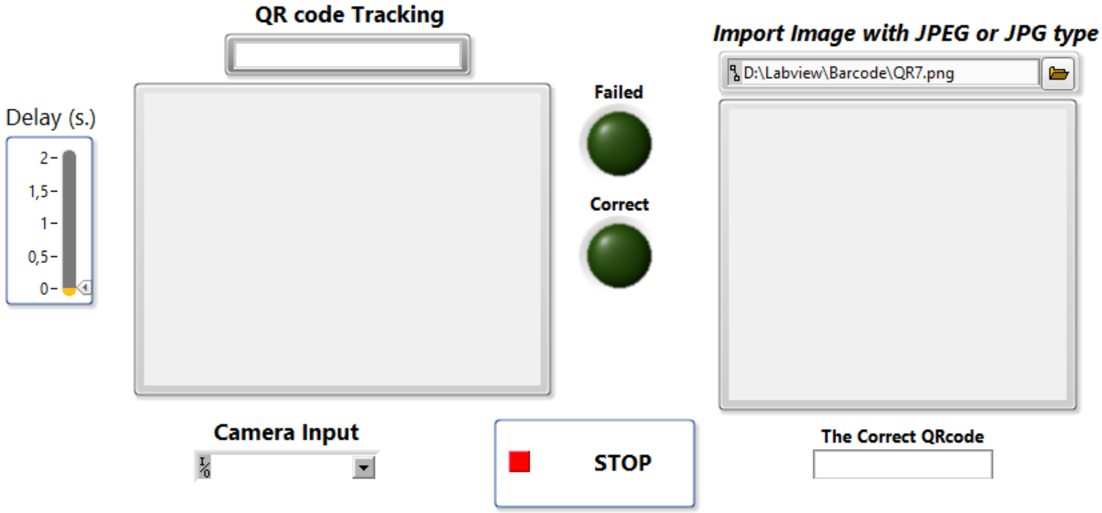

Fig. 7 LapVIEW interface when executing the system

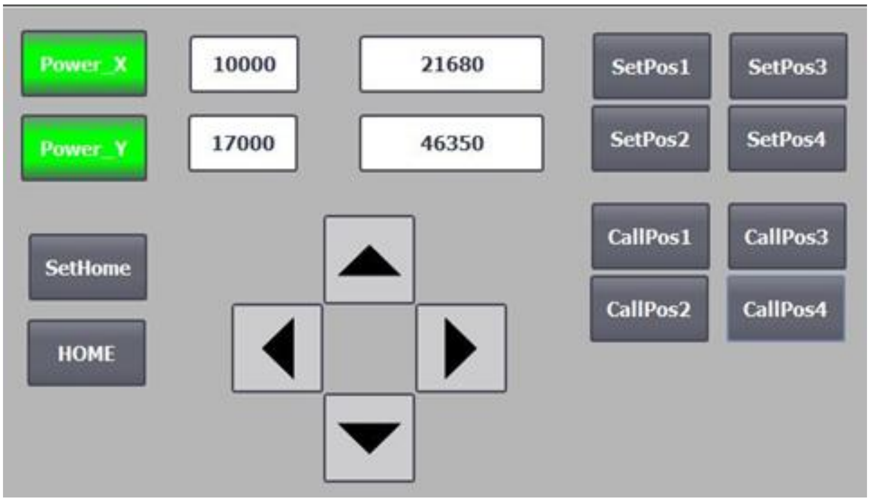

Fig. 8 WinCC interface when executing the system

After conducting numerous test runs, the results can be obtained as presented in Table 1. It can be seen from this table the following comments:

- The model exhibits high accuracy (>90%) with rapid response times.

- Factors influencing system deviation include lighting conditions, distance between the camera and the product, noise levels, and the quality of the images captured by the camera.

Table 1: Experiment results

	Correct QR Code	**Falled QR Code**
Detection Count	100	100
Correct Recognition Count	95	92
Accuracy	95%	92%

V. CONCLUSION AND FUTURE WORK

5.1 Conclusions

This research presents and implements several key tasks:

(1) Development of an image processing program for QR code recognition. This program is applied to an automated product sorting model, utilizing a pneumatic gripper controlled by a PLC and a WINCC monitoring system, thereby ensuring high sorting accuracy for labels with printing errors.

(2) The current focus of the image processing program lies in analyzing pixel regions. However, it lacks flexibility in allowing users to dynamically expand or reduce the processing area to accommodate various labels and printed boxes.

(3) The application of similar image processing technology holds potential for eliminating manual inspection and reducing production errors. It can be extended to similar fields, such as size inspection of product packaging in bottling plants, as well as the verification of concentricity and conformity to standard models in mechanical manufacturing fields like ball bearing production and mechanical machining.

5.2 Future work

To enhance the system's versatility and ease of operation, future research will concentrate on minimizing its size, weight, and operational complexity. The objective is to achieve a compact, user-friendly system while upholding high technical accuracy. Further improvements will prioritize operational safety and long-term stability. This will involve integrating infrared sensors to detect human intervention during operation, an emergency stop button to halt the system in case of incidents, collision sensors, and other safety features. Enhancing the system's flexibility will entail enabling users to dynamically expand or reduce the processing area, accommodating the diverse requirements of different QR codes and printing box types.

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