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A drug-grasping robot for traditional Chinese medicine pharmacies based on STM32

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Abstract
With the vigorous development of traditional Chinese medicine, traditional Chinese medicine pharmacies are facing challenges such as a wide variety of drugs, cumbersome manual operations, and easy cross-contamination in their daily operations. The traditional manual method of picking up drugs is not only inefficient but also prone to errors, which seriously affects the service quality of traditional Chinese medicine pharmacies. For this problem, this paper designs and implements a smart Chinese medicine pharmacy drug grasping robot system based on STM32 and machine vision. The system adopts a hierarchical control architecture, and the Host Computer deploys the YOLOv8 deep learning algorithm on the PC end to achieve high-precision recognition and positioning of 100 common Chinese medicinal materials. Taking the STM32 single-chip microcomputer as the system scheduling core, it is responsible for multimedia human-computer interaction and logical arbitration. The Arduino Mega2560 is paired with a Ramps1.4 expansion board as the motion control slave to drive the Delta parallel mechanical arm and the flexible gripper to achieve efficient grasping. In addition, the system integrates the remote interaction function of the mobile APP, achieving intelligent operation that is remotely controllable. The experimental results show that the average recognition accuracy rate of the system for Chinese medicinal materials reaches over 95%, and the success rate of grasping exceeds 90%, significantly improving the automation level of traditional Chinese medicine dispensing. System integration and testing were carried out for the feasibility and stability of the above-mentioned functions. By optimizing the control logic through Embedded Firmware Development, the robot can achieve a series of movements such as automatic object search, precise grasping, and remote interaction, and can also realize the function of intelligent prescription form analysis. The research results can provide technical demonstrations and references for the intelligent transformation of the traditional Chinese medicine industry.
Keywords: *Smart Chinese Medicine Pharmacy , STM32 , YOLOv8 , Flexible grasping , Machine vision*

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I. Introduction

At present, the dispensing of traditional Chinese medicine in most hospitals and pharmacies still mainly relies on manual weighing and grasping. This traditional model faces many challenges: First, Chinese medicinal materials come in various forms, such as roots, stems, leaves, and fruits, making it difficult to automatically capture them. Second, prolonged manual work can easily lead to fatigue, resulting in a decline in the accuracy of picking up medicine or even taking the wrong medicine. Thirdly, a dusty environment is detrimental to the health of medical staff. Therefore, developing a robot for a traditional Chinese medicine pharmacy that can intelligently recognize and flexibly grasp is of great practical significance for promoting the intelligent upgrade of the traditional Chinese medicine industry.

In recent years, significant progress has been made in the field of medical automation both at home and abroad, especially in pharmacy automation. Many Western countries have introduced dispensing robots. Qihong Pan et al. have built an intelligent pharmacy management platform, which greatly simplifies the dispensing process [1]. The automated pharmacy equipment of YUYAMA in Japan [2] and Rowa in Germany has occupied the major global markets, but their technical routes mainly target standard-packaged boxed drugs or regular tablets. Domestic research on the automation of traditional Chinese medicine mainly focuses on the "intelligent traditional Chinese medicine dispensing cabinet" model [3], that is, the prepared traditional Chinese medicine packages are discharged through vibrating discs or screw discharge mechanisms. Although this mode is highly efficient, it imposes certain restrictions on the freedom of medicinal material combination, and the sharing of different medicinal materials in the same channel can easily lead to cross-contamination of flavors.

In the field of grasping, traditional tandem robotic arms (such as six-axis robotic arms) are highly flexible but relatively slow, making it difficult to meet the dispensing speed requirements during peak hours in pharmacies. The Delta parallel robot, due to its lightweight dynamic platform design, features extremely high acceleration and working rhythm, and is often used in food sorting [4]. However, in the field of traditional Chinese medicine, how to cooperate with visual algorithms to process the myriad forms of medicinal materials and how to design end effector that do not damage the medicinal materials remain the current research difficulties.

Based on the above research, it has become an inevitable trend to study the drug grasping and measurement robot for traditional Chinese medicine pharmacies based on STM32. This paper designs a multi-functional and intelligent drug grasping robot, as shown in Fig 1, aiming to address the current problems of low efficiency and high error rate faced by traditional Chinese medicine pharmacies. By precisely controlling the grasping force and position, it promotes the deep integration of traditional Chinese medicine and modern technology.

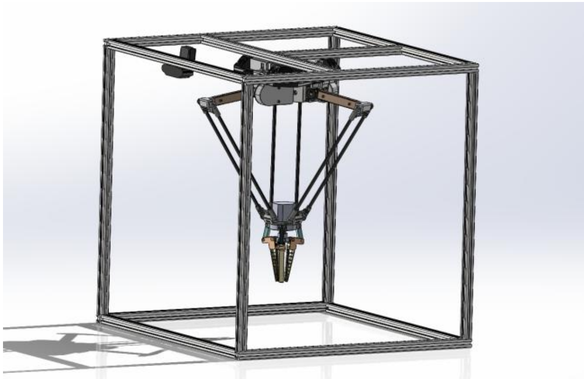

Fig. 1. Model of the drug-grasping robot for traditional Chinese medicine pharmacy

II. Design and Analysis of the Mechanism for Drug Grasping Robots

2.1 *Design Requirements Analysis*

According to the actual working environment of the smart Chinese medicine pharmacy[5] and the standardization requirements of the modern dispensing process, the design of this system needs to comprehensively consider key technical indicators in multiple dimensions such as visual perception ability, mechanical operation efficiency, stability of grasping quality, and safety of human-computer interaction.

At the visual perception level, given the wide variety and complex texture features of traditional Chinese medicine pieces, the system must have a strong generalization recognition ability, and be capable of achieving high-precision classification and positioning of no less than 100 common types of Chinese medicinal materials (covering different physical forms such as root and stem, flower and leaf, fruit, and mineral types) to meet the basic needs of daily prescription dispensing.

In terms of operational efficiency and motion performance, to effectively alleviate the queuing phenomenon of picking up medicine during peak hours in pharmacies, the robotic arm system needs to have high-speed dynamic response characteristics. It is required that the complete operation cycle of "visual recognition - path planning - grasping - placing" be controlled within 30 seconds at a time to match the rhythm of manual dispensing or automatic dispensing machines. In view of the extremely fragile physical characteristics of Chinese medicinal materials (especially dried flower and leaf types and brittle root and stem types), the design of end effectors faces strict requirements. The system must adopt a clamping mechanism with force control or flexible buffering function to ensure that the damage rate of medicinal materials during the grasping process is less than 1%, truly achieving "non-destructive" flexible operation and avoiding the loss of effective components or morphological damage of medicinal materials due to excessive mechanical force.

In terms of human-computer interaction and system security, to lower the operational threshold for pharmacists and adapt to the development trend of the Internet of Things, the system not only needs to support offline voice command interaction and remote monitoring via mobile apps, but also must be equipped with a hardware-level emergency stop protection mechanism. When communication anomalies are detected or emergency stop instructions are received, the system should be able to cut off the power supply of the motion execution unit through physical means, thereby comprehensively ensuring the safety of operators and equipment.

2.2 *Overall System Architecture Design*

The architecture of the multi-functional drug grasping robot is mainly divided into three parts, namely the perception and decision-making layer, the core scheduling layer, and the motion execution layer. The three work together to achieve the automatic drug grasping function, as shown in Fig 2.

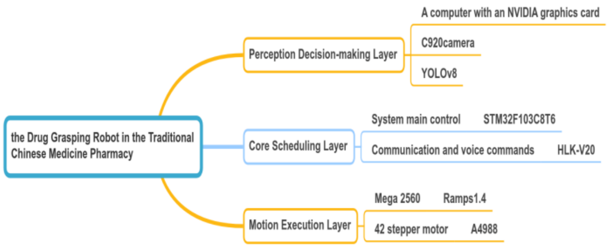

Fig. 2. Functional Analysis of the drug-grasping robot for traditional Chinese medicine pharmacy

2.2.1 *Perception Decision-making Layer*

The perception decision-making layer, namely the Host Computer, runs on a high-performance computer equipped with an independent graphics card. Connect the Technologist C920 camera via USB, run the YOLOv8 algorithm for image acquisition and reasoning, identify and calculate the category and center coordinates of the target medicinal materials, and send the data through the USB-to-TEL serial port.

2.2.2 *Core Scheduling Layer*

The STM32F103C8T6 is adopted as the system main control. It is responsible for receiving the coordinate data of the Host Computer, processing the voice instructions of HLK-V20, communicating with the mobile phone APP via Bluetooth, and managing the task queue.

2.2.3 *Motion Execution Layer*

The Arduino Mega2560 is paired with a Ramps1.4 expansion board. As a dedicated motion control card, it receives G-code instructions sent by STM32 and drives four A4988 actuators (three control arm axes and one control gripper axis) through inverse kinematics calculation to achieve precise motion.

2.3 *Pharmacy layout design*

The workspace of the Delta robot is an inverted cone. To maximize the utilization of space, this design adopts a circular (or honeycomb) layout. Arrange the transparent containers holding traditional Chinese medicine in concentric circles around the center of the robotic arm, with the camera looking down vertically to ensure that all the medicine boxes are within the field of view. This layout reduces the travel of the robotic arm and improves the grasping efficiency.

III.Mechanical structure and end effector design

3.1 *Overall framework and Delta Institution*

The main frame of the system is constructed with 2020 industrial aluminum profiles, with dimensions of [640mm×600mm×640mm]. It is fixed with Angle codes and T-nuts, ensuring rigidity during high-speed operation.

The Deltaparallel Robot [6] consists of a static platform, a dynamic platform and three symmetrical side chains, as shown in Fig 3. Each branch chain consists of a driving arm and a driven arm. The active arm is connected to the stepper motor. The driven arm is composed of two parallel carbon fiber rods, with both ends connected by universal ball joints. This parallelogram structure restricts the rotational freedom of the moving platform, keeping it always horizontal, which is highly suitable for drug grasping and translation operations.

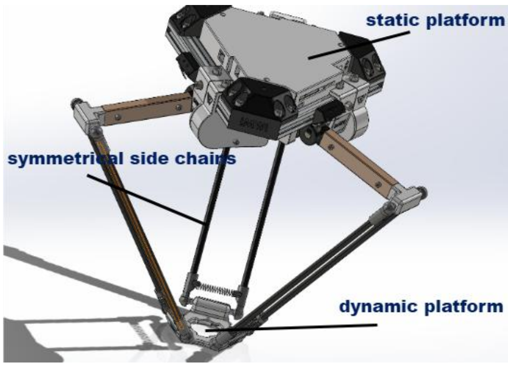

Fig. 3. The structure of the Delta Parallel Robot

3.2 The motion principle and control implementation of the Delta robotic arm

The Delta parallel robotic arm is the core moving component of this system. Unlike the common tandem robotic arms, the Delta robotic arm looks more like a suspended triangular structure. It is driven by three stepper motors at the top and connected to the mobile platform at the bottom through three sets of parallel carbon fiber connecting rods.

The greatest advantage of this structure lies in its "speed" and "stability". Since the motors are all fixed on the top of the rack and do not need to move along with the arms, they have very little inertia during movement and are very suitable for grasping light Chinese medicinal materials.

In terms of control, we encountered a core issue: How can we make the three motors rotate at specific angles so that the bottom gripper can precisely reach the spatial coordinates we desire? This is known in engineering as "inverse kinematics solution"[7].

Given the extreme complexity of the mathematical derivation, this project adopted the Marlin open-source firmware, which is very mature in the field of 3D printing, as shown in the Fig 4. We flashed the Marlin firmware onto the Arduino Mega2560 main control board and entered the actual measured parameters of the robotic arm (such as the length of the connecting rod, the radius of the swing arm, etc.) in the configuration file. In this way, the STM32 main control only needs to send simple coordinate instructions (such as G1 X10 Y20) just like commanding a 3D printer. The algorithm inside the Mega2560 will automatically calculate how many degrees the three motors should rotate, greatly reducing the development difficulty and ensuring the stability of operation.

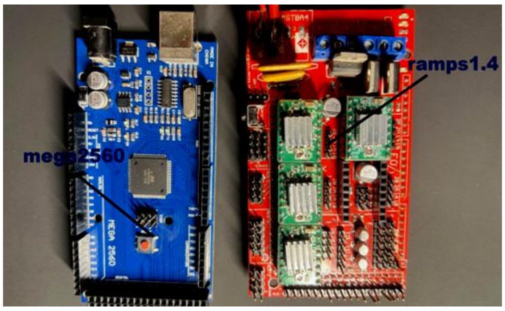

Fig. 4. Mega2560 and ramps1.4

3.3 Design of Flexible Grippers

This is a component specially designed for this project to address the issue of "fragility of traditional Chinese medicine". Most mechanical claws on the market are made of metal or hard plastic. When grasping crisp licorice slices or fragile medicinal materials like flowers and leaves, if the force is slightly too strong, the medicine will be crushed.

To solve this problem, we designed and fabricated a wire-driven three-jaw flexible fixture, as shown in the Fig 5. We used TPU (a soft plastic as elastic as rubber) as the material and printed three fingers through a 3D printer. This material has a large surface friction force and feels very soft when pinched, with a built-in buffering effect. In terms of structure, it adopts a design with three fingers distributed in a triangular pattern. Compared with two fingers, three fingers can automatically focus and grasp irregularly shaped objects (such as blocky poria cocos and round goji berries) more steadily.

For the drive, we used a stepper motor in combination with a lead screw. The opening and closing are achieved by pulling the connecting rod inside the finger. When the fingers come into contact with the medicinal herbs, the soft fingertips will deform and "wrap" the herbs along their shape instead of tightly "clamping" them. Experiments have proved that this method can not only pick up the medicinal materials but also will not cause damage.

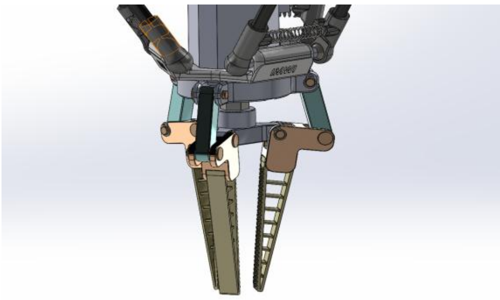

Fig. 5. Flexible Grippers

3.4 Interaction and assistance module

Speech recognition module: Hailink HLK-V20 is selected. This module is equipped with a high-performance neural network processor and supports offline voice command word recognition. Through the configuration tool provided by the manufacturer, 20 instructions such as "Grab Angelica sinensis", "Grab Goji berries", "Stop working", and "Reset" were burned.

Camera: Logitech C920, supporting 1080P resolution, auto-focus, USB2.0 interface for direct connection to the host computer.

IV.Hardware circuit and control system design

4.1 STM32 main control circuit board

As the scheduling core of the entire robot system, the performance of the main control unit directly determines the response speed and interaction experience of the system. After a comprehensive consideration of cost and performance, the STM32F103C8T6 minimum system board based on the ARM Cortex-M3 core was selected for this system. This chip has a main frequency of 72MHz and abundant peripheral resources, which is sufficient to support the demand for concurrent processing of multiple tasks.

To achieve efficient collaboration among the Host Computer's vision, the Slave Controller's motion, and human-computer interaction devices, we have modularly divided the communication interfaces of STM32 and constructed a stable multi-level communication link

Firstly, the system enables the USART1 interface (PA9/PA10) as the "visual perception channel", with a baud rate of 115200bps, specifically for receiving the visual recognition results and coordinate data (class_id, x, y) sent by the PC host computer;

Secondly, the USART2 interface (PA2/PA3) is utilized as the "motion control channel", and it is also connected to the Arduino Mega2560 at a high-speed baud rate of 115200bps, responsible for sending the calculated G-code motion instructions in real time.

In addition, the USART3 interface (PB10/PB11) is defined as the "human-computer interaction channel". Through time-division multiplexing or soft serial port expansion technology, the HLK-V20 voice module and the HC-05 Bluetooth module are simultaneously mounted, achieving real-time response to user voice commands and control signals from mobile phone apps.

In terms of ensuring the safety of system operation, a hardware-level emergency stop mechanism has been specially introduced in the design. We configured the PA0 pin as a high-priority external interrupt input and connected it to the physical emergency stop button. The control logic is set as follows: Once the emergency stop signal is detected to be triggered, the internal program of STM32 will immediately disconnect all communication tasks, stop sending instructions to the Mega2560, and simultaneously raise the Enable pin of the Mega2560 driver board. This dual insurance mechanism combining software and hardware can ensure that in the event of an accident, the motor of the robotic arm will instantly lose power and lock, providing the greatest guarantee for the safety of the experiment.

4.2 Mega2560 + Ramps1.4

Main control board: Arduino Mega2560 R3, featuring a rich array of IO ports, suitable for multi-channel motor control.

Expansion board: Ramps 1.4 (RepRap Arduino Mega Pololu Shield). This board is specially designed for 3D printers and integrates a motor drive slot, a limit switch interface and a power interface.

Motor drive: The A4988 drive module is selected and configured with 16 subdivisions. The application of subdivision technology has greatly reduced the low-frequency vibration of stepper motors, making the grasping process more stable.

Stepper motors: Four 42 stepper motors (model 17HS4401) are selected, with three for Delta arm drive and one for the extruder interface (E0) to drive the flexible gripper.

4.3 Interaction and power module

Voice module: The HLK-V20 offline voice module from Hailink is selected. This module does not require an Internet connection and has a response delay of less than 200ms. By presetting terms such as "Grab Angelica sinensis" and "Reset" through the configuration tool, the module recognizes them and outputs the corresponding Hex instructions to STM32.

Power supply system: A 12V/10A switching power supply is directly used to power the Ramps1.4 board and drive the stepper motor. The LM2596 DC-DC step-down module converts 12V to 5V to supply power to the STM32, Bluetooth module, voice module and servo, achieving isolation between power supply and logic power and enhancing the system's anti-interference capability.

V.A visual recognition algorithm for traditional Chinese medicine based on YOLOv8

5.1 Overview of Convolutional Neural Networks and YOLOv8

Object detection is the core task of machine vision. Compared with the two-stage algorithms of the R-CNN series, the YOLO (You Only Look Once) series algorithms achieve end-to-end detection through the idea of regression and are extremely fast. YOLOv8 is an image recognition model released by Ultralytics. It optimizes the Backbone network (Backbone) and detection Head (Head) on the basis of the commonly used YOLOv5, and introduces the Anchor-Free mechanism. Its performance is more outstanding in small target detection and complex backgrounds. It is highly suitable for the complex texture targets of traditional Chinese medicinal materials[8].

5.2 Dataset construction and preprocessing

Image acquisition: In a laboratory environment, a realistic capture scene was simulated. By adjusting different light intensitions (natural light, fluorescent lamp supplementary light) and the placement angles of medicinal materials, 100 typical Chinese medicinal materials including Angelica sinensis, Astragalus membranaceus, Lycium barbarum, red dates, and licorice were captured. A total of 3,000 original images were collected.

Data annotation: Manual annotation was performed using LabelImg software, as shown in the figure, to generate a.txt tag file in YOLO format, as showed in Fig 6.

Data augmentation: To prevent overfitting of the model and enhance generalization ability, techniques such as Mosaic data augmentation, random clipping, and color jitter (HSV transformation) were adopted to expand the dataset to 6,000 images, which were then divided into a training set, a validation set, and a test set in an 8:1:1 ratio.

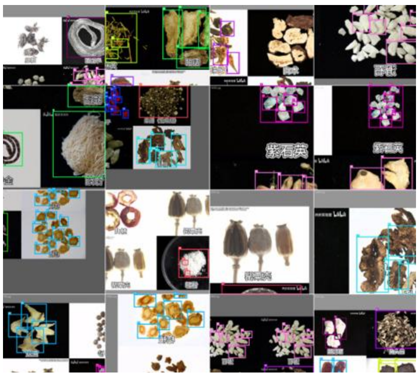

Fig. 6. Some identification detection instances

5.3 Coordinate transformation and hand-eye calibration

YOLOv8 outputs the pixel coordinates (u, v) of the target center on the image plane, while the control of the robotic arm requires physical spatial coordinates (x, y). The system adopts the classic nine-point calibration method to solve the perspective transformation matrix.

Place the calibration plate on the working plane and record the true coordinates (xi, yi) of the 9 feature points in the robotic arm coordinate system.

Read the pixel coordinates (ui,vi) of these 9 points through the camera.

Solve the homography matrix H by using the least square method.

In actual operation, the recognized pixel coordinates are converted into physical coordinates in real time by using matrix H.

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = H \cdot \begin{bmatrix} u \\ v \\ 1 \end{bmatrix}$$

During actual operation, the system substitutes the (u, v) output by YOLOv8 into the above formula to calculate the physical coordinates (X, Y) of the target in real time. For height Z, since the Chinese medicinal materials are laid relatively flat, it is temporarily set to a fixed grasping height, or an ultrasonic sensor is used to assist with distance measurement.

VI.Conclusion

This paper designs and implements a set of intelligent traditional Chinese medicine grasping robot system based on STM32 and machine vision. It innovatively constructs a low-cost dual-core heterogeneous control architecture of "STM32 logical scheduling +Mega2560 motion execution", and uses the YOLOv8 deep learning algorithm to overcome the high-precision recognition problem of unstructured traditional Chinese medicinal materials. By integrating the self-developed TPU wire-driven flexible end effector with the voice /APP multimodal interaction module, the "flexible and non-destructive grasping" of fragile medicinal materials and intelligent human-machine collaboration have been successfully achieved, verifying the application potential of automation technology in the scenario of traditional Chinese medicine dispensing. Limited by the current experimental conditions, the system still has room for improvement in three-dimensional perception and precise measurement at present. In the future, it is planned to introduce RGB-D depth cameras to solve the problem of stacking and positioning of medicinal materials, and integrate tactile sensors and electronic scales to build a "grasping - weighing" closed-loop feedback system, thereby further enhancing the intelligence level and clinical practical value of the system.

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