Design of Fruit-Picking Robot Based on Intelligent Internet of Things Technology

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Abstract. In order to solve the problems of intensive fruit planting scale, rising labor costs, and rural labor force loss, a fruit-picking robot based on intelligent Internet of Things is designed in this paper. Fruit-picking robot uses raspberry pie 4B and STM32 board as the main part. The employed modules include USB high-performance camera, ultrasonic ranging, color sensor, wireless transmission, gear control, GPS, laser radar ranging and gyroscope. Using YOLO algorithm and D-H parameter method to achieve accurate identification of target fruit, accurate picking of ripe fruit and stable mobility of the machine. This can improve the adaptability to environmental changes for the fruit-picking robot. Users can remotely control the fruit-picking robot through the cloud, which can improve the production efficiency and quality of fruit agricultural products, and support modernization and sustainable development of agricultural production.

Keywords: Internet of Things · laser radar ranging · YOLO algorithm · accurate picking

1 Introduction

With the continuous advancement of the tide of scientific and technological progress, the Internet of Things technology has gradually integrated into every corner of society. Especially in the traditional industry of agriculture, the impact of the Internet of Things is particularly profound. The Government of the People's Republic of China attaches great importance to the development of the Internet of Things technology, and points out in several policy documents such as the 14th Five-Year Digital Economy Development Plan, emphasizing the importance of promoting the digital transformation of agriculture, and clarifying the core position of the Internet of Things technology in it. Under such a policy background, the research and development and application of the intelligent Internet of Things fruit-picking robot not only represents the innovation and breakthrough of agricultural science and technology, but also represents the concrete practice in response to the national rural revitalization strategy.

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Traditional picking robots generally only target a specific fruit and have the problems of low identification accuracy and poor working effect. To solve the above problems, this design takes STM32F104 as the control core, combines Raspberry PI for image information processing and integrates a deep learning model to improve the picking accuracy. The machine can realize the function of independently planning the picking path, intelligent identification, screening, positioning, and picking fruit. In addition, QT is used to build a cloud data platform to realize real-time analysis and remote control of picking data. The design of the machine greatly improves the efficiency and quality of agricultural production while significantly reducing the physical labor of farmers, improves the working conditions, and has a positive effect in attracting and stabilizing the rural labor force.

2 Design of the System

The system design aims to complete the whole picking process intelligently. The overall design is divided into upper system design and lower system design. The upper layer system includes the data collection and processing module and the control operation module. Among them, the data collection and processing module takes the raspberry pie as the main body to process the image information, and the fruit photos collected by the raspberry party judge the size, color, and other information and sends the data to the STM32 controller through serial port communication. The control operation module takes STM32 as the main body and combines multiple sensor modules and steering gear to realize the precise control of the picking attitude of the mechanical arm. The lower system is mainly responsible for the movement of the machine position, with the ranging module, electric adjustment, motor, track, and other devices, mainly to realize the movement function of the fruit picking machine. The diagram of designed fruit-picking robot system is shown in Fig. 1.

2.1 Data Collection and Processing Module

The Raspberry Pi can connect a variety of sensors and art machines with powerful computing power and rich extended interfaces making it ideal for real-time image acquisition and processing. The Raspberry Pi is used to connect with the USB high-performance binocular camera and display screen, and the data collection and processing module can efficiently and accurately process the picture information. The USB camera captures the fruit information, and the Raspberry Pi uses edge detection, color segmentation, and other algorithms to segment the image into different areas, extract useful feature information, and send the position, size, maturity, and other information of the target fruit to the STM32 controller through serial port communication. At the same time, the display will display the image location information after being processed by Raspberry Pi to monitor the working state of the fruit-picking robot.

2.2 Control and Operation Module

This module is the core area of the machine command issued. The area will use STM32 as the controller, the specific model is selected STM32F4 series, the series of microcontrollers that integrates high performance, low power consumption, and rich peripheral

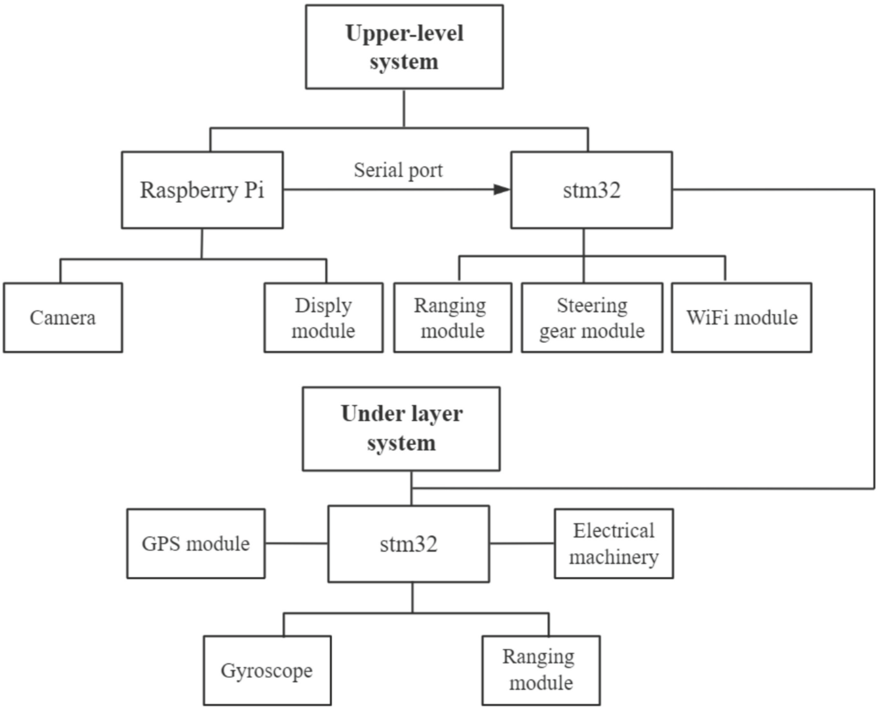

Fig. 1. Diagram of fruit-picking robot system

interface. STM32 receives the position, size, and maturity information sent by Raspberry Pi through the serial port and calculates the moving data of the cloud head and claw by using the D-H parameter method. Finally, the PWM wave output controls the rotation angle of the steering gear through the I/O port, to realize the movement of the mechanical arm and the realization of the grasping action. At the same time, STM32 is connected with an ultrasonic sensor, laser ranging sensor, and other devices to further supplement the fruit position information, and achieve the purpose of accurately grasping ripe fruit. The main workflow of the operation module is shown in Fig. 2.

Lower layer system is directly controlled by STM 32, responsible for the movement of the machine, including the track, motor device, GPS module, infrared ranging module, and gyroscope required for obtaining data. Using the characteristics of STM32F4 series MCU supporting the expansion of external memory, the map data is loaded into the memory of STM 32, and the corresponding data structure and algorithm are designed to realize the path planning and position matching operation in the navigation process.

3 Design of the System Hardware

The hardware circuit design of the system mainly includes the target detection module, steering gear control module, power supply module, Wireless transmission module, ranging and measuring module. The specific circuit connection is shown in Fig. 3.

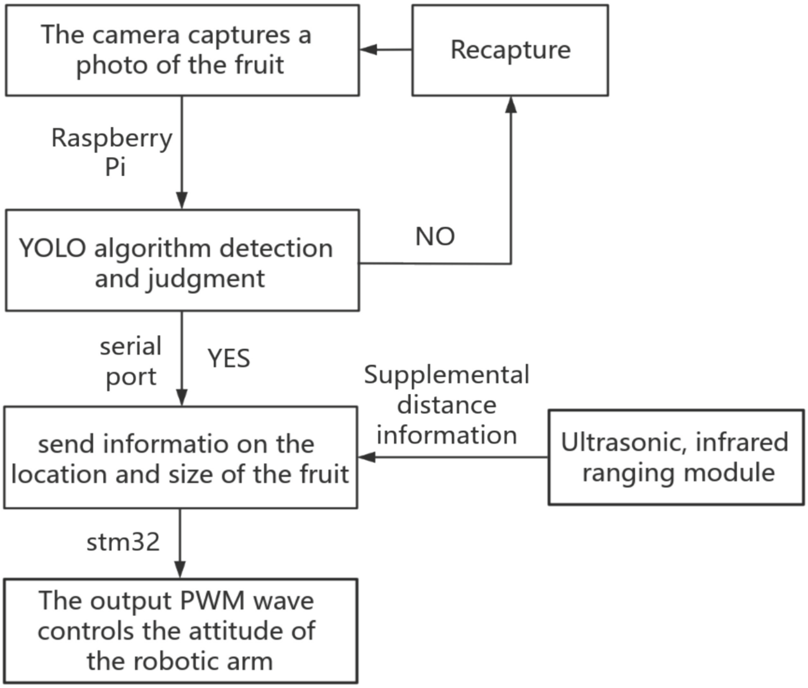

Fig. 2. Workflow chart of the operation module

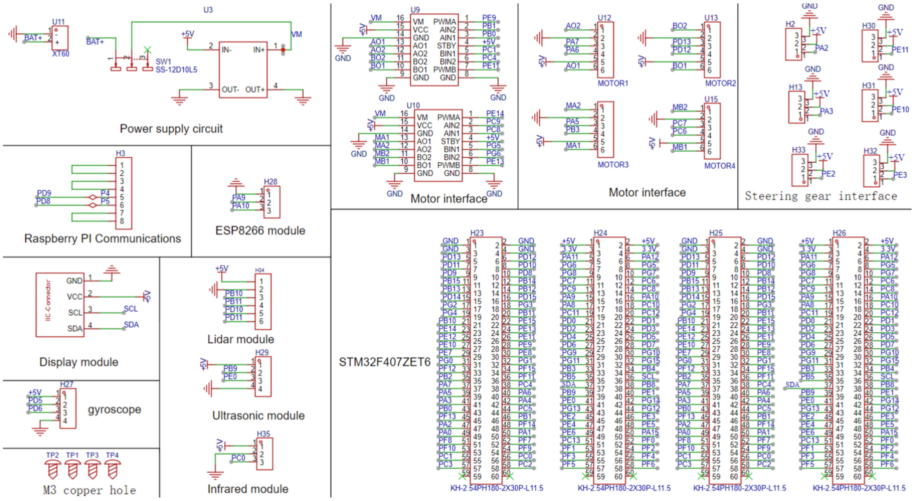

Fig. 3. Diagram of circuit connection

3.1 Target Detection Module

This module is used to calculate the position information of the target fruit and provide corresponding parameters for the robotic arm-picking attitude. It is mainly obtained by high-performance binocular cameras, ultrasonic ranging, and infrared sensors as data supplement. High-performance binocular cameras often support faster frame rates, providing higher resolution and higher color reduction images. Meanwhile, target detection and image segmentation are used to extract the features. After the fruit is identified, its position in the image can be determined and then converted to the actual physical position. Infrared sensors can detect the heat of an object and determine the position of the object based on its heat distribution. During ripening, they usually produce heat different from their surroundings, using this feature to capture the distance from the target fruit. The ultrasonic sensor sends the ultrasonic pulse and measures its return time to determine the distance of the target fruit. Image-based, infrared, and ultrasonic auxiliary ways can provide accurate information for the robotic arm to make the corresponding picking attitude. The following analysis is the specific process of the binocular camera positioning the 3-D coordinates.

To improve the accuracy of picking, a 100° binocular camera is used to locate the fruit in 3-D coordinates. Due to the different physical structure of the binocular camera, using OpenCV to determine the internal and external parameters and rotation translation matrix of the camera, and use the above parameters to ensure that the left and right images are on the same level. Then using SGBM technology, compare the pixels in the left and right images, find the best corresponding point of each pixel in the left and right images, and calculate the parallax. Finally, according to the principle of triangle similarity, the three-dimensional coordinates of the object in space are calculated using disparity and the parameters of the camera. Figure 4 shows the binocular positioning model, where the P points in space are P1 (u1, v1) and P2 (u2, v2). P2, 01, and 02 are the light centers of the two cameras, B is the distance between the two light centers, f is the focal length, and the disparity is $k =$ u1-u2. According analysis, we can obtain,

$$\frac{Z}{Z-f} = \frac{B}{B-k} \tag{1}$$

$$x = \frac{u1B}{k}, y = \frac{v1B}{k}, z = \frac{Bf}{k} \tag{2}$$

where, x is the X-axis coordinate of the target fruit, y is the Y-axis coordinate of the target fruit, and z is the Z-axis coordinate of the target fruit.

3.2 Steering Gear Control Module

The steering gear drive module is mainly responsible for controlling the change of picking attitude from the robot. The steering gear can accurately control the Angle and speed, making the movement of the mechanical arm more accurate and controllable. This design controls the rotation of the base, the upper and lower movement of the arm, and the opening and closing of the claws. When the pulse width of the PWM signal is within a specific range, the rudder opportunity correspondingly rotates up to the corresponding

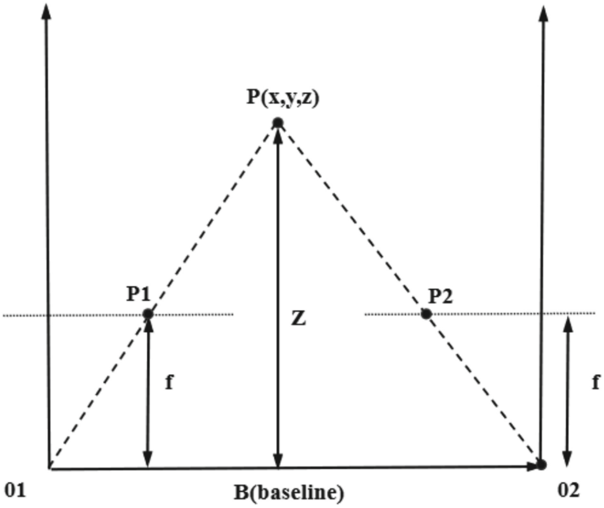

Fig. 4. Binocular localization model

angular position by adjusting the pulse width of the PWM signal. The three steering gears of the robotic arm rotate at different angles according to the position information of the fruit to realize the harvesting function and conveying into the box. The following is a mechanical analysis of the robotic arm picking. This design uses the six degrees of freedom robotic arm to pick the target fruit. STM32 needs to produce PWM waves with different pulse widths according to the three-dimensional coordinates of the fruit space to control the change in the posture of robot. To simplify the analysis process, the mechanical arm is projected to a two-dimensional plane for specific analysis and ignores the mechanical claw.

Map the front view and the top view of the robotic arm to the two-dimensional space to get Fig. 5, analyze Fig. 5(b), we can obtain,

$$tan\theta = \frac{y}{x} \tag{3}$$

Using geometric relations and x, y, and z, respectively, there is

$$x = \left[L_1 \cdot sin\theta_1 + L_2 \cdot sin(\theta_1 + \theta_2) + L_3 \cdot \sin(\theta_1 + \theta_2 + \theta_3)\right] \cdot cos\theta \tag{4}$$

$$y = \left[L_1 \cdot sin\theta_1 + L_2 \cdot sin(\theta_1 + \theta_2) + L_3 \cdot \sin(\theta_1 + \theta_2 + \theta_3)\right] \cdot sin\theta \tag{5}$$

$$z = L_1 \cdot cos\theta_1 + L_2 \cdot cos(\theta_1 + \theta_2) + L_3 \cdot cos(\theta_1 + \theta_2 + \theta_3) \tag{6}$$

where the connecting rod value x, y, z, which is assumed to L_1, L_2, L_3 are fixed for the manipulator, which is the obtained coordinate position for the convenience of calculation and reading, it is assumed,

$$a = \frac{x}{cos\theta} \tag{7}$$

Using the above formula and Eq. (4), Eq. (6), we can know

$$a - L_1 \cdot sin\theta_1 = L_2 \cdot sin(\theta_1 + \theta_2) + L_3 \cdot sin\,(\theta_1 + \theta_2 + \theta_3) \tag{8}$$

$$z - L_1 \cdot cos\theta_1 = L_2 \cdot cos(\theta_1 + \theta_2) + L_3 \cdot cos(\theta_1 + \theta_2 + \theta_3) \tag{9}$$

Combine Eq. (8), Eq. (9) for further simplification, then there is

$$cos\theta_3 = \left[a^2 + x^2 + {L_1}^2 - {L_2}^2 + {L_3}^2 - 2a \cdot L_1 \cdot sin\theta_1 - 2x \cdot L_1 \cdot cos\theta_1\,\right] \cdot \frac{1}{2L_2 \cdot L_3} \tag{10}$$

At this point, it is worthwhile to make $m = L_2 \cdot sin\theta_1 + L_3 \cdot sin(\theta_1 + \theta_3)$, $n = L_2 \cdot cos\theta_1 \; + L_3 \cdot cos(\theta_1 + \theta_3)$, $t = a - L_1 \cdot sin\theta_1$, expand the Eq. (4) and there is,

$$t = cos\theta_2 \cdot m \; + sin\theta_2 \cdot n \tag{11}$$

Change Eq. (11),

$$t - sin\theta_2 \cdot n = m \cdot \sqrt{1 - sin^2\theta_2} \tag{12}$$

Similarly, Eq. (12),

$$sin^2\theta_2\left(m^2 + n^2\right) - 2sin\theta_2 nt \; + t^2 - m^2 = 0 \tag{13}$$

At this point, it can be solved,

$$sin\theta_2 \; = \frac{nt \; + \; m\sqrt{m^2 \; + n^2 \; - t^2}}{m^2 \; + n^2} \tag{14}$$

In summary, the inverse function of the Eqs. (3), (10), and (14) can be obtained by solving $\theta, \theta_2, \theta_2, \theta_3$. Among them, θ_2 and θ_3 are related to θ_1, by traversing the calculation of all the values of θ, θ_1, θ_2 and θ_3, from which to choose the smallest rudder force of a group of that is the optimal solution.

3.3 Power Supply System

The power supply mode is mainly powered by lithium batteries, while the system will add solar panels to collect energy to provide charging service for lithium batteries and achieve the purpose of improving endurance. The process is to use DC-DC voltage stabilization module to transfer different voltages to single-chip microcomputer, Raspberry Pi, motor, and other modules respectively. As a high energy density battery, lithium battery has light quality, high output power, and strong endurance. Improve charging controller to convert the solar energy into electric energy, increase working time of the machine, and improve picking efficiency of the machine.

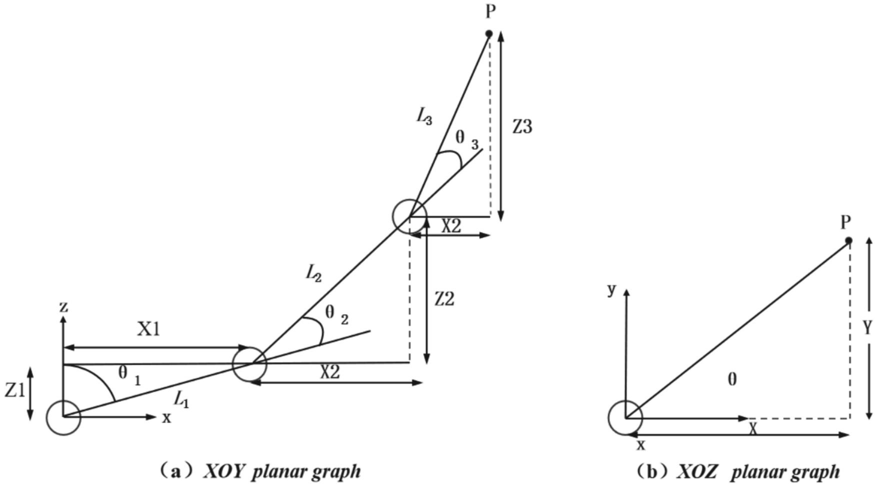

Fig. 5. The 2-D mapping plan of the robotic arm

3.4 Wireless Transmission Module

The wireless transmission terminal uses ESP8266 module. ESP8266 Is a low-cost, high-performance Wi-Fi module. It integrates a TCP/IP protocol stack and can easily connect to Wi-Fi networks to communicate with other devices via serial ports. ESP8266 connect with STM32 through serial communication interface to realize remote control and data transmission functions. At the remote control end, MQTT protocol is used to send different remote instructions, which can make the robot produce corresponding gestures, such as 20 cm forward, stopping the machine operation, etc. In terms of data transmission function, ESP8266 sends picking data to cloud server, such as picking quantity, working time, walking path, etc. This can realize real-time detection and analysis of the system in the cloud.

3.5 The Ranging and Measuring Module

The ranging module mainly includes ultrasonic ranging, infrared ranging, and laser ranging. The following focus is on infrared ranging.

The infrared sensor is used in this system to supplement distance of picked claw from target fruit. The infrared sensor uses principle of infrared detection distance to measure specific distance from the target fruit. Its working schematics are shown in Fig. 6. Firstly, the infrared light source emits infrared light and passes through the lens to hit the target fruit. When the infrared light reflects and hits the photodetector, its position will affect electrical conductivity of detector. By measuring electrical conductivity, the distance between the target and the sensor can be calculated by using the infrared light source, the infrared reflection point on the object, and the geometric relationship of the photodetector.

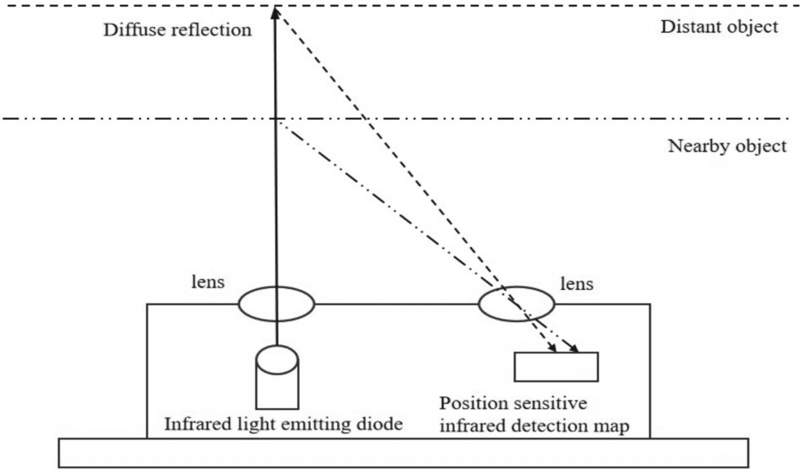

Fig. 6. Diagram of the ranging module for working schematic

4 Introduction to the Software Algorithm Design

4.1 Target Detection and Classification Algorithm

The project uses a target detection and classification algorithm in the Baidu flying pulp (PaddlePaddle) deep learning framework to obtain the target fruit's position, size, and maturity information. Target detection algorithms can help the robot identify the position and shape of the fruit, while classification algorithms can identify the maturity of the fruit. In this way, the robot can accurately locate and identify the ripe fruit and take action to pick accordingly. The Baidu fly plasma framework provides rich deep-learning models and tools that can support the training and deployment of target detection and classification tasks. By using these algorithms, the project can realize automatic detection of fruit maturity, and combine the information of infrared ranging sensors to realize an intelligent orchard-picking system.

This design uses the YOLOv5 model in Baidu fly pulp. Figure 7 shows the network structure of YOLOv5. The main processes are as follows: 1. Apply Mosaic data enhancement technology on the input end, integrate adaptive anchor frame calculation and adaptive image zoom, and achieve a high score, Anchor. 2. In the Backbone section, the NewCSP-Darknet53 model was used. The Focus module is used for slice manipulation, the CSP 1_X module performs feature fusion, and the SPP module produces a fixed-length output. 3. The Neck part combines FPN and PAN modules to enhance multiscale linguistic expression and strong localization information, and achieves the feature fusion of the previous step through CSP 2_X. 4. In the Prediction part, the GIoU_Loss loss function was used for the localization loss calculation.

The algorithm has a significant increase in detection speed and model size, more than twice that of YOLOv4, and reduces model volume by about 90%. The process of model training using YOLOv5 includes data preparation and model training. Firstly, image datasets containing fruits of different sizes and colors were collected to provide material for machine learning characteristics of different mature fruits. Then, the YOLO model was trained to learn fruit features, classify fruit species, and accurately locate the location of the specific target fruit. With the optimization of the model parameters and the increasing accuracy of the training time, it will be further improved.

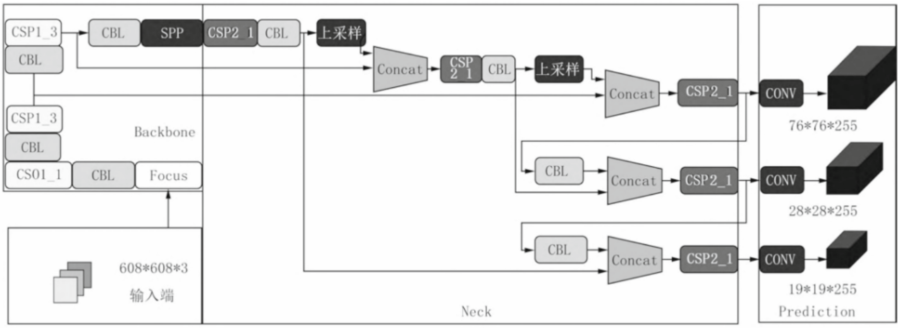

Fig. 7. Diagram of YOLOv5 network structure

4.2 The PID Control Algorithm

PID controller as the most widely used controller has a dynamic control process in the past, present, and future characteristics of the main information, the control diagram is shown in Fig. 8.

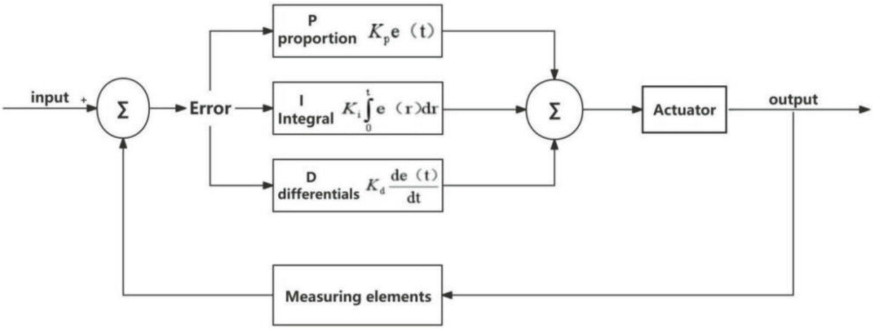

Fig. 8. Schematic of PID control

In this project, we use the PID closed-loop algorithm for picking robot picking attitude accurate control. Considering the single chip cannot handle continuous quantity, practical application PID algorithm discretization, dispersion after the PID algorithm as shown in the formula: Result = KPE _ know + KI (Err _ know + E_last_all) + KD (E _ no-E_last) in which KP is the proportional coefficient, KI is the integral coefficient, KD is the differential coefficient, E_now is the current error, E_last is the last error, and

E_last_all is the subsequent error. We evaluated the control effect under various parameter combinations by building a simulation model, testing different combinations of proportional coefficients using the control variable method, and adjusting the sampling period. This can shorten the debugging cycle, and avoid blind adjustment. The optimization process of PID algorithm parameters is based on the error, which can quickly get the suitable control signal. Finally, the PID debugging of the posture of the mechanical arm is completed.

4.3 User Visualization and Cloud System Construction

To achieve the purpose of visual detection and systematic data analysis, this design uses QT platform and Message Queuing Telemetry Transport (MQTT) protocol to design cloud system and realizes the robot as the MQTT client to communicate with the cloud MQTT server. As a cross-platform C++ application development framework, Qt has rich functions and components. It is easy to learn and use, and provides a powerful integrated development environment. Supporting open source and commercial licensing, which is suitable for various types of application development. As a lightweight message transmission protocol, MQTT is widely used in the Internet of Things communication with characteristics of low overhead, simplicity, and ease of use. Specific functions include cloud data analysis and instruction sending. The practice process of cloud data analysis function is as follows: the six-axis robot sends the collected data to the cloud through MQTT. After successfully receiving the data, the cloud data analysis system conducts data processing and analysis, including real-time monitoring, picking data visualization, exception detection, and other functions. For instruction sender, users can send instructions to cloud through the interface of QT platform, and the instructions are transmitted to the six-axis robot through MQTT protocol to control its movement, and posture or perform specific tasks.

5 Comprehensive System Test

System testing is a comprehensive software engineering activity designed to conduct a comprehensive evaluation and inspection of the complete software system. For the software system detection of the fruit-picking robot, the team first focused on performance of the YOLO model implemented based on Baidu fly pulp (PaddlePaddle) deep learning framework. To ensure that the fruit-picking robot can maintain stability and high accuracy of mature fruit recognition in diversified real environment. During the test, the model training time and the number of iteration rounds are intentionally shortened: the model training time is 2 h, the number of data set iteration rounds is 100 rounds, and different light, background, and fruit type conditions are set to verify ability of the model to identify mature fruits. In actual production, Recall rate, Precision rate, and MAP (average accuracy) are commonly used to measure quality of the target detection, the better the effect. The box_loss, obj_loss, cls_loss represent location loss, confidence loss and classification loss respectively, which are inversely related to the detection quality. Val/box_loss, Val/obj_loss, Val/cls_loss are used to verify the value of location loss, confidence loss and classification loss. As shown in Fig. 9, the precision rate reaches 96%, the average accuracy (0.5) reaches 98%, and the recall rate reaches 98%. Meanwhile, the positioning loss, confidence loss, and classification loss decrease exponentially with the number of iteration rounds, which proves that the machine can meet the demand of actual agricultural production. The specific picking effect is shown in Fig. 10, where NSB represents the non-target fruit, SB is the non-mature fruit, and Flower is the desired fruit. The model can accurately identify ripe fruits in a different light and without shooting angles to achieve the experimental purpose.

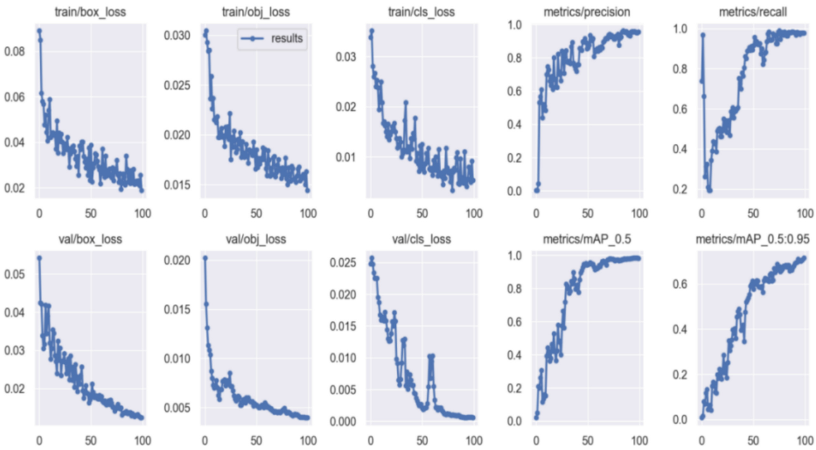

Fig. 9. Process diagram of model testing

The team then tested the effect of PID algorithm on attitude control of robotic arm. The PID algorithm is responsible for adjusting the posture of the robotic arm according to the system feedback to ensure accuracy and efficiency of the fruit-picking action. In the experiment, three experimental groups of different kinds of fruits are set up. The robot started to pick fruits of each group in turn and observe response time of mechanical arm and speed of reaching a new attitude to evaluate real-time performance of PID algorithm. As shown in Table 1, the three fruit species are apple, orange, and strawberry, the average fruit diameter is 7.13 cm, 6.32 cm, and 4.26 cm, and the average response time of single picking manipulator arm of apple, orange, and strawberry is 11.97 s, 9.53 s, 6.15 s, and the average speed of the manipulator arm reaching a new attitude when picking apple, orange and strawberry is 43 cm/s, 50 cm/s and 35 cm/s, respectively. The PID algorithm showed good results in controlling the response time and speed of the robotic arm with high real-time performance.

The above experimental results prove that the software system of the intelligent Internet of Things fruit-picking robot is stable, accurate, and real-time, and the robot can accurately pick fruit.

Fig. 10. Results of picking effect

Table 1. Fruit picking test results of different species

Fruit type	Average fruit diameter (cm)	The number of picking	Total Mechanical Arm response time (s)	The average single Secondary picking robotic arm response time (s)	Average velocity of the robotic arm reaching the new pose (cm/s)
apple	7.13	100	1197	11.97	43
orange	6.32	100	953	9.53	50
strawberry	4.26	100	615	6.15	35

6 Summary

To sum up, intelligent Internet of Things technology in fruit robot research has certain practical application value, combined with the machine vision, automatic control, robot operation, and big data analysis technology, design the wisdom of Internet fruit robot can through real-time perception, intelligent analysis, accurate stable fruit picking operation, is expected to play a bigger role in the future agricultural production, promote the process of agricultural modernization.

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