RESEARCH ON REMOTE OPERATING SYSTEM OF PICKING ROBOT BASED ON BIG DATA AND WIFI

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基于大数据和 WIFI 的采摘机器人远程操作系统研究

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DOI: https://doi.org/10.35633/inmateh-64-44

Keywords: *big data, WIFI, picking robot, remote operating system*

ABSTRACT

Agricultural mechanization has become the main mode of agricultural production and represents the development direction of modern agriculture. The amount of data generated in the agricultural production process is extremely huge, so it is necessary to introduce the concept and analysis method of big data. Combining agricultural robots with big data can improve the performance and application effect of robots. This paper combines big data, WLAN technology and robot technology to realize man-machine remote cooperation platform. This gives full play to the advantages that people are good at object recognition and robots are good at execution, and improves the fruit picking efficiency. The target fruit positioning and recognition system aided by machine vision is adopted to realize the accurate positioning of the fruit to be picked. Design of LFM control signal fitting based on big data clustering. In order to verify the feasibility of the scheme, taking the tomato picking robot as an example, the communication error and control accuracy using big data and WIFI (Wireless Fidelity) technology were tested, and the positioning and navigation efficiency with and without remote monitoring system was compared. Test results show that using big data and WIFI remote monitoring technology can effectively improve the efficiency and accuracy of positioning and navigation of remote operating system, which is of great significance for the design of automatic control system of picking robot.

摘要

农业机械化已成为农业生产的主要方式，代表了现代农业的发展方向。农业生产过程中产生的数据量巨大，有必要引入大数据的概念和分析方法。将农业机器人与大数据相结合，可以提高机器人的性能和应用效果。本文结合大数据、无线局域网技术和机器人技术，实现了人机远程协作平台。这充分发挥了人善于识别物体、机器人善于执行的优势，提高了采摘效率。采用机器视觉辅助的目标水果定位识别系统，实现对被采摘水果的精确定位。基于大数据聚类的 LFM 控制信号拟合设计。为了验证该方案的可行性，以番茄采摘机器人为例，利用大数据和 WIFI 技术对其通信误差和控制精度进行了测试，并对有无远程监控系统的定位导航效率进行了比较。试验结果表明，采用大数据和 WIFI 远程监控技术可以有效提高远程操作系统的定位导航效率和精度，对采摘机器人自动控制系统的设计具有重要意义。

INTRODUCTION

The 21st century is an era of information development. Computer technology, information collection and processing technology have made great progress, and have automatically entered the field of agricultural production. Under the new situation, the production mode and technology have greatly promoted the renewal and development of agricultural production, and further promoted the intelligentization of agricultural production *(Boesch A. et al., 2020)*. In this form, the field fruit picking robot has attracted the attention of agricultural production, and has become an important development direction of theoretical intelligent control of agricultural production. Therefore, in this form, it is of practical significance to explore the influence of field fruit picking robots on agricultural production.

There are many labor-intensive operations in agricultural mechanization production, among which fruit and vegetable picking is the most time-consuming and laborious link in the agricultural production chain with strong seasonality, complex working environment and high labor intensity.

As a large agricultural country, China needs to spend a lot of manpower and material resources every year, and with the aging of the population, China's agricultural labor force is gradually decreasing, resulting in a corresponding increase in agricultural production costs, which greatly reduces the market competitiveness of products *(Francois J. M. et al., 2020)*. Remote control technology enables people to completely control the controlled machine at the other end of the network through a simple terminal, thus realizing the information acquisition and powerful control function of the controlled machine at the other end *(Jin Z et al., 2020)*. Because of the complexity of the working environment of the picking robot, it is unrealistic to rely on the wired network to control the robot remotely. However, due to the limitation of transmission speed and distance, the application of traditional WIFI mobile network in remote control of picking robot is also limited *(Joppa M. et al., 2018)*.

The announced fruit harvesting robot has the characteristics of automation and intelligence, and achieved good research results, but the cost performance of the fully autonomous fruit harvesting robot is far from people's expectations. Robot experts deeply reflect on the research direction of autonomous robots, and think that due to the limitation of robot-related technologies, it is difficult to achieve the goal of developing robots that can work autonomously in complex environments for a long time in the future *(Krawczyk A. I. et al., 2020)*. More and more science and technology try to cross-integrate with network technology to realize the self-evolution of technology to meet the requirements of the new era. Distance education, teleconferencing and remote monitoring have gradually become an important part of life. Therefore, how to combine robots with big data Internet technology and develop commercially valuable robots by using existing or future technologies in the network has become an important subject in robotics. At present, in the classification of robot technology, teleoperation semi-autonomous robot is the closest technical direction to this form. Telerobot has been used in space, deep sea and dangerous operations, but there are few cases of its application in agriculture.

With the development of new generation information technologies such as cloud computing and Internet of Things, big data and WIFI technologies have been applied to various fields. Cloud platform adopts distributed storage mode and parallel computing, which can effectively improve the utilization rate of computing resources and reduce the cost of computing and storage resources through resource sharing. The advantage of WIFI transmission is that it is easy to regroup and maintain without connecting communication lines, but there are many difficulties in WIFI communication, such as unreliable WIFI channel, dynamic random attenuation characteristics of WIFI channel, weak anti-interference ability and so on *(Ma X et al., 2021)*. Therefore, a set of picking robot remote operating system based on big data and WIFI is designed, which can realize the navigation and remote control of picking robot.

The research of fruit picking robot is mainly divided into four directions: the visual system of picking robot, the design of picking execution terminal, the obstacle avoidance and motion planning of manipulator, and the navigation of robot in natural environment. The fruit picking robot works in unstructured environment, which requires the system to have high intelligence and intelligent behavior similar to human. At present, the visual system based on visible light is generally regarded as the most important environmental sensing component of fruit picking robot, which has the following functions: fruit target segmentation, recognition and positioning, recognition and positioning of obstacles such as vines, robot navigation, motion servo control based on visual feedback, etc.

In the control theory, the man-machine cooperation model can be understood as a closed-loop system with man as a feedback link, which is one of the earliest and most studied theoretical branches in teleoperation related technologies *(Mrozik D. et al., 2020)*. Man-machine interaction is the main research object of this research direction. How to provide efficient interactive interface and humanized input mode on the premise of as little data transmission as possible is a hot research issue.

Oktarina Y. et al., (2021) applied the feedback technologies such as prediction technology, augmented reality and virtual reality, and the input technologies such as advanced instruction and voice recognition realized the online control of two educational robots, and the interface had the characteristics of flexible control *(Olesen A. S. et al., 2020).* The design shared seven cameras, which put forward strict requirements for network quality. *Rahul T et al., (2019),* developed a remote teaching robot system by studying the remote control mode of robot. Due to the problem of network bandwidth, the visual field feedback is not ideal. The network-controlled robot in reference *(Wang Z. W. et al., 2019)* can be controlled to complete picking, placing and transporting operations.

Geng L. et al., (2020) developed a strawberry picking robot with a three-degree-of-freedom orthogonal coordinate system, which can be used for strawberry harvesting in ridge cultivation.

The eggplant harvesting robot developed by *Yi D., (2019),* picks eggplant in laboratory environment at an average speed of 64.1 seconds, with a success rate of 62.5%. The low picking success rate of the robot is mainly due to the long time consumption of data processing and the accuracy of visual positioning. *Krishnamurthy S. L. et al., (2020),* simplifies the working environment of the robot by adopting the principle of agricultural mechatronics, and designs a cucumber picking robot, which collects at an average rate of 45 seconds, with a success rate of about 80% and a visual inspection success rate as high as 95%. The software and hardware performance of the platform affects the picking rate. *Li Y. B. et al., (2020),* developed a field strawberry picking robot with Cartesian structure. Two sets of cameras were used for rough positioning and target detail detection. Under normal circumstances, the correct rate of strawberry recognition is 93.6%, but in complex environments such as blocked light, the recognition rate is 70.8%, and picking a single strawberry takes 16.6 seconds, which is still subject to visual problems.

To sum up, the technology of fruit and vegetable picking robot is one of the most dynamic research hots pots in the world, but most of them are still in the laboratory research stage, and there are no products available for practical production. At home, the research in this field has just started, and compared with the international advanced level, there is still a big gap. It is urgent to intensify efforts to speed up the research work in this field, catch up with and surpass the research pace of international counterparts, and meet the actual needs of China's agricultural modernization development.

MATERIALS AND METHODS

Big data processing process

Big data is a collection of data collected by machine vision, GPS positioning and sensors, which contains information related to robot operation and can be obtained through a series of analysis and processing processes. The analysis process of big data involves the entry and reading of PB-level data, so large-scale modeling and calculation are needed. The big data analysis hardware carried by the robot is a PC Server type server with x86 architecture, and the configuration includes Ruilong AMDRYZEN 7 type 2-way 8-core CPU, DDR4 type 128GB memory and IntelI350T2 type Gigabit network card, which can meet the actual requirements in terms of computing speed and storage space. This technology can run a simple parallel computing model, has strong fault tolerance and scalability, and has a good analysis and processing effect on large-scale data.

The data collected by various devices carried by the robot enter the switch through the network and transmission interface, and the switch is connected with the data collector to perform the functions of data exchange and convergence, and finally transmit to the big data processor. The above transmission process implements IEEE1588 time synchronization protocol, which can reduce the exchange delay and improve the real-time and accuracy of data. On this basis, carry out follow-up analysis and processing. The analysis process of big data includes preprocessing, content analysis, information mining and result display in turn, realizing the data-centered analysis mode.

In view of the diverse features of big data structure, parallel processing is adopted to improve the analysis speed. The processing of big data is shown in Figure 1.

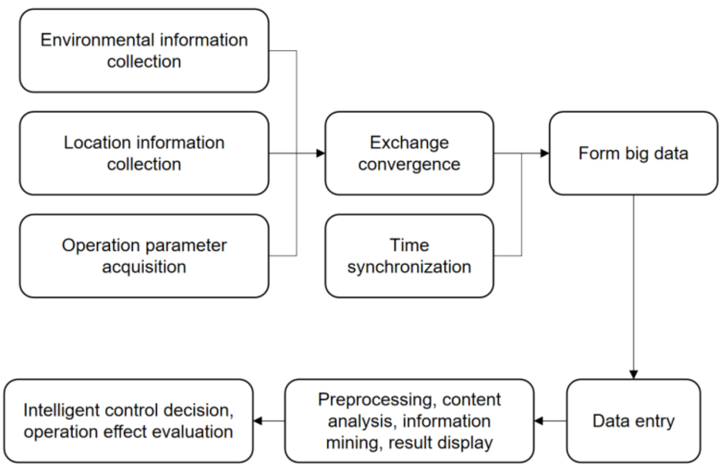

Fig. 1 - Big data processing process

Parallel processing is to comprehensively monitor and classify big data in real time while recording data, and distribute data to corresponding application systems according to types; Then, run the decision-making aided by professional knowledge base to provide the basis for information mining; Finally, the results of comprehensive monitoring, analysis and processing are gathered into the storage and management module to form an application function database, form the intelligent control decision of the robot, and evaluate the operation effect.

Linear frequency modulation control signal fitting based on big data clustering

Firstly, the distributed structure model of big data in control system is established. According to the concept of fuzzy control, the fuzzy control of big data in control system is studied, and the limited data set of massive control data in control system is established as:

$$Y=\{y_1,y_2,\cdots,y_n\}\subset R \tag{1}$$

In which Y represents a finite data set; n represents the number of samples included in the big data distributed structure model in the control system; R represents the vector space of big data clustering under arbitrary norm. When the clustering channel fitting factor of the finite data set Y is 0, the formula (2) is satisfied at this time:

$$\rho(y)=\frac{2}{1+\exp|-h\cdot \operatorname{sgn}(y)|} \tag{2}$$

In the formula, ρ represents the clustering channel fitting factor; h represents the iteration times of big data clustering; *sgn* stands for symbolic function. In the distributed structure of big data in control system, there is an iterative function of fuzzy control, and the function can converge the clustering center of data. When the control system is in a state where the initial value of the cluster center is unknown, the distributed structure of big data in the control system will simulate the control data with nonlinear and time-varying LFM control signals, thus providing help for basic feature extraction and realizing the optimal clustering of data.

Then, using the fitting idea of fuzzy control and industrial robot control system, the LFM signal of big data information flow in the control system is fitted and processed, and the big data information characteristic points of the control system are calculated by combining the big data clustering algorithm. The formula is:

$$X(a,b)=\sum\left[(a_i,b_i)-(a_i+\Delta ab_i+\Delta b)\right]^2 \tag{3}$$

In the formula, $X(a,b)$ represents the feature point function; $\triangle a$ and $\triangle b$ represent the two-dimensional characteristic displacement of big data information flow of control system; (a_i,b_i) denotes chirp characteristics. According to formula (3), the fitting of LFM control signal in the control system is completed.

WLAN topology

As shown in fig. 2, there are three topologies of WLAN, which are basic service set, independent basic service set and extended service set:

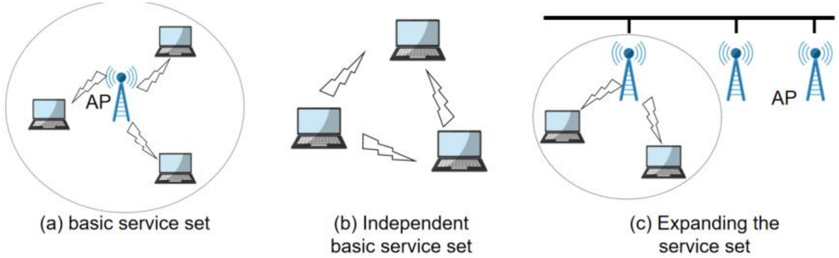

Fig. 2 - WLAN topology

The central station of BSS (Basic Service Set) is a WIFI access point. All network devices connected to the access point are controlled by it, and its network structure is shown in Figure 2(a). Due to the power limitation, the coverage of each WIFI access point is very limited, so this structure is suitable for the network demand with little service space. The disadvantage of this structure is poor reliability, and the failure of WIFI access point will lead to the collapse of the whole network.

IBSS (Independent Basic Service Set) network has no central node, and its basic network structure is shown in Figure 2(b). IBSS network, also known as P2P network or Ad-Hoc network, is a dynamically built WIFI network. All nodes in the network are equal, interconnected by the same identification number and password, and all nodes communicate through CSMA/CA MAC protocol on a common channel to realize point-to-point and point-to-multipoint communication.

ESS (Extended Service Set) is a WIFI communication structure established for the small coverage of BSS, which meets the network requirements of large space coverage. The structure is shown in Figure 2(c). In fact, this structure is to connect multiple BSS networks to realize the expansion of BSS networks.

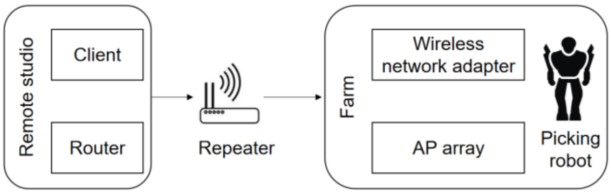

Fig. 3 - WLAN deployment scheme

The robot platform developed in this paper will be applied in the field. Because the field occupies a large area, it is difficult to achieve full coverage of signals by BSS structure, so ESS structure is adopted to deploy the network. As shown in the WLAN deployment scheme in fig. 3, the solid line is wired connection and the lightning symbol is WIFI connection. WIFI relay can greatly extend the coverage of WLAN, and information transmission between buildings with a distance of more than 500 meters can be realized through a pair of relays, which provides support for monitoring fruit picking robots in the office.

Positioning algorithm of picking robot

When the picking robot is positioned, in order to make the robot respond quickly, it can use machine vision and adopt the multi-hop self-organizing WIFI network node positioning model algorithm, and can get the information of picking targets or fruits to be picked in advance, and these positions' information can be marked with sensor nodes in advance. It is assumed that the picking operation area is a two-dimensional spatial area plane, and there is a sensor network in the area plane, which can be expressed as $S=\{S_1, S_2, \cdots, S_{m+n}\}$. Where m represents the marked position node; n represents an unmarked location node. Positioning coordinates can be expressed as:

$$pos(S_a)=(x_a, y_a)T, P=1,\cdots,m+n \tag{4}$$

Among them, the position of $S_i \in B$ has been marked, and the positions of other nodes $S_j \in U$ are unknown; $B=\{S_{i|i=1,2,\cdots,m}, S_{i|i=m+1,2,\cdots,m+n}\}$, the minimum hop count and distance collected at the marked position are respectively stored in two sets of data sets. The hop count from node S_i to S_j is:

$$h(S_i, S_j)=H=\{0,1\cdots\} \tag{5}$$

The euclidean distance from node S_i to S_j is:

$$d(s_i, s_j)=\sqrt{(x_i-x_j)^2+(y_i-y_j)^2} \tag{6}$$

The positioning nodes of the picking robot are distributed in the multi-hop self-organizing network to form a dynamically distributed real-time positioning virtual environment, which can lock the position of the fruit to be picked. This design adopts tree network structure, the self-organizing network is equivalent to trunk, and the positioning node is equivalent to branch. Among them, the main part of multimedia information is equivalent to leaves, while the redundant part of data is dynamically allocated to the leaf structure. The tree structure function is expressed by F, and the following structural tree formula is generally adopted as:

$$H(e,f,k)=\begin{cases} F(f_c)(e=f) \\ F\left(\left(H\left(e,\frac{e+f-1}{2}\right),F,\left(H\left(\frac{e+f+1}{2}\right),j,F\right)\right)(e<f)\right) \end{cases} \tag{7}$$

Among them, e,f represents the signal strength with or without interference, and when e=f, the communication ability is the best; When $e<f$ is used, the signal needs to be denoised.

Assuming that the virtual storage space of the multi-hop network positioning node is represented by $S=[S_1,S_2,\cdots,S_i]^T$, the expression of the branch structure is:

$$Q(S)=\prod_{i=1}^{n}Q(S_i) \tag{8}$$

The multi-hop self-organizing network of picking robot will consume a lot of energy in the positioning process, and the maximum allowable distance of power loss is:

$$y=\frac{Y_m-Y_n-Y_c-2K_p-L_p}{\lambda_a-\lambda_b} \tag{9}$$

In which Y_m represents completely lost power; Y_n represents the receiving sensitivity in case of interference; Y_c represents WIFI rate; λ_a, λ_b respectively represents WIFI consumption coefficient; K_p represents the loss at the interface; L_p indicates the maximum communication rate of multi-hop ad hoc network.

Among them, the communication limit distance of ad hoc network is:

$$S=\frac{P}{k} \tag{10}$$

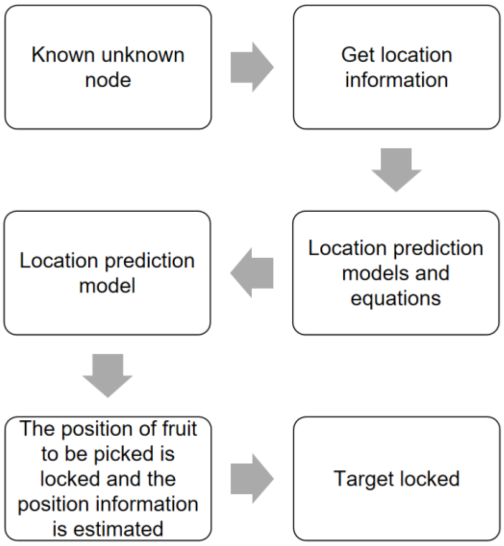

Fig. 4 - The flow of determining the location node of picking robot

The prediction model is obtained from the obtained estimation items. When positioning, not only the known positioning nodes can be directly positioned, but also the coordinates of unknown nodes can be calculated. The process is shown in Figure 4. By substituting known positioning nodes into the ranging model, the corresponding distance information can be obtained, and by combining the position coordinates and distance information of known nodes, the location area of unknown nodes can be estimated, and finally the area to be picked can be locked.

Design of WIFI data transmission program for picking robot

In the WIFI data transmission part of picking robot, the master-slave WIFI receiving programs all adopt interrupt response mode, which saves system overhead and has good real-time performance. The sending program is written in the form of function module and can be called directly. After receiving the data, the communication host WIFI repackages the USB and outputs it to the robot control computer, so that it can make a judgment and issue a control command. The flow chart of picking robot WIFI transceiver program is shown in fig. 5.

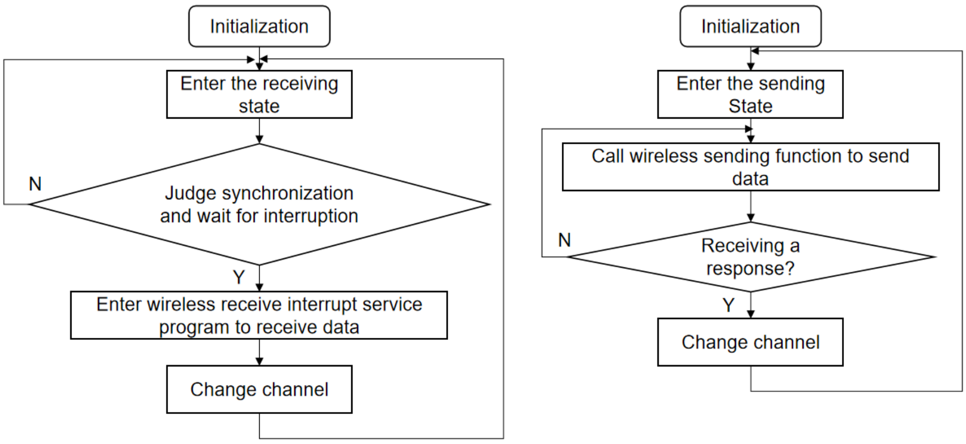

Fig. 5 - WIFI transceiver program flow chart of picking robot

Interactive interface based on depth image

At present, the interactive flow of the control interface of the picking robot system is mainly process-oriented. Process-oriented interaction process is that after analyzing the goal of the task, people interact with the robot step by step according to the process of achieving the goal, and control the robot to complete the task according to the process [26]. The disadvantage of the operation mode based on this idea is that users are forced to disassemble the task objectives into the combination of small tasks, and pay attention to the details of task execution in the process of task execution, so they cannot divert their attention to other places before a task is completed. This operation mode is extremely dependent on people's familiarity with the system, relevant operation experience and people's attention.

How to clearly point out the operation object to the robot is a problem that human-computer interaction tries to solve. For autonomous control robots, the object model description method is generally adopted, which requires the invariant features that can fully describe the object and can be understood by the machine. If we take direct control, we can avoid the description of the operation object, but it is too cumbersome to directly control the movement of every joint of the robot.

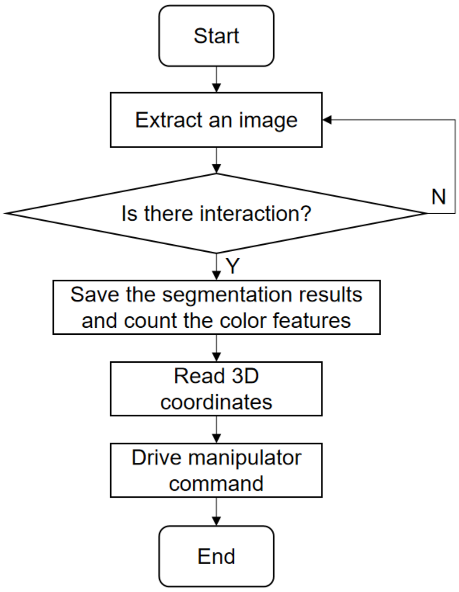

Fig. 6 - Interface interaction flow based on depth image

Fig. 6 is an interactive flow chart, in which the interface continuously displays the latest robot visual field image in the cache, and when the user's interactive action is sensed, it is fixed in the frame to wait for the interaction to end. The user selects the target on the image with the mouse circle, and the system uses the interactive results to segment the image by flooding in the background, and performs the following actions.

Save the segmentation results and provide picking object samples for subsequent research

The color features of segmentation results are counted to provide support for image segmentation algorithms. After reading the three-dimensional coordinates of the object corresponding to the segmentation result from the server, and confirming that it does not exceed the motion range and whether it will cause the interference of the mechanical body, the command to drive the mechanical arm is issued, so that the motion control module of the robot on-site server can pick the fruit.

RESULTS

The contradiction between the rapid development of fruit and vegetable production and the shortage of agricultural labor force and excessive labor intensity has become increasingly apparent, and the complex human labor of replacing selective harvesting can only be realized through the in-depth study of picking robot technology. The research and development of fruit and vegetable picking robot is of great significance for reducing the labor intensity of agricultural practitioners, liberating agricultural labor and improving the intensive production level of fruits and vegetables.

Tomato is the favorite of people from all over the world, and it is also the most demanding fruit and vegetable in the world. However, the non-human harvest of fresh fruit is one of the most difficult operations. At the same time, tomato is also one of the most difficult fruit and vegetable varieties picked by robots. At present, facing the demand of fresh food, common tomatoes are usually picked with single fruit, while cherry tomatoes are picked in clusters. For most common tomato varieties and cultivation methods at present, compared with fruits and vegetables such as cucumber, eggplant and apple, there are 3~5 tomato fruits per ear, which grow densely and touch each other, and the difference of fruit growth orientation is more significant, thus posing a greater challenge to the intelligent picking of robots.

The close and overlapping occlusion between fruits is more serious. For the vision system of the picking robot, although the mature tomato fruits can be easily identified by color difference, it is difficult to segment or even completely block the images of multiple fruits, which makes it difficult to identify and locate the target fruits. Tomatoes grow into ears and touch each other, which causes the clamping space of the picking robot to the target fruit to be limited, the clamping action fails or the adjacent fruit is bruised; The growth orientation of tomato fruit varies greatly, and the relationship between posture and force changes every time; The fruit stalks are short and different in length, which makes it difficult for the mechanical cutter to cut the fruit stalks smoothly. However, the mechanical action law of twisting and breaking the fruit stalks changes greatly, and the success rate is limited, which further increases the difficulty of picking.

In this section, the remote operating system of picking robot based on big data and WIFI designed in this paper is applied to tomato picking robot and analyzed. The tomato picking robot is shown in Figure 7.

Fig. 7 -Tomato picking robot

In order to realize the autonomous walking of the automatic guided vehicle of the picking robot, the most important thing is that the front-end acquisition equipment identifies the picking environment to plan the autonomous walking route and access the video information in the server, which can be divided into data flow and information flow according to different functions, as shown in Figure 8.

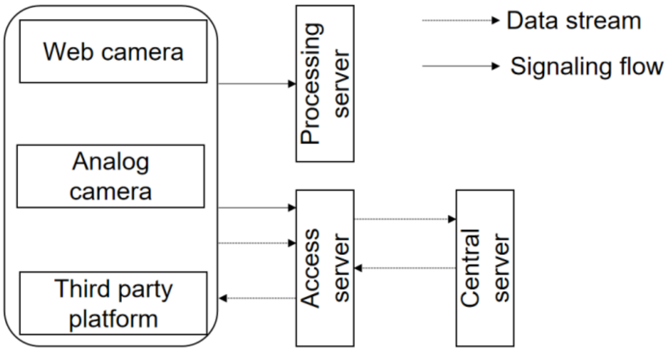

Fig. 8 - Frame diagram of video acquisition system

In order to reduce the burden of the front-end camera, the video stream is not directly sent to the streaming media server, but accessed to the platform first, so as to facilitate different customers to access the same stream. By collecting the picking environment and identifying the route of the cloud platform server, the picking robot can automatically guide the AGV system to carry out route planning, so as to realize autonomous walking. The walking route can also be displayed on the GIS map in real time, and the remote monitoring system can make reasonable scheduling according to the operation situation of the picking robot.

The tomato picking robot has a guide car as its carrier, which can navigate autonomously during formation and scheduling, and the remote system can make reasonable scheduling and planning according to the real-time position of the guide car equipment. In order to verify the influence of remote monitoring system and WIFI control system on the operation effect of picking robot, and to test the reliability of monitoring and control system, the communication error and control accuracy of monitoring and control system were measured respectively, and the operation situations of using and not applying monitoring and control system were compared. Test results of communication error and control accuracy are shown in Table 1.

Table 1

Statistical results of communication error and control accuracy

Statistical serial number	Communication error packet loss rate %	Navigation accuracy/ %
1	0.25	98.3
2	0.27	99.1
3	0.33	97.5
4	0.28	98.5

Through the statistical results of many tests, it can be seen that the communication error of the remote monitoring and control system is low, the maximum error is not more than 0.5% according to the packet loss rate, and the navigation accuracy of the automatic guided vehicle of the picking robot is over 90%, which meets the design requirements of the automatic guided equipment of the picking robot.

Table 2

Comparison of positioning and navigation efficiency

Statistical serial number	Use remote monitoring and control system to locate time /s	Positioning time without remote monitoring and control system/s
1	3.36	5.67
2	3.25	5.82
3	3.29	5.90
4	3.55	5.64

Table 2 shows the comparison results of positioning and navigation efficiency of picking robot with and without remote monitoring and WIFI control system. It can be seen from Table 2 that the navigation efficiency of picking robot using remote monitoring and control system is high, which verifies the feasibility of the scheme.

CONCLUSIONS

In view of the dilemma that the autonomous fruit and vegetable picking robot still can't meet the market requirements after a lot of research, a fruit picking robot system based on big data and WIFI is designed by combining WLAN and fruit picking robot platform. WLAN is one of the most widely used WIFI communication means at present, and it is the best choice for civil teleoperation system in terms of technology, maturity of framework and economy. Communication between PC and picking robot is realized. When working, the picking robot sends its own position and motion information to the background PC, which uses big data technology to analyze the running status of the picking robot and provide reference information for the remote control of the picking robot. The communication error and control accuracy of the system are tested. The results show that the communication error of the system is small and the control accuracy is high, which can meet the design requirements of the remote system of the picking robot. Finally, the positioning and navigation efficiency is tested, and the results show that the WIFI control system based on big data technology has high positioning and navigation efficiency, which plays an important role in the design of automatic control system of picking robot.

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