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Design and Test of Tomatoes Harvesting Robot *

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***Abstract* - In order to improve robotic harvesting for fresh tomato and reduce the amount of human labor, this paper designed a tomato intelligent picking robot. The picking robot included: the vision positioning unit, the picking gripper, the control system and carrying platform. Based on the working principle of each component, the working process of picking robot was revised. Based on HIS color model for image segmentation, the recognition accuracy was improved. The sacs filled with constant pressure air were adopted as the grasping component of the picking end-effector, to prevent the fruits from being damaged. The performance test of picking robot indicated that vision positioning module and the gripper module ran well. The execution time of a single harvest cycle was about 24s, and the success rate for harvesting tomatoes was 83.9%.**

Index Terms - tomato, harvesting robot, machine vision, flexible gripper, robot control.

I. INTRODUCTION

China is a most country of fresh tomato production and consumer in the world, where about 730 thousands of fresh tomato is cultivated and average annual consumption of one person is 21kg. However, it is the most labor-intensive and t time-consuming production step to pick the fresh tomato by human. Picking robot could effectively reduce labor intensity and improve labor productivity. So the research of picking robot has a practical significance.

In the developed countries of Western Europe and Japan, many researches on robotic picking equipment for fruits and vegetables have been obtained. Van [1] designed a cucumber harvesting robot system and walked on the track between crops. Based on the binocular stereo vision, the cucumber was identified and located. In Japan, Kondo [2] designed a tomato harvesting robot system, and an grasper with fingers and sucker was used to hold the fruit. Although the success rate for harvesting tomatoes was not acceptable for actual usage. Compared with the numerous foreign researches, the study of fruit and vegetable picking robot was started later in China. CAU [3] has designed cucumber harvesting robot in greenhouse, in which the spectral image was used to distinguish the cucumber from the leaves, and the successful harvest rate can reach 85%. Northwest A&F University [4] designed a strawberry harvesting robot with 4-DOF Cartesian arm, which used two CCD cameras to identify the positioning of strawberry.

In this paper, we introduced the tomato harvesting robot used for the elevated cultivate model, which has have an advantage over the traditional model in the space utility rate and fruit output. The new structured-light vision unit and screwing grasper is supposed to improve the robotic harvesting performance, which is different from the existing harvester.

II. WORK CONDITION

The work environment for tomato harvesting robot is shown in Fig.1. The machine can move on the rails to pick tomatoes in its both sides. The rails center is 600mm away from the plants of both sides. As a new cultivation model, the tomato stem is hung with the top of greenhouse by the string, so that the tomatoes can be fixed in the height between 100-600mm above the rail through releasing the string, after the lower ones are picked. The leaves close the height of ripe fruit were cut, to insure the fruit get enough nutrient, and which make the robotic harvesting easier.

Fig.1 Work condition of tomatoes robot

III. HARVESTING ROBOT SYSTEM

The new model of tomato harvesting robot system is shown in Fig.2, which contains a vision unit for identifying the mature fruits, a jointed manipulator of 4 freedom degrees, a railed vehicle and the system controller. The vision unit, which consists of a color camera, a linear laser projector and a electric slider, is used to identify and locate the mature fruits. The controller receives and processes image data from vision unit, then sends control signal to the manipulator, the end-effector and the vehicle through CAN bus. The vehicle carries the whole system moving on the rail at speed of 2m/s, until receives the stop signal from the controller when the mature fruits were identified in the camera field. The jointed manipulator positions the end-effector to approach the target fruit, and moves it back to the container after the fruit was

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separated from the plant. A twist-typed end-effector is adopted to pick the fruit, and the air pump supplies high-pressure gas source for it.

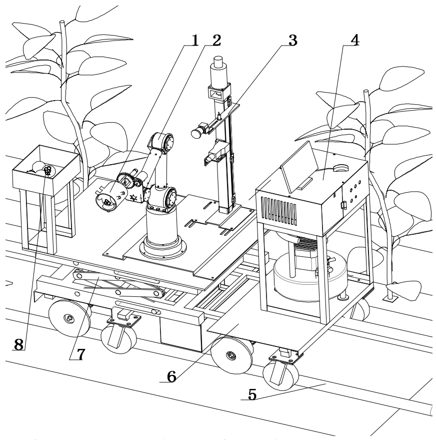

Fig.2 Tomatoes harvesting robot system
1.Gripper 2.Manipulator 3.Vision positioning system 4.Controller 5. Track 6.Mobile platform 7.Lifts 8.Fruit basket

A. Vision positioning system

For picking robot, the visual unit [5] is the key part to identify and locate the fruit, which is composed of the CCD camera, the linear-structured laser generator, the sliding driver. As shown in Fig.3, the camera and line laser generator was respectively fixed on the holder and sliding driver. the identification algorithm based on the structured-light vision could position tomatoes rapidly and accurately.

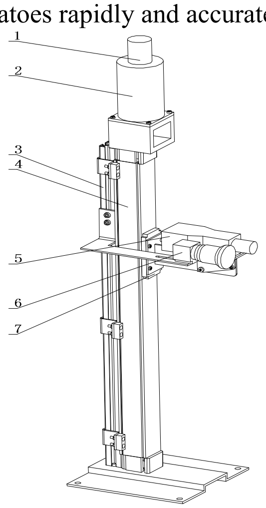

Fig.3 Model of line-structured laser vision system
1. Encoder 2. Servo motor 3. Holder 4. Linear guide 5. Line laser generator 6. CCD camera 7. Slider

The workflow of the vision system is represented as follows. Firstly, when the camera gets a picture of the plant, the algorithm will detect if the mature fruits exist in the current view field. Secondly, once the mature fruit area is recognized, the linear laser will be powered and begin to scan the whole camera view. If the laser strip is recognized arriving at the mature fruit center area, the image coordinate of the laser and the scanning displacement will be saved. Finally, based on the measurement principle of the linear structured-light vision, the three-dimensional position of the mature fruit can be located. For segmenting tomatoes from stems and leaves, we needed an appropriate color model. RGB and HSI are commonly used in the agricultural robot vision recognition algorithm. The RGB image not only contains color information, also includes the brightness information. RGB color model makes the image information became complex due to the change of light. HSI color model describes the image color information by using hue, saturation and intensity. This model separates brightness from color, effectively avoiding the problem between color and brightness, so it's suitable for image recognition algorithm[6-8]. In this paper, the images of RGB color space were transformed to HIS color model.

The image shown in Fig.4 is taken by the vision system in the greenhouse under the luminous intensity of 60klux. Based on the analysis on the color property of the mature tomato, the thresholds, the maximum interclass variances of H and S values, are used for the color image segmentation as Eq. (1).

$$\begin{cases} |H_i - 63| \le 200 \\ |S_i - 97| \le 50 \end{cases} \tag{1}$$

After the color image segmentation, the size S_i and the circularity ratio r_i of the candidate area in the binary image are counted. The fruit area should meet the following requirements as Eq.(2), if not, the white area will be deleted as noise pixels. The finally result is shown in Fig.5.

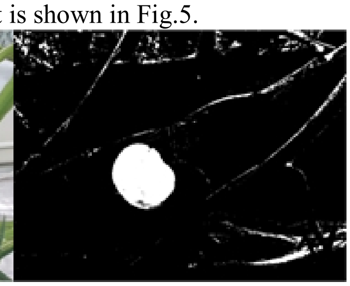

Fig.4 Original image Fig.5 Threshold segmentation image

B. Picking gripper

The gripper is installed on the end of the manipulator arm to hold and separate the fruit from the plant. Considering the tomato fruit's characteristics, such as clustered, soft, and shortly-stalked, a sleeve-shaped grasper was used to hold the fruit, and the screwing operating is adopted to separate the fruit which is supposed to achieve nondestructive and reliable clamping and separation.

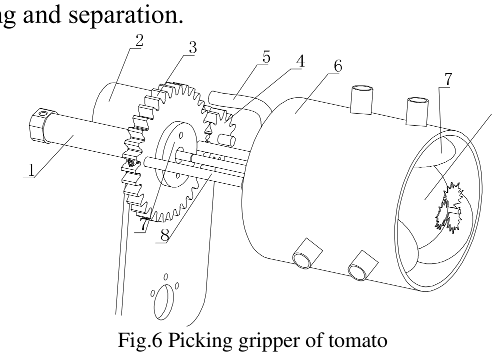

Fig.6 Picking gripper of tomato
1. telescopic cylinder 2. screwing motor 3. main gear 4.small gear 5. air tube 6. sleeve 7. air float 8. fruit

This gripper is consisted of the holding sleeve, the air float, screwing motor and gear. The holding unit is mainly composed of a sleeve and six air floats. The screwing unit is mainly composed of a screwing motor, a main gear and a small gear. When the picking gripper moves to the target position, the solenoid valve is closed, the telescopic cylinder makes the sleeve extend, so that the fruit is inserted into the sleeve. Then, the constant pressure air is inflated into the air float, and it will be expended rapidly until clamp the fruit tightly. Because the air pressure in the float is constant, the fruit is hold with a constant force, which would prevent the tomato from being damaged.Finally, the screwing motor drives the sleeve and the fruit to rotate back and forth, until the pedicel separate from the fruit.

C. Controller

The control system of the tomato picking robot is composed of the information acquisition unit, the IPC operation control unit, and the motion execution unit. The information acquisition unit is composed of a camera, an image acquisition card, a linear laser generator and an encoder. The image information is acquired by the camera and the image acquisition card, it can gain the space coordinate by identify the fruit through the image recognition algorithm and the linear laser generator. The IPC operation control unit will plan the motion of the manipulator arm after receives the data collected by the information acquisition unit, and send the information of angle and speed data to the manipulator arm and the screw motor driver of the motion execution unit. The motion execution unit will do the corresponding movement after receives control instructions.

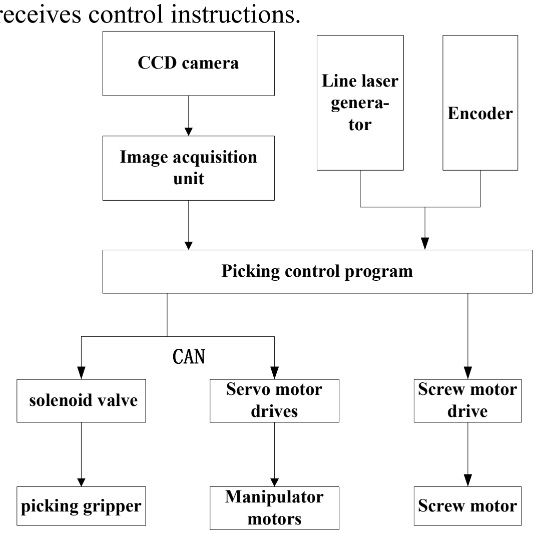

Fig.7 Structure of control system of tomatoes robot

IV. HARVESTING ROBOT SYSTEM

The operation process of the picking robot: After the system is opened, the camera begins to get image information, then identify whether there is ripe tomato in the view of the camera through the image recognition algorithm. When detect the ripe fruit, start the linear laser generator and scan up and down in the view of the camera, then locate the spatial location of the fruit according to the linear laser positioning principle.

After that, the manipulator arm guides the picking gripper to the target position after receive the position information, and takes adsorption, clamping and screwing to the fruit, finally put the fruit in the basket. Then the manipulator arm resets and completes the picking operation. Move the rail platform for the next picking operation, until reach the end of the track. The flow chart is shown in Fig.8.

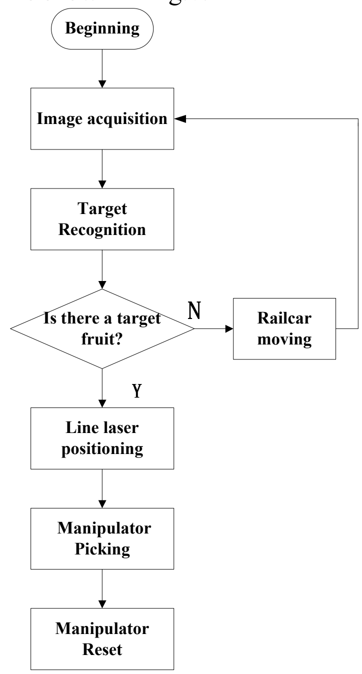

Fig.8 Operation process of robotic harvesting

V. PERFORMANCE TEST

In order to verify efficiency and accuracy of the tomato picking robot, it does tests in greenhouse. The experiment, to test precision of the vision system, was carried out between 15:00 and 18:30 on August 14th 2014 in Beijing Special Vegetable Garden as Fig.9.

Fig.9 Field test of robotic harvesting and picking gripper

A. Picking efficiency

Tomato robot moves in track and discoveries the target. After calculation, the aspects of the consume time is obtained as shown in TABLE I. In an ideal situation, it picks a single tomato need take about 24s.

TABLE I
EXECUTION TIME OF ROBOT OPERATION

NO.	Processed links	time/s
1	Identification and location	4.0
2	Movement of arm	12.0
3	Gripper picking	8.0
4	Reset arm	12.0

From TABLE I indicate: a lot of time spent on movement of the robot arm. It should be improved the design of arm to reduce their time-consuming.

B. Picking success rate

Tomato picking robot to do two tests .The illumination of first test is 48000lx and the illumination of second test is about 25000lx. The success rate of tomato's picking operations as shown in TABLE II.

TABLE II
PERFORMANCE TEST RESULT

NO.	performance test result		success rate /%
	Success	failure	
1	47	9	83.9
2	54	14	79.4

As can be seen from the test data indicate that the success rate of picking robot have almost the same in different illumination. The illumination has no impact on the vision positioning system. The reasons for picking failure: (1) the overlapping or deformity fruit isn't identified, it causes picking failure. (2)stems and leaves will interfere with picking gripper operation, so that the gripper can't be accurately picking.

VI. CONCLUSION

(1) The experiments indicate that base on HIS color model for image segmentation, the recognition accuracy was improved; the vision positioning module and the gripper module ran well.

(2)The experiments indicate that the execution time of a single harvest cycle was about 24s, and the success rate for harvesting tomatoes was 83.9%.

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