MULTI-OPERATION ROBOT FOR FRUIT PRODUCTION

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ABSTRACT

It is said that robot can be used for multi-purpose use by changing end-effector or/and visual sensor with its software. In this study, it was investigated what multi-purpose robot for fruit-production was using a tomato harvesting robot and a robot to work in vineyard. Tomato harvesting robot consisted of manipulator, end-effector, visual sensor and traveling device. Plant training system of larger size tomato is similar with that of cherry-tomato. Two end-effectors were prepared for larger size tomato and cherry-tomato fruit harvesting operations, while the rest components were not changed for the different work objects. A color TV camera could be used for the both work objects, however fruit detecting algorithm and extracted features from image should be changed. As for the grape-robot, several end-effectors for harvesting, berry thinning, bagging and spraying were developed and experimented after attaching each end-effector to manipulator end. The manipulator was a polar coordinate type and had five degrees of freedom so that it could have enough working space for the operations. It was observed that visual sensor was necessary for harvesting, bagging and berry-thinning operations and that spraying operation requires another sensor for keeping certain distance between trellis and end-effector. From the experimental results, it was considered that multi-operations by the same robot could be appropriately done on the same or similar plant training system changing some robot components. One of the important results on having function of multi-operation was to be able to make working period of the robot longer.

Key Word : Robot, tomato, cherry tomato, grape, multi-purpose

INTRODUCTION

Harvesting robots, grafting robots, planting robots and many other kinds of robots have been studied so far ("Amaha and Takakura (1989)","Arima et al.(1994)", "Fujiura et al.(1990)","Harrell et al.(1990)","Kawamura et al.(1984)","Kondo et al.(1993a)","Ting et al.(1990)"). Most of these robots were developed for specific operations and work objects. However, robot with manipulator has much potential capability to apply for the other operations and maybe for another work object, because manipulator whose degrees of freedom are like human being's arm has much flexibility to work many kinds of operations. When a robot will be used for another operation, not only changing end-effector but also changing sensor system and its software will be required. In case of applying for another plant, the configuration of plant should be similar. Otherwise, work efficiency of the robot operation will become low. The plant training system, therefore, may have to be uniformed into several types for developing multi-operation robot.

In this paper, a harvesting robot for larger size tomato and cherry tomato is described. In addition, a robot to work in vineyard for harvesting, berry thinning, bagging and spraying operation is introduced as a robot which can do several kinds of operations for the same object.

ROBOT FOR HARVESTING TOMATO FRUIT

Physical properties and training system of tomato plant

Most of tomato plants have methodical phyllotaxis that all flower clusters emerge in the same direction. Tomato seedlings are usually transplanted so that the clusters may be directed to aisle side of ridge and they are grown vertically with supports until all the fruits of clusters are harvested. Cherry tomato plant also has the same properties and is transplanted in the same way. The fruit cluster has several fruits in case of larger size tomato and about a couple of dozens of fruit in case of cherry tomato. Both peduncles have joints where fruits can be picked off easily by bending or nipping instead of cutting.

Manipulator

Seven degrees of freedom manipulator was used to harvest the larger size tomato and the cherry tomato fruits as shown Fig.1 ("Kondo et al.(1993a)"). This manipulator could have high manipulatability when it had a harvesting posture. The manipulator consisted of two prismatic joints and five rotational joints. The lengths of upper arm and fore arm were 250 mm and 200 mm, while strokes of the prismatic joints are 200 mm in horizontal direction and 300 mm in vertical direction.

End-effector for larger size tomato

Fig.2 shows an end-effector for harvesting larger size tomato fruit ("Kondo et al.(1993b)"). It had two fingers with a suction pad. The pad was able to suck a fruit pneumatically to separate it from the cluster by the pad moving back and forth in the end-effector, because several fruits had adjacent positions one another and stems were also closed to the fruit cluster sometimes. The suction pad was straightly driven by DC motor and rack and pinion. A pressure sensor was installed to know whether the pad sucked fruit or not. The cross-sectional area of pad was 1.84 cm^2 and the suction force was about 10 N in the experiment. The fingers were controlled to grasp the fruit under appropriate pressure preventing them from slipping on the surface of fruit and from squeezing the fruit.

End-effector for cherry tomato

Fig.3 shows an end-effector for harvesting cherry tomato fruit ("Kondo et al.(1995)"). The end-effector could suck a fruit into the head pneumatically by blower. Three pairs of photo-interrupter could detect the position of fruit in the end-effector. When the fruit took an appropriate position, its peduncle was nipped around its joint by nipper closing. If the fruit had not the position, manipulator moved the end-effector's position back or forth until the photo-interrupter told the appropriate position of fruit. The harvested fruit was transported to a container through tube attached to the end-effector. The inner size of head was 40mm. The nipper was opened and closed by two springs and a solenoid actuator.

Visual sensor

A color CCD camera could be used to discriminate both fruits from their stems and leaves based on R, B, and G components, because matured tomato fruits had red color ("Kondo and Endo (1987a)"). The positions of the fruits were also able to be detected basically by binocular stereo vision. However, it would be better for cherry tomato fruit to combine with visual feedback control, since fruit number of cherry tomato were more than that of larger size tomato and it was difficult to detect the fruit positions precisely because of many pairs of correspondence between two image set.

Traveling device

A four wheel type traveling device which could travel in the ridge automatically was used for mounting the robot. This kind of traveling device was already commercialized as a vehicle for transporting in greenhouse.

ROBOT FOR GRAPEVINE

Plant training system

Most of Grapevines are trained on trellis in Japan to prevent from sickness due to high humid in summer season. The height from the ground to the trellis is about 170 cm. The training system makes the robot harvesting easier, because bunches hang down from the trellis, although manual harvest is laborious.

Manipulator

Fig.4 shows the basic mechanism of manipulator to work in vineyard according to positions of grape bunches, assuming that the robot travels along the main scaffold ("Kondo (1995)"). This is a polar coordinate manipulator with five degrees of freedom. The manipulator end could be moved on horizontal plane below the trellis at a constant speed under CP control. The length of the arm was 1.6 m, and the stroke was 1 m.

Harvesting end-effector

An end-effector to grasp and cut a rachis was designed as shown in Fig 5 ("Kondo (1995)") so that grape bunches would not shatter and the white powder which enhanced the marketing value would not be removed at harvest time. The grasping force and the cutting force of the rachis were 10 N and 100 N respectively. In addition, a function of pushing of bunch was added to the end-effector to enable the end-effector to grasp a very short rachis also at harvest time, to reduce the swinging of the bunch at the time of carrying, and to orient the bunch at the time of release.

Berry thinning end-effector

Berry thinning operation is usually performed to enhance its marketing value so that size of each berry can be appropriately bigger, although much labor is required for this operation. Fig.6 shows an end-effector for berry thinning ("Monta et al.(1992)"). This end-effector could remove all the berries in the upper part of bunch to expose the rachis for the harvesting end-effector grasping easily, could thin berries in the middle part of bunch and could cut rachis of lower part of bunch down to standardize the bunch size.

Bagging end-effector

Fig.7 shows bagging operation by a bagging end-effector ("Monta et al.(1995)"). This end-effector could keep several bags with spring plates and put one of them to the bunch. The spring plate could be open and close by pressure of robotic fingers. This operation is performed to protect the bunch from bird, insect, rain drop, sunburn and so on, however his operation is always not necessary to be done, if a roof over the trellis and a net on the side of the field are perfectly equipped for protecting from them.

End-effector for Spraying

If a spray nozzle is attached to the manipulator end, the robot could spray chemicals. This operation is desired to be automated soon to keep operator's health. Other spraying machines, therefore, have also been developed such as a speed sprayer not using robot with manipulator, however spraying operation using manipulator is much more precise than the other machines and can save chemicals.

Visual sensor

In case that the berry color is different from its background, a color TV camera can be used for discriminating the bunch hung down from the trellis. But, the thinning and bagging operations are performed when the bunch is young and green color. In case of that, a TV camera with infrared sensitivity or another sensor is desirable ("Kondo and Endo (1987b)"). To measure the 3D positions of bunches, a method of visual feedback using TV camera attached to the manipulator end was reported ("Kondo and Endo (1990)"). A photo-electric sensor using PSD array also could effectively detect the positions ("Fujiura et al.(1992)").

Traveling device

This robot was a bigger than the tomato harvesting robot and its mass was about 200kg. A crawler type traveling device was prepared for mounting the robot. The width of the crawler was 360 mm, and the ground contact length was 1,010 mm. The width of the traveling device was 1,400 mm, the length was 2,300 mm, and the height from ground to the plate on which the robot was mounted was 420 mm. The traveling speed of the device could be changed from 0 to 2 m/s. In the experiment, the device was steered manually, and the engine stopped when the robot operated.

EXPERIMENTAL RESULTS AND DISCUSSION

Experiments for tomato harvesting

Harvesting experiments were carried out in greenhouse changing the end-effectors and their attachments accompanying change of the end-effectors. It was observed that the robot could harvest the both fruits satisfactorily, because the plant training system and configuration of larger size tomato plant were similar with that of cherry tomato plant. The sensing system of the color TV camera could discriminate the both fruits and determine their positions, however the software for machine vision and robot control should be changed for specific work object. It was found that there was possibility a same robot could work for the work objects with a similar plant configuration.

Experiments for grapevine

Harvesting, berry thinning, bagging and spraying experiments were done in the field and in laboratory. The operations should be performed on different growing stages. The sensing system of only the color TV camera was, therefore, not enough to detect the work object. Especially, it was difficult to detect a very young bunch which did not hang down yet from trellis in berry thinning operation. In addition, sensing system to measure the distance from the trellis to the manipulator end such as an ultrasonic sensor was necessary for spraying operation. Generally speaking, the harvesting time for fruit tree is once in a year that is different from plants in greenhouse. It was considered important that developing many kinds of end-effectors and sensing systems for many operations makes working period of the robot longer.

CONCLUSION

From the experimental results, it was considered that multi-operations by same robot could be appropriately done on the same or similar plant training system changing some robot components. However, the function of multi-operation may not be necessary, if the robot can work all year, since adding different operation to the robot induces low work efficiency. It is apparent that the specific operation machine has much higher work efficiency. The tomato harvesting robot will be used very frequently as well known that plants in greenhouse are harvested all the year. In case of fruit tree, each operation is carried out once in a year. The multi-operation is more desirable for the robot to work in orchard, but several operations are still difficult to be done by robot using nowadays technologies. It is, therefore, important to classify the operations robot can do and robot cannot do, and to construct a system which the operator works with the robot together.

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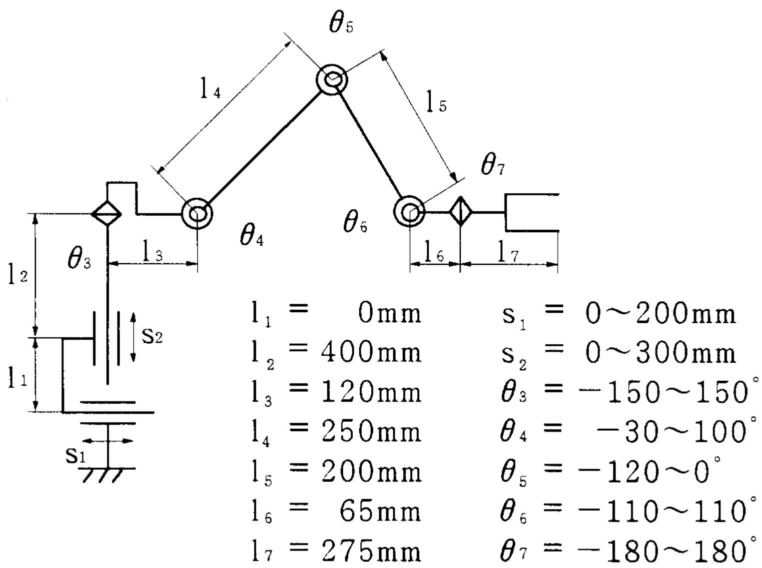


Fig. 1 Basic mechanism of tomato harvesting manipulator.

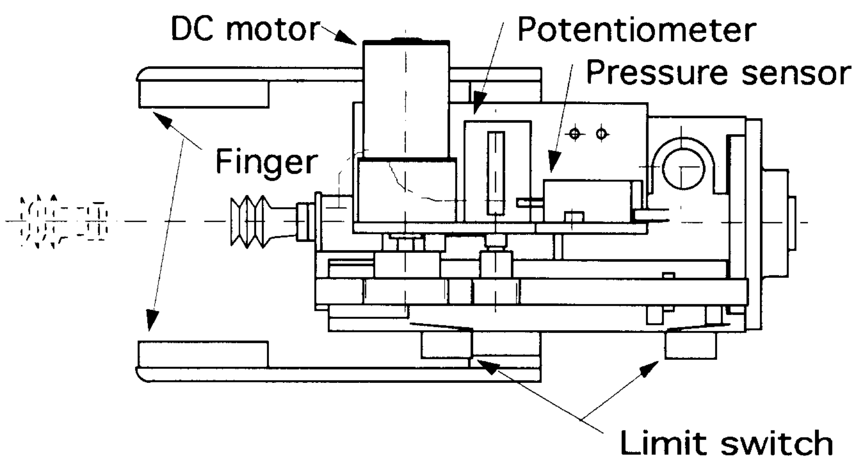
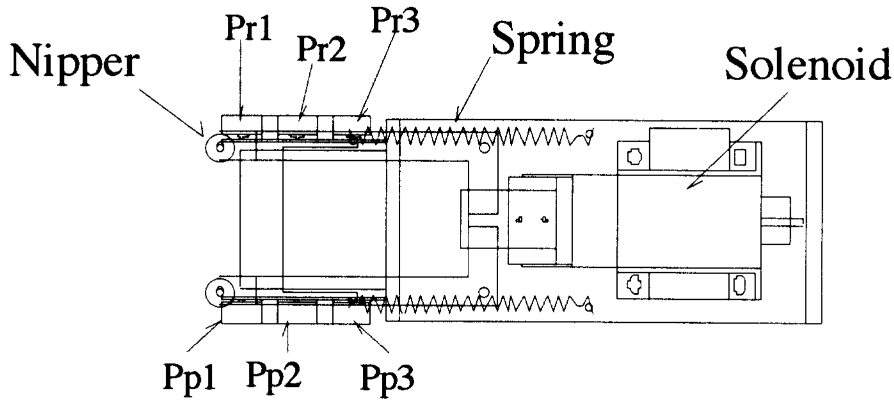
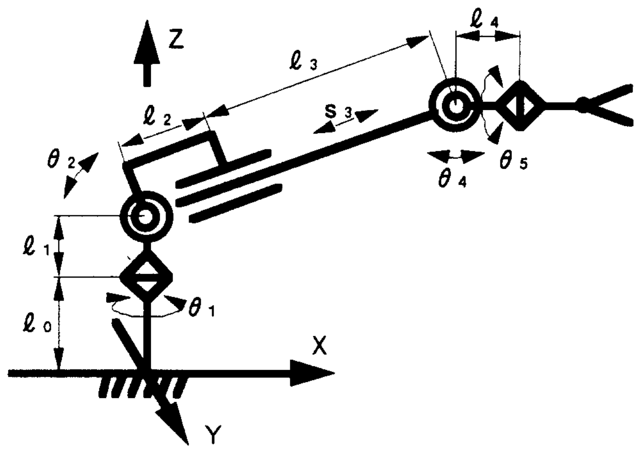


Fig.2 End-effector for harvesting larger size tomato fruit.



Ppi: Photo interrupter (Projector)
Pri: Photo interrupter (Receiver)
(i=1-3)

Fig.3 End-effector for harvesting cherry tomato fruit.



Waist	: θ_1 = -130～130°	ℓ_0 =	800mm
Shoulder	: θ_2 = -40～ 30°	ℓ_1 =	0mm
Arm	: s_3 = 0～1000mm	ℓ_2 =	0mm
Wrist 1	: θ_4 = -70～ 70°	ℓ_3 =	630mm
Wrist 2	: θ_5 = -90～ 90°	ℓ_4 =	0mm

Fig.4 Basic mechanism of manipulator for grapevine.

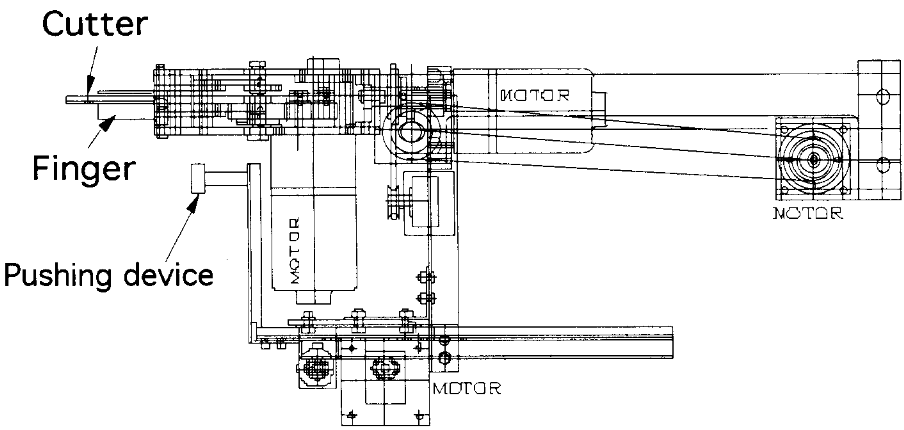


Fig.5 Harvesting end-effector.

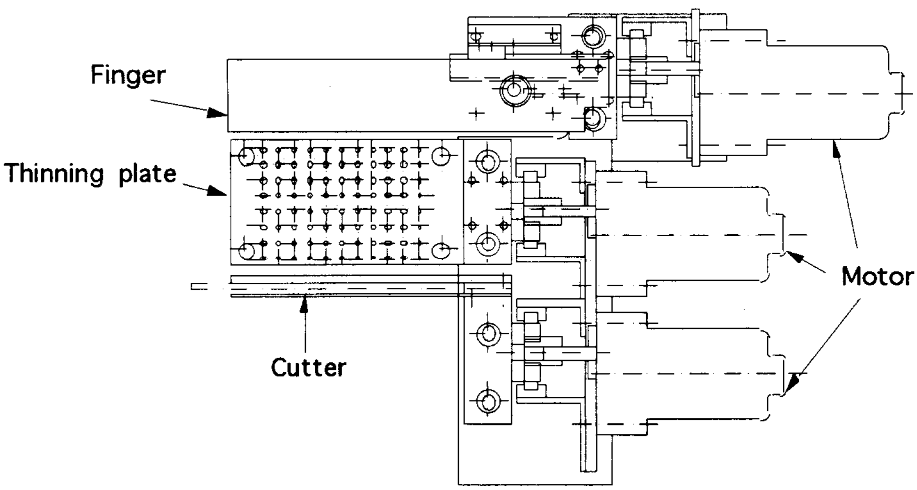


Fig.6 Thinning end-effector.

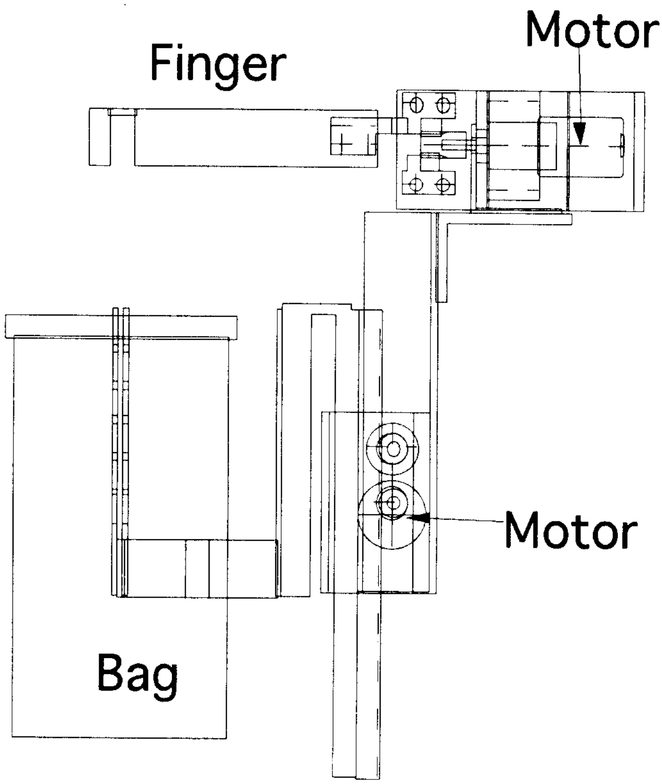


Fig.7 Bagging end-effector.