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Tele-robotics in Agriculture
- Tomato Harvesting Experiment -

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Abstract: In this study, tele-robotics was researched to actualize robots in agriculture. The robot system consisted of a data collecting robot, several robots that performed their own agricultural operations, a server, client computers and networks between robots and computers. In this paper, as a first step, harvesting experiments were carried out. From the results, it was observed that the tele-robotics had feasibility to propel the robotization in agriculture. The tele-robotics has advantages not only that human workers are released from the severe working environment but also that the greenhouse can be monitored and controlled anytime and anywhere.
Keywords: Tele-robotics, Data Collecting Robot, Harvesting Robot, 3-D Information, Laser Scanner, Color Camera

Introduction

Many agricultural robots have been researched in the world since 1980's, however most of the robots are at the present state far from the stage of practical application because of the complexity of agricultural operations. For example, it is easy for a robot to cut a branch when a scissors is attached to the manipulator tip, but it is difficult to judge whether the branch should be cut or not. However, robotization in agriculture can be promoted if human workers support the weak ability of robot such as ability in judgment, incompletion of machine vision.

In this study, tele-robotics was researched to actualize robots in agriculture. The robot system consisted of a data -collecting robot, several robots that performed their own agricultural operations, a server (host computer), client computers and networks between robots and computers. In this paper, as a first step, a harvesting experiment was carried out. A laser scanner and a color CCD camera were mounted on the data-collecting robot and were moved vertically to obtain 3-D images and color images of target fruits. The harvesting robot had a 7 DOF manipulator and a multi-fingered end-effector to pick a fruit by bending. First, color images and 3-D distance data in a greenhouse were captured by the data-collecting robot and were send to a server through a wireless LAN. Secondly, discrimination of ripe fruits and calculation of fruit locations were conducted based on the color and 3-D information. The results were stored in the server. The operator could access the server at anytime and anywhere through an internet. The operator could check the judgment by the robot (server) and could modify it on the display when the server judged wrongly or there were additional operations to be done by robots. The modified data were sent to a harvesting robot from the server through a wireless LAN. Finally, the target fruits were picked by the harvesting robot.

From the results, it was observed that the tele-robotics had feasibility to propel the robotization in agriculture. The tele-robotics has advantages not only that human workers are released from the severe working environment but also that the greenhouse can be cared anytime and anywhere.

Materials and Methods

1. Concept of Tele-robotics in Agriculture

Tele-robotics is expanding the field of its applications, such as operations in a nuclear facility, remote surgical operations and an appreciation of art in a remote museum, and so on. In Japan, approximately 400 lives were lost due to farm working every year, therefore agriculture can be a target of tele-robotics because there are many danger and severe operations in agriculture. It is considered that the working environment can be improved when tele-robotics is introduced into agriculture. We assumed following conditions for tele-robotics in agriculture.

One's own field/greenhouse should be monitored anywhere and anytime : In this study, internet was used to communicate with robots.

Minimize the human work load when human workers

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control the robot system : Master slave, supervisory control and teleexintence have been developed to control tele -operating robots. In this study, supervisory control, where robots received simple orders from human workers and accomplished their tasks, was employed to achieve the high working efficiency. The judgements by robots are checked and modified by human workers. Robots automatically carry out operations according to the modified orders. The accumulated robotic technology can be used effectively because many robots have been developed aiming at full automatic control.

Multiple operations should be carried out : Effective multipurpose robot systems can be actualised when multiple operations are carried out by robots, not only harvesting but also fertilizing, trimming, spraying operations. One operator can control several robots at a time.

Fig. 1 shows a concept of tele-robotics assumed in this research. The robot system consisted of a data collecting robot, several robots that performed their own agricultural operations, a server (host computer), client computers and networks between robots and computers. In this paper, as a first step, harvesting experiments were carried out. A laser scanner and a color CCD camera were mounted on the data collecting robot and were moved vertically to obtain 3-D images and color images of target fruits. The harvesting robot had a 7 DOF manipulator and a multi-fingered end -effector to pick a fruit by bending. First, color images and 3-D image in a greenhouse were captured by the data collecting robot and were send to a server through a wireless LAN. Secondly, discrimination of ripe fruits and calculation of fruit locations were conducted based on the color and 3-D information. The results were stored in the server. The operator could access the server at anytime and anywhere through an internet. The operator could check the judgment by the robot (server) and could modify it on the display when the server judged wrongly or there were additional operations to be done by the robot. The modified data were sent to a harvesting robot from the server through a wireless LAN. Finally, the target fruits were picked by the harvesting robot.

2. Robots

(1) Data collecting robot

A data collecting robot consists of a laser scanner (Sick, Inc.) to measure distance to the object, color TV camera to capture color image, lift to move the sensing system vertically and traveling device. The laser scanner measures the distance between scanner and the object based on the time-of-flight. A pulsed laser beam is transmitted and reflected by the object. The time between emission and reception of the impulse is proportional to the distance. The pulsed laser beam is deflected by an internal rotating mirror so that a fan-shaped scan is made of surrounding area. The contour of the target area is determined from the sequence of impulses received. Any objects, regardless of their shape, color or surface structure, can be measured without any contact. Table 1 shows the specifications of the laser scanner. The maximum range and the resolution are 150 m and 10 mm, respectively. The range to an object with minimum reflectivity of 1.8% is 4m. In a radial field

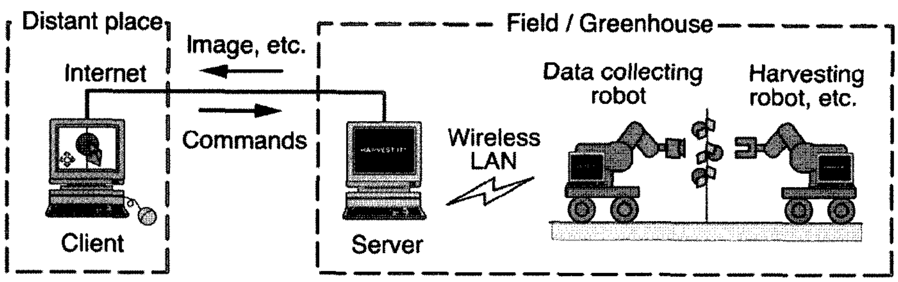

Fig. 1 Concept of tele- robotics.

Table 1 Specifications of laser scanner

Angular resolution (°)	0.25	0.5	1.0
Max. scanning angle (°)	100	100/180	100/180
Max. number of measurements	401	201/361	101/181
Response times (ms)	52	26	13

of vision (100° or 180°), a light impulse is emitted every 0.25°, 0.5° or 1°. The laser scanner is available for detecting human because the laser protection class is 1, eye-safe type. The measurement data is given out in binary format via the RS 232/RS 422 interface.

The fixed laser scanner can measure 2-D information by making a fan-shaped scan. However, targets of agricultural robot exist in 3-D space and their shapes vary according to the height. For example, in Japan, fruit trees, such as grape, kiwi and pear, are trained on a horizontal trellis suited above a human being's head to prevent the plants from being harmed by the high humidity in the summer season. A pipe to support the trellis which is erected vertical on the ground hardly change shapes according to the height, however, a tree curves and branches in all directions. Leaves and twigs hang down from the trellis. Therefore, it is necessary for a robot to capture information according to the height in order to decide a path of its manipulator so that the robot can achieve its task while avoiding a collision with objects (Monta,M., et al., 2002). In this study, a vertical movement was provided to the laser scanner to carry out a 3-D measurement. The laser scanner was moved vertically by a lift as shown in Fig. 2. A table to mount the laser scanner was driven up and down by an AC motor and a ball bearing screw. The displacement of the table was detected by an encoder connected the ball bearing screw. Moving speed and operating distance of the table were 72.2 mm/s and 300 mm, respectively.

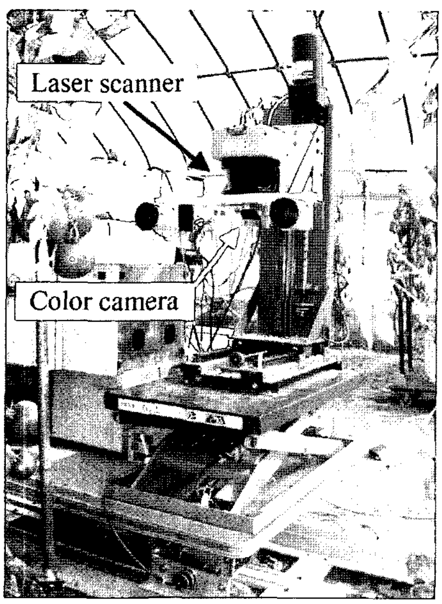

Fig. 2 Sensing system equipped with laser scanner and color camera.

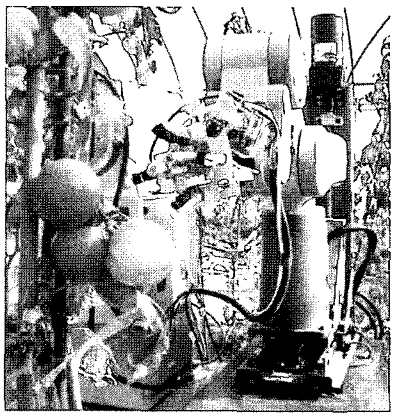

Fig. 3 Tomato harvesting robot.

(2) Harvesting robot

Fig. 3 shows tomato harvesting robot which consists of 5 DOF articulated manipulator, 2 DOF prismatic joint, multi-fingered end-effector and traveling device. The end-effector has four flexible fingers to grasp a fruit and suction cup which moves back and forth to separate a target fruit from the cluster. The fingers open and close when the suction cup moves forward and backward respectively. The end-effector harvests a fruit by bending the fruit at a joint of peduncle instead of cutting the peduncle.

Results and Discussion

1. Tomato Harvesting Experiments

(1) Discrimination of plants

The tomato fruit cluster has several fruits, however it is not always that all the fruits in a same cluster mature simultaneously. Therefore, discrimination of fruits by the sensing system is required to practice a selective harvesting. In this study, 3-D images measured by the laser scanner and color images captured by the color TV camera are combined to discriminate ripe fruits from others.

The procedure of discrimination was as follows. The laser scanner and the color camera acquired data at regular interval while the table moved. First, a color image was made by linking extracted center area from each image when the table finished the vertical movement, as shown in Fig. 4-a). Discrimination of ripe fruits in a cluster from their background in the linked image was carried out based on a certain thresholding value using R and G (Fig. 4-b)).

Secondly, a 3-D image was produced by linking 2-D data that were scanned at regular interval. Then, recognition of object was carried out. Distance between a detected point and neighboring points were calculated to the entire points in the 3-D image. When the distance between neigh-

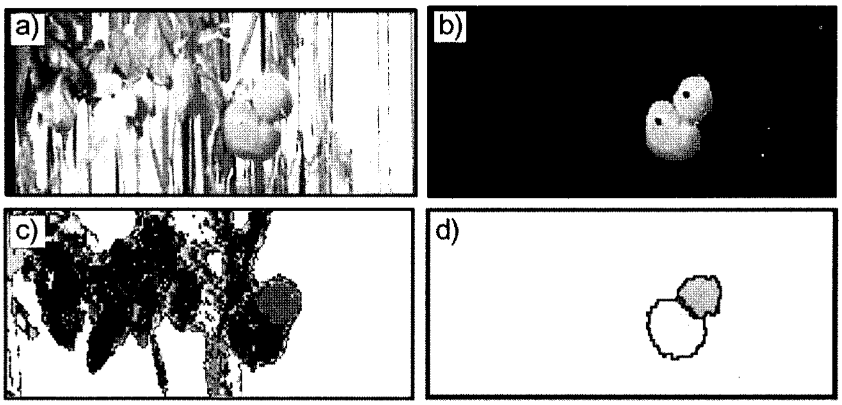

Fig. 4 Discrimination method of tomato fruits.

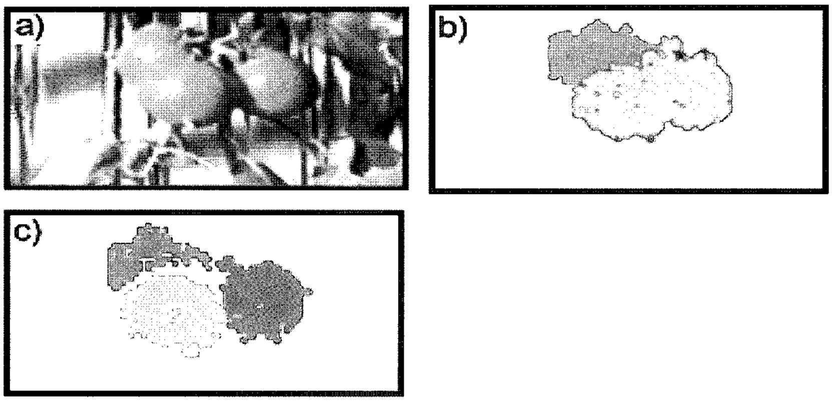

Fig. 5 Discrimination by using Sobel operator.

boring points was less than a thresholding value, it was considered that they belonged to same object. Fig. 4-c) shows the processed image including the fruits, the leaves and the supports.

Finally, the objects, that corresponded to the location of red fruits in the linked color image, was discriminated as ripe fruits, as shown in Fig. 4-d). From the result, the adjacent fruits were discriminated as individual fruits while they might be detected as one object by the color image.

Fig. 5-b) shows an example when each fruit was not discriminated successfully. In this case, there were three ripe fruits in a cluster (Fig. 5-a); linked image), however two fruits were detected as one object because distance between detected points of both fruits was less than the thresholding value. To solve this problem, Sobel operator was applied to the 3-D image. Sobel operator is used to detect edges in a binary image. Fig. 5-c) shows a result when 3×3 Sobel operator was applied to the 3-D image. From the result, it was observed that each fruit was discriminated successfully by detecting edges of objects (Monta, M. and K. Namba, 2003).

(2) Harvesting experiments

Tomato harvesting experiments were carried out in a greenhouse (Fig. 6). First, the data collecting robot collected 3-D images and color images of the plants and transferred the data to the server. Discrimination and recognition of ripe fruits in a cluster were carried out based on the data from the data collecting robot. The results were stored in the server. The operator could access the server at anytime and anywhere through an internet. The operator could check the judgment by the robot (server) and could modify it on the display when the server judged wrongly or there were additional operations to be done by the robot. The modified data were sent to a harvesting robot from the server through a wireless LAN. Finally, the target fruits were picked by the harvesting robot.

Fig.7 shows an example of the display. The upper figure is an image captured by the color camera and the lower one is a judgment by the server.

From the harvesting experiments, approximately 80% of ripe fruits were discriminated successfully. Incorrect judgments and discriminations were modified by the operator, then the

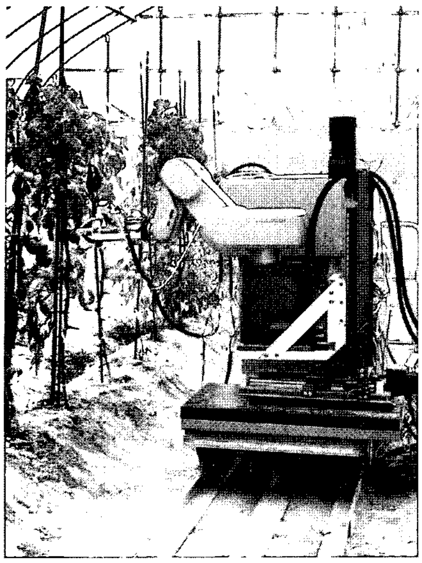

Fig. 6 Tomato harvesting experiment.

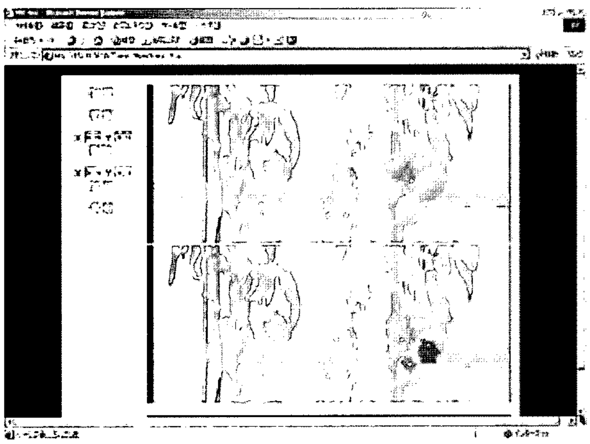

Fig. 7 Display of client.

modified data were sent to the harvesting robot.

In this experiment, no machine vision was mounted on the harvesting robot. Several fruits were not harvested because their locations were changed when other fruits in the same cluster was harvested. It was considered that a simple external sensor to detect the change of fruit location should be attached to the harvesting robot.

Conclusion

In this paper, as a first step of tele-robotics in agriculture, the harvesting experiments were carried out. From the results, it was considered that the tele-robotics for agricultural use had several advantage. It is possible for operators to make reservations on robotic farm working in the same manner as they operate electric appliances. For example, robots start working so that a certain quantity of fruits for a shipment are harvest in time. Furthermore, a greenhouse can be controlled and monitored from a distance at anytime even if an operator is sick.

In the near future, traceability of agricultural products can be constructed when information collected by robots are combined.

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