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# BASIC MECHANISM OF ROBOT ADAPTED TO PHYSICAL PROPERTIES OF TOMATO PLANT

N. Kondo, M. Monta, Y. Shibano, and K. Mohri
Faculty of Agriculture
Okayama University
1-1-1, Tsushima-Naka, Okayama, Japan

## ABSTRACT

In this paper, it is reported that manipulator and hand required for harvesting tomato were studied. At first, basic physical properties of tomato plant were investigated such as positions of fruit, length of stems and leaves, width between ridges and so on. Secondly, basic mechanisms of articulate manipulators with 5 to 7 degrees of freedom were investigated by using evaluation indexes such as operational space, measure of manipulatability, posture diversity and so on. From the results, an articulate manipulator with 7 degrees of freedom was selected and the manipulator was manufactured as a trial according to the mechanism. Thirdly, physical properties about fruit and peduncle of tomato were also researched such as diameter, length, picking force and so on. Based on the properties, tomato harvesting hand with absorptive pad were also made as a trial. Finally, after the hand was attached to the manipulator, harvesting experiment was done in greenhouse. It was observed that the robot could harvest satisfactorily, not only since the robot adapted to physical properties of tomato plant was manufactured but also since phyllotaxis of tomatoes was so methodical that all fruit clusters emerged in the same direction.

## INTRODUCTION

Agricultural robots, which harvest tomato, cucumber, grape, orange and so on by their manipulators, have been studied in recent years in Japan. But the manipulators in the studies have almost ordinary mechanisms, so that physical properties of crop plants or agricultural products have not been considered enough such as three-dimensional position of each plant organ and fruit picking direction. On the other side, plant training and cultivation methods have been changed so that its productivity and quality can be improved and that farmer can work easily. But the robot cannot often work efficiently in the present training, since its visual sensor, manipulator, hand and travelling device are inferior to those of the farmer. These factors cause to stop practical application of the robot.

In this paper, mechanism of harvesting robot which was adapted to the physical properties of tomato plant was studied. Especially, basic mechanism of manipulator was investigated by evaluating indexes and hand with absorptive pad was contrived in order to adapt them to physical properties of tomato plant.

## MATERIALS AND METHODS

1. Physical properties and cultivation method of tomato

Fig.1 shows phyllotaxis of almost tomatoes planted for fresh marketing in Japan. It is methodical that all flower clusters ( I ~ V ) emerge in the same direction. Therefore tomatoes are transplanted so that the clusters may be directed to aisle side of ridge and they are grown vertically with supports until all fruits of the sixth cluster are harvested. Not only farmers but also harvesting robot can work easily in this training. Recently a cultivation method of only first cluster on water culture is tried in order to increase quality of fruits. It is considered the training is also benefiting to the robot since the height of fruits become almost same.

The cluster has several fruits and the peduncle has a joint in many varieties of the tomatoes. When farmer harvests ripe fruits one by one in the cluster, he can pick off them easily by bending at the joints instead of cutting. The picking force was measured on three planes as shown in Fig.2. It was obtained that the force increased in proportion to the cross-sectional area of joint and in order of XY, YZ, XZ plane from the result. The angles of bending on YZ and XZ planes were about 90°, while 2 or 3 rotations were needed to remove on XY plane. It is considered proper that the robot accesses the fruit on XZ plane when leaves and stems do not exist before the fruit and on YZ plane when the obstacles exist. Other measured items are shown in Table 1.

2. Manipulator

Tomato harvesting robot was already studied and an articulated manipulator with 5 degrees of freedom was reported. But the operational space of manipulator did not to include the range of the positions of all the fruits. Besides the manipulatability of the posture of manipulator happens to be very low, even when the manipulator moves to a fruit whose position is included in the operational space. In this study, basic mechanism of manipulator which was adapted to the physical properties of tomato was investigated from the view points of operational space, measure of manipulatability, space for obstacle avoidance, redundant space, and posture diversity. The evaluation indexes are defined as below.

Operational Space:

A region which manipulator end can move in 3 dimensional space is called operational space. Crop growing region must be included in the space. Comparing the different type manipulator, normarized volume index which was expressed as Eq.(1) is usually used.

$$V_n = \frac{V}{4\pi L^3/3} \qquad (1)$$

where V is volume of operational space and L is sum of link lengths.

Measure of manipulatability:

The configration of manipulator is evaluated by measure of manipulatability which expresses easiness to move manipulator end. The measure of manipulatability is called as follows;

$$\boldsymbol{r} = \boldsymbol{f}(\boldsymbol{\theta}) \qquad (2)$$

where **r** is vector which expresses hand position and posture, $\boldsymbol{\theta}$ is vector of joint angles.

$$\dot{\boldsymbol{r}} = \boldsymbol{J}(\boldsymbol{\theta})\,\dot{\boldsymbol{\theta}} \qquad (3)$$

where $\dot{\boldsymbol{r}} = d\boldsymbol{r}/dt$, $\dot{\boldsymbol{\theta}} = d\boldsymbol{\theta}/dt$, $\boldsymbol{J}(\boldsymbol{\theta}) = d\boldsymbol{f}(\boldsymbol{\theta})/d\boldsymbol{\theta}$ and **J** ( $\boldsymbol{\theta}$ ) is called Jacobian matrix. Measure of manipulatability is defined as Eq.(4).

$$w = \sqrt{\det \boldsymbol{J}(\boldsymbol{\theta})\boldsymbol{J}^T(\boldsymbol{\theta})} \qquad (4)$$

When manipulator is not redundant, measure of manipulatability is expressed by Eq.(5).

$$w = |\det \boldsymbol{J}(\boldsymbol{\theta})| \qquad (5)$$

In case of manipulator with 2 degrees of freedom, Jacobian matrix is calculated by Eq.(6) and measure of manipulatability is by Eq.(7).

$$\boldsymbol{J}(\boldsymbol{\theta}) = \begin{bmatrix} l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) & l_2\cos(\theta_1+\theta_2) \\ -l_1\sin\theta_1 - l_2\sin(\theta_1+\theta_2) & -l_2\sin(\theta_1+\theta_2) \end{bmatrix} \qquad (6)$$

$$w = l_1 l_2 |\sin\theta_2| \qquad (7)$$

Space for obstacle avoidance:

Robots working in the field need to access objects after avoiding obstacles which are stems and leaves sometimes. Area of figure which formed mainly by upper arm and fore arm is called space for obstacle avoidance.

Redundant space, and posture diversity:

Middle point of redundant manipulator can be moved even if base and end of the manipulator are fixed. The space which formed by middle point is called redundant space. The angle of the accessing direction of manipulator end is called poisture diversity.

These evaluation indexes have not been used in studies on manipulator. But it is important especially for agricultural robot to decide the mechanism of manipulator by using the indexes. Four

Manipulators shown in Fig.3 were investigated on 2 dimensional space by using the evaluating indexes under the condition of Table 2 (joints added ※ were neglected in Fig.3). Fig.4 to 6 show the results. From the results, a manipulator with 7 degrees of freedom which was consisted of 2 prismatic joints and 5 rotational joints was selected. Fig.7 shows the mechanism of manipulator. Fig.8 shows the manipulator made as a trial according to the investigated mechanism. The lengths of upper arm and fore arm were 250 mm and 200 mm, and tool length was 150 mm, while strokes of the prismatic joints are 200 mm (horizontal direction) and 300 mm (vertical direction).

3. Hand

The fruit cluster has several fruits which are adjacent one another. Hand which is constructed of two plates injures other fruits or stems sometimes when the robot harvests. Therefore the two plates hand with absorptive pad was made to harvest fruits one by one as shown in Fig.9. The pad was able to absorb a fruit pneumatically to separate it from the cluster by the pad moving forward and backward in the hand, using pinion and rack. When the pad absorbed the fruit, pressure sensor sensed it and the pad stopped moving. The cross-sectional area of pad was 1.84 $cm^2$ and the adsorptive force was about 10 N.

4. Harvesting Experiment

Tomato harvesting experiments were done in a greenhouse and a laboratory under algorithm of Fig.10. At first, after the manipulator took standard configuration, images were input by visual sensor. If the fruit position calculated from the images was in working range of the manipulator, the manipulator moved to the fruit passing a midpoint. In this experiment, two accessing methods of manipulator were adopted; a method that the midpoint position was provided on the horizontal line which connected the hand of standard configuration with the fruit (method on XZ plane) and the other method that the position was at an angle 45 degree under with respect to the horizontal line (method on YZ plane). Secondly, the hand gripped the fruit and picked it off at the joint by bending after the pad adsorbed and separated it from the other fruits. If the pad could not adsorb, the hand moved forward more 10 mm. Thirdly, passing the midpoint, the hand released the fruit on a tray and the manipulator took standard configuration again.

## RESULTS AND DISCUSSIONS

Fig.11 shows the result of harvesting experiment on YZ plane. In the figure, posture ① is standard configuration, ② is posture which only prismatic joint was moved, ③ is posture at the midpoint, ④ is posture at harvesting, ⑤ are postures which moved 10 mm forward and the pad adsorbed the fruit, ⑥ is gripping posture after separating the fruit from the others, and ⑦ is bending postures at the joint. 10 mm moving when the pad could not adsorb was effective, since the the visual sensor has respective error of about 10 mm, detecting the fruit position in the field. From the experimental results, it was observed that the robot was able to harvest the fruits which existed before leaves and stems satisfactorily, and that fruits and stems near by the objects were not injured.

Besides, it was considered that the robot could work more easily if the length, shape, position, and growth habit of the objects had been standardized by environmental control and the knowledge data of the plant had been input to the robot before working.

## CONCLUSIONS

This cultivation method was effective so that the tomato fruits were easy to be detected and accessed by the robot because of the transplanting direction and the regularity of the tomato plant. When we develop a robot or new production system, we need to investigate the cultivating method and plant training of object. It is important to study not only on engineering side but also on biological and chemical sides such as breeding, new cultivation method and plant training for the robot or mechanical system.

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Table 1 Average value of measured item

| Measured item | Average value |
|---|---|
| Fruit diameter | 62.1mm |
| Fruit weight | 130.0g |
| Peduncle diameter | 4.2mm |
| Peduncle length | 61.4mm |
| Joint diameter | 5.7mm |
| Joint angle | 147° |
| Distance between calyx and joint | 9.3mm |
| Picking force | 7.2N |
| Picking angle | 80° |
| Fruit moving distance | 50mm |

Table 2 Condition on manipulator

| Item | Condition |
|---|---|
| Degree of freedom | 2 to 4 |
| Type of joint | rotating joint or prismatic joint |
| Link length | 350mm (when including 2 rotating joints)<br>233mm (when including 3 rotating joints)<br>Ratio among link lengths = 1 : 1 |
| Displacement of joint | -90～180° |
| Working Configration | It has more than 80% of maximum value of measure of manipulatability.<br>Forearm can have access from below horizontal direction. |
| Stroke of prismatic joint | as short as possible |
| Distance between base and object | 450mm |
| Height of base | 450mm |

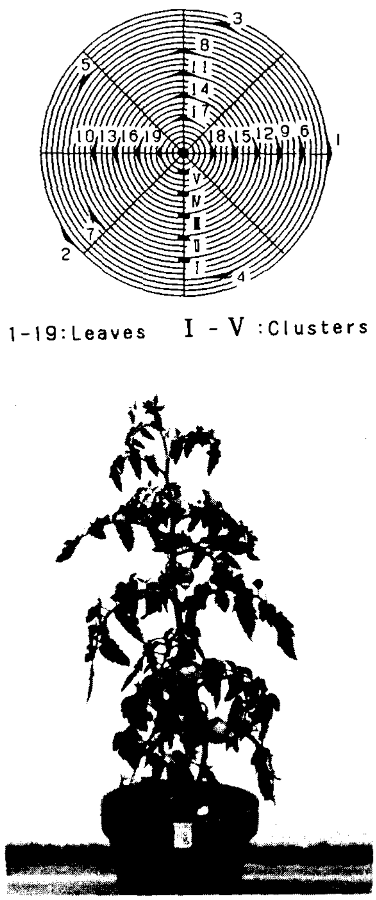


Fig.1 Phyllotaxis of tomato

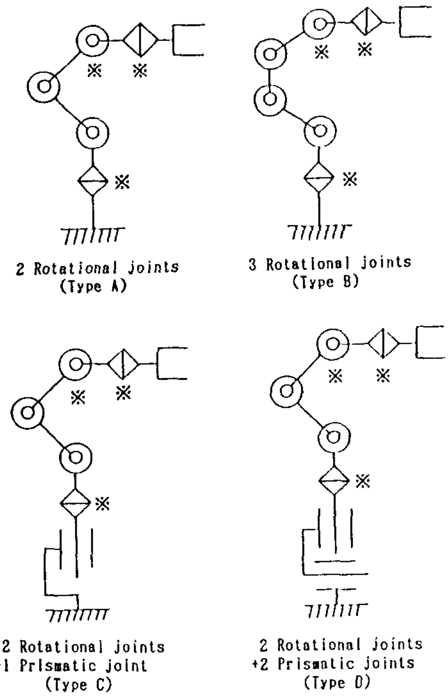


Fig.3 Investigated mechanisms of manipulators

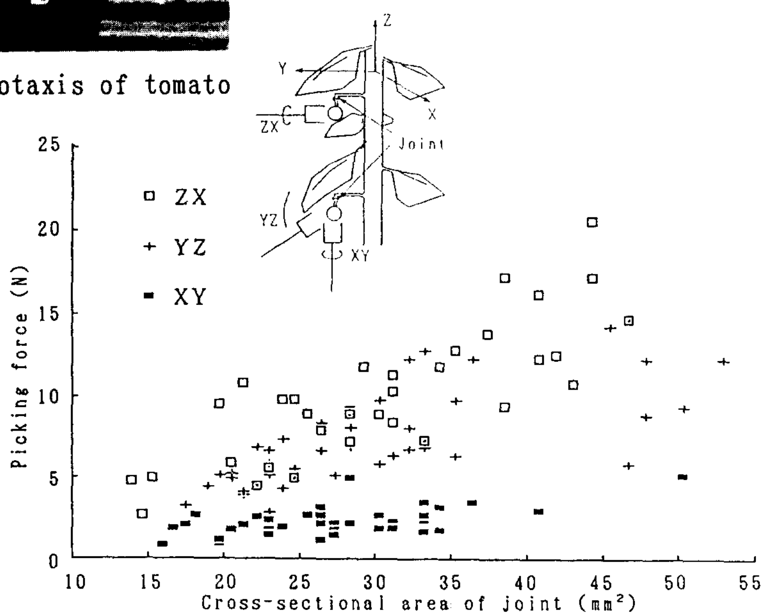


Fig.2 Relationship betweeen cross-sectional area of joint and picking force

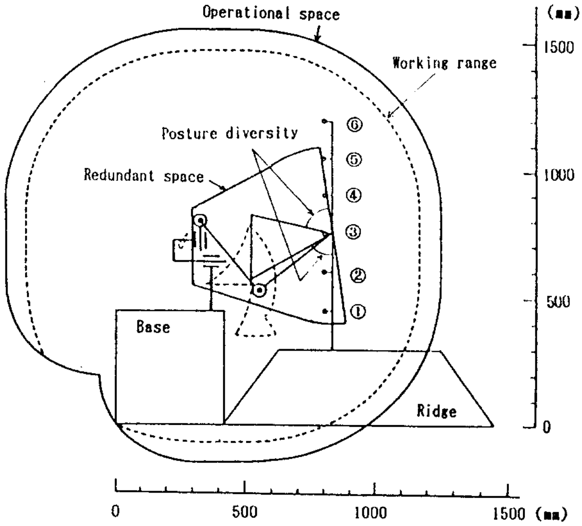


Fig.4 Result of evaluation indexes
(Type D manipulator, Fruit No.③)

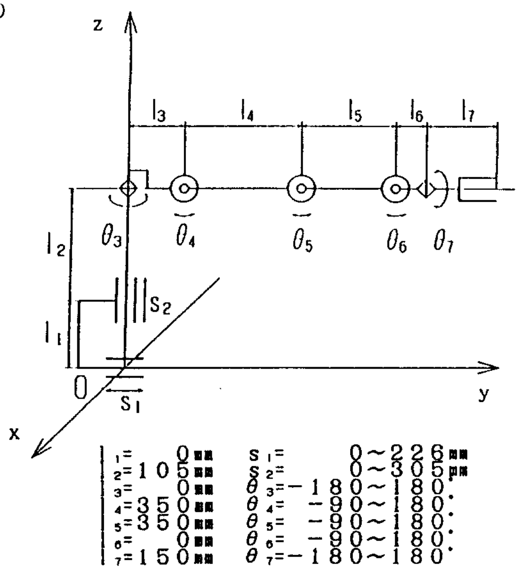


Fig.7 Mechanism of manipulator for working in tomato field

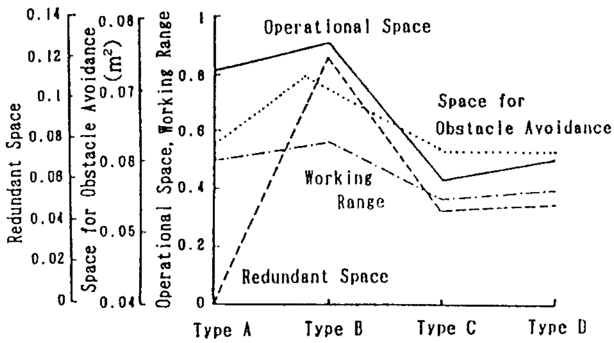


Fig.5 Result of evaluation indexes related to area

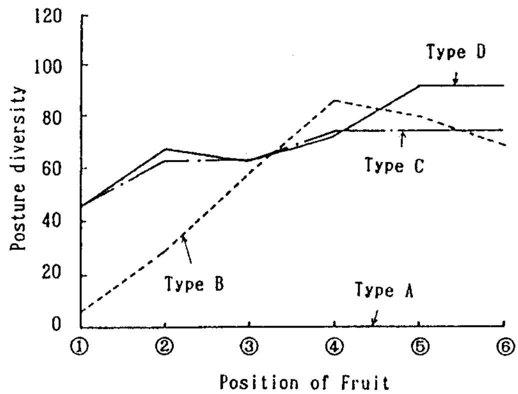


Fig.6 Result of posture diversity

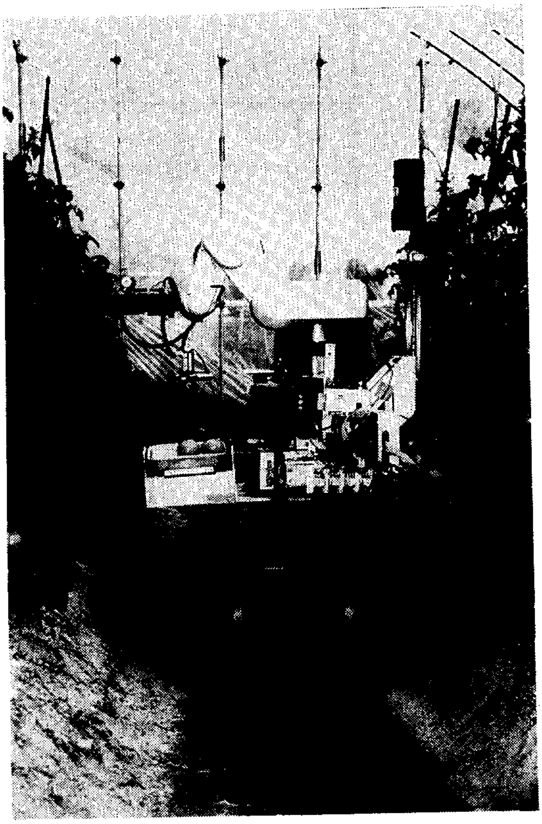

Fig.8 Toamto harvesting robot

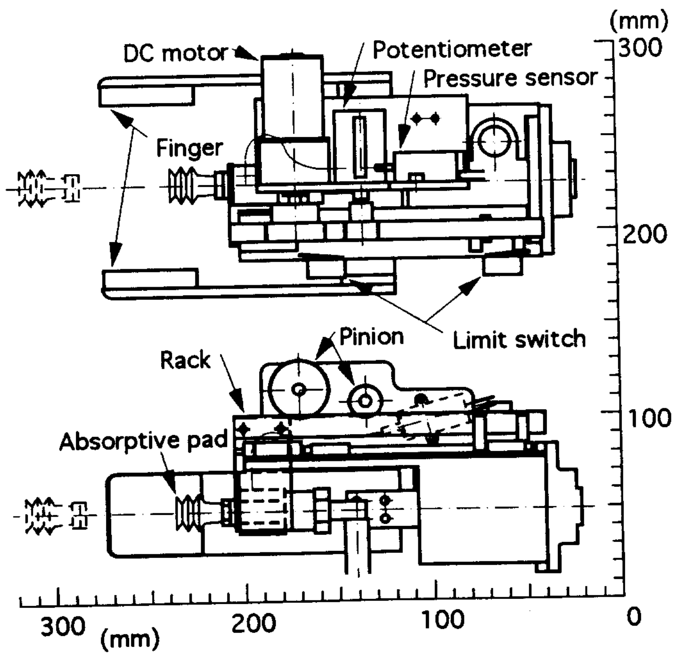


Fig.9 Harvesting hand

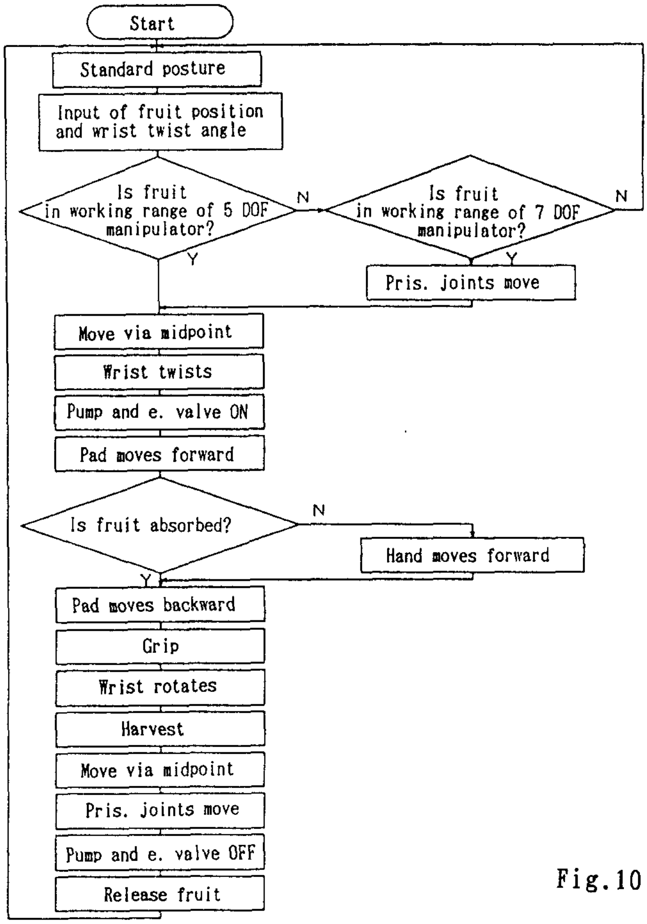


Fig.10 Flowchart of experiment

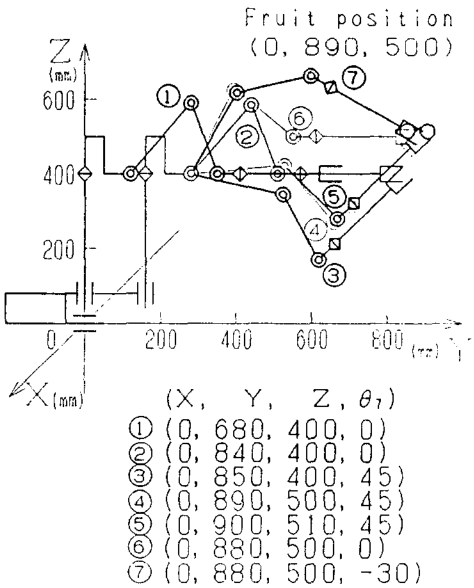


Fig.11 Experimental result