ROBOTS FOR BIOPRODUCTION SYSTEMS

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Abstract : It is no doubt that automation including robotics is essential for high productive and efficient bioproduction systems. Since the study of a tomato harvesting robot was started 16 years ago in Japan, robotic technologies have been applied to many bioproduction systems in the world such as harvesting, transplanting, grafting, weeding, spraying, milking, tilling, fertilizing, and so on. Some of them were already commercialized. Recently, furthermore, studies related to man-machine interface started. In this paper, robots for seedling production, harvesting, furthermore, human cooperative robot system are described. *Copyright © 2000 IFAC*

Keywords : Robots, Automation, Agriculture, Production systems, Handling, Man/machine, Sensor systems

1. INTRODUCTION

Since the study of a tomato harvesting robot was started 16 years ago in Japan (Kawamura, et al., 1984), robotic technologies have been applied to many bioproduction systems in the world such as harvesting, transplanting, grafting, weeding, spraying, milking, tilling, fertilizing, and so on (Kondo, et al.,1996b,c; Okamoto, et al., 1992; Simonton, 1990; Ting, et al.,1990a,b; Hwang, et al.,1997; Ahmad, et al.,1999; Hogewerf, et al.,1992; Okazaki, et al., 1996; Kuipers, 1996; Yukumoto, et al., 1995). For example, harvesting robots for oranges, apples, grapes, tomatoes, cherry tomatoes, cucumbers, strawberries, melons, watermelons, mushrooms, etc., seedling production robots have been studied in the USA, Europe and Asia (Harrell, et al.,1990; Fujiura, et al.,1990; Grand,1984; Bourey, et al., 1990; Sittichareonchai, et al., 1989; Kondo, 1991; Monta, et al., 1998a,b, 1995a,b,c; Kondo, et al.,1993, 1994a,b, 1995, 1998a; Fujiura, et al.,1995; Arima, et al.,1994a,b; Kollenburg-Crisan, et al., 1997; Wolf, et al.,1990; Umeda, et al.,1997; Reed, et al.,1995). Grafting, transplanting, and wool-sharing robots were already commercialized (Suzuki, et al., 1995; Australian Wool Corporation, 1988; Kuipers, 1996). Recently, studies related to man-machine interface started, such as a human cooperative robot system, a man-robot communication system, tele-operative system for bioproduction, and so on (Monta, et al., 1998c,d,e, 1997; Matsuo, et al., 1998). In this paper, a seedling production robot for chrysanthemum, strawberry harvesting robots, and a human cooperative robot system are described as examples of robots for bioproduction systems.

2.AUTOMATION FOR SEEDLING PRODUCTION

Importance of seedling production has increased to grow uniform and high quality plant, since plug trays have been spread. Many automation systems for seedling productions have been developed such as grafting systems, cutting sticking systems, transplanting systems, and so on. Several types of grafting robots and a transplanting system were commercialized in Japan.

Chrysanthemum is the most typical cut flower which has occupied about 30 % of the total production value of cut flower in recent years in Japan. It is said that several hundred million chrysanthemum seedlings are produced every year in Japan. Cutting sticking operation is essential in the chrysanthemum production system to enhance its productivity. Here, a chrysanthemum cutting sticking robot system is described as an example of the robots for seedling production systems.

2.1 Procedure of Chrysanthemum Seedling and Automation System

The procedure to produce chrysanthemum seedlings is as follows; (1) pick cuttings from mother plants of chrysanthemum. (2) preserve the cuttings in a refrigerator to get an appropriate amount of cuttings for sticking at a time. (3) stick them into a plug tray after refreshment in the water for a night.

Fig. 1 shows the procedure. Transplanters have already commercialized and can be used for transplanting the cuttings in the field. In the procedure(3), the cuttings should be separated one by one from a cutting bundle, and furthermore a few lower leaves of the cutting should be removed before being stuck into a plug tray. Procedure(1) and (3) are still done by manual, so earlier developments of machine systems are desired.

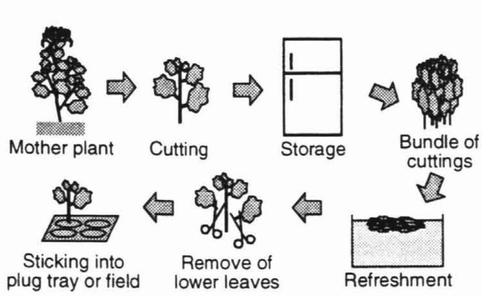

Fig.1. Chrysanthemum seedling production procedure.

The procedure(3) includes three sections when an automation for the procedure; (a) A cutting providing section to singulate the cutting from a bundle of cuttings which was stored in a refrigerator and to transport the cutting to the next stage, (b) A leaf removing section for the lower leaves. The lower leaves can be obstacles when other cuttings are stuck into a tray and when cuttings are transplanted to the field by a transplanter. and (c) A sticking section to stick ten cuttings at a time. The tray used in this system had 220 cells (10x22).

To automate the three sections, the following operations were considered; First, a bundle of cutting is put into a water tank. The cuttings are spread out on the water by vibration of the water tank. The cuttings are picked by a manipulator based on information of its position from a machine vision system. Secondly, another machine vision system recognizes shape, size and direction of the cutting transported from the water tank. Another manipulator grasps a grasping point on a main stem of the cutting indicated through the machine vision system to transport to a leaf removing device, and the lower leaves are cut. Finally, the manipulator transports the cutting from the leaf removing device to the sticking device and then the cuttings are stuck into a plug tray. Fig.2 shows the robotic chrysanthemum cutting sticking system.

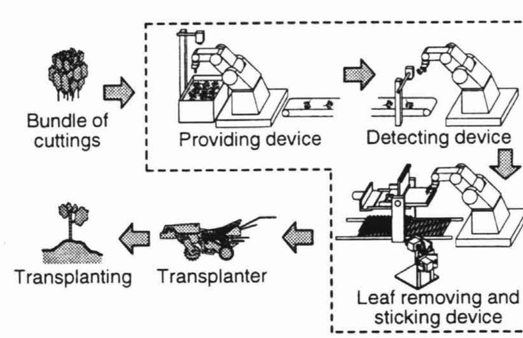

Fig.2. Automation system for chrysanthemum cutting sticking operation.

2.2 Cutting providing system

Cuttings are usually preserved in a refrigerator for a few weeks to stick a certain amount of them into a tray at a time. It is, therefore, necessary to refresh the cuttings in the water for several hours before sticking. In addition, the cuttings are sometimes soaked in chemical water to hasten root of cutting. It is easy for a human worker to separate a cutting one by one, however it is difficult for a machine to do that with similar method, because a mechanical hand is not so flexible and the cutting shape is very complicated. In this system, a manipulator with 5 degrees of freedom and a water tank were used as shown in Fig. 3.

Putting a bundle of cuttings into the water tank, the cuttings were spread out on the water in 5 to 7 seconds by vibration produced by a solenoid actuator.

An image of the cuttings acquired by a monochrome

TV camera whose sensitivity included not only visible region but also near infrared region could effectively tell the positions of cuttings to the manipulator, since the chrysanthemum cutting had much higher reflectance in the near infrared region. In this experiment, an 850 nm interference optical filter was used to enhance the contrast of cutting in the image. The floating cuttings on the water were picked up by the long fingers attached to the end-effector one by one. (Kondo, et al., 1999, 1998b)

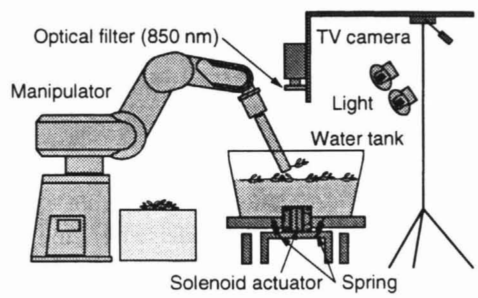

Fig.3. Cutting providing system.

2.3 Machine vision system

To transfer the cutting and to remove its lower leaves properly, detection of a grasping point of cutting for the manipulator is required. Another monochrome TV camera was used with an 850 nm interference optical filter to capture an image of the cutting.

Fig.4 shows the algorithm to detect the grasping point. After thresholding an acquired image, complexity of boundary line of cutting on a binary image is investigated using threshold value T1 and candidate points of stem tip are found. If only one candidate point is found in the image, the point is assumed as a stem tip. When there are more than two points, the complexity of boundary line around the candidate points is detailed and points which are not adapted to condition of main stem are removed using threshold value T2. The condition is that boundary lines around the stem tip have much linearity. Further, if only one candidate point remains at that time, the point is assumed as the stem tip. In case of plural points remaining, the whole boundary line is detailed and region of leaves is detected. A candidate point which has a certain distance from the region of leaves is determined as the stem tip using a threshold angle. When the points which are not corresponded to this condition and when plural points remain even after the procedure, the cutting is supposed to be transferred back, because it is not able to obtain a point to be assumed as the stem tip. The grasping point was defined as the position of 10 mm above the stem tip (Kondo, et al., 1996a).

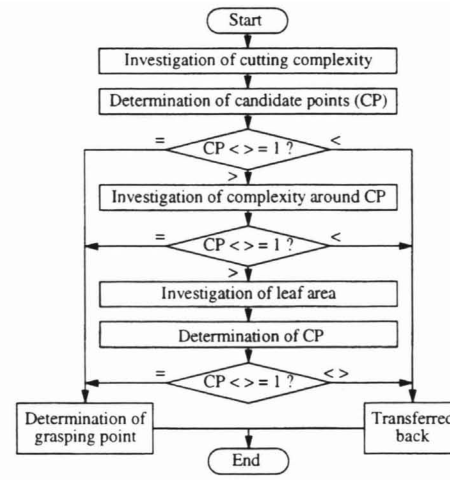

Fig.4. Flowchart of machine vision algorithm to detect grasping point.

2.4 Leaf removing device

Fig.5 shows a schematic diagram of procedures of cutting sticking operation. A manipulator was necessary to transport the cutting from the leaf removing device to the sticking device. An articulated 5 DOF manipulator was used in this system. The manipulator had 2 aluminum plates as fingers whose length and width were 60 mm and 10 mm respectively to grasp the cutting at the end of the stem.

The leaf removing device consisted of a frame with a cutter and a movable plate with a rubber board. The movable plate was opened and closed by a solenoid actuator to cut the lower leaves and to arrange the shape of the upper large leaves by Y-shaped cutter as shown in Fig.6. Two sets of the removing devices were manufactured, and were placed at an angle of 90 degrees to remove the lower leaves completely, since each leaf of chrysanthemum basically emerges making an angle of every 144 degrees. The cutting are transferred to the sticking device by the manipulator after this operation. (Monta et al., 1995d)

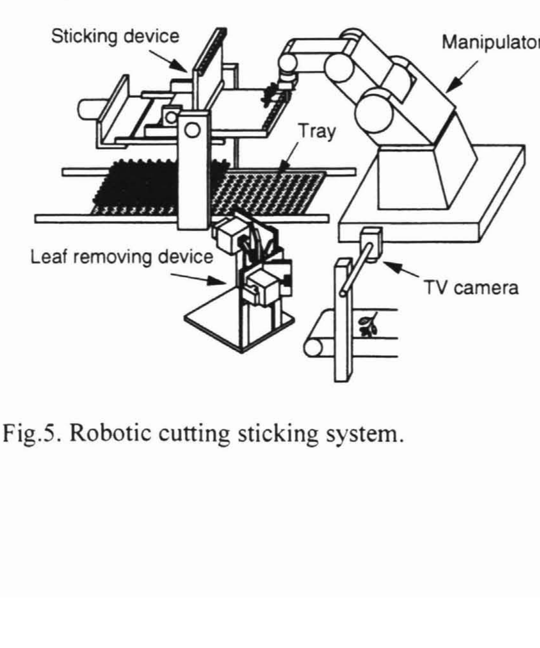

Fig.5. Robotic cutting sticking system.

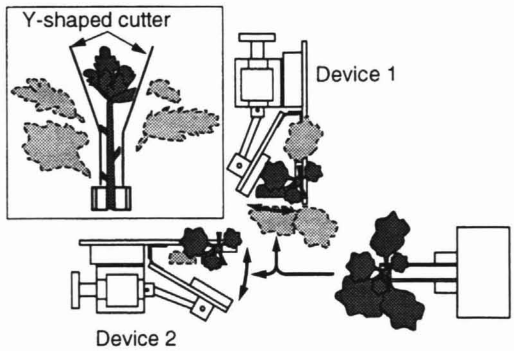

Fig.6. Leaf removing device.

2.5 Sticking device

The sticking device mainly consisted of a table for cuttings and a holding plate. The manipulator transported cuttings to the table, while the holding plate waited until ten cuttings were put on the table. The holding plate was closed as soon as the ten cuttings were put on the table and stuck them to the plug tray at a time. (Monta et al., 1995d)

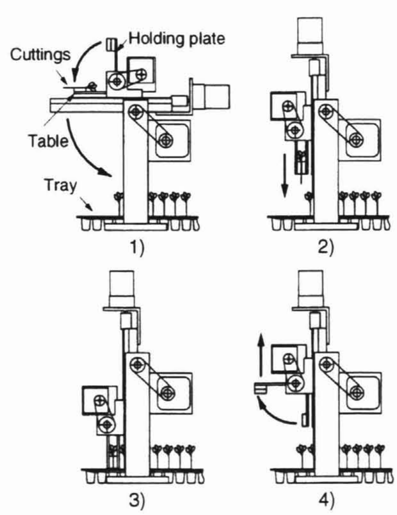

Fig.7. Motion of sticking device.

2.6 Prototype model for sticking robot

Based on the robotic components, a prototype automation system was made for commercialization by an electric industrial company. The system could stick a cutting in 5 or 6 seconds and its success rate was 95%. To develop a commercialized model, it is considered not only that the performance of each robotic component should be improved but also that no-bent and uniform cuttings are needed to be provided. That is to say, both engineering and biological approaches are important for completing this system.

3. ROBOTS FOR HARVESTING OPERATION

There have been many applications of robotic technologies to harvesting operations in the world such as for apple, grape, orange, watermelon, tomato, cherry tomato, cucumber, and so on. The fruit harvesting robots with manipulators are entering the final stage before commercialization in agricultural machinery companies.

When the harvesting robots are developed, there are many problems to be solved compared with the cutting sticking robot in room. The work objects for the robots have various physical properties such as size, color, shape, hardness, texture and etc., even when they are same plant varieties. In addition, the robots are required to work in the various environmental conditions. Therefore, the robots must recognize and understand the physical properties of objects and are able to work on various environmental conditions in fields or greenhouse. That means that the robots have to be so robust that they could protect themselves from troubles caused by the environmental conditions. On the other side, plant training systems and cultivation methods have to be changed so that not only its productivity and quality can be improved but also the robots and farmers can work easily. Here, strawberry harvesting robots are introduced as an example of the harvesting robots.

3.1 Strawberry plant

Most of strawberry plants are usually cultivated on ground covered by mulch in two plant training systems in Japan: their fruits are grown on the horizontal plane and on side wall of the ridge. Strawberry harvesting is monotonous and laborious operation, because fruit number is large and farmers are forced to bend their waists for long time (1400 hours/10 a in a year).

Recently, table top culture for strawberry have been spread to reduce the long time and painful harvesting tasks. Strawberries are transplanted into bags filled by peat-moss and the bags are put on two parallel pipes. Since the pipes are hung down from greenhouse structure, legs for the table are not necessary and robot can easily move under the table. Only fruits are hung down from the bags, while leaves and stems grow on the table, therefore this training system is suitable for harvesting by robots.

3.2 A robot for annual hill culture

Fig.8 shows a harvesting robot for strawberry grown on horizontal plane of the ridge. The robot mainly consisted of a manipulator, an end-effector, a visual sensor, and a traveling device. The outlines of the robotic components are described below.

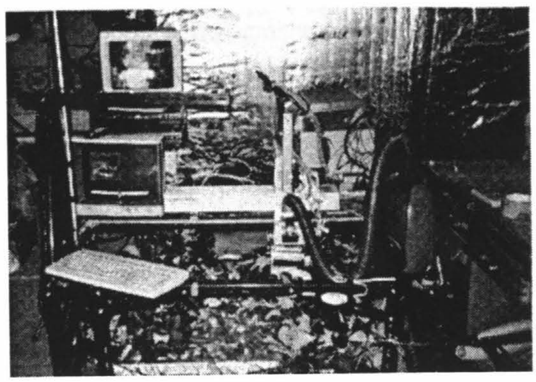

Fig.8. A harvesting robot for strawberry grown on horizontal plane of the ridge

3.2.1 Manipulator. As shown in Fig.8, a cartesian coordinate manipulator with 3DOF was used for the robot. Strokes of the X, Y, and Z-axis were 400 mm, 300 mm, and 200 mm respectively. The maximum composed speed of the X and Y-axis was 700mm/s and moving speed of Z-axis was 150 mm/s.

3.2.2 End-effector. Fig.9 shows a harvesting end-effector. The harvesting action of the end-effector was as follows: After detecting a target fruit position by a visual sensor, the end-effector moved downward until the sucking head reached ground. Since a limit switch was attached to the sucking head, it was possible to stop moving manipulator as well as measuring distance between the visual sensor and ground. The end-effector was connected to a vacuum device and the target fruit could be sucked into the sucking head. When two pairs of photo-interrupters detected the fruit in the sucking head, manipulator moved upward and internal cylinder rotated to cut its peduncle. Even if the peduncle was not cut, open-close section was closed and detached the fruit from the peduncle. The internal cylinder was rotated by motor 1, while the open-close section was driven by motor 2. To keep sucked fruit in the inner cylinder, a net was put on the top of the cylinder. After harvesting, the fruit was transported to a tray by the manipulator. (Kondo, et al. 1998a)

3.2.3 Visual sensor. A color CCD camera was used as the visual sensor to detect target fruits. It is not difficult to discriminate mature fruits from immature fruits, leaves, stems, and background, because only mature fruits have red color. Three dimensional positions of the mature fruits were measured from a two dimensional image acquired by the camera and from the measured distance between the camera and ground when the end-effector reached ground. The measured distance was kept and was accumulated in a computer memory to use an average value of the accumulated distances for the next harvesting.

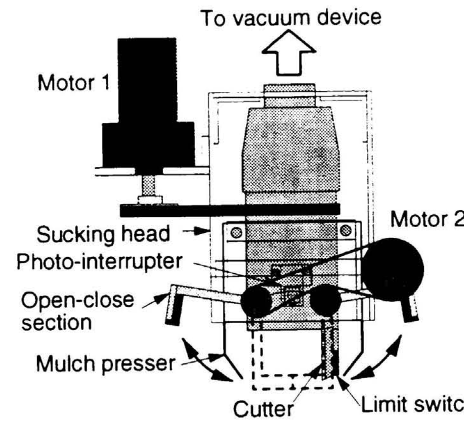

Fig.9. Strawberry harvesting end-effector.

3.2.4 Harvesting experiment. The robot was mounted on a four wheel-gantry type traveling device as shown in Fig.8. In this experiment, the traveling device was manually moved over a ridge. The robot attempted to harvest for 11 mature fruits whose mass was between 5 g and 40 g. From the result, it was observed that all mature fruits could be harvested and that 7 fruits were harvested at the first attempt, while 4 fruits were done at the second or third attempt. Robotic harvesting period until transporting a fruit to a tray was around 6-7 seconds.

Although the success rate was 100%, some adjacent immature fruits were sucked with half of the target fruits. It was considered that control of volume flow rate of the vacuum device and immature fruit position detection were necessary from engineering view point and that control of peduncle length was desired from horticultural view point in order to reduce the sucked immature fruits. Kondo,N., et al., 2000)

3.3 A robot for table top culture

Fig.10 shows a harvesting robot for table top culture. This robot had no traveling device, because an axis of manipulator played a role of traveling device. Since the robot could be simple and cheap compared with the other robots, it was considered that this robot was the closest to be commercialized.

3.3.1 Manipulator. A three DOF cartesian coordinate manipulator was made using three DC motors as shown in Fig.11. X-axis of the manipulator was attached to the table and the robot moved at a speed of 188 mm/s along the table. Y-axis guided the end-effector to fruits at a speed of 295 mm/s. Both rotational motions of the X and Y-axis motors were converted into prismatic motions by pinions and racks. Z-axis motor made vertical movement by a screw at a speed of 167 mm/s. Mass of the robot except X-axis was 6.5 kg. Since strokes of the three axes were 1800, 110, and 200 mm (X, Y, Z-axis respectively) in this experiment, total mass including X-axis was about 10 kg.

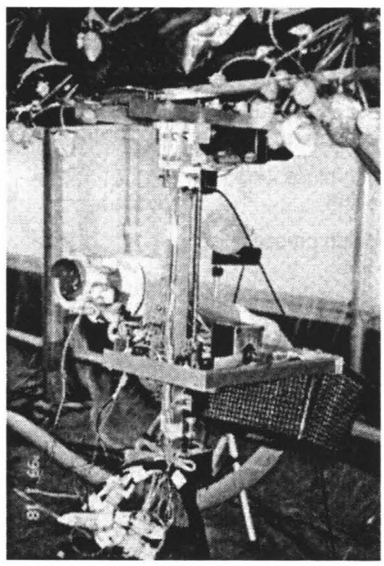

Fig.10. A robot for table top culture.

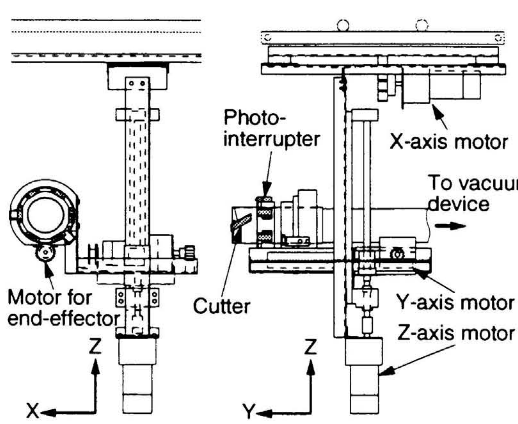

Fig.11. Manipulator and end-effector.

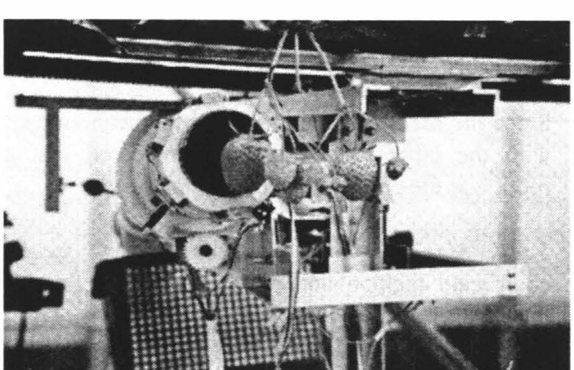

Fig.12. End-effector for table top culture.

3.3.2 End-effector. Fig.12 shows an end-effector for the robot. The principle was same with the end-effector for annual hill culture in Fig.9. Its rotational motion was made by a motor attached to the end-effector instead of manipulator's joint. Harvested fruits were transported through tube to a tray by vacuum force.

3.3.3 Visual sensor. As a visual sensor, the same color CCD camera with the previous TV camera was used. Fruit detection algorithm was also similar. To detect three dimensional position of target fruit, an average value of the accumulated distances obtained when the robot harvested fruits was used.

3.3.4 Harvesting experiment. Harvesting experiments were conducted in a greenhouse and 22 fruits were provided for the robot. Harvesting period of the robot was 3-10 seconds and success rate was 100 %, but the same problem happened (immature fruits were sucked together). It was also found that some parts of peduncles were left after harvesting, because the peduncle was cut by the cutter. It was desired that the peduncle was cut at calyx when a fruit was harvested.

Strawberry plant has several advantages when a harvesting robot is developed compared with the other plants: (1). It is easy to discriminate mature fruit by color CCD camera, since the fruit color is red. (2). Fruit size is so small that can be handled and can be transported quickly by vacuum force. (3). It is possible to be few obstacles around fruits, since peduncle length is controllable. (4). Mechanism of manipulator can be simple and small, since the fruit growing region is small. From these advantages, it is considered that strawberry harvesting robot has much feasibility to be commercialized. To commercialize these robotic systems, improvement of the end-effectors and development of plant cultivation system to be adaptable to the robotic performance are desired. The cultivation system should be adaptable also to human operators, because the robot is not perfect and needs human help. Especially the last type of robot is the simplest and is the closest to be commercialized, it is expected that the type of robot is applied to another plant or to another bioproduction system such as a plant factory system or another closed production system.

4. HUMAN COOPERATIVE ROBOT SYSTEM

As mentioned above, many robots for bioproduction systems have been developed. In the future, robots will be able to perform more kinds of operations in addition to harvesting, transplanting, grafting and so on. However, it is difficult to consider that the robots perform all kinds of farm working automatically instead of human workers because several agricultural operations are too complicated for the robots. For example, a pruning operation to trim branches is done by using the human long experience and knowledge. Therefore, it is difficult for the robots whose skills are inferior to that of human being to do this kind of operation, even if we use present high technology for robots. In other words, the robots will be engaged in agriculture with the human workers in the future. For example, the robots harvest fruits while the human workers weeding in the neighboring place, or a human worker remove branches and leaves twining round a robot, and so on. Therefore, it is considered that a human cooperative robot system is required for the future bioproduction systems.

To realize a human cooperative robot system, one of the most important is its safety. Industrial robots in the factories are surrounded by iron barriers in order to avoid accidents. The robot will be controlled to stop by an emergency system when a human worker enters a working area of the robot. It is difficult, however, to apply such a system to agricultural robots because agricultural robots have to travel in green houses and fields. Furthermore, this kind of system is not always efficient from a viewpoint of working efficiency. Robots have no choice but to work or stop when a human worker enters the working area. A human cooperative robot system should be not only safe but also efficient.

4.1 Safety and Efficient Robot System

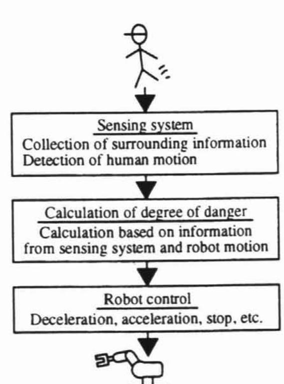

Fig.13. Scheme of safe and efficient robot system.

We supposed a safety and efficient robot system consisted of three sub-systems, as shown in Fig.13. The first one is a sensing system for sensing objects around the robot. Especially, a detection of human motion is its prime task. The second one is a sub-system to calculate a degree of danger based on information from the sensing system and the robot. Finally, the robot motion is decided by the third sub-system which outputs commands to the robot in proportion to the degree of danger, such as acceleration, deceleration, stop and avoidance. Eventually, the robot can achieve tasks safely and efficiently without doing needless motions.

4.2 Sensing System

Visual sensors are frequently used for robots to obtain external information because they can collect much information and can process and extract necessary information when optical filters and image processing are combined. However, it is difficult for visual sensors to discriminate a human worker from a background and to extract only human information in the field or the greenhouse where several objects are arranged at random. Besides, general visual sensors can not measure a distance to each part of a target easily. Therefore the sensing system consisted of ultrasonic sensors to measure distance to the objects, and Pyroelectric infrared sensors for sensing of human body in this research.

Ultrasonic sensor was rotated 180 degrees by a pulse motor so that its scanning area could be enlarged. The ultrasonic sensor stopped rotating for 25 ms to measure a distance to the object after rotated 5 degrees. This motion was repeated until the sensor rotated 180 degrees. Eventually, 37 measurements were performed by one scanning of 180 degrees. The necessary time to perform a scanning including a calculating time was 1 s.

Pyroelectric infrared sensors were used for detecting of a human existence. This sensor is a passive type that detects moving infrared rays ranging from 5 to 14 μm radiated from objects. It is suitable for detecting of a human body because a peak wave length of infrared rays radiated from a human body is about 9-10 μm. Detecting distance and angle of view of the sensor can be enlarged up to 5 m and 119 degrees (H) x 38 degrees (V), respectively, when a polyethylene Fresnel's lens is mounted in front of the sensor. The sensor has an analog output terminal ranging from 0 to +5 V and a digital output terminal which outputs +5 V when an analog signal exceeds threshold values.

In the field and the greenhouse, there are many kinds of objects besides a human worker, therefore, a human worker should be discriminated from others before being detected its location. The ultrasonic sensor can measure the distance to the object, however, can not sense whether it is a human or not. The infrared sensor can detect an existence of human worker around a robot, however can not measure the distance. Therefore, information of both sensors were combined to discriminate a human worker from a background. Method of discrimination is as follows. First, ultrasonic sensors started to scan.

If infrared sensors did not detect a human worker around a robot, distance information of background were stored. Secondly, as soon as infrared sensors detected a human worker approaching a robot, distance information of the background were eliminated from distance information including the human worker. Eventually, only the human information was extracted, and then a human location was calculated. Fig.6 shows an example of discrimination. (Monta, et al., 1997)

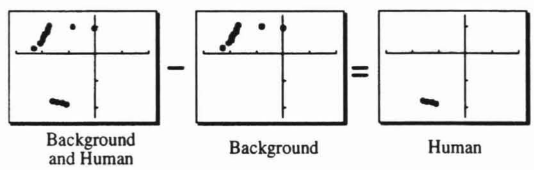

Fig.14. Method of discrimination.

4.3 Degree of Danger

When a robot is controlled in proportion to a value of degree of danger, a function which numerically expresses a danger should be required. In this study, distance and relative speed and moving direction between a human worker and a robot were considered as parameters which composed a function.

The following function for a degree of danger was used (Eq.(1)). In this case, the robot motion was supposed that the manipulator tip moved in a line motion at a speed of V_r , and that a human worker moved parallel to the x-axis at a speed of V_h as shown in Fig.15. The area within broken lines indicates the work space of manipulator. (Monta, et al., 1998c,e)

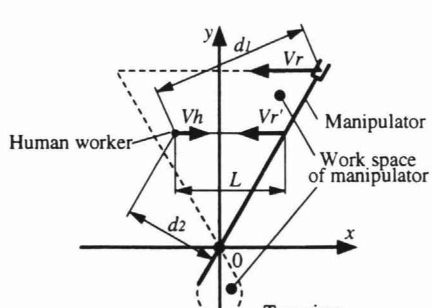

Fig.15. Parameters of Function for Degree of Danger.

$$D = \left(\frac{V^2}{L} k_1 + \frac{k_2}{d_1^2} + \frac{k_3}{d_2^2} \right) \alpha + \beta \qquad (1)$$

where

D = degree of danger

V = relative speed between human worker and manipulator (x axis direction)

L = distance between human worker and manipulator (x axis direction)

d_1= distance between human worker and manipulator end (end-effector)

d_2= shortest distance between human worker and manipulator

k_1, k_2, k_3 = coefficient

α = coefficient related to distance from work space of manipulator

β = constant related to inside/outside of operational space of manipulator

4.4 Manipulator Control

Fig.16 shows an arrangement of sensors mounted on the robot to work in vineyard. Four ultrasonic sensors and ten infrared sensors were mounted around the waist joint of manipulator at intervals of 60 degrees and 30 degrees, respectively.

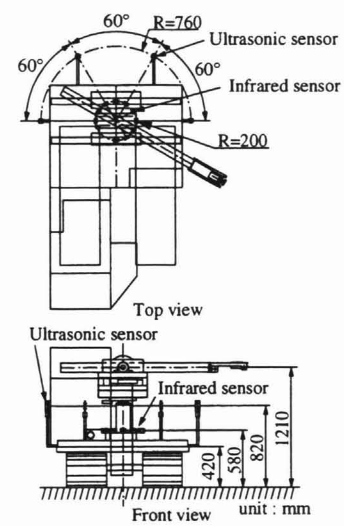

Fig.16. Arrangement of sensors.

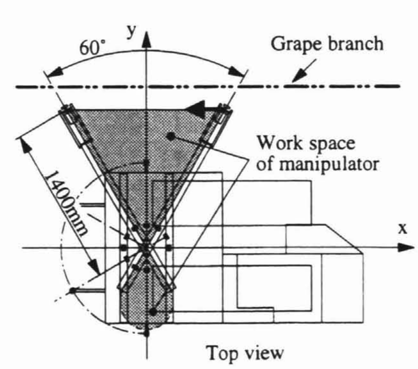

Fig.17. Motion of robot.

Manipulator control experiment was carried out in the vineyard by using the robot equipped the sensing system as shown in Fig.17. Assuming an actual operation, the robot was oriented so that its traveling device could move along a grape branch, although a movement by the traveling device was not performed during the experiments. In the experiment, the manipulator tip performed a linear motion parallel to the grape branch at an initial speed of 100 mm/s within a rotational angle of 60 degrees. Black-colored portion indicates the work space of manipulator. (Monta, et al., 1998d,e)

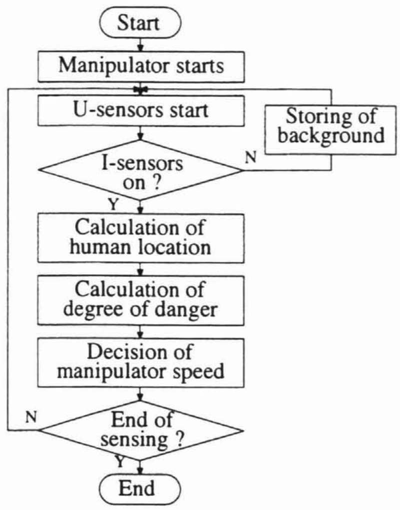

Fig.18. Flowchart of experiment.

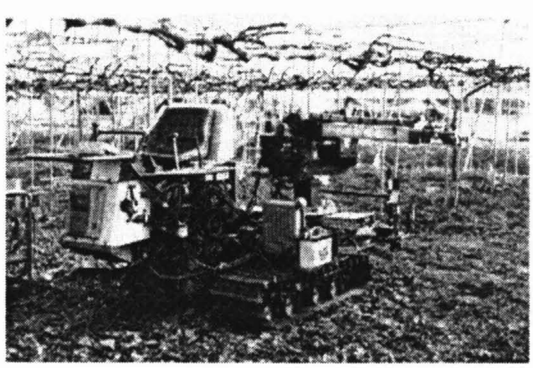

Fig.19. Robot equipped sensing system.

Manipulator control experiment was carried out according to a flowchart in Fig.18. First, the manipulator started to move at an initial speed of 100 mm/s and ultrasonic sensors started to scan. Human location, moving direction and moving speed were calculated after human discrimination and detection procedures were performed, as soon as infrared sensors detected a human worker within the sensing area. Then, a degree of danger was calculated based on information of the human worker and the robot. Finally, a speed of manipulator tip was controlled (100, 60, 30 and 0 mm/s) in proportion to the value of degree of danger. Fig.19 shows the robot equipped the sensing system in the field.

Fig.20 shows an example of experimental results and Table 1 shows data of the human worker and the manipulator. Numbers in figures and tables indicate order of motions.

A human worker approached the manipulator from sideward and stopped the inside of the work space of manipulator. When the human worker approached the manipulator at a high speed, the manipulator reduced speed from 100 mm/s to 30 mm/s because the value of degree of danger became higher. After that, the manipulator continued to move at a low speed, even though the human worker stopped inside the work space of manipulator. Finally, the manipulator stopped moving to avoid a collision when the value of degree of danger exceeded the threshold value.

From the results, the manipulator could safely and efficiently do the tasks by changing speed in proportion to the value of degree of danger, even if the human worker was inside the work space of manipulator. In this research, the target was human worker. However, safety for robots, agricultural facilities and plants should be considered in the future.

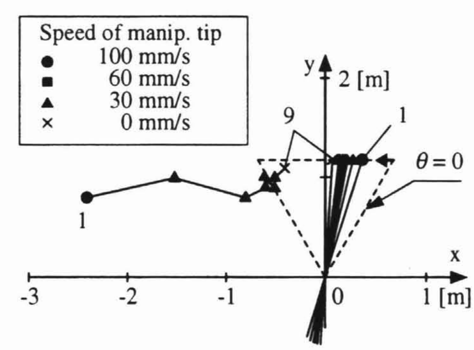

Fig.20. Experimental results.

Table 1 Experimental result

Data No.	D	Human (x, y)*	Human *Vh* [m/s]	Manipulator θ [°]	Manipulator *Vr* [m/s]
1	0.000	(-2.4, 0.8)	0.00	13	100
2	0.192	(-1.5, 1.0)	1.72	17	30
3	0.673	(-0.8, 0.8)	0.51	19	30
4	0.418	(-0.6, 0.9)	0.21	20	30
5	0.262	(-0.6, 0.9)	0.00	21	30
6	0.337	(-0.6, 1.0)	0.10	23	30
7	0.449	(-0.5, 0.9)	0.00	24	30
8	0.546	(-0.5, 1.0)	0.10	26	30
9	0.922	(-0.4, 1.1)	0.00	27	0

* unit : mm

5. CONCLUSIONS

Robotics for bioproduction systems are constructed based on many kinds of engineering technologies such as sensing technologies, information technologies, artificial intelligence, and so on, as introduced in this paper. However there are limitation of robot performance using only current engineering technologies, therefore, integration of engineering and horticultural technologies is required to promote the realistic robotizaion for bioporuction systems. Furthermore, the technologies related to human cooperative and friendly systems will be essential for the safe and efficient bioproduction systems with robots

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