Fruit harvesting robot and grading robot

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1. Introduction

Studies on harvesting robots with manipulator were started with the tomato fruit harvesting robot since 30 years ago by Prof. Kawamura, Kyoto University [1]. The robot consisted of a 5 DOF manipulator, a harvesting end-effector, a color TV camera which was used for stereo vision, and a battery car for traveling in the ridges as shown in **Figure 1**. Following the harvesting robot, the robotic technologies were applied to cherry tomato, strawberry, cucumber, eggplant, cabbage mushroom, orange, apple, grape melon, watermelon, asparagus and etc. The components of the first harvesting robot were not so big different from current harvesting robots under development at universities and research institutes.

Although some of the developed robots can automatically perform fruit harvesting operations with a 60-70 % success rate or more under the greenhouse conditions, the robots are still slow and their costs are expensive so that they cannot be practically used in the greenhouse or in the field yet at this moment [2-4].

On the other hand, a fruit grading robot with manipulator was commercialized 10 years ago, while many types of grading machines and non-destructive sensors have been developed [5-14] to apply to many types of fruits. Some robots are now used in east Asian countries in addition to the fruit packing robots which were practically used in the fruit grading facilities since more than 20 years ago, because indoor environmental conditions are suitable for the robots and many operators could be substituted by the robots. Recently grading robots are applied not only to fruits but also to leaves. The reasons why many robots were used in the facilities are that they can operate much faster than human workers and that the robotic systems can be purchased not by single farmer but by farmers' groups or some associations due to higher performance. In addition, the fruit grading robot can collect very precise information from handled fruits during operation by machine vision and NIR inspection systems, which can be usable for precision agriculture.

In this presentation, current situations and future prospects of challenging projects of fruit harvesting robots for practical utilization in greenhouses and commercialized grading robot systems will be described. Furthermore, a mobile grading robot will be also introduced for propelling precision agriculture in future.

2. Harvesting Robot

2.1. Tomato Cluster Harvesting Robot

Many harvesting robots have been studied so far since the first tomato harvesting robot was developed in 1982, but no harvesting robot has been commercialized yet. The most common difficulties are followings:

1) Slow operation speed: one third of human operator's speed or less speed
2) Expensive cost
3) Necessity of changing plant training system and cultivation method for robotic operation

To solve the first difficulty, a tomato fruit cluster harvesting robot was developed as shown in

Figure 2. Previous fruit harvesting robots could harvest individual fruits, while this robot can harvest a whole fruit cluster that makes several times higher performance because a fruit cluster has several fruits.

In addition to this robot, NARO (National Agriculture and Food Research Organization) Institute of Vegetable and Tea Science developed a simple tomato fruit cluster harvesting robot which had a 3 DOF Cartesian Coordinate Manipulator for harvesting fruit clusters hung down at similar height from an iron bar as shown in **Figure 3** (right). This robot is very simple and cheaper but requires the change into a special plant training system as in the figure (left).

2.2. Strawberry Harvesting Robot

BRAIN (Bio-oriented Technology Research Advancement Institution) and Shibuya Seiki Co., Ltd. have developed strawberry harvesting robots which can automatically work in the night time. **Figure 4** shows one of the robots, which has a performance to harvest fruits for 30 a per night. The latest model of the robots has reached higher success rate for the harvesting operation. The success rate, however depends on seasons, because strawberry plants grow rapid and many stems and peduncles are crossed one another in December so that it may be difficult to harvest all of them, while the plants lose the vigor and many peduncles just hang down in April and May, which is easier condition for robotic harvesting.

3. Grading Robot

3.1. Fruit Grading Robot

A grading robot for deciduous fruits such as peaches, pears, and apples to automatically provide fruits from containers and to inspect all sides of fruit was developed in 2002 [14] and is now working practically (**Fig.5**). The grading robot consists of a 3 DOF manipulator, 12 suction pads as end-effector, 12 color TV cameras, and 28 lighting devices. 12 fruits were sucked up together by a manipulator and 12 bottom images of fruits were acquired during the manipulator moving to trays on a conveyor line. Before releasing the fruits to the carriers on a grading line, 4 side images of each fruit were acquired by rotating the suction pads for 270 degrees. The stroke of the manipulator was about 1.2 m and it took about 4.3 seconds to move back to the initial position that meant that this robot could grade three fruits per second. The grading robot was being evolved into a new model based on developing relevant technologies.

The reason why the grading robot was practically used was that it can substitute about 10 operators. Although the robot system is too expensive for single farmer to purchase, farmers' groups are affordable to pay with govenmental financial supports. The robot system is usually introduced to a cooperative grading facility located in a local region where many fruits are produced.

Fruit packing robots were already commerciallied before the grading robots and have been widely used in the world as well as palletizing robots. Recently grading robots were applied not only to fruits but also to perilla leaves (green leaves assorted with some dishes). The robot system can pick each leaf from a bundle of leaves and put on a conveyor. A machine vision system measures the leaf size and shape from top camera and other robots sort them based on the extracted features from the images.

3.2. Mobile Grading Machine

Grading facilities are widely spread in the world as described above and play an important role for informatization in agriculture. It encourages producers to conduct precision agriculture based on the information accumulated in the database. The information also contributes to consumers as traceability data for food safety and security and can be data for risk management. However, what producers can know is whole field (orchard) information, even if the grading machine collects the individual fruit data, because they cannot know which fruit tree each fruit came from, in case that they do not separate the fruits properly based on the fruit tree positions during harvesting time.

Figure 6 shows a mobile grading machine for orange fruits, which is enable producers to conduct tree management [15]. Operators manually harvest fruits in front of the tree and put them into the machine. The machine can measure colors, sizes, shape, and qualities of the harvested fruits. Because the machine has a GPS, all the data can be linked to the fruit tree and can create maps as shown in **Figure 7**. It is considered that this kind of mobile grading machine can conduct more precise agriculture based on the maps.

4. Conclusions

In recent years, problems with the quality of food supply are becoming increasingly significant worldwide, with particular concerns surrounding, imported or exported foods due to the different criteria and unfamiliar food culture in many countries. To solve these problems, information of products showing their histories is essential. Grading robots with sensing systems have replaced human labor and have contributed to increasing the market value of products and producing uniform products. The robots can give us many kinds of important information such as color, size, shape, and qualities, while harvesting robots can assign less information such as harvested time and date, product position in plant, and plant color.

Mobile grading machines can give products information obtained from both grading robots and harvesting robots. From the view points on informatization to products, a mobile grading machine which can follow and work together with human operators will be desirable. Regarding harvesting robot, we have to continue challenging development of "cheap and high efficient robot supporting aged producers and adapting diverse plants' properties in complicated and various natural environmental conditions." Especially in plant factory where more intensive plant production is conducted than greenhouse, harvesting robots are much desirable in order to keep hygiene condition in the factory. In addition to the role of the informatization, support of environmental conservation and aging society in local region and support of production of functional agricultural products for healthy life may be required as the agricultural robots' roles in near future.

Considering history of agricultural robot researches, we started with adoption of industrial robots to agricultural fields and investigated robotic mechanisms based on plant properties for a decade since 1982. That can be called "Agricultural Robot, the first generation". As the second generation, we studied on fusion between horticultural and engineering technologies and constructed fundamentals of relation among human, plant and robot for the next decade. Currently, it can be said that precision agriculture oriented robots have been studied for accumulation and utilization of the information as the third generation since 2002 when the fruit grading robot was commercialized. Then, it is observed that we may be facing the fourth generation to develop human health oriented robot, aged producer supporting robot and environmental conservation oriented robot. That means that agricultural robots' roles are much diversifying.

References

[1] **Kawamura N., Namikawa K., Fujiura T., Ura m.,** 1984. Study on agricultural robot (Part 1). *Journal of the JSAM* .46(3), 353-358.

[2] **Kondo N., Ting K.C.**, 1998. Robotics for Bioproduction Systems, edited by N. Kondo and K. C. Ting, St. Joseph, Mich.: ASAE, 1-274.

[3] **Kondo N., Monta M., Noguchi N**., 2006. Agri-Robots (II) –Mechanisms and Practice-, Corona Publishing Co., Ltd., Tokyo: 1-223

[4] **Rajendra P., Kondo N., Ninomiya K., Kamata J., Kurita M., Shiigi T., Hayashi S,**

Yoshida H., Kohno Y., Machine Vision Algorithm for Robots to Harvest Strawberries in Tabletop Culture Greenhouses, EAEF 2(1), 24-30 (2009).

[5] **Miller, B.K., Delwiche, M.J**., 1991. Peach defect detection with machine vision. Transaction of ASAE 34(6): 2588-2597.

[6] **Okamura, N.K., Delwiche, M.J., Thompson, J.F.**, 1991. Raisin Grading by machine Vision. ASAE Paper No.91-7011.

[7] **Rehkugler, G.E., Throop, J.A**., 1986. Apple sorting with machne vision. Trans. ASAE 29(5): 1388-1397.

[8] **Shaw, W. E**. 1990. Machine Vision for Detecting Defects on Fruits and Vegetables, Food Processing Automation, Proceedings of the 1990 Conference, ASAE: 50-59.

[9] **Tao, Y., Morrow, C.T., Heinemann, P.H., Sommer, J.H.,** 1990. Automated Machine vision Inspection of Potatoes. ASAE Paper No.90-3531.

[10] **Njoroge, J., K. Ninomiya, N. Kondo, H. Toita**. 2002. Automated Fruit Grading System using Image Processing. Proceedings of SICE annual conference 2002 in Osaka, MP18-3 on CD-ROM.

[11] **Lu R. and Ariana D.**, 2002. A Near-Infrared Sensing Technique for Measuring Internal Quality of Apple Fruit, Applied Engineering in Agriculture, 18 (5): 585-590.

[12] **Kondo, N., Kakemizu G.,** 2000. Detection method and devices for gloss of eggplant surface. Japanese Current Patent Application No.2000-360892 (in Japanese).

[13] **Sagara Y.** 1998. Recent Development of Sorting and Grading Systems for Fresh Fruits and Vegetables (in Japanese). J. JASM 60(2):167-174.

[14] **Kondo, N**. 2004. Fruit Grading Robot, IEEE/ASME International Conference on Advanced Intelligent Mechatronics on CD-ROM.

[15] **Kohno Y., Kondo N., Iida M., Kurita M., Shiigi T., Ogawa Y., Kaichi T. and Okamoto S.,** 2011. Development of a Mobile Grading Machine for Citrus Fruit, EAEF 4(1): 7-11.

Figure 1 - The first tomato harvesting robot (Kyoto Univ.). *Source: [1]*

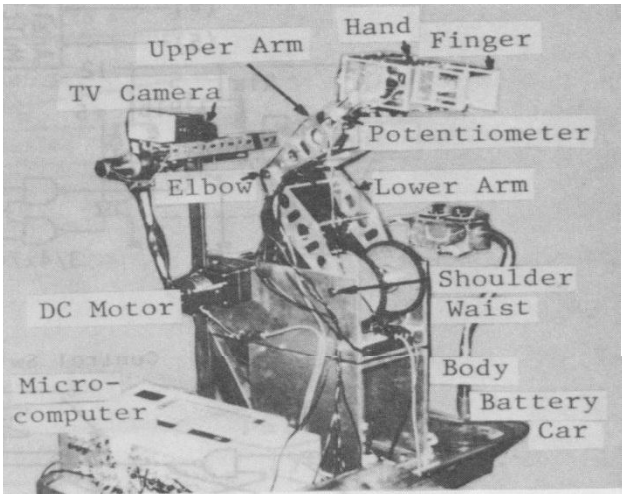

Figure 2 - A Fruit Cluster Harvesting Robot (Kyoto Univ.)

Figure 3 - A Simple Tomato Fruit Cluster Harvesting Robot with a Special Plant Training System by NARO Institute of Vegetable and Tea

Figure 4 - A Special Tomato Plant Training System and a Strawberry Harvesting Robot by BRAIN and Shibuya Seiki Co., Ltd. *Source: [3]*

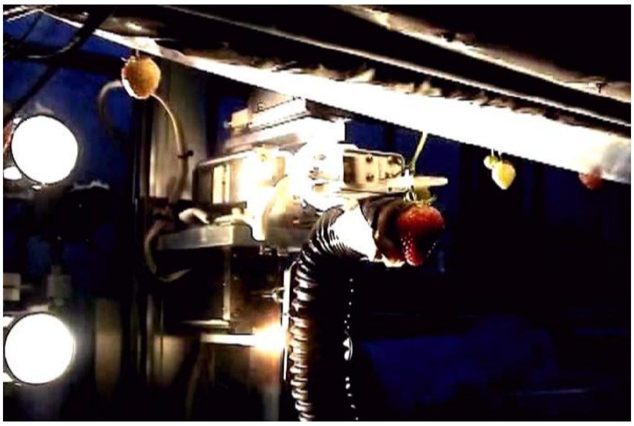

Figure 5 - A Fruit Grading Robot by Ishii Co., Ltd.

Figure 6 - A Mobile Grading Robot for Orange Fruits (Kyoto Univ.). *Source: [15]*

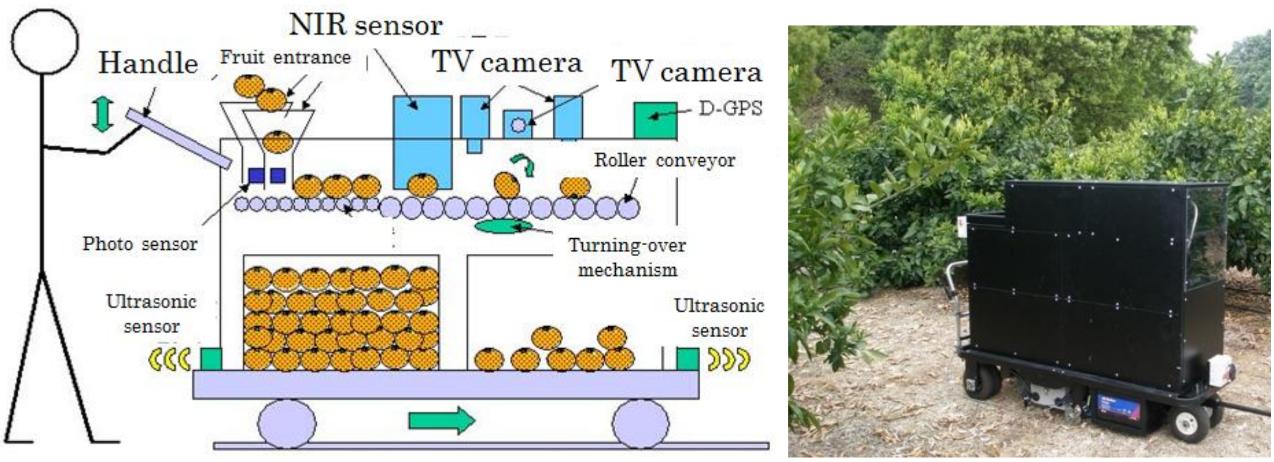

Figure 7 - A Map for average sugar content (color), yield (height), and canopy size (diameter) of orange fruits