Tomato-Harvesting-Robot Competition Towards Smart Agriculture

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Abstract

In agriculture, the aging and depopulation of farmers cause the shortages of farmers and manpower. Most of commercialized robots are industrial robots for factory automation, and most of robots for the first industry, agriculture, forestry and fisheries are still under developing. The reasons are cost-efficiency of the robotization, safety of the works using robots, difficulty of outdoor operations, and knowledge transfer problem from farmers to computer, etc. As one of solutions for the problems, robot technology into the agriculture is expected to contribute to the laborsaving, improvement of production, production line automation, and also the management toward smart-agriculture. We organize the Tomato-harvesting-robot competition to offer the research field and welcome researchers into agricultural robotics.

Keywords: tomato harvesting, agriculture robot, smart agriculture, competition.

1. Introduction

In agriculture, a decrease in the number of farmers, an aging population, and a shortage of successors are significant problems. Ministry of Agriculture, Forestry and Fisheries of Japan reported that Japanese self-sufficiency ratio for food is about 40 percent, which is lowest level among developed countries. For such urgent problems, smart agriculture is expected to be an innovative method of utilizing robot technology and information communication technology, and researches aiming to realize smart agriculture have been carried out such as the autonomous operation of agricultural machinery, automation of harvesting, and monitoring of the field environment and crops, etc. Most of commercialized robots are for factory automation of automobile, and most robots for agriculture, forestry and fisheries are under developing. The reasons for the late social implementation are cost-efficiency of

the robotization, safety of the works using robots, difficulty of outdoor operations, and knowledge transfer problem from farmers to computer, etc. If we can overcome these difficulties and implement the robots into agricultural fields, robots can contribute to the laborsaving, improvement of production, production line automation. Also, the management of agricultural products such as quality, quantity, and condition of environment become possible and the smart-agriculture will be realized.

For the autonomous operation of agricultural machinery, Noguchi proposed a robot farming system [1] that consists of intelligent robot vehicles to automate farming activities from planting to supplying products to consumers and described the importance of simultaneous operations by developing a multiple robot system. For the automation of harvesting, Kawamura et. al. developed a mobile robot with manipulator and proposed the tomato harvesting method using image

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processing and visual feedback [2][3]. Kondo et. al. proposed the method to improve the success ratio of tomato harvesting and speed-up technique [4][5]. Ota et. al. proposed the path planning method to pick up tomato [6]. Yaguchi et al. developed an end-effector that grasped a fruit using grippers and plucked it from the separation layer in the peduncle [7]. They described the results of harvesting experiments conducted on an actual farm, demonstrating that the harvesting time was shortened by improving the harvesting motion [8]. Yoshida et al. developed a robot that har- vested a cluster of cherry tomatoes [9][10]. They focused on detecting the peduncles that the robot required when harvesting the clusters. For the monitoring of the field environment and crops, Fukatsu et al. described a remote monitoring method that responded flexibly and dynamically to changes in the field environment for long-term field monitoring [11] which consists of field servers, small monitoring sensor nodes. Fukui et al. developed a robot that estimated the volume of tomato fruits to create a database of fruit growth [12] by detecting fruits based on a human attention model, saliency [13].

Tomato is one of important fruit vegetables and most tomatoes are produced in the greenhouses, or large-scale farms, where the high temperature and humidity, and long harvest age force the farmers heavy works. With an aim to promote the automation of tomato harvesting, we have organized the tomato harvesting robot competition. In this paper, we introduce the Tomato-Harvesting-Robot Competition.

2. Tomato-Harvesting-Robot Competition

The Tomato-Harvesting-Robot competition started in 2014 and 7th competition was held in 2020, which consists of two leagues, the Senior League and the Junior League. The target competitors for Senior League are supposed to be the teams with automated robots, and the Junior League are for high school or junior high school students, whom are asked to build robots with LEGO Mindstorms.

2.1 Senior League

The Senior League supposes that teams composed of undergraduate, graduate students or developers join the league with tomato harvesting robots, and compete the accuracy and speed of harvesting. The two kinds of competition field are designed, the one is the rail-style area and another is the free-style area. The rail-style area is designed to have the similar environment with the large-scale tomato factory, where pairs of pipes are arranged on the ground to control the temperature

of the greenhouse, and pipes are also used as the rails for the platform trucks on which the workers sit down, harvest and carry tomatoes. The diameter of pipes is 50 mm and the distance between pipes is 600 mm. The position of tomato is always adjusted between 800 to 1200 mm heights as the tomato plants are growing up. The free-style area is for the robots of general tomato fields in outdoor environment in future. In the first to 6th competitions, artificial grasses are put on the field with the sizes of 3600 x 3600 mm instead of soils. The setting of tomato position is the same with the rail-style area.

The required specifications for robots are shown in Table 1. The projected area of the robot on the ground is within the 800 x 800 mm square including a box for storing tomatoes, and no height limitation. The robots should have an emergency stop switch on the easy-to-find location of robots. As recommendations, the weight of the robot is less than 50 kg and the electric power of each motor is less than 70 W.

The robots are classified mainly two types, manual control and autonomous control, and the former robots are classified by whether the operator observes tomato directly or indirectly using cameras mounted on robots, and by robot locomotion whether the robot uses rail or not. Totally, the robots are categorized into 6 types depend on operation and locomotion method as shown in Table 2. The success points for a tomato change depending on robot categories. the point for one tomato of category (1) manual control, direct tomato observation, and rail-type is 2, and that of category (6) autonomous control, free-type is 16.

The senior league consists of 3 stages as shown in Fig.2. In first stage, the basic function of the robot is evaluated whether the robot can move, have a manipulator and an end-effector, and recognize tomato. Single tomatoes are hanged from a bar and the robot that can touch a tomato proceeds to the second stage.

In the second stage, the robot harvests a tomato from a tomato cluster. If the robot gives damage to tomato, get -1 point for each damage tomato, and the damage to tomato plant is big minus points. And the target tomatoes should be redder than the reference tomato indicated by the committee. In the final stage, the robots harvest tomato from plant body as shown in Fig. 3, for the 1st competition.
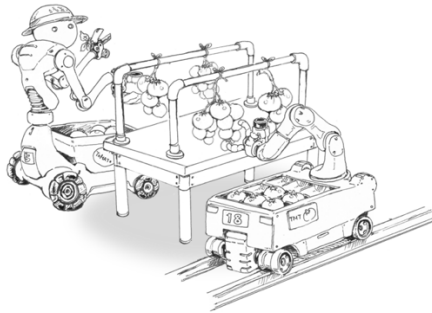
Table 1 Required Specifications for Robots

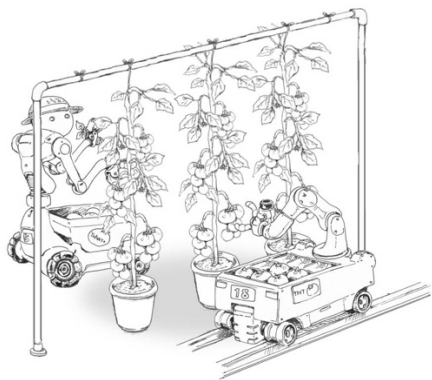| Requirement | Max. Size | W:800mm D:800mm No height limitation |
	Safety	Emergency Stop Switch
Recommend	Max. Weight	Max. 50kg
	Max. Motor Power	Max. 70W each

Table 2 Robot Classification by Operation Method

Robot Control	Manual				Autonomous	
Operator Manipulation	Direct Observation of Tomato		Indirect Observation of Tomato		Start and Stop commands	
Mode of Locomotion	Rail-type	Free-type	Rail-type	Free-type	Rail-type	Free-type
Category	(1)	(2)	(3)	(4)	(5)	(6)
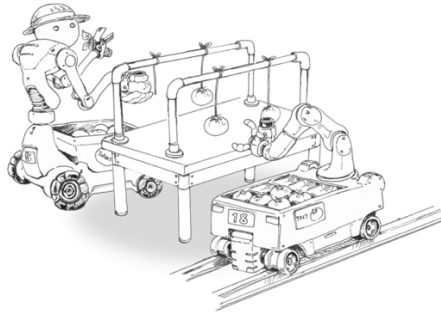
Fig. 2 The overview of the final stages of the senior league in the 1st competition

2.1. *Ju* 2.2 *Junior League*

Figure 3 shows the concept of Junior League. We set the subjects to make the model of an autonomous transport system of tomatoes harvesting, such as the transportation and sorting of harvested tomatoes. Competition subjects are shown below.
(1) Line Trace
 The robot moves along the white course line using the color sensor. In the harvest field, Tomato boxes are arranged. The robot can find three RGB colored tomato boxes if moves along the line.
(2) Color Identification
 The robot explores the area and recognize color signs along course line, and find three RGB colored tomatoes in boxes (tomato box).
(3) Mechanism Design and Control
 To pick up the tomato boxes, participants are expected to design and make a robot arm to get a tomato box. The robot is required to store, transport and relocate the boxes to the assigned storage area. After picking up the box, the robot is to return to the course line. Then, the robot carries the box to the specific storage location.
(4) Object detection
 After putting the tomato boxes to the storage locations, the robot should return to the course line. Finally, the robot goes the charging station which is put at the position with a certain distance away from the course line. The robot must find the stop position by the distance measuring sensor.

Each team consists of 3 or 4 students and makes a robot using LEGO Mindstorms. The basic specification for robot is that the sizes of the robot are within 300 x 300 [mm] on the ground. The robot can have structural change after starting, so that the initial robot structure is regarded as the robot size.
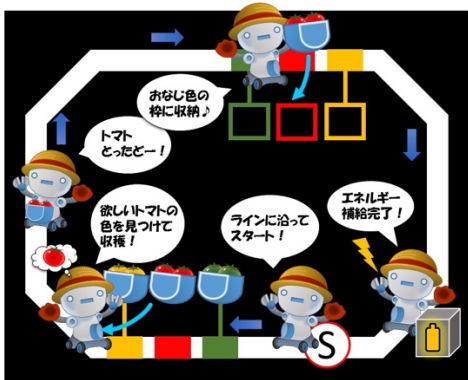

(A) FIRST STAGE: PICK UP SINGLE TOMATO

(B) SECOND STAGE: PICK UP A TOMATO FROM TOMATO CLUSTER

(C) FINAL STAGE: PICK UP A TOMATO FROM TOMATO PLANT

Fig. 1 The three stages of the senior league.

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Fig. 3 The concept of Junior League

3. Regulation Changes toward Smart Agriculture

The regulation of the competition is changed by evaluating the achievement of teams toward actual greenhouse toward smart agriculture.

Table 3 shows the history of regulation changes. The first competition was held in 2014 with Senior League. From the second competition, Junior League started as the outreach activity of agricultural robotics. From the third competition, a bump was put on the free-style area to motivate the improvement of mobility for rough terrain. In the fifth competition, the black board shown in Fig.2, which is placed for making the image processing easy, was removed and the robot are asked to find tomatoes in various colors. From the 7th competition in 2020, the working field moved to an experimental greenhouse, so that the robot need the color consistency algorithm against sunlight environment. Junior league was held as in each school via internet.

The winner teams are shown in Table 4. The first winner robot from team JSK, the Univ. of Tokyo (Fig.4) joined the category (T-4) and the robot was operated by human in the remote place and succeeded to have 5 tomatoes in 10 min. 2 teams joined to autonomous categories could not harvest a tomato. In the 6th competition, the robot of Kyutech team whose category is T-5 autonomous robot for the rail-style field (Fig.5), succeeded to harvest 13 tomatoes in 10 min in the 2nd stage and 5 tomatoes in the final stage. The teams selected for the final stage of 7th competition, all teams entries for the category T-5, autonomous robot in the rail-style field. The winner is the team of National Institute Technology, Kitakyushu College (Fig.6) succeeded to take about 20 tomatoes in the greenhouse. The performance of each team

grows up to harvest tomatoes autonomously in spite of the lighting condition changes. Moreover, some journal papers are published based on the results of the competitions such as [7][8][14]15].

Table 3 History of regulation changes

N-th	Year	Rule & Changes
1	2014	Senior League started with 6 categories from T1 (manual operation) to T6 (autonomous) and 2 kinds of working fields (rail and artificial grass)in indoor field (Gymnastium). The black boards are set behind tomato plants.
2	2015	Senior: No rule change. Junior: Junior League started. Lego mindstorm is used for basic platform.
3	2016	Senior: Bump is placed in the center of grass field. Junior: No rule chage.
4	2017	No rule change.
5	2018	Senior: Slope is placed instead of Bump in the grass field. The black boards are removed. In scoring, success rate is added. Junior: Original arm made of stationery is allowed. Tomato box removed.
6	2019	No rule change.
7	2020	Senior: Video evaluation instaed of 1st and 2nd rounds. The cometition field is changed to the ourdoor experimental green house. The grass field is changed to the soil field. Junior: Online cometition in each school.

Table 4 Results of competition and Winner teams

N-th	Year	Senior Teams	Junior Teams	Winner	2nd Place
1	2014	9	–	Inaba-Okada Lab., Univ. of Tokyo	National Institute of Technology, Kitakyushu College
2	2015	14	16	Hayashi Lab., Kyutech	Team SS
3	2016	12	23	Kyushu Polytech	NAIST
4	2017	12	18	Hayashi Lab., Kyutech	Ishii Lab., Kyutech
5	2018	9	23	Hayashi Lab., Kyutech	Kyushu Polytech
6	2019	9	25	Ishii Lab., Kyutech	NAIST
7	2020	8	13	National Institute of Technology, Kitakyushu College	Hayashi Lab., Kyutech

Fig.4 The winner robot of the 1st competition, JSK team from Univ. of Tokyo.

Fig. 5 The winner robot of the 6th competition, Kyutech team. The robot harvested 5 tomatoes in the final stage.

Fig.6 The winner robot of the 7th competition, National Institute of Technology, Kitakyushu College. The robot harvested 20 tomatoes in the experimental greenhouse.

4. Summary

We have organized the Tomato-Harvesting-Robot competition to promote agricultural robots and provide the test field for tomato harvesting. The performance of robots are growing up gradually and the regulation of the competition is revised to be closed to the actual working environment. Currently, the winner robot can harvest a tomato within 30 seconds in the sunlight condition. In the next, we expect to have robots working in the soil field and in the night time.

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