Development of a Tomato Harvesting Robot for Farm Field

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Abstract

The 9th Tomato Harvesting Robot Competition was held at the green house in Kitakyushu Science and Research Park. The competition consisted of two leagues for different field areas: rail-style for greenhouses and free-style for open fields. Our team competed in the free-style league. Participation in the free-style category required the following: tomato harvesting mechanism; mobility mechanism to move on the rough terrain; camera to photograph tomato; and self-location system. We developed a 3-axis cartesian coordinates manipulator tomato harvesting robot using crawler to move on soil and using suction and cutting to harvest the tomatoes. In this paper, we described the system architecture of tomato harvesting robot and the results of 9th Tomato Harvesting Robot Competition in 2022.

Keywords: *Tomato-Harvesting Robot, Crawler, move on soil*

1. Introduction

The current rapid aging of Japan's population and declining birthrate has raised concerns about labor shortages in the near future. In the agricultural sector, in particular, the number of key agricultural workers dropped to 1,363,000 by 2020, and the percentage of workers aged 65 or older was as high as 69.6%, making labor shortage a serious problem. In addition, the stable production and quality assurance of food in the near future are threatened, and an immediate solution to the problem and improvement of the situation are desired [1]. We aim to address these problems through the realization of smart agriculture, increasing efficiency while minimizing manual labor through productivity improvement and automation of production lines. Part of this effort is the development of automatic tomato harvesting machines for automating labor-intensive and manpower-intensive harvesting and transportation tasks in the agricultural field. Most tomatoes are either produced in greenhouses or in open fields, and the introduction of robots is desired because of the high temperature, high humidity, and long work hours required in harvesting them. Tomatoes are not encased by hard shells, thus requiring the use of end-effectors and harvesting techniques that can delicately handle them without damaging their surface or interior. In this context, with the aim of advancing automatic harvesting by developing and sharing basic technologies for harvesting robots, a competition for automatic tomato harvesting robots has been organized by the Center for Socio-Robotic Synthesis, Kyushu Institute of Technology since 2014 [2]. The Tomato Robot Competition evaluates the accuracy and speed of the harvesting robot's harvesting motion. This paper describes the design specifications of the “Tomato Vacumer,” a tomato harvesting robot developed for the competition, and the control technology used to ensure accurate harvesting.

2. Tomato harvesting robot

2.1. *Robot behavior and configuration*

Fig.1 shows the appearance of the tomato harvesting robot. The robot is equipped with a 3-axis Cartesian manipulator, a harvesting mechanism, a moving mechanism, and a vision sensor. Modular structure of the electrical circuits facilitates maintenance. The development of a tomato harvesting robot is described in [3]. The system configuration, image processing, and moving mechanism have been modified for the competition.

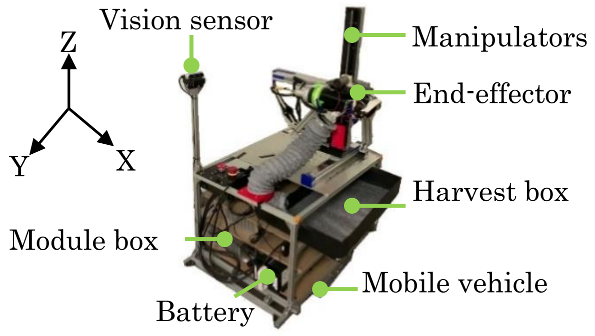


Fig1. Tomato harvesting robot

2.2. *System configuration*

The tomato harvesting robot is controlled using Intel's NUC as the main PC and NVIDIA's Jetson AGX Xavier as the sub-PC. The NUC runs MATLAB and Simulink by MathWorks, while the Jetson runs Python and OpenCV. The main PC and the sub-PC are connected via the ROS network and send and receive data in both directions. Fig.2 shows the system configuration. The main PC mainly controls each manipulator, end-effector, and moving mechanism using Simulink models. In Simulink1, command values are sent to other Simulink models according to the harvesting strategy using Stateflow, a tool for designing state transition control schemes. Simulink 2, 3, and 4 receive command values from Simulink 1 and transfer them to the connected Arduino microcontroller via serial communication. The Arduino then processes and controls the connected manipulators, end-effectors, and moving mechanisms. Also, rosbag is used for logging. Two ROS Nodes are running on the sub-PC. Node1 publishes RealSenseD435 RGB and depth images to the ROS network at regular intervals. Node2 starts processing when it receives a command value to execute image processing from Simulink1 and publishes the result.

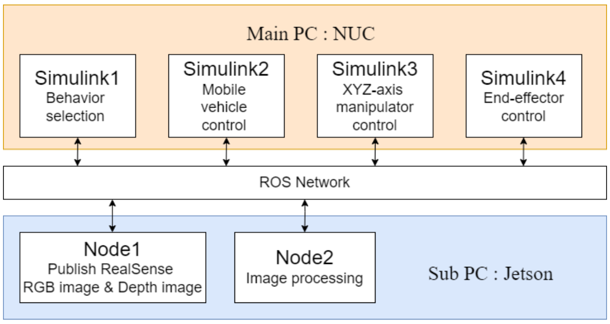


Fig2. System Configuration Diagram

2.3. *Mobile vehicle*

CuGo by CuGoRex was selected as the mobile mechanism for movement on soil. Crawlers were selected as the moving mechanism to enable back-and-forth movement and right-and-left turning in the soil. An encoder is installed to measure the move distance by acquiring the rotation speed and to control the rotation speed by PID control. Fig.3 shows the appearance of the crawler used in the tomato harvesting robot.

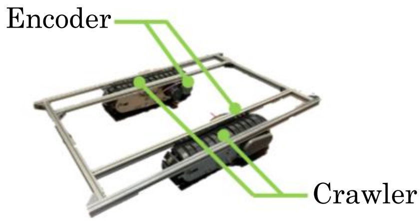


Fig3. Mobile vehicle

2.4. *Orientation control*

An IMU (Adafruit BNO055) is installed to maintain the straightness of the tomato harvesting robot. On-off control is performed based on the difference between the yaw angle output by the IMU and the yaw angle at the time the move command is received. If the difference is greater than the threshold, the speed of one crawler is increased to correct the heading.

2.5. *Faster image processing*

Conventional image processing using only Simulink models was deemed to be time-consuming. The reason is that MATLAB and Simulink do not support alignment of RGB and depth images, so the 3D point cloud is converted once and the depth image is restored again. Therefore, image processing is done by the sub-PC and was developed in Python. The average processing time per image using the conventional system was 318 ms. Using the modified system significantly reduced this to 7 ms.

3. Harvest strategy

Fig.4 shows a flowchart of the harvesting operation. First the tomato harvesting robot searches for tomatoes. If a tomato is detected, the robot stops moving and finds the coordinates of the center of the tomato in the image. The coordinates obtained are in the image coordinate system, so they are converted to world coordinates. The YZ-axis manipulator is then moved. After that, suction is started, and the X-axis manipulator is moved. A laser and an optical sensor are located inside the harvesting mechanism, and if the tomato is inside the harvesting mechanism, the laser is intercepted, and the tomato is judged to be within grasp. The blade at the lower jaw of the harvesting mechanism closes upward to cut the fruit stalk. The X-axis manipulator returns to the initial position before the suction stops. The lower opens and releases the tomato, which falls and rolls along the hose connected to the harvesting box to complete the harvesting process.

4. Competition rules

The operating environment for the tomato harvesting robot in the freestyle category was inside a greenhouse where tomatoes are grown. The robot was placed on a 2000×8000 mm soil area as shown in Fig.5. 10 minutes, two rounds of competition. The robot is operated from an arbitrary position within it [4].

5. Experiment in soil

To evaluate the performance of the tomato harvesting robot, an experiment was conducted in a field like the freestyle area. The robot's first step was to move to the right to detect tomatoes. Harvesting operation would then be performed after detecting tomatoes. After harvesting, it would start moving again by 4 m before reversing direction and start searching again. Fig.6 shows the motion data of the robot with respect to time (from top to bottom) – number of crawler revolutions; yaw, roll, and pitch angles; movement direction (0:stop, 1:left, 2:right); mode number within the harvest strategy (0: stop, 10 to 19: prepare for operation, 20 to 29: search for tomatoes, 30 to 39: harvest tomatoes, 40 to 49: harvest complete, 50 to 59: induce fruit, 60 to 69: harvest complete); flag for tomato detection (0: not detected, 1: detected); X-coordinate self-position; Y-coordinate self-position; and self-position in XY-coordinates. The robot started to move at around 8 seconds and detected the tomatoes after around 11 seconds before stopping to start harvesting them.

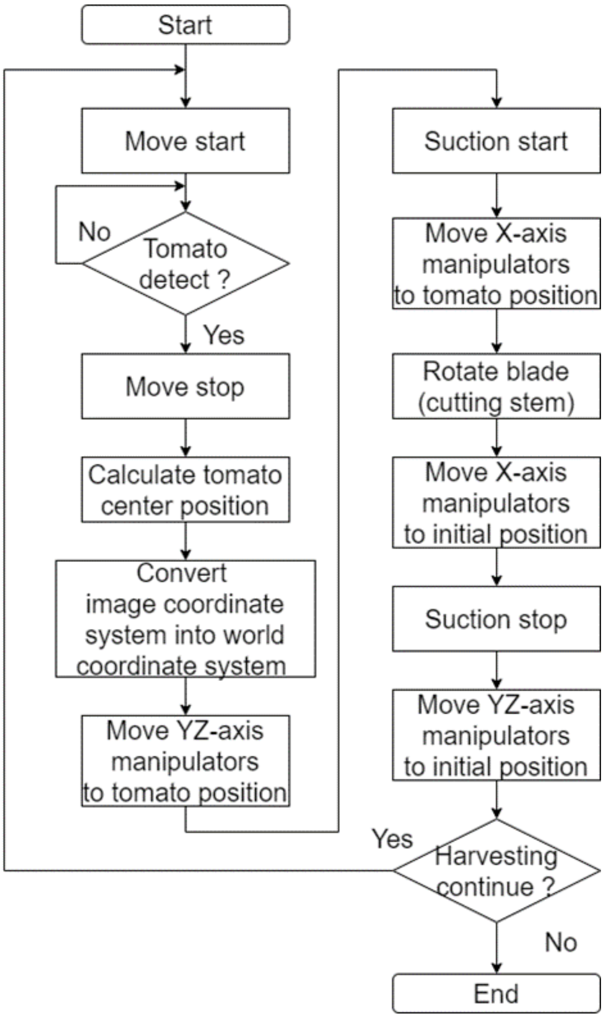


Fig. 4 Flowchart of the harvesting operation

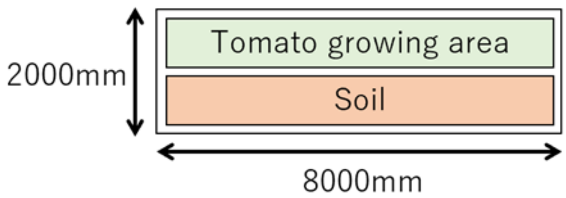
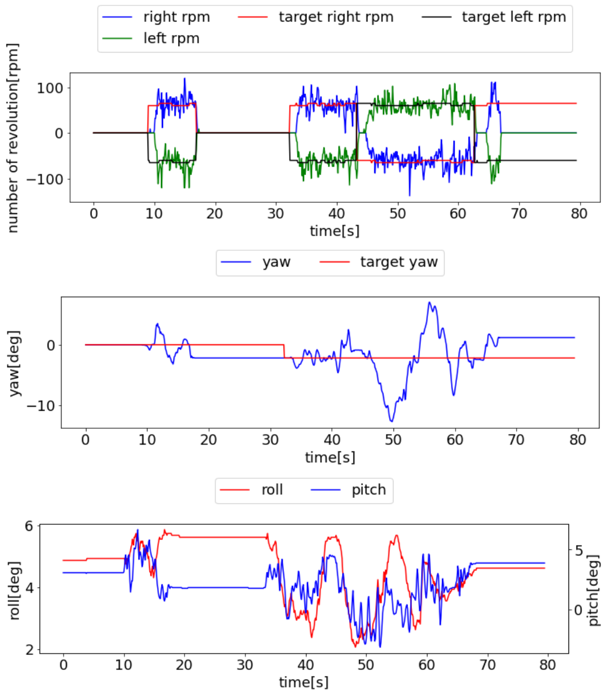


Fig. 5 Free-style competition area

Harvesting was finished at 30 seconds and the robot started searching again. The direction of movement was reversed because it advanced to the set distance of 4 meters after 45 seconds. The movement was reversed again after 60 seconds. Crawler control by PID control overshot due to poor gain adjustment relative to the target speed. The moving mechanism was smaller than that of the tomato robot, so the robot would sway to the left and right when it moved. However, the manipulator moved during harvesting, but the robot itself did not sway due to the movement of the manipulator. In addition, the heading was corrected based on the yaw angle during the movement, but the swing could have been so large that the difference from the target angle exceeded 10 degrees. The crawlers were found to be particularly sensitive to soil conditions, and would not run if there were stones between them, but would rotate only on one side, resulting in a misorientation. As a result, the azimuth was off, so the robot moved forward by about 0.1 m.



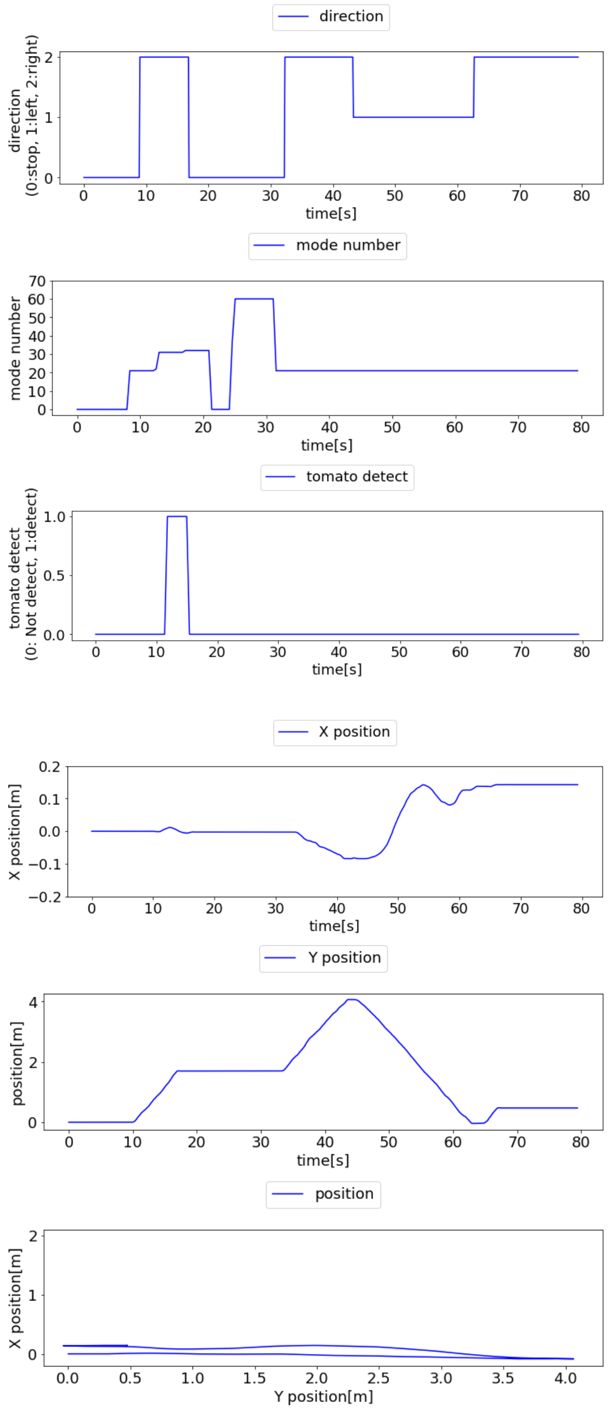


Fig 6. Tomato robot motion data

6. Conclusion

We improved the movement mechanism and the program to compete in the Tomato Robotics Competition. For image processing, speed was improved by migrating from Simulink to Python without changing the content of the process. The mobile mechanism was able to run on the soil, but it was not able to correct the orientation and moved forward. In the future, we will revise the algorithm of orientation correction and develop a system that is less affected by soil conditions.

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