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Dual-arm Robot Design and Testing for Harvesting Tomato in Greenhouse

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Abstract: In order to improve the efficiency of robotic harvesting in unstructured environment, a modular concept of dual-arm robot for harvesting tomatoes is proposed in this paper. The objective to develop a modular robotic system which works based on human-robot collaboration is reached. Due to the complexity of working environment, an artificial recognition approach conducted by operator through marking the tomato object on the graphic user interface is used for tomato recognition and localization. A dual-arm frame equipped with two 3 DoF manipulators and two different type end-effectors used to pick tomatoes is designed and tested respectively. The cooperation of two end-effectors could improve the harvesting efficiency significantly. The EtherCAT bus based control and communication system is adopted to increases the reliability and speed of motion control and data communication. Concerning control software, a graphic user interface was designed to exchange the operator's commands and display the state information of robot. The performances of field test showed the efficiency of the developed robot system, some shortcomings of the robot were also found for future work.

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1. INTRODUCTION

As one of the most important processes in agriculture production, the harvesting work is not only a tiresome task but also requiring a large amount of skilled labour in a certain period Moreover, the tomato trees in greenhouse are tall which increases the risk of injury for farmers. Projecting into the future, the issue of labour shortage is expected to become a huge challenge to agricultural industry (Gongal et al., 2015). The harvesting robot was firstly proposed by Schertz and Brown (1968) as a potential way to combat the agricultural labour crisis. Harvesting robots are designed to sense the complex agricultural environment using various sensors and use that information, together with a goal, to perform some actions (Edan et al., 1994). These actions are to move the tool of an end-effector to grasp or pick a fruit object. Although harvesting robots hold ample promise for the future, currently the overall performance of harvesting robot is often insufficient to compete with manual operation (Grift et al. 2008). The bottlenecks to promote the commercial application of harvesting robots are the low efficiency and high cost (Edan et al., 1999).

Combining human workers and robots synergistically is a viable approach to increase the success rate of robotic harvesting. This approach for the robotic harvesting is to separate the fruit recognition stage from the harvest stage by marking the target fruit a priori. In the Agribot project, a robot prototype was designed and built for a novel artificial harvesting strategy in unstructured environments, involving a human-machine task distribution (Ceres et al., 1998). The operator performed the detection and precise location of fruits by means of a laser range finder. Ji et al. (2014) introduced an assistant-mark approach to recognize and locate the picking-point for robotic harvesting. Oren et al. (2012) also defined and implemented a collaboration of a human operator and robot applied to target fruit detection. Experimental results indicated that the fruit recognition system based on human-robot collaboration increased the success detection rate to 94% and reduce the time consumption by 20%.

Another way toward the goal of efficient robotic harvesting is to build a multi-arm robotic harvester. A number of manipulators are mounted on a mobile robot platform, and each manipulator is assigned specific fruit to harvest. Zion et al., (2014) from Israel has designed a multi-arm melons harvesting robot which enabled the maximum number of melons to be harvested. According to the idea of multi-robot cooperation for fruit harvesting, Noguchi et al. (2004) also proposed a master-slave robot system for field operations. In this multiple robot system, a high level of autonomy to the robot was achieved to allow them to cope with unexpected events and obstacles. Modular design is a practical and feasible way to reduce the investment of harvesting robot (Hwang and Kim, 2003).

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In this paper, a dual-arm robot for harvesting tomato in greenhouse scene was modular designed and field testing. Firstly, the overview and workflow of the developed dual-arm harvesting robot were described in the paper. Then, 5 major functional modules of the harvesting robot were introduced, and some shortcomings of the developed system were summarized according to the field tests. Finally, the remainder of this article present a summary about the study of dual-arm harvesting robot and outlook of this study.

2. OVERVIEW OF THE ROBOT

2.1 The Structure of Prototype Robot

The proposed robot system was designed to fit Venlo type greenhouse, in which the heating pipes was used as guided rail. The platform vehicle designed as a carrier was driven on the heating pipes. Except these auxiliary units, the dual-arm harvesting robot was composed of 5 major functional modules which are dual-arm type robotic manipulator, exchangeable modular type end-effectors, vision system equipped with stereoscope camera, EtherCAT based communication and control system, and graphic user interface. As shown in Fig. 1, a stereo camera mounted on the top of the robot platform was used to acquire the image of working scenes and provide 3D position of tomato object. The robotic dual-arm constituted by two 3 DoF manipulators was used to position the end-effector to the picking-point. A saw cutting device was designed as end-effector which could cut the stem of tomato. The other end-effector was used to grasp the tomato for avoiding tomato shaking caused by the cutting operation. The robot system adopted tele-operative concept through developing wireless remote data and signal communication and graphic user interface. The machine control system of each manipulator was built based on direct current (DC) servo motors and EtherCAT bus.

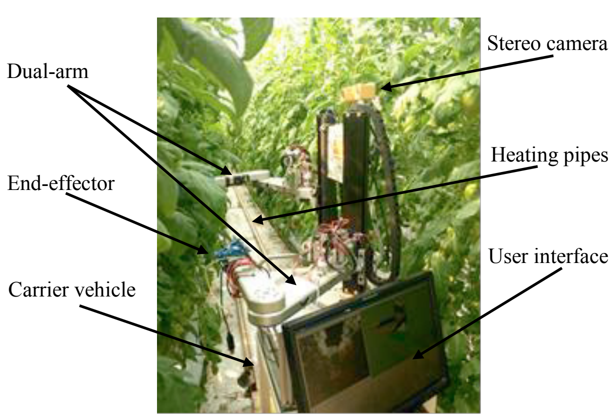

Fig. 1. Integrated dual-arm robotic system for harvesting tomato.

2.2 The Workflow of Tomato Harvesting Robot

Considering unreliability of autonomous fruit detection for various fruit harvesting robots in unstructured environment, the fruit recognition is the most difficult challenge to improve the effectively of robotic harvester. For solving the obstacles mentioned above, a human-robot collaboration strategy was introduced into the framework of proposed system. The fruit recognition task was implemented by operator through pointing out the target tomato on the screen interface which displayed the working site. Then, the spatial position of the marked tomato was obtained by stereo camera. Excepting fruit recognition, the order of carrier vehicle driving was also given by operator through user interface. The other operations were conducted by robot itself. All the task sequence of picking operation for the dual-arm robot was shown in Fig. 2.

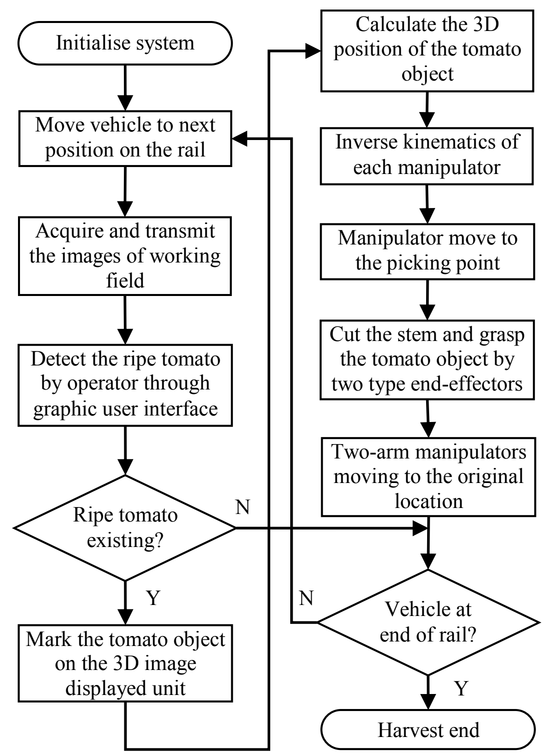

Fig. 2. The workflow of tomato harvesting robot.

3. THE MODULAR ROBOT SYSTEM

3.1 Dual-arm Manipulator

Fig. 3(a) shows the developed dual-arm robotic manipulator which was composed of two 3 degrees of freedom (DoF) Cartesian type robot manipulators. The 3 DoF Cartesian type robot manipulators were owned one prismatic joint and two rotational joints to ensure the proper workspace. Fig. 3 (b) shows the simulation results of reachable workspaces of the dual-arm robot manipulators. Totally 6000 red and blue dots were used to display the possible picking-point of each arm respectively. The common area of red and blue dots is the workspaces. According to the width of the simulation results, the distance between each picking point on heating pipes was designed as 400mm. The frame of dual-arm manipulators also can rotate 180 degrees according to the central axis. Overall geometrical and kinematic parameters of the proposed dual-arm robot manipulators were given in Table 1.

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