

Design of Autonomous Driving Algorithms for Fruit harvesting in orchards

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Abstract—This paper designs an autonomous driving methodology in an orchard with a mobile robot attached to a manipulator to harvest fruit. We propose a methodology for mobile robots to recognize fruit trees and create paths to harvest fruit, and investigate LiDAR, IMU, image, and GPS sensors for various environment perceptions. In addition, the diagram of the driving platform for testing the algorithm and the configuration of the autonomous driving algorithm were designed.

Index Terms—agricultural automation, autonomous driving algorithms, autonomous navigation, orchard

I. INTRODUCTION

In the agricultural field, there are many difficulties such as a decrease in productivity due to an aging population, high wages, and rising raw material prices along with a shortage of manpower. Therefore, smart farm-related technologies that combine cutting-edge technologies such as IoT, AI, and robot technology are being tried in the agricultural field [1].

Techniques for harvesting agricultural products are essential among various tasks that require automation from agriculture. In addition, the work of harvesting agricultural products in the outfield is required not only a lot of labor but also a high proficiency and workers who have a high proficiency and physical workers. In order to solve this problem, the robot can approach the outfield's slope, and dangerous areas, perform work, replace the labor force, and expect to improve productivity through the machine. The various methods for automatically harvesting the crops and driving autonomously are emerging [2], [3].

For autonomous driving in orchards or agricultural fields, high-accuracy environment recognition technology is required. The studies conducted so far recognize the surroundings and drive with various sensors attached to the platform, such as 2D and 3D LiDAR, radar, GPS, IMU, and image sensors. GPS-based autonomous driving technology has a weakness in that the signal is distorted in mountainous terrain with trees or high ground so that the robot can drive to the wrong blind spot. Vision technology using image sensors is widely used because of its low price compared to other sensor types, but

outdoor light environments such as backlight and shadows have a big impact on performance. Although LiDAR is more expensive than image sensors, it is not significantly affected by outdoor sunlight. LiDAR is a technology for measuring the distance to an object by shooting a laser at a specific angle and measuring the time of a continuous signal that is reflected from the object and returns. This operates stably even in an outdoor environment due to the active generation of signals and the directness of the laser signal. In addition, The accuracy is improved by correcting the robot's localization information by using the IMU sensor together with the aforementioned sensors. When autonomous driving in an orchard, there are studies using GPS [4]–[6], image [7]–[14], LiDAR [15]–[17], and ultrasonic [18] sensors respectively. Also, researches on the fusion of GPS and image sensors [19] or GPS and LiDAR sensors [20] are in progress.

To realize a mobile robot that autonomously drives in an orchard, it is necessary to select appropriate sensors and develop an efficient and highly accurate autonomous driving algorithm. In general, these driving algorithms are based on information about the positions and poses of robots and obstacles acquired through sensors in an orchard environment with high terrain and many obstacles [21]. Also, when mobile manipulators harvest fruits autonomously drive, the mountainous terrain of the orchard must be considered and the route must be planned in sync with the manipulator's work. In this paper, we propose a methodology for autonomous driving of a mobile manipulator for fruit harvesting in an orchard and describe the configuration of the platform system and the list of sensors under consideration.

II. SYSTEM DESCRIPTION

A. Autonomous driving methods for fruit harvesting

For the manipulator attached to the mobile robot to autonomously drive while assisting in harvesting fruits, path planning is required as shown in Fig. 1. When the mobile manipulator finishes harvesting at a specific location on a tree, it moves to the unharvested location in a circular motion around the tree as shown 1 in Fig. 1. After harvesting from one tree, as shown 2 in Fig. 1, it finds the next unharvested tree, creates a path autonomously, and moves.

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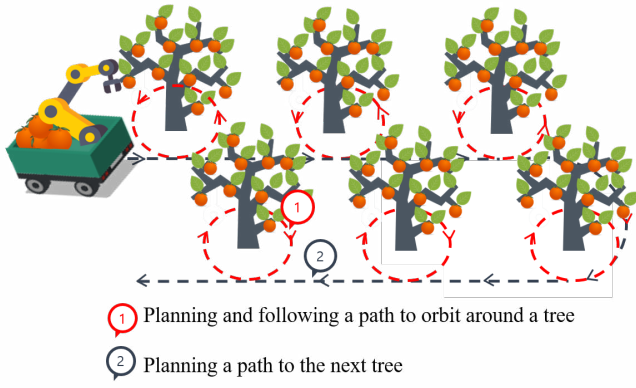


Fig. 1. Methodology for creating paths to harvest fruit

There are two main directions for autonomous driving technology that finds and moves to the next tree. First, it is a global location navigation method that distinguishes between harvested and non-harvested trees based on a map created in advance through SLAM (Simultaneous localization and mapping) and creates an efficient route for driving. The second is a local relative navigation method that searches a route in real-time without a previously created map and draws a map. In the second method, the reason for accumulating map information while searching for paths in real-time is to distinguish between harvested trees and non-harvested trees. Orchard farmers prefer the second method for convenience and efficiency, but the technical difficulty is high to maintain a high autonomous driving success rate.

B. Sensors

Sensors play a hugely important role in the autonomous driving algorithm in which the mobile robot recognizes the surrounding environment, efficiently avoids obstacles, and navigates the shortest path. As shown in Fig. 2, the sensors applied to the autonomous driving system in the orchard include LiDAR, IMU, image, and GPS sensor. By applying

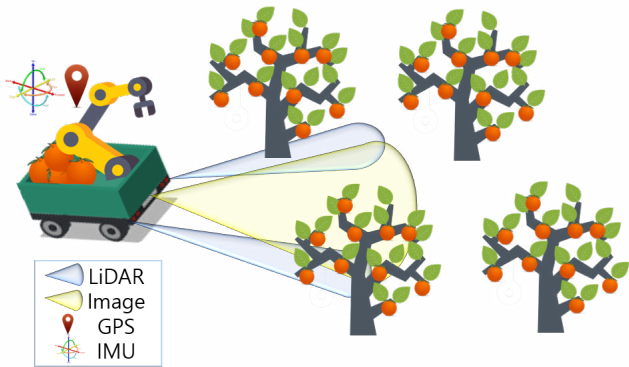


Fig. 2. Environment example of sensor fusion for path planning.

sensor fusion technology, we want to develop an environment recognition algorithm that identifies multiple objects seen easily in orchards such as ladders, boxes, ducks, fruit

trees, etc. Combinations under consideration so far include 3D LiDAR, image, GPS, and IMU sensors. The list and specifications of those sensors are described in Table I. Among the sensors shown in Table I, we plan to research finding a low-cost sensor combination for commercialization while showing high performance in an orchard environment.

TABLE I
LIST OF CANDIDATE SENSORS.

Sensor name	Specifications		
	Type	Resolution/Precision	FOV
VL-R1	3D LiDAR	0.125 [°]	145×9.6 [°]
CygLiDAR-D1	3D LiDAR	160 × 60 (Pixel)	120×65 [°]
HPS-3D160	3D LiDAR	160 × 60 (Pixel)	76×32 [°]
IMX219	RGB	3280 × 2464 (Pixel)	170 [°]
SEN-16778	RGB	640×480 (Pixel)	99×81.9 [°]
WT901C	IMU	0.05[°]	-

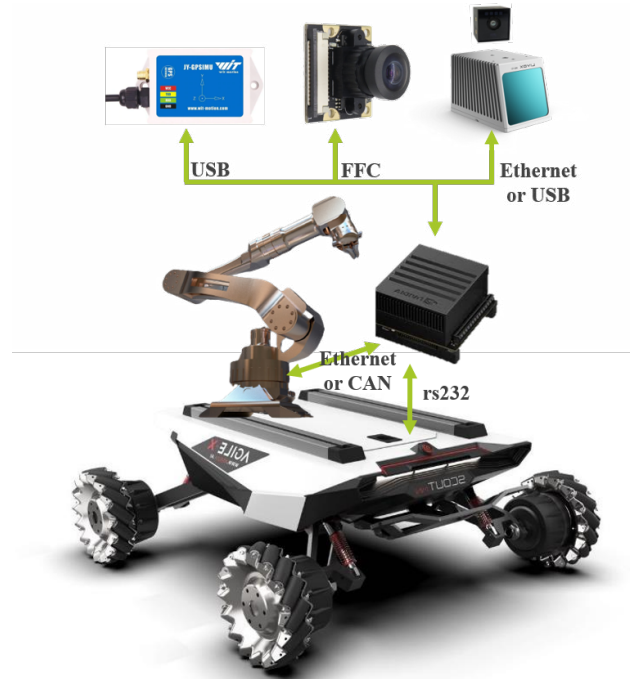


Fig. 3. Hardware diagram of fruit harvesting robot.

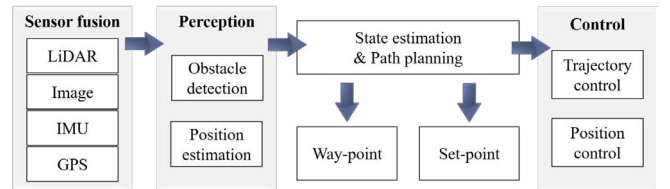


Fig. 4. Flowchart of path planning and following algorithm for fruit harvesting.

C. System Design

The system configuration for testing the autonomous driving algorithm in the orchard is shown in Fig. 3. Agile's scout

mini [22] with the 4WD driving model was selected to set up the driving platform. The module with integrated IMU and GPS was connected via USB, and the camera and lidar sensor were also connected to the embedded board, respectively. The board creates a driving route through an autonomous driving algorithm, calculates the driving speed, and transmits it to the mobile robot through RS-231 communication.

The Fig. 4 shows the flow chart of the autonomous driving algorithm of the fruit-harvesting robot. The algorithm is divided into Sensors, Perception, State estimation and Path Planning, and Control modules. By collecting data from various sensors in the sensor module, obstacles and fruit trees are detected in the perception part, and positions and poses are derived. Subsequently, this information is estimated and the path planner generates a path. Based on this information, the control module controls the trajectory and position based on the robot's kinematics and driving model.

III. CONCLUSION

In this paper, an autonomous driving methodology of a mobile robot with a manipulator was designed. To plan a path for a mobile robot in an orchard, several sensors in dynamic environments such as lidar, IMU, image, and GPS sensors were considered. In addition, the configuration of the hardware and algorithm of the autonomous driving system was described. In future work, we will collect sensor data from the orchard and then simulate it using ROS and Gazebo based on the designed algorithm. Also, an orchard testbed will be built with artificial trees indoors and the algorithm will be tested using a mobile robot for indoor and outdoor use.

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