Evaluation of Maps Constructed by Crawler-type Agricultural Robot in Different Farms

Takuya Fujinaga
Department of Electronics Engineering and Computer Science, Fukuoka University,
8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan

Tsuneo Nakanishi
Department of Electronics Engineering and Computer Science, Fukuoka University,
8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan

E-mail: t.fujinaga.wz@fukuoka-u.ac.jp, tun@ fukuoka-u.ac.jp

Abstract

Various studies have been carried out with the aim of realizing smart agriculture. Many of them have targeted at large field and large-scale facility that are relatively easy to verify and implement robots and IoT devices etc. On the other hand, although the ratio of small-scale facility is high in Japanese agriculture, there are few cases of study targeting small-scale facility. We aim to develop an agricultural robot for supporting agricultural work that can move autonomously in the field for small-scale greenhouse. This paper evaluates maps of three different environments (strawberry farm, herb farm and vegetable farm) constructed using the developed agricultural robot. In addition, through verification experiments and evaluation results, we describe the requirements and concerns for operating robot in small-scale greenhouse.

Keywords: Agricultural robot, Environmental map, Smart Agriculture, SLAM

1. Introduction

While the world population is increasing, the population in Japan is decreasing [1], and so is the agricultural working population [2]. Therefore, it is predicted that Japan, which relies on imports for a large amount of food, will depend more on foreign countries for food. The Ministry of Agriculture, Forestry and Fisheries drew a blueprint of the Agricultural DX (Digital Transformation) concept as a solution to resolve problems brought by aging and shortage of agricultural workers [3]. The initiative aims for farming with high production efficiency using data by utilizing technologies such as robots, artificial intelligence (AI), and the Internet of Things (IoT) in the field. In addition, it aims to provide agricultural products and foods with capturing the needs of consumers shown by the data.

Research and development such as autonomy of agricultural machinery [4], automation of agricultural work (harvesting and monitoring) [5], measurement of growth state of agricultural products [6] have been carried out toward the realization of agricultural DX and smart agriculture. However, only less than 20% of agricultural management bodies practice agriculture based on data. While the focus is on smarter large-scale agriculture, there are few research and development cases targeting small-scale agriculture. In Japanese facility horticulture, the proportion of small-scale facility of 1 ha or less is high [7]. Moreover, many farmers have given up on farming. There are issues such as whether cost-effectiveness can be obtained when introducing robots, AI, IoT, etc. into small-scale agriculture. However, in order to quantitatively evaluate the effect, it is necessary to develop agricultural robot and system for small-scale agriculture and verify them in the actual environment. Also, such development and verification not only can be expected to reduce the workload, but also contribute to the promotion of understanding and introduction of agricultural DX to farmers.

This study defines a farm with a planted area of 1 ha or less as a small scale and focus on agricultural robots for small-scale facility that produces crops. In small facility, few farmers perform multiple farming works (pesticide spraying, monitoring, harvesting, etc.). Therefore, Multi-functional agricultural robots are desired rather than mono-functional agricultural robots for large-scale facility (for example, harvesting robot and transport robot). In an outdoor farm with a vast site area, it is possible to autonomously drive agricultural machinery such as tractors using GPS [4]. In a plant factory, rails are laid to adjust the temperature in the greenhouse, reduce the workload, and improve efficiency, and it has been proposed to move the robots on the rails for harvesting and monitoring [5]. On the other hand, in small-scale facility, it is difficult to perform high-precision positioning by GPS compared to completely outdoors. In addition, the moving environment differs depending on the crops cultivated, and the behavior of robots is limited.

We have developed a prototype for the purpose of developing and operating a general-purpose agricultural work support robot for small-scale facility. Also, aiming at autonomous operation of the robot, as the first step, we verified the map construction of the facility using the prototype. This paper describes the outline of the prototype and the results of verification experiments for map construction conducted in three different farms (strawberry farm, herb farm, and vegetable farm). We also discuss requirements and concerns for operating the robot in small-scale facility obtained from the verification experiments are described.

2. Development of agricultural work support robot

First, the development requirements for a general-purpose agricultural work support are described. Agricultural work includes pinching, harvesting, pesticide spraying, and monitoring growth state. For robot to perform such agricultural work, the robot needs a moving mechanism to move in the facility, sensors to

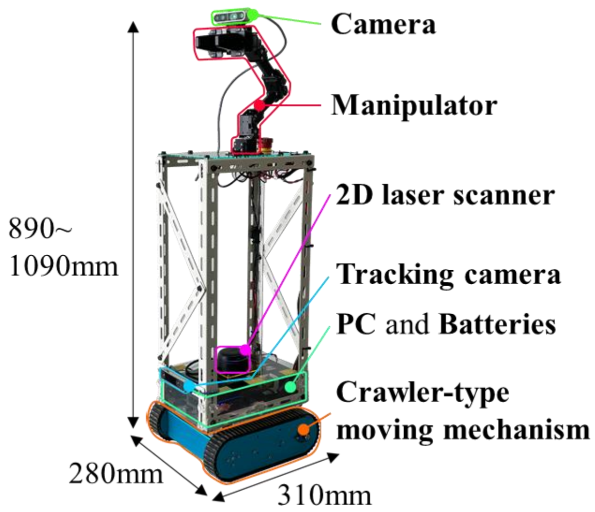


Fig. 1. Prototype developed for agricultural robot.

detect environment, plants and harvested objects, and manipulator or work machine to carry out agricultural work. The following functions are also required: map construction of an environment, self-position estimation, path planning, object detection, control of a manipulator or a working machine, and a decision-making system that integrates them. In addition, the robot needs to be sized so that it can move between ridges or cultivation beds in the facility and approach the target crops.

In this study, we have developed a prototype to meet the above requirements (Fig. 1). The prototype consists of the following elements.

- Crawler-type moving mechanism (NEXUS ROBOT, New Tracked Mobile Tank Robot Kit 10022) that allows the facility to move on soil
- 2D laser scanner (SLAMTEC, RPLIDAR A3) for map construction and self-position estimation
- 4DOF vertical articulated manipulator (ROBOTIS, OpenMANIPULATOR-X) for carrying out agricultural work (It has an end effector for gripping agricultural products.)
- RGB-D Camera (Intel RealSense Depth Camera D435i) for detecting plants
- Tracking camera (Intel, RealSense Tracking Camera T265) for estimating the self-position without depending on the ground environment (The odometry using the encoder mounted on the moving mechanism causes an estimation error due to slipping during moving.)
- PC for control (CPU: 3.5Ghz, Intel Core-i7, Memory: 32GB, OS: Ubuntu 16.04), and the software development was used ROS (Robot Operating System).

- Batteries (two types): one (12 V, 18 Ah) for manipulators and moving mechanisms, and the other (19 V, 20Ah) for PC

The size of the prototype is 310 mm in length, 280 mm in width, 890 to 1090 mm in height (variable depending on the operation of the manipulator), and the weight is 12.5 kg.

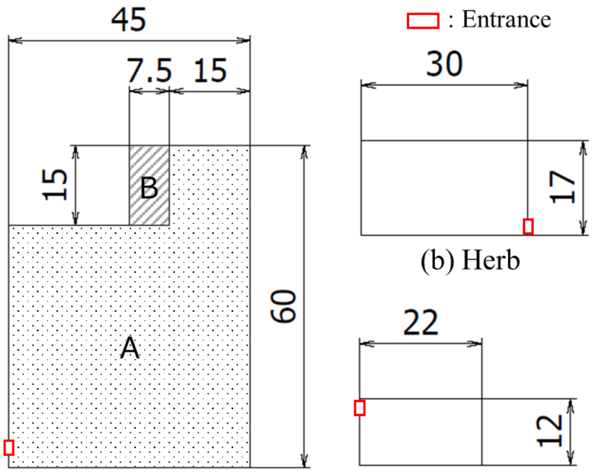
3. Verification of map construction

3.1. *Experimental method*

We conducted verification experiments to construct maps under different environments, with the aim of autonomously operating a prototype developed for the operation of a general-purpose agricultural work support robot in a small-scale facility. The experiments were carried out at three farms (greenhouses): *ichigokirari* which grows strawberries, *Kojima farm* which grows herbs, and greenhouse for practicing agricultural IoT [8] which is an experimental facility for introducing robot, IoT and AI technologies in the agriculture (Various vegetables such as tomato, asparagus, and cucumber are cultivated in this greenhouse.).

In this paper, each farm is called a strawberry farm, an herb farm, and a vegetable farm. The outlines and photographs taken at entrances of the farms are shown in Figs. 2 and 3, respectively. The strawberry farm and the herb farm do elevated cultivation, their grounds are covered with the general agricultural sheet, and the vegetable farm does soil cultivation. Note that equipment and tools for agricultural work are installed and temporarily put in each farm, and no consideration is given to operating the robot.

The experiments were conducted on August 31, 2021, September 1 and November 30, at the strawberry farm, on September 14 at the herb farm, and on September 3 at the vegetable farm. In the strawberry farm in August and September, strawberries were not cultivated in the cultivation beds as shown in Fig. 4(a) before planting the seedlings. On the other hand, in November, seedlings have been planted and flowering has begun as shown in Fig. 4(b). Fig. 4(a) and (b) are photographs of the inside of area B in Fig. 2(a). As can be seen from these photographs, a white sheet is wrapped around the cultivation beds in Fig. 4(b). This sheet has the role of keeping the culture medium warm. It is wrapped around the cultivation beds in November when



(a) Strawberry (b) Herb (c) Vegetable

Fig. 2. Outlines of the farms where the verification experiments were conducted (The unit is meter.).

(a) Strawberry (b) Herb (c) Vegetable

Fig. 3. Photographs of the farms where the verification experiments were conducted.

(a) Before (August) (b) After (November)

Fig.4. Photographs before and after planting in the strawberry farm.

the temperature begins to drop after planting is carried out in September. In this paper, in addition to the evaluation of maps under different environments, we focus on area B in Fig. 2(a) and compare the constructed maps before and after the sheet is wrapped.

In the experiments, the prototype was visually controlled remotely using a remote controller, and data for constructing an environmental map was acquired. However, if the prototype could not move due to equipment and tools for agricultural work, human intervention was required. Using the data of the 2D laser scanner and the tracking camera, we constructed maps by gmapping that can construct a 2D map with the existing package for SLAM (Simultaneous Localization and Mapping) of ROS.

3.2. *Results*

The environmental maps constructed in three different farms are shown in Fig. 5 and Fig. 6. Fig. 5(a) is the area A of the strawberry farm, (b) is the herb farm, and (c) is the vegetable farm. Fig. 6(a) is shown before planting in the strawberry farm area B, and (b) is shown after planting. In Fig. 5 and Fig. 6, the size of the farm measured from the constructed maps and its actual size are shown (The actual size in parentheses. The unit is meter.). Regarding the accuracy, the error was +2 m for the strawberry farm, the error was +1 m for the herb farm, and the error was +1 m for the vegetable farm compared to the actual size.

In the strawberry farm and the herb farm, the cultivation beds are supported by the props as shown in Fig. 3 (a) and (b). The props can be confirmed from Fig. 5(a), (b) and Fig. 6(a). On the other hand, in the map Fig. 6(b) constructed in the area B of the strawberry farm after planting, the props of the cultivation beds cannot be confirmed. The cultivation beds are covered with sheet, and the sheet can be confirmed in Fig. 6(b). Therefore, the cultivation area is clear. In addition, each farm connects one greenhouse (single building), and there are beams at the connecting part (the part that becomes the end of the single building). The beams can also be confirmed in Fig. 5(a) and (b). There are two areas in the vegetable farm. One is the area where vegetables are cultivated and becomes soil (The plant area in Fig. 5(c)),

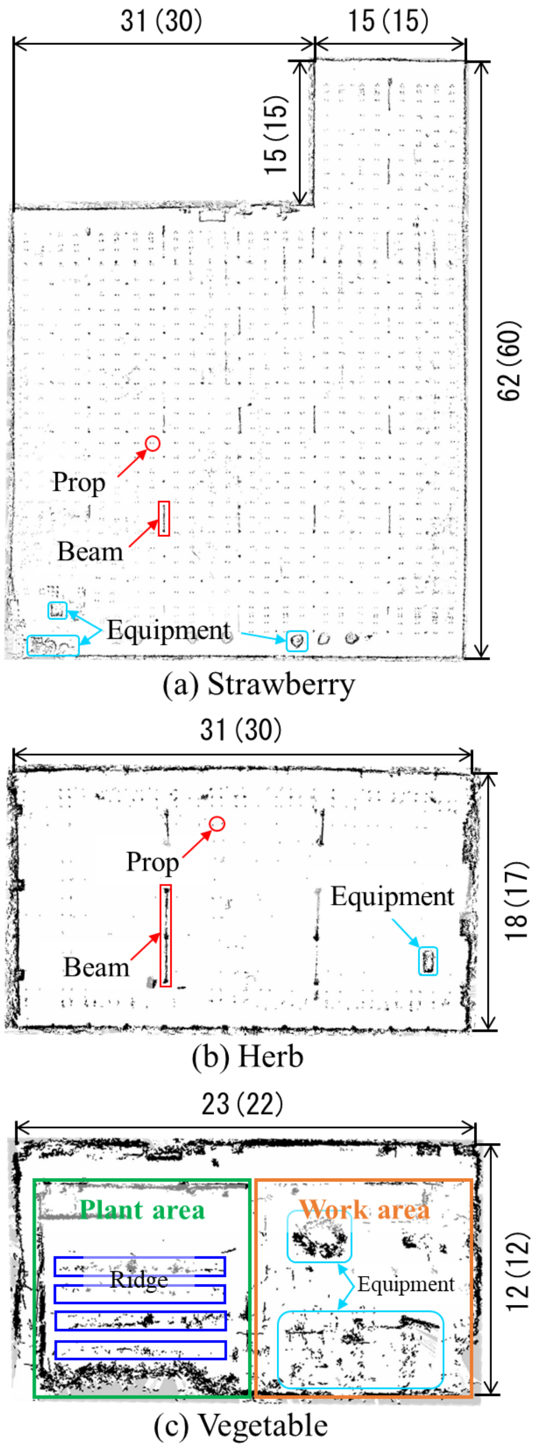


Fig. 5. Maps constructed in verification experiments (The unit is meter.).

and the other is the area where boards are laid for work (The work area in Fig. 5(c)). Ridges can be seen in the plant area and work desks can be seen in the work area from Fig. 5(c). Agricultural tools installed or temporarily put in the farm are also confirmed from each map.

4. Discussion

4.1. Verification results of map construction

For robot to move autonomously in the farm, it is necessary to detect obstacles in the farm and avoid them. From the results of the verification experiments, the outer shape of the farm can be grasped. Although the props and beams in the farm are confirmed, the robot need to detect and avoid those obstacles. There is noise in the constructed maps, it is necessary for the robot to distinguish them only from the geometrical features such as props and beams. It is thought that mounting an additional camera or 3D laser scanner on the robot will make it easier to distinguish between them and avoid obstacles but adding sensors will increase costs.

On the other hand, it is considered that autonomous moving is possible with only the minimum sensors and processing by changing the farm environment from the verification results. The sheet was not wrapped around the cultivation beds in the experiment conducted before planting. When the map Fig. 6(a) constructed in that environment is used, it is difficult for the robot to move autonomously in the farm without detect the cultivation beds. If so, the cultivation beds are connected as shown in Fig. 4(a), but in Fig. 6(a), only the props of the cultivation beds can be confirmed. Therefore, when trying to find the optimum solution without some conditions in the path planning during autonomous moving, the path in the middle of the connected cultivation beds will be a candidate. However, in the map Fig. 6(b) constructed in an environment where the sheet is wrapped around the cultivation beds as shown in Fig. 4(b), the row of connected cultivation beds can be confirmed and the area where the robot can move becomes clear. Note that in map construction in such an environment, the data from 2D laser scanner will be two parallel lines representing the cultivation beds. To deal with the degeneracy in map construction, this prototype used information of point cloud data from 2D laser scanner and odometry from tracking camera.

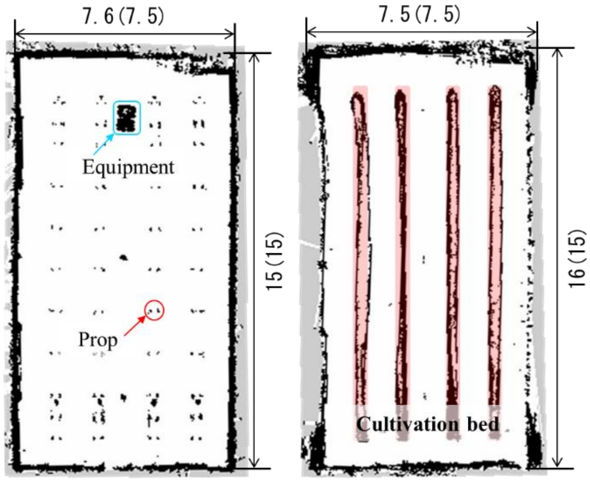


Fig.6. Maps before and after planting in the strawberry farm.

We target small-scale facility, and farmers are concerned about the cost-effectiveness of introducing robots, AI, IoT, and so on. At present, the prototype has the configuration that is considered necessary to support agricultural work. However, instead of simply adding sensors, it is a future task to clarify the requirements for agricultural work support robots and the farm environmental conditions for the robots by repeating verification experiments on various farms. The requirements and concerns in the robot operation obtained from the verification experiments are described in the next section.

4.2. *Operation of robot in small-scale facility*

This prototype was designed to a size that allows it to move between ridges or cultivation beds (The width is 280 mm). It was able to move at the farms conducted in the verification experiments. However, there were places where it was not possible to move due to equipment and agricultural tools. In such places, it is necessary to take measures such as avoiding obstacles by the robot or making the environment easy for the robot to move.

There are undulating spot and places where watering hoses and agricultural tools are temporarily put. For autonomy, moving performance for overcoming undulations and hoses, and algorithm for detecting agricultural tools, etc. are required. The strawberry farm and herb farm have relatively sturdy agricultural sheet laid on the ground. On the other hand, the vegetable farm use film-shaped sheet for covering ridges, and there were cases where the prototype involved the sheet. There were also muddy spots, it is difficult for the prototype to move to such spots. In robot operation, after understanding the cultivation method of the farm and the characteristics of the facility, it is necessary to clarify the objects that need to be detect and make a path plan for autonomous movement.

Small-scale facility is managed by fewer workers than larger facilities. So, small-scale facility has a small cultivation area, and it is easy for workers to move within the farm. Taking advantage of this point, an operation method in which a person helps a robot can be considered as an example. For example, the robot grasps the map of the farm and the location of static equipment (props, beams, etc.), detect dynamic objects (hoses, agricultural tools, etc.). When a problem such as unavoidable occurs, the robot stops and warns the farmer, then the problem is solved by human intervention.

The operation of robot in small-scale facility needs to be customized according to the scale of farmer's management. In some cases, complete autonomy may be desired by adding sensors, and in other cases, it may be desirable to have minimum components and cooperate with humans. We aim to develop a farm work support robot that can handle any situation.

5. Conclusion

This paper described the outline of prototype for a general-purpose agricultural work support robot and the experiments for map construction carried out in three farms. The outer shape of each farm was able to be grasped from the constructed map. The accuracy was a maximum error of +2 m, and some equipment were confirmed. In addition, we showed that changing the farm environment may be effective for autonomous moving of robot. The requirements and concerns in robot operation obtained through verification experiments were described. As the next step, we aim for autonomous moving in the farm based on the constructed map.

Acknowledgements

In the experiments, we received much cooperation from Mr. Seigo Tanaka of *ichigokirari*, Mr. Hiromitsu Kojima of *Kojima farm*, and Prof. Kazuo Ishii of Kyushu Institute of Technology. We would like to express our sincere gratitude for their kind assistance. This work was supported by JSPS KAKENHI Grant Number JP21K20604.

References

1. Statistics Bureau of Japan.
2. Ministry of Agriculture, Forestry and Fisheries. (In Japanese)
3. Ministry of Agriculture, Forestry and Fisheries.
4. N. Noguchi, “Agriculture Vehicle Robot”, Journal of Robotics and Mechatronics, 30(2), pp. 165-172 (2018).
5. T. Fujinaga, S. Yasukawa, K. Ishii, “Tomato Growth State Map for the Automation of Monitoring and Harvesting”, Journal of Robotics and Mechatronics, 32(6), pp. 1279-1291 (2020).
6. K. Shimomoto, K. Takayama, N. Takahashi, H. Nishina, K. Inaba, Y. Isoyama, S. OH, “Real-time Monitoring of Photosynthesis and Tran-spiration of a Fully-grown Tomato Plant in Green-house”, Environmental Control in Biology, 58(3), pp. 51-57 (2020).
7. Ministry of Agriculture, Forestry and Fisheries.
8. enPiT-Pro, Practical laboratory exercises on agriculture,