Practical Exercise on An Autonomous Driving System Using Mobile Devices and IoT Devices for An Agricultural Tractor

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Abstract

The current method of agriculture is expected to make sustainable production difficult due to the effects of a declining and aging workforce. To solve these issues, research and development of smart agriculture technologies, including automated tractor operation, have been underway. We have developed an autonomous driving system for a commercially mini-tractor using mobile and IoT devices to more facilitate the introduction of automated driving technology for tractors. In addition, the exercise was conducted for students to implement and operate this system with an aim of education for robotics engineers. This exercise consists of lectures and development exercises for the system. The demonstration results showed that the students' difficulty level was able to set appropriate difficulty. The results of the rubric also showed that the students improved their proficiency in the algorithms and programming of applications that are fundamental to autonomous driving systems.

Keywords: Smart agriculture, Autonomous driving, Tractor, Mechatronics exercise

1. Introduction

According to the survey by the Ministry of Agriculture, Forestry and Fisheries in Japan, the number of core agricultural workers is expected to decrease to 1/4 of the current level (from 1.16 million to 0.30 million) over the next 20 years [1]. Therefore, improving the efficiency of agricultural work and reducing the manpower for agricultural work has been required. To solve this problem, a production method called "smart agriculture" that applies robotics and Internet-of-Things (IoT) technology has been proposed, and a lot of research and development has been conducted. We have focused on an autonomous driving system for tractor, one of contents of smart agriculture. Tractors can perform many agricultural tasks. Therefore, we think that an autonomous operating system makes it possible to reduce time required for agricultural work and perform multiple tasks simultaneously. A tractor with an autonomous driving system has already been put into practical use and commercialized [2], [3], [4]. Also, installing automatic steering devices as an automation method for common tractors [5] has been promoted. We also think that exercises for training engineers who can develop autonomous driving systems that can be introduced by agricultural workers are needed for promotion of smart agriculture. Interdisciplinary education for human resources development for an autonomous driving system is required [6]. The exercise for an autonomous driving system is one example of small-scale RC cars being used as targets for implementation [7], but there are few cases of tractors being used as targets. Therefore, we have designed an exercise based on the development of an autonomous driving system for a tractor. This paper reports on the outline, the equipment used, and the results of the exercise.

2. Exercise

2.1. *Outline*

This exercise has been conducted as part of the exercises for the "Joint Graduate School Intelligent car, Robotics & AI" [8]. This joint graduate school has been the collaboration between the University of Kitakyushu, Waseda University, and our university since 2019 (The previous joint graduate school began in 2009). This exercise is a short, intensive two-week course, and students taking part include not only students from joint universities but also students from National College of Technology and bachelor students from other universities. This year period is the first year that this exercise has been conducted.

In this exercise, we hold lectures and practices on system development to develop an autonomous driving system for a tractor equipped with an autonomous driving unit, as shown in Fig. 1 and Fig. 2. The hardware required for the system configuration, the mini-tractor, tablet, and autonomous driving unit, are provided. Students try to learn their understanding of mechatronics, semiconductor devices, and communications through lectures and acquire the method for developing applications, sensing, and motion control to realize an autonomous driving system through practice.

2.2. *Mechatronics exercise*

In the mechatronics exercises, students practiced turning on LEDs using digital I/O and PWM, acquiring sensor values using A/D conversion and UART communication, and controlling servo motors by circuits with Arduino microcomputers, which are also used in the autonomous driving unit. We also hold practice analog circuits using operational amplifiers and full-bridge motor drive circuits using FETs to understand the semiconductor devices used in the exercise. Additionally, we hold lectures and practice on network communications used in the exercise.

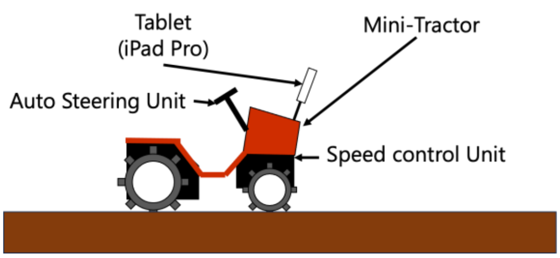

Fig. 1 Overview of autonomous driving system

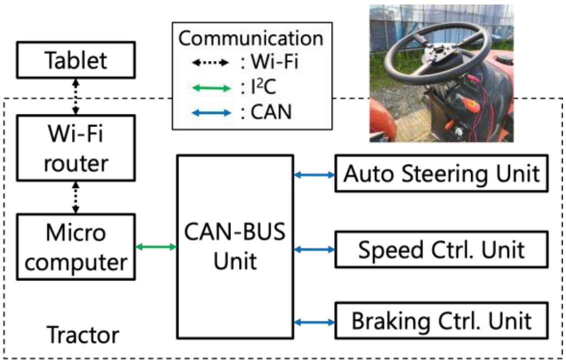

Fig. 2 Hardware configuration of the system

2.3. *System development exercise*

In the developing system, we use Unity, which is used to develop Augmented Reality (AR) applications. In this environment, we write code by C# as the programming language, so we carry out some basic exercises using this language. The exercises on developing an autonomous driving system are conducted in three parts: exercises on the programming language used in the development environment, exercises on handling sensor information on tablet devices, and exercises on implementing autonomous steering and obstacle detection. As the next step, we carry out an exercise to acquire sensor information on the application: the tablet's self-position and posture and depth images obtained from the LiDAR sensor installed on the tablet. The acquired information is displayed on the application screen, as shown in Fig. 3, and an exercise is carried out to use it on the application. As the final step, we carry out exercises on the algorithms for autonomous steering and obstacle detection that are necessary to realize an autonomous driving system. We explain and practice the Pure pursuit method [9], which is widely used in the field of autonomous driving for the autonomous steering algorithm and a nearest point search using a depth image for the obstacle detection algorithm.

2.4. *Final exercise and demonstration*

As the final practice of this exercise, the students are divided into some groups to develop an autonomous driving system for a tractor and then to demonstrate and present their development. The course for the demonstration is shown in Fig. 4. In this course, the following three tasks are set on the course so that the content of the previous exercises can be applied.

1. Autonomous steering near target points
2. Autonomous obstacle avoidance
3. Autonomous stopping around starting position

In task 1, the tractor is required to pass through the position outside of the two specified positions. In task 2,

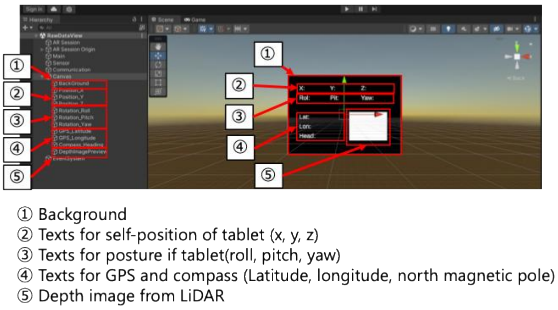

Fig. 3 Example of application GUI

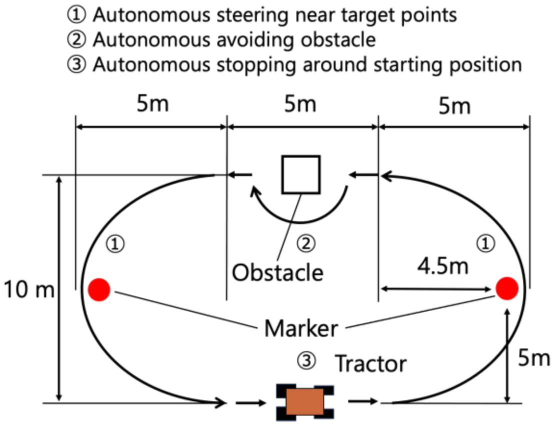

Fig. 4 Overview of course for demonstration

the tractor is required to move while avoiding obstacles that are randomly placed within a certain range. In task 3, after completing tasks 1 and 2, the robot is required to return to the starting point and stop. The evaluation criteria and scores for the demonstration are shown in Table 1. The maximum total score of tasks is 50. The score of task 1 is evaluated for each target point. In this exercise, students tested the system they had developed in their groups on the course set up outdoors, as shown in Fig. 5.

Table 1 The evaluation criteria and scores

Task	Criteria	Score
1	Passing outside the target position	+15
	Passing inside the target position	+10
	Going off the course	0
2	Success of obstacle avoidance	+10
	Success of stopping	+5
	No avoiding or stopping	0
3	Stopping inside of the area	+10
	Stopping outside of the area	+5
	No stopping	0

Fig. 5 Demonstration practice on the course

3. Results

3.1. *Demonstration results*

Table 2 shows the demonstration scores. The number of groups in this exercise was three, and each team had between three and four members. As a summary of the demonstration results, Group 3 completed all of the tasks. The other groups found it difficult to complete task 1-1. In addition, one of the tasks in this exercise was creating the application's GUI. The students used the development methods they had learned in the exercise to devise and implement the functions necessary for the autonomous driving system, such as displaying the tractor's current status and setting parameters for autonomous driving.

3.2. *Proficiency evaluation by rubric*

In this exercise, the proficiency of the students is evaluated using a rubric. The survey using the rubric is conducted before and after the exercise. The students evaluate their own proficiency on each item of the rubric on a four-point scale: Novice (N), Intermediate (I), Proficient (P), and Distinguished (D). The items of the rubric for this exercise are listed below. The result of the rubric is also shown in Table 3.

1. Proficiency of embedded microcontrollers and surrounding electronic circuits
2. Proficiency of sensing technology
3. Proficiency of programming for developing an application
4. Proficiency of technology related to autonomous driving for tractor

Table 2 The score results of the demonstration

Group	Score				
	1-1	1-2	2	3	Total
1	0	0	0	0	0
2	10	0	0	0	10
3	15	10	10	5	40

Table 3 The results of the rubric survey

Contents	Proficiency [%]			
	N	I	P	D
1-before	82	0	9	9
1-after	0	73	9	18
2-before	73	18	0	9
2-after	0	73	18	9
3-before	100	0	0	0
3-after	0	18	36	46
4-before	91	9	0	0
4-after	9	9	27	55

4. Discussion

The result of the demonstration showed that Group 3 had successfully completed all of the tasks. Group 2 was unable to complete all of the tasks in the demonstration due to communication problems, but they completed all of the tasks in the practice for the demonstration. We think that the difficulty level of the tasks on the demonstration was appropriate because the result is not that not all of the teams could complete all the tasks or all the tasks easily. We think the tasks will be necessary to set something closer to tractor-based farming tasks while maintaining this difficulty level.

The results of the rubric showed that the progress of the students' proficiency through the exercises resulted in a significant increase in the items related to programming for tablet applications (Item 3) and technology related to autonomous driving systems (Item 4). In this exercise, these two items are particularly required for developing an application for the demonstration. Therefore, we think that the students' proficiency increased as they progressed with the development. The level of proficiency in embed computer and electronic circuits (item 1) and sensing (item 2) increased less than the two items above. We think this is because we provided packaged versions of the autonomous driving unit and tablet sensor acquisition program. Therefore, there were not many opportunities to apply the knowledge in application development. In order to improve these skills, teaching materials and tasks that can be applied to all contents. However, an autonomous driving system requires many underlying technologies, and time available for exercise is limited. For this reason, we think discussing the packaging of teaching materials and assignment settings is necessary based on the above contents.

5. Conclusion

In this paper, we have designed and carried out exercises on the subject of an autonomous driving system for a tractor and evaluated the results, with the aim of developing human resources who can develop autonomous tractor driving systems that are easy for agricultural workers to install. The demonstration results showed that the students' difficulty level was able to set appropriate difficulty. The results of the rubric also showed that the students improved their proficiency in the algorithms and programming of applications that are fundamental to autonomous driving systems. The future works are considering the demonstration tasks closer to farming work using a tractor and the scope of packaging teaching materials for the underlying technology involved in an autonomous driving system.

Acknowledgements

This exercise have been supported by the Subsidy for Advanced Human Resources Development Projects in the Field of Car Electronics, etc. by City of Kitakyushu and Kitakyushu Foundation for the Advancement of Industry, Science and Technology (FAIS).

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