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Autonomous Traveling Control of Crawler-Type Mobile Robot for Supporting Agricultural Work

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Abstract

This paper describes an autonomous human-following control algorithm for a crawler-type mobile robot that works with an agricultural worker. To support an agricultural worker harvesting and transporting crops, the robot must follow the worker. The robot reduces the burden on agricultural workers by transporting crops. Therefore, we have developed a crawler-type mobile robot. In order to detect the worker and identify its own position, the robot senses around itself using only a laser range finder as an environmental recognition sensor. We propose an autonomous human-following control algorithm that can follow the worker automatically. The usefulness of the proposed control algorithm is demonstrated by experimental results using our developed crawler-type mobile robot.

1. Introduction

Agricultural workers in Japan are aging and their number is decreasing.[1] Agricultural work includes many heavy tasks such as spraying pesticides, harvesting, and transporting crops. Moreover, it is difficult to employ new workers because of the unstable income. Therefore, it is necessary to produce crops at large-scale farms efficiently. However, it is difficult to manage large-scale farms with a few workers. With this background, agricultural automation has attracted attention for cost reduction and ensuring a stable yield.

To solve these problems, several types of agricultural robot have been researched and developed [2]. Most of the robots were developed to move and work autonomously, such as for automatic harvesting. However, these harvesting robots do not have satisfactory performance because they can not work as fast as humans. Therefore, the concept of cooperation between a human and a robot has been proposed. That is, robots that support agricultural tasks such as harvesting and transportation are required. To achieve this, robot motion to follow a worker is essential in various scenes. In order

to realize such motion, some developed robots use cameras to recognize the worker [3], [4]. However, in outdoors environments such as farms, the brightness of the surroundings changes greatly with the time of day, so the detection accuracy may decrease when using cameras.

In this paper, we develop an agricultural mobile robot which is driven by a crawler mechanism. A laser range finder (LRF) is mounted on the mobile robot to detect obstacles and people surrounding the robot. Moreover, off-road traveling capability is required since tracks on a farm may not be paved. Here, as an example of farm tasks, we consider support in harvesting and transportation works, and propose a human-following control algorithm for the robot so that it can follow a worker requiring support in these tasks. Experimental results using our developed crawler-type mobile robot demonstrate the usefulness of the proposed control algorithm.

2. Crawler-Type Mobile Robot

Figure 1 shows the appearance of the developed electric crawler-type mobile robot, which has an LRF to detect objects in front of it. The top of the robot is flat so that a harvesting module or transporting container can be mounted. Specifications of the robot are listed in Table 1. The total size of the robot was determined in consideration of the traveling lane width in a large-scale greenhouse.

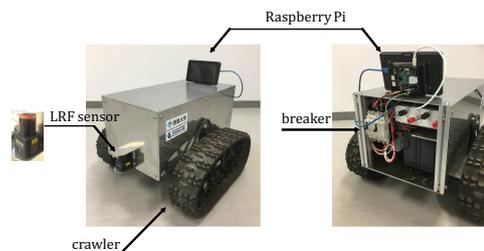


Figure 1: Developed electric crawler-type mobile robot

Table 1: Specifications of developed robot

Size	600 (W) × 600 (L) × 400 (H) mm
LRF	HOKUYO, UST-10LX
Motor	Nissei, VHLD28L/R-20N400L2
Battery	Lead acid, 24 V, 24 Ah
Main computer	Raspberry Pi 3 Model B

The left and right crawlers of the robot are independently driven by brushless DC motors with gears and mechanical chains.

Figure 2 shows the hardware system configuration of the robot. A single-board Raspberry Pi 3 computer is mounted on the robot to control the motors and process the distance data measured by the LRF. The LRF is mounted in the front of the robot and can measure the distance between the robot and objects in each direction by infrared rays. Specifications of the tested LRF are listed in Table 2. The Raspberry Pi 3 processes the information of the LRF and outputs it as a speed reference to the motor driver. In this study, the robot uses only the LRF to detect and follow a human.

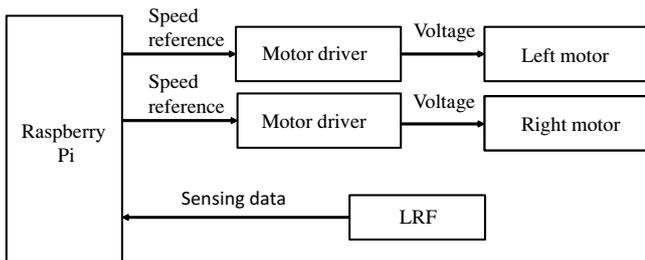


Figure 2: Hardware system configuration

Table 2: Specifications of tested LRF

Detecting range	0.06 – 10 m
Light wavelength	905 nm
Detection accuracy	40 mm
Scanning angle range	270°
Angular resolution	0.25°
Scanning time	25 ms

3. Human Following System

In harvesting work, the robot is required to follow the worker while keeping a fixed distance. Therefore, we developed an autonomous human-following system based on only measurement data of the LRF. In the human following motion, it is necessary to distinguish human legs and other ob-

jects using by the LRF data. The LRF is mounted at a height of 200 mm in front of the robot as shown in Fig.1.

3.1 Leg detection method

In order to detect the distance and direction of human legs in polar coordinates with the origin at the robot, the measured distance and direction data of the LRF are labeled for each object. In the labeling process, it is assumed that two neighboring data with a distance of 30 mm or less from each other are the same object. The size of the object is calculated from the average distance \bar{l} and angle width ϕ of the measured data to distinguish human legs from other objects. Here, the size of the object w is approximated by the length of the arc as

$$w = \bar{l} \times \phi \quad (1)$$

In this paper, we assume that the human leg has a diameter of 100 to 300 mm depending on the detection angle. Therefore, we categorize objects with sizes of 100 to 300 mm as legs and sizes of less than 100 mm and over 300 mm as obstacles.

3.2 Human following control algorithm

In order to follow human legs, we propose a human-following control algorithm whose concept is shown in Fig.3. The control algorithm consists of five fundamental types of motion: forward, stop, backward, turn left, and turn right. The robot switches between these types of motion based on the position of the nearest leg from the robot in order to keep distance of 0.65 to 0.75m from the neasest human leg.

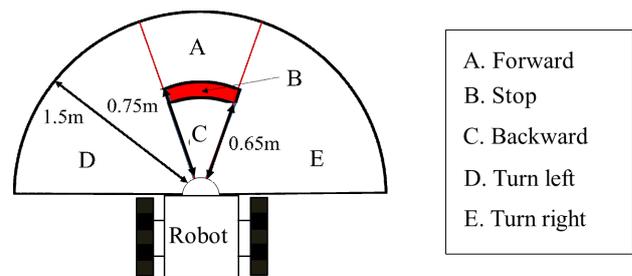


Figure 3: Concept of human following control algorithm

In Fig.3, if a human leg is located area A, the robot advances and approaches the leg until the leg enters area B as shown in Fig.4(a). Moreover, if the human approaches the robot so that the leg is located in area C, the robot moves backward until the leg is no longer area C as shown in Fig.4(c). Moreover, when the robot detects a human leg in area D or E, it robot changes direction by spinning to the left or right the robot changes the direction by spinning to left or right until the human legs is positioned forward area A, B or

C.2 When a human leg is located in area B or the robot does not detect any human legs in the detection range of 1.5 m, the robot stops as shown in Fig.4(b).

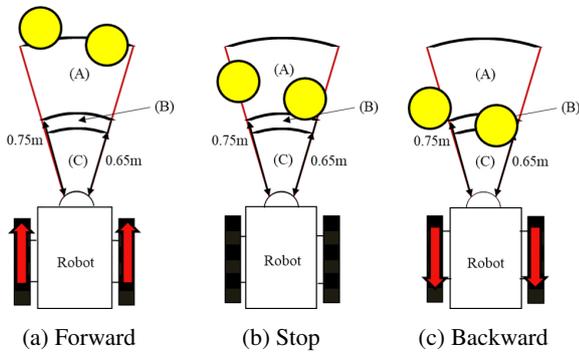


Figure 4: Examples of fundamental motion

4. Experimental Results

4.1 Test field

In order to confirm the validity of the proposed control algorithm, we prepared the test field shown in Fig.5. Four poles with a diameter of 2 cm, which is smaller than a human leg, are arranged at the four corners of a square of side 1.2 m. These poles simulate agricultural materials which are frequently used in a general greenhouse.

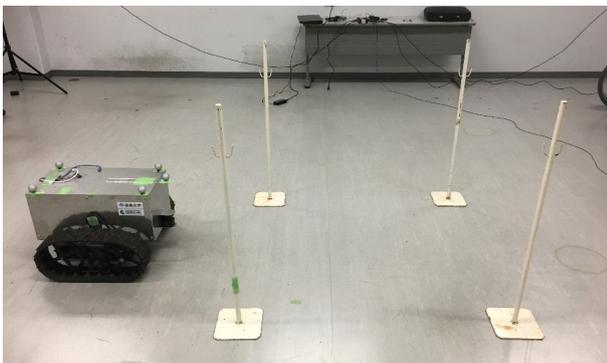


Figure 5: Test field for experiment

4.2 Distance-maintaining performance

In the proposed algorithm, the robot distinguishes human legs from other objects by the size, and detects only objects with the size of human legs. To confirm the distance-maintaining performance, a running test was conducted.

The sequence of the experiment is as follows: (a) stand 1.5 m in front of the robot, (b) move for 1.0 m away from the robot, (c) move 1.0 m toward the robot, (d) and (e) move 1.0

m away from the robot then move 1.0 m toward it. Here, each sequence takes about 5 and is executed at intervals of about 5 s.

Figure 6 shows the distance of both the robot and the human legs from the reference point (the initial position of the robot). These data were measured by using the OptiTrack motion capture system, which can capture markers on a human and robot and calculate distance between the reference point and each marker. Figure 7 shows the control commands (1: forward, 0: stop, -1: backward) and the distance between the robot and the nearest human leg measured by the LRF mounted on the robot. In sequence (a), the robot approaches the leg after the distance from the leg becomes less than 1.5 m, and stops, keeping the distance from the leg at 0.75 m. In sequences (b) and (d), the robot follows the leg, keeping a distance from the leg of 0.75 m, when the leg moves away. Conversely in sequences (c) and (e), the robot from the leg to keep the distance at 0.65 m when the approaches. From the experimental results, we confirmed that the robot can follow a human leg during human motion. In addition, it is confirmed that the robot can maintain an almost constant distance from the leg of between 0.65 and 0.75 m in a steady state.

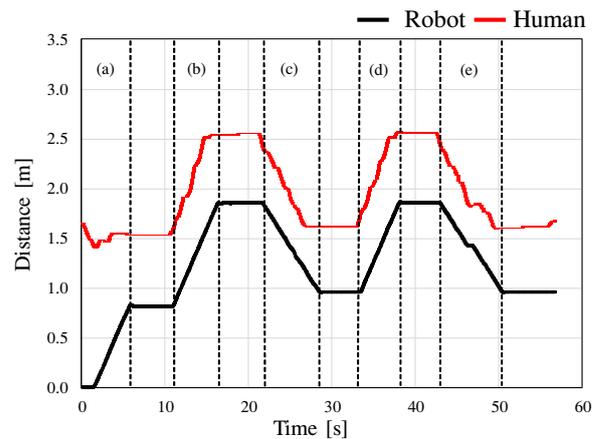


Figure 6: Responses during distance-maintaining control

4.3 Human-following control performance

Figure 8 illustrates the route from point 1 to point 4 walked by a human in the experiment. In this situation, the robot needs to recognize the human leg with certainty, since there are four poles as obstacles, and to follow the human so that the distance between the robot and the human leg is maintained in the desired length range (0.65-0.70 m).

Figure 9 shows trajectories of the human legs and the robot. These data were measured by the motion capture system. Here, the trajectories of the human legs are not continuous because the cameras have blind spots due to the posture of the human. The results confirmed that the robot can au-

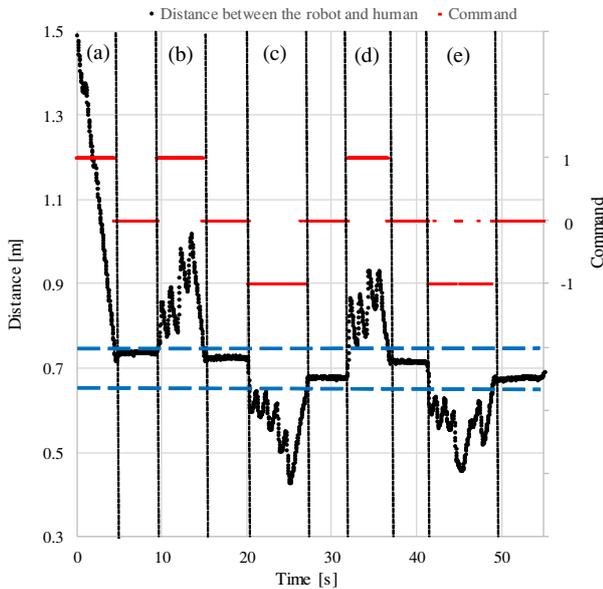


Figure 7: Distance data of LRF

tonomously follow the human leg while ignoring the pole-shaped obstacles. However, it seems that the rotation radius of the robot trajectory is smaller than that of the human. In response to the curved trajectory of the human, the robot moves inside the curve, since the robot always faces the nearest leg in the control algorithm. Therefore, it is necessary to design a control algorithm that can follow the trajectory of a human so that the robot can be used in a greenhouse with many obstacles and narrow passages.

5. Conclusions

In this study, we developed an electric crawler-type mobile robot for supporting agricultural work and also proposed a human-following control algorithm. From several experimental results, we confirmed that the robot can follow a human while keeping a certain distance by using the proposed control algorithm. However, currently the robot only has the function of following a human. Future tasks are to implement an obstacle avoidance function while following a human so that the robot can detect obstacles on paths in a greenhouse and realize autonomous traveling while avoiding collisions.

References

- [1] Ministry of Agriculture, Forestry and Fisheries in Japan: http://www.maff.go.jp/j/wpaper/w_maff/h23_h/trend/part1/.
- [2] N. Nakao, H. Suzuki, T. Kitajima, A. Kuwahara and T. Yasuno: Path planning and traveling control for pesticide-spraying robot in greenhouse, *Journal of Signal Processing*, Vol. 21, No. 4, pp.175-178, 2017.

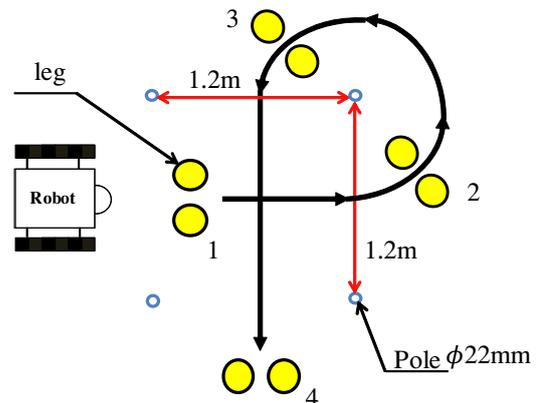


Figure 8: Reference route used in experiment

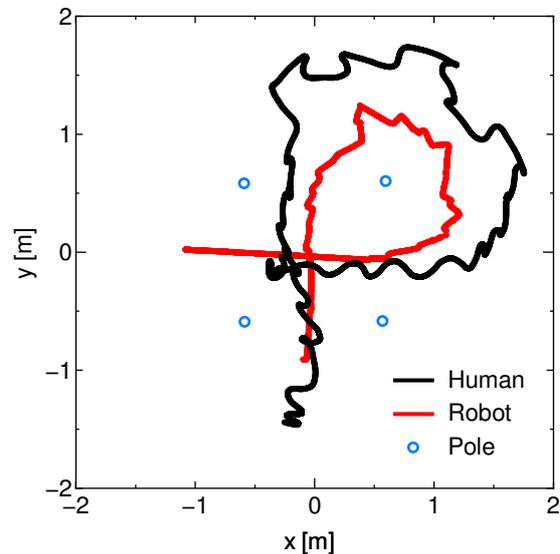


Figure 9: Trajectories of human legs and robot

- [3] Y. Tarutomo, K. Watanabe and K. Kobayashi: Development of human tracking algorithm for human following mobile robot, *21st Fuzzy System Symposium*, pp.842-847, 2005.
- [4] Y. Isobe, G. Masuyama and K. Umeda : Target tracking with a mobile robot based on detection of illumination variation using automatic adjustment of a stereo camera, *21st Robotics Symposia*, pp.68-73, 2016.