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Development of a Weed Suppression Robot for Rice Cultivation: Weed Suppression and Posture Control

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***Abstract*—**Weed suppression and weeding are necessary measures for rice cultivation. Weed suppression precedes the process of weeding. It means suppressing the growth of young weeds and creating a weed-less environment. If we suppress the growth of weeds, we can reduce the number of weeds in a paddy field. This would result in a reduction of the weeding work load.

In this paper, we will show how we developed a weed suppression robot for the purpose of reducing the weeding work load. The robot has a laser range finder for autonomous mobility and a robot arm for weed suppression. It travels along the rice rows without stepping on and injuring the rice plants in a paddy field. The robot arm applies force to the weed seedlings and thereby suppresses the growth of weeds. This paper will explain the methodology of the autonomous mobile, the experiment in weed suppression, and the method of controlling the robot's posture on uneven ground.

***Keywords*—**Mobile robot, Paddy field, Robot arm, Weed.

I. INTRODUCTION

IN recent years, people have become increasingly conscious about food safety. The safety of the rice which we usually eat is gathering attention too. It is said that organic farming is one of great farming methods because it does not use weed killers or chemical fertilizers. However, in organic farming, farmers must remove weeds with their hands. It is very laborious work for them. Also, we heard from some farmers that animals damage rice plants at night. Therefore, the development of an agricultural management robot which helps organic farming is required and it needs to be movable both day and night.

Kameyama developed an agricultural management robot which has a floater and small wheel as a transfer mechanism [1]. This robot can remove weeds in inter-row spacing, but cannot remove weeds in intra-row spacing. Therefore, we propose removing weeds by using a robot arm. The robot arm is able to remove weeds in both inter-row and intra-row spacing because we can freely control the robot arm.

On the other hand, many researchers developed weeding robots which have autonomous mobility by means of image processing [2]-[7]. However, these robots cannot work in a paddy field at night because image processing requires light. Therefore, we propose an autonomous mobile method which operates by means of a laser range finder (LRF). The LRF does not require light because it has an optical distance sensor. Our robot can work in a paddy field in daytime and nighttime by means of an LRF. As a study of LRFs, Lee et al. surveyed characteristics and performance of LRFs [8].

II. WEED SUPPRESSION ROBOT

The robot consists of two DC motors, an LRF, an azimuth sensor, an ultrasonic sensor, a tilt sensor, seven servo motors (to provide posture control for the LRF, stereo camera and the robot arm), two microcomputers, and a Bluetooth system (to wirelessly connect the remote control and the data collection to the PC). LRF data, such as sensor information obtained by robot, is transmitted to the PC via Bluetooth. The data is processed in the PC and the robot control information is then transmitted to the robot. The robot autonomously travels while avoiding rice plants in accordance with the received control information.

The robot recognizes the rice plants by means of its LRF, and can move autonomously in a paddy field in daytime and nighttime. In addition, the robot can be operated by remote control with a PC. The operator looks at the image of the stereo camera on the PC screen and operates it by using the PC's keyboard. The robot can suppress the growth of the weeds by using the robot arm and it can also weed a paddy field. The robot controls the robot arm and can apply appropriate force to the weeds as it has three degrees of freedom (Fig. 1).

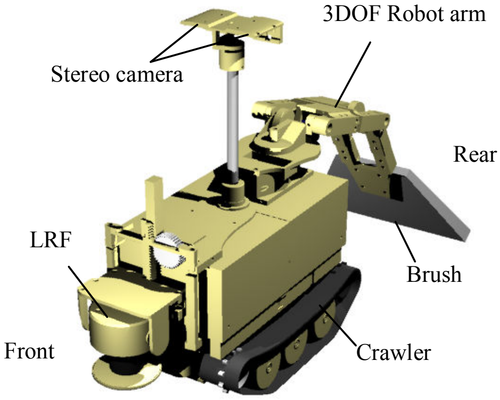

Fig. 1 Overall 3D design of the weed suppression robot

Table I shows specifications of the weed suppression robot.

TABLE I
SPECIFICATIONS OF THE WEED SUPPRESSION ROBOT

Quantity	Value
Length (with robot arm)	400mm (870mm)
Width (with robot arm)	190mm (310mm)
Height (with stereo camera)	250mm (700mm)
Crawler belt width	56mm×2
Weight	5.76kg

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III. AUTONOMOUS MOBILE METHOD

It is necessary for the weed suppression robot to have 24-hour mobility in paddy fields. Therefore, the robot uses the URG-04LX laser range finder made by Hokuyo Automatic Co., Ltd. It does not require lighting apparatus at night. The weed suppression robot gets data on the position of the rice plants from the LRF and decides on a path that does not come in contact with rice plants.

We use the potential method [9] in order to attain autonomous mobility. This method involves the attraction of repulsion of an obstacle to the target position. The overlapping plurality of this attraction and repulsion determines the path to the target position which avoids the obstacle.

In a potential method using rice row data, the obstacle is the detection point of rice plants by LRF and target position is considered to be the center of an appropriate distance between the rows of rice plants from the robot.

$$U = \begin{cases} 0 & \text{for } d > S \\ \frac{S-d}{S-R} \times G & \text{for } R < d \leq S \\ \infty & \text{for } d \leq R \end{cases} \qquad (1)$$

Here, U denotes the magnitude of the resultant response vector. S is the radius of the repulsion to occur from the obstacle, R is the radius of the obstacle, d is the distance to the obstacle from the robot, and G is gain. Transfer pathway of the robot is in a direction away from the obstacle.

The target transfer pathway is obtained from the data of the left and right rice rows, and the center of the rice row between the rows of rice plants is found using the “least squares” method. Next, we calculated the combined force of attraction and repulsion. Also, we can display the movement path of the robot on the PC display from the calculated data. We displayed the result of the potential method to a PC using OpenGL. It confirmed that there was no contact between the robot and rice plants, as can be seen in Fig. 2.

We considered the movement control using the potential method. By controlling the duty ratio of the left and right motors from the angle of the resultant force of the robot center obtained by potential method, the robot performed straight, right turn, left turn, and changes in the direction of travel.

IV. WEED SUPPRESSION EXPERIMENT

We heard from a rice farmer that we can easily suppress the growth of weeds and the kill them by applying force to the weed seedlings. In this study, we verified the effect of weed suppression and the number of times of effective weed suppression needed to be carried out in one week. We made an indoor paddy field for this experiment (length is 1630 mm, width is 1020 mm).

We set out the rice plants at the same intervals as would be found in a real paddy field (Fig. 3). The inter-row spacing where the robot runs was 300mm; the intra-row spacing was 150mm. The water level was 50mm and the room temperature was 24 degrees Celsius. We used two metal halide lamps in place of natural sunlight.

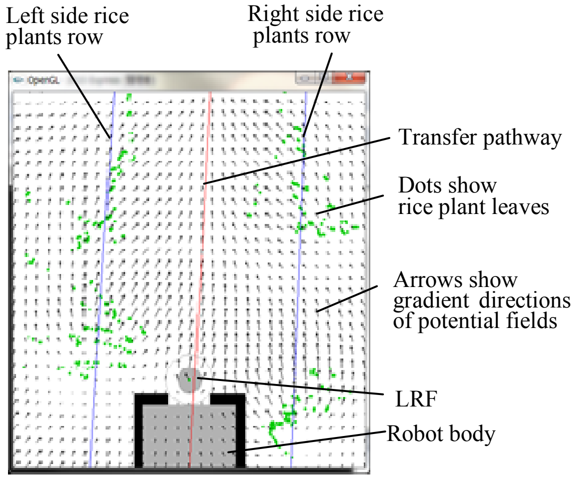


Fig. 2 Graphics of the potential method

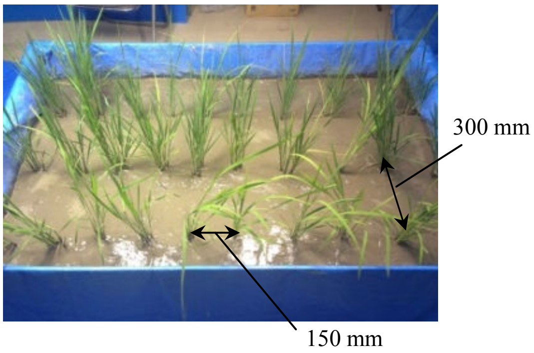


Fig. 3 Indoor paddy field

The weed suppression robot applies force to weeds by means of crawlers and a brush for weed suppression. Crawlers can only apply force to inter-row spacing of weeds but the brush apply force to all weeds in the paddy field because it is wider than the inter-row spacing (the width of the brush is 310 mm). In addition, because the brush is soft, the robot does not injure the rice plants even if the brush comes in contact with them.

In this experiment, the robot runs along only the left inter-row spacing in the indoor paddy field (Fig. 4). It does not run along the right inter-row spacing. We made a comparison of the left inter-row spacing, which was subjected to weed suppression, and the right inter-row spacing which was not subjected to weed suppression, and we confirmed the effect of weed suppression.

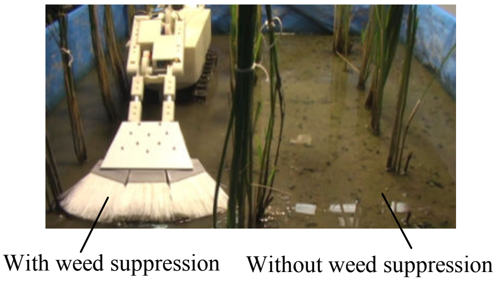
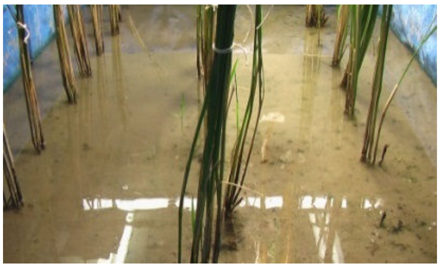
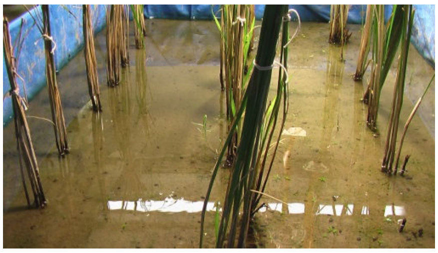


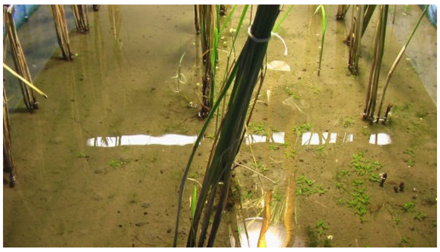
Fig. 4 Weed suppression experiment



(a) Initial state



(b) State after one week



(c) State after two weeks

(d) State after one month

Fig. 5 Changes in surface of the paddy field

Over one month, we performed weed suppression once a week with the weed suppression robot. In the first instance, there was comparatively little difference between the amount of weeds produced with weed suppression and the amount produced without weed suppression. However, when we performed weed suppression with the robot twice a week for one month, there was a clear difference in the amount of weeds produced with and without weed suppression.

Fig. 5 shows changes on the surface of the paddy field when we performed weed suppression with the robot twice a week for one month. Fig. 5 (a) shows the initial state of the weed suppression experiment. Fig. 5 (d) shows the state after one month of the weed suppression experiment. In the initial state, most of the weeds do not grow. In the area where weed suppression did not take place, the weeds grew and filled in the surface of the paddy field. However, in the area where weed suppression did take place, almost none of the weeds grew.

From these experimental results, we confirmed that the robot can suppress the growth of weeds by means of crawlers and a brush when weed suppression takes place twice a week.

V. POSTURE CONTROL IN UNEVEN GROUND

When the robot moves over uneven ground, it is liable to incline. This inclination may affect the function of the LRF and the robot arm.

In particular, the robot cannot detect the rice plants when the LRF is inclined as shown in Fig. 6. In this case, the robot does not have autonomy of movement. In addition, the brush tip of the robot arm rises from the surface of the paddy field when the robot is inclined, as shown in Fig. 6, which results in the robot being unable to apply force to the weeds.

Therefore, it is necessary to perform the posture control of the LRF and the robot arm when on uneven ground.

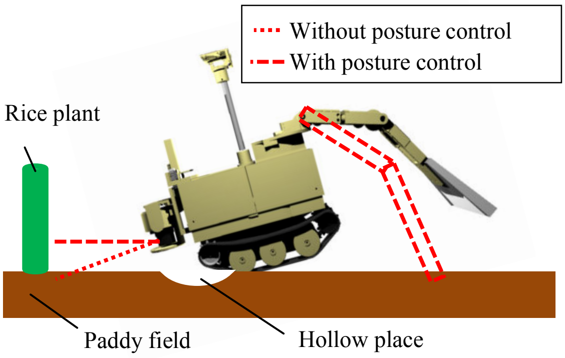


Fig. 6 The robot's posture in uneven ground

The robot measures its pitch angle (θ_p) with a tilt sensor and drives servo motors for posture control of the LRF and the robot arm.

We used an ADXL311JE made by Analog Devices Inc. as a tilt sensor. It is a low power, complete dual-axis accelerometer with signal conditioned voltage outputs, all on a single monolithic IC. When the sensor is oriented so both its X-axis and Y-axis are parallel to the earth's surface, we can use it as a two-axis tilt sensor with a roll axis and a pitch axis. The output tilts in degrees are calculated as follows:

$$\theta_p = sin^{-1}\left(\frac{V_{xout}-\frac{V_{cc}}{2}}{0.167}\right)\times\frac{180}{\pi} \quad (2)$$

$$\theta_r = cos^{-1}\left(\frac{V_{yout}-\frac{V_{cc}}{2}}{0.167}\right)\times\frac{180}{\pi} \quad (3)$$

Here, θ_p is the pitch angle. θ_r is the roll angle. Vx_{out} is the output voltage of X-axis. Vy_{out} is the output voltage of Y axis. V_{cc} is the power supply voltage.

When we give the LRF rotary control of $-\theta_p$, its sensing plane is parallel to the surface of the paddy field. Conversely, the kinematical expression of the robot arm is calculated as follows:

$$x' = \sqrt{{l_1}^2 + {l_2}^2}\, cos\left(\theta_p + tan^{-1}\left(\frac{l_2}{l_1}\right)\right) - l_1 \tag{4}$$

$$z' = \sqrt{{l_1}^2 + {l_2}^2}\, sin\left(\theta_p + tan^{-1}\left(\frac{l_2}{l_1}\right)\right) - l_2 \tag{5}$$

$$\begin{bmatrix} x_c \\ z_c \end{bmatrix} = \begin{bmatrix} cos\,\theta_p\,(x - x') - sin\,\theta_p (z - z') \\ sin\,\theta_p\,(x - x') + cos\,\theta_p\,(z - z') \end{bmatrix} \tag{6}$$

$$\theta_1 = tan^{-1}\left(\frac{x_c}{y}\right) \tag{7}$$

$$\theta_2 = cos^{-1}\left(\frac{a_2^2 - a_3^2 + \left(\sqrt{{x_c}^2 + y^2} - a_1\right) + {z_c}^2}{2a_2a_3\sqrt{\left(\sqrt{{x_c}^2+y^2} - a_1\right)^2 + {z_c}^2}}\right) \pm tan^{-1}\left(\frac{z_c}{\sqrt{{x_c}^2+y^2} - a_1}\right) \tag{8}$$

$$\theta_3 = \pm\left(\pi - \cos^{-1}\left[\frac{a_2^2 + a_3^2 - \left\{\left(\sqrt{{x_c}^2+y^2} - a_1\right)^2 + {z_c}^2\right\}}{2a_2a_3}\right]\right) \tag{9}$$

Here, θ_1 is the joint angle of the swivel axis as shown in Fig. 7. θ_2 is the joint angle of the upper arm. θ_3 is the joint angle of the fore arm. a_1 is the length of the swivel axis. a_2 is the length of the upper arm. a_3 is the length of the fore arm and end effecter. l_1 is the length from the robot's rotary axis to the bottom of the robot in the vertical direction of the swivel axis. l_2 is the height from the bottom of the robot to the swivel axis. x is the X coordinate of the robot arm's tip, y is the Y coordinate of the robot arm's tip and z is the Z coordinate of the robot arm's tip.

When the robot is inclined, x' is displacement of the swivel axis's X coordinate from the world coordinate and z' is the displacement of the swivel axis's Z coordinate from the world coordinate. x_c is the X coordinate of the target position. z_c is the Z coordinate of the target position.

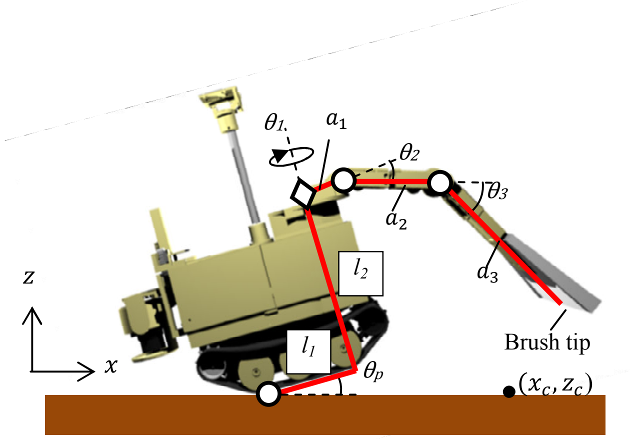


Fig. 7 Parameters for posture control of the robot arm

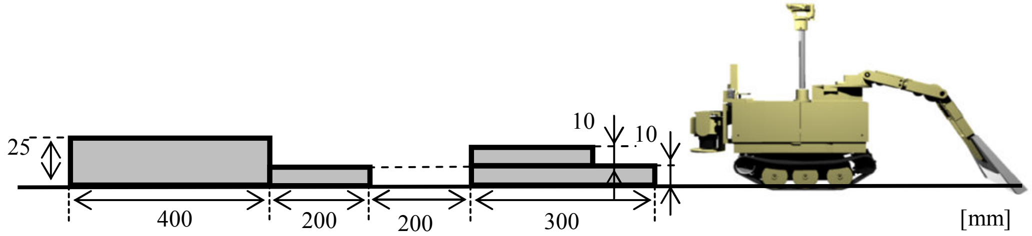
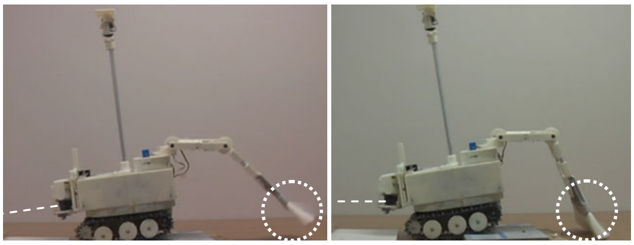


Fig. 8 Posture control preliminary experiment

Fig. 8 shows an experiment of the posture control of the robot and Fig. 9 shows its results. Fig. 9 (a) shows the robot without posture control, and Fig. 9 (b) shows it with posture control. From Fig. 9 (b), we confirmed that the LRF keeps parallel to the ground by posture control if the robot is inclined. In addition, we confirmed that the brush tip of the robot arm came in contact with the ground.

From this result, we realized the robot can perform the posture control of the LRF and the robot arm in a paddy field with uneven ground.



(a) Without posture control (b) With posture control

Fig. 9 Results of the posture control preliminary experiment

Fig. 10 shows the change in the robot's inclination (θ_p) and its arm's joint angle with posture control in the preliminary experiment. Here, θ_1 is always 0 because we consider the control of the pitch angle. When θ_p changes, θ_2 and θ_3 are found by a microcomputer in the robot and the robot moves its arm to the target position on the basis of the θ_2-value and the θ_3-value.

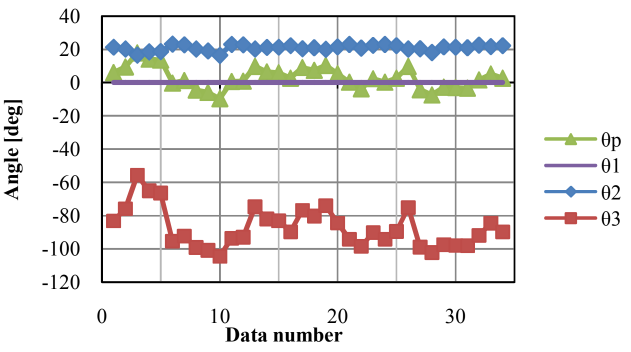


Fig. 10 Change of the robot's pitch angle and the robot arm's joint angles with posture control in the preliminary experiment

We then performed an experiment on the posture control of the robot arm in the paddy field (Fig. 11). We confirmed that the brush tip of the robot arm came in contact with the weeds in the field even if the robot inclined.

Fig. 11 Experiment of the posture control in paddy field

VI. CONCLUSION

In this paper, we developed a weed suppression robot for rice cultivation. We proposed a weed suppression method by means of a robot arm, an autonomous mobile method enabled by LRF and posture control on uneven ground.

The robot arm can suppress the growth of weeds by applying force to the weeds twice a week. By using LRF scanning obstacle data and a potential method, we confirmed the stability of the autonomous mobile and obstacle avoidance in the paddy field. We performed posture control of the LRF and the robot arm, and confirmed the efficacy of the posture control.

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