Feasibility Study of Weeding Robots in Rice Fields Inspired by Natural Ducks

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ABSTRACT

The objective of this research project is to develop a robotic weeding system for rice fields that will enable chemical-free rice farming, giving us safer and more valuable rice. We take the approach of moving a large number of robots around the field, which prevents weed seeds from sprouting. This is inspired by an existing rice farming method that utilizes natural ducks. One of the major research issues is to develop a robot body and locomotion method that will have sufficient weeding ability when working in the field. This paper reports on the results of a feasibility study of our artificial duck robots in an actual rice field, in which the robots demonstrate sufficient mobility for successful weeding.

Categories and Subject Descriptors

I.2.9 [**Robotics**]: Autonomous vehicle

General Terms

Design

Keywords

Agricultural robot, loose soil, rug wheel

1. INTRODUCTION

There is recent awareness that food can be safer if no (or fewer) chemicals are used in farming, particularly for rice in some East Asian countries. This becomes feasible if we can remove weeds from rice fields without using chemicals, or at least prevent the weeds from sprouting. One such rice farming method is called natural duck farming. A group of ducks is released into a rice field, where they move around, stirring the soil with their feet. Weed seeds are kicked up and float on the water surface, thereby disrupting the conditions for weed sprouting. The principle of weeding by natural ducks is illustrated in Fig. 1 and is an established farming method. However, there are substantial costs in maintaining the ducks and the farmer cannot easily control where they move to and their direction of movement because they are living creatures.

The goal of this research project is to develop a robotic weeding system for rice fields. The task of the robots is simply to sweep the entire area of a rice field, traveling on wheels that are designed to dig into the soil to a sufficient depth and to stir the surface water, as shown in Fig. 2. We have three main research issues.

The first issue is to develop a wheel locomotion mechanism that can travel along the loose soil of a rice field. Because the wheels can easily slip and become stuck in loose soil, we need to design a suitable shape for the wheel and a corresponding control method. Furthermore, it is very difficult for the robots not to contact the rice plants, because the channels between rows of plants are very narrow. We therefore designed a small and light robot with special wheels that offer sufficient mobility for the rice field while not damaging the rice plants, even if the robot runs over them.

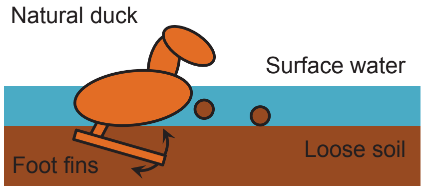

Figure 1. Weeding by a natural duck in rice field. The webbed feet f the natural duck kick weed seeds up from the loose soil to the water surface, preventing the weeds from sprouting.

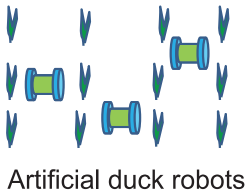

Fig. 2. Artificial duck robots in a rice field. The task of the robots is to sweep the entire area of the field, kicking up weed seeds frequently.

The second issue is to develop a robot body that is water and mud proof and easily maintained. This is because the robots will be used on actual farms and operated by farmers, who are not robot experts.

Finally, there is the issue of weeding ability. We have to test whether the robot-based method can really prevent weeds and its cost compared to other weeding methods such as natural duck farming.

The objective of this study was to investigate if a robotic weeding system using artificial duck robots can prevent the sprouting of weed seeds, in terms of the above three research issues. We have developed a robot locomotion system and body, we have tested them in an actual rice field and we can show that our robots have sufficient weeding capability. The details will be presented in the remainder of this paper.

First, however, we should refer to previous work involving agricultural robots in rice or paddy fields, such as a study using

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robots for weed detection [1] and others on robotic weeding [2, 3]. For weed detection and control, vision sensors have been introduced [4, 5]. However, these were for crop fields and are not applicable to rice fields with surface water.

One report [6] reviews the use of autonomous agricultural robots in Japan, including its rice fields. However, most robotic systems are directed to the automation of rice transplanting [7, 8, 9], rather than weeding.

One research project [10, 11] is similar to our approach, being inspired by natural duck farming. Their robot bridges each line of planted rice, moving carefully to avoid crossing the line of plants. This is because the robot is heavy and could damage the plants if it hits or runs over them. In contrast, our robot is designed to be small and light, which will avoid damage to plants if it runs over them. However, we had to design the body and wheels to avoid plant damage in addition to developing a wheel speed controller for smooth motion on loose soil.

2. BODY AND WHEEL DESIGN AND PRODUCTION

First, consider the robot structure. To meet the requirements of weeding, the robot should dig up the surface of the loose soil and stir the surface water. Therefore, the wheel should have a large contact area with the surface. However, too large a contact area could break up the loose soil, causing wheel slip, which would result in the robot being stuck in the field. Furthermore, the robots are moving in a rice field, where the rice plants are obstacles to the robots. Even if we design a wheel that can run over the rice plants, small robots would be preferable.

We have therefore developed the robot structure shown in Fig. 3. To keep the robot small, we have adopted a two-differential-wheel structure with a grounding bar, which prevents counter rotation of the body when the wheels encounter heavy loads. Each wheel has a set of horizontal bars, which provide a larger contact area than that for a narrow wheel, but less than that for a wide wheel. In addition, the gap between the bars is wide enough for a rice plant to be bent rather than damaged if the wheel goes over it. The overall structure is shown in Fig. 3.

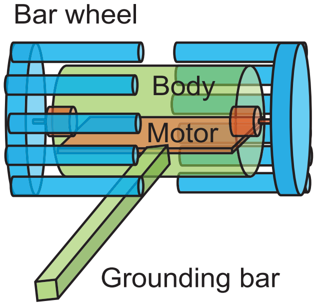


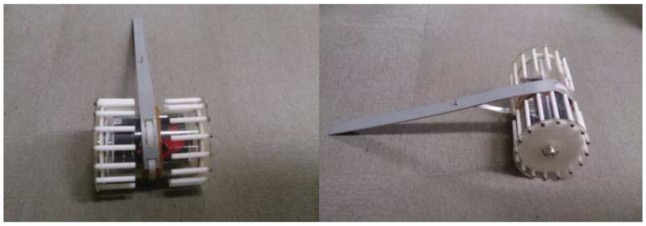
Fig. 3. Robot structure. The body shape is a cylinder with a grounding bar. At each end of the cylinder is a controllable wheel with a set of bars.

Following the identification of a suitable structure, our design principles call for a small lightweight robot. We can specify the robot dimensional constraints shown in Table 1. Furthermore, we have determined the required wheel torque and wheel speed, considering the robot weight and the robot working speed for weeding by field sweeping.

Table 1. Specifications for the weeding robot.

Item	Specification
Overall width between ends	< 220 mm
Wheel diameter	< 150 mm
Total weight	< 2 kg
Maximum wheel torque	> 15 kgf cm = 1.47 Nm
Maximum translational speed	> 0.3 m/sec

We have developed a robot meeting these specifications. It includes two geared DC motors for locomotion, an embedded CPU, a motor driver IC and a radio communication device, together with fixtures and assemblies. The cylinder body is made of a transparent acrylic material to enable observation of the status of the CPU and IC. The robot is controlled manually via a remote joystick. The wheel design enables changing to different numbers of bars or bars of different lengths. The robot has a rechargeable battery that works for 60 to 90 minutes after a full recharge. A snapshot of the robot is shown in Fig. 4. We will investigate the mobility of the robot in the next section.



(a)Front view of develop robot. (b) Front view of develop robot.

Fig. 4. Snapshots of developed robot.

3. VERIFICATION OF MOBILITY OF DEVELOPED ROBOT IN ACTUAL RICE FIELD

3.1 Overview of Verification Experiments in an Actual Rice Field

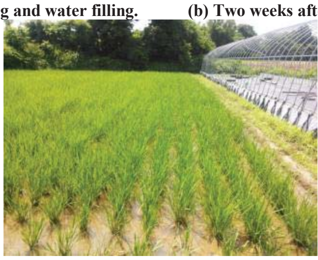
In 2013, we tested the robot in an actual rice farm. The field was located at Aizu-Wakamatsu city in Japan, and was about 20 × 20 m. It was available not only for testing the robot, but its rice was to be harvested in the autumn season as a real agricultural activity.

The sequence of activities involved the following dates, which are typical for rice farming:

1. Plowing and putting water in the field on May 12th and 13th in preparation for transplantation (see Fig. 5(a)).
2. Transplanting young rice plants into the field on May 15th and 16th. We start weeding, using the prototype robot, one week after transplantation, because we should wait for the growing roots of the young rice plants to be tough enough for robotic weeding.
3. The rice field two weeks after transplantation is shown in Fig. 5(b). The height of the plants is about 0.2 m.
4. The field six weeks after transplantation is shown in Fig. 5(c). The height of the plants is now about 0.4 m.

After that date, the robot is not used because the rice plants have grown sufficiently for no weeding to be needed. In actual duck farming, they would be kept out of the rice field. We operated the robot in the field twice a week over the six weeks, carrying out 13 runs in total.

(a) Just after plowing and water filling. **(b) Two weeks after transplanting.**



(c) Six weeks after transplanting.

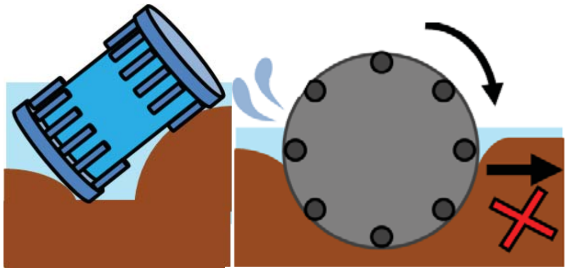
Fig. 5. Snapshots of the test rice field.

3.2 Before Transplanting

We tested the prototype robot with no rice plants before transplantation, to investigate the basic mobility of the robot. At that time, there was loose soil with 0.05 to 0.10 m of water above it. The robot can move around the field if the field is flat and the rods of the left and right wheels contact the soil to almost the same extent. This is shown in Fig. 6.

However, if there is a certain amount of slope, as shown in Fig. 7(a), the robot can get stuck because the left and right wheels are loaded differently, causing a differential slip. In such a situation, as it rotates, a wheel can dig into the soil, and the robot will be stuck, as shown in Fig. 7 (b).

Fig. 6. Snapshot of a robot run before transplantation.



(b) The robot encounters a sloping surface. **(a) A wheel digs into the ground.**

Fig. 6. Snapshot of a robot run before transplantation.

3.3 Two Weeks after Transplanting

To transplant the rice plants, a heavy automatic planting machine is employed, whereby the soil is being contacted and dug with a transplanting device, which loosens the soil. Furthermore, at this stage of rice farming, the field is filled with a large quantity of surface water. Therefore, the soil will be very loose and the robot can often slip. However, in practice, the design of the bar wheels enables them to retain a driving force for the robot. A snapshot of the robot is shown in Fig. 8.

One of the major interests at this stage is to see if young rice plants can recover if the robot runs over them. Figure 9 shows this situation. It appears that the plants have fallen over, but they have not been uprooted. Two days later, they have recovered and we cannot distinguish them from other plants. Therefore, our design for the robot and its wheels is validated. We surmise that the robot presses only lightly on the rice plants, because of the large contact area of the bars in the wheel, the light weight of the robot and the buoyancy force of the internally spacious cylinder body.

On the other hand, these robot operations were insufficient for weeding. We operated the robots twice a week, with each run covering one-third of the rice field. Figure 10 shows small weeds around the larger rice plants.

Fig. 8. Snapshot of a robot run two weeks after transplanting.

Fig. 9. A robot runs over the rice plants.

Fig. 10. Weeds in the rice field two weeks after transplanting

3.4 Six Weeks after Transplanting

Six weeks after the transplantation, the rice plants are nearly fully grown. At this stage, we reduce the surface water to a low level for farming reasons. Figure 11 is a snapshot of the robot at this time, showing that it is difficult for the robot to move around in the rice field because there is little room between plants for the robot. In addition, the robot cannot run over the rice plants because they are now too high and dense, as shown in Fig. 12. Therefore, this ends the weeding season for our robot.

Fig. 11. A robot six weeks after transplanting.

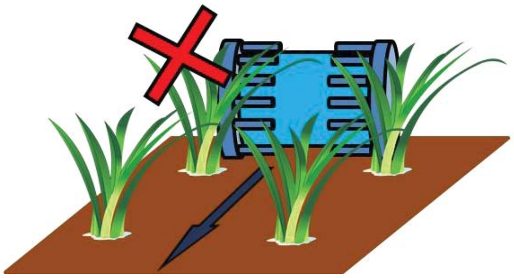
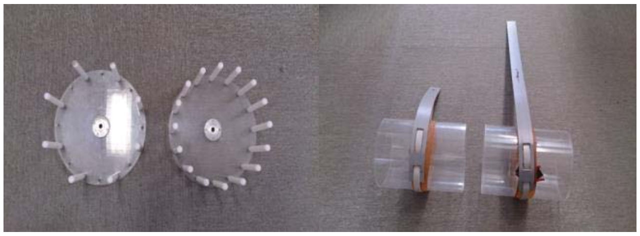


Fig. 12. The robot cannot go between the plants because they are too large to go between and too high and dense to run over.

3.5 Robot Tuning

One of the variable parameters of the prototype robot is the number of bars in the wheel. We have investigated using both 16 and 32 bars for the wheels, as shown in Fig. 13(a). The 32-bar wheel was found to have better mobility and greater stirring capability in the surface water, which helps to prevent weed sprouting.

Similarly, we investigated two grounding-bar lengths, as shown in Fig. 13 (b). The longer bar (0.2 m) gives better mobility in a straight line, but it can collide with the rice plants when turning, sometimes causing damage by digging them up. On the other hand, the shorter bar (0.1 m) is good enough for straight-line motion and for turning in most cases. However, on occasion, the bar can stick deep into the soil, causing the robot to be stuck. The length of the ground bar therefore remains a design issue.



(a) The number of bars in the wheel (b) The length of ground bar

Fig. 13. Tunable aspects of the robot.

CONCLUSIONS

This paper has reported on the 2013 feasibility test of a prototype robotic weeding system inspired by natural ducks. The concept of the system has been verified, and the design of the robot and its wheels has demonstrated sufficient mobility in a rice field, while causing no significant damage to the rice plants. It is expected that it could control weeds in an actual rice field if the robots were operated frequently.

We continue the development of the robotic weeding system. In weeding experiments in 2014 (not described in this paper), we could successfully control weeding by two or three robots operating 60 to 90 minutes a day for two months. We expect that it can become a commercial system in the near future if we can develop a robot self-navigation method for sweeping an entire rice field, with robot localization to an accuracy of 0.5 m.

ACKNOWLEDGMENT

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REDERENCE

[1] T. Bak and H. Jakobsen, “Agricultural robotic platform with four wheel steering for weed detection”, Biosystems Engineering, vol. 87, no. 2, pp. 125–136, 2004.

[2] D.C. Slaughter, D.K. Giles and D. Downey, “Autonomous robotic weed control systems: A review”, Computers and Electronics in Agriculture, vol. 61, no. 1, pp. 63–78, 2008.

[3] T. Bakker, C.J. van Asselt, J. Bontsema, J. Müller, G. van Straten, “Systematic design of an autonomous platform for robotic weeding”, vol. 47, no. 2, pp. 63–73, 2010.

[4] J. Blasco, N. Aleixos, J.M. Roger, G. Rabatel and E. Moltó, “AE—automation and emerging technologies: robotic weed control using machine vision”, Biosystems Engineering, vol. 83, no. 2, pp. 149–157, 2002.

[5] N.D. Tillett, T. Hague, A.C. Grundy and A.P. Dedousis, “Mechanical within-row weed control for transplanted crops using computer vision”, Biosystems Engineering, vol. 99, no. 2, pp. 171–178, 2008.

[6] T. Torii, “Research in autonomous agriculture vehicles in Japan”, Computers and Electronics in Agriculture, vol. 25, nos. 1–2, pp. 133–153, 2000.

[7] B. Chen, S. Tojo and K. Watanabe, “Machine vision for a micro weeding robot in a paddy field”, Biosystems Engineering, vol. 85, no. 4, pp. 393–404, 2003.

[8] Y. Nagasaka, H. Saito, K. Tamaki, M. Seki, K. Kobayashi and K. Taniwaki, “An autonomous rice transplanter guided by global positioning system and inertial measurement unit”, Journal of Field Robotics, vol. 26, nos. 6–7, pp. 537–548, 2009.

[9] Y. Kaizua and K. Imoub, “A dual-spectral camera system for paddy rice seedling row detection”, Computers and Electronics in Agriculture, vol. 63, no. 1, pp. 49–56, 2008.

[10] T. Mitusi, T. Kobayashi. T. Kagiya, Y. Asano and N. Bando, “Research on the advanced technology for organic agriculture – Development of rice field rover for weeding out”, 5th Research Report of Gifu Prefectural Research Institute of Information Technology, pp. 33–36, 2003.

[11] K. Fujii, K. Tabata, T. Yokoyama, H. Hirayu and Y. Endo, “Development of a small weeding robot “AIGAMO ROBOT” for paddy fields”, 15th Research Report of Gifu Prefectural Research Institute of Information Technology, pp. 32–34, 2014.