Development of a Robot Combine Harvester

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Abstract

The aim of this study was to develop a robot combine harvester that can perform automatic running and harvesting in the field. To achieve this goal, an RTK-GPS receiver with an IMU was used for the acquisition of position and posture data, and the combine harvester was controlled by sending messages to a CAN-based control system. During harvesting, the robot follows a predetermined path called a navigation map. To make a navigation map, two path plans were examined. Field experiments showed that the robot can follow predetermined path plans with a high level of accuracy (0.03 m) and that the accuracy is sufficient for the requirements (0.15 m) of harvesting paddy rice and wheat in Japan.

[Keywords] robot, combine harvester, navigation, path plan

I Introduction

Agriculture in Japan is facing various problems, the most serious being the shortage and aging of the agricultural labor force. To solve this problem, the Ministry of Agriculture, Forestry and Fishery has started a plan to encourage the development of robots for agricultural use.

In Japan, many different types of agricultural robots have been developed and are under development. Prior to this study, for example, a wheel-type robot tractor was developed in Hokkaido University, and it can be operated at a speed of 1.5 m/s with an error of only 6 cm (Kise et al., 2002). A crawler-type robot tractor was also developed in the same university (Takai et al., 2010). Other examples are a robot rice transplanting machine (Nagasaka et al., 2004) and a robot combine harvester (Iida et al., 2006). A real-time kinematic GPS (RTK-GPS) receiver and an IMU/GPS compass were utilized in all of those studies. An RTK-GPS receiver embedded with an IMU was also used in this study. This is because an RTK-GPS receiver alone is insufficient for precise control. Consequently, an IMU or a GPS compass is commonly required as a heading angle or yaw sensor.

In this study, a robot combine harvester was developed by using the navigation method discussed above. The main advantage of this robot combine harvester is that it can follow different navigation maps in two ways during harvesting. One way is called a human-like path plan, which imitates what human beings do during paddy rice or wheat harvesting, and the other is called a high-efficiency path plan. During harvesting with the second path plan, there is no need for the robot to decrease its speed when turning from one path to the next, thus increasing the efficiency of harvesting. Moreover, this path plan can only be conducted by a robot with an RTK-GPS receiver, because it is impossible for human beings, even highly proficient farmers, to conduct this harvesting in the field.

II Materials and methods

1. Research platform – AG1100

The platform used in this experiment was an AG1100 combine harvester manufactured by Yanmar Co., Ltd. as shown in Fig. 1.

Specifications of the combine harvester are shown in Table 1.

The combine harvester can work in three gears. Usually during harvesting, it works in the medium gear, with a speed of 0 to 2.0 m/s. It has an engine output of 80.9 kW, which is approximately 110 horsepower. This is the largest combine harvester produced in Japan, because the size of a field is no larger than 100 m by 30 m in Honshu region.

The combine harvester is controlled by sending commands via a CAN bus, and the structure of the

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The control system is shown in Fig. 2. A PC is connected to the CAN bus via a communication card, and there is an ECU inside the combine harvester that conducts the communication work and can shield the combine harvester from incorrect CAN messages. On the other hand, the RTK-GPS receiver with an IMU is connected to the PC. A modem is used to provide correction signals to the receiver. Moreover, the combine harvester can work in both manual mode and automatic mode. In automatic mode, it can only be controlled by a computer. The safety of the system is also improved, since when there is no command sent every 200 ms, the combine harvester will automatically stop.

2. Navigation

A Topcon AGI-3 (RTK-GPS + IMU) receiver was used in this study, because it can provide both position and posture data of the combine harvester to the computer. It communicates with the computer via a serial cable, which is commonly used and control via a serial cable is easy.

The receiver can output NMEA-0183 format GPS data in various formats, such as GGA, GGK and VTG. By using VRS (Virtual Reference Station), its accuracy can be up to ±3 cm. Posture data are also outputted via the same serial cable. The accuracy of the output is about 0.5 deg.

An advantage of this GPS receiver is that the output of posture data is corrected, thus solving the problem of IMU data always drifting. However, one disadvantage of this receiver is that the speed of the vehicle should be more than 0.3 m/s when the device is being used. Otherwise, the GPS and IMU would output incorrect values.

Usually, the GPS and IMU receiver should be mounted to the center of gravity. However, in this study, due to the structure of the combine harvester, the receiver was mounted on the top of the cabin so as to be closer to the header.

In terms of navigation, the robot needs a navigation map to follow. In order to follow the navigation map, its steering is controlled by the method developed by Kise et al. in Hokkaido University (Kise et al., 2001).

3. Working plan

(1) Human-like path plan

In this study, the robot combine harvester harvested from the perimeter of the field to the center, as farmers do in the field. This path plan is called a human-like path plan. An illustration of this path plan is shown in Fig. 3. In this figure, the numbers are the order of paths, and the arrows show where the robot combine harvester should start a path and in which direction the robot should start.

This path plan is adopted mainly because wheat plants are sometimes run over by the right crawler when a standard 2-meter-wide header, which is slightly shorter than the right crawler, is used in the combine harvester. In this path plan, however, the right crawler is always running on the harvested area and can avoid running over the crop. This path plan can also be used for wheat
harvesting with a 2.5-meter-wide header, although there is no risk of running over the crop.

At the end of each path, the combine harvester should turn to the next path. Two turning methods were designed for the robot, turning with forward movement and turning with backward movement, as shown in Fig. 4. The turning includes 5 steps. Since the implement or header is in front of the vehicle, a combine harvester requires a large space for turning. The first step of turning is to go forward to ensure that there is enough space to turn. The second step is to turn 90 deg, and the third step is to go to a proper spot for entering the next path. It is possible for the combine harvester to go either forward or backward. The next step is to go another 90 deg so that the vehicle’s heading is the same as the heading of next path. Finally, the robot looks for the entrance of the next path and completes step 5.

(2) High-efficiency path plan

There is another path plan for the robot combine harvester as shown in Fig. 5. There are 18 paths in total in this high-efficiency path plan. The paths can be divided into two groups with 9 paths in each group. In these two groups, only turning directions are different (In the first 9 paths, the robot turns left and in the next 9 paths, the robot turns right). This path plan has to be realized with a 2.5-meter-header for wheat to avoid running over wheat crops.

This path plan is created for higher efficiency of harvesting, and the difference mainly lies in turning. In the human-like path plan, there is a straight movement either forward or backward. This straight movement can take a long time when the current path is a long distance from the next path. In the high-efficiency path plan, however, there are no straight movements when the combine harvester turns at the end of each path — it should either skip 4 paths (as turning from path 1 to path 2) or skip 3 paths (as turning from path 2 to path 3). The turning is shown in Fig. 6. This is possible based on the fact that when turning parameters of the robot are properly set, the turning diameter can be exactly the same as the distance between the current and next path.

By using this path plan, efficiency of harvesting can be improved, since there is no need for the robot combine harvester to stop and go forward or backward. When the combine harvester runs with a 2-meter-wide header and the running speed is 1 m/s, this change can save up to 5 minutes when the robot harvests a field with 18 paths, in which the distance going forward and backward is about 300 m in total. Given that the size of a farm in Honshu area of Japan is small, turning at the head land of a field accounts for a higher ratio of all harvesting time. Thus, this method can greatly increase the efficiency of harvesting.

In addition, this turning method can only be done by a robot with GPS receivers, since it is impossible for a human being to determine the entrance point of the next path in the field when the crop is not harvested line by line.

4. Experimental method

To test a robot combine harvester’s accuracy, it is
crucially important to test both straight running and turning. During straight running, if the combine harvester can follow a straight line, it may avoid running over crops. During turning, sometimes the combine harvester cannot turn a perfect right angle due to the delay of the IMU and it is still important that the vehicle can find the entrance of the next path and enter it with the least lateral error and heading error. In this study, both the accuracy in a straight path and that in turning were tested.

In addition, the two ways of path planning should be tested separately, since turning and the order of paths are totally different.

Two field experiments were conducted in the experimental field in Hokkaido University and on a farm near Memuro Town, Hokkaido. The objectives of these experiments were to test whether the robot could complete the predetermined path plan and how accurately the combine harvester can run. GPS coordinates of the map were preliminarily measured. In both tests, the 2.5-meter-header was used and the combine harvester was set to navigate at a speed of 1 m/s. During the navigation, GPS and IMU data of the combine harvester were recorded. After the experiments, the accuracy was evaluated.

III Results and discussion

1. Human-like path plan test

By using the method described in section 2.4, a navigation map to test the robot was made. The navigation map included 4 paths, with the paths being shifted according to the direction of traveling, since the position of the header is different from that of the GPS receiver. Fig. 7 shows the navigation map with the robot’s GPS trajectory. The distance between adjacent paths is 2.3 m, and the length of each path is approximately 85 m.

During turning, forward and backward movements were also tested. The results showed that the combine harvester can follow the turning plan and can find its way to the next path. Data recorded were turning from path 1 to path 2 and turning from path 3 to path 4, as shown in Fig. 7. The trajectories in the small figures are those of the center of the crawlers, while the trajectory in the large figure is that of the GPS receiver. That is why they are in different positions, although they are from the same experiment. Because of the delay of the IMU or the slipperiness of the ground, the combine harvester may turn to a degree either greater or less than 90 deg. However, the robot can still find its way to the next path.

The lateral error of the first path is shown in Fig. 8, in which the initial heading error is about 0.25 m. In about 5 to 6 s, the robot found its way and went into the ±0.05 m range. From this point to the end of the path, the RMS value of the lateral error was 0.032 m and the maximum value was 0.071 m. Fig. 8 also shows the heading error of the same path. In this path, the RMS value of heading error was 0.943 deg, with a maximum of 2.38 deg.

Fig. 9 shows the lateral error in the whole test. At the beginning of each path, the lateral error was about 0.15 m. Then the vehicle’s accuracy became higher and it usually ran within a ±0.05 m range. Fig. 9 also shows the heading errors in these four paths. Like the lateral error, when the vehicle entered a new path, the heading error...
was largest, around $-3$ deg. The performance of the vehicle ensures that there is no crop left after harvesting.

2. High-efficiency path plan test

Using the method described in Section 2.5, a navigation map was made for the high-efficiency path plan. The map is shown in Fig. 10. In the navigation map, the distance between adjacent paths is 2.3 m, and the length of each path is approximately 50 m. The map is shifted according to the robot’s traveling direction, since there is some difference between the GPS receiver’s position and the header’s position. Fig. 10 also shows the result of the combine traversing all of the paths.

Fig. 11 shows the lateral error and heading error in a typical test for the high-efficiency path plan. At the beginning of each path, the lateral error was about 0.07 m. Then the vehicle ran towards the target line. Most of the time during the test, the robot was running in a $\pm 0.05$ m range. The RMS value of the running was 0.030 m. Accordingly, the RMS value of the heading error was 1.22 deg.
IV Conclusions

In this study, a robot combine harvester was developed, as shown in Fig. 12. It can be controlled by sending commands via a CAN bus. In order to achieve a high level of accuracy and record the data for analysis, an RTK-GPS receiver embedded with an IMU was used. The robot can perform two path plans. For a human-like path plan, turning with a forward or backward movement was used, and for a high-efficiency path-plan, by tuning the turning parameter, the combine could turn directly into the next path without forward or backward turning. In addition, the high-efficiency path plan can greatly improve the harvesting efficiency, and it cannot be conducted without a GPS receiver on the robot. Results of the two field tests showed that the RMS values of lateral error were 0.032m and 0.030m for human-like path-plan and high-efficiency path-plan, respectively. The field experiments also showed that the accuracy of the combine harvester can be used for wheat harvesting.

A shortcoming of the robot is that when the grain tank is full, it has to be driven by a human being to the unloading point where the grains are unloaded. In future studies, it is expected that the combine harvester will be able to generate an unloading path by itself and navigate automatically to the unloading point. With this function, the robot combine harvester can work by itself in the whole process of harvesting and it will free human beings from the work. Finally, the robot’s control parameters should also be improved so that when it finishes turning and enters a new path, lateral and heading errors can be minimized.

References


Question time limit: 31. March. 2015

Fig. 12 Robot combine harvesting wheat

As of March 31, 2015, the robot combine harvester can be used for wheat harvesting.