4th IFAC Conference on Modelling and Control in Agriculture,
Horticulture and Post Harvest Industry
August 27-30, 2013. Espoo, Finland

A Robot System for Paddy Field Farming in Japan

K. Tamaki*, Y. Nagasaka*, K. Nishiwaki*, M. Saito*, Y. Kikuchi*, K. Motobayashi*

** National Agriculture and Food Research Organization*
Tsukuba, Japan (Tel: +81-29-838-8815; e-mail: tama@affrc.go.jp)

Abstract: The objective of this research is to realize fully robot-operated farming from tillage to harvest in large-scale agriculture such as cultivation of rice, wheat and soybean in Japan. For this purpose, three types of robot have been developed; the first is robot tractor, the second are rice transplanter robots, the third are combine harvester robots. RTK-GPS and inertia measurement unit (IMU), or GPS compass, are used for navigation system. Robots have Controller Area Network (CAN) bus that all sensors and PC can be connected in common among other robots such as tractors, rice transplanters, and combine harvesters. These robots could be done autonomous operation in paddy field. In addition, moving between the fields for effective operations and safe guideline for robot system were discussed.

Keywords: field robotics, tractor, rice transplanter, combine harvester, RTK-GPS, IMU

1. INTRODUCTION

In Japan, the rapid aging of farm workers and depopulation of farming communities are currently becoming a major concern. The number of farmers was 4.82 million in 1990 and is decreasing to 2.60 million in 2010. This decrease has been continuing for over 50 years. The farmer's average age is over 65 years old (MAFF 2012). On the other hand, the management areas of the local leading figure are increasing. That their management areas are increasing is not the same meaning to that the area of one field is getting big scale. One field size is not changed and number of fields of their management is increasing. Japanese agriculture is almost paddy field farming. As paddy field is seasonally-flooded, Japanese standard size of paddy field is 0.3 ha (30 m * 100 m) that is smaller than up-land field. The operation that big size tractor which is over 150 PS runs at high speed attaching wide implement is not suitable for small size paddy field. This issue can be solved using farming robot to perform farm operation accurately at the right time. Such operation allows one operator to control multiple vehicles. One of the goals of this project is to realize a fully robotized field operation system (tillage, planting, harvesting etc.) in rice production. As a step towards that goal, we have been developing three types; the first is a robot tractor which is used for tillage and puddling, the second are rice transplanter robots which can simultaneously perform transplanting, fertilizing and herbicide applicating, the third are combine harvester robot for rice. In addition robots for wheat and soybean which are conversion crops of rice have been developing, for example, soybean combine harvester, seeder for wheat and soybean.

Rice transplanter robot already started to develop in 1999 (Nagasaka et all 1999; 2004, 2009, 2011). In 2008 we started this robot farming project that build a farming system using various robots. A part of this research was financialized by joint research project started in 2010 with Hokkaido University (project leader Prof. Noboru Noguchi), Kyoto University, Topcon Co., Ltd., Bosch Co., Ltd, Hitachi Solutions, Ltd., and YANMAR Co., Ltd (Noguchi and Barawid 2011, Kataoka et all 2013). In Hokkaido which is the Northern part of Japan large scale agriculture is performed in big fields. On the other hand in Japan except Hokkaido field size is smaller. In this paper we report about the project research of robot system for large-scale agriculture that small fields disperse and are located.

2. MATERIAL and METHODS

2.1 Robot platforms

In this project the base unit machine are commercialized agricultural machines on the market. Fig. 1 shows the robot tractor which was modified to be controlled steering by stepping motor. Steering, the direction of travelling (forward, neutral, backward), engine speed, travelling speed, rear hitch position and PTO speed can be controlled via can-bus. Base unit is 47.8 kW four-wheel-drive tractor, YANMAR EG65.

Two types rice transplanter robots are shown in Fig. 2. Base units are KUBOTA SPU650, 7.7 kW and ISEKI PZ60, 8.3 kW. Their actuators and controllers for the steering, HST (Hydro Static Transmission) and hitch-control-switch can be controlled by the computer through can-bus system. They

Fig. 1 Robot tractor

Fig. 2 Two Rice Transplanter robots

Fig. 3 Robot Combine Harvester for Rice

Fig. 4 Robot Combine harvester for soybean with a light truck loading grain container

were supplementary added on commercially available, human-operated, six-row rice transplanter. The steering motor and HST control motor were added. Two robots are needed to demonstrate that one operator can use two robots simultaneously in the fields. The robot combine harvester for rice is shown in Fig. 3. The base machine of this robot is head-feeding combine harvester for cutting 4 rows, ISEKI HF443, 31.6 kW. It is a Japanese style combine which feed only head of crop into threshing unit. Therefore required engine power is smaller than combine harvester as European style combine. Head-feed combine harvester can be used for rice, wheat and barley. But it is not suitable for soybean. Fig. 4 shows Robot combine harvester for soybean with a man-operated light truck loading grain container. Base machine is ISEKI HC350, 25.7 kW. Different from rice harvesting, the ground soil moisture content is low, not only crawler type vehicle but wheel type vehicle can be used in soybean field.

These robots have two operation modes; the first is an autonomous mode, the second is a manual operation mode. When driving on the road to move to the field, robot in manual operation mode was controlled by riding operator. According to the travel distance self-propelling by riding operator or loading to track is chosen. In manual operation mode robot is able to be controlled in the same way as a common agricultural machine. After entering the paddy field riding operator sets the robot in an autonomous mode and gets off the robot. The operator directs the robot to start autonomous operation with a radio switch. During robot's autonomous operation the operator can perform other work; move other robots, supply of the material, transportation of harvested crop, etc. After autonomous operation the robot stops at a decided place of the field and waits for the operator. When using a robot system in a farm, several ways of operating systems can be supposed. The most organized system is the system that several robots are controlled intensively in operation centre such as railway train operation control systems. That system can be realized within a defined area that general vehicle and people cannot enter in. In these area robots can be run freely on the road. But while there are few such areas in current Japan, it is decided that robots don't run on the public road and autonomous operations are carried only in paddy fields.

2.2 Navigation system

The RTK-GPS, Trimble MS750 or SPS751, with Virtual Reference Station (VRS) is used for position measurement. Measuring accuracy is 0.02 m. The IMU, Japan Aviation Electronics Industry, Limited JCS7401A, is used to detect roll, pitch and heading angle (Fig. 5). Measuring accuracy of IMU is less than 2 degree/min. Travelling surface is so soft in the time of pudlling and rice transplanting that it is necessary to measure the roll and pitch angle, while a combine harvester don’t need their angle for its originally equipped with a body levelling system. GPS compass, Hemisphere V100, is replaced IMU which is expensive on a combine harvester (Fig. 6). All sensors and PC are connected to CAN-bus that ISO 11783 protocol was used in communicating among the nodes, therefore computers and sensors can share various command and sensing data (Fig. 7). By using CAN-bus system, sensors and PC can be used in common among other machines such as tractors, rice transplanters, and combine harvesters. Fig. 8 shows CAN-bus ECU that was named ‘NARO CAN BOARD’ developed by our laboratory by using Microchip dsPIC30F6010A. This board has 16-bit input / output function, 2 ch CAN modules, 6 ch 10-bit ADC, 8 ch PWM motor controller, and so on.

Fig. 5 RTK-GPS with VRS modem and IMU

Fig. 6 GPS compass using for combine harvester

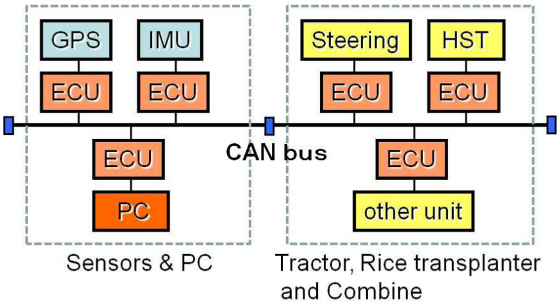

Fig. 7 Schematic of diagram of robots

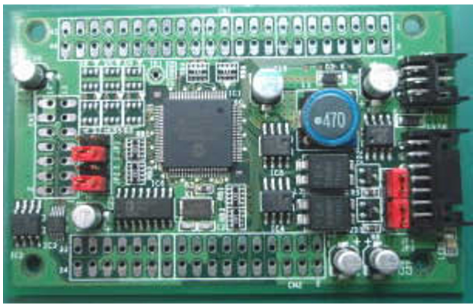

Fig. 8 ECU for CAN-bus

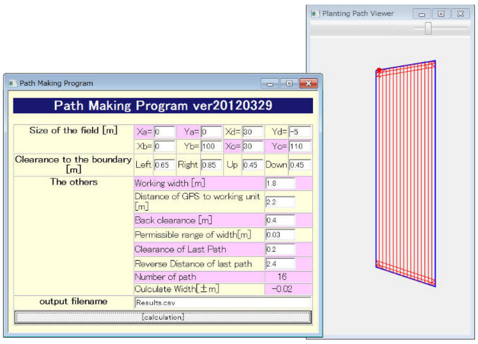

Fig. 9 PMP (Path Making Program for robots)

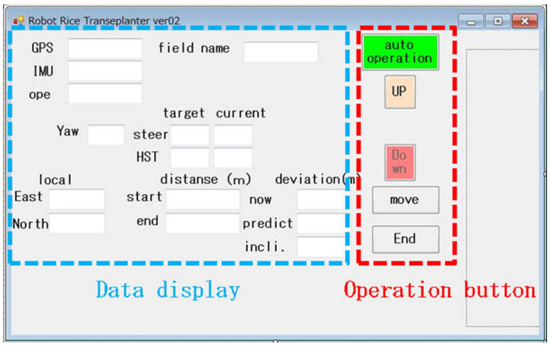

Fig. 10 Touch panel console

2.3 Software

The shape of Japanese standard paddy field is a rectangle or trapezoid. It is necessary for the coordinate of the characteristic point of the field to be made a survey beforehand and recorded as a data file. Robot operation path is preliminarily designed according to the shape of the paddy field by PMP (Path Making Program for robots) (Fig. 9). This software outputs working path for robots by inputting farm size and machine dimensions such as the work width.

Fig. 10 shows the user interface of operation panel. 'Touch panel computer', Interface Corporation TPC-B016SB10 (s) was used. The touch panel console is comprised of two parts; left side is a part to indicate the state of robot, right side is a part to operate a robot with buttons. The buttons which an operator operates are only five buttons. Operator presses the 'up' or 'down' button to go up and down the working unit. At the time of moving to the field, operator presses the 'move' button. Computer starts to check the current position by using GPS data. If a robot enters the field that is already installed in database, computer displays the field name and path on the panel. When operator presses the 'auto operation' button, the robot is set in an autonomous mode. Operator gets off the robot and starts the robot to do autonomous operation with a radio switch on.

Robot operation is conducted along with the working path. By reference to the lateral deviation and heading angle error from the desired working path, the steering is controlled so that the deviation from the desired path becomes minimal. The travelling speed is also designed according to the distance from the edge of the paddy field. Start and stop of planting operations are done synchronized with up-and-down motion of the operation unit at the headland. The machine turns at the headland and then enters into the next working path. When the quality of GPS data is low such as 'not fixed', the operation will be stop until it gets a 'fix'. Because the sky of paddy fields in a flat area hardly has an obstacle, it is unusual not to get a 'fix'. Even if fix may break off by a placement state of the GPS satellites, the GPS receiver will get a 'fix' in several minutes.

3. RESULTS and DISCUSSION

3.1 Robot operation in the field

A recorded working path of the rice transplanter robot at 0.3 ha (30 m x 100 m) paddy field is shown in Fig. 11. In this experiment, lateral deviation from the desired path for total straight-ahead operations was 0.04 m (RMS), heading angle error was 1.1° (RMS). Non-stop fully untouched rice transplanting operation for a 0.3 ha (30 m x 100 m) paddy field including headland was completed in 56 min in this experiment.

The recorded path of soybean harvesting in 0.3 ha field is shown in Fig. 12. In outer circumferences man-operated harvesting was done in three times go-around to get turning space. Because the capacity of combine's grain tank has a limit, unloading operation is necessary when grain tank is full. In the case of Fig. 12 unloading truck was travelling side by

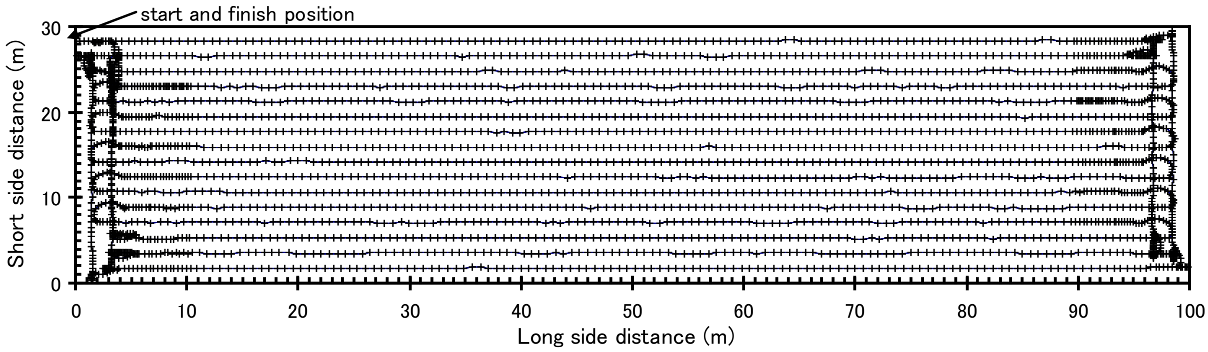

Fig. 10 Recorded path of autonomous rice transplanting operation in 0.3 ha paddy field

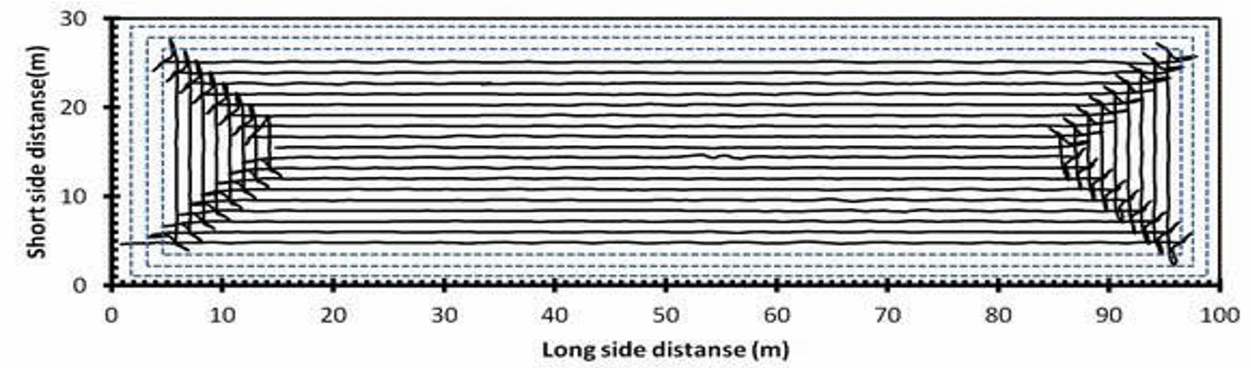

Fig. 11 Recorded path of soybean harvesting in 0.3 ha field

side with autonomous harvesting combine when grain tank was filled, there was no time loss of unloading.

Other robots as tractor and rice combine harvester also could be done autonomous operation in paddy field (Saito et al 2012).

3.2 Moving between the fields

Travelling speed of agriculture machine is regulated to 35 km/h in the public road of Japan. The travelling speed of small size tractor, rice transplanter and combine harvester may be less than 15 km/h. If travel distance is long, it is necessary to load a robot with the track. Fig. 12 shows that rice transplanter robot was loaded to truck that has self-loading function. In this case, time to fix a robot to the truck using wire rope is necessary. Loading time was 15 minutes and unloading time was 5 minutes. Average speed of truck was 30 km/h and travelling speed of rice transplanter robot was 4.5 km/h. Fig. 13 shows that the relation of travel distance and required time was calculated in both of the case of loading with a truck and the case of self-propelling. In the case of loading with a truck, initial time of loading and unloading was 20 minutes. The inclination of a straight line of loading a truck was different from in the case of self-propelling. Both straight lines crossed at 1.76 km. It showed that if travel distance is shorter than 1.76 km, self-propelling is advantageous. In many cases in Japan, travel distance to the field is smaller than 1.76 km, many agriculture machine moves by itself without loaded with a truck.

Fig. 12 Rice transplanter robot loaded a truck with

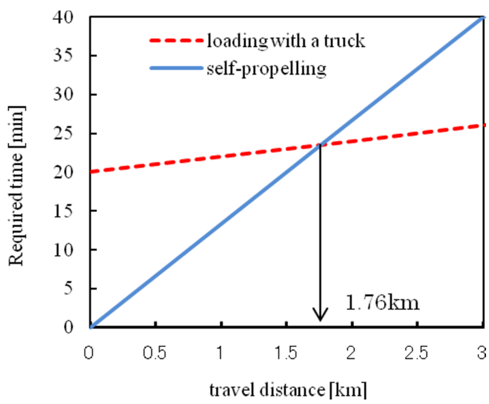

Fig. 13 Required time and travel distance in the case of rice transplanter robot

Fig. 14 rice transplanter robot attached a bicycle

After autonomous operation of robot starts, operator needs the means of moving. It is thought that a bicycle is the most realistic means now. Bicycle is light and can be run in 12 km/h or more. Fig. 14 shows the rice transplanter robot attached a bicycle at the time of moving to the field. By this method, one operator was able to operate two rice transplanter robots in two 1 km away paddy fields in spring of 2013.

3.3 Safe guideline for robot system

Safe guideline for robot system has been considered by this project. That is the framework to operate robots more safely including not only obstacle sensors but the indication methods to person, warning lights, warning sounds and operating methods of multiple robots. The risk assessment that assumed the scene which robots operate autonomously is conducted. While a robot is doing an autonomous operation, a safe system is necessary. It is necessary to detect the obstacle including the person by attaching sensors in the direction of travel. But when there are the crop on the front of a machine like combine harvesting, obstacle detection by sensors is not easy. As fortunately paddy field is flat, it is easy to overlook the field. Before autonomous operation of a robot, it ensures to some extent the security to confirm that there is not a person in the field. Paddy field is seasonally-flooded and it has boundary established unlike up-land field or grassland. The boundary is the elevated ridge between paddy fields to save about water. The height is 20-30 cm, and the width is about 30 cm (Fig. 15). Because attitude of a robot will be to make a big change if a robot is going to climb over a boundary with some cause, it is thought that it is not difficult to prevent going out from a field by using attitude data and GPS data. It is thought that the safety increases by field check before the autonomous operation and by the use of the boundary of paddy fields.

Fig. 15 The boundary between two paddy fields

4. CONCLUSION

The research on the development of a robot system in Japan has been carried out. Basic robots that can do operations from tillage to harvesting are developed. And the operation procedure including then moving between the fields was considered. These results showed that a robot farming system could turn into the labor of a person in Japan of the near future. In future the feasibility test for practical use will be conducted in two years.

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