Autonomous rice field operation project in NARO

Yoshisada Nagasaka, Katsuhiko Tamaki, Kentaro Nishiwaki, Masahiro Saito,
Kota Motobayashi, Yutaka Kikuchi and Hisashi Hosokawa

Division of Farm Mechanization and Systems
Agricultural Research Center
National Agriculture Research Organization
Tsukuba, Ibaraki, Japan
zentei@affrc.go.jp

Abstract - We are engaged in research about autonomous rice field operation. Our research goal is to develop fully automated operating system for rice production such as tilling, puddling, transplanting and harvesting. To make these operations, we have developed an automated tractor, a rice transplanter and a combine harvester. These automated agricultural machines are guided by a global positioning system (GPS) and an attitude sensor. Because each machine is used for a limited period of time in a year, we plan to share a main control computer and navigation sensors among automated machines. We expect to deliver autonomous operation in paddy field at lower cost and to shorten the development period of each machine. In this paper, we report about research project outline and current status of each automated machine.

Key words: autonomous operation, paddy field, global positioning system, tractor, rice transplanter, combine harvester

I. Introduction

During the last two decades, the agricultural population in Japan decreased by 47 percent. It was 4.82 million in 1990, but it became 2.60 million in 2010. The average age of farmer is over 65. Then the average area operated by a single farmer has been increasing but it is difficult to enough consolidate the fields. The usual size of a paddy field is 0.3 ha (100 m × 30 m). These days we can obtain the paddy fields whose size is more than 1 ha, but it is still rare. Because of low soil bearing capacity of paddy field, the size of the operating machine is limited. When an automated operation is realized, that will permit a single operator to control a number of machines in several scattered fields and it will improve the operation efficiency.

There are several researches about automated operation. A tilling robot guided by laser range finder [1], GPS guided tractor [2], a vision guided tractor [3], a stereo vision guided tractor [4], a vision guided combine harvester [5], GPS guided combine harvester [6] were developed.

In National Agriculture Research Organization, we had a research project about autonomous rice field operation ([7], [8], [9]). Our research goal is to develop fully automated operating system for rice production such as tilling, puddling, transplanting and harvesting. In this project, we have developed automated agricultural machines such as a rice transplanter, a combine harvester, and a tractor. In Japan, these machines are operated only for a short period in a year. When sensors, computers and actuators communicate by the same protocol, each machine can share the sensors and computers with other machines and the total system cost can be reduced. We also plan to use the same communication protocols among sensor and actuator nodes according to the ISO 11783.

In this paper, we report about their hardware, control protocols and the results of experiments.

II. Paddy Field Operation in Japan

Figure 1 shows the flow of the common paddy field operation in Japan. In spring, rotary tilling and rotary harrow puddling are made with a tractor. Then a few days after puddling, rice transplanting is made with rice transplanter. Basal fertilizer is applied before rotary tilling or at the same time of rice transplanting. It takes three or four weeks to grow rice seedling. After rice transplanting, weedicide, insecticide, fungicide and additional fertilizer are applied during growing period. Rice is harvested in autumn with combine harvester. After harvesting, rotary tilling is made again.

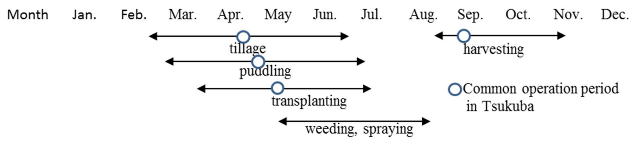

Figure 1 flow of the paddy field operation in a year

III. Sensors In Vehicle Network

A. In vehicle Network

Figure 2 shows the schematic of automated machines. The sensors, actuators, controllers, and the main computer are connected to the CAN bus. The sensors and the main computer were designed so that they were easy to be disconnected. The ISO 11783 protocol was used in communicating among the nodes. We plan to share the sensors and the main computer among each machine such as a tractor, rice transplanter and a combine harvester (Figure 3).

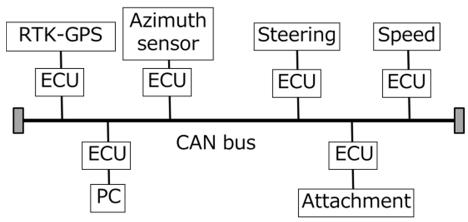

Figure 2 schematic of automated machines

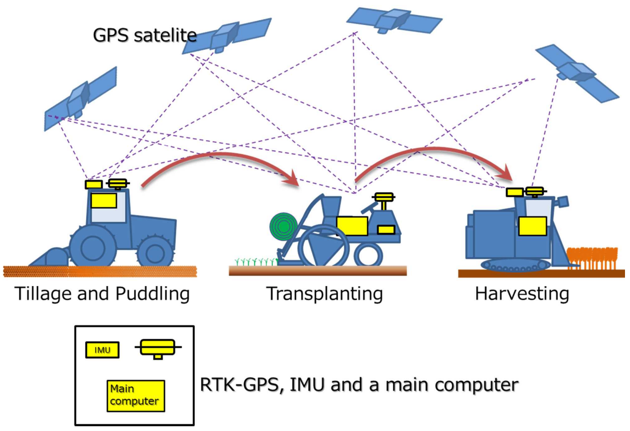

Figure 3 sharing the sensors and the main computer among each machine

B. Sensors and computers

An MS750 GPS receiver, manufactured by Trimble Navigation Ltd. (Sunnyvale, CA), is used to locate the vehicle position. The measuring accuracy is 0.02 m. The GPS position data output cycle is 10 Hz, and the data were transferred to the CAN bus. A GPS receiver received reference data from a network-based reference station. The Japanese Geographical Survey Institute (GSI) permits GPS-based control stations to use real-time data from the GPS Earth Observation Network system (GEONET). JENOBA Co., LTD. (Tokyo, Japan) and Nippon GPS Data Service Corporation, LTD. (Tokyo, Japan) process the data of GEONET and deliver the reference data every second in the RTCM or CMR format through packet communication through a cellular phone network. The GPS reference data is received using data modem. The baud rate for modem communication was set to 38,400 bps.

The GPS position data needs to be verified to determine the inclination of the vehicle in paddy fields. An inertial measurement unit (IMU) was used to measure the roll, pitch, and heading angle for a tractor and a rice transplanter. A combine harvester has a horizon control mechanism and it doesn't need to correct the inclination. We use GPS compass to sense the heading angle of a combine harvester. The azimuth sensor output cycle was 10 Hz.

The main computer received data from the GPS and azimuth nodes. It then calculated the control parameters based on the given reference trajectory. It also recorded GPS position data, azimuth data and inclination corrected position data to the internal solid state disk. The resulting actuator commands were then sent to the actuator node through the CAN bus at 10 Hz frequency. Each actuator node received the control parameters from the main computer at 10 Hz and then controlled the actuators at 10 Hz.

IV. Automated Machines

We have developed one automated tractor, two rice transpalnter and a combine harvester. We show the each machine as follows.

A. automated tractor (Yanmar EG65)

Figure 4 shows an automated tractor. A base tractor is EG65 manufactured by Yanmar Co., Ltd. (Osaka, Japan). It has 47.8 kW (65 PS) engine power output. A GPS antenna was set over the front part of the cabin roof in 3 m high from the ground surface.

Figure 4 an automated tractor

A geared motor was attached to the steering system of the front wheels. An absolute rotary encoder was connected to the king pin axis of the front wheel to sense the steering angle. Hydraulic Mechanical Transmission (HMT) is controlled with analog voltage output by a computer. Three point Hitch is also controlled by a computer. This automated tractor makes rotary tilling and rotary puddling in a paddy field.

The desired traveling path was planned before the operation began. We measure the four corner points of the square field and then make the traveling path manually. The steering angle is controlled according to the deviation from the desired path and the error of the desired direction. At the head land, it turns and enters to adjacent next path.

B. automated rice transplanter 1 (Kubota SPU650)

Figure 5 shows an automated rice transplanter 1. A base unit was a SPU650 six-row rice transplanter, manufactured by Kubota Corporation (Osaka, Japan). It was equipped with an 11kW (15 PS) engine power output. A GPS antenna was set over the front axle of rice transplanter. The antenna was 2m high from the ground surface when the rice transplanter was put on the level ground.

Figure 5 an automated rice transplanter 1

A geared servomotor was attached to the steering system of the front wheels. An absolute rotary encoder was connected to the steering axle to sense the steering angle. Hydrostatic static transmission (HST) is actuated by another servomotor. Attachment lifting-up and down, start and stop of the transplanting is also controlled by a computer.

Path planning, control method and operating method is almost as same as an automated tractor.

To make unmanned rice transplanting operation in one field, it needs enough seedlings. We also modify the rice transplanting attachment to use long mat type hydroponic seedlings [10]. It is ten times longer than conventional rice seedling mat and one seedling mat covers 0.05ha field. Japanese standard size of rice field is 0.3 ha, so six-row rice transplanter can make non-stop operation in one standard size field (figure 6).

Figure 6 long mat type hydroponic seedlings

C. automated rice transplanter 2 (Iseki PZ60)

Figure 7 shows an automated rice transplanter 2. A base unit was a PZ60 six-row rice transplanter, manufactured by Iseki & Co. Ltd. (Matsuyama, Japan). It was equipped with a 9.7kW (13 PS) engine power output. A GPS antenna is set over 0.4m front offset from the front axle of rice transplanter. The antenna is 1.2m high from the ground surface when the rice transplanter is put on the level ground.

Figure 7 an automated rice transplanter 2

A geared motor was attached to the steering system of the front wheels. The size of motor is larger than that of the automated rice transplanter 1, so the steering speed is higher. An absolute rotary encoder was connected to the steering axle to sense the steering angle. Hydrostatic static transmission (HST) is actuated by a servomotor. Attachment lifting-up and down, start and stop of the transplanting is also controlled by a computer.

Path planning, control method and operating method is almost as same as an automated tractor. This rice transplanter is also modified to use long mat type hydroponic seedlings.

D. automated combine harvester 1 (Iseki HFG443)

Figure 8 shows an automated combine harvester. A base unit was a *HFG443* four-row head-feeding combine harvester, manufactured by Iseki & Co. Ltd. (Matsuyama, Japan). It was equipped with a 31.6kW (43 PS) engine power output. A GPS antenna was set over the middle of the cabin roof in 3.2 m high from the ground surface. A GPS compass is also set on the roof.

Figure 8 an automated combine harvester

This combine harvester has HST for speed control. A geared motor actuates HST lever and controls the speed. Traveling direction is controlled with changing left or right brake pressure which is proposal to analog input voltage from 0 to 5 V.

The desired traveling path was planned before the operation began. We measure the four corner points of the square field and then make the traveling path manually.

From the first to third path near the edge of rice field is operated by human because we have some obstacles near the edge of the field such as water plug or drain outlet. We need to avoid breaking such obstacles and a combine harvester itself. From the second going around path, it starts automated operation. When the grain tank is filled to the capacity, it stops and human operator unloads rice to the track manually.

III. Experiments and Results

A. Tilling and puddling

An automated tractor made rotary tilling and rotary harrow puddling (figure 9). The operating width was 2 m. When the overlap was set to 0.1 m for each path, it rototilled all field.

Figure 9 rotary tilling and puddling operation

B. rice transplanting

Figure 10 shows the entire recorded path of the rice transplanter. These data are corrected for the effects of the vehicle inclination. Fully automated rice transplanting was successfully performed. The operating speed was 0.9 m/s and the machine took about 50 min to complete planting the entire field. The lateral deviation of the desired path was less than 0.1 m during straight operation.

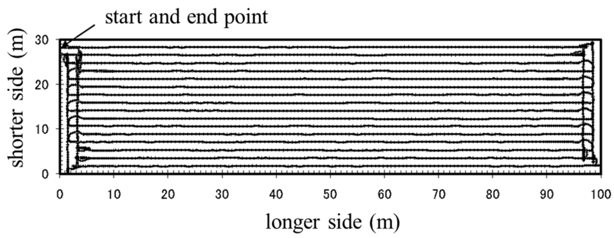

Figure 10 the recorded path of the rice transplanter

We also made other experiments. One is that an operator used two rice tranplanter at distantly-positioned fields. The other is that an operator used two rice tranplanter in the same field (figure 11).

Figure 11 two automated rice tranplanter works in the same field at the same time

C. harvesting

Figure 12 shows the recorded path of the combine harvester after staring automated operation.

It took 1.76 hour for one field harvesting and the lateral deviation of the desired path was less than 0.1 m. It was enough accurate for harvesting and the automated combine harvester worked well during the operation.

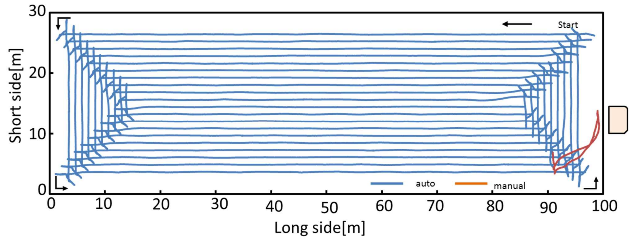

Figure 12 the recorded path of harvesting

IV. CONCLUSIONS

We introduce current status of our autonomous rice field research project. Unmanned operations for tilling, puddling, rice transplanting and harvesting were achieved. The CAN bus based network system worked well during the operation in each automated machine.

We are going to try adding safety system for each machine. We also need to optimize operation process when an operator uses multiple machines at the same time.

REFERENCES

[1] Y. Matsuo, S. Yamamoto, O. Yukumoto, "Development of tilling robot and operation software", *Paper presented at the Automation Technology for Off-road Equipment, Chicago, IL*, July 2002

[2] S. Gan-Mor, R. L. Clark, B. L. Upchurch, "Implement lateral position accuracy under RTK-GPS tractor guidance" *Computers and Electronics in Agriculture*, vol59, pp.31-38, July 2007

[3] J. Billingsley, M. Schoenfisch, "The successful development of a vision guidance system for agriculture," *Computers and Electronics in Agriculture*, vol. 16, pp.147–163, September 1997

[4] F. Rovira-Más, Q. Zhang, J. F. Reid, "Stereo vision three-dimensional terrain maps for precision agriculture", *Computers and Electronics in Agriculture*, vol. 60, pp.133-143, September 2008

[5] E. R. Benson, J. F. Reid, Q. Zhang, "Machine vision-based guidance system for an agricultural small-grain harvester", *Transactions of the ASAE,* vol. 46, no. 4, pp.1255–1264, April 2003

[6] M. Iida, Y. Yamada, "Rice harvesting operations using an autonomous combine harvester with a GPS and FOG," Paper presented at the Automation Technology for Off-road Equipment, Bonn, Germany, September 2006

[7] N. Murakami et al., "Development of a teleoperation system for agricultural vehicles," *Computers and Electronics in Agriculture*, vol. 63, no. 1, pp. 81-88, August 2008.

[8] Y. Nagasaka et al., "An Autonomous Rice Transplanter Guided by GPS and IMU," *Journal of field robotics*, vol.26, no. 6, pp. 537-548, June 2009.

[9] K. Tamaki, Y. Nagasaka, K. Kobayashi, "A rice transplanting robot contribute to credible food safety system," *ARSO2009 conference*, November 2009.

[10] K. Tasaka, "Outline of raising and transplanting technology for long mat type hydroponic rice seedlings", Paper presented at EurAgEng, Oslo, Norway, August 1998.