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Automatic Operation of Light Tractor with Sprayer in Paddy Fields

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Abstract

When a sprayer spreads pesticides in the field, the operator on board is exposed to the mist of pesticides. The automatic operation without operator on board could certainly alleviate such a shortcoming. A joint research team organized by NARC and Mitsubishi Farm Machinery Co. Ltd. Developed and tested an automatic operation method by the light tractor "Paddy vehicle" with a sprayer. The operation system included a straight line automatic operation which followed the rows of rice plants and a turning action supported by a remote controller handled by the operator. The paddy vehicle equipped with a boom sprayer could carry out automatic spraying operations without an operator on board in the paddy fields. The automatic forward movement of the vehicle following the straight row of rice plants, the automatic turning by the computerized program, and the maneuver remotely controlled by the operator on the road for the accurate position ready for the next stroke were tested. The operation of the paddy vehicle was found to be successful as had been intended from the design stage. This new automatic operation system enables 1 operator to handle 2 or more paddy vehicles simultaneously in paddy fields.

Discipline: Agricultural machinery
Additional key words: robot, pest control

Introduction

Agricultural mechanization has made remarkable progress recently. However from the standpoint of healthy environment for farmers who operate such machines often on board, agricultural machines currently commercialized are not satisfactory when operated for many hours by farmers. The vibration as well as the noise of such machines can be potentially harmful to the health of the operator. Furthermore, the operator on board of the sprayer may be exposed to the mist of pesticides. It is thus necessary to develop machines which can be operated more comfortably and more safely. In future, mechanization technology should be geared to provide physical comfort and safety to the machine operator at the maximum possible level along with high efficiency and high precision.

The development of an automatically operated machine, i.e. farm robot[1–4], without an operator on board could fulfill such requirement. The operator of the multipurpose type light tractor "paddy vehicle" with the boom sprayer is exposed to pesticides while working which is harmful to health. Thus, a more advanced pest control technology which would eliminate the need of an operator sitting on board of the paddy vehicle was designed and developed. An experimental paddy vehicle which would not require an operator on board during the operation was developed through research conducted jointly by the National Agriculture Research Center and the Mitsubishi Farm Machinery Co. Ltd.

The Japanese rice transplanter is a suitable machine for traveling in paddy fields. The riding type transplanter was modified into the "paddy vehicle" which enabled to remove the planting device and then attach the devices for multipurpose operations. Moreover, the joint research team also set up the vehicle operation system by remote control, coupled with preprogramed autonomous vehicle movement.

Paddy vehicle

1) Main characteristics of the paddy vehicle

The clearance of the paddy vehicle with row crop wheels between the body frame and ground is higher than that of the normal type rice transplanter for traveling between the rice plants which grow up. The drive mechanism of the paddy vehicle is a 4-wheel drive. Power take off (PTO) and a hydraulic apparatus were installed. The engine power was 5.6 kW and the weight was 550 kg (Fig 1, Table 1).

2) Automatic search operation

The paddy vehicle is equipped with 1 pair of specifically designed contact sensors at the front of the body. The contact sensors search for the rows of rice plants through a contact rod. The output signals from the sensors are then input to the on-board computer. The computer automatically controls the steering wheel operation. Both contact sensors installed on the right and left-hand sides of the body can indicate the absence of rice plants. The steering wheel is automatically controlled even when only one of the sensors, either on the right or on the left-hand sides emits such signals.

Table 1. Specification of paddy vehicle

Length (mm)	2,850
Width (mm)	1,560
Height (mm)	1,550
Mass (kg)	550
Min. clearance (mm)	600
Distance of wheel axles (mm)	1,200
Trade (mm)	1,200
Drive	4-wheel drive
Steering	Power-assisted
Transmission	Front 6, Back 3
Engine output	5.7 kW/1,800 rpm

3) Turning at the edge of the paddy field

When the paddy vehicle has reached the edge of the field, both sensors on the right and on the left-hand sides signal "free-state". Then the computer indicates that the body of the vehicle should be turned by an azimuth sensor with a gyroscope. The on-board computer with the program whereby the vehicle makes a 90° turn, moves forward over a fixed distance, and then makes another 90° turn.

4) Remote control operation

Functions including steering, brake, throttle, speed changer, PTO drive, and the emergency stop, can be remotely controlled, only when it is necessary. The effective distance of the radio remote controller is approximately 200 m, which is sufficient to cover the entire area of the paddy field with a rectangular shape, the length being less than 100 m. When the paddy vehicle has completed two 90° turns at the edge of the field, the remote controller is used to steer wheels of the vehicle into the right position in the rows of rice plants.

New automatic operation technique supported by the operator

This automatic operation technique system involves operations which can be easily controlled automatically, and which require some support by a person during the progression of the field opera-

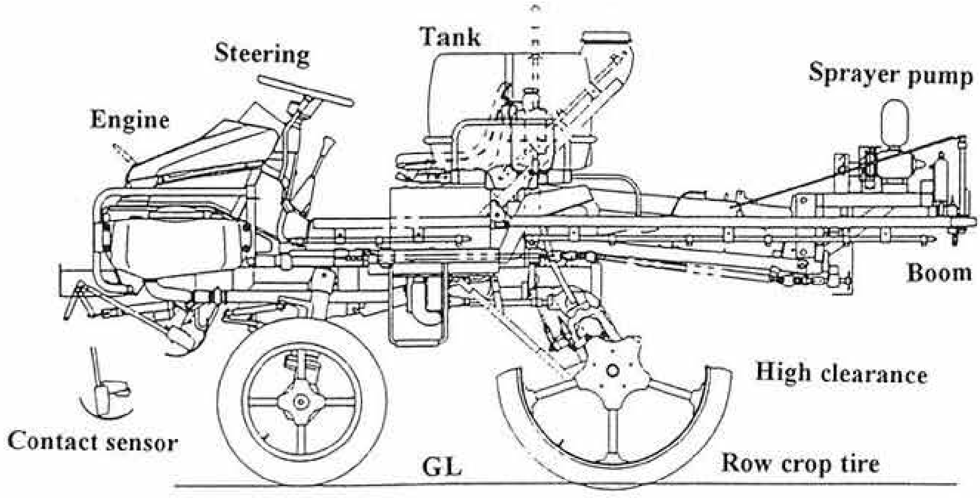

Fig. 1. Schematic diagram of the paddy vehicle

tions. Most of the paddy field operations such as rice transplanting, application of fertilizers and pesticides, and harvesting, require some supplementary operations such as supply of the seedlings and fertilizers, and taking out of grain. A person who carries out such supplementary operations can assist and support the field operating automatically performed by the paddy vehicle.

Automatic turning of the paddy vehicle at the edge of the field is a difficult performance. Especially, steering to the next stroke is extremely difficult even in light of the most recent technological advances. In contrast, it is easy for a person to drive the paddy vehicle to the next rows for servicing with a remote control device. This new automatic work system depends on the remote control operation only when the paddy vehicle turns at the edge of the field, and depends on the automatic operation while the vehicle moves forward between the rows of rice plants which are grown in straight rows.

Methods

1) Experimental field and rice plants

The fields used for the experiment were puddled paddy fields. The dimensions of the paddy fields A and B were 90 m by 90 m, and 30 m by 100 m, respectively. The stage of the rice plants in field A corresponded to 45 days after seeding by drill sowing, and that of the rice plants in field B, to 30 days after transplanting.

Some significant issues which required a close observation during the field experiment included the soil penetration resistance, bending strength of rice plants in the paddy field, traveling velocity of the vehicle in the field, the time required to complete a turn for the next stroke, and the operation time required to complete the assigned job in the given paddy field.

2) Implements for experiment and operation

The spraying width of the boom sprayer was 7.5 m. The sprayer was fitted with a pump driven by PTO and 2 pesticide tanks, 90 L each. The spray boom was mounted at the rear of the paddy vehicle.

The operator did not drive the paddy vehicle on board. Only when the vehicle turned at the edge of the field, did the operator observe the vehicle from the side road of the field to operate the steering wheels of the paddy vehicle by remote radio

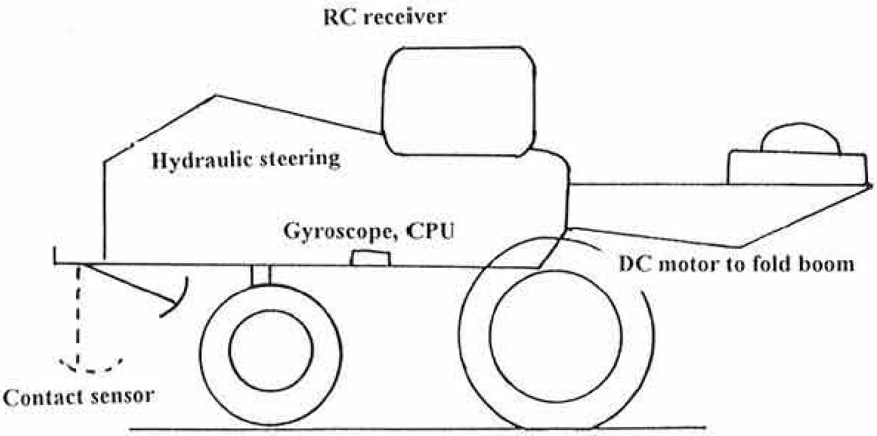

Fig. 2. Devices for automatic control

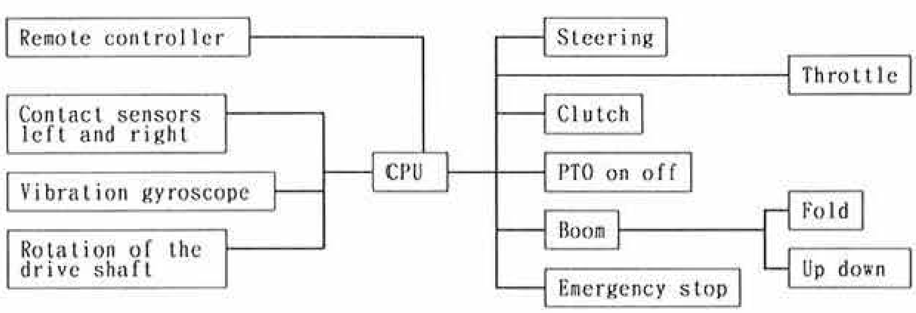

Fig. 3. Automatic and remote control system

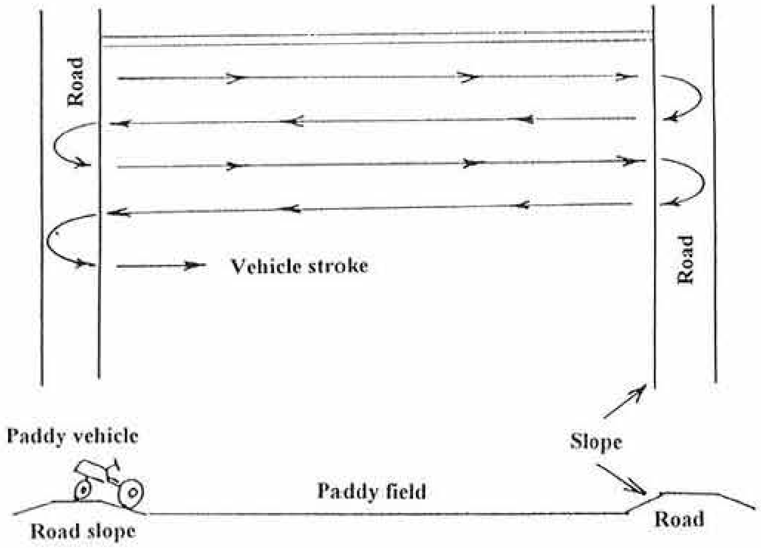

Fig. 4. Experimental paddy field

controller.

When the paddy vehicle reached the edge of the field, it turned by an automatic steering operation, and then automatically stopped and waited for the operator outside the field to remotely control it for steering via radio. After moving the vehicle in the desired position for the next stroke, the operator changed the channels of the remote controller from the manual control mode to the auto-propelling mode. The wheels of the paddy vehicle moved forward between rows of rice plants automatically without an operator on board.

Results of the experiment

1) Auto-traveling by contact sensors

The special functions of an automatic operation were examined in the development steps. Some main characteristics of the operation of the vehicle were initially tested with the use of a remote control device. Automatic turning and automatic stopping engineered by the computer program were successfully tested on a paved road.

The contact sensor was composed of a contact rod, a spring, a rotary encoder, and the installation leg with shoe. The installation leg can be folded and can be moved freely at the installation point on the vehicle. Even when the body of the vehicle moved up and down while automatically moving forward on the paddy field, the distance between the sensor and the surface of the paddy field remained constant. In the experiment, the sensor could sense the young rice plants whose average height was about 30 cm. Although the softer sensing rod with a higher sensitivity accurately sensed young rice, it outputted the wrong signal by also sensing weeds. The harder sensing rod with less sensitivity did not sense either weeds or young rice plants. In order to determine the appropriate level of sensitivity of the sensing rod to be used, adjustment of the sensing parts required tests for many hours.

2) Turning action at the edge of the paddy field

Turning of the paddy vehicle is controlled by the program installed in the computerized controller. When the vehicle reached the edge of the field, the contact sensors perceived that no more rice plants grew beyond that point. After perceiving the end of the row, the controller with CPU ordered to stop PTO and to fold the spraying boom several seconds later. At the same time, the body of the vehicle turned at an angle of 90° by the automatic steering operation. Then, the vehicle moved over a distance of 7.5 m for the next stroke. Again, the vehicle automatically turned with an angle of 90° and stopped. The results of such automatic turning test by the computerized program were as follows.

The contact sensors accurately perceived and detected the end of rows at the edge of the field. The accuracy of 90° turns which were controlled with the gyroscope was close enough for practical purposes.

3) Resumption of automatic operation after turning

The paddy vehicle stopped moving by making two 90° automatic turns as described previously. At this point, a restart signal via remote control sent by the operator is required to direct the body to resume

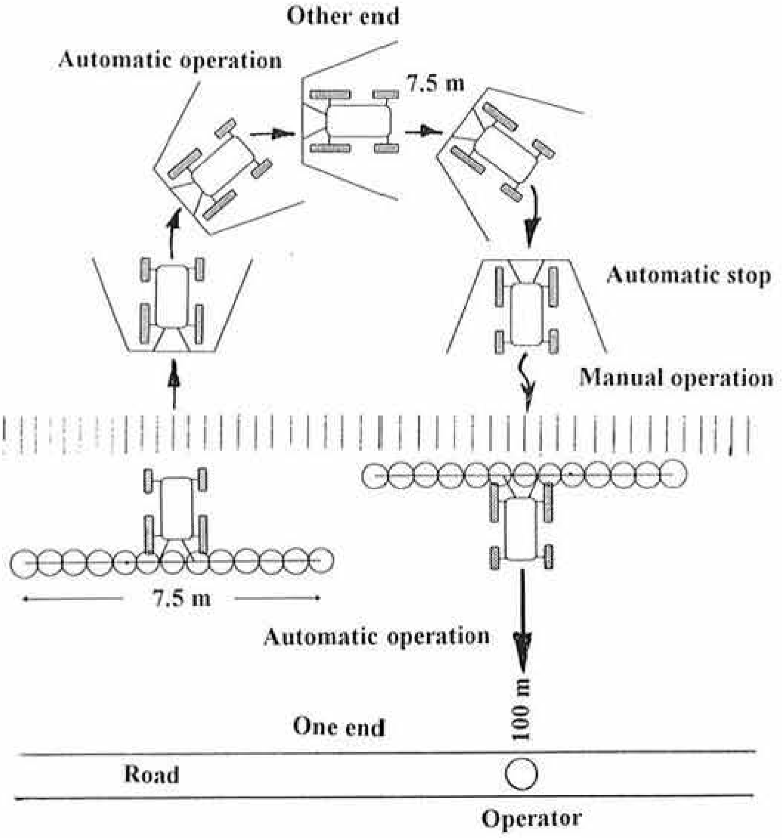

Fig. 5. Automatic + manual control at the end of paddy field

the automatic straight-forward movement. The operator observing the position of the vehicle from the side road sends a signal via remote control for the wheels to penetrate between the appropriate rows of rice plants. This operation is easily handled in the side road. The vehicle which has reached the other side road is remotely controlled by the operator who is observing the vehicle from a certain distance across the field on the side road. In the experiment, the operator was able to locate the front of the row where the vehicle across the field should penetrate into the field for the next stroke, thus successfully restarting the automatic operation of the vehicle. Actually, the operator did not really see exactly the area where the wheels of the vehicle should penetrate in the 30 cm space available between each row of rice plants in the field, because the operator was conducting a remotely controlled operation from the location of the side road. However, when the vehicle was restarted at an inaccurate position, the contact sensor led the wheels between the desired row of rice plants by rapid steering maneuvers. The distance which the wheel had to cover from an inaccurate position to the space available between rice plants was less than 1 m. The difference between the targeted rows into which the vehicle intended to penetrate and the rows into which the vehicle penetrated was 1 row. Consequently the use of the boom sprayer showed an overlap of approximately 1 m. Therefore, the above-described difference of 1 row was found to be acceptable.

4) Operation time

The speed of the automatic forward movement of the paddy vehicle was set at 0.5 m/s, which is suitable for effective spraying. In the experimental paddy field, the average speed of the vehicle was 0.45 m/s. The process of automatic turning of the vehicle started when the vehicle stopped at the end of the rows, and ended when the vehicle had completed the two 90° turns previously described, thus setting itself is a position for the next stroke. This process took 35 s on the average. Then, the process of maneuvers to secure the accurate position of the vehicle via remote control by the operator until the vehicle resumed automatic forward movement required 20 s on the average, ranging from 10 to 30 s. The total time required to complete the automatic operation by the vehicle with the sprayer attached in the 30 a field was 18 min, excluding the

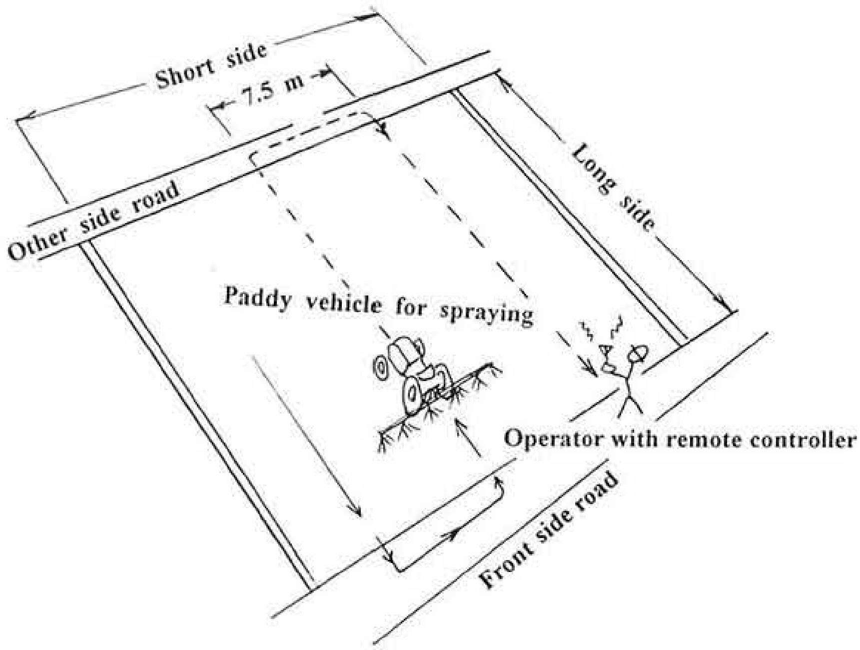

Fig. 6. Automatic operation of the paddy vehicle with a sprayer

time required to supply pesticides.

Discussion and conclusion

With the paddy vehicle completing each stroke of spraying jobs by automatic forward movement between the straight rows of rice plants, and also automatically making turns on the side road after each stroke of spraying, the operator can support the vehicle with a sprayer using a remote controller on the side road. It was possible for the operator to manage the spraying of pesticides in avoiding the mist of the pesticides. The operator was in charge of the support for the vehicle to turn accurately and the supply of pesticides. The operator did not have to be engaged in any physical work, while the paddy vehicle was performing the spraying by automatically moving forward between the rows. Then the operator was able to put another paddy vehicle into operation in another field. With this new automatic system, 2 or more paddy vehicles could be operated simultaneously by a single person.

The concept of 1 operator per machine had been considered to be essential for currently commercialized machines such as tractors. This concept may no longer be valid, because the new automatic operation system in which several paddy vehicles are handled by 1 operator simultaneously was eventually developed. It was generally considered that large-size machines were indispensable to achieve high efficiency, based on the concept of 1 operator in charge of 1 machine. By this new automatic method, in contrast, a number of machines larger than the number of operators can be operated simultaneously. As a result, the simultaneous use of several automatic small-size machines was found to be more efficient than the conventional operation of 1 large-size machine. Small machines such as the paddy vehicle described in this report are suitable for the paddy fields of Japan. This method could be applied to harvesting and other field operations by the joint research team. In the near future, automatic implements such as this paddy vehicle could be widely used in paddy fields. The operators will not have to be on-board. Instead, they will support the operation of automatic machines on the side road.

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