An Automated Rice Transplanter with RTKGPS and FOG

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Abstract

      An automated rice transplanting system has been developed. This study's objective was to develop an automated operation system to make precise operation more efficient. A real-time kinematic GPS (RTKGPS) was used to locate the position and fiber optic gyro (FOG) sensors to measure the direction and the inclination of the vehicle. RTKGPS has 2-cm precision at 10-Hz data output, but the vehicle inclination influences the position data and the position data has about 70-ms delay. The influence of the vehicle inclination is corrected by measuring the inclination with FOG sensors. The RTKGPS receiver generates one pulse per second as cues for measuring the position. A timer was used to synchronize measuring the position with the inclination every 100 ms. When the vehicle was driven straight automatically, the deviation from the desired straight path was less than 10 cm. The GPS data quality indicator was obtained during the operation, and the operation was interrupted when GPS could not locate the precise position.

[Keywords] Automated operation, rice transplanter, RTKGPS, FOG

1. Introduction

      Recently in Japan, there has been a trend to consolidate and enlarge paddy fields. However, while the number of operators is decreasing, the workload of operators is increasing. Therefore, a more efficient operating system is required. If an automated operating system were developed, one person could operate multiple machines. This study's objective was to develop an automated operation system to make precise operation more efficient. In order to realize automated operation, it is necessary to locate the position and direction of the vehicle in the program and to drive precisely. In recent research, Yukumoto et al. used an optical wave range finder and magnetic azimuth sensor[1]. Noguchi et al. used image processing and a magnetic azimuth sensor[2]. But these techniques require equipment on the field and location precision will be influenced by the weather. Inoue et al. used differential GPS and an FOG sensor[3]. Elkaim et al. used carrier phase differential GPS[4]. They obtained good results for tillage, but these lack the requisite precision for rice transplanting. Because the inter-row spacing of rice plants is about 30 cm, the vehicles must be driven accurately. However, unevenness of the ground and side slip of the wheel distort the vehicle direction. Therefore, compared with driving on solid terrain, it is difficult to drive a vehicle straight in paddy fields. Consequently, in 1996, the authors used an RTKGPS to locate the precise position[5]. It has 1-cm precision at 1-Hz output, but the time delay is long,

and the authors could not obtain a sufficiently precise real time position. In 1997, new RTKGPS receivers were used and the vehicle control method was improved [6]. The time delay was shortened, and location precision and deviation from the desired path were improved. In 1998, a new rice transplanter was modified[7] and long mat type hydroponic rice seedlings developed in the Japan National Agriculture Research Center were used[8]. The long mat type has sufficient seedling capacity to transplant one field without reloading. In 1999, the authors used the latest RTKGPS receivers and corrected the drift of the FOG sensor[9]. In this paper, the outline of an automated rice transplanter is reported.

2. Materials and methods
2.1 Rice transplanter

The authors modified a 6-row rice transplanter, the transmission of which has HST. Fig. 1 shows the rice transplanter and Fig. 2 shows the scheme of an automated rice transplanting system. An RTKGPS was used to obtain the position of the rice transplanter. It has 3-cm precision at 10-Hz data output. The RTKGPS reference station and rover station communicated via 5-mW output wireless modems and its baud rate was 9600 bps. An FOG was used to measure the yaw angle and an inclination-measuring apparatus was used to measure the roll and pitch angle. RTKGPS data output latency was around 70 milliseconds. One pulse per second output

Fig. 1 Automated rice transplanter

from the RTKGPS shows the timing of the measuring position. A timer counter board was used to measure 100 milliseconds and the yaw, the roll and the pitch angle were measured at 10 Hz and synchronized with locating the position. As the vehicle inclination influences the position data, the corrected position was calculated. The main computer CPU was Intel DX4 100 MHz running under PC-DOS. The steering and the engine throttle were controlled by DC motors and the brake, the clutch, HST lever and the up-down controller of the transplanting module were controlled by electrical linear cylinders. The positions of the brake and the clutch actuator were sensed by limit switches and others were sensed by rotary encoders. The control program was developed with C.
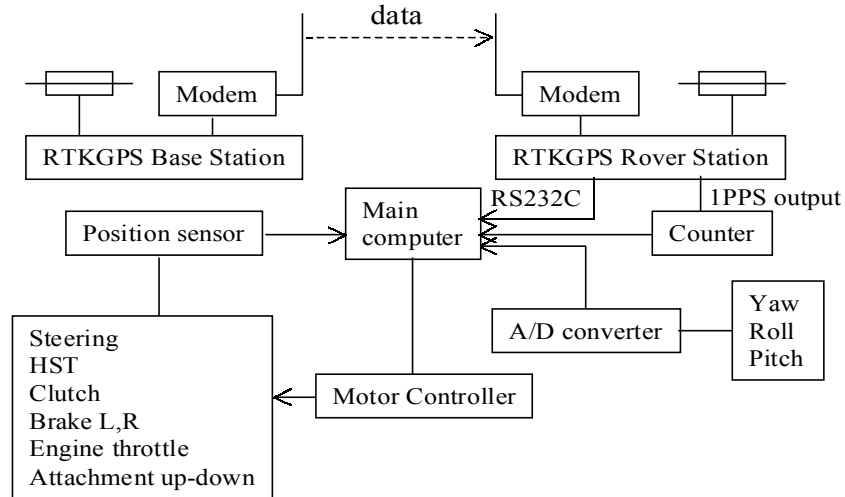
Fig. 2 Automated rice transplanting system

2.2 Correction of the inclination

The GPS rover station must communicate with the reference station to receive the reference data over a radio link. The rover receiver requires synchronized GPS measurement data from the reference station once per second. This study used 5-mW output wireless
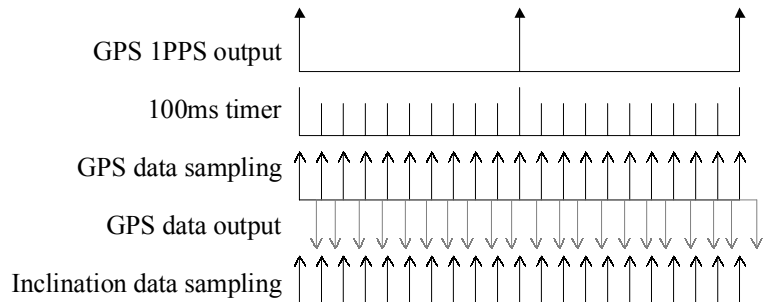

Fig.3 Synchronization of GPS and the inclination data

modems between the reference and rover stations. The rover receiver's data output delay is about 70 milliseconds and the output interval is irregular. Therefore, the measuring inclination must be synchronized with locating the vehicle position. Fig. 3 shows the flow of the data sampling. The RTKGPS receiver has an output of 1 pulse per second. In order to restore this timing fluctuation, a pulse counter board was used in the PC. When 1PPS output pulse is received by the counter board, the board starts counting every 100 ms. The yaw, the roll and the pitch angle data are A/D converted every count.

When a rice transplanter travels in a paddy field, the roll and pitch angle is about 3 degrees. In this system, the GPS antenna is fixed on the rice transplanter. Assuming the antenna height is 2 m, the horizontal distance between the top of the antenna and the bottom is 10.5 cm when the roll angle is 3 degrees. As the GPS data is the position of the antenna top, the influence of the roll and pitch must be corrected.

When the point measured by GPS is assumed as $P_1(x_1,y_1,h_1)$, the roll angle is θ, the

pitch angle is ϕ, the yaw angle is ψ and the height of the GPS antenna is h. The desired

straight path is given as the following equation:

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$$Y = kX + C \qquad (1).$$

The corrected position P_{crr} is expressed as follows:

$$p_{crr}\left(p_1 - \frac{h}{\sqrt{1+k'^2}}(k'\sin\theta + \sin\phi), \quad q_1 - \frac{h}{\sqrt{1+k'^2}}(k'\sin\phi - \sin\theta), \quad h_1 - h\cos\theta\cos\phi\right)$$

$$\cos\psi' = \left(\sqrt{1 + (\tan\psi\,\frac{\cos\theta}{\cos\phi})^2}\right)^{-1} \qquad\qquad k' = \frac{\sin\psi' - k\cos\psi'}{\cos\psi' - k\sin\psi'}$$

2.3 Correction of initial yaw angle offset

It is very difficult to set the vehicle direction parallel to the traveling direction. The FOG sensor cannot sense the azimuth and it has drift. So, to sense the initial yaw angle, the deviation from the desired path calculated by the yaw angle and vehicle speed was compared with the deviation calculated by GPS data (Fig. 4). Then, the offset angle was calculated and the yaw angle was corrected.

The deviation from the desired path measured by RTKGPS is assumed as d_{GPS} and the deviation calculated by the yaw angle $\psi(i)$ and the vehicle speed $v(i)$ is d_{Gyro}. $v(i)$ is measured by GPS.

Fig. 4 Correction of initial yaw angle offset

d_{Gyro} is estimated as the following equation (2). In this equation, n is the time after starting calculation and t_s is the sampling interval. d_{Gyro} is calculated 15 seconds after starting operation.
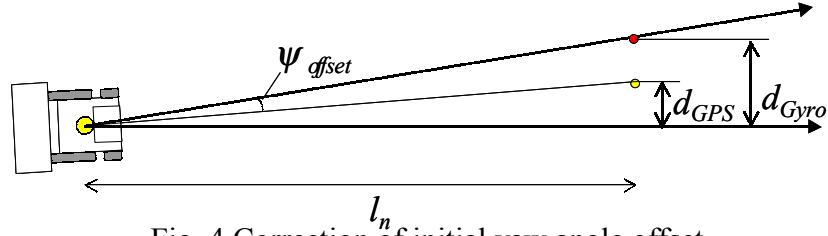
$$d_{Gyro} = \sum_{i=0}^{n/t_s} v(i) \cdot \psi(i) \qquad (2).$$

Then, the distance from the starting point is l_n, and the offset of the yaw angle ψ_{offset} is calculated as the following equation (3). In this equation, it is supposed that d_{GPS} and d_{Gyro} are sufficiently smaller than l_n.

$$\psi_{offset} = \arctan\left(d_{Gyro}/l_n\right) - \arctan\left(d_{GPS}/l_n\right) \cong \left(d_{Gyro} - d_{GPS}\right)/l_n \qquad (3).$$

2.4 Vehicle control method

Before starting operation, the computer must create a desired path along which the rice transplanter travels and an aim point. In this study, the paddy field is assumed to be rectangular. The four corners A, B, C and D in the field were measured previously. Before starting, the rice transplanter is at point P_n. Fig. 5 shows the method for calculating the aim point. First, a line parallel to line AB is drawn over P_n; this is line l_1. l_1 is the desired path along which the rice transplanter travels. Line l_1 and line BC intersect at P_{e1}. P_{e1} is the aim point of the operation. When the vehicle reaches P_{e1}, the next desired line l_2 and the aim point P_{e2} are calculated. Line l_2 is drawn at an interval of 1.8 m to l_1. Line l_2 and line AD intersect

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at P_{e2}.

The rice transplanter must be driven along the desired path. The steering is controlled to get back as closely as possible to the desired path. When the deviation from the target line is assumed as d and the yaw angle is ψ, the aiming steering angle δ_{aim} is given as the following equation. K_{p1}, K_{p2} and are decided by the vehicle speed.

$$\delta_{aim} = K_{p1}d + K_{p2}\psi \qquad (4)$$

At the headland, the rice transplanter moves forward and backward to turn so as to minimize the headland space. Fig. 6 shows the control way of turning. The width of the headland is 3.5 m. When the rice transplanter reaches the edge of the field, it moves backward 40 cm in a straight line. While the rice transplanter is turning and the yaw angle is less than 160 degrees, only the yaw angle is obtained, the steering angle is maintained at 40 degrees and one side brake is applied. When the yaw angle is greater than 160 degrees, the rice transplanter is controlled to get back as closely as possible to the next

Fig. 5 Decision of the aim point

Fig. 6 Control way of turning

desired path. If the rice transplanter does not get sufficiently close to the new desired path after turning, the steering is controlled to get as close as possible to the desired path when it moves backward.

The GPS data quality indicator is monitored while the rice transplanter travels automatically, and if the radio link between the GPS base station and the GPS rover station is disconnected, the clutch is released and the operation is interrupted.

3. Results and discussion

The experiment was conducted 4 days after puddling. Fig. 7 shows the path of the GPS antenna, and in this data, the influence of the vehicle inclination was corrected. The deviation from the desired straight path was less than 10 cm at a traveling speed of 0.8 m/s during the operation. The rice transplanter went forward and backward in a 20 m×100 m square field 4 times. As the turning radius of the vehicle at the headland was around 2 m, it was easy to get back as close as possible to the new desired path after turning.

In this experiment, conventional mat type rice seedlings were used and two persons supplied them to the rice transplanter every two returning operations at the edge of the field. At the headland, it took 50 seconds to turn and to get back as close as possible to the new desired path. The turning time was shortened by about 30 seconds, which is dependant on the use of HST. It took more than 100 seconds to change the moving direction in the previous model. The operating time was 22 minutes per 10a.
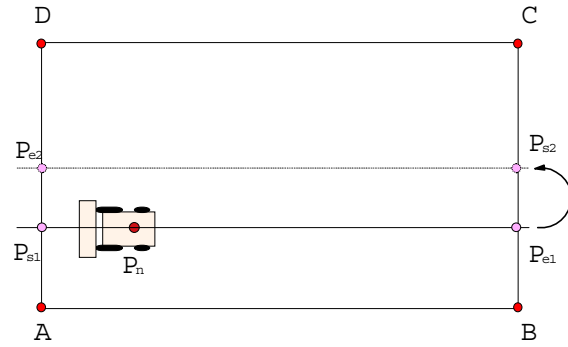
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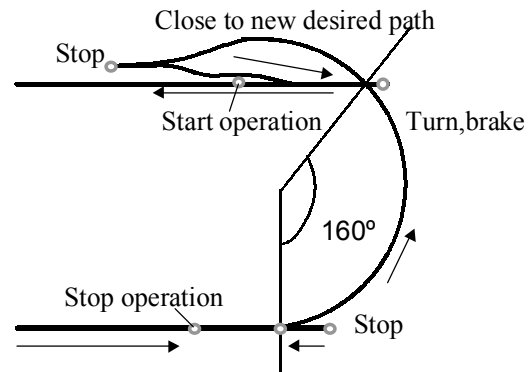
When the data communication between the RTKGPS base and rover station via radio link was disconnected, the clutch was released and operation was interrupted. Then, as soon as the radio link was connected, operation started again.
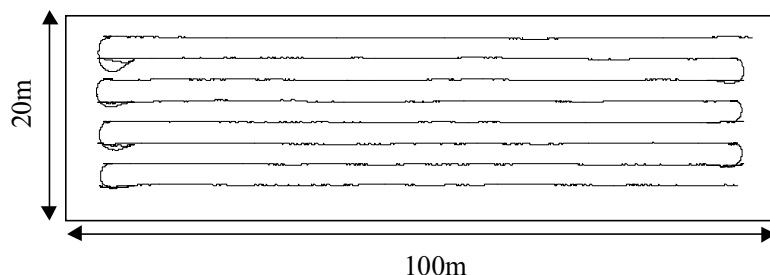

Fig. 7 The path of the automated rice transplanter

4. Conclusions

In this study, a new 6-row rice transplanter was developed. RTKGPS was used to locate the precise position and FOG sensors were used to measure the inclination and direction of the vehicle. As the inclination of the vehicle was corrected and the data sampling timing was synchronized, in this experiment, the deviation from the desired straight path was less than 10 cm when the rice transplanter traveled 100 m in a paddy field. This rice transplanter has HST and it is easy to change the travel direction. Therefore, compared to the previous automated rice transplanter, the turning time was shortened by about 30 seconds and operation efficiency was improved. The operating time was 22 minutes per 10a at the 20 m×100 m field. The operation could be interrupted when the GPS receiver lost the precise position by obtaining the GPS data quality indicator and precise operation could be maintained.

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