A Control Method of Driving a Paddy Vehicle Straight Ahead for Automatic Operation

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ABSTRACT

A method for automatically driving paddy vehicles, such as rice transplanters, etc., straight ahead in a paddy field was investigated. The direction of such vehicles must be precisely controlled to do the operations as straight. However, the alignment of the front wheels becomes distorted due to the unevenness of the ground, preventing the vehicle from going straight. If the proper alignment of the front wheels is maintained, the vehicle can be driven straight ahead greater precision. To investigate the influence of the ground unevenness, the behavior of a paddy vehicle running over an obstacle was quantified. The left wheel ran over an obstacle on a flat concrete road surface. When the steering wheel was free, the front wheels were forced toward the left when vehicle went up the obstacle and toward the right when the vehicle went down it. The torsion of the wheel when the vehicle went down the obstacle was larger than that when it went up, so it turned right 5 degrees. Since hydraulic control steering decreased the steering angle, it turned right 3 degrees. These results suggest that a vehicle can be driven straight ahead with high precision when the steering angle is changed in response to the direction and inclination of the vehicle. Such results were obtained in a paddy field tests.

Key Words : paddy vehicle, obstacle , inclination of vehicle, torsion of the wheel

INTRODUCTION

Large paddy fields impose heavy tasks on a vehicle operator. Therefore it is necessary to develop an automatic steering system for a vehicle in a paddy field, especially to drive it straight ahead with high precision. Nonami *et al.*(1994)[1,2] reported automatic control of a rice transplanter, but did not discuss the influence of bumpiness and inclination on a vehicle. In a paddy field, bumps are made by a tractor or vehicle wheel. When a vehicle runs over the bumps, the alignment of front wheels are distorted, preventing the vehicle from going straight. The objective of this report was to analyze the influence of the ground unevenness on the behavior of a paddy vehicle, and to investigate a control method. A simulation was done and the torsion of steering, the steering angle and the roll, the pitch and the yaw angle are measured in experiments.

SIMULATION

In the simulation, an isosceles triangular obstacle was used to simulate a bump on a flat surface. The side and front views of the front wheels are shown in Fig. 1. In the side view, the radius of the wheel is r, the inclination of the obstacle is θ, that of the vehicle is θ_1, the angle between the line which tied center to the contact of the wheel and the axle is ϕ_1 and the horizontal distance between the top of the obstacle and center of the wheel is l_1. In the front view, the wheel inclination is ϕ_2.

When the vehicle goes up the obstacle, the axle inclines backward. The wheel makes contact with the obstacle in front of the axle.

$$\phi_1 = \theta - \theta_1$$

and the distance between the axle and the contact , d, is

$$d = r\sin\phi_1$$

The load on the front wheels is w, so the force of the wheel axle direction w' is

$$w' = w\sin\phi_2$$

Since the contact is in front of the axle, so the torsion of the wheel T is

$$T = w'd$$

When the wheel passes the top before the axle does,

$$l_1 = r\sin(\phi_1 + \theta_1)$$

When ϕ_1 is obtained from the above expression, d is decided. After the axle passes the top,

$$l_1 = r\sin(\phi_1 - \theta_1)$$

When ϕ_1 is obtained from the above expression, d is decided.

Finally, when the vehicle goes down the obstacle, ϕ_1 is

$$\phi_1 = \theta + \theta_1$$

At this time, the contact between the wheel and the obstacle is behind the axle and d becomes greater than that when it goes up. So the torsion when a vehicle goes down is larger than that when it goes up.

The load w is assumed to be 2452N(250kgf), the base length of the obstacle is 48cm, θ is 27.5 degrees and r is 30cm. The left wheel runs over the obstacle. The displacement of advance is x, and x is 0 when the center of the wheel is in 30cm front of the obstacle. The result of the simulation is shown in Fig. 2. While a vehicle goes up, the torsion on the left increases as the vehicle advances. When the wheel reaches the top of the obstacle, the torsion is maximum. After that, ϕ_2 increases, but due to the rapid decrease of d, T also decreases. When the top of the obstacle is immediately below the axle, the torsion is 0. After the axle passes over the top while the vehicle goes down, the torsion on the right increases. When the hypotenuse of obstacle equals the tangent of the wheel, the torsion is maximum. Then the torsion decreases.

According to these results, when the steering wheel was free, the front wheel was forced toward the left at first, then after passing the top it was forced toward the right. Since the torsion on the right was larger than that on the left, the vehicle would be traveling in the right direction after running over the obstacle. When the rear wheel runs over the obstacle, a similar result is obtained. But since the rear wheel is fixed, the affect on the direction of advance would be small.

MATERIALS AND METHODS

The paddy vehicle used in this experiment is shown in Fig. 3. When the vehicle was driven by computer, the steering gear was made to be moved by hydraulic cylinder which was controlled by a servo valve. The hydraulic circuit is shown in Fig. 4. The steering angle was measured with a potentiometer, the torsion with a load cell, the roll and the pitch angle with an attitude measuring apparatus and the yaw angle with an fiber optical gyro sensor. The performance of the attitude measuring apparatus and fiber optical gyro sensor are shown in Tables 1 and 2.

An obstacle was put on the flat concrete road surface. When the left wheel of the paddy vehicle ran over it, the steering angle, the torsion of the steering, the roll, the pitch and the yaw angle were measured and recorded in a data recorder. Experiments on the concrete road surface were made under two conditions; the steering wheel was free and in the other hydraulic control was used. In hydraulic control, the allowance of the steering angle was set to 1 degree, so if the steering angle changed more than this value, the front wheel was straightened. The velocity of the vehicle was 0.3m/s.

In the experiments in a paddy field, the same items were measured.

RESULTS AND DISCUSSION

When the front wheel ran over the obstacle with free steering wheel, the roll angle was not output because the front wheel axles are mobile. The results are shown in Fig. 5. The torsion was forced probably due to the friction within the cylinder. The torsion on the left became maximum as the wheel was going up, about *40* N-m with a steering angle of *5* degrees. When the pitch angle was near the maximum, the torsion and steering angle were both *0*. The torsion on the right became maximum as the wheel was going down, reaching about *60* N-m with a steering angle of *12* degrees. The yaw angle changed about 1 second after the steering angle changed. This result was similar to the simulation, and the vehicle traveled in the right direction after running over the obstacle. When the rear wheel ran over the obstacle, the alignment of the front wheel was distorted. But this distortion was only quarter of the front wheel running over, and the steering angle was not so influenced.

The results for the hydraulic control are shown in Fig. 6. The torsion on the left became maximum as the wheel went up, reaching about 80 N-m with a steering angle of *3* degrees. The steering was forced against the torsion, so the steering angle was changed to the right before the pitch angle reached the maximum. The torsion on the right became maximum as the wheel went down, reaching about *100* N-m with a steering angle of *8* degrees. The vehicle traveled in the right direction after running over the obstacle, but the steering angle changed 2/3 that of the free steering wheel. So if the steering is fastened when the vehicle goes down the obstacle, the change of traveling direction can be reduced. And the yaw angle was influenced as the roll angle increases.

Fig. 7 shows the result when the steering wheel was free in a paddy field. From 2 to 4 seconds, when the pitch angle was changed from 1 degree to -2 degrees , the steering angle changed from 1 degree right to 0.8 degree left. In this case, it is thought the left wheel went up the bump and the torsion on the left was added. If the inclination of the vehicle is enough large and the steering is forced against the distortion, it is thought the change of traveling direction can be reduced. And if the inclination of the vehicle is small and the steering is straightened , it is thought the vehicle runs straight ahead.

CONCLUSIONS

When the vehicle run over the obstacle, the contact between the ground and the wheel differed from right to left and the wheel axle inclines. Then the torsion of the wheel is occurred. So the alignment of the front wheels is distorted. If the speed of the steering changed according to the inclination of the vehicle, it could be driven straight ahead with high precision.

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Table 1. Performance of the attitude measuring apparatus

entry	Output
Measure angle	±45 degree
Scale factor	4.5 degree/Volt
Resolution	0.2 degree
Linearity	±1%
Horizontal accuracy	0.2 degree
Free drift	2 degree/min
Frequency response	200 Hz
Output voltage	±10 V (Full scale)
temperature	-10～50℃
Humidity	under 95%RH

Table 2. Performance of the fiber optical gyro sensor

entry	Output
Measure angle	±180 degree
Range	±10,20,45,90,180 degree
Resolution	0.01 degree (at range±10)
Linearity	±1%
Bias stability	±3 degree/h
Angle drift	±0.5 degree/h
Frequency response	20 Hz
Output voltage	±5 V (Full scale)
Mistake alignment	under 7 mrad
temperature	-10～50℃
Humidity	under 85%RH

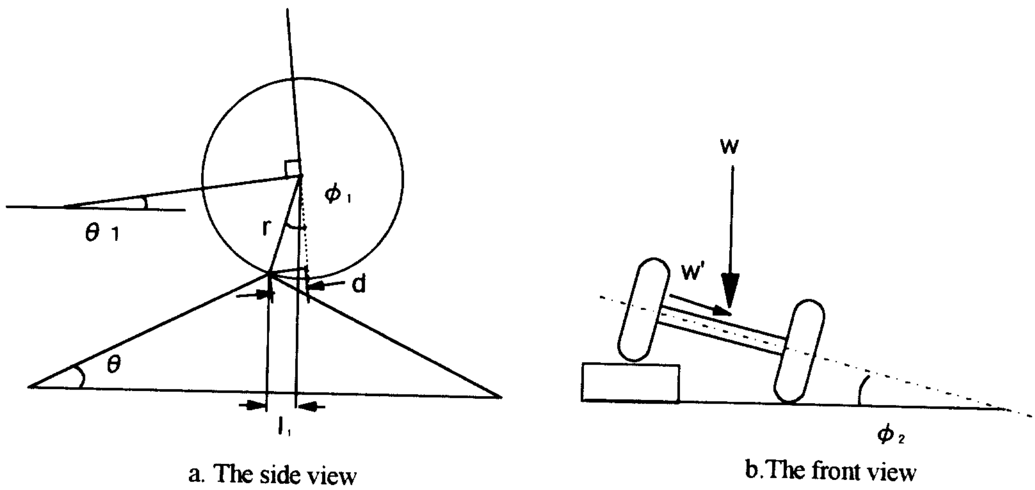

Fig. 1 The obstacle and the wheel

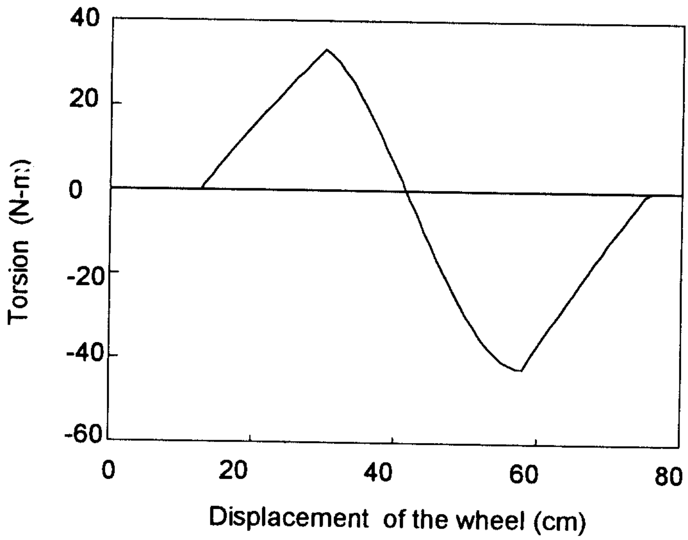

Fig. 2 Result of simulationl

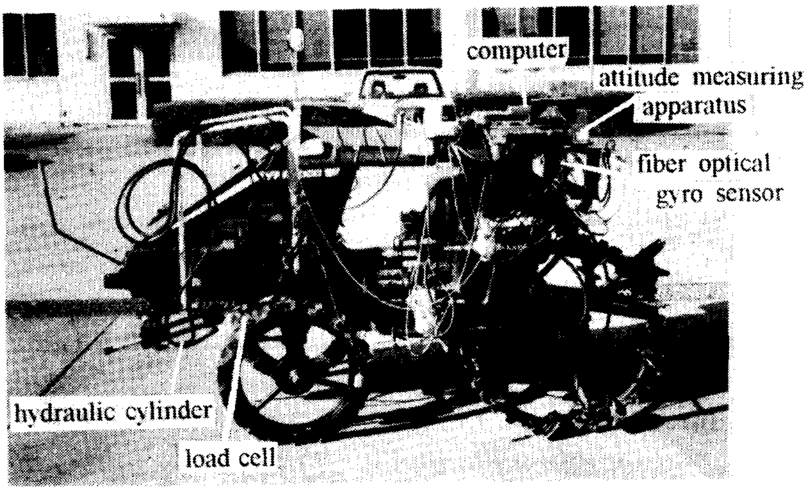

Fig. 3 The paddy vehicle

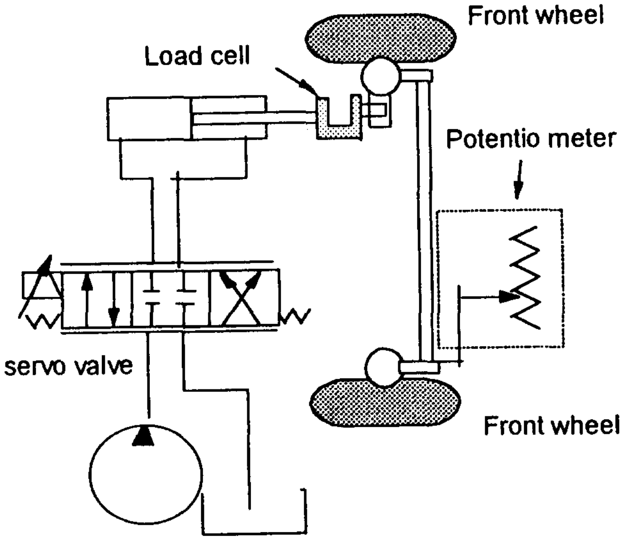

Fig. 4. Steering control system

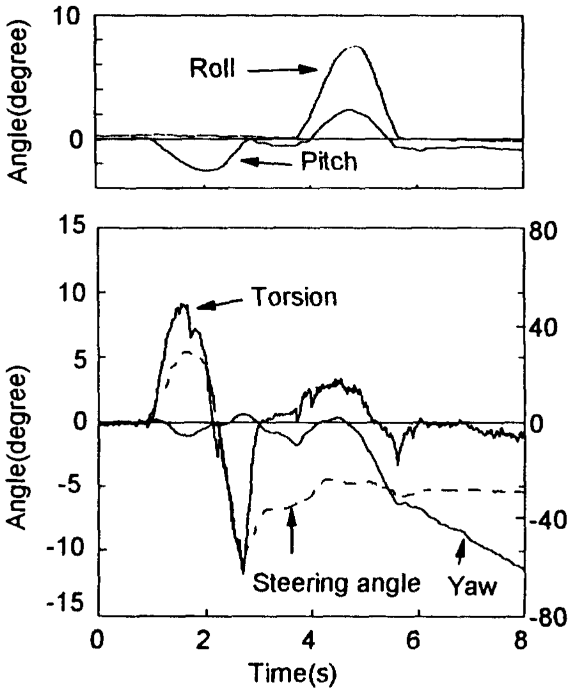

Fig. 5. The change of angles when the steering wheel was free on the flat concrete surface

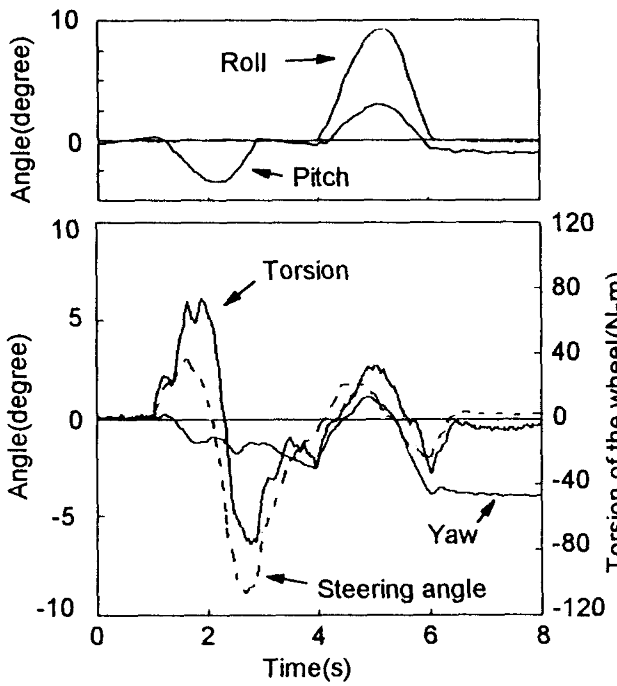

Fig. 6. The change of angles when the steering is under hydraulic control

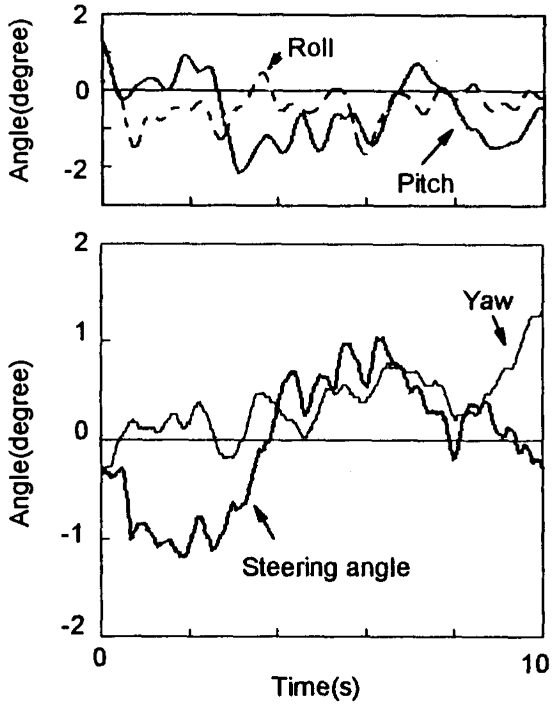

Fig. 7. The change of angles when the steering wheel is free in a paddy field