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傾斜地におけるトラクタの開ループ特性
Open-loop Characteristics of a Farm Tractor on Sloped Terrain

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I Introduction

In agricultural field-operation, tractor is the most widely used vehicle. Many researches, therefore, have been conducted to investigate the characteristics of tractor motion. But most of them are for flatland environment. In Japan most of the lands are under mountainous area, especially the grasslands or meadows are usually in hilly areas, where farm tractors perform various tasks. To overcome the shortage of skilled-labor in agriculture, research on automation of farm vehicles is now getting a pace in Japan. Recently Torisu et al. (2002) are conducting research on the tractor guidance on sloped terrain. The investigation for the open-loop characteristics of vehicle motion on sloped terrain is a part of this research.

Bell (2000) studied the automatic tractor guidance on sloped terrain, but he did not study the behavior of vehicle motion on the slope. Rehkugler et al. (1978) predicted steering and heading responses by simulation. Their analysis was based on static assumptions. Therefore, the effects of ride motion and tire slip were ignored. Crolla et al. (1984) studied the tractor handling during control loss on sloping ground. They concentrated their study on the measures to avoid accident often occurring on the sloping ground, where the travel paths of tractor are considered along uphill and downhill directions. According to them, one of the causes of accident was lack of grip between the tractor wheel and the ground. In such case, equilibrium in the plane of the slope is lost and the resultant sliding motion has been referred to as a "control loss" because recovery from such a slide was not easily achieved. Crolla et al. used a mathematical model to describe the tractor behavior on sloped terrain. To simulate the actual behavior of tractor motion on the slope, a range of parameter values and initial conditions must be measured. Clearly this presents difficulties, particularly those due to random variations in ground surface profiles, tire-ground friction forces, slope variations, etc. Since these parameter values vary depending on many factors, it is very difficult to formulate an appropriate mathematical model to represent the vehicle input-output relationship on the slope. Crolla et al. finally agreed that the mathematical model used to simulate the tractor behavior on slope was less accurate. Therefore, the objectives of this study are to investigate the open-loop characteristics of vehicle on slope-land environment.

II Test Field and Autonomous Tractor

1. Test field and experiment conditions

The experiments were performed at Takizawa Farm of Iwate University in May 2003. The test field was a sloped terrain meadow, and a 30 m long contour line was used for the experiments. The average slope inclination was 9°. The tractor velocity was 0.5 m/s throughout the test.

2. Autonomous tractor

The specification of the autonomous tractor is shown in Table 1.

Table 1 Specifications of the test tractor

Type		Mitsubishi MT2501D
Length × Width	[m]	2.71 x 1.31
Wheelbase	[m]	1.595
Weight	[kg]	1125
Rated Power	[kW]	18
Drive Mode		4WD
Tire Type		High lug

The tractor was equipped with a 1.0 GHz Pentium PC as the sensor-signal processor and steering control unit. It was also equipped with an 82W DC motor as the steering actuator, a potentiometer to measure the steering angles, a magnetic sensor to measure the engine rpm in other words the vehicle velocity, and a fiber optic gyroscope (FOG) of JG-35FD model to measure the heading angle. The FOG could measure heading angle within the range of ±180° and angular velocity within the range of ±100° /s. Its angular drift is less than ±1.5°/h. The tested tractor and instrumentation is shown in Fig.1. The equipment used to measure the vehicle

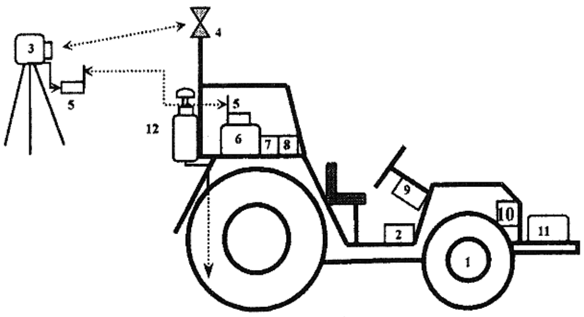


Fig. 1 Instrumentation in the Tested Tractor

positions was a Total Station of Leica TCA1105 model, which has 2 mm positioning accuracy. A prism, as a pair of Total Station (TS), was mounted on the tractor rear and was placed at a height of 1.89 m from the ground and 1.314 m behind the tractor's center of gravity. Two SS wireless modems were used to transmit the signals of the tractor-position from the Total Station to the PC. The Total Station can locate the prism mounted on vehicle within 3.0 km range; however, the modem used had a maximum range of 0.2 km. The expected time interval of data –transfer from TS to PC was 0.5 sec. But due to the limitation of TS, there was a little variation in the time interval. Fortunately, this had insignificant effect on the system.

Ⅲ Experiment methods

To study the open-loop characteristics of vehicle motion on slope, two types of field test were conducted with the prototype tractor:

(a) Rectilinear motion test,

(b) Circular motion test.

Instead of human operator, a tractor mounted PC and other equipments were used to operate the tractor in the test. For each test the PC generated the designed steering-actuation signals and accordingly the DC motor rotated the steering wheel.

1. Rectilinear motion test

The rectilinear motion test was conducted on a 8° inclined surface where the ground was roughly uniform and covered with short grasses. The desired travel path was along a straight contour line. Prior to the travel, the lateral position (at the center of gravity), steering and heading angle of the vehicle were initialized to 0.0 m, 0 ° and 0 ° respectively with respect to the desired path. During travel the PC generated 0° steering actuation signals throughout the test. The tractor velocity was fixed at 0.5 m/s.

2. Circular motion test

The circular motion test was conducted on the same inclined surface where the rectilinear motion test was performed. But the inclination of the test surface was varied in the range of 8° ~9° . The circular motion tests were conducted for fixing the steering wheel at two separate steering angles: 30° and 40° . For each fixed-steering the test was performed twice: once in the clockwise and the other in the anticlockwise directions of motion. During the travel the PC continuously generated same steering actuation signals (for instance 30°). The vehicle velocity was 0.5 m/s.

3. Data acquisition

The vehicle position, heading angle, steering angle and velocity were continuously recorded in the control computer at about 0.5 sec regular intervals. The data flow in the system is shown in Fig.2.

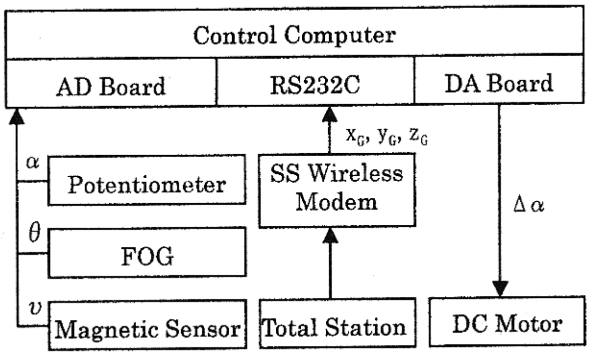
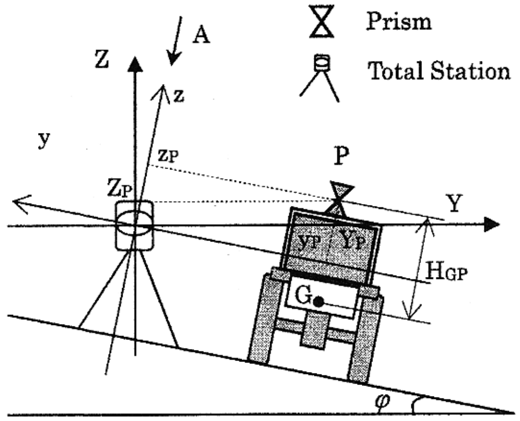


Fig. 2 Data flow in the system

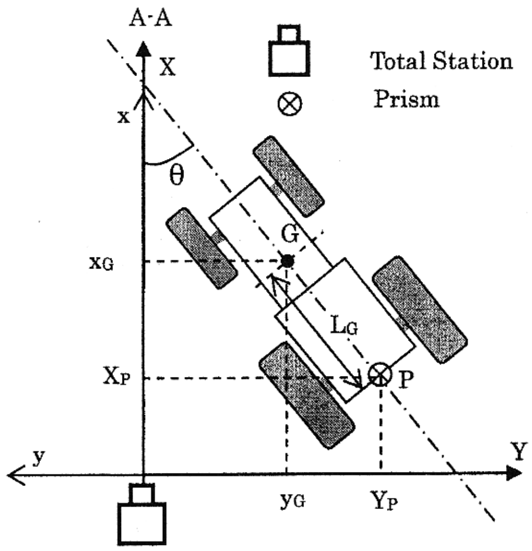
Where the heading angle(θ), steering angle (α) and velocity (v) were got through AD Board; the control steering angle ($\Delta\alpha$) was sent via DA Board; and the vehicle position (x_G, y_G, z_G) was attained by RS232C port. To get the data related to the slope, coordinate transformation was performed. Fig. 3 shows the relationship of the Total Station-fixed (XYZ) and the slope-fixed coordinate (xyz). The transition can be expressed as

$$\begin{bmatrix} x_G \\ y_G \\ z_G \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -\cos\varphi & \sin\varphi \\ 0 & \sin\varphi & \cos\varphi \end{bmatrix} \begin{bmatrix} X_P \\ Y_P \\ Z_P \end{bmatrix} + \begin{bmatrix} L_G\cos\varphi \\ L_G\sin\varphi \\ -H_{GP} \end{bmatrix}$$

Where (x_G, y_G, z_G) is the position of the center of gravity in the slope-fixed coordinate; (X_P, Y_P, Z_P) is the position of the prism in the Total Station-fixed coordinate; φ is the slope inclination; H_{GP} is the height from prism to the center of gravity; L_G is the distance from the prism to the center of gravity along the vehicle's centerline.



(a) Front View

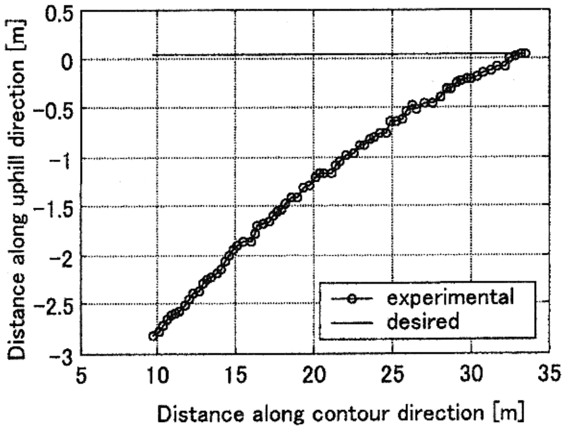


(b) A-A Viewgraph

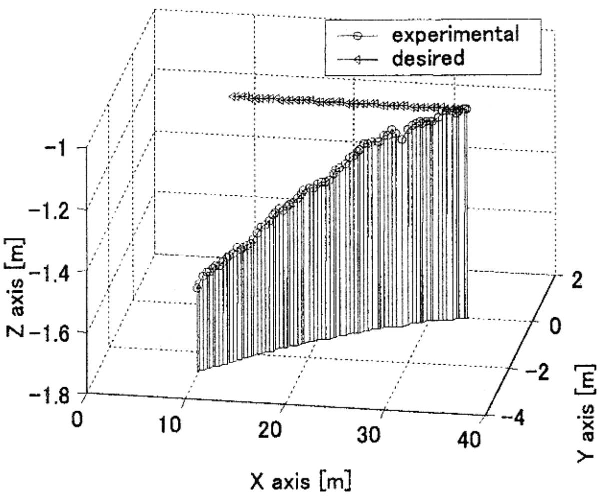
Fig. 3 Relationship of Total Station-fixed and slope-fixed coordinate

IV Results and discussion

The trajectories of the rectilinear-motion tests are shown in Fig. 4. The desired path of the vehicle was along a contour line of 8° slope and the steering angle was fixed at 0° in the test. Figure 5 is the time history of the steering angle. The average steering angle is -0.052° , the maximum and minimum are 0.618° and -1.168° respectively. Due to the strong influence of gravitational force significant lateral slippage occurred and the vehicle gradually moved downward from the desired course. After 23 m longitudinal travel the lateral deviation of the vehicle was 2.9 m. The deviation rate varies with the change of ground inclination, soil condition, surface undulation, etc. Figure 6 shows the trajectories of the rectilinear-motion on 12° slope.



(a) 2D trajectories of rectilinear motion on the slope



(b) 3D trajectories of rectilinear motion on the slope

Fig.4 2D (a) and 3D (b) trajectories of rectilinear motion on 8° slope

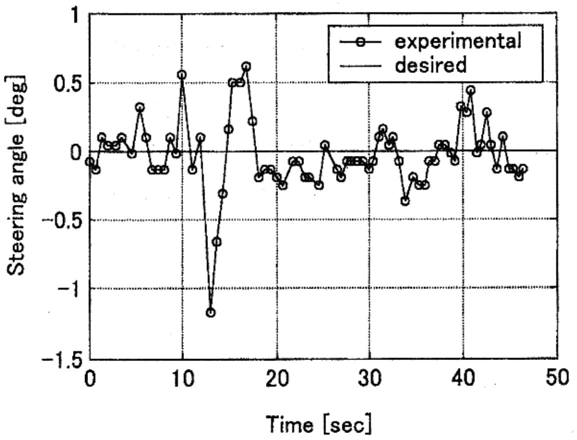


Fig.5 Time history of the steering angle in the rectilinear test on 8° slope

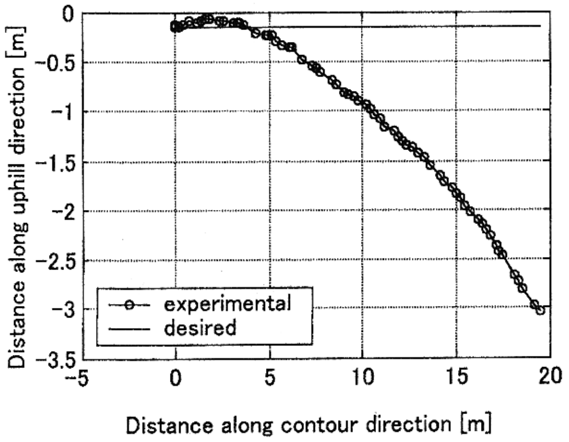
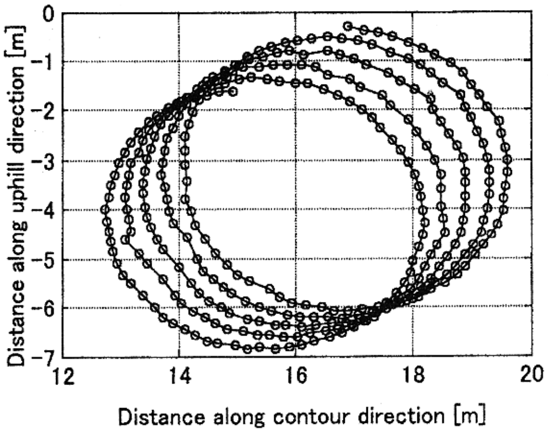


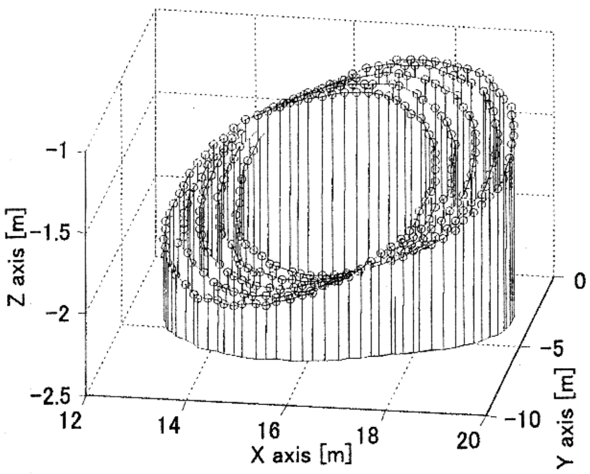
Fig. 6 Trajectories of rectilinear motion on 12° slope

Figure 7 and 8 respectively show the 2D and 3D trajectory of the clockwise circular turn on 9° sloped terrain. The steering angle was fixed at 30°. And the time history of the steering angle and heading angle are shown in Fig. 9 and 10 respectively. In Fig.9, the average steering angle is -29.505° , the maximum and the minimum are -26.505° and -32.095° respectively. Figure 11 shows the anticlockwise circular turn for similar condition to that of the clockwise circular turn. From these figures one important fact becomes clear that in circular motion the vehicle deviation on slope-land is not directly downward, which was unintuitive prior to this test. The centers of the circular turns have a trend to follow the trajectory obtained in the rectilinear motion test.



Direction: clockwise
Slope inclination: 9°
Steering angle: -30°

Fig.7 2D experimental trajectory of the circular motion on sloped terrain



Direction: clockwise
Slope inclination: 9°
Steering angle: -30°

Fig.8 3D experimental trajectory of the circular motion on sloped terrain

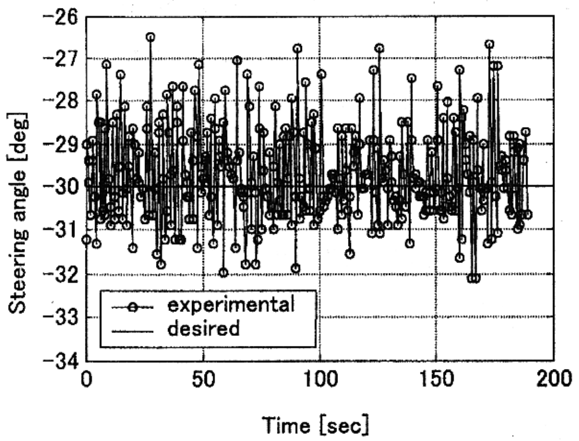


Fig.9 Time history of the steering angle for the circular motion on 9° slope

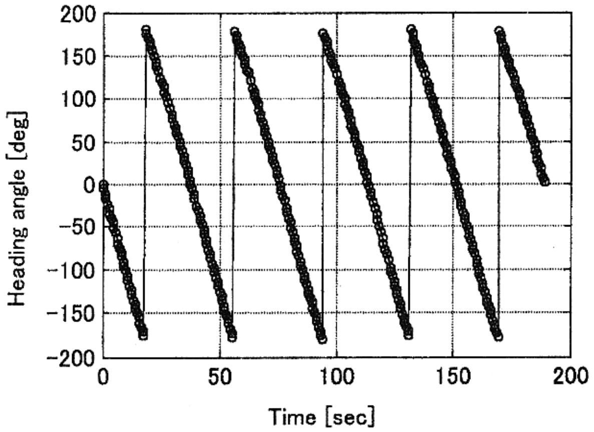
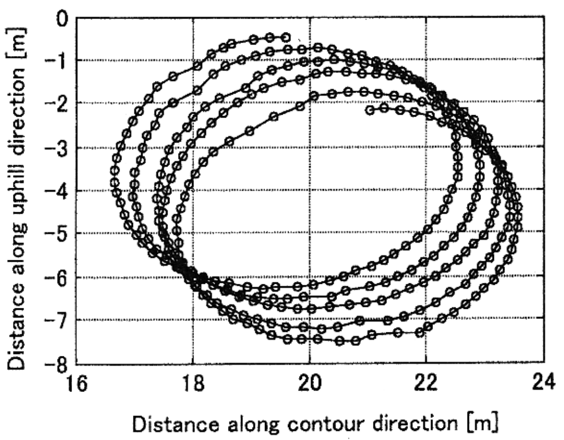


Fig.10 Time history of the heading angle for the circular motion on 9° slope



Direction: anticlockwise
Slope inclination: 9°
Steering angle: 30°

Fig.11 Experimental trajectory of the circular motion on sloped terrain

V Conclusion

A series of tests were conducted on sloped terrain to investigate the open-loop characteristics of vehicle motion on sloped terrain. Following conclusions were made from the study:

1. Vehicle motion on the slope is strongly nonlinear. It is difficult to formulate a dynamic model to represent the vehicle input-output relationship on sloped terrain.

2. If the vehicle makes circular motion on slope, its centers of the circular turns will be towards the diagonal of the contour line and the downhill direction. And the direction of the resultant vehicle deviation also depends on the direction of vehicle motion, that is, on clockwise or anticlockwise motion.

3. This study provided some ideas for formulating an artificial intelligence (AI) model --a vehicle neural network model.

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