DEVELOPMENT OF LEVEE WEEDING ROBOT
- Pathway Control System on the Strait Levee -

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ABSTRACT

The objective of this research work is to develop an autonomous levee-weeding robot. In this paper, pathway control system for the robot is developed and simulated. A prototype autonomous vehicle for levee weeding is also developed and used in the actual test.

The results obtained in this research work is summarized as follows; 1) The simulated typical time history of lateral displacements and heading angle of the vehicle in straight run shows that the vehicle tendency is always to achieve the target path from any of its deviated position and heading angle. 2) The test run on an asphalt surface by the prototype crawler-type vehicle is in good agreement with the simulation results.

Keyword: Levee, Weeding, Robot, Autonomous Vehicle

INTRODUCTION

Levee weeding is one of the most difficult works in paddy fields in Japan and is carried out 3 to 4 times a year (Takeda et al.,1996). The most popular weeding machine is bush cutter, but levee weeding by the bush cutter takes a lot of time and causes severe fatigue to farmers. Because the average Japanese farmer is getting older and most of the work in paddy fields is done by riding type machines except for weeding on levee, there is therefore need to develop an effective levee weeding machine.

Although it is an important operation, very little research work has been done on the automation of rice-field levee weeding. Therefore, the final goal of this research work is to develop an autonomous levee-weeding robot for large-scale farms. It has two distinct functions: auto-piloting of the vehicle and weeding the levee. A crawler-type vehicle is chosen as the test vehicle. Due to larger traction area, it will be more stable on the levee path compared to a wheeled vehicle.

A kinematic model for describing the vehicle movement and fictive point model for maneuvering the vehicle are combined to simulate the vehicle tracking characteristics. A basic prototype autonomous vehicle for levee weeding is developed and analyzed.

THEORY

Mathematical Modeling

It is essential to derive a vehicle maneuvering mathematical model that is used in its auto navigation system. While weeding on the levee, the mower-mounting vehicle must run at slow speed, so as not have significant slippage or other lateral forces under this condition. Therefore, kinematic model can be applied for the vehicle equations.

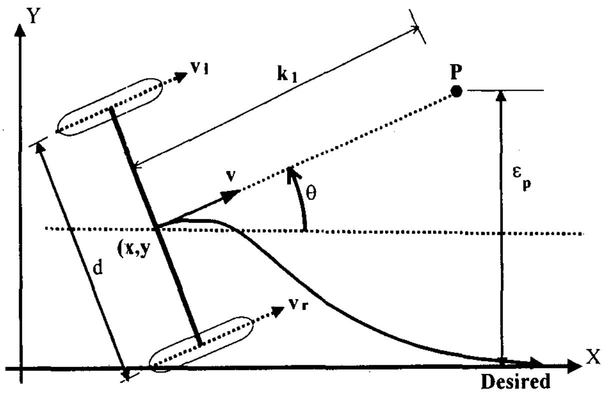


Fig.1 Schematic diagram of vehicle and the fictive point

The following assumptions were made for developing a kinematic model of a crawler type vehicle,:

a) The effects of external side forces are negligible;

b) The vehicle is moving on a flat, smooth and hard surface;

c) Pitch, bounce and roll motions are ignored. Hence, the vehicle has three degrees of freedom.

Figure 1 shows the schematic diagram of the vehicle. The kinematic model for the vehicle is expressed as follows:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \qquad (1)$$

Where v is velocity of the vehicle; θ is the vehicle heading angle; and x, y, are the coordinate values at the center of the wheel axle. This model can be linearized for small heading angle ($\theta<20°$) as follows:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \qquad (2)$$

Controller

The automation task for the vehicle appears to be the design of a controller which steers the vehicle along a given reference path and minimize its lateral and angular deviations (Unyelioglu, K.H., et al, 1996). In automobile engineering, the "look ahead" model has been used to perform lane change maneuver of the vehicle. In this research work, the following control law for steering strategy of the vehicle is utilized.

Control Law

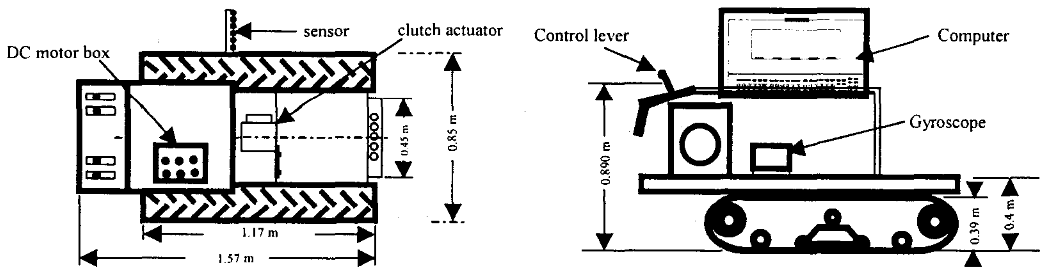
In designing the controller, the concept of "look ahead" method is applied. At k_1 distance ahead of the vehicle, a fictive point P is considered (Fig. 1). On-tracking of the vehicle is attained by minimizing the deviation, ε_p, between the desired path and fictive point P. The steering angle α can be defined as follows:

$$\alpha = k_1 k_2 \theta + k_2 y \qquad (3)$$

PROCEDURES

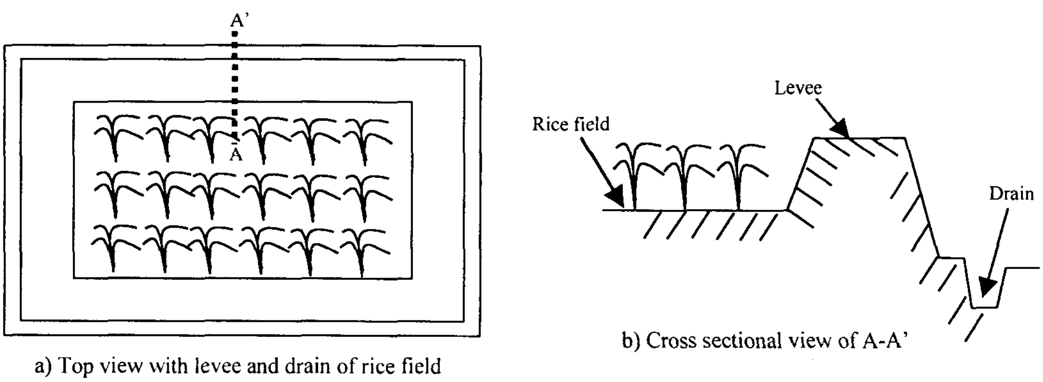
Tested Vehicle

A prototype crawler-type vehicle is used in the experiment and the schematic diagram of the vehicle is shown in Fig. 2. Width of the vehicle is 0.85 m and length is 1.57 m (Fig.2a). Two hydraulic cylinders are installed as the actuator of the clutches to perform turning behavior of the vehicle. To measure the lateral displacement of the vehicle, a beam-type sensor assembly is used. The sensor has six sensing elements placed on a flat bar spaced 4 cm apart from each other and this bar is perpendicularly fixed on the vehicle body. A fiber optical gyroscope is installed to measure the vehicle-heading angle. A computer is used for calculation and process of input data of sensors and gyroscope, and also for controling the clutch actuator.



(a) Top view (b) Side view

Fig. 2. Top and side view of a crawler type vehicle with accessories



a) Top view with levee and drain of rice field b) Cross sectional view of A-A'

Fig. 3. Top view and cross section of a rice field and levee

The levee of rice field that is considered for the simulation and used in the experiment is an earthed trapezoidal shaped structure. Width of its top flat surface varies with field size. A farm of 40a, with a ridge 1 m wide, 0.4 m for the inner inclined surface and 0.7 m for the outer inclined surface was chosen for the experiment (Fig.2).

Working Principle

When the vehicle is in motion, gyroscope and beam-sensor detect the direction of vehicle body and lateral deviation respectively and send these information to the computer. Using this feedback information, controller determines the magnitude of actuation time for the hydraulic cylinder, which controls the clutches and thereby controls the steeling angle of the vehicle. The experiment was performed on the test course in the laboratory. Artificial levee-edge was made using concrete blocks so that the beam-sensor can detect the edge and can obtain the lateral position of the vehicle. The block diagram of the vehicle system is shown in Fig.4.

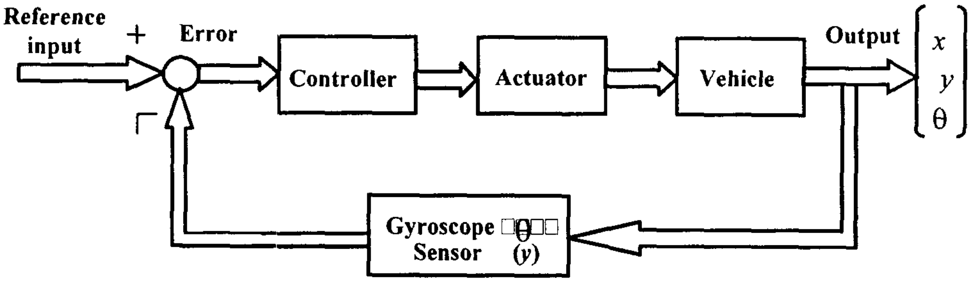


Fig.4. Block diagram of vehicle system

RESULTS AND DISCUSSION

Simulation Results

Using the control law, computer simulations are carried out to find out the on-tracking ability of the controller. The typical results for the effect of coefficient k_1 and k_2 are shown in Fig. 5 and 6. In equation (3), if deviation of y direction is 0, the vehicle should have turned through $\alpha = -\theta$. So each parameter sets of Fig.5 are set such that $k_1 k_2 = -1$, and then simulated curves are plotted under this condition. It is clear from the Fig. 5 that negative bigger value of k_2 makes steep turn of the vehicle to follow the desired path. And the heading angle of the vehicle also makes an urgent turn when k_2 is a negative big value. But urgent turn is not desirable on the limited space on the levee, thus the set of parameter $k_1 = 0.86$ and $k_2 = -1.16$ seems to be the best combination for the vehicle control.

External disturbances of random magnitude at random time interval are added to the lateral displacement $y(t)$ and vehicle heading angle $\theta(t)$. The simulated time histories of lateral deviation and heading angle of the vehicle are shown in Fig. 7 and Fig. 8 respectively. These two figures show that the vehicle tendency is always to move towards the desired path from any of its lateral and angular deviations. Therefore, the controllers were found appropriate to keep the vehicle on the desired path.

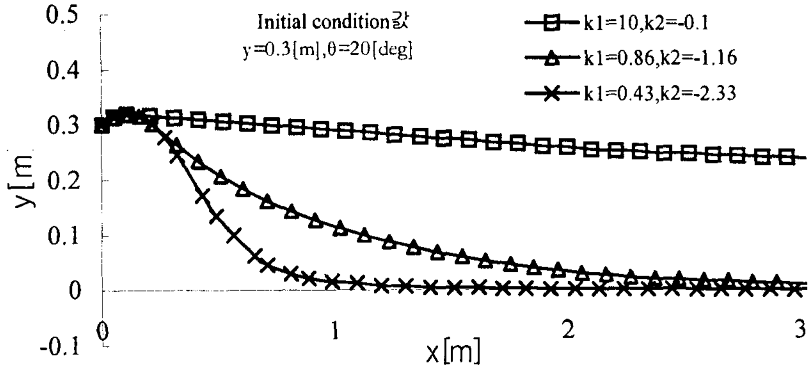


Fig.5. Simulated trajectories for different combinations of fictive length evaluation factors

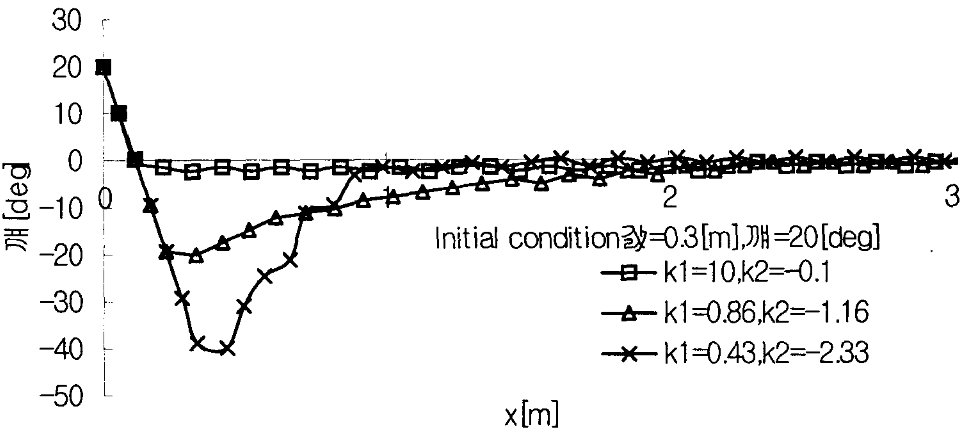


Fig. 6. Position history of heading angle for different combinations of fictive length evaluation factors

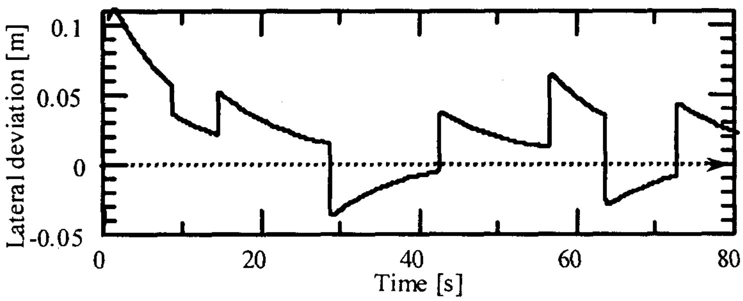


Fig. 7 Time history of lateral deviation of the vehicle when subjected to lateral and angular disturbance

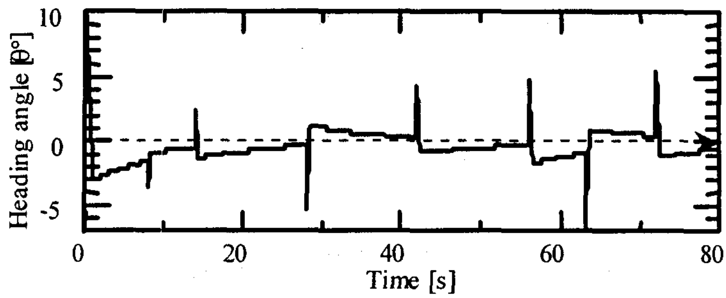


Fig. 8 Time history of heading angle of the vehicle when subjected to lateral and angular disturbance

Experimental Results

The experiment was performed only for straight run operation. Initially the vehicle was allowed to start running from a lateral and angular deviation, so that its on-tracking capability can be observed. During the motion of the vehicle, trajectory of the center point of wheelbase was marked on the floor by colored ink from an intravenous drip at regular time interval. A straight line was marked on the floor to represent the desired path. The longitudinal and lateral position values (x, y) were measured manually. The experimental results are shown in Fig. 9 and Fig. 11. Whereas Fig. 10 is simulated result of time history of heading angle on the same initial condition of the experiment. There are some deviations between experimental and simulated results. This deviation seems to occur by the adjustment of the movement of hydraulic cylinders and clutch mechanism. The deviation can be allowed so that it is within several centimeters, but the deviation seems to be smaller by the adjustment of the clutch actuators. Fig. 10 and 11 show the change of heading angle. It can not be compared directly, but the heading angle converges approximately to 0 in a short time. These figures indicate that on-tracking is attained gradually, thus validating the control of the prototype vehicle.

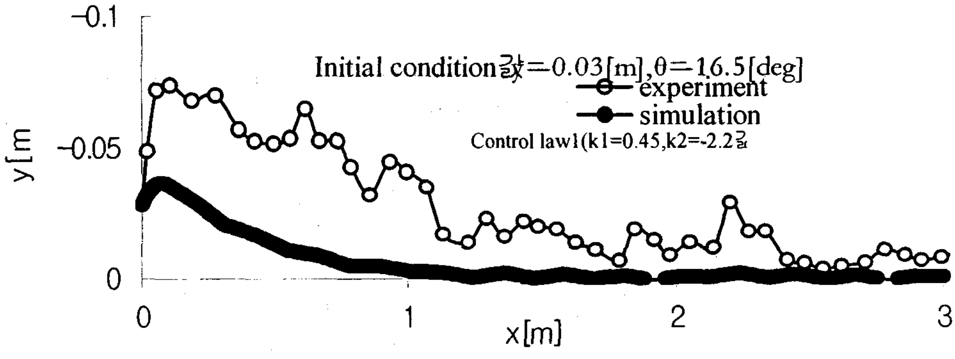


Fig. 9. Trajectories of simulation and experiment

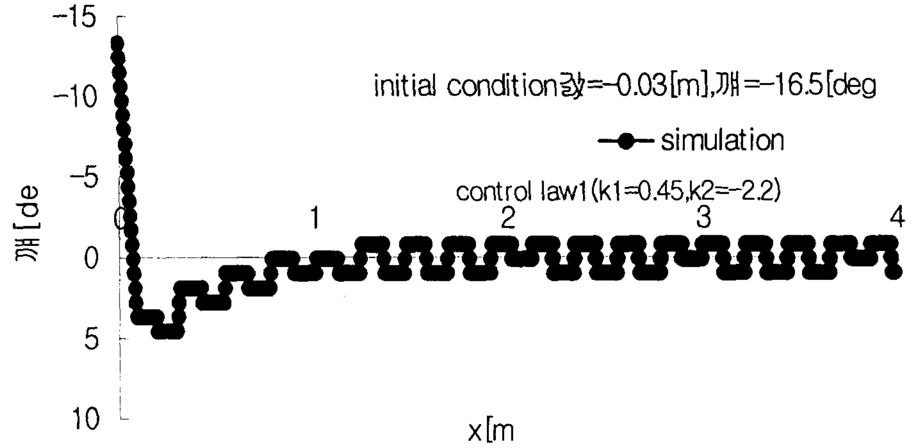


Fig. 10. Simulated position history of heading angle

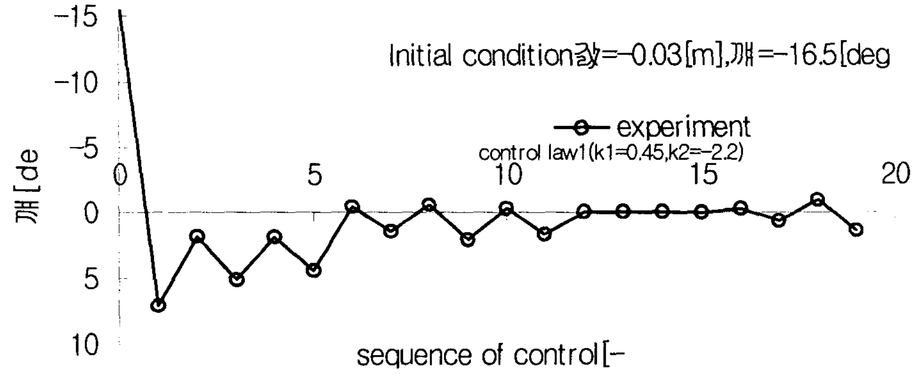


Fig. 11. History of heading angle with respect to the control sequence of clutch change

CONCLUSIONS

A kinematic model of a crawler-type vehicle that is focused on the levee weeding machine was formulated. A fictive point model was applied for the control strategy of the vehicle to perform on-tracking of the strait desired path. The nature of the parameters included in the control law were analyzed. Simulation result against lateral and angular disturbances showed good approach in on-tracking. Experimental result showed the capability of the control law for actual application. For the better auto-piloting system, some of the problems identified with regards to the actuating speed of the clutch mechanism need to be addressed.

NOMENCLATURE

d= distance between center of crawlers
ε_p= lateral error/displacement from the desired course
P= a fictive point
θ= vehicle heading (yaw) angle
α=steering angle
v_r= right wheel velocity
v_l= left wheel velocity
v= wheel velocity
x= longitudinal coordinate
y= lateral coordinate

REFERENCES

1. Takeda, J. and Aburakawa, K (1996). Fundamental research on robotics for weeding paddy field levees (part 1), JSAM, Tohoku branch report., 43, 35-38.
2. Unyelioglu, K.A., Hatipoglu, D. and Ozguner, U (1996). Design and stability analysis of a lane following controller. IEEE Trans. on control systems technology.