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Ridge-path control simulation for crawler-type robot

O Muhammad Ali ASHRAF, Jun-ichi TAKEDA and Ryo TORISU

Department of Agricultural Engineering, Faculty of Agriculture, Iwate University
Ueda 3-18-8, Morioka 020-8550, Japan, Tel:(019)621-6267, Fax:(019) 621-6204
E-mail:a2398001@iwate-u.ac.jp

[Key words] Ridge-path, controller, simulation, automation, and crawler-type vehicle

1. Introduction

In Japan, farm workers are getting old and retiring from farming[1]. On the other hand, new generation does not like to work in agricultural farms. Therefore, the automation of farm work is a burning issue for the stability of agricultural future of Japan. Numerous research work have been done for this purpose. Subsequently, at present almost all the agricultural farm work are mechanized but only a few are fully automated. On the view point of time and labor consumption, weeding on ridge (levee) of paddy field is an important task to consider for automation. Till to date, there are two types of ridge weeding machine available in Japan: a) hand operated mower and b) self-propelled ridge-mower. For small-scale farm, these may be sufficient, but for large-scale farm, use of these mowers are still insufficient, since the ridge is big; thereby it consumes lot of time and physical labor. Very little research work, as far as we could ascertain, has been done for the total automation of ridge weeding. Therefore, the final goal of this research work is to develop an automatic ridge-weeding robot for large farm, which can relief human operator. The automatic ridge-weeder will have two distinct functions: automatic control of the vehicle, and weeding operation by the mower. In the present paper, we only focussed on the control of vehicle, which can move around on the ridge automatically.

The ridge width varies depending on farm size. A four-wheel tractor may not be appropriate for working on ridge as an autonomous vehicle, since any wheel can move out from the horizontal surface of the ridge, due to the disturbance. Crawler-type vehicle, however, may be more suitable in this case for its stability.

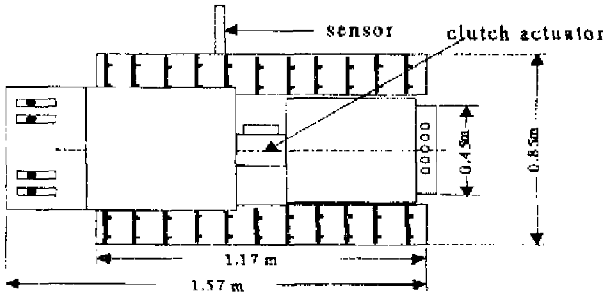
The automation task for the vehicle, at first sight, appears to be the design of a controller which steers the vehicle along a given reference path on the farm. Millions of human operators perform this task quite well using visual perceptions for lane keeping control. They use "look ahead" information by measuring the lateral and angular displacements at certain distance, ahead of the vehicle. A similar effect can be achieved by knowing the position of the vehicle, using radar reflective strips[2] or using magnetic field, DPS, total-station, etc[3]. In designing the controller, the concept of "look ahead" method is very important. An automatic steering is expected to achieve tight tracking performance[4]. The controller, therefore, should be sufficient enough to correct the disturbances in lateral and angular deviations, and should be stable for all ground-path conditions.

The objectives of this study are:
(1) to develop a mathematical model for the crawler tractor,
(2) to develop a controller which can enable the vehicle to run along the desired straight path against any lateral and angular deviations caused by the disturbances,
(3) to develop navigation system and
(4) to test autopiloting by a prototype crawler.

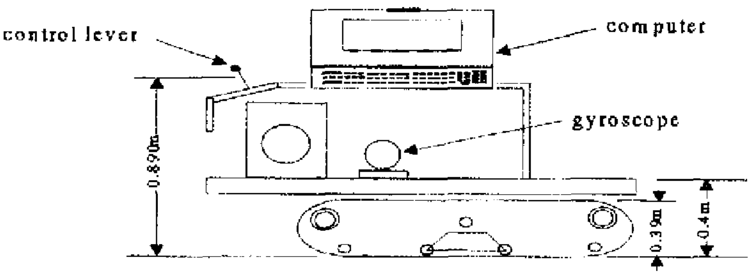
2. Theory and Experiment

2.1. Prototype vehicle

Test vehicle: A prototype crawler-type vehicle is used in the experiment, as shown in Fig.1. The crawler chosen has two steering clutch mechanisms that control its operation. The boundary width of the tractor is 0.85 m. and length is 1.57 m (Fig. 1). To measure the lateral displacement of the vehicle, a beam-type sensor-system was made and installed to it. The sensor has six sensing elements placed on a flat bar spaced at five cm apart from each other. A gyroscope is also installed to the vehicle to get the vehicle-heading angle continuously. A DC motor is installed as an actuator. A computer system is also installed for the calculation and processing of input data from sensor and gyroscope, and also for operational command to control the clutch actuator (Fig.1).



(a) Top view



(b) Side view

Fig1. Schematic diagram of a crawler type tractor

Ridge: The ridge path of paddy field is an earthen trapezoidal shaped structure. The width of its' top flat surface varies with field size. A farm of 40a was chosen for the experiment, the ridge of which has 1 m in top horizontal surface, 0.7 m in inner inclined surface and 0.4 m in outer inclined surface (Fig.2).

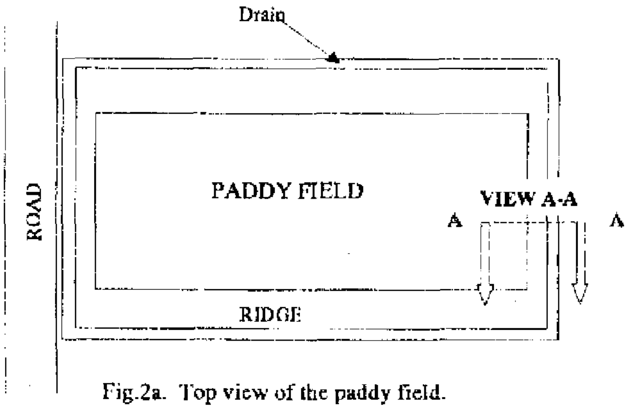
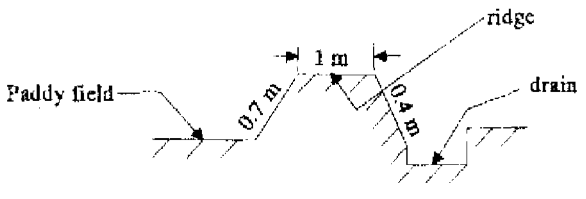


Fig.2a. Top view of the paddy field.

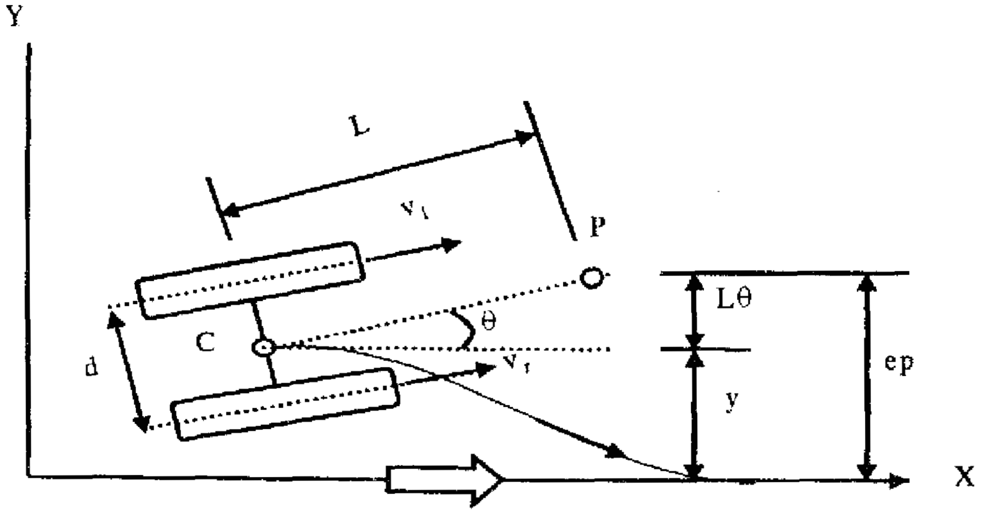


VIEW A-A

Fig. 2b. Cross section of the ridge.

2.3. Mathematical model and its control

Vehicle model: In developing a kinematic model of a crawler, the following assumptions were made: a) the effect of all external forces are neglected; b) the vehicle is moving over a smooth, hard and flat surface; c) bounce, pitch and roll motions are ignored. Hence, the vehicle has two degrees of freedom, corresponding to the lateral displacement 'y' and heading (yaw) angle 'θ' (Fig.3).



Desired path along x-axis

Fig.3. A schematic diagram of vehicle

The model equation of the vehicle is as follows:

$$\frac{d}{dt}\begin{bmatrix}\theta \\ x \\ y\end{bmatrix} = \begin{bmatrix}\frac{vr-vl}{d} & 0 & 0 \\ 0 & \frac{vr+vl}{2} & 0 \\ 0 & 0 & \frac{vr+vl}{2}\end{bmatrix}\begin{bmatrix}1 \\ \cos\theta(t) \\ \sin\theta(t)\end{bmatrix} \quad \text{.........(1)}$$

The layout of the ridge of paddy field is a rectangular type field, which has two distinct path: straight and corner. The model equations, therefore, can be linearized for the straight portion of the path, as the vehicle heading angle remains almost within 20 degree during it's run. With the change of path direction the 'sign' of the equations also changes.

The linear model is as follows:

$$\frac{d}{dt}\begin{bmatrix}\theta \\ x \\ y\end{bmatrix} = \begin{bmatrix}\frac{vr-vl}{d} & 0 & 0 \\ 0 & \frac{vr+vl}{2} & 0 \\ 0 & 0 & \frac{vr+vl}{2}\end{bmatrix}\begin{bmatrix}1 \\ 1 \\ \theta(t)\end{bmatrix} \quad \text{.......(2)}$$

Control law: While driving a vehicle, the human operator usually looks at a point ahead of the vehicle and compares the deviation of that point with the desired path. Thereby, he makes necessary correction in steering. This concept was applied while developing a controller; i.e., at "L" distance ahead of the vehicle, a fictive point "P" is considered. On tracking of the vehicle is attained by minimizing the deviation "ep", between the desired path and fictive point "P" and the deviation "cp" is defined as follows:

$$ep(u1,u2)=y+L\theta.$$

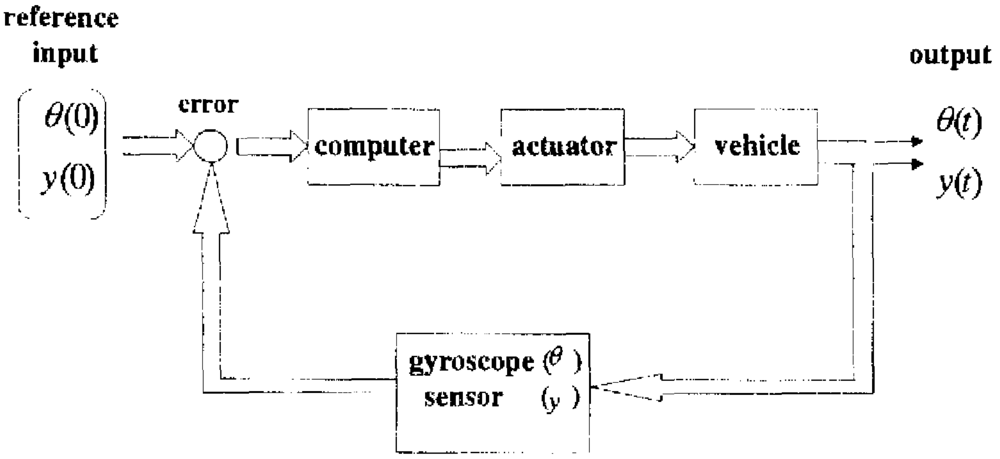
From the minimization, the optimal input function (u1,u2) is derived and listed in Table 1.

Table 1. List of input function

	Condition	Feedback input function
To minimize "ep"	ep>0	$\begin{pmatrix}u1\\u2\end{pmatrix}=\begin{pmatrix}0\\1\end{pmatrix}$
	ep=0	$\begin{pmatrix}u1\\u2\end{pmatrix}=\begin{pmatrix}1\\1\end{pmatrix}$
	ep<0	$\begin{pmatrix}u1\\u2\end{pmatrix}=\begin{pmatrix}1\\0\end{pmatrix}$

Where, $vr=v_0*u1$ and $vl= v_0*u2$.

The block diagram of the vehicle system was shown in Fig.4.



3. Results:

3.1. Simulation results:

A computer simulation is made on the On-tracking and turning control of the vehicle. For the on-tracking control, random external disturbances are added to the lateral displacement 'y(t)' and vehicle attitude 'θ(t)'. The typical time history of lateral deviations of the vehicle in straight path motion is shown in Fig.5. The result shows that the lateral deviation is decreasing under external disturbances. Figure 6 shows the time history of heading angle of the vehicle in the straight path motion. These results indicate the validity of the control law.

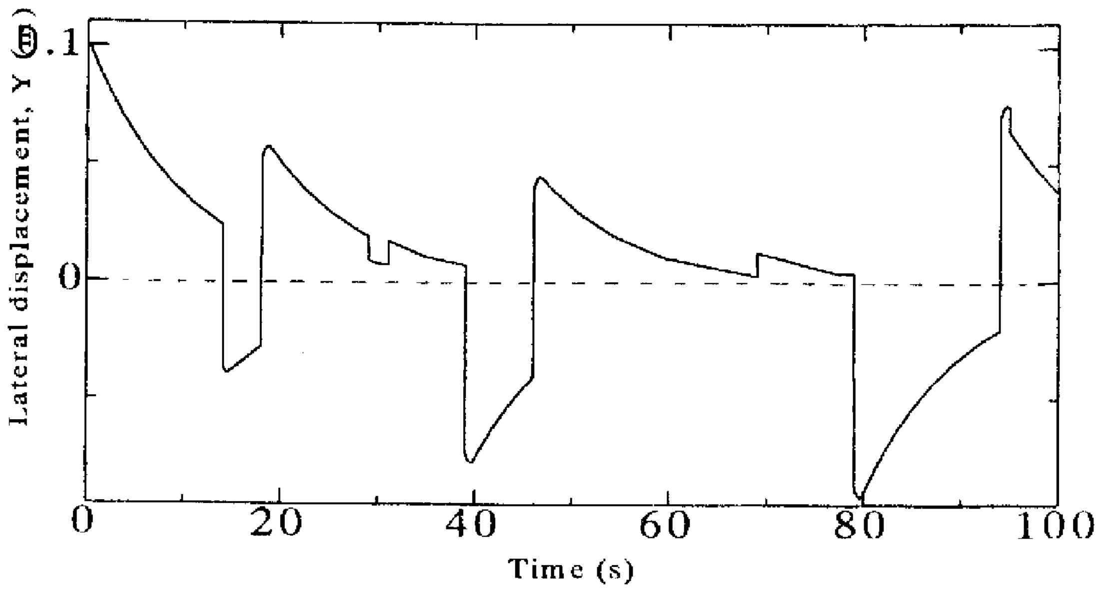


Fig.5. Time history of lateral displacement in straight path running

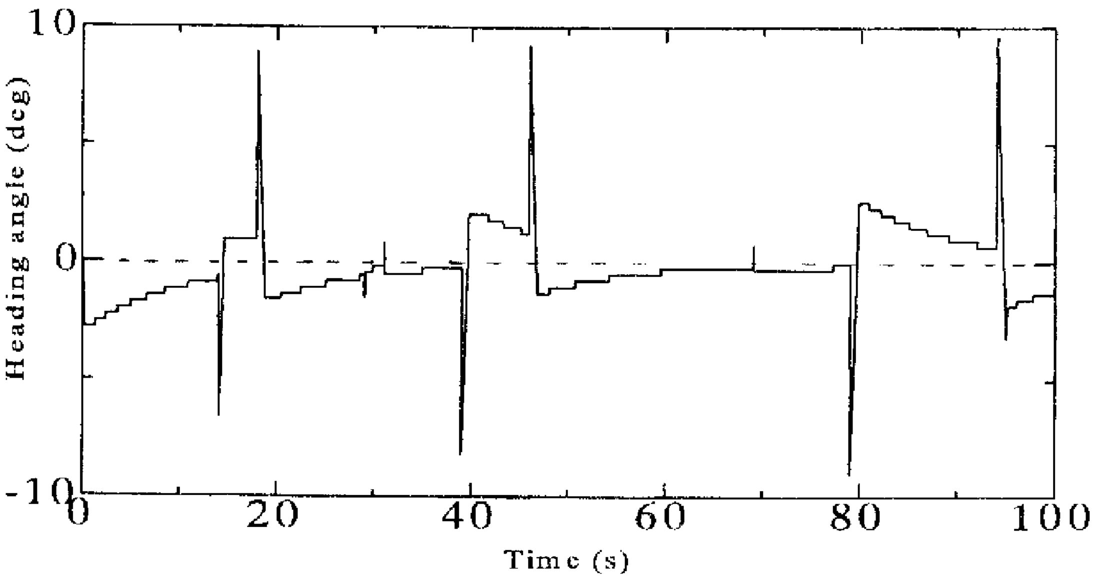


Fig.6. Time history of heading angle in straight path running

Figure 7 & 8 show the time history of left and right input functions [u1(t), u2(t)] respectively.

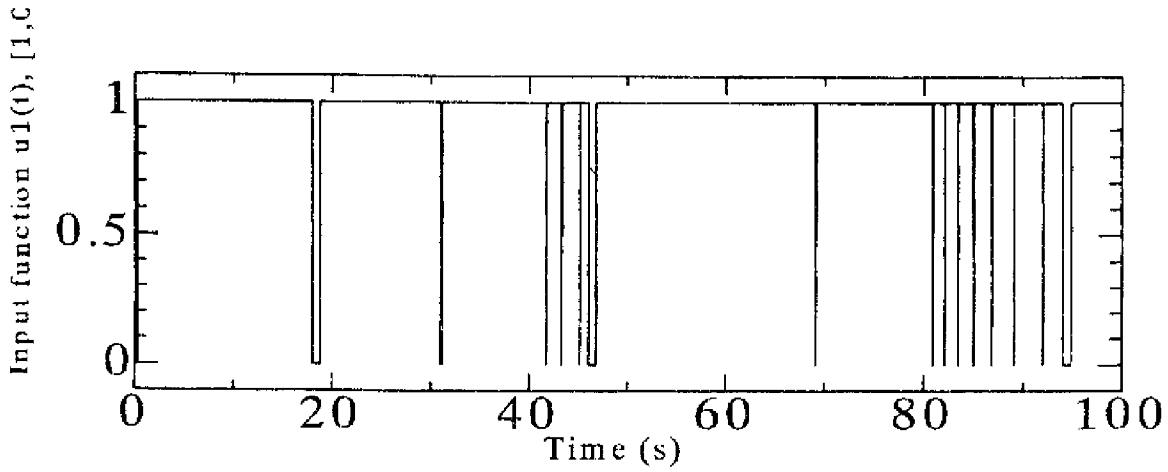


Fig.7. Time history of right input function u1(t)[1,0]

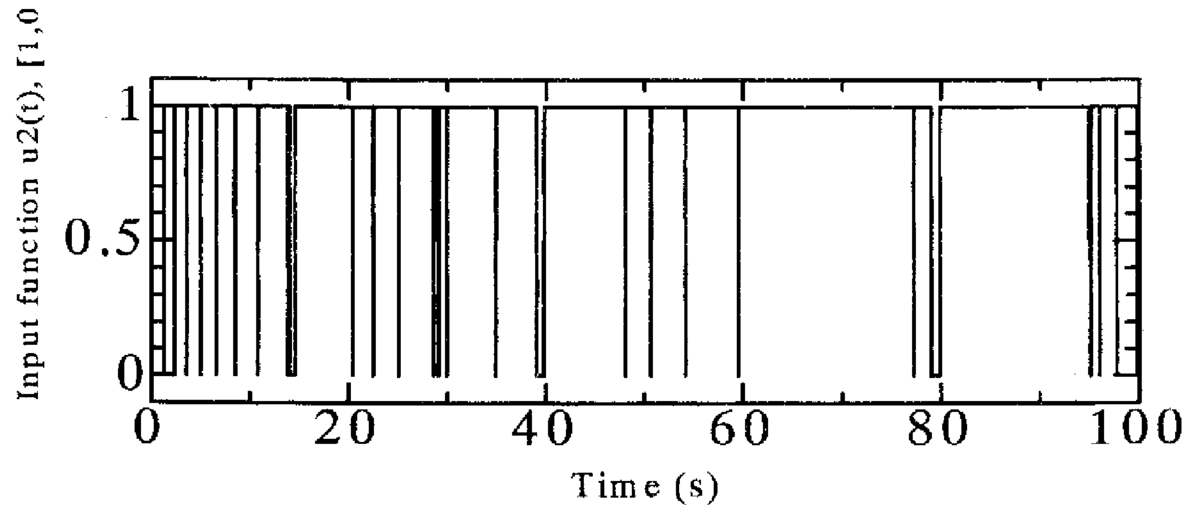


Fig.8. Time history of left input function u2(t)[1,0]

Figure 9 shows the simulation results on the on-tracking control and turning control trajectory of the vehicle on a rectangular shape ridge path.

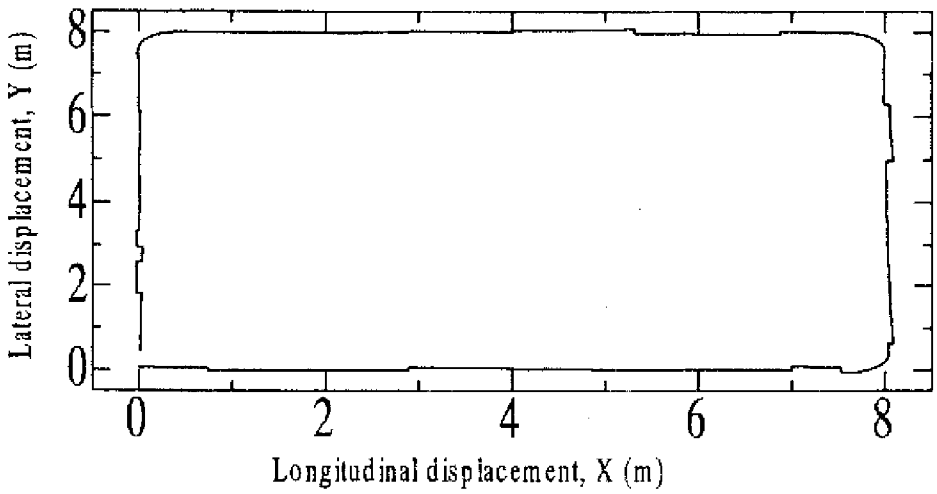


Fig.9. On-tracking trajectory of vehicle in ridge path running

3.2. Experimental results:

The results of the experiment that performed with the prototype vehicle, are shown in Fig.10 & 11 as time history of lateral deviations and that of vehicle attitude in straight path running respectively. The figures indicate that both of lateral deviation and heading angle decreases with time, validating the control of the prototype vehicle.

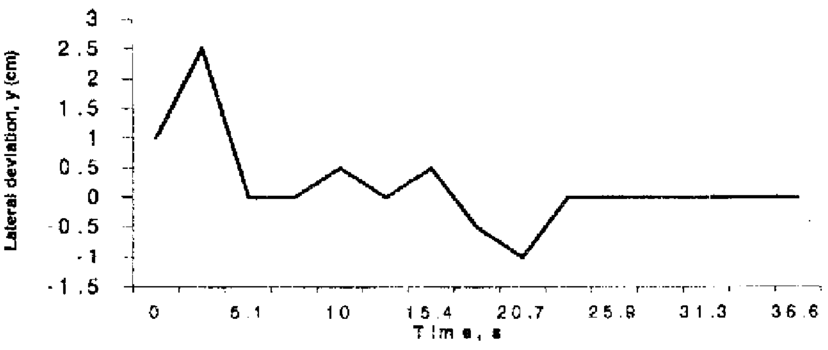


Fig.10. Time history of lateral displacement in straight path running

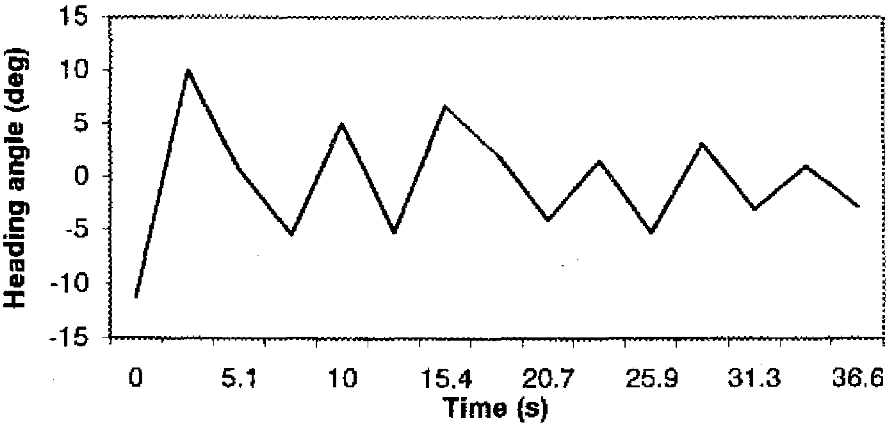


Fig.11. Time history of vehicle attitude (theta)

4. Discussion:

In simulation, the length (L) of fictive point is considered 2 m ahead of the vehicle. In the experiment, the fictive distance (l) is almost half of L. For straight path, the on-tracking performance is better for longer distance of the fictive point than that of for shorter distance. With the decrease in length of the fictive point, the unstability of the vehicle increases. For this reason, the stability of vehicle attitude in simulation appears more stable than that of experiment.

Conclusion:

Main results of autopiloting the crawler on the ride path are summarised as follows:

1. A kinematic model of the lateral displacement and heading angle of a crawler tractor running in a straight and turning path was formulated. The simulation results obtained showed good results in the on-tracking control and turning control ability.
2. The controller was made by using the concept of "look ahead" or fictive point method. Results indicate greater stability of the crawler tractor when the fictive point is further ahead.
3. The crawler was equipped with a navigation system such as photosensor and gyroscope. Tests of the actual autopilot crawer were done. Results showed the capability for the application of the control law. For the better autopiloting system, some problems are identified with regards to the location of the sensors and adjustment of the fictive point.

Nomenclature:

C= center of wheel axle of the vehicle
d= distance between wheels
ep= lateral error/displacement from the desired course
L= distance between point C and point P
P= a fictive point, ahead of the vehicle
θ= vehicle heading (yaw) angle
u1= mode of clutch for right wheel
u2= mode of clutch for left wheel
vr= right wheel velocity
vl= left wheel velocity
v_0= wheel velocity
x= longitudinal displacement of point C
y= lateral displacement of point C

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