AUTONOMOUS TRACTOR-LIKE ROBOT TRAVELING ALONG THE CONTOUR LINE ON THE SLOPE TERRAIN

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ABSTRACT

The objective of this study is to develop a method that is able to realize autonomous traveling for tractor-like robot on the slope terrain. A neural network (NN) and genetic algorithms (GAs) have been used for resolving nonlinear problems in this system. The NN is applied to create a vehicle simulator that is capable to describe the motion of the tractor robot on the slope, while it is impossible by the common dynamics way. Using this vehicle simulator, a control law optimized by GAs was established and installed in the computer to control the steering wheel of tractor robot. The autonomous traveling carried out on a 14-degree slope had initial successful results.

Key Word : Autonomous Tractor-Like Robot, Neural Network, Target Data, Genetic Algorithms, Slope Terrain

INTRODUCTION

With the declining trend of farming population and the aging of farmers, the agricultural future of Japan is facing serious problems. Current research works are being carried out to develop agricultural robots to perform farm works with less human involvement. Many of the agricultural farms, especially some dry land and forage land are hilly slope lands, where plenty of works need to be done by agricultural vehicles.

The objective of this study is to develop an autonomous tractor-like robot that can travel along the desired paths on the slope terrain, based on a control system combining NN and GAs, which is taken as one of major method in agricultural robot control system on flat field recently "Noguchi and Terao (1997)". So as to realize this performance, the first step is to develop a dynamic model for autonomous tractor traveling along the contour line on the slope. For this purpose, it is necessary to formulate tractor inputs and outputs relationship, and establish a control law for the desired path. When the driver-less tractor is moving along the contour line on the slope, external disturbance such as gravitational force, pulls the tractor to the direction of down hillside. Nonlinearity for tractor dynamics increases compared to travel on a flat surface. So it is too hard to formulate vehicle equations by common dynamic methods. The NN is one of the best approaches for nonlinear systems with its high learning ability. In this study, it has been used to create a dynamic model and was used in the optimum simulation of control law for realizing autonomous travel along the contour line. GAs, having an excellent exploring ability, was adopted as an optimization method to develop this control law, which was verified by the experiments.

VEHICLE SIMULATOR

The selection of simulator

The vehicle simulator in this study is a dynamic model, in which a given state of motion at any moment, produces the next state in a short time Δt. Artificial NN has strong behavior of solving such complex nonlinear problem using backpropagation (BP) algorithm "Agui et al. (1993)" to train the NN, whose adjusted interconnecting weights could include all of the affective elements such as uneven condition of slope and any external forces etc. Therefore, NN was applied as a simulator to establish inputs and outputs relationship of state of motion.

Architecture of NN

Fig.1 shows the architecture of NN "Noguchi and Terao (1994)" in this study. The cascaded multilayer network contains 4 layers, a set of 6 input and 3 output nodes. Sigmoid transfer function (Agui and Nagahashi, 1993) as shown by Eq.(1) is used as the threshold function.

$$f(x) = \frac{1}{1 + \exp(-\varepsilon \cdot x)} \qquad (1)$$

where

Input: Operational variable $u_k = (\alpha_k, \Delta\alpha_k)^T$

State variable $z_k = (Vx_k, Vy_k, \omega_k, \theta_k)^T$

Output: State variable $\hat{z}_{k+1} = (Vx_{k+1}, Vy_{k+1}, \omega_{k+1})^T$.

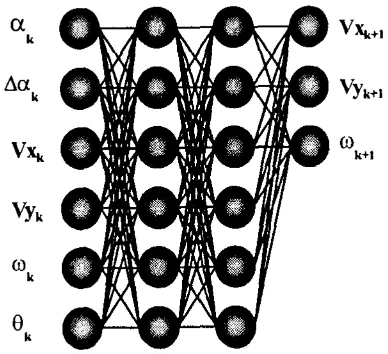

Fig.1 Schematic of NN Architecture

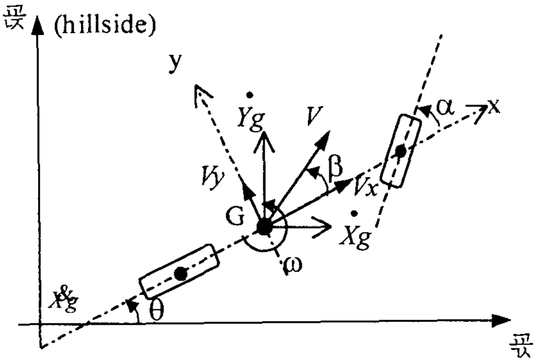

Fig.2 Coordinate System

α_k: Steering angle (°)

$\Delta\alpha_k$: Steering angular velocity (°/s)

θ_k: Heading angle (°)

v_{Xk}: Velocity at x direction (m/s)

v_{Yk}: Velocity at y direction (m/s)

ω_k: Heading angular velocity (°/s)

$\dot{X}g$: Velocity at X direction (m/s)

$\dot{Y}g$: Velocity at Y direction (m/s)

X-Y: Slop coordinate system (m)

x-y: Vehicle barycentric coordinate (m)

Target data of NN

Desired pairs of target data (each set of inputs is paired with a set of desired outputs) are necessary for training of NN. In this study, the training data are the recorded experiment data in real time when the tractor was running on the slope along a sine wave. Then these data were used as the pairs of target data to adjust the interconnecting weights in the backpropagation algorithm "Agui and Nagahashi (1993)".

The state variables measured in experiment are steering angle α, heading angle θ, and coordinates of center of gravity G (x_g, y_g). The other input variables are calculated by these 3 variables as follow (Reference to Fig.2).

$$\Delta\alpha_k = \frac{\alpha_{k+1} - \alpha_k}{\Delta t} \qquad V_k = \frac{\dot{X}g_k}{\cos(\theta + \beta)} \qquad \omega_k = \frac{\theta_{k+1} - \theta_k}{\Delta t}$$

$$\begin{cases} \dot{X}g_k = \dfrac{Xg_{k+1} - Xg_k}{\Delta t} \\ \dot{Y}g_k = \dfrac{Yg_{k+1} - Yg_k}{\Delta t} \end{cases} \qquad \beta_k = \tan^{-1}\left(\frac{\dot{Y}g_k}{\dot{X}g_k}\right) - \theta_k \qquad \begin{cases} Vx_k = V_k \cos\beta_k \\ Vy_k = V_k \sin\beta_k \end{cases}$$

However, the computed data must be normalized between 0.0 and 1.0 before use, and the normalization ranges of data are constrained by the maximum and minimum of the raw data.

Experiment for testing target data

Optical fiber gyroscope, potentiometer, and total station have been used to measure heading angle, steering angle and displacement of center of gravity respectively (See Fig.9). A computer on the tractor equipped with AD and DA converter processes analog signals from sensors, and outputs voltage to a DC motor to control the steering wheel in the autonomous traveling experiment merely.

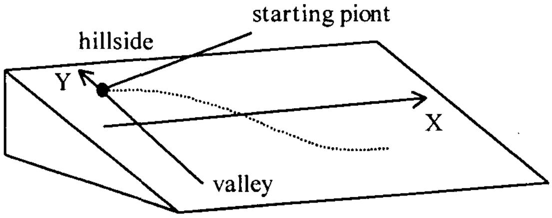

Fig.3 Setting of Coordinate

The experiment was carried out on the 14-degree inclination slope at Touhoku National Agriculture Experiment Station. Setting of coordinates is shown in the Fig.3. The tractor moved along the sine wave, whose wavelength is 16 meters and amplitude 4 meters. Contour line travel (Fig.4) driving by operator was done also. Sampling time was 0.5s, and the tractor's state data were measured at this interval. Tested tractor is a 4WD type with a rate power of 18KW. The tractor was set at an average velocity around 0.5m/s.

The accuracy of vehicle simulator

After NN was trained by BP using the target data, the modified NN had been used to produce vehicle simulator. In the simulation, time series of tractor's states of motion were computed by the vehicle simulator, and only $\Delta\alpha$ was given by the actual data tested in the sine wave traveling. Fig.5 shows the comparison between the result of the simulation and actual locus of the tractor, which had acceptable errors and the locus were very close. Therefore this simulator is thought to be capable of describing the motion of the vehicle on the slope.

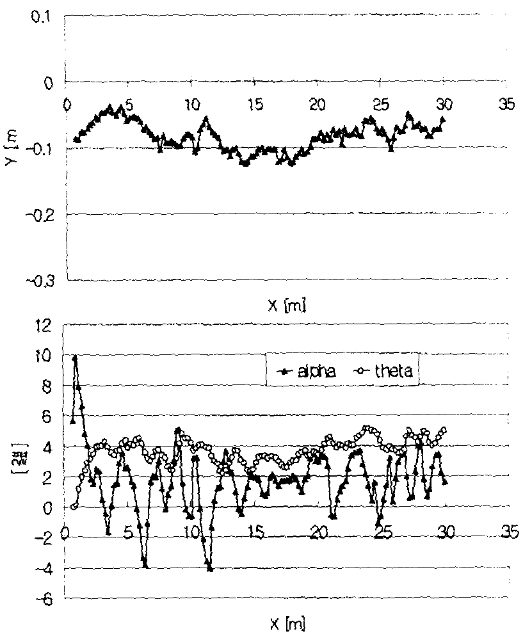

Fig.4 Traveling Locus and Chang of Angles along the Contour Line Driving by Operator

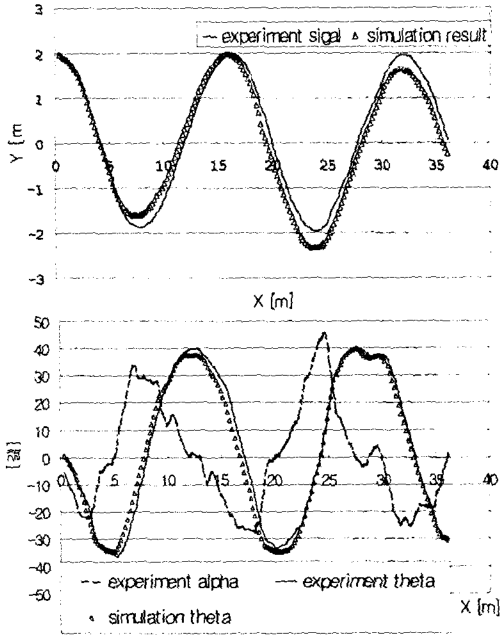

Fig.5 Traveling Locus along the Sine Wave

OPTIMIZATION CONTROL LAW

Optimization method

How to operate steering wheel under various states of motion automatically is the principal task, hence the steering angle of tractor became the object of the optimization in this study.

Continuous state of motion is relatively hard to forecast when the tractor is running along the contour line on uneven slope. In this study, a control law responding to the motion state was developed by GAs "Noguchi and Terao (1994)", which is thought as a very effective nonlinear searching method than other algorithms, having a population of exploiting points in the global space "Goldberg (1989)".

Optimization problem

There are two critical state variable for traveling on the slope. One is the deviation ε, which is the difference between the objective value Y=0 and the center of vehicle gravity Yg, another is the vehicle 's heading angle θ. The optimization problem in this study is to derive the optimum steering angle α, being responsible for ε and θ under any state. The relation of α and (ε,θ) is expressed by Eq.(2).

$$\alpha = f(\varepsilon, \theta) \qquad (2)$$

Since this function is not easily obtainable, it was converted into a matrix form, which is called control matrix. The constrained state domain was defined as a 2-dimension space (See Fig.6): the deviation ε and heading angle θ, the motion space was divided into arbitrary masses, where the locus is located. Then the operational variable α

under each state were inserted in corresponding locus, and then the masses were connected into a string. After the trial, this matrix was set as 6×6, ε at a scale of 10cm, and θ at 5°. Thus, both the total mass and length of string are 36.

Optimum control law

x-axis, determined as the datum axis shown in Fig.3, was set in the same direction as that for forward motion of the vehicle. Traveling along the datum axis is taken as the objective of optimization. Here, the evaluation function was defined by Eq.(3).

$$J = \int_0^{tf} \varepsilon^2 dt = \int_0^{tf} Y_g^2 dt \qquad (3)$$

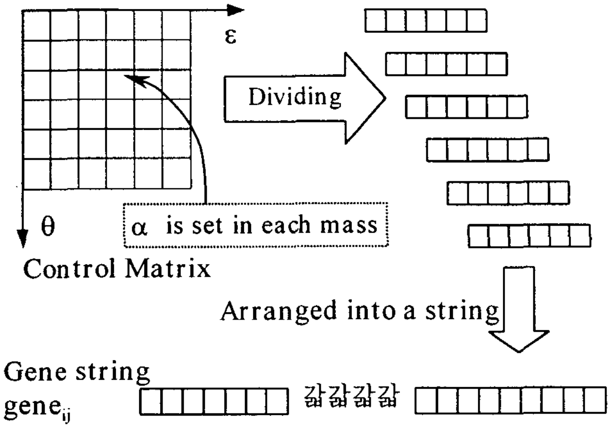

Fig.6 Transfer from matrix to gene string

GAs was applied to search for an optimum α string to minimize the objective value. The parameters of GAs were given as follow: T (10000), iteration of generation; M (50), size of population; L (36), length of string; Pc (0.6), probability of crossover; Pm (0.05), probability of mutation.

In the optimization, the string was substitute into the vehicle simulator illustrated previously, to calculate the fitness of individual. The fitness of individuals was given by Eq.(4).

$$f = (J + LP)^{-1} \qquad (4)$$

where $J = \sum_{i=0}^{tf} Y_g^2$

LP: the penalty when vehicle couldn't reach the goal.

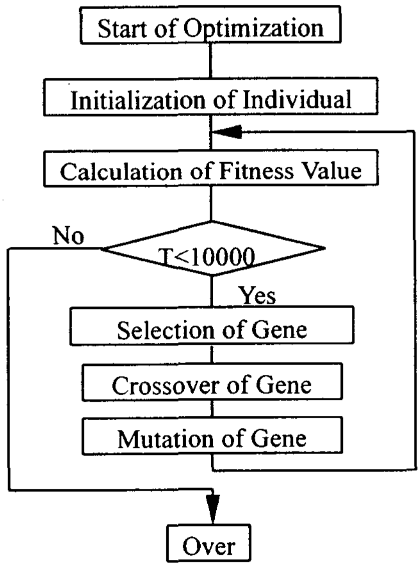

Fig.7 Optimization procedure

Simple GAs "Agui and Nagao (1993)" composes 3 operators: reproduction, crossover and mutation. The flowchart of optimization procedure is shown in Fig.7. Table 1 shows the optimized control matrix. Steering angles in the matrix were substituted into the vehicle simulator, calculated optimum trajectory is shown in Fig.8.

Table 1. Optimized Matrix

α		ε (cm)					
		>20	10~20	0~10	0 ~ -10	-10 ~ -20	< -20
θ (°)	> 10	-20	-20	-12	-10	-4	0
	5 ~10	-20	-20	-10	-4	-2	2
	0 ~ 5	-12	-8	0	4	14	16
	-5 ~ 0	-8	-4	10	12	14	18
	-10 ~ -5	-6	10	16	20	20	20
	< -10	6	10	18	20	20	20

The deviation of trajectory is within ±0.05m, and vehicle of the simulation travels along the datum axis and directed towards the hillside with 2~4° heading angle.

AUTONOMOUS TRAVEL ON THE SLOPE TERRAIN

The control law was installed in the computer on the tractor-like robot. Autonomous travel had been carried out on 14-degree slope forage land at same slope where the target data pairs had been tested. The testing system is shown in Fig.9.

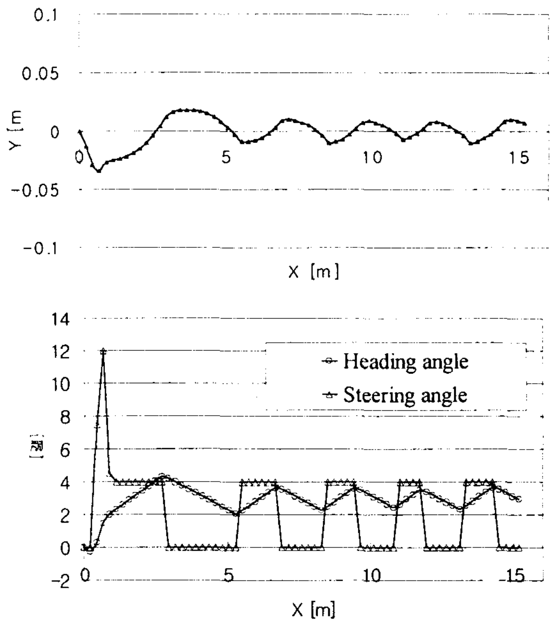

Fig. 8 Optimum Trajectory

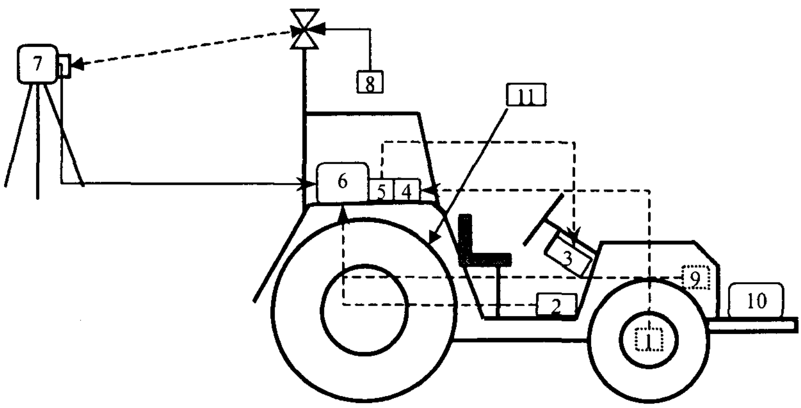

Fig.9 Tested tractor and instrumentation

1.Potentiometer (DTP-05MDS)
2.Optical fiber gyroscope (TA7345)
3.DC motor (SS60E3-L4-25)
4.Strain amplifier (DPM-305A)
5.DC motor driver (MS-100C1215)
6.Computer with DA/AD board
7.Total Station Positioning System (TPS1100)
8.Laser reflect prism
9.Magnetic sensor (Mp-950)
10.AC generator (EX-900 HONDA)
11.Tested tractor (MT2501D)

RESULTS AND DISCUSSION

Fig.10 and Fig.11 show the locus of autonomous tractor robot travel on the slope terrain. Whether the tractor robot started traveling from the origin or not, the trajectories would gradually converge within –0.3~-0.1m, and the heading angle changed between 3~8°.

It could be noticed that any of the locus after motion becoming stable and closing to the line of Y=0.2m, never cross the datum axis to the positive side. Because tests were done after snow, the soil was damp, and the surface of the slope was slippery than that in the test of target data. But it could be observed clearly that tractor-like robot is able to travel along the contour line.

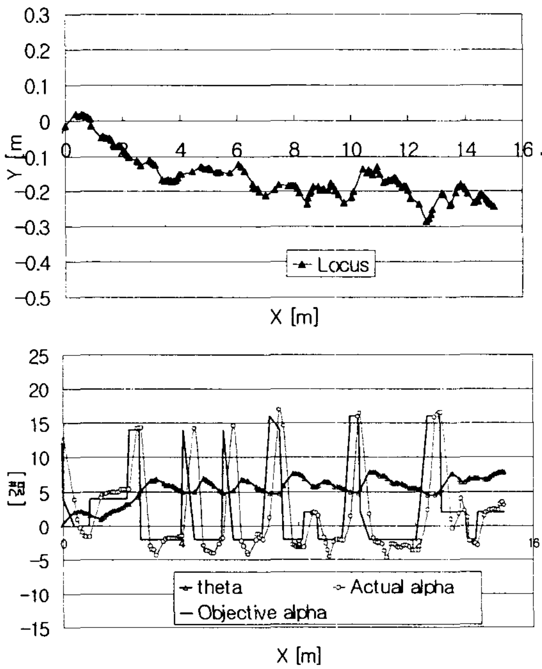

Fig10 Traveling on the contour line

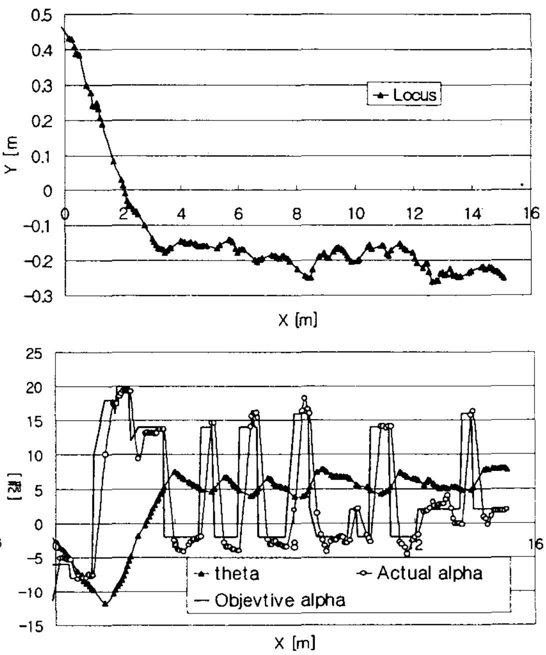

Fig.11 Traveling on the contour line

Although the soil condition was different, it could be said that the travel along the contour line was successful. Therefore, it is clearly that the developed method using NN and GAs is effective for creating a law for the tractor-like robot on the slope.

CONCLUSIONS

This study initially obtained a successful result. It proved that NN is adaptive in establishing a dynamic model of agricultural vehicle robot on the slope terrain. The trajectory calculated by vehicle simulator could match with that of actual tractor. GAs were applied as the nonlinear algorithm method to create optimum control law successfully. Autonomous traveling tractor-like robot controlled by this rule could track along the desired course. The control method explored in the study would have a wide application in autonomous agricultural robot on the uneven farmland.

RECOMMENDATION

In the near future, the autonomous travel test should be done on slopes with various inclinations, to try to clarify the function $\alpha = f(\varepsilon, \theta)$. There is also need to make a general control law, which is adaptive for arbitrary slope terrain.

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