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Backward Movement Control with Two-Trailer Truck System Using Genetic Programming

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Abstract

In this paper, we propose a control system using genetic programming (GP) for backward movement control of a two-trailer truck, known as a non-holonomic system. We have already acheived the control of a single trailer using GP. In this study, we aim to design a control system for complex problem of two trailers. In order to verify the effectiveness of the proposed method, it is compared to neurocontroller (NC) sytem evolved by genetic algorithm (GA).

1 Introduction

Backward movement control of a trailer-truck system is one of the typical nonholonomic system control problems. Difficulties of this control problem are caused by the complex dynamics of nonliner system and also by the need to consider its structural limitations such as the "jackknife" phenomenon occurring when the angle between truck and trailer exceeds the limitation. Furthermore, this control problem becomes more difficult when the number of connected trailers is increased. To achieve this control, fuzzy system [1] and neuro controller (NC) have been proposed. There are several training methods of NC, such as the back-propagation (BP) algorithm [2], or the genetic algorithm (GA) [3].

In this paper, we use genetic programming (GP) method [4] for backward movement control of a trailer-truck. GP genetically breeds populations of computer programs and equations to solve problems, and the individuals in populations have hierarchical structures of functions and its arguments (terminals). In our previous study [5], we have already acheived the backward movement control of a single trailer with GP. As a next study, we desire to increase the number of trailers to two as a more difficult system. To examine the effectiveness of the control system, we will compare our system with a simple NC control system evolved by GA.

2 Model of two trailers-truck system

Figure 1 and Table 1 show the simple diagram of a model and parameters of the two-trailer truck system, respectively. Dynamics of this system is represented as follows:

$$x_0(t+1) = x_0(t) + \frac{v \cdot \Delta t}{l} \tan[u(t)] \quad (1)$$

$$x_1(t) = x_0(t) - x_2(t) \quad (2)$$

$$x_2(t+1) = x_2(t) + \frac{v \cdot \Delta t}{L} \sin[x_1(t)] \quad (3)$$

$$x_3(t) = x_2(t) - x_4(t) \quad (4)$$

$$x_4(t+1) = x_4(t) + \frac{v \cdot \Delta t}{L} \sin[x_3(t)] \quad (5)$$

$$x_5(t+1) = x_5(t) + v \cdot \Delta t \cdot \cos[x_3(t)] \times \sin\left[\frac{x_4(t+1) + x_4(t)}{2}\right] \quad (6)$$

$$x_6(t+1) = x_6(t) + v \cdot \Delta t \cdot \cos[x_3(t)] \times \cos\left[\frac{x_4(t+1) + x_4(t)}{2}\right] \quad (7)$$

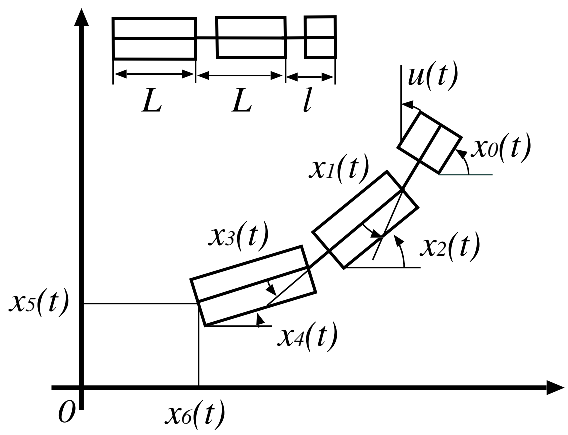

Figure 1: Model of two trailers-truck system

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Table 1: Parameters of two trailers-truck system

l	truck length (0.129[m])
L	trailer length (0.124[m])
Δt	sampling time (0.5[s])
v	truck speed (-0.03[m/s])
$x_0(t)$	truck angle
$x_1(t)$	angle between truck and 1st trailer
$x_2(t)$	first trailer angle
$x_3(t)$	angle between 1st trailer and 2nd trailer
$x_4(t)$	second trailer angle
$x_5(t)$	vertical position of 2nd trailer
$x_6(t)$	horizontal position of 2nd trailer
$u(t)$	front wheel angle ($\lvert u\rvert \leq \pi/2$[rad])

3 Control system design for the trailer

The purpose of backward movement control is to make the horizontal state with zero vertical position. Namely that the desired states in this problem are $x_1(t) = x_3(t) = x_4(t) = x_5(t) = 0$. Furthermore, it is necessary to consider the limitation of front wheel angle ($|u(t)| \leq \pi/2$[rad]) and limitation of the "jack-knife" phenomenon ($|x_1(t)|$, $|x_3(t)| \leq \pi/2$[rad]) in this control problem.

3.1 GP control system

GP method generates a tree structure, which is composed of function and terminal nodes. In our GP method, function trees receive errors of the desired state and present state as an inputs, and output front wheel angle. The terminal nodes shown in Table 2 are errors $dx_i(t)$ between targets x_i^{ref} and present states $x_i(t)$ $(i = 1, 3, 4, 5)$, and a random number. The function nodes shown in Table 3 are mathematical expressions, such as addition (+), subtraction (−), multiplication (∗), and moreover, hyperbolic tangent function (tanh) is adopted. The tanh function is a nonlinear function and it is used as activation function of neural network as its shape is alike a sigmoid function, and its values are within the range of [-1, 1]. Therefore, we expect this function to take effect to generate appropriate wheel angle not to exceed its limit. In addition, we consider that this function's non-linearity is suitable for the dynamics of the target system.

The number of GP population is set to $N = 100$, the initial depth of function trees is set to 7, the maximum depth after crossover is set to 30. The probabilities of crossover and mutation are 0.8 and 0.2, respectively. Figure 2 shows how to evolve function trees of GP. Trees are updated by repeating crossover and mutation of trees each other.

Table 2: Terminal nodes

terminal	description
$dx_1(t)$	error of $x_1(t)$ and x_1^{ref}
$dx_3(t)$	error of $x_3(t)$ and x_3^{ref}
$dx_4(t)$	error of $x_4(t)$ and x_4^{ref}
$dx_5(t)$	error of $x_5(t)$ and x_5^{ref}
rand	random number [−10, 10]

Table 3: Function nodes

function	branch	description
+	2	sum of the branches
−	2	subtract 1 from 2 branches
∗	2	multiply of the branches
tanh	1	hyperbolic tangent of the branch

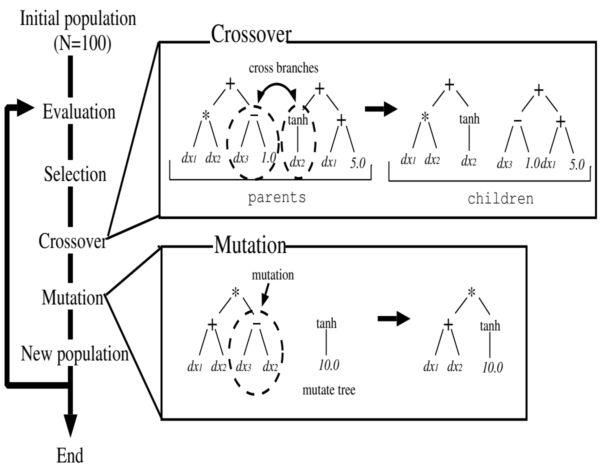

Figure 2: GP trees evolution

3.2 NC control system evolved by GA

To examine the effectiveness of our control system, we will compare with NC control system evolved by GA. Like GP control system, the NC also receives the error signals and outputs front wheel angle. The structure of the NC is a three-layered feedforward neural network with 4-10-1 architecture. A sigmoid activation function is introduced into hidden layer while a linear function is kept for the input and output layers. NC has the connecting weights which are updated by GA.

The number of NCs treated in GA is set to 100, the gene length in GA is 16 bit. Similarly to GP, the crossover and mutation rates in GA are 0.8 and 0.2, respectively.

4 Evaluation method

During the training with GP or GA of NC, evaluation value E is computed using following equation,

$$E = \sum_{p=1}^{P} [(x_1^{ref} - x_{1p}^{end})^2 + (x_3^{ref} - x_{3p}^{end})^2 \\ (x_4^{ref} - x_{4p}^{end})^2 + (x_5^{ref} - x_{5p}^{end})^2] \quad (8)$$

where x_i^{ref} are the desired states ($x_i^{ref} = 0$, $i = 1, 3, 4, 5$), x_{ip}^{end} are the final states for trailer-truck which starts from initial position p. P denotes the total number of initial positions, in this test $P = 9$. Table 4 shows the nine initial positions of training, the initial horizontal position is $x_6 = 0.6$ [m]. Trailer system starts from each position, and it is controlled for 100 steps.

Moreover, during the control, when the limitation of front wheel angle is exceeded, or the "jackknife" phenomenon occurs, the control sequence break and a penalty of 100 points is added to E.

Table 4: Initial position for test

p	x_0,x_2,x_4 [rad]	x_5 [m]	x_6 [m]
1	0		
2	$\pi/2$	0.0	
3	π		
4	0		
5	$\pi/2$	0.3	0.6
6	π		
7	0		
8	$\pi/2$	0.6	
9	π		

5 Simulation result

In this study, we use 200 generations for GP in the proposed method and 300 generations for GA in NC system. We judge that the control process succeeds if its evaluation value is less than 10^{-4}. Figure 3 shows the evaluation result of GP training. It can be seen that the evaluation fell into local minimum value until the 97th generation, it caused a training delay. The depth of the generated trees of GP is 2 and a typical form is (tanh dx_1) or (tanh dx_3). However, after those generations it turns to train. At the end of training, evaluation E became 8.76×10^{-7} which is much smaller than the judge value. In our opinion, the reason of the turning of training is as follows: In local minimum state there are only almost similar tree populations with small depth therefore they could not generate variety of populations. But, there are another type of populations remained with wrong evaluation values. If they have enough larger depth, they might generate better populations.

To confirm generalization ability of the control systems, we set the trailer-truck to an untrained position as initial position, with angle $x_0 = x_2 = x_4 = 2\pi/3$ [rad], vertical and horizontal $x_5 = 0.5$ [m], $x_6 = 0.6$ [m]. Figure 4 shows the control results trained by GP and NC respectively (sampling every 14 steps). From this position, both control systems performed good control of backward movement toward the desired state. Figure 5 shows a detailed comparison of the control results. From this figure, the result of GP control is earlier converged to the desired state than NC control. Moreover, the evaluation values in this control are $E = 7.79 \times 10^{-10}$ (using GP), and $E = 2.03 \times 10^{-7}$ (using NC), hence GP performed with a smaller error.

Figure 6 shows the front wheel angle. It appears that both controllers are similar that the front wheel angle is operated in the positive direction in the first steps. NC control system operated to 0.92 [rad] which is larger than the angle obtained by GP control ($u = 0.63$ [rad]). And then, the wheel is turned quickly to positive direction and negative direction, then it gradually converged to 0 [rad]. After these turns of the wheel, GP control did not need further obvious operations while NC control operated small turns of the wheel about three times. From these observations, it is clear that GP control has a ability to operate the front wheel angle smoothly.

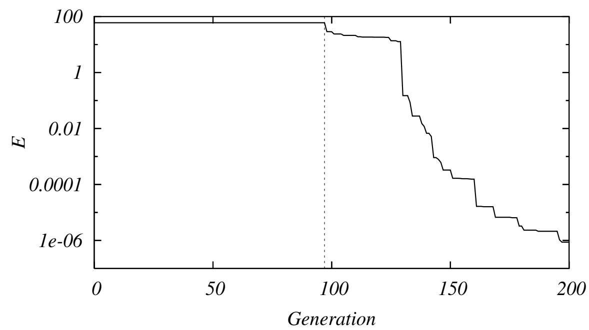

Figure 3: Evaluation value of GP training

6 Conclusions

In this paper, we proposed the method of backward movement control for two-trailer truck system using GP. The GP generates the function trees which contain a nonlinear function and three mathematical ex-

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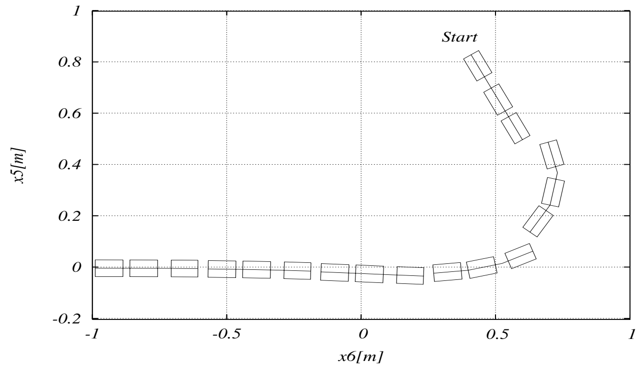
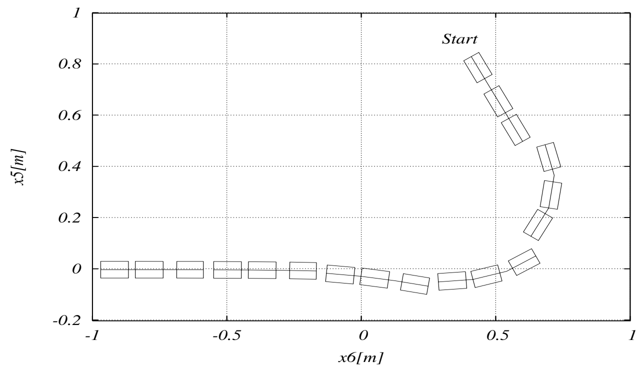


(a) Results of GP control



(b) Results of NC control

Figure 4: Control of the two-trailer truck system

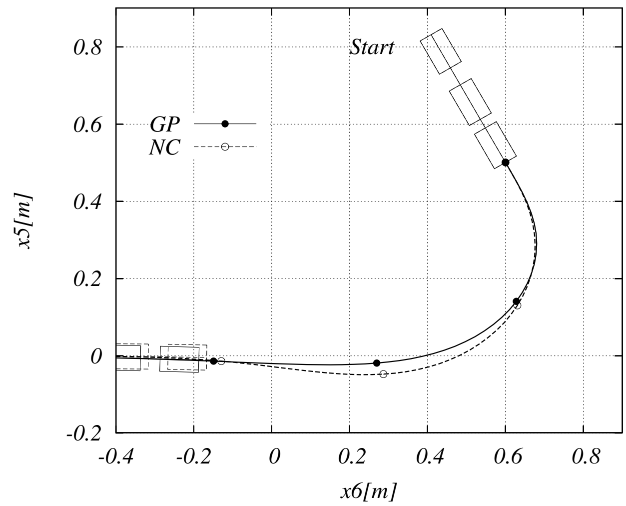


Figure 5: Comparison of the control systems

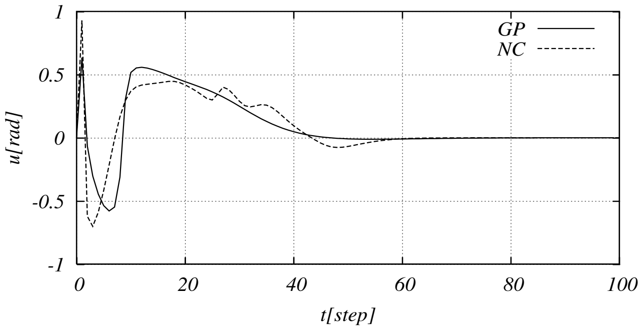


Figure 6: Front wheel angle u

pressions. The simulation results showed that GP is possible to design the control system for two-trailer system. Also, the GP control was compared to NC control and the effectiveness of the proposed controller was confirmed, that is the GP control could converged to the desired state earlier than the NC. Moreover, the GP control operated trailer truck more smoothly than NC.

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