A Controller Design Method for an Articulated Vehicle Employing Self-Oraganizing Relationship(SOR) Network

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Abstract

In this paper, we design a trailer-truck back-up controller by using the Self-Organizing Relationship (SOR) network with fuzzy inference based evaluation. The proposed method facilitates embedding designers' know-how and observation-based knowledge to controller design. Furthermore, the controller designed by using proposed method is robust against physical parameter variation.

1 Introduction

Trailer-truck back-up control is very difficult even for expert drivers as well as non-experts, because the mechanism of the trailer-truck includes nonlinearities and instabilities. Besides, the control has to be achieved while avoiding an uncontrollable state called jackknifed-state. Therefore, trailer-truck back-up control is well-known benchmark in the field of nonlinear control. Generally, the controllers are designed by using nonlinear control theories[1] or soft-computing techniques[2][3]. In the former method, mathematical model of the trailer-truck and advanced mathematical knowledge are required. In the latter one, typical methods are based on neural networks and rule-based fuzzy controls. However, correct I/O relationship (*i.e.* supervisor) of the controller is required for learning of neural networks. A detailed knowledge of the I/O relationship has to be given by experts to design rule-based fuzzy controllers. In addition, fine adjustment of the fuzzy if-then rules is required. It means that, to design the trailer-truck back-up controller using traditional methods are difficult for non-expert designers.

In this paper, we design the trailer-truck back-up controller employing the Self-Organizing Relationship (SOR) network[4]. The SOR network is effective when the desired I/O relationship of the controller is not available but can be evaluated. The desired I/O relationship is extracted by learning of the SOR network using I/O vectors and their evaluations. The evaluation of the I/O vectors should be given quantitatively when the SOR network is applied to control problems. However, it is difficult to represent an evaluation function for the I/O vectors of SOR network in complicated applications such as trailer-truck back-up control. In order to calculate the evaluation values for the I/O vectors without mathematical evaluation functions, we propose a new method in which a fuzzy inference is used. In proposed method, designers' know-how and observation-based knowledge can be embedded to the evaluation of the controllers I/O relationship. Therefore, the knowledge-based controller can be designed easily by using the SOR network with fuzzy inference based evaluation.

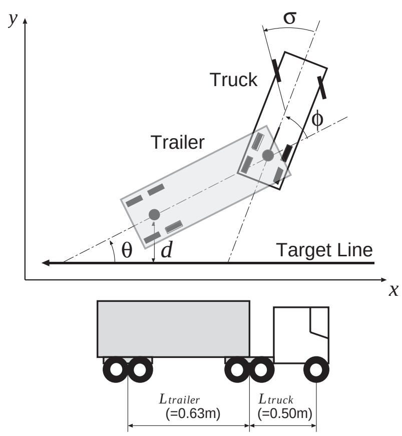
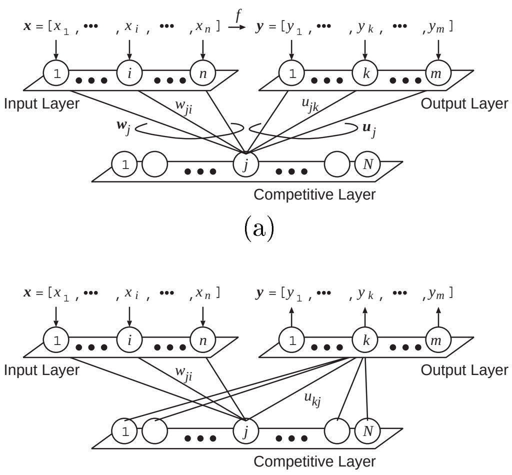


Figure 1: *Model of the semi-trailer.*

2 Trailer-Truck Back-Up Control

The model of the semi-trailer type trailer-truck used in this paper is shown in Fig.1. The control objective is to make the trailer-truck follow a straight target line only backward movement at constant velocity from various initial states. In other words, a 3-input-1-output regulator should be designed. The inputs are the connection angle between trailer and truck ϕ, the angle of the trailer θ and the distance between the



(a)

(b)

Figure 2: *The structure of SOR network. (a)Learning mode, (b)Execution mode.*

trailer-truck and the target line d, and, the output is the front wheel angle of truck σ.

3 Controller Design

3.1 The SOR Network

The SOR network[4] consists of the input layer, the output layer and the competitive layer, in which n, m, and N units are respectively included as shown in Fig.2. The j-th unit in the competitive layer is connected to the units in the input and the output layers with weight vectors respectively. The network can be established by learning in order to approximate the desired I/O relationship of the object system. The SOR network has two modes, learning mode and execution mode. In learning mode (Fig.2(a)), the random I/O vectors are applied as learning vectors, to the input and the output layers together with the evaluation for the I/O vector pair. The evaluation may be assigned by the network designer, given by the intuition of the user or obtained by examining the system under test. The value of evaluation is positive and negative in accordance with judgment of the designer, preference of the user or score of examination. The positive causes the self-organization of attraction to the learning vector and the negative one does that of repulsion from the learning vector. The weight vectors are arranged in area where desired I/O vector pairs exist by learning. After the learning the SOR network is ready to use as the I/O relationship generator in execution mode (Fig.2(b)). The output of the network represents the weighted average of output vectors by the similarity measure between the reference vector and the actual input vector.

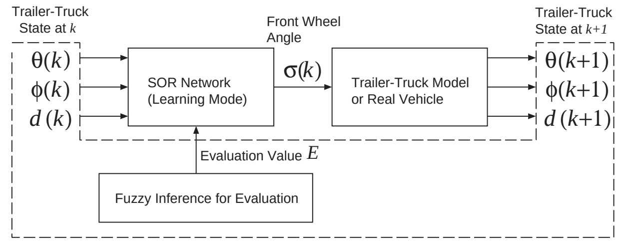


Figure 3: *Data acquisition and evaluation process.*

3.2 Data Acquisition and Evaluation

In computer simulation, it is assumed that the kinematics model of the trailer-truck is given. Fig.3 shows procedure of learning vectors acquisition. At first, the state of the trailer-truck at k $(\phi(k), \theta(k), d(k))$ is randomly given. Then, front wheel angle $(\sigma(k))$ is randomly given as an operation at state k. These values are elements of the learning vectors. As a result of operation, the state at $k+1$ is calculated using kinematics model. The designer should evaluate the I/O relationship of the controller with fuzzy inference by observing the state at k and $k+1$. The antecedent variables of the fuzzy inference are the state of the trailer-truck $(\phi(k), \theta(k), d(k))$ at k, and the consequent variable is the decreace of the error between state k and $k+1$. The decreace of the error is normalized and its range is from -1 to 1. These fuzzy if-then rules are constructed based on four fundamental control strategies given by designers' commonsense.

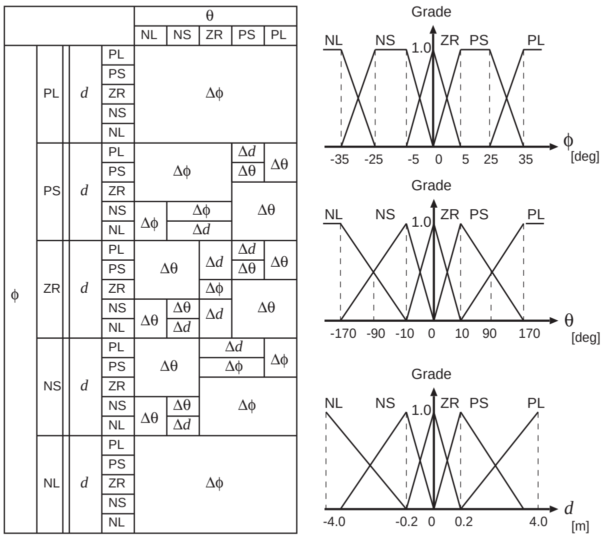
(Strategy 1) If the connection angle ϕ is large, it should be decreased to avoid jackknifed-state.

(Strategy 2) If the trailer-truck is directed away from the target line, the direction should be corrected to meke the trailer-truck approach the target line.

(Strategy 3) If the trailer-truck move in a direction opposite to the target direction, the direction should be corrected to meke the trailer-truck move in the target direction.

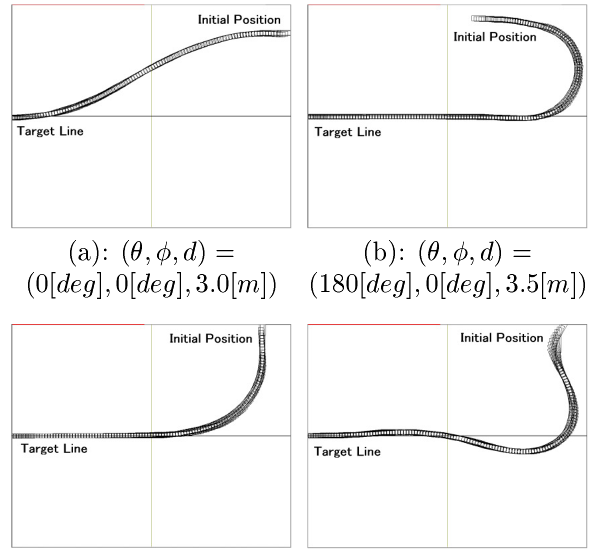
(Strategy 4) If the control strategies 1-3 are satisfied, the trailer-truck should be controlled to follow the target line while regulating both the distance d and the angle θ.

Particularly, the strategy 1 is most important, because the trailer-truck should be controlled while avoiding falling into uncontrollable state. These strategies are represented by fuzzy if-then rules and fuzzy membership functions shown in Fig.4(a)(b).



(a) (b)

Figure 4: *Fuzzy if-then rules for evaluation. (a)Rule table. (b)Membership functions. The consequent variables* $\Delta\phi$*,* $\Delta\theta$*,* Δd *represents normalized decrease of error between state* k *and* $k+1$*.*



(a): $(\theta, \phi, d) = (0[deg], 0[deg], 3.0[m])$
(b): $(\theta, \phi, d) = (180[deg], 0[deg], 3.5[m])$
(c): $(\theta, \phi, d) = (90[deg], 0[deg], 3.0[m])$
(d): $(\theta, \phi, d) = (90[deg], -30[deg], 3.0[m])$

Figure 5: *Simulation results from various initial states.*

3.3 Learning of SOR network

As the learning vectors, 50000 vectors are acquired and evaluated by the proposed method. For details of learning process, refer to references [4][5].

4 Simulation Results

Simulation results are shown in Fig.5. In each figure, the lengths of the work space are 10.0m and 8.0m for the x and y axes, respectively. The trailer-truck is controlled to satisfy the control objective from the various initial states while avoiding jackknifed-state. Fig.6 shows that the time series of the I/O variables of controller in case of Fig.5(c). It should noted that the trailer-truck-specific operation "countersteering" is achieved at the beginning of the control, though details of the operation were not supervised in evaluation process.

Generally, the difficulty of the trailer-truck back-up control mainly relies on variation of the length ratio between trailer and truck. To verify the robustness of the controller against length ratio variation, some trailer-trucks with different length ratio are controlled by the controller which is designed for the trailer-truck with length ratio $L_{trailer}/L_{truck} = 1.26$. The values of length ratio are, 0.75, 1.0, 1.26, 1.50, 1.75, 2.0. Fig.7 shows trajectories in phase space. The controller is stable for the range from 1.26 to 2.0 though the overshoot becomes large as the ratio increases. On the other hand, the controller is unstable for the ratio 0.75, and the trailer-truck fell into jackknifed-state. In case that the ratio is 1.0, the controller is narrow stable. This is because the back-up control becomes difficult as the trailer length becomes short. In case that the ratio takes off significantly, the controller should be re-designed.

5 Practical Experimental Results

In the experimental system, the coordinates of three markers attached to trailer-truck are detected by CCD cameras and motion capture system. In the PC, the angles ϕ, θ and the distance d are calculated and the front wheel angle σ (*i.e.* the output of the SOR network) is calculated. The weight vectors of the SOR network used in the experiment are the same to those used in the computer simulation. Fig.8 shows the experimental result. Each picture was taken every five seconds. The black line in the figures is the target line. The initial values of the distance and angles are $\phi = 0$[degree], $\theta = 135$[degree], and $d = 2.5$[m] as shown in Fig.8 (a). The angle of the trailer becomes smaller and the trailer-truck follows the target line finally. In cases of other initial values, it is confirmed that the trailer-truck can follow the target line.

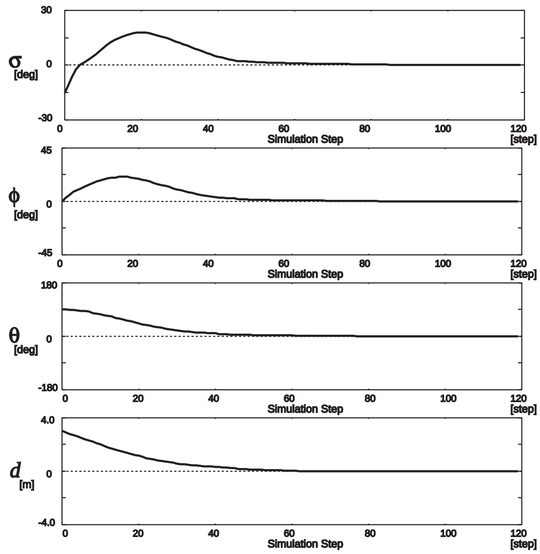


Figure 6: *Time series of I/O variables of controller.*

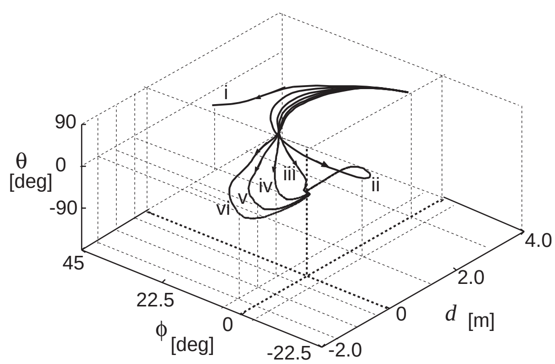
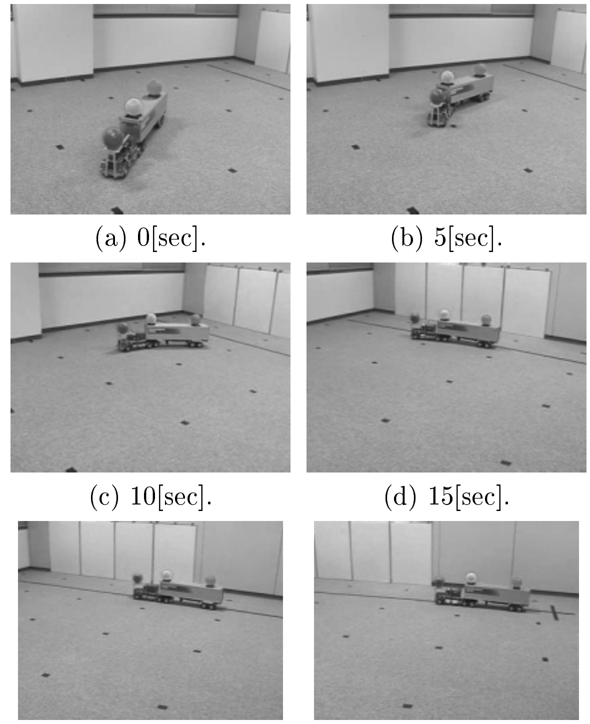


Figure 7: *Trajectories in phase space. Initial state:* $(\phi, \theta, d) = (0[deg], 90[deg], 3.0[m])$*. The length ratio=* $i : 0.75$, $ii : 1.0$, $iii : 1.26$, $iv : 1.50$, $v : 1.75$, $vi : 2.00$.

6 Conclusion

In this paper, we proposed a controller design method for trailer-truck back-up control by using SOR network with fuzzy inference based evaluation. The back-up controls both in computer simulations and practical experiments are successfully achieved by using the proposed method. The controller design is achieved with only common sense (special knowledge of experts is not needed) which is used for evaluating I/O relationship. Furthermore, the controller designed by the proposed method is robust against physical parameter variation of the trailer-truck.



(a) 0[sec]. (b) 5[sec].

(c) 10[sec]. (d) 15[sec].

(e) 20[sec]. (f) 25[sec].

Figure 8: *Practical experimental result. Initial state:* $(\theta, \phi, d) = (135[deg], 0[deg], 2.5[m])$

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