Route Tracking Control of Tractor-Trailer Vehicles based on Fuzzy Controller

Hiroki Takenaga, Masami Konishi and Jun Imai
Department of Electrical and Electronic Engineering,
The Graduate school of Natural Science and Technology
Okayama University
3-1-1 Tsushima-naka, Okayama 700-8530, Japan
(Tel.: +81-86-251-8123;Email:takenaga@cntr.elec.okayama-u.ac.jp)

***Abstract*—Recently, Factory Automation is actively been carried out in industry. Usually, a single AGV is used to transport products for factory automation. While, a Tractor-Trailer Vehicle can load much more products compared with a single AGV. Addition to this, transportation time can be shortened by separating containers. But, it is not so easy to drive the trailer according to the orbit during running of the Tractor-Trailer Vehicle. In this study, fuzzy control scheme is studied to support satisfactory route tracing of a tractor-trailer vehicle. To extruct the control rules, a fuzzy control system is developed.**

Keywords: Tractor-Trailer Vehicle, route tracking, Fuzzy control, Fuzzy classifier, GA

I. Introduction

Tractor-Trailer Vehicle has a high transportation efficiency, because it can transfer a lot of loads at a time. Also, transportation with the container enables to transfer loads with low-cost. The material and product are transported a with Tractor-Trailer Vehicle not only in a public road but also in a production plant. However, it has a problem to induce an accident because its control is very difficult compared with a single AGV. As for the control rules applicable to a single AGV is studied and its effects are reported[1-3]. To prevent the trouble, it is necessary to run smoothly. There are several researches on the moving supporting system[4-6], but not concerning the automation.

Conventionally, Running of AGV in the factory is attained to run along the lane embedded to the floor. On the other hand, the method of recognizing the running zone painted on the floor may be effectve when the layout of the factory is frequently changed where many small sized lot are produced. By the method, the route can be changed with a low cost compared with the conventional method.

In the study, running that uses the latter method is studied. Here, the research to provide the intelligence to AGV together with the research on the route planning is made. As for the intelligence, AGV recognizes running environment by an image processing. The route is to be flexibly changed when there is an obstacle. However, it induces a loss in transportation because it takes a time for rerouting and run for longer distance. Furthermore, it is preferable to continue running when the obstacle is small compared with the width of the route and there remains the width that the AGV can pass along. However, to do such operation of a connected vehicle, designed of the running orbit of the trailer becomes a difficult problem. If the tractor can pass the narrow road, the trailer can't through the road because it moves along the inside or the outside line compared with tractor's moving line.

In this study, to know the running orbit of the trailer, the running rules that reduce the margin between the running orbit and the target orbit are pursuit.

II. Transfer system of Tractor-trailer Vehicles

The block diagram of the proposed transportation control system for Tractor-Trailer Vehicles is shown in Fig.1. The transportation system is made of six parts as described in the following.

1) Route planning system plans the route from given Start node to Goal node. Here, the decided route is a rough planned transportation, and not a strict running lane.
2) Orbit making system generates the ideal orbit of running from the planned route.
3) Controller determines the steering and the velocity inputs to the vehicle to run along to the aimed orbit.
4) Tractor-trailer vehicle runs according to the given inputs.
5) The error margin of ideal orbit and position of vehicle is calculated by image processing while running. Moreover, the situation of the route is checked by the processing, if the obstacle exists. If it is necessary to change the aimed orbit, orbit making system output results for rerouting. In the acquisition of the position by the image, the measuring error is considered.
6) Input to the Rule system is the error and compared with the rule pattern known beforehand. If it fits one of the rules, output Δv and $\Delta \phi$ for the vehicle to approach the ideal orbit. These Δv and $\Delta \phi$ are fedback to the vehicle model.

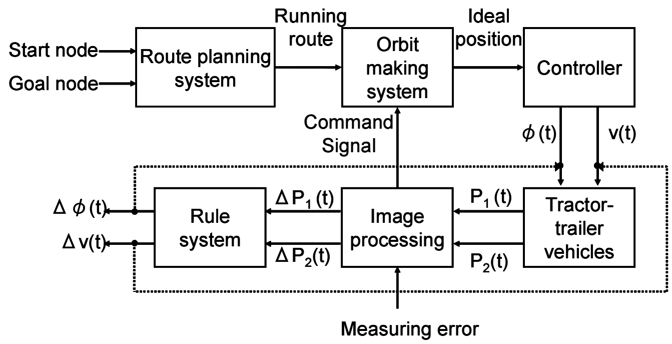

Fig. 1. Transportation system

III. Model of tractor-trailer vehicles

The model of Tractor-Trailer Vehicle is shown in Fig.2.

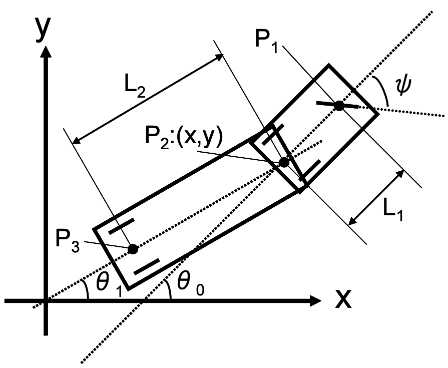

Fig. 2. Model of Tractor-Trailer Vehicles

Here, L_1 is a distance between the tractor's front wheel and the couple point, L_2 is a distance between the couple point and the trailer's rear wheel, $x,\ y$ are coordinates of the couple point, θ_0 is the angle of the tractor to x axis, θ_1 is the angle of the trailer to y axis, and ψ is the angle of the tractor's front wheel to the tractor.

$$\frac{d}{dt}\begin{bmatrix} x \\ y \\ \theta_0 \\ \theta_1 \\ \psi \end{bmatrix} = \begin{bmatrix} \cos\theta_0 & 0 \\ \sin\theta_0 & 0 \\ \frac{\tan\psi}{L} & 0 \\ \frac{\sin(\theta_0-\theta_1)}{L_2} & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \tag{1}$$

Next, the evaluation function is explained. In this study, the gap of the trailer is paid to attention as mentioned above. Therefore, the evaluation value is given as written in Eq.(2).

$$\begin{aligned} J=&(\text{Average of error margin at } P_2) \\ &+ (\text{Maximum value of error margin at } P_2) \\ &+ (\text{Average of error margin at } P_3) \\ &+ (\text{Maximum value of error margin at } P_3) \end{aligned} \tag{2}$$

Where the margin is the gap of P_2 and P_3 seen from the ideal orbit. The maximum value becomes most important elements for evalution, though the mean value is also an important element. Therefore, the weighting factor is not considered in the evaluation function.

IV. Fuzzy classifier system[7-10]

In this section, rule selection by using fuzzy classifier system(FCS) is explained. Control rules are developed based on the fuzzy classifier. The rule extraction engine is made by Genetic Algorithm(GA). FCS is a system which makes and selects IF-THEN rules in order to achieve some purposes. IF-THEN rule has a condition part and a conclusion part, and if the conclusion part fit the present condition, act up to the conclusion part. Membership functions as shown in Fig.3 are used for the fuzzy classifier, and it have vagueness. Generically, threshold levels of membership functions are optimized by GA.

A. Rule of FCS

The running rule of Tractor-Trailer Vehicles is given here. The rules of the IF-THEN form are generally used as Fuzzy Rules. One of the running rule is shown in the following.

If ϵ_1 is ZO AND
ϵ_2 is ZO AND
ϵ_3 is ZO AND
δ_1 is PB AND
δ_2 is NS AND
δ_3 is NS,
THEN steer is PS AND
v is PS.

Where ϵ is the position error of the vehicle from its aimd orbit, and δ is the time derivative of the position error from its aimed orbit.

The condition part is assumed to be the changes in the position and each point of P1, P2, and P3 of the vehicle. The conclusion part is appointed to the steering and speed changes. All rules allocate PB, PS, ZO, NS, and NB in a descending order.

Next, the membership function will be explained. The membership function is shown in Fig.3. A general isosceles triangle membership was used.

The membership function related to a position is shown in Fig.3(a). It is set that the maximum values $\epsilon_{1_{\max}}$ and $\epsilon_{2_{\max}}$ are 0.5[m]. And, it is assumed that $\epsilon_{3_{\max}}$ is 0.4[m] because it is seldom to run off from the ideal orbit compared with $\epsilon_{1_{\max}}$ and $\epsilon_{2_{\max}}$.

The membership function related to the change in the position is shown in Fig.3(b). It is decided $\delta_{1\max}$=0.10[m/s], $\delta_{2\max}$=0.08[m/s] and $\delta_{3\max}$=0.04[m/s] for similar reasons for $\epsilon_{3_{\max}}$.

The membership function related to steering is shown in Fig.3(c). Because the amount of operation is the additional output of the controller, the value of $\Delta u_{\max}$ is set 40[deg]. The shape of membership function related to Δu is unique.

Because it is necessary to select a value close to 0[deg] from two kinds of Δu in determining the steering value from the membership function, and also Δu=0[deg] is at ZO.

The membership function set to velocity is shown in Fig.3(d). It works to limit output value of the controller. It is assumed that $\Delta v_{\max}$=100[%] and $\Delta v_{\min}$=40[%]. If Δv is 100[%], input the vehicle is directly given, and if Δv is 50[%], input value is made half. The shape of the membership function related to $\Delta v_{\max}$ is also unusual. Because it is required to select a large value from two kinds of Δv in determining the velocity using the membership function.

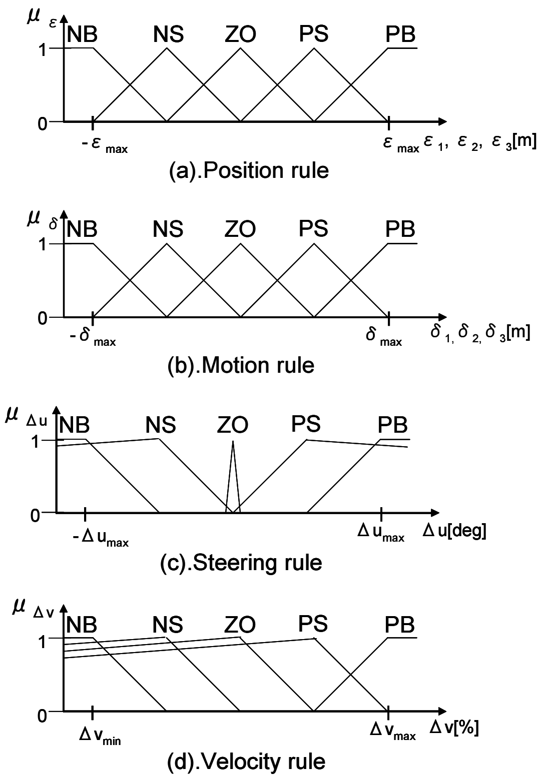

Fig. 3. Membership function

B. Method of rule making[3,11]

Procedure of the rule making is as shown in Fig.4. First, running by the initial rule and allocate the utility. The utility is the counted number to which the rule is applied, and if running by using the rules is succeed, allocate the utility to the rules. Afterwards, the rule not used by running is deleted, and the rule is made at random without duplication. The running and the evaluation are iterated by using the new rule. GA operation made once per several-times in this operation. The rule that exists in the solution is replaced in GA. Thus, it aims at the improvement of the evaluation value by renewing the combination. When the duplicated solution exists after GA operation, another solution is generated randomly. Refinement of the rule is not made, if there are a lot of abandoned rules by GA are generated.

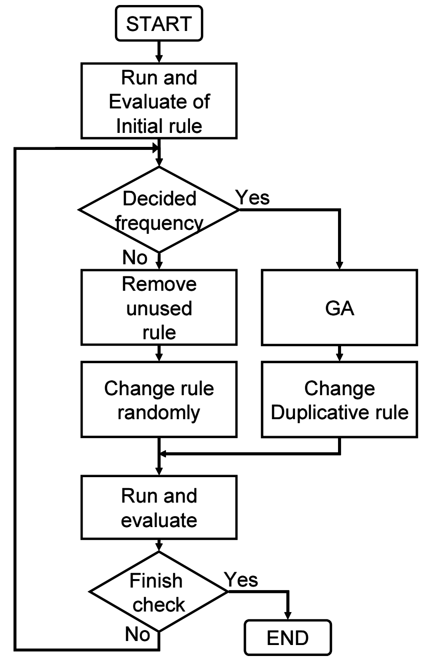

Fig. 4. Method of rule making

C. Construction of rule data base

Here, the construction of rule data base is explained. The rule data base is prepared according to the following steps.

STEP1:Making of standard value

First, to evaluate running result, make standard value. It runs by using controller such as always Δu=0[deg] and Δv=100[%]. Standard value is made by using Eq.(2).

STEP2:Correction of orbit by manual running

Next, rule is run manually. Adjustments of Δu and Δv are made at constant intervals, to realize the operation that approaches the ideal orbit.

STEP3:Extraction of rule

The evaluation values are compared with standard value when arriving at the target point after repeating the operations of STEP2. If error margins become small more than the standard values calculated in STEP1, all rules used by the running are stored in the data base. The made rule has a condition in the condition part and a manual operation in the conclusion part.

V. Simulation

A. Problem setting for simulation

- Vehicles and ideal orbit

  In this simulation, we set parameters as L_1=0.2[m], L_2=0.4[m], θ_0=0[deg], θ_1=0[deg], ψ=0[deg] and maximum velocity is set 0.5[m/s]. Moreover, the Runge-Kutta method is used in the simulation. It assumes that dt=0.005[s]. The sampling-time is set 0.2[s] considering to involve the image processing in the future.

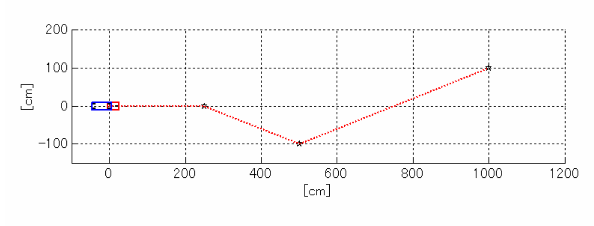

Fig. 5. Idial orbit

- Fuzzy Classifier System

  154 running rules are made in data base by manual running three times. And setting the number of solution as 20, rules in a solution as 20, crossover rate is set as 0.1, mutation rate is set as 0.1, generations are set as 10, decided frequency in Fig.4 is set 5 respectively.

  Moreover, to prevent excessive time of the running simulations, judge the mistake to running when the vehicle begins running for the traveling opposite direction in the ideal orbit and when vehicles do not reach destination even if the calculation frequency exceeds 10000 times.

B. Result of running test

Result of running test only by the conventional controller are shown in Fig.6. The conventional control is a preview feedforward control based on optimal regulator[12]. As shown in Fig.6, only by the controller, it is understood to induce a big error margin when the orbit changes.

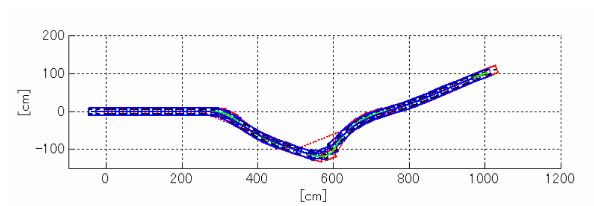

Fig. 6. Running by controller

While, result of running by the rule based system additional to the conventional controller are shown in Fig.7. It becomes possible to approach the ideal orbit by using the rule base derived by Fuzzy classifier system.

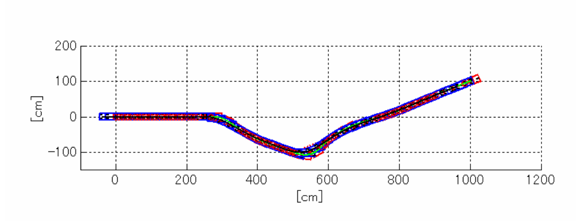

Fig. 7. Running by fuzzy rule too

The comparison between the average and maximum value of the error margin of each point in running is made. Table I shows the result in the case of running only by conventional controller.

TABLE I
EVALUTION OF RUNNING BY CONVENTIONAL CONTROLLER

	P_1	P_2	P_3
average	0.074	0.066	0.051
maximum value	0.499	0.459	0.337

On the other hand, the result of running by using rule based system is shown in Table II. It can be confirmed that evaluation values are improved at all points including P_1 not added as an evaluation point. And, the criterion shown in Eq.(2) became 0.432[m] by using fuzzy rule and is less than the half compared with 0.913[m] that is the result of running by the conventional controller.

TABLE II
EVALUTION OF RUNNING BY FUZZY RULE

	P_1	P_2	P_3
average	0.040	0.034	0.022
maximum value	0.274	0.239	0.136

It is confirmed that by using the extracted rules the orbit can approach the ideal one.

C. Verification of developed rules

The made rule was verified. It indicate the part of the applied rule on running in Fig.7. The places where the rule is used are shown in Fig.8.

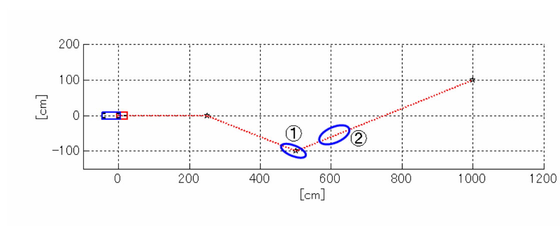

Fig. 8. Test positions for rules

- First rule

  The first rule is applied to the place of ① in Fig.8. When, the target orbit of P_1 changes, the error margin with the ideal orbit grows. Then, the steer angle is added and quick correspondence is done. The rule applied to the position ① is indicated in following. And position of vehicles are shown in Table III when the rule A is applied.

Rule A:

If ϵ_1 is PS AND
ϵ_2 is PS AND
ϵ_3 is PS AND
δ_1 is PS AND
δ_2 is ZO AND
δ_3 is ZO,
THEN steer is PB AND
v is NS.

TABLE III
CONDITION OF APPLY RULE IN POSITION ①

	P_1	P_2	P_3
ϵ	0.169	0.042	0.012
δ	0.051	0.037	-0.002

In the following, the method of determination of Δu and Δv is explained.

STEP1:Calculate membership value of each position

First, the membership value of P_1 is calculated. If it match P_1 while running, μ_{ϵ_1} the membership value of ϵ_1 is calculated like in Fig.10(a). And similarly μ_{ϵ_2} and μ_{ϵ_3} are calculated like in Fig.10(b)(c).

STEP2:Determine μ_ϵ

The membership value of position is determined. Because rules are connected through Fuzzy algorithm, use the smallest value of membership. Therefore, μ_ϵ is determined by following Eq.(3).

$$\mu_\epsilon = \min\{\mu_{\epsilon_1}, \mu_{\epsilon_2}, \mu_{\epsilon_3}\} \quad (3)$$

STEP3:Calculate membership value for change of each position

Next, the membership value of δ_1 is calculated. If it match change of P_1 while running, the membership value μ_{δ_1} is calculated like in Fig.10(d). And μ_{δ_2} and μ_{δ_3} are similarly calculated like in Fig.10(e),(f).

STEP4:Determine μ_δ

The membership value of change of position is determined. Because rules are to be connected through Fuzzy algorithm, use the smallest value of membership. Therefore, μ_ϵ is determined by following Eq.(4).

$$\mu_\delta = \min\{\mu_{\delta_1}, \mu_{\delta_2}, \mu_{\delta_3}\} \quad (4)$$

STEP5:Determine Δu and Δv

Determine Δu and Δv by using final membership value calculated by Eq.(5). It is decided amount of additional operation, Δu in membership value equal to μ as shown in Fig.10(g). And Δv is similarly calculated like in Fig.10(h).

$$\mu = \min\{\mu_\delta, \mu_\epsilon\} \quad (5)$$

- Second rule

The second rule is applied in the place of ②. At the stage where it is approaching the ideal orbit, it reduces the amount of additional operation compared with place of ②. As the result, it approaches the ideal orbit in short distance. Rule that applied in position ② is indicated in the following. And position of vehicles are shown in Table IV when Rule B is applied.

Rule B:

If ϵ_1 is ZO AND
ϵ_2 is PS AND
ϵ_3 is PS AND
δ_1 is NS AND
δ_2 is NS AND
δ_3 is ZO,
THEN steer is PS AND
v is PB.

TABLE IV
CONDITION OF APPLY RULE IN POSITION ②

	P_1	P_2	P_3
ϵ	-0.005	0.055	0.117
δ	-0.020	-0.029	-0.012

D. Running in other route

The running experiment in another orbit is done by using the rule made for the orbit of Fig.5. The other orbit is reversed from that shown in Fig.5. Results of running are shown in Fig.9. When running by using controller, the same evalution value as Table I is obtained. It is understood that the application of rules can improve the evalution value in running.

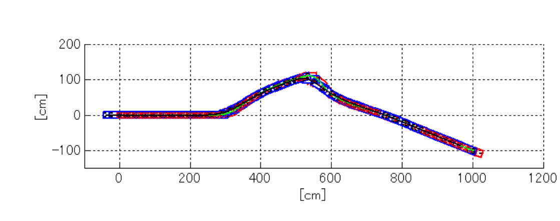

Fig. 9. Running in other route

The average and maximum values of each point are inidicated in Table V. And, the evaluation value by Eq.(2) is 0.451[m]. It is understood from Table V that the evalution value is improved. Here, the applied rules are changed for running of this orbit. Therefore, it is necessary to research better rules applicable to many patterns flexibly.

It is necessary to extract the rule in a lot of running orbits, and to make rule system that any situation can correspond flexibly. Moreover,it is found the problems that method of rule

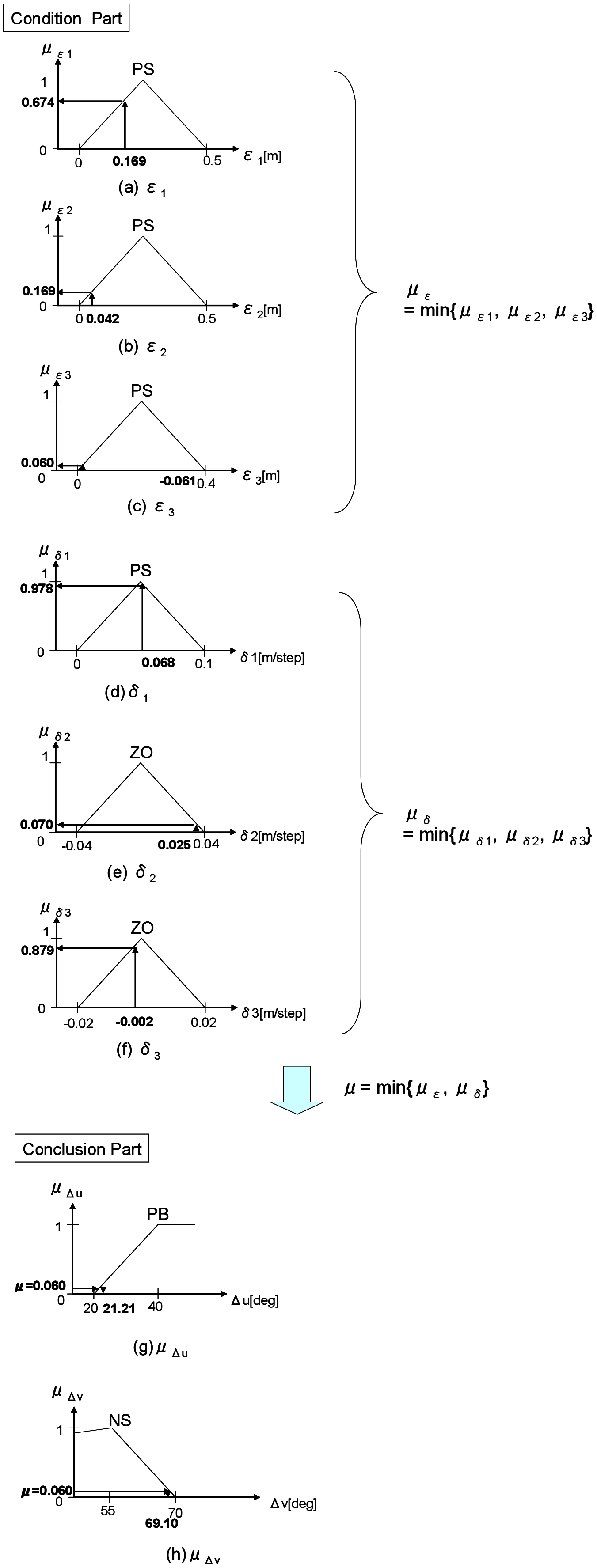

Fig. 10. Application results for test position

TABLE V
EVALUTION VALUE OF RUNNING IN OTHER ROUTE

	P_1	P_2	P_3
average	0.044	0.037	0.023
maximum value	0.304	0.258	0.133

search and the method to avoid the conflicted rules are to be made more effeciently.

VI. CONCLUSION

In this study, factory automation by using a Tractor-Trailer is targeted. As the first step of providing intelligence to the vehicle, rule extraction for the improving running control to lesson the error margin between the aimed orbit and the actual one. The Fuzzy Classifier System is constructed to extract the rules. The conditions used in the control rules are the running state and its time derivative. The conclusions used in the rules are the velocity and the steering of the vehicle. The output of the fuzzy controller is added to the conventional controller to enforce the follow up ability of the vehicle to the aimed orbit. The problem is left for the extrapolation cases. To resolve the problem, it is necessary to continue move learning of rules using much more case studies. The collision avoidance with obstacles is the future work to be solved.

REFERENCES

[1] Anthony G.Pipe et.al., “Experiments on a Pittsburgh-style Fuzzy Classifier System for Mobile Robotics”, IEEE International Symposium on Intelligent Control, pp. 61-66, 2002.

[2] Hiroyuki INOUE and Katsuari KAMEI, “An Acquisition of Fuzzy Rules for Mobile Robot Using Fuzzy Classifier Systems”, Japan Society for Fuzzy Theory and Intelligent Informatics, *A Fine Journal*, ,2004.

[3] T.Furuhashi et.al., “A New Approach to Genetic Based Machine Learning and an Efficient Finding of Fuzzy Rules - Proposal of Nagoya Approach -”, Lecture Notes in Artificial Intelligence, pp.173-189, 1995.

[4] Masanori Harada et.al., “Improvement of Stability for Driver-Car-Trailer System at High Speed”, JSME, vol.659, pp.2278-2283, 2001.

[5] Nobutaka WADA et.al., “Robust Tracking Control of a Nonholomic Mobile Robot in the Presence of Disturbances”, JSME International Journal, vol.47, No.2, pp.694-701, 2004.

[6] Jian Wang and Chun-Yi Su et.al., “Robust Motion Tracking Control of Partially Nonholonomic Mechanical Systems”, Robotics and Autonomous Systems, vol.54, pp.332-341, 2006.

[7] John R.Clymer, “Simulation of a Vehicle Traffic Control Network Using a Fuzzy Classifier System”, IEEE Simulation Symposium, pp. 285 - 291, 2002.

[8] Ludmila I. Kuncheva and Lakhmi C. Jain, “Designing Classifier Fusion Systems by Genetic Algorithm”, IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION, VOL.4,NO.4, pp. 327 - 336, 2000.

[9] Hisao Ishibuchi et.al., “Construction of fuzzy classification systems with rectangular fuzzy rules using genetic algorithms”, Fuzzy Sets and Systems, pp. 237-253, 1994.

[10] Yoshihiro Abe, Masami Konishi and Jun Imai, “Acquisition of Tuning Rules for Hot Strip Looper System based on Fuzzy Classifier System”, Proceedings of ICICIC 2008(CD-ROM).

[11] N. E. Nawa, T. Furuhashi et.al., “A Study on the Discovery of Relevant Fuzzy Rules Using Pseudo-Bacterial Genetic Algorithm”, Trans. on Industrial Electronics, vol.46, No.6, pp.1080-1089, 1999.

[12] Shuji MABUCHI, Masami KONISHI, and Jun IMAI, “Tracking Control of Combination Vehicles with Preview Feedforward Compensation”, Memoirs of the Faculty of Engineering, Okayama University, Vol. 43, pp. 32-38, January 2009, pp.32-38, 2009.
Shuji MABUCHI, Masami KONISHI, and Jun IMAI