Control System Of Train Speed Based On Fuzzy Logic Controller

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Control System of Train Speed Based on Fuzzy Logic Controller

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***Abstract*—This study aims to implement fuzzy logic controller using Mamdani and defuzzification method of Centroid, as a controller for train speed. Research methodology employed consists of Modeling, Design, Testing, and Analysis. At Modeling phase, the system is modeled utilizing transfer function model; at Design phase, the system with fuzzy logic controller is designed; at Testing phase, system output is examined by utilizing four types of testing (testing of rise and fall, testing of pulse input, and testing with simulated scenarios); at Analysis phase, system output is analyzed based on rise time, fall time, settling time, and average steady-state error. The results showed that when tested with the reference speed of rise and fall, the system with fuzzy logic controller has an average value of rise time 2.3 seconds, fall time 2.44 seconds, and settling time 3.58 seconds; when tested with testing of pulse input, the system has an average value of rise time 2.359 seconds, fall time 4.238 seconds, and settling time 4.1125 seconds. Train simulation results with additional resistance showed that system using fuzzy logic controller has an average value of error 2%.**

Keywords*— *fuzzy logic controller; Centroid; Mamdani; train speed system

I. INTRODUCTION

The speed of train acts as crucial instrument on train. Implementation of apposite method of control system on train speed is imperative so that the train can work more efficiently. The researches on train have been expanding. Control application using algorithm is also used.

The use of first control algorithm on Automatic Train Operation (ATO) was in London in 1968 [5]. Presently diverse types of intelligent control has been applied. There are applications of pure control and hybrid control. In [11], fuzzy logic is applied to the system of ATO; the model system used is based on ATO design; fuzzy is compared with the system using PID (Proportional-Integral-Derivative). Reference [7] compares two models of high-speed train, namely single-mass (SM) model and unit-displacement multi-particle (UDMP) models; direct fuzzy logic controller is applied to SM model and fuzzy controller using implication logic is applied to UDMP model. Reference [12] utilizes fuzzy predictive control for ATC (Automatic Train Control), which controls passenger comfort, accuracy of train stopgap, and running time. In [4], braking control on the system of ATO is based on Switching Control Fuzzy-PID; the model system employed is in the form of transfer function based on experimental data. Reference [3] compares the utilization of PID controller with single-neuron PID controller on the model of train speed which is in the form of transfer function. Sekine and Nishimura [10] implement two-degree Fuzzy Neural Network Control on ATO; the results showed that the number of fuzzy rules is diminished but control of ATO escalates.

Moreover, certain variables are subsumed in the study on train. Reference [5] incorporates a variable of running condition on High-Speed ATO; fuzzy rules are used to control train running process. Reference [6] incorporates the variables of working conditions, such as traction, idling, and brake, which are tuned using fuzzy rules; predictive calculate method is also applied to diminish time delay of fuzzy rules and to enhance transportation efficiency. Reference [1] incorporates a variable of energy consumption; the method used is MAX MIN Ant System (MMAS) to optimize speed code; fuzzy-PID gain scheduler is employed to regulate the acceleration of the train in order to tracking performance is in accordance with a predetermined speed code.

Nonetheless, of all of the researches, there is no pure-fuzzy application on train model in the form of transfer function. In this study, we endeavor to apply fuzzy logic controller (FLC) by using Mamdani and defuzzification method of Centroid, on train model in the form of transfer function derived from [3]. The result curves are displayed on Simulink and then analyzed using the approaches of rise time (Tr), fall time (Tf), settling time (Ts), and average steady-state error.

II. RESEARCH METHODOLOGY

The phases of the research methodology employed are Modeling, Design, Testing, and Analysis. At Modeling phase, train braking system is modeled in the form of transfer function. The system has an input of signal power and an output of speed. Fig. 1 shows a simple instance of braking system using compressed-air.

At Design phase, fuzzy logic controller is designed and applied to the system. In general, fuzzy logic controller employed comprises fuzzification, inference, and defuzzification. Fuzzy logic controller has two inputs: error and delta error (derror), and one output: control signal [9]. Fuzzy method used is Mamdani and defuzzification method used is Centroid. Fig. 2 shows basic structure of fuzzy logic controller.

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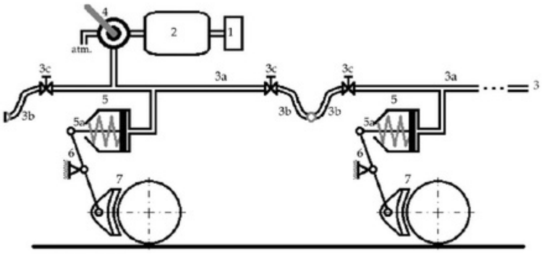

Fig. 1. System schematic of compressed-air braking [2]

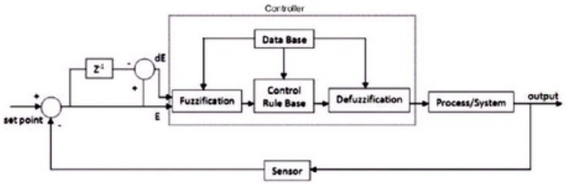

Fig. 2. Basic structure of fuzzy logic controller system [9]

At Testing phase, the system output in the form of speed is examined using four types of testing: testing of rise and fall value, testing of pulse input, and testing with simulation. The system with fuzzy logic controller is compared to the system with PID controller. Parameters of Kp, Ki, and Kd on PID controller are obtained from [3].

At Analysis phase, the output system is analyzed using the approaches of Tr, Tf, Ts, and steady-state error [8]. Then analysis results of the system with fuzzy logic controller are compared to the system with PID controller.

III. MODELING AND DESIGN

Overall system is interpreted as an integration of train braking system with controller. Meanwhile, train braking system is modeled in the form of transfer function. Transfer function model is deployed to represent train braking system. Based on [3], transfer function of train braking system is shown on (1).

$$G(s) = G_n(s)G_0(s) = \frac{612}{s+0.34}\,\frac{1}{8621s+822.4} \tag{1}$$

Gn(s) has an input of power signal and an output of traction. G0(s) is component of model possessing varied value, with additional resistance as the input and speed as the output. Fig. 3 shows a block diagram of function transfer model of the system.

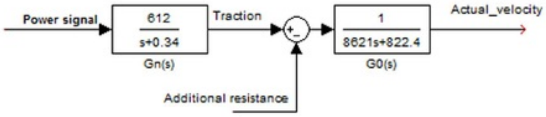

Fig. 3. Block diagram of system transfer funcion

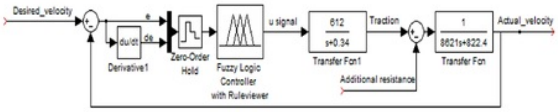

Fig. 4. Block diagram of system with fuzzy logic controller

A controller is supplemented to the model of train braking system. It aims to control output value of the system, i.e. speed, to match desired speed reference. The input of fuzzy logic controller is error value (error) which is the difference value between desirable speed and actual speed, and derror which is the difference value between current error and previous error per second.

The output of fuzzy logic controller is control signal (u) which act as an input to the model of train braking system. Fig. 4 shows a block diagram of the system with fuzzy logic controller.

At Fuzzification phase, the types of membership functions employed on input (error and derror) and output (control signal u) are triangular and trapezoidal. Meantime, the value of membership function parameters is determined by assuming the largest Desired_velocity value, i.e. 15 m/s. Fig. 5 shows a graph of error value when the system without a controller is given a step signal input of 15 m/s. From the graph, it is known that when given an input of 15 m/s, the largest error value is 15.

Fig. 6 shows membership functions of error. There are five linguistic variables employed, i.e. NL (Negative Large), NS (Negative Small), Z (Zero), PS (Positive Small), and PL (Positive Large). NL and PL have a trapezoidal shape, while NS, Z, and PS have a triangular shape.

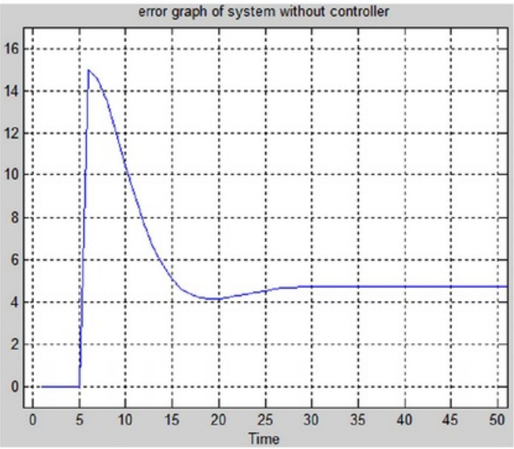

Fig. 5. error graph of system without controller

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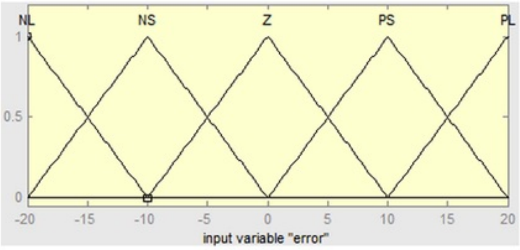

Fig. 6. Membership functions of error

According to Fig. 7, when the system without a controller is given a step signal input of 15 m/s, the highest alteration value of error or derror is 15. Nevertheless, after comparative tests using fuzzy logic controller, the graph of system response is rapidly more adaptive if the upper and lower limits of derror parameters have value less than 15 and -15, i.e. 7 and -7, so as the upper and lower limits on derror parameters are 7 and -7.

Fig. 8 shows membership functions of derror. There are five linguistic variables used, i.e. NL (Negative Large), NS (Negative Small), Z (Zero), PS (Positive Small), and PL (Positive Large). NL and PL have a trapezoidal shape, while NS, Z, and PS have a triangular shape.

Control signal u applies the parameters of upper and lower limits which are more immense than error and derror that actual velocity can be more responsive and adaptive. The parameters of upper and lower limits on the signal u are 200 and -200.

Fig. 9 shows membership functions of u. Membership functions of u have 7 linguistic variables, i.e. NL (Negative Large), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), and PL (Positive Large). NL and PL have a trapezoidal shape, while NM, NS, Z, PS, and PM have a triangular shape.

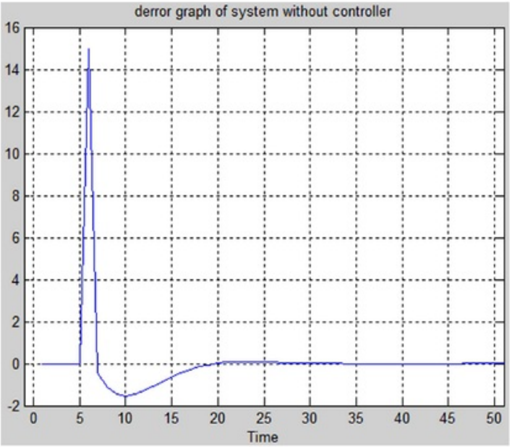

Fig. 7. derror graph of system without controller

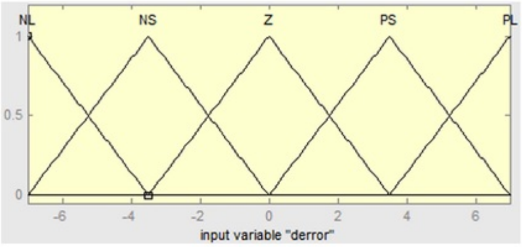

Fig. 8. Membership functions of derror

TABLE I. RULES OF FUZZY LOGIC CONTROLLER

derror	**error**				
	NL	***NS***	***Z***	***PS***	***PL***
NL	NL	NL	NM	Z	PS
NS	NL	NL	NS	PS	PM
Z	NL	NM	Z	PM	PL
PS	NM	NS	PS	PL	PL
PL	NS	Z	PM	PL	PL

At Inference phase, various rules are specified. Determination of rules established is shown on Table I. The columns consist of NL, NS, Z, PS, and PL, notifying the names of linguistic variables of membership functions of error. The rows consist of NL, NS, Z, PS, and PL, notifying the names of linguistic variables of membership functions of derror. Then the content of the table is linguistic variables of membership functions of signal u.

At Defuzzification phase, fuzzy-shaped value of u is then converted into a crisp value to be used by the system. This conversion is aimed to defuzzification phase. Defuzzification method employed in this study is Centroid method, i.e. the determination of crisp values acquired from weight point of the result curve of decision-making process [13]. The formula of Centroid method is shown on (2).

$$y^* = \frac{\sum y\mu_R(y)}{\sum \mu_R(y)} \qquad (2)$$

where y* is a crisp value. Fig. 10 shows three-dimensional graph of error, derror, and u relation.

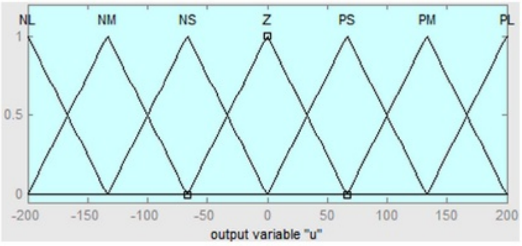

Fig. 9. Membership functions of control signal, u

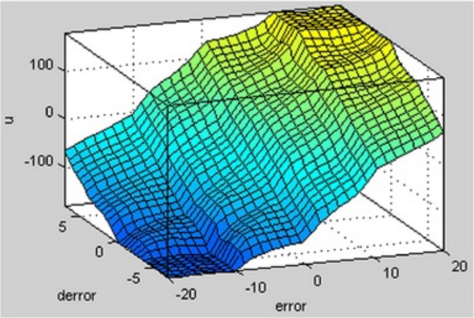

Fig. 10. Surface graph of fuzzy logic controller

The design of additional resistance is applied for simulation examination. The simulation performed is almost the same as that is executed in [3]. The formula of additional resistance is shown on (3).

$$w_j = w_i + w_r + w_s = \begin{cases} i + \frac{600}{R} + 0.00013L_s\ (R > L_c) \\ i + \frac{600}{R} . \frac{L_r}{L_c} + 0.00013L_s\ (R \le L_c) \end{cases} \tag{3}$$

with the following caption: wi, wr, and ws are respectively the resistances of ramp (downhill/uphill track), curve, and tunnel. i is slope value on the ramp. R is the radius of the curve. Lr is the length of the curve. Lc is the length of the train. Ls is the length of the tunnel.

The scenarios conducted are as follows: the mileage is 2000 m; the train must stop (speed 0 m/s) after a distance of 2000 m; the length of the train is 2000 m; the general speed limit is 15 m/s; radius of the curve is assumed 500 m; the value of tunnel resistance, ws, is neglected; the distance from 1000 m to 1500 m is a curve with a speed limit of 10.5 m/s; the distance from 200 m to 400 m is an uphill track with slope value of 6; the distance from 1100 m to 1300 m is a downhill track with slope value of -6; the rest track is flat and straight track; it is assumed that 100 m before the train heads toward the curve or stops, train speed must be altered to adjust the prescribed speed limit.

From several scenarios aloft, additional resistance can be calculated by splitting it into seven parts. The graph of additional resistance values is shown on Fig. 11.

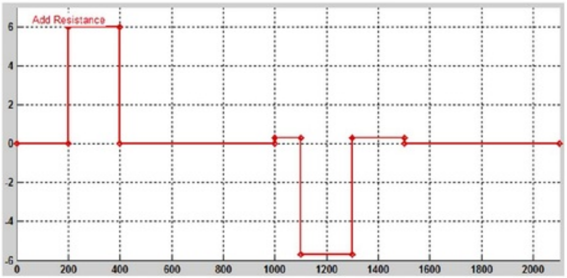

Fig. 11. Graph of additional resistance

IV. TESTING AND ANALYSIS

There are four types of testing performed, i.e. testing of rise and fall value, testing of pulse input, and testing of simulation on the system. Fig. 12 shows testing of rise on the system with fuzzy logic controller and PID controller. Rise testing is executed five times (a, b, c, d, and e), while fall testing is executed five times as well (a, b, c, d, and e). Fig. 13 shows testing of fall on the system with fuzzy logic controller and PID controller.

Table II shows the comparison of rise time and settling time of the system with fuzzy logic controller and PID controller on testing of rise, whereas Table III shows the comparison of fall time and settling time on testing of fall.

Fig. 14. shows testing of pulse input on the system with fuzzy logic controller and PID controller. Testing of pulse input is executed ten times (a, b, c, d, e, f, g, h, i, and j) with one rise time, one fall time, and two settling times for each pulse. Table IV shows the comparison of rise time and settling time of the system with fuzzy logic controller and PID controller on testing of pulse input, whereas Table V shows the comparison of fall time and settling time.

TABLE II. COMPARISON OF RISE TIME AND SETTLING TIME ON TESTING OF RISE

Part	Rise time		Settling time	
	FLC	*PID*	*FLC*	*PID*
a (0-5 m/s)	1.89 s	6.48 s	2.92 s	5.36 s
b (5-10 m/s)	2.07 s	6.54 s	4.25 s	5.34 s
c (10-15 m/s)	2.28 s	6.55 s	_	5.4 s
d (15-20 m/s)	2.48 s	6.55 s	_	5.4 s
e (20-25 m/s)	2.8 s	6.55 s	_	5.4 s
Average	2.3 s	6.53 s	3.58 s	5.38 s

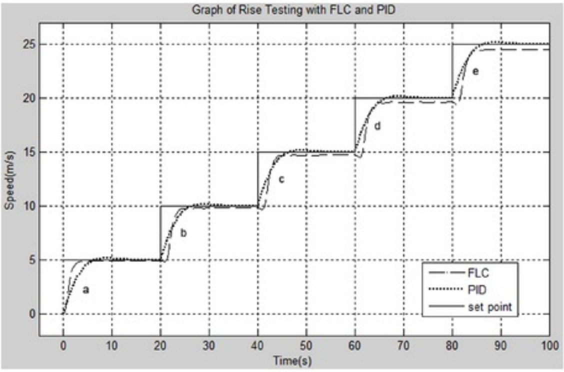

Fig. 12. Graph of testing of rise with FLC and PID

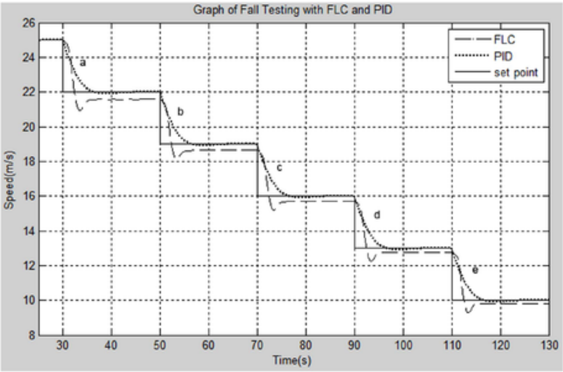

Fig. 13. Graph of testing of rise with FLC and PID

The scenarios conducted on simulation testing are based on the design of additional resistance. From the scenarios, desired speed can be adjusted. This study attempted to reorder the results from [3] and then compared fuzzy logic controller with PID controller in the identical case study.

TABLE III. COMPARISON OF FALL TIME AND SETTLING TIME ON TESTING OF FALL

Part	Fall time		Settling time	
	FLC	*PID*	*FLC*	*PID*
a (25-22 m/s)	2.39 s	6.32 s	_	10.36 s
b (22-19 m/s)	2.35 s	6.51 s	_	5.38 s
c (19-16 m/s)	2.42 s	6.54 s	_	5.4 s
d (16-13 m/s)	2.48 s	6.55 s	_	5.4 s
e (13-10 m/s)	2.54 s	6.55 s	_	5.4 s
Average	2.44 s	6.49 s	_	5.38 s

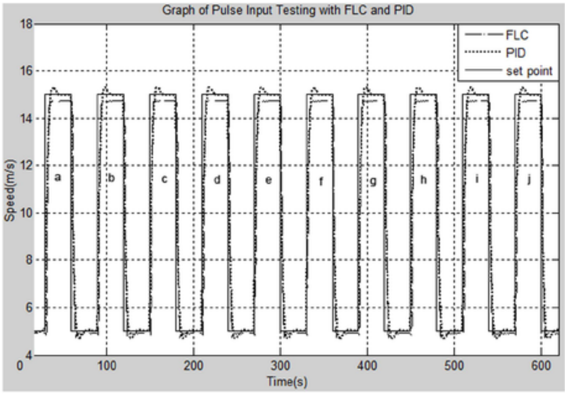

Fig. 14. Graph of testing of pulse input with FLC and PID

Fig 15. shows a graph of comparison between fuzzy logic controller and PID controller. If the graphs of fuzzy logic controller and PID controller are displayed into a single graph, it can be viewed that the system with PID controller (error value is less than 0.1%) surpasses the system with fuzzy logic controller (error value 2%).

TABLE IV. COMPARISON OF RISE TIME AND SETTLING TIME ON TESTING OF PULSE INPUT

Part	Rise time		Settling time	
	FLC	*PID*	*FLC*	*PID*
a (time at 30 s)	2.36 s	6.49 s	4.42 s	5.37 s
b (time at 90 s)	2.36 s	6.49 s	4.42 s	5.35 s
c (time at 150 s)	2.36 s	6.49 s	4.4 s	5.35 s
d (time at 210 s)	2.36 s	6.49 s	4.41 s	5.35 s
e (time at 270 s)	2.36 s	6.49 s	4.4 s	5.35 s
f (time at 330 s)	2.36 s	6.49 s	4.4 s	5.35 s
g (time at 390 s)	2.36 s	6.49 s	4.4 s	5.35 s
h (time at 450 s)	2.36 s	6.49 s	4.4 s	5.35 s
i (time at 510 s)	2.35 s	6.49 s	4.4 s	5.35 s
j (time at 570 s)	2.36 s	6.49 s	4.4 s	5.35 s
Average	2.359 s	6.49 s	4.405 s	5.352 s

TABLE V. COMPARISON OF FALL TIME AND SETTLING TIME ON TESTING OF PULSE INPUT

Part	Fall time		Settling time	
	FLC	*PID*	*FLC*	*PID*
a (time at 60 s)	4.24 s	6.46 s	3.82 s	5.35 s
b (time at 120 s)	4.24 s	6.46 s	3.82 s	5.35 s
c (time at 180 s)	4.24 s	6.46 s	3.82 s	5.35 s
d (time at 240 s)	4.24 s	6.46 s	3.82 s	5.35 s
e (time at 300 s)	4.24 s	6.46 s	3.82 s	5.35 s
f (time at 360 s)	4.24 s	6.46 s	3.82 s	5.35 s
g (time at 420 s)	4.24 s	6.46 s	3.82 s	5.35 s
h (time at 480 s)	4.23 s	6.46 s	3.82 s	5.35 s
i (time at 540 s)	4.24 s	6.46 s	3.82 s	5.35 s
j (time at 600 s)	4.23 s	6.46 s	3.82 s	5.35 s
Average	4.238 s	6.46 s	3.82 s	5.35 s

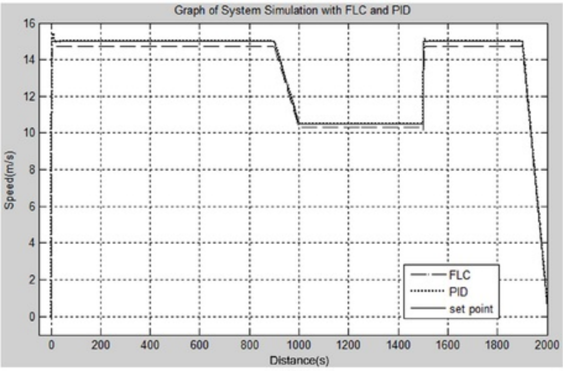

Fig. 15. Graph of system simulation with FLC and PID

V. CONCLUSION

This paper proposed fuzzy logic controller using Mamdani method and defuzzification using Centroid. The methods is applied to the tansfer-function model of train speed system. Of the four distinct testing types, using the approach of Tr, FLC surpasses PID; using the approach of Tf, FLC also surpasses PID; using the approach of Ts, FLC also surpasses PID while FLC showed instability on rise and fall testing; using the approach of average steady-state error, PID surpasses FLC. Nonetheless, although FLC transcends PID (on the approaches of Tr, Tf, and Ts), the level of steadiness and accuracy of FLC is still inferior to PID.

REFERENCES

[1] B. Ke, C. Lin, and C. Lai, “Optimization of train-speed trajectory and control for mass rapid transit systems”, Control Eng. Practice, vol. 19, pp. 675-687, July 2011.

[2] C. Cruceanu, “Train Braking”, Reliability and safety in railway, pp. 29-74, 2012.

[3] C. Xianxian, Z. Yue, and H. Hai, “Train speed control algorithm based on PID controller and single-neuron PID controller”, Second WRI Global Congr on Intelligent Syst., pp. 107-110, 2010.

[4] G. Bing, D. Hairong, and Z. Yanxin., “Speed adjustment braking of Automatic Train Operation system based on fuzzy-PID switching control”, Sixth Int. Conf. on Fuzzy Syst. and Knowledge Discovery, pp. 577-580, 2009.

[5] H. Dong, L. Li, and B. Ning, “Fuzzy switch of high-speed ATO systems based on running conditions”, Proc. of the IEEE Int. Conf. on Inform. and Automation, pp. 619-622, June 2010.

[6] H. Dong, L. Li, B. Ning, and Z. Hou, “Fuzzy tuning of ATO system in train speed control with multiple working conditions”, Proc. of 29th Chinese Control Conf., pp. 1697-1700, July 2010.

[7] H. Dong, S. Gao, B. Ning, and L. Li, “Extended fuzzy logic controller for high speed train”, Neural Computing and Applicat., vol. 22, pp. 321-328, February 2013.

[8] K. Ogata, Modern Control Engineering, 5th ed., Englewoods Cliff, New Jersey: Prentice-Hall, Inc., 2010.

[9] S. Kuswadi, Kendali Cerdas Teori dan Aplikasi Praktisnya, Yogyakarta: ANDI, 2007.

[10] S. Sekine and M. Nishimura, “Application of fuzzy neural network control to Automatic Train Operation”, Int. Joint Conf. of the Fourth IEEE Int. Conf. on Fuzzy Syst. and The Second Int. Fuzzy Eng. Symp., pp. 39-40, March 1995.

[11] S. Yasunobu, S. Miyamoto, and H. Ihara, “Fuzzy control for Automatic Train Operation system”, Int. Conf. On Transportation Syst., pp. 33-39, 1983.

[12] S. Yasunobu, S. Miyamoto, and H. Ihara, “A fuzzy control for train automatic stop control”, Trans. of Soc. of Instrument and Control Engineers , E-2, 1-9, 2002.

[13] Suyanto, Soft Computing, Bandung: Informatika Bandung, 2008.

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