The Optimal Steering Control System using Imperialist Competitive Algorithm (ICA) on Vehicles with Steer-by-Wire System

Fachrudin Hunaini*, Imam Robandi** and Nyoman Sutantra***

ABSTRACT

Steer-by-wire is the electrical steering systems on vehicles that are expected with the development of an optimal control system can improve the dynamic performance of the vehicle. To get the optimal control system, in this paper, carried out an optimization of the parameters of control system on the vehicle model using Imperialist Competitive Algorithm (ICA). The control system is built in cascade, namely Fuzzy Logic Control (FLC) to suppress errors in the lateral motion and the Proportional, Integral and Derivative control (PID) to minimize the error in the yaw motion. Simulations performed on vehicle models with 10 Degree Of Freedom (DOF), the plant input using the variables of steering that expressed in the desired trajectory, and the plant output is lateral and yaw motion. The simulation results showed that the FLC-PID control system which optimized by using ICA can maintain the movement of the vehicle according to the desired trajectory with lower error and higher speed limits.

Key word — Fuzzy Logic Control, Imperialist Competitive Algorithm, Steering Control.

1 Introduction

In the longitudinal direction of movement of the vehicle should be arranged to always be right in the path specified, if there a movement of vehicles in the direction which does not in accordance, it means there a mistake in the direction of the lateral motion. To maintain or minimize the error, it would require a control on the lateral motion [1], [2]. Likewise when movement the vehicle is turning, it will tend to occur the longitudinal force difference between the right and left wheels resulting in a vehicle will experience the yaw motion which pinned on the Centre of Gravity (COG), to reduce the error of the yaw motion then the vehicle requires the yaw motion control [3]. On the condition of vehicle was speeding to the longitudinal direction and then perform the maneuver, the movement of vehicle dynamics can be represented as lateral and yaw motion [4].

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Computing technology has a lot to provide soft computing to perform control functions and optimization. Currently, the vehicle steering control system based on behaviors become the main alternative to the use of the steering control system [5]. Some Artificial Intelligence (AI) techniques have been widely applied to the control and optimization systems. Fuzzy Logic including a technique that is widely applied to vehicle steering control [6]–[9], but to get the parameters that are required by a Fuzzy Logic Control (FLC) is not an easy job. Soft computing offers a combination and integration of more than one technique Artificial Intellegence aiming to tune the fuzzy parameters automatically, among others, Fuzzy adaptive [8], Genetic Fuzzy [6] and Fuzzy-Particle Swarm Optimization [9].

R. Eberhart and J. Kennedy in 1995 Proposed an optimization method based on swarm intelligence, which is called behavioral inspired algorithm as an alternative to genetic algorithm, that is often called evolution-based procedures [10]. In the development of AI, A. Adriansyah and S. H. M. Amin stated that the Particle Swarm Optimization (PSO) is an optimization method that simpler and has the ability to achieve a faster convergence of the GA, because this method works only depends on the function of speed and position [11].

On the other side, Esmael Atashpaz Gargari, et al. in 2007 introduced the evolutionary algorithm inspired by imperialistic competition, which further called the Imperialist Competitive Algorithm (ICA). ICA applications in the optimization of a mathematical function can provide the results of the optimization process better than using PSO and GA methods [12]–[14]. Ashkan Mohammadzadeh Jasour, et. all. [15] designed a fuzzy controller that optimized with searching for the optimal variables of the membership functions using ICA to control the speed of the vehicle, and show that fuzzy controller optimized by ICA has better performance than the expert controller.

In this paper was developed an AI-based control system that applied to the model fully automatic steer-by-wire system that represented on the vehicle model with 10 Degree Of

Freedom (DOF) [9], [16]. The strategy of control system that was developed, consisting of two stages of control, in cascade, namely, the first is the lateral motion controller and the second is the yaw motion controller. The structure of control systems built using FLC as a major control on the lateral motion and Proportional-Integral-Derivative controller (PID) as a further control on the yaw motion. To obtain the parameters of the optimal control system on the FLC and PID used an optimization method of ICA. The expected results of this simulation on active steering control with the use of FLC and PID control tuned by ICA can improve vehicle dynamic performance.

2. Vehicle Dynamics Model

Based on the theory of vehicle dynamics, vehicle has two major functions in controlling the movement of vehicles, namely control lateral and control longitudinal [17], but to further represent the whole movement of the vehicle either vertical or horizontal direction, the models built in this paper uses a vehicle model with a 10-DOF that consists of a 7-DOF vehicle ride model and 3-DOF vehicle handling model.

Vehicle ride models expressed in 7 of mathematical equations [16], consists of forces equations on the vehicle body (sprung mass single) that includes freedom of movement; vertical movement of the vehicle body (heaving), nodding movement of the vehicle body (pitching), the movement of swaying from side to side of the vehicle body (rolling) and the vertical movement of each wheel (four unsprung masses) [16], [18], [19].

Vehicle handling models expressed in 3 of mathematical equation [16], consists of forces equations on the movement of the car body, namely the lateral, longitudinal and yaw motion. Lateral motion and longitudinal motion is movement along the x-axis and y-axis are expressed in lateral acceleration (A_y) and longitudinal acceleration (A_x) so that the lateral motion and the longitudinal motion can be obtained by double integration of the lateral and longitudinal acceleration [16], [20], [21].

Based on the tenth of mathematical equation above, ie 7 DOF of ride models and 3 DOF of handling models that are mathematically linked using Calspan tire models [8], [22], [23] then was built vehicles models using MATLAB-Simulink software as shown in Fig. 1.

The design of the vehicle model with 10 DOF that focuses on setting the direction of the front wheels of the vehicle as the output of a plant and the plant input in the form variations of steer angle (δ) of the steering wheel. Plant output in the form of the direction of the front wheels of vehicles stated in the three movements of the vehicle, namely lateral motion (y), the longitudinal motion (x) and yaw motion (r), the yaw motion will affect the moment of inertia around the z-axis (Js), which will cause changes in roll and pitch angles on COG (θ and φ) [9], so that will further affecting the entire force in the direction of the z-axis (bounching, pitching, rolling and all vertical Reviews directions for each wheel).

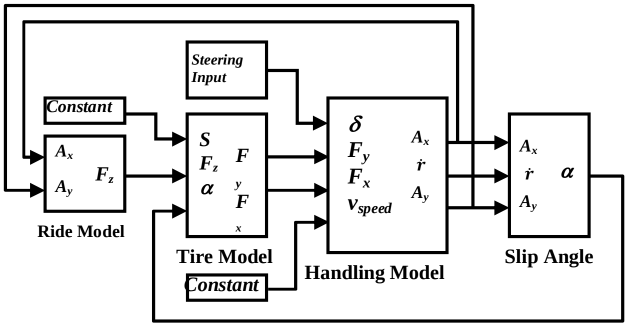


Fig. 1. Vehicle Model in MATLAB – SIMULINK

3. Optimization of Control Systems

Steering control system (active steer) of the vehicle that was built in this paper uses two controllers in a cascade [16], [24], [25], FLC as the main control and PID control as the auxiliary control. The control strategies developed are setting towards front wheels of the vehicle to fit the reference, namely the desired trajectory in the form of a double line change and sine steer trajectory. Block diagram of the control strategy that is built for the active steering control simulation are shown in Fig. 2. The role of control systems are; FLC is used to suppress the error y (3) among; lateral motion y (2) against the desired trajectory (1) corresponding to the longitudinal motion coordinates x, whereas the PID the control is used to reduce errors, speed up risetime, and reduce overshot / undershot among yaw motion (5) against the setting point which is the output of the FLC (4). The ideal condition of fuzzy control results (output FLC) is vehicle movement no longer have a lateral motion y, so that the output FLC will be setting point on PID control to minimize the yaw motion error (6). Both the control systems will work optimally if supported by the design of composition the optimal parameter values of the control system, in this paper, both the value of the parameter at FLC and PID the control is determined through the optimization process by using ICA.

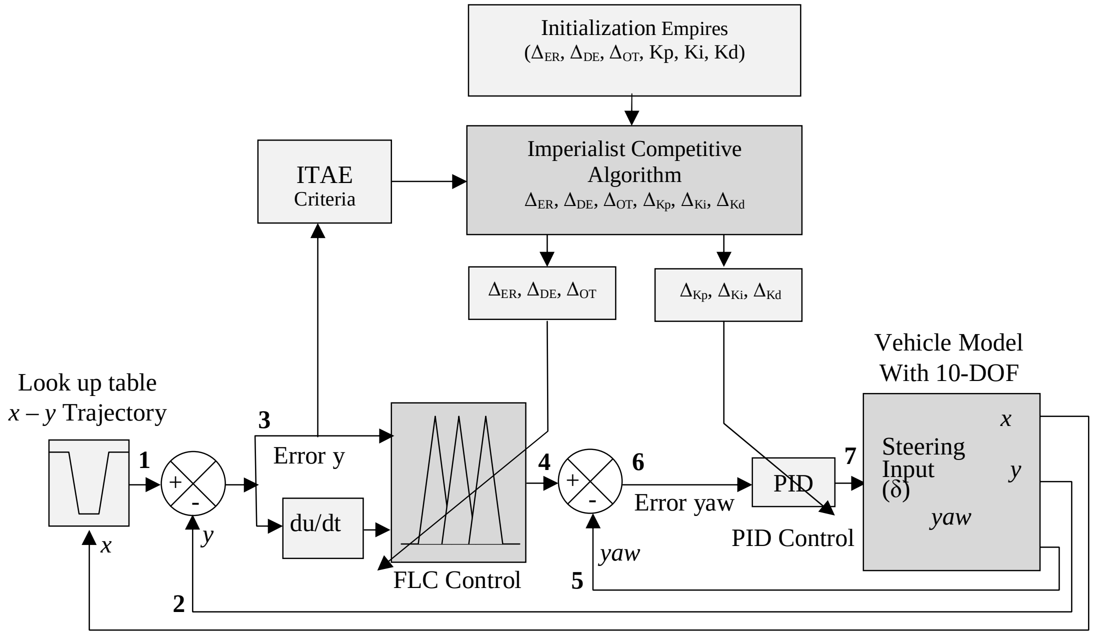


Fig. 2. The Control and Optimization Structure for automatic steering on vehicle model

3.1. Fuzzy Logic Controller (FLC)

FLC is designed using two inputs, namely error (ER) and delta errors (DE) as well as using one control output (OT). The main structure of the FLC, consisting of: crisp variables fuzzification, fuzzy rules and defuzzyfication [26].

Fuzzification of crisp variables is the conversion value of input and output of control system into a fuzzy variable by using the technique of membership function (MF). Fuzzy rules are a set of rules consisting of some fuzzy rules that are grouped into the rule base for decision making (inference process) so that got action of necessary control. MF is a function to express the degree of membership of fuzzy. Forms MF used in this paper are one MF in the form of a triangle (Triangular shaped) and two MF in the form of a trapezium (trapezoidal shape), each rule base on the control input (error and error delta) and FLC control output consists 3 MF, each MF has term language, negative (N), Zero (Z), Positive (P), so that the number of the required rule base is 9 rules as shown in Table 1.

Table 1. Rule base of Fuzzy Logic Controller

Delta error	Error		
	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

The shape of triangular and trapezoidal of each MF may change based on the width and midpoint depends on the variables of multiplier, then the multiplier is called (Δ_i). This means that all parameters of each MF is a function of Δ, so that when the value of Δ be changed then parameter every MF will change involves a change in the position of (C_n) and width (W_n) of MF as shown in Fig. 3 and 4.

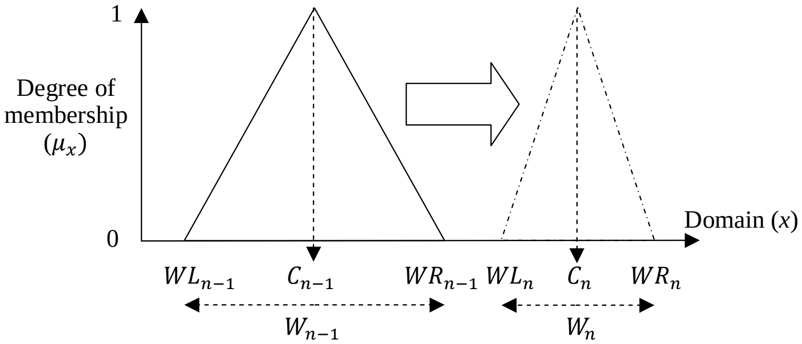


Fig. 3. Parameter of triangular membership function

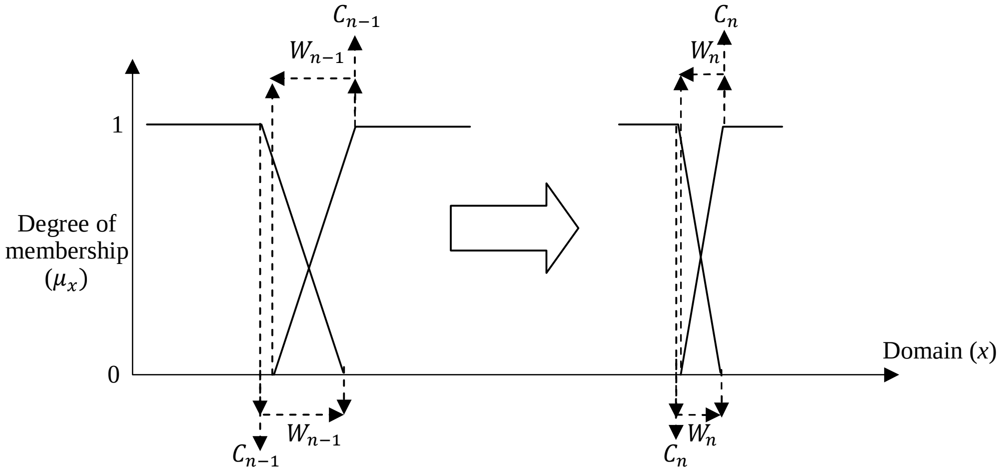


Fig. 4. Parameter of trapezoidal membership function

Multiplier value Δ_i (Δ_{ER}, Δ_{DE}, Δ_{OT}) consists of; Δ_{ER} as the multiplier for MF of input of the error; Δ_{DE} as the multiplier for MF of input on the delta error; and Δ_{OT} as the multiplier for MF of FLC output. Determination of width and midpoint on each MF is expressed in Fig. 4 and is expressed as the following equation:

Changes of the trapezoidal and triangular position are:

$$C_{n+1} = C_n \times \Delta \tag{1}$$

Changes of the trapezoidal and triangular wide are:

$$W_{n+1} = W_n \times \Delta \quad \text{(For trapezoidal MF)} \tag{2}$$

$$W_{n+1} = WR_{n+1} - WL_{n+1} \quad \text{(For triangular MF)} \tag{3}$$

$$WR_{n+1} = WR_n \times \Delta \tag{4}$$

$$WL_{n+1} = WL_n \times \Delta \tag{5}$$

The C, WR, and WL, respectively expressed the position, the width of the right and left side of the midpoint of MF, whereas subscript "n" is the initial value and "n + 1" is the new value after the change of the value of Δ, so that each MF parameter will be changed include the change in position C and the width W of the MF. The change of value of Δ as shown in Fig. 5.

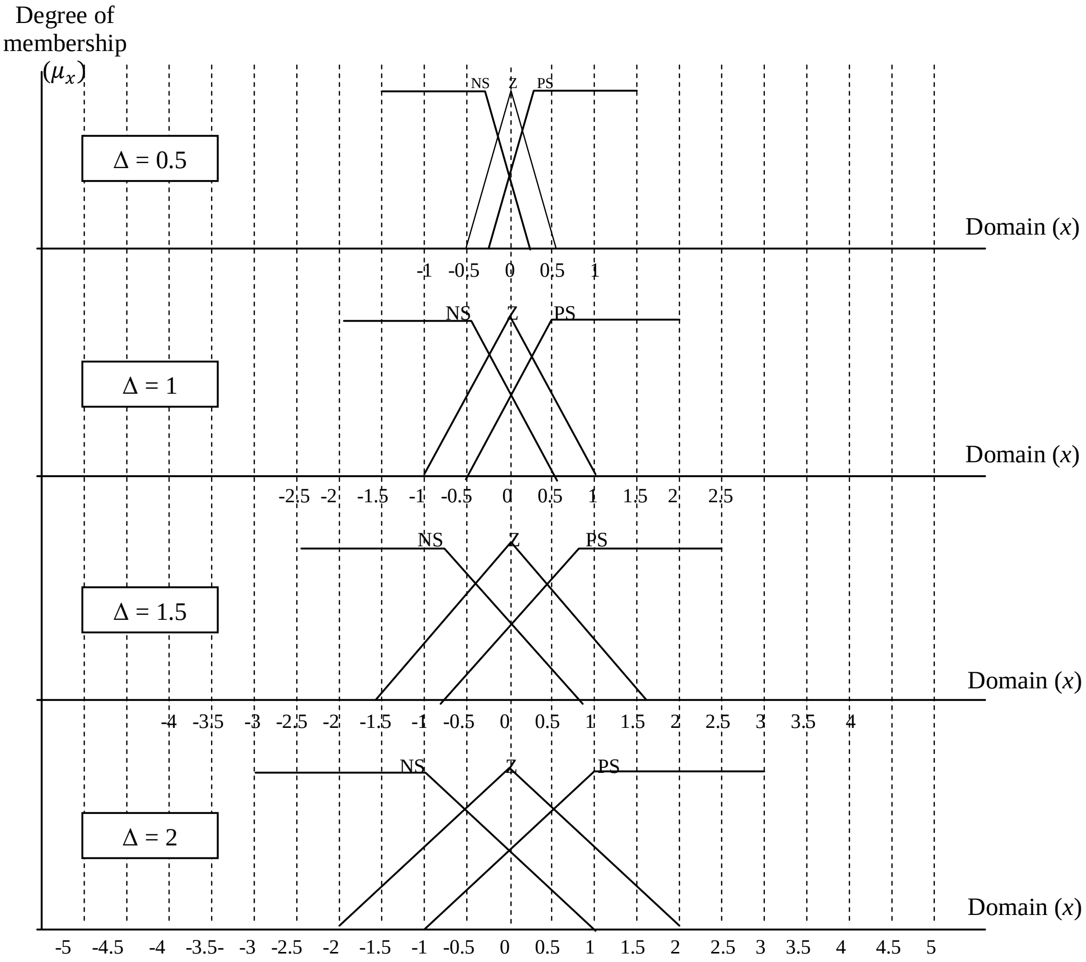


Fig. 5. Change the width and center of the membership function

The value of the multiplier Δ_{ER}, Δ_{DE}, and Δ_{OT} can be determined by trial and error, but in this paper, the value of the multiplier is obtained through a learning process that is repeatedly until an optimal value is reached by using ICA.

Defuzzyfication is a process to change go back all the fuzzy variable on the crisp variable, Defuzzyfication methods used is the centroid.

3.2. PID Control

PID control is a control system which popular because of the simplicity of its structure, as well as the ease of tuning the control parameters [27]. In this paper, the PID control used as a second control to eliminate the error between the set point of the yaw motion. Proportional control (P) used to accelerate the rate of response of the system (rise time), Integral control (I) used to minimize or eliminate the steady-state error of the system and Derivative Control (D) used to reduce the overshot / undershot. Performance P, I, and D controls is highly dependent on the determination of the constant value of Kp, Ki and Kd. In this paper the PID control optimized by determining the constant value of Kp, Ki and Kd through the learning process, or by tune the parameters of Kp, Ki and Kd up to be achieved the composition of the optimal values of all constants by using ICA. Setting point used on the PID control is the output of FLC, this case gives meaning of that the vehicle has been moved without lateral forces, or in other words that the yaw motion is equal to zero.

3.3. Imperialist Competitive Algorithm (ICA)

ICA is a new optimization strategy that is inspired by imperialistic competition among the empire, Such on other optimization methods, ICA starts with an initial population called the initial empire. Each individual of an empire is a country. There are two kinds of countries; namely the countries of the colony and the imperialist countries that collectively forming an empire. During the competition, a weak empire will collapse and the stronger will be the ruler of the colony. Imperialistic competition will reach convergent if there is only one empire and its colonies are in the same position and have the same cost as the imperialist [12], [13]. In search of the optimal value, ICA uses a number of structured variable values to be optimized. This arrangement is called "country" in Nvar- dimensional of optimization.

Each country has a 1x Nvar of array. So it can be defined:

$$country = [p_1, p_2, p_3, \dots, p_{Nvar}] \tag{6}$$

The values of the variables in these country are represented as the number of floating point. Cost of the country which have been found will be evaluated by the cost function f on the variable ($p_1, p_2, p_3, \dots, p_N$) then,

$$cost = f\,(country) = f\,(p_1, p_2, p_3, \dots, p_N) \tag{7}$$

the total strength of the empire caused by the force of the imperialist countries. But the strength of the colony an empire has the effect of the total strength of the empire. Models in the total costs are:

$$T\,C\,n = Cost\ imperialist_n + \xi\ mean\ Cost\ colonies\ of\ empire_n \qquad (8)$$

Where such models is the total strength of of the n^{th} empire as a positive number which can defined as less than 1. A value for the ξ is caused by total strength of the empire for the be defined by the imperialists and the increase in value will be increase the pattern of colonies that have been determined. Empire who have less power will be destroyed in imperialist competition and their colonies will be divided into several empire. Within almost all implementations, can eliminate the empire when it lost all the colonies [13].

4. Simulation Results and Discussion

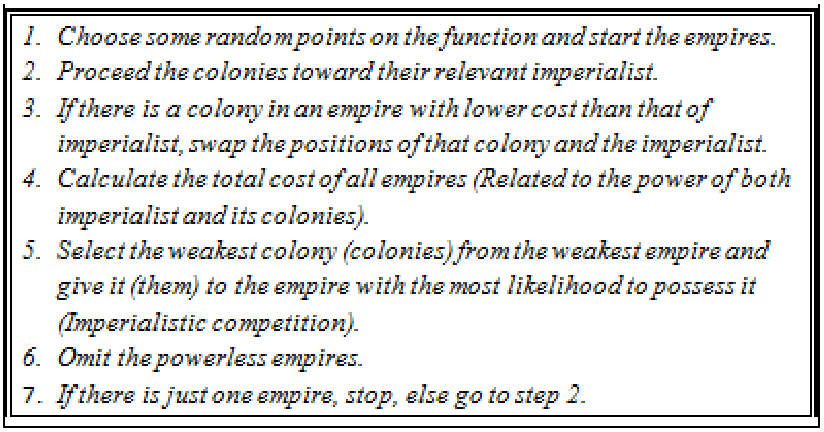
Simulation of optimal control on the lateral and yaw motion in the steering system of the vehicle begins with optimize the parameters of FLC and PID control system using ICA, then the simulation results are compared against the PSO method.

In this paper, ICA optimizing six variables which consists three variables to determine the parameters of the FLC namely the multiplier; Δ_{ER}; Δ_{DE} and Δ_{OT} well as three variables to determine the parameters of PID control in the form of the constants Kp, Ki and Kd.

The parameters used in the ICA;

Number of initial countries = 50;
Number of Initial Imperialists = 8;
Number of Decades = 50;
Revolution Rate = 0.3;
Assimilation coefficient = 3;
Assimilation angle coefficient = 0.5;
Zeta = 0.02;
Damp Ratio = 0.99;
Uniting Threshold = 0.02;

Optimization steps using the ICA [14] as shown in Fig. 6:



1. *Choose some random points on the function and start the empires.*
2. *Proceed the colonies toward their relevant imperialist.*
3. *If there is a colony in an empire with lower cost than that of imperialist, swap the positions of that colony and the imperialist.*
4. *Calculate the total cost of all empires (Related to the power of both imperialist and its colonies).*
5. *Select the weakest colony (colonies) from the weakest empire and give it (them) to the empire with the most likelihood to possess it (Imperialistic competition).*
6. *Omit the powerless empires.*
7. *If there is just one empire, stop, else go to step 2.*

Fig. 6. Optimization steps using the ICA

The parameters of the vehicle model are used as shown in Table 2.

Table 2. Parameters of Vehicle models

No	*Parameters*	*Value*
1	*Vehicle mass*	1700 kg
2	*Vehicle sprung mass*	1520 kg
3	*Coefficient of friction*	0.85
4	*Front track width*	1.5 m
5	*Rear track width*	1.5 m
6	*Tyre rolling radius*	0.285 m
7	*Wheelbase*	2.7 m
8	*Distance between front axle to COG*	1.11 m
9	*Distance between rear axle to COG*	1.59 m
10	*Pitch stiffness constant*	4000 $\mathrm{Nm^{-1}}$
11	*Roll stiffness constant*	2400 $\mathrm{Nm^{-1}}$
12	*Centre of gravity height*	0.55 m
13	*Pitch moment of inertia*	425 kg $\mathrm{m^2}$
14	*Roll moment of inertia*	425 kg $\mathrm{m^2}$
15	*Yaw moment of inertia*	3125 kg $\mathrm{m^2}$
16	*Wheel moment of inertia*	1.1 kg $\mathrm{m^2}$
17	*Pitch damping constant*	170000 $\mathrm{Nm^{-1}s^{-1}}$
18	*Roll damping constant*	90000 $\mathrm{Nm^{-1}s^{-1}}$

Optimizations that has been done using ICA can achieve convergence on 19th iterations while the optimization using PSO can achieve convergence only up to the third iteration as shown in Fig. 7. The optimization is done either using ICA and PSO is iterative process until the maximum iteration = 50, which applied on both FLC and PID control system of vehicle models with steering input on plant in the form of lookup table x - y trajectory (double lane change) at a constant speed of 13.88 m / s. This means that on control system has been occurred learning that begins with a random parameter values and in the end can determine the values of the optimal parameters with the error restrictions of the smallest lateral motion. The size of the error is used in the optimization process is ITAE, while the size of the error is used on the simulation is Continues Root Mean Square Error (C-RMS error) as shown in Table 3.

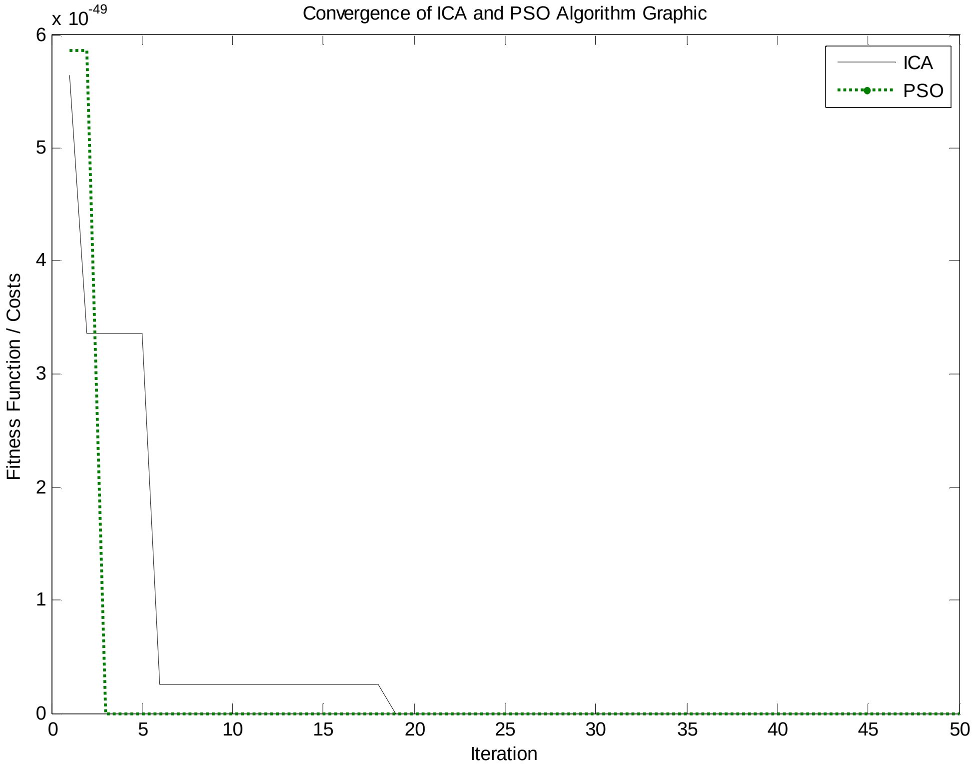


Fig. 7. Convergence of ICA and PSO Optimization

Table 3. Optimization results of ICA and PSO (Speed = 13.88m (*Speed*=13.88m/s)

	Convergence	*Error*		*Parameters*					
		ITAE	C-RMS	Δ_{ER}	Δ_{DE}	Δ_{OT}	Kp	Ki	Kd
ICA	19	2.0523e-48	0.003487	1.4222	67.6211	0.8415	522.2821	9.1026	6.5722
PSO	3	3.1224e-43	0.003981	1.3670	67.1499	0.6773	521.9355	10.2314	6.2524

The error value obtained from the optimization using ICA is smaller than using PSO, but on optimization using PSO achieve faster convergence than the ICA, this further strengthens the assertion that the PSO is a method which premature in achieving convergence.

The value of Δ_{ER}, Δ_{DE}, and Δ_{OT} obtained is a multiplier factor to determine the width and position of each of the MF and the value of Kp, Ki and Kd is the expression value for the parameter Proportional, Integral and Derivative. The optimal shape of the MF can be seen in Fig. 8 and the value of the width and the midpoint of the MF in the which is optimally FLC, is shown in Table 4.

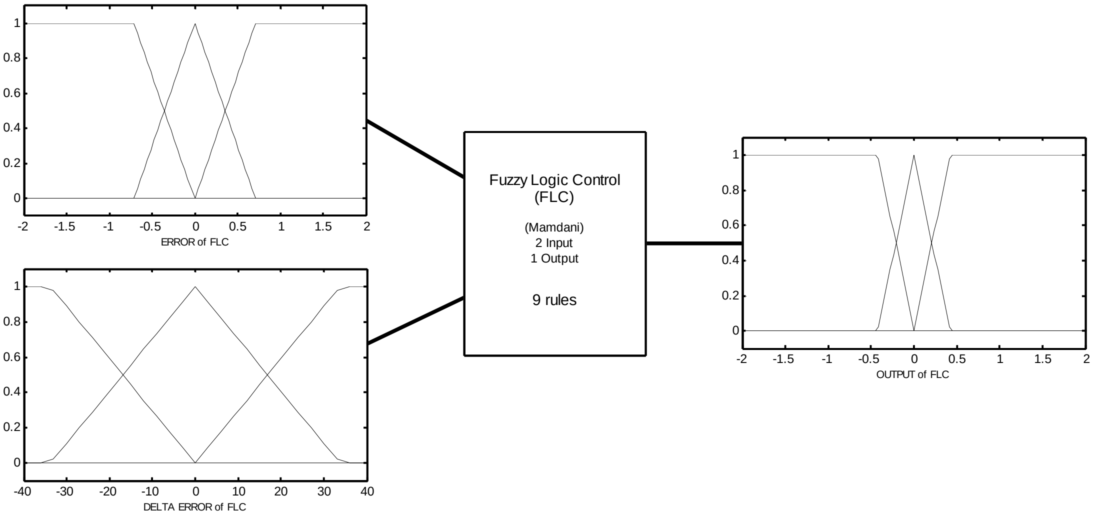


Fig. 8. The results of the MF which optimally in the FLC

Table 4. The width and midpoint of the MF yang optimal

ERROR INPUT			
Δ_{ER} = 1.4222	Width Left	Midpoint	Width Right
NS	-0.7111	-0.7111	0
Z	-0.7111	0	0.7111
PS	0	0.7111	0.7111
DELTA ERROR INPUT			
Δ_{DE} = 67.6211	Width Left	Midpoint	Width Right
NS	-33.81055	-33.81055	0
Z	-33.81055	0	33.81055
PS	0	33.81055	33.81055
OUTPUT			
Δ_{OT} = 0.7617	Width Left	Midpoint	Width Right
NS	-0.38085	-0.38085	0
Z	-0.38085	0	0.8415
PS	0	0.38085	0.38085

The results of optimization of vehicle steering control system is expressed in Fig. 9 where shows that the movement of the vehicle with the optimal control system can adjust well on the desired trajectory (double lane change trajectory). Fig. 10 and 11 show two of the four responses of the optimal control system against the desired trajectory during vehicle maneuvers, in Fig. 10 occurs when the vehicle is moving in the x direction and then veering towards y hence happened overshot to the x direction. Otherwise on Fig. 11, the vehicle is moving in the y direction and then veering towards x hence happened overshot on the y direction and in Fig. 12 are the characteristics of the optimal control system which includes; Lateral motion error, output FLC (setting point of the yaw motion), the output of the yaw motion control, yaw motion error and the output of the vehicle steering control system.

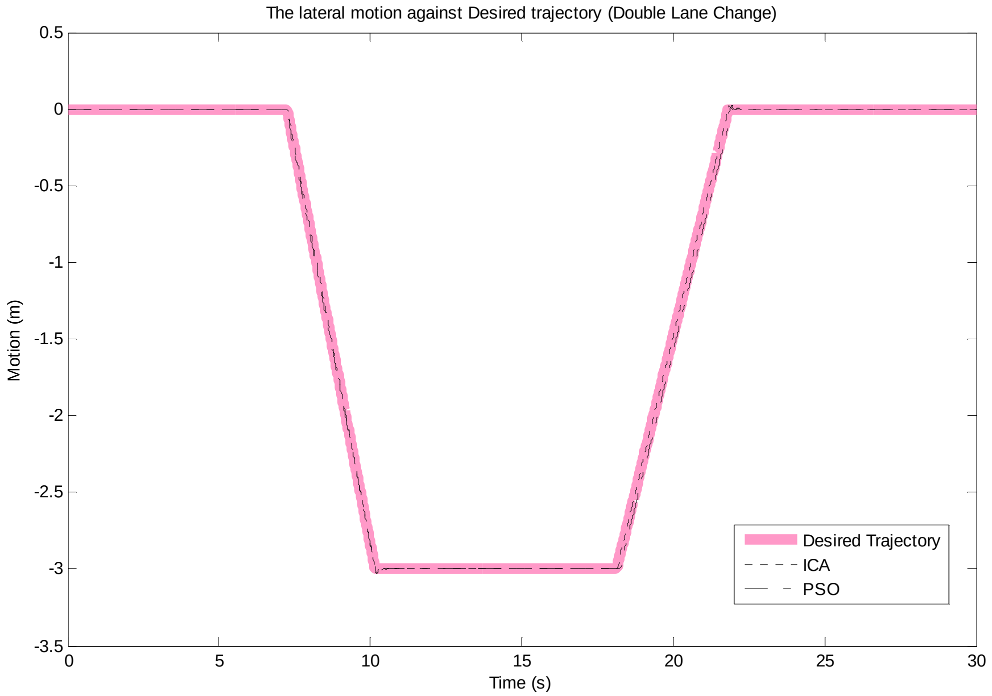


Fig. 9. The Lateral motion and the desired trajectory (Double Lane Change)

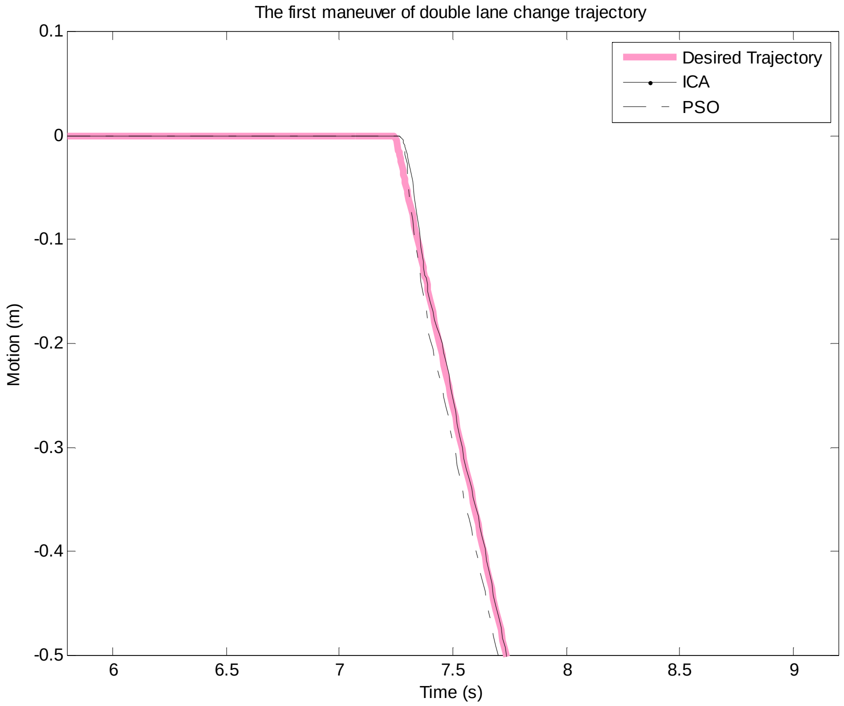


Fig. 10. The first maneuver of double lane change trajectory

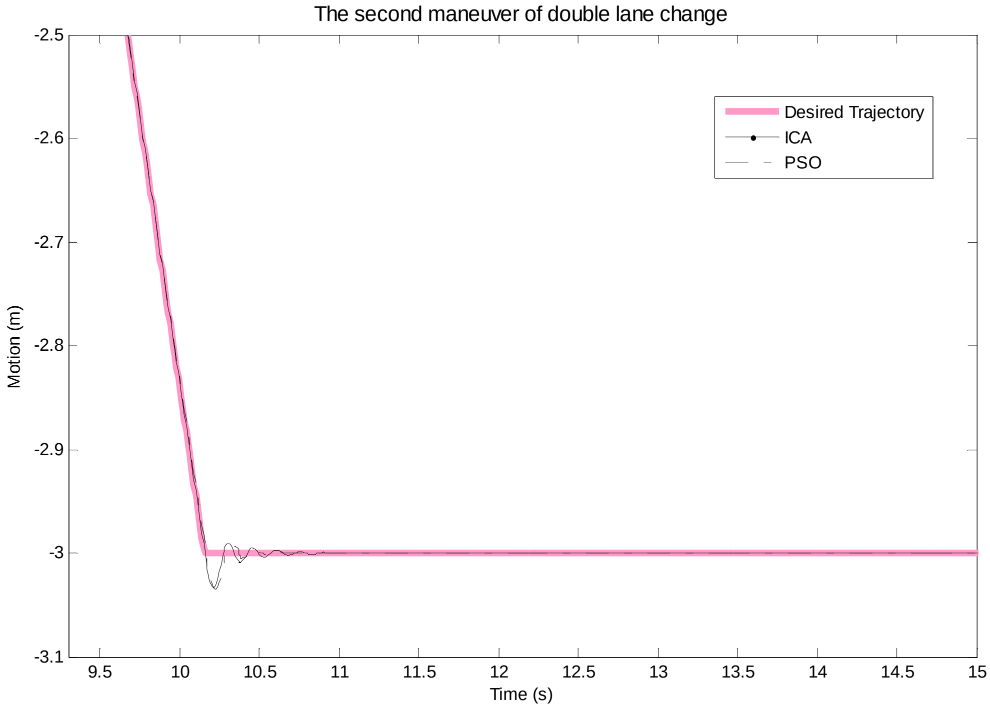


Fig. 11. The second maneuver of double lane change trajectory

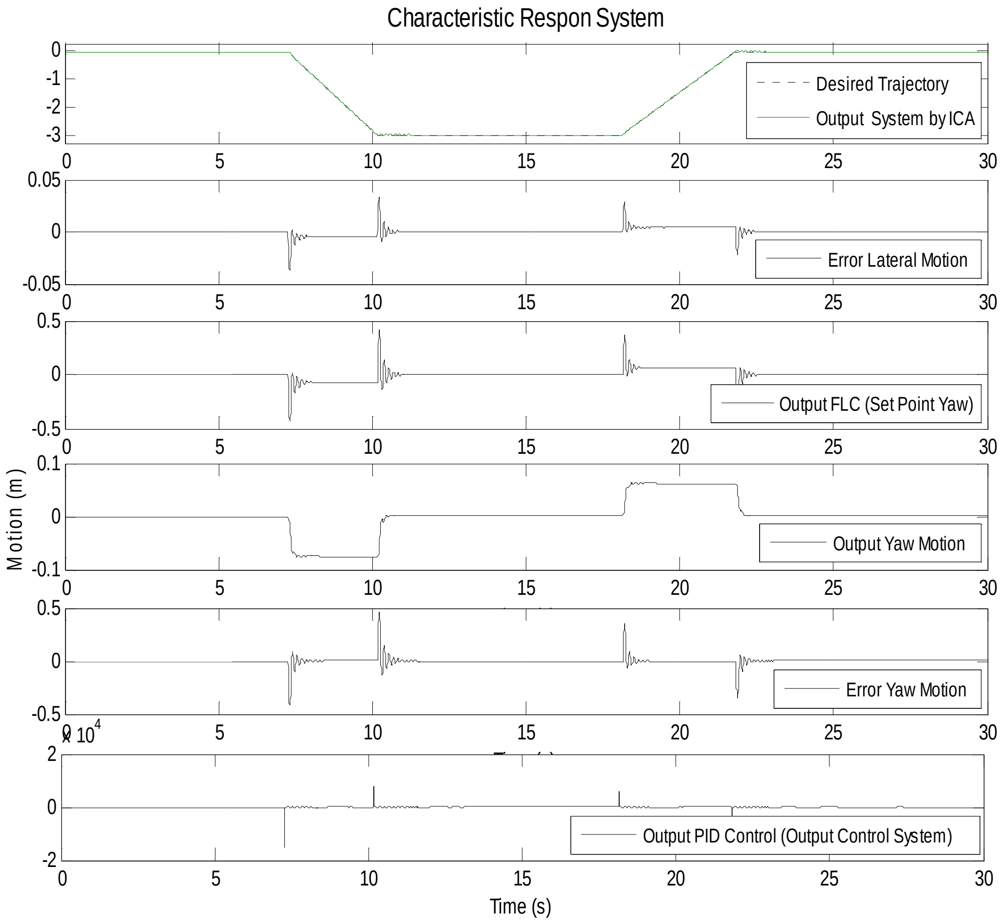


Fig. 12. The characteristics of optimal control system

The results of the optimal control system simulation using ICA (FLC-PID tuned by ICA) is expressed in the form of C-RMS error compared with the results of the optimal control system simulation using a PSO (FLC-PID tuned by PSO), as shown in Table 5. The overall average value of C-RMS error on testing using the FLC-PID tuned by ICA is smaller than the test FLC-PID tuned by PSO, and the smallest value of C-RMS error 0.002720 reached at a speed of 60 Km/h.

Table 5. Benchmark of Control Systems

No	*Velocity*		C-RMS *Error* *Double Lane Change*	
	Km/h	m/s	FLC – PID *tuned by* ICA	FLC – PID *tuned by* PSO
1	10	2.77	0.043310	0.055950
2	20	5.55	0.010390	0.012580
3	30	8.33	0.005456	0.006690
4	40	11.11	0.004043	0.004799
5	50	13.89	0.003487	0.003981
6	60	16.67	**0.002720**	**0.003458**
7	70	19.45	*time out*	*time out*

5. Conclusion

The simulation results of the optimal control system on the vehicle steering system, it was found that by using Fuzzy Logic Control (FLC) on the lateral motion and PID control on the yaw motion that tuned by using ICA (FLC-PID tuned by ICA) then each MF of FLC has optimal parameter values as well as to parameters of to PID control. This means that the ICA has worked well to get the optimal parameter values of the control system namely the position and width of the MF in the input and output FLC as well as the constants of gain of the PID control. Furthermore it can be stated that the optimal control system that has been built for controlling a vehicle steering system always be able to maintain the movement of the vehicle to the desired trajectory with the lower error and higher speed limits Compared by optimal control system that tuned using PSO (FLC-PID tuned by PSO).

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References

[1] R. T. O’Brien, P. A. Iglesias, and T. J. Urban, “Vehicle lateral control for automated highway systems,” *IEEE Trans. Control Syst. Technol.*, vol. 4, no. 3, pp. 266 –273, May 1996.

[2] F. Hunaini, I. Robandi, and N. Sutantra, “Model and Simulation of Vehicle Lateral Stability Control,” presented at the 2nd APTECS, 2010, International Seminar on Applied Technology, Science, and Arts, Surabaya, ITS, 2010, p. 26.

[3] V. Cerone, M. Milanese, and D. Regruto, “Yaw Stability Control Design Through a Mixed-Sensitivity Approach,” *IEEE Trans. Control Syst. Technol.*, vol. 17, no. 5, pp. 1096 –1104, Sep. 2009.

[4] J. Villagra, B. d’ Andrea-Novel, H. Mounier, and M. Pengov, “Flatness-Based Vehicle Steering Control Strategy With SDRE Feedback Gains Tuned Via a Sensitivity Approach,” *IEEE Trans. Control Syst. Technol.*, vol. 15, no. 3, pp. 554 –565, May 2007.

[5] S. H. M. Amin and A. Adriansyah, “Particle Swarm Fuzzy Controller for Behavior-based Mobile Robot,” presented at the 9th International Conference on Control, Automation, Robotics and Vision, 2006. ICARCV ’06, Singapore, 2006, pp. 1 –6.

[6] L. Cai, A. B. Rad, and W.-L. Chan, “A Genetic Fuzzy Controller for Vehicle Automatic Steering Control,” *IEEE Trans. Veh. Technol.*, vol. 56, no. 2, pp. 529 –543, Mar. 2007.

[7] K. R. S. Kodagoda, W. S. Wijesoma, and E. K. Teoh, “Fuzzy speed and steering control of an AGV,” *IEEE Trans. Control Syst. Technol.*, vol. 10, no. 1, pp. 112 –120, Jan. 2002.

[8] E. P. Ping, K. Hudha, and H. Jamaluddin, “Hardware-in-the-loop simulation of automatic steering control for lanekeeping manoeuvre: outer-loop and inner-loop control design,” *Int. J. Veh. Saf.*, vol. 5, no. 1, pp. 35–59, 2010.

[9] F. Hunaini, I. Robandi, and N. Sutantra, “Modeling and Simulation Of Vehicle Stability Control On Steer By Wire System Using Fuzzy Logic Control And PID Control Tuned By PSO,” presented at the 3rd International Conference on Engineering and ICT (ICEI2012), Melaka, Malaysia, 2012, p. 85.

[10] J. Kennedy and R. Eberhart, “Particle swarm optimization,” presented at the , IEEE International Conference on Neural Networks, 1995. Proceedings, 1995, vol. 4, pp. 1942 –1948 vol.4.

[11] A. Adriansyah and S. H. M. Amin, “Learning of fuzzy-behaviours using Particle Swarm Optimisation in behaviour-based mobile robot,” *Int J Intell Syst Technol Appl*, vol. 5, no. 1/2, pp. 49–67, May 2008.

[12] E. Atashpaz-Gargari and C. Lucas, “Imperialist competitive algorithm: An algorithm for optimization inspired by imperialistic competition,” in *IEEE Congress on Evolutionary Computation, 2007. CEC 2007*, 2007, pp. 4661–4667.

[13] E. Atashpaz Gargari and F. Hashemzadeh, “Colonial competitive algorithm: A novel approach for PID controller design in MIMO distillation column process,” *Int. J. Intell. Comput. Cybern.*, vol. 1, no. 3, pp. 337–355, 2008.

[14] M. H. F. Zarandi, M. Zarinbal, N. Ghanbari, and I. B. Turksen, “A new fuzzy functions model tuned by hybridizing imperialist competitive algorithm and simulated annealing. Application: Stock price prediction,” *Inf. Sci.*, vol. 222, pp. 213–228, Feb. 2013.

[15] A. Mohammadzadeh Jasour and E. Atashpaz Gargari, “Vehicle Fuzzy Controller Design Using Imperialist Competitive Algorithm,” *Second First Iran. Jt. Congr. Fuzzy Intell. Syst. Tehran Iran*, 2008.

[16] F. Hunaini, I. Robandi, and N. Sutantra, “Optimization of automatic steering control on vehicle with steer by wire system using particle swarm optimization,” *Turk. J. Electr. Eng. Comput. Sci.*, vol. To be published, Available online 18 December 2013, pp. 1–35, Dec. 2013.

[17] P. Falcone, F. Borrelli, J. Asgari, H. E. Tseng, and D. Hrovat, “Predictive Active Steering Control for Autonomous Vehicle Systems,” *IEEE Trans. Control Syst. Technol.*, vol. 15, no. 3, pp. 566 –580, May 2007.

[18] K. Hudha, Z. A. Kadir, M. R. Said, and H. Jamaluddin, “Modelling, validation and roll moment rejection control of pneumatically actuated active roll control for improving vehicle lateral dynamics performance,” *Int. J. Eng. Syst. Model. Simul.*, vol. 1, no. 2/3, p. 122, 2009.

[19] F. Ahmad, K. Hudha, and H. Jamaluddin, “Gain Scheduling PID Control with Pitch Moment Rejection for Reducing Vehicle Dive and Squat,” *Int. J. Veh. Saf.*, vol. 4, no. 1, pp. 1–30, 2009.

[20] P. Falcone, F. Borrelli, J. Asgari, H. E. Tseng, and D. Hrovat, “Predictive Active Steering Control for Autonomous Vehicle Systems,” *IEEE Trans. Control Syst. Technol.*, vol. 15, no. 3, pp. 566 –580, May 2007.

[21] M. R. Stone and M. A. Demetriou, “Modeling and simulation of vehicle ride and handling performance,” presented at the Proceedings of the 2000 IEEE International Symposium on Intelligent Control, 2000, Rio Patras, 2000, pp. 85 –90.

[22] K. Hudha, Z. A. Kadir, M. R. Said, and H. Jamaluddin, “Modelling, validation and roll moment rejection control of pneumatically actuated active roll control for improving vehicle lateral dynamics performance,” *Int. J. Eng. Syst. Model. Simul.*, vol. 1, no. 2/3, p. 122, 2009.

[23] F. bin Ahmad, K. Hudha, and H. Jamaluddin, “Gain Scheduling PID Control with Pitch Moment Rejection for Reducing Vehicle Dive and Squat,” *Int. J. Veh. Saf.*, vol. 4, no. 1, 2009.

[24] F. Hunaini, I. Robandi, and N. Sutantra, “Vehicle Stability Control On Steer By Wire System Using Fuzzy Logic,” in *ICAST,2011, The International Student Conference on Advanced Science and Technology*, Shandong University, Jinan, China, 2011, pp. 3–4–p.

[26] Z. A. Obaid, N. Sulaiman, M. H. Marhaban, and M. N. Hamidon, “Analysis and Performance Evaluation of PD-like Fuzzy Logic Controller Design Based on Matlab and FPGA,” *IAENG Int. J. Comput. Sci. 372 IJCS37204*, vol. 37, pp. 146–156, 2010.

[27] F. Xiuwei, F. Li, and K. Feng, “Research of Automotive Steer-by-Wire Control Based on Integral Partition PID Control,” in *3rd International Conference on Genetic and Evolutionary Computing, 2009. WGEC ’09*, Guilin, China, 2009, pp. 561–564.

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