Journal of Theoretical and Applied Information Technology
10th May 2016. Vol.87. No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

LATERAL AND YAW MOTION CONTROL OF THE VEHICLE USING FUZZY LOGIC AND PID BEING OPTIMIZED BY FIREFLY ALGORITHM

[1]FACHRUDIN HUNAINI, [2]IMAM ROBANDI, [3]NYOMAN SUTANTRA

[1,2] Electrical Engineering Dept., Institut of Technology Sepuluh Nopember (ITS), Indonesia,

[3] Mechanical Engineering Dept., Institut of Technology Sepuluh Nopember (ITS), Indonesia,

[1]Electrical Engineering Dept., Widyagama University, Malang, Indonesia

E-mail: [1]fachrudin09@mhs.ee.its.ac.id, [2]robandi@ee.its.ac.id, [3]tantra@me.its.ac.id

ABSTRACT

The aim of this paper is to control the lateral and yaw motion of the vehicle in order to always fix at the desired trajectory. The controller used was fuzzy logic control (FLC) for lateral motion control and PID control is used to control the yaw motion arranged cascade. To obtain optimal control parameters is used Firefly Algorithm (FA) optimization method as one of the methods swarm intelligence which is much simpler both in concept and implementation, but it is very efficient and can outperform the other conventional algorithms. Simulation of optimal control FLC-PID using FA applied to the vehicle model with 10 DOF (Degree of Freedom) of vehicle dynamics. The simulation results showed that the lateral and yaw motion can be maintained in accordance with the desired trajectory expressed in Continues-root mean square (C-RMS) error smaller than using the Particle Swarm Optimization (PSO).

Keywords: *Lateral, Yaw, Fuzzy Logic Control (FLC), PID, Firefly Algorithm (FA)*

1. INTRODUCTION

The movement of vehicles to the horizontal direction has two coordinates which consists of longitudinal motion and lateral motion. In terms of the vehicle was speeding in the longitudinal direction and then perform maneuvers so vehicle dynamics can be represented on the lateral and yaw motion [1]. The movement of vehicles always expected to remain at the desired trajectory without experiencing the moving sideways or experiencing lateral motion errors, therefore, the vehicle requires a lateral motion controller [2]. Similarly, when the vehicle turns or maneuvers will experience the difference in longitudinal force on the right and left wheels so that the vehicle experiencing yaw motion centered on Centre of Gravity (COG), to reduce the yaw motion error, then the vehicle requires a yaw motion controller [3]. The movement of vehicles can be represented in models of vehicles consisting of various mathematical equations [4], [5] and based on the concept vehicle dynamics, vehicle model has two main functions in the control of movement of vehicles, the controller lateral and longitudinal controller [6].

Fuzzy Logic Control (FLC) is the application of Artificial Intelligence has been used as a reliable control system for controlling nonlinear systems, but to obtain the parameters required by FLC is not easy work. Therefore, needed process of training and learning by using optimization methods to tune the parameters of FLC [7]–[9].

In the development of optimization technology, Xin-She Yang in 2010 [10] inspired by the behavior of fireflies blinking to attract the other fireflies and make it as a metaheuristic algorithm called Firefly algorithm (FA). The General formulation of this algorithm is presented in modeling of mathematical analysis to solve the problem with the aim of equivalence function. The results are compared to the other alternative techniques showed that the FA is able to generate an optimal solution that better and correctly [11]. Specifically, although the FA have many similarities with other algorithms based on artificial intelligence, such as the famous called the Particle Swarm Optimization (PSO), is far more simple both in concept and implementation, so it is a very efficient algorithm for solving many problems of optimization [12].

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

This paper develops an optimal control system which is applied to vehicle models. The structure of the control system built using FLC as the main controller to lateral motion and using conventional control systems are common and reliable enough used to linear system that is the controller Proportional, Integral and Derivative (PID) [13] as the next controller to yaw motion To obtain the parameters of optimal control system, used FA optimization method. Simulations performed through a Software In the Loop Simulations (SILS) with the input in the form desired trajectory (Double lane change). Vehicle models built involves a 10-DOF (Degree of Freedom), which consists of 7-DOF model of ride vehicles (rolling, pitching, bounching and vertical displacement of each wheel) and 3-DOF model of handling vehicle (longitudinal motion, lateral motion and yaw motion). The simulation results show that the control system with the use of PLC and PID controller tuned by FA can further improve the vehicle dynamic performance compared with PSO. System performance expressed by lateral and yaw motion error in the form of Continuous Root Mean Error (C-RMS) along the desired trajectory.

2. VEHICLE MODEL

Vehicles model built representing 10-DOF that consists of 7-DOF model of vehicle ride and 3-DOF model of vehicle handling [7]. The vehicle Ride model represented as 7-DOF expressed in seven mathematical equations, consisting of the equation to the vehicle body (single sprung mass), which 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) [4], [5]. Suspension is modeled as a passive viscosity damper with a spring element and tire modeled as a simple linear spring without damping [14]. Referring to Figure 1, the balance of forces on the sprung mass (heaving) is given as follows:

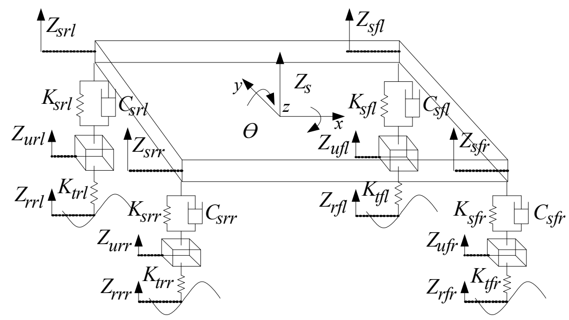

Figure 1. Vehicle Ride Model

Handling vehicle models represented as 3-DOF means having 3 mathematical equations which consist of equations movement of the car body in the direction of lateral, longitudinal and yaw motion [6], [15] as in figure 2. Lateral motion and longitudinal motion is the movement of vehicles along the *x*-axis and *y*-axis are expressed in lateral acceleration (*ay*) and longitudinal acceleration (*ax*) so that lateral motion and longitudinal motion can be obtained by twice integration of lateral and longitudinal acceleration.

Figure 2. Vehicle Handling Model

3. OPTIMAL CONTROL SYSTEM

Optimal control systems consist of two methods were used that FLC as the main control system to lateral motion and PID as the auxiliary control to yaw motion . The parameters of the control system are designed to be able to optimized using FA as shown in Figure 3.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Figure 3: Optimal Control System Structure

3.1. Fuzzy Logic Control (FLC)

FLC based on a logical model that represents the thinking process of an operator while controlling a system [16]. This approach is natural because the rules of FLC emulate human behavior through a statement of conditional linguistics [17]. Closed loop control system on the FLC with ER (error) and DE (delta error) as input FLC and OT as the quantities given to the plant. This rule like the decision-making table contains a combination of input and output happens to be executed. In general the preparation of rules set FLC in the control process will be changed according to the error and delta error [18].

Membership Function (MF) as the a function to express the degree of fuzzy membership that can be triangular (Triangular Function). In this paper every MF on the input and output consists of three MF in the form of two trapezium and one triangle so that the total rule base that is required is 9 rule. Each MF has a language term ; Negative Big (NB), Zero (Z), Positive Big (PB). In this paper the width and position of each MF have the ability to be able to tuned simultaneously on the input and output parameters of the FLC whose value depends on the multiplier factor Δ as shown in Figures 4, 5 and 6 [8].

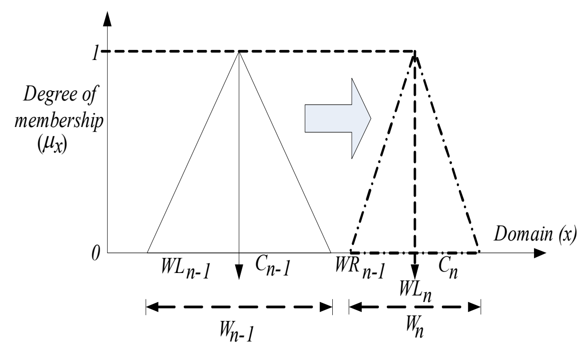

Figure 4: MF Triangular Parameter

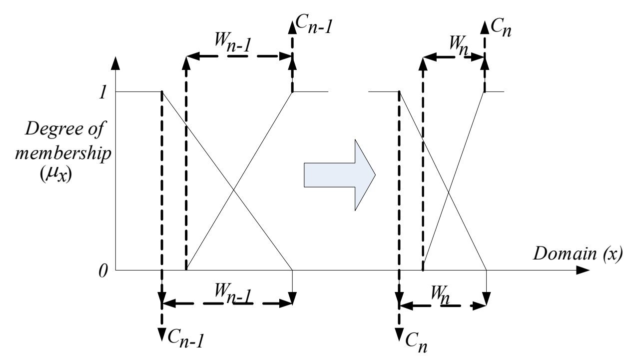

Figure 5: MF Trapezium Parameter

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Figure. 6. Change the Width and Position of MF

Determination of width and position of the MF is expressed as follows:
Change the position of the triangular (midpoint) and the trapezium (upper point):

$$C_{new} = C_{initial} \times \Delta \quad (1)$$

Change the width of the triangular and trapezium:

$$W_{new} = W_{initial} \times \Delta \quad \text{(trapezium)} \quad (2)$$

$$W_{new} = WR_{new} - WL_{new} \quad \text{(triangular)} \quad (3)$$

$$WR_{new} = WR_{initial} \times \Delta \quad (4)$$

$$WL_{new} = WL_{initial} \times \Delta \quad (5)$$

C, WR, and *WL* respectively is the position of the midpoint, wide right and wide left, while the subscript "initial" is the initial value and the "new" is the value after the change in the value of Δ, so that when the value of Δ change, the parameters of each MF will change includes a change of position midpoint and width (W) of the form of MF.

The value of Δ_i (Δ_{ER}, Δ_{DE}, Δ_{OT}) consists of; Δ_{ER} as the a multiplier factor of MF parameters to input errors; Δ_{DE} as the a multiplier factor of MF parameters to input error delta; and Δ_{OT} as the a multiplier factor of MF parameters to FLC output. The value of the multiplier factor; Δ_{ER}, Δ_{DE}, and Δ_{OT} can be determined by trial and error, but in this paper the value is determined through the iteration process to achieve optimal value using FA optimization.

3.2. PID Controller

PID controller is known as the control system that is powerful and superior, consisting of Proportional (P) controller to accelerate the rate of system response (rise time), Integral (I) controller to minimize or eliminate the error steady-state of the system and Derivative (D) controller to reduce overshoot or undershoot [13], [19]. In the application, the PID controller action might still be less than satisfactory, because if the controllers in the set very sensitive then the resulting overshoot will be more sensitive to the oscillations generated will be higher. Meanwhile, when the controller is set insensitive, it overshoot can be minimized, but the time required will be longer [13]. Controller Performance P, I, and D depends on the determination of the constants K_p, K_i and K_d. In this

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

paper, the value of the constants K_p, K_i and K_d are determined through a learning process on the system controller or tuning parameters to achieve optimal composition using optimization methods FA.

4. FIREFLY ALGORITHM OPTIMIZATIOAN

Dr. Xin-She Yang, 2010, formulates FA that all the fireflies were unisex and mutually attracted to each other. Attractiveness comparable to the brightness of a firefly, the lower brightness level will be attracted and moved to fireflies with a higher brightness level, the brightness can be decreased with increasing distance and the absorption of light due to air factor determined by the objective function value proportional to the light intensity [20]. There are two things interrelated and very important in the FA namely the light intensity and attractiveness functions. Attractiveness affected by the level of light intensity, light intensity levels on a firefly (I) can be expressed as follows [11],

$$I(x) = f(x) \tag{6}$$

To the value of f as the level of light intensity comparable to the solution of the problem objective function to search $f(x)$. Attractiveness (β) which is worth relative, because the intensity of light should be seen and assessed by the other fireflies. Thus, the assessment results will differ depending on the distance (r_{ij}) between a firefly with each other. The distance between firefly i and j at location x, x_i and x_j can be determined when done laying the point where fireflies are distributed randomly in the Cartesian diagram with formula [11]:

$$r_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \tag{7}$$

the difference of the coordinates of the location of firefly i, against firefly j is the distance between them (r_{ij}).

The movement of firefly i moving towards the best light intensity levels, can be seen from the following equation [11], [20]:

$$x_i = x_i + \beta_i * exp\left(-\gamma r_{ij}^2\right) * \left(x_j - x_i\right) + \alpha * \left(rand - \tfrac{1}{2}\right) \tag{8}$$

$$\beta(r) = \beta_0 * e(-\gamma r^m),\ (m \geq 1) \tag{9}$$

The initial variable of x_i shows the initial position fireflies are at the location x, then the second equation that consists of the variable $\beta_0 = 1.0$ this variable is the value of an initial attractive on fireflies, variable (exp) exponential, variable $\gamma = 1.0$ is the value for the level of absorption on surrounding environment of firefly namely air, and the last variable *right* is the difference of initial distance between firefly I and j. All the variables on the second equation is given from a firefly attractive function that determines the level of brightness. Furthermore, the third equation consists of the difference between the value of the solution on firefly i to firefly j. Then the movement equation function firefly random (*rand*), which showed the presence of random numbers range between [0,1]. α variables that have a range between [0,1] commonly determined by the value of 0.2. All variables were formed on the movement equation firefly guarantee the workings of fast algorithm towards an optimal solution [12].

The standard procedure for applying the FA are as follows:

1. Initialization firefly population, the number of iterations and the parameter FA.
2. Evaluation of the fitness function on each firefly.
3. Initialization initial fitness function as the determination of the level of initial light intensity.
4. Update the movement of each firefly uses the movement equation.
5. Comparing each candidate best firefly of the value of the fitness function in order to get the best value firefly.
6. Repeat the iterations to get a firefly with better fitness function.

5. SIMULATION RESULTS

Simulation of optimal control lateral and yaw motion of the vehicle, preceded by a parameter optimization of FLC and PID control system using FA and compared using PSO. In this paper, the FA and PSO optimizes six variables that consist three variables to determine the parameters of MF on FLC namely a multiplier factor; Δ_{ER} for input errors; Δ_{DE} for input delta error and Δ_{OT} to output FLC and three variables to determine the parameters of PID control in the form of constants K_p, K_i and K_d.

The parameters used in FA;

Maximum iteration	= 30,
Maximum Generation	= 30,
Coefficient beta	= 0,5
Coefficient alfa	= 0,5
Coefficient gamma	= 0,5

Optimization performed is the iterative simulation process up to 30 iterations on both of control system with input plant x - y trajectory

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

(double lane change) at a constant speed namely 13.89 m/s. This means that on control systems there is a learning process with random parameters and ultimately to determine the values of parameters are the most optimal to the lateral motion of the smallest error. Limitation of error used in the optimization process is ITAE, while the performance of error used in the simulation is Continues Root Mean Square Error (C-RMS error) as shown in Table 1, and Table 2 is the optimal parameters of the optimization results to the control system FLC and PID , Figure 7 shows the output response of the plant to the desired vehicle trajectory padakecepatan 13.89 m / s.

Table 1: Optimization Results of FA and PSO (Speed=13.88m/s)

	ITAE	C-RMS error	
		Lateral motion	Yaw motion
FA	6.4521e-51	0.007284	0.0469
PSO	1.3467e-54	0.010640	0.04714

Table 2: Optimal Parameters

	Optimal Parameters of Control System					
	Δ_{ER}	Δ_{DE}	Δ_{OT}	Kp	Ki	Kd
FA	1.0991	86.8241	0.3540	312.1410	4.3541	5.8571
PSO	1.7119	87.325	0.4345	327.408	4.7650	5.9935

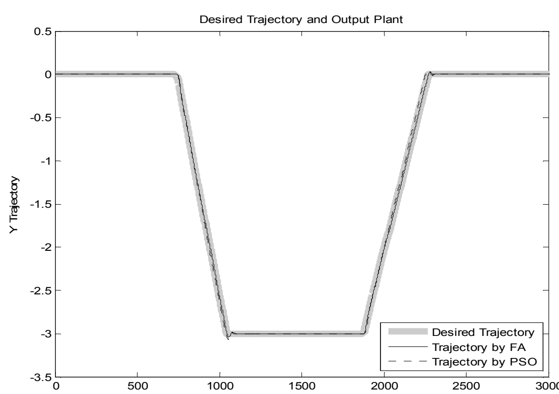

Figure 7: Double Lane Change of output plant and Desired Trajectory

Value of Δ_{ER}, Δ_{DE}, and Δ_{OT} obtained is a multiplier factor to determine the width and position of the centre of the triangular of each MF where the initial value before it optimized is 1, and the value of K_p, K_i and K_d is the expression value of the constant for the parameter Proportional, Integral and Derivative. Further to six parameters obtained from the optimization process referred to as the optimal parameter control systems for process simulation. Simulation of the optimal control system of vehicles using the FLA (FLC-PID tuned by FA) also compared to the control system optimized using PSO (FL-PID tuned by PSO) with a variable speed of 10-100 km / h as shown in Table 3 and C-RMS error of the lateral and yaw motion at various speeds of vehicles as in Figure 8. Figure 9, 10 and 11 respectively show the lateral and yaw motion error and the characteristics of the optimal control system.

Table 3: C-RMS error of Lateral and Yaw Motion

No	Velocity		C-RMS Error Double Lane Change			
	Km/h	m/s	FL – PID tuned by PSO		FL – PID tuned by FA	
			Lateral	*Yaw*	*Lateral*	*Yaw*
1	10	2.77	0.23050	0.22830	0.06432	0.19283
2	20	5.55	0.04133	0.11260	0.02471	0.08641
3	30	8.33	0.02087	0.06975	0.01620	0.06162
4	40	11.11	0.01401	0.04936	0.00892	0.04217
5	50	13.89	0.01064	0.03929	0.00671	0.03302
6	60	16.67	0.00897	0.03726	0.00616	0.02658
7	70	19.45	0.00814	0.03913	0.00543	0.02221
8	80	22.22	0.00855	0.04599	0.00573	0.02898
9	90	24.99	0.01091	0.05589	0.00828	0.03229
10	100	27.77	*time out*	*time out*	*time out*	*time out*
Rata-rata			0.039324	0.075286	0.016273	0.058457

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

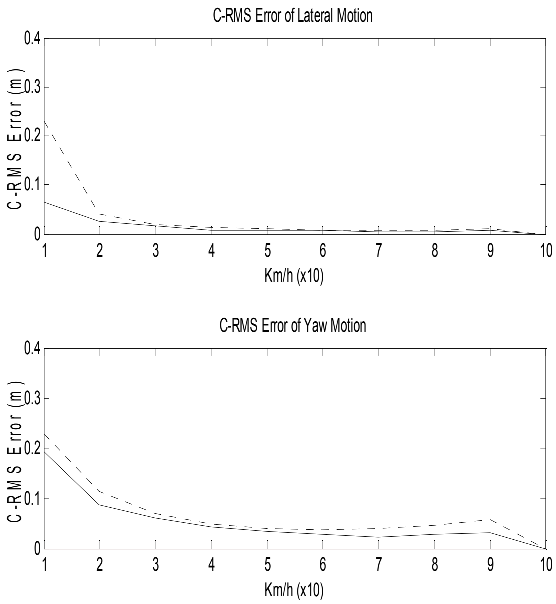

Figure 8: C-RMS error of Lateral and Yaw Motion

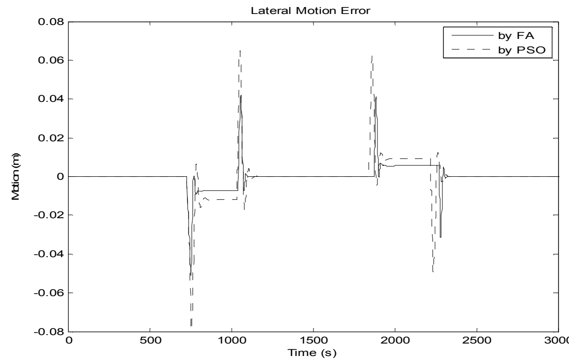

Figure 9: Lateral Motion Error

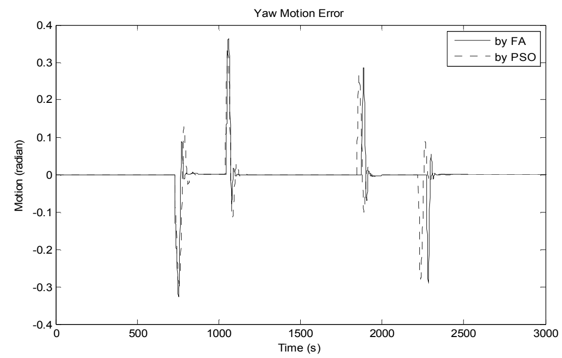

Figure 10: Yaw Motion Error

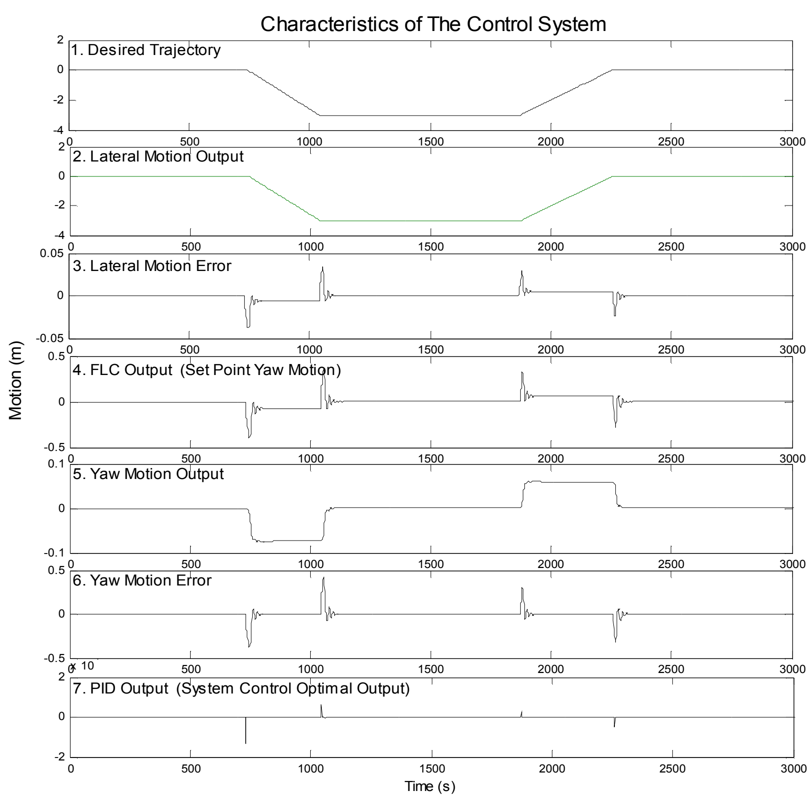

Figure 11: Characteristics of the Optimal Control System

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

6. CONCLUSION

The simulation results showed that with the use of Fuzzy Logic Control (FLC) system on lateral motion and PID control system on the yaw motion tuned by Firefly Algorithm (FA) (FLC-PID tuned by FA), the movement of the vehicle can be maintained according to the desired trajectory with an error lower compared by using Fuzzy Logic Control system and the PID tuned by PSO (FL-PID tuned by PSO).

REFERENCES:

[1] 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.

[2] 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.

[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] 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.

[5] 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.

[6] 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.

[7] H. Fachrudin, I. Robandi, and N. Sutantra, "The Optimal Steering Control System using Imperialist Competitive Algorithm on Vehicles with Steer-by-Wire System," *Iran. J. Electr. Electron. Eng.*, vol. 11, no. 1, pp. 25–35, 2015.

[8] H. Fachrudin, I. Robandi, and N. Sutantra, "Optimization of automatic steering control on a vehicle with a steer-by-wire system using particle swarm optimization," *Turk. J. Electr. Eng. Comput. Sci.*, vol. 24, no 2, pp. 541 – 557, Feb. 2016.

[9] H. Fachrudin, I. Robandi, and N. Sutantra, "Optimization Control System using the Quantum Behaved Particle Swarm Optimization on Vehicle Steering Control System with Steer-by-Wire System," *J. Teknol.*, vol. 71, no. 2, pp. 91 – 98, Nov. 2014.

[10] X.-S. Yang, "Firefly Algorithms for Multimodal Optimization," in *Stochastic Algorithms: Foundations and Applications*, O. Watanabe and T. Zeugmann, Eds. Springer Berlin Heidelberg, 2009, pp. 169–178.

[11] X. S. Yang, "Firefly algorithm, stochastic test functions and design optimisation," *Int. J. Bio-Inspired Comput.*, vol. 2, no. 2, pp. 78–84, 2010.

[12] A. H. Adil Hashmi, "Firefly Algorithm for Unconstrained Optimization," *IOSR J. Comput. Eng.*, vol. 11, no. 1, pp. 75–78, 2013.

[13] K. H. Ang, G. Chong, and Y. Li, "PID control system analysis, design, and technology," *IEEE Trans. Control Syst. Technol.*, vol. 13, no. 4, pp. 559–576, Jul. 2005.

[14] R. Darus and Y. M. Sam, "Modeling and control active suspension system for a full car model," in *5th International Colloquium on Signal Processing Its Applications, 2009. CSPA 2009*, 2009, pp. 13–18.

[15] 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.

[16] J. Jantzen, "Design Of Fuzzy Controllers," Technical University of Denmark, Department of Automation, Bldg 326, DK-2800 Lyngby, DENMARK., Tech. report no 98-E 864 (design), Sep. 1999.

[17] A. Z. Lotfi, "Fuzzy Logic Toolbox," *MATLAB Users Guide*, 1998.

[18] S. Wei, M. Liu, and Y. Song, "The Optimizing of Fuzzy Control Rule Based on Particle Swarm Optimization Algorithms," in *Proceedings of the 2009 Third International Conference on Genetic and Evolutionary*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Computing, Washington, DC, USA, 2009, pp. 645–648.

[19] A. E. A. Awouda and R. Bin Mamat, "Refine PID tuning rule using ITAE criteria," in *2010 The 2nd International Conference on Computer and Automation Engineering (ICCAE)*, 2010, vol. 5, pp. 171–176.

[20] X.-S. Yang, "Firefly Algorithms for Multimodal Optimization," *ArXiv10031466 Math*, Mar. 2010.