# Optimization of Active Steering Control on Vehicle with Steer by Wire System Using Imperialist Competitive Algorithm (ICA)

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***Abstract*-This paper presents the simulation of vehicle steering control system using the Imperialist Competitive Algorithm (ICA) for optimizing Proportional Integral Derivative (PID) control parameters to suppress errors on lateral motion and the yaw motion of vehicles. The vehicles are represented in the model vehicle with 10 degrees of Freedom of vehicle dynamics system. The simulation results show that the PID control tuned by the ICA in the vehicle steering control system can adjust the plant output to the desired trajectory so that the stability of the vehicle is maintained. Vehicle yaw error and lateral error can be reduced by using ICA to determine PID parameter. The main advantage of proposed optimization is faster and more accurate compared with standard PID controller. And then the error of the controller is reduced too. The results obtained are of vehicle motion can be maintained in accordance with the desired trajectory with smaller error and was able to achieve higher speeds than with the control system using optimized without parameters. This paper only deals with software simulation to proof the effect of ICA-PID optimization. The hardware implementation will be investigated in the next future.**

***Keywords—Vehicle, Lateral and Yaw motion, PID, ICA***

## I. INTRODUCTION

PID (Proportional-Integral-Derivative controller) is a controller for determining the precision instrumentation system with the characteristics of their feedback on the proficiency level system. Steer-by-Wire system is one part of a large system of technological developments in the electric car that is expected to be the vehicles of the future with a high performance control. Steer by wire system is the absence of a conventional relationship on a vehicle steering system in which the mechanical linkage between steering wheel and front wheels on the vehicle removed and replaced by electric propulsion [1].

There are two types of characteristics of the steer-by-wire system applied that is semi-automatic and fully automatic steer-by-wire system. Semi-automatic is a steer-by-wire system that uses a steer wheel to determine the direction of the front wheels while the fully automatic vehicle steer-by-wire system without using the steer wheel, to determine the direction of the front wheels of vehicles used pre-programmed trajectory.

Much research has been developed on a fully automatic steer-by-wire system, among others, devoted to research on the input trajectory that uses look-ahead and look-down systems [2], using GPS technology [3] and a trajectory that uses the lane guidance [4]. Likewise has developed research on active steering control, among others, an adaptive nonlinear control scheme aimed at the improvement of the handling properties of vehicles [5].

One of the problems that arise are required an effort to improve the performance of fully automatic steer-by-wire system, an effort which still very likely is the development of methods of control, as this would apply to all forms of input trajectory is used. The use of Artificial Intelligence (AI) is very helpful in speeding up the process of control, in this case, the PID control is a controller reliable enough, but it must be supported by a quickly and accurately method for tuning the parameters required in order to achieve precise control, imperialist competitive algorithm (ICA) is the optimization method which offers a fast and accurately process optimization for PID tuning parameters [6] [7].

In this paper developed a model of a fully automatic steer-by-wire is represented in the simulation of active steering control of the vehicle model with 10 degrees of freedom (DOF), which consists of a 7-DOF vehicle ride model and 3-DOF vehicle handling model [8], [9]. The control structures that was built consists of two stages in the cascade, the lateral motion control is used to eliminate unwanted the lateral movement, as well as setting point in the next control namely the yaw motion control which is complementary steering control system. Both of control systems using PID control tuned by ICA. The expected results of the simulation of active steering control using PID control tuned by ICA can improve the dynamic performance of the vehicle.

The systematic in this paper consist of; 1) The introduction and the review of relevant research that has been done. 2) Represents the vehicle model with 10 DOF vehicles dynamic. 3) Control structure model for simulating active steering control, PID control tuned by ICA. 4) The results of the simulation and 5) Conclusions.

## II. VEHICLE MODEL FOR CONTROL DESIGN

Based on the concept of vehicle dynamics, vehicle model was built as a plant in the active steering control system using the 10 degree of freedom (DOF) which consists of 7-DOF of vehicle ride and 3-DOF models of vehicle handling models.

### *A. Vehicle Ride Model*

Vehicle Ride model is represented as a 7-DOF system which is expressed in a mathematical equation 7 is composed of mathematical equations on the car body has a freedom of movement to heave or bounce, pitching, rolling and Vertical Direction for call now wheel [8],[9] .

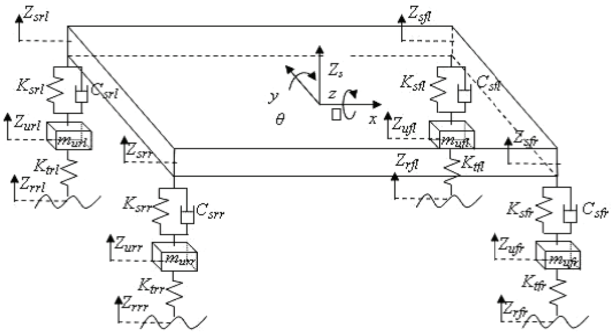

Fig. 1. Vehicle Ride Model

Bouncing of the car body ($Z_s$)

$$\begin{aligned} m_s\ddot{Z}_s = & -2\left(K_{s,f}+K_{s,r}\right)Z_s-2\left(C_{s,f}+C_{s,r}\right)\dot{Z}_s \\ & +2\left(aK_{s,f}-bC_{s,r}\right)\theta+2\left(aC_{s,f}-bC_{s,r}\right)\dot{\theta} \\ & +K_{sf}Z_{u,fl}+C_{s,f}\dot{Z}_{u,fl}+K_{sf}Z_{u,fr} \\ & +C_{s,f}\dot{Z}_{u,fr}K_{sr}Z_{u,rl}+C_{s,r}\dot{Z}_{u,rl}+K_{sr}Z_{u,rr} \\ & +C_{s,r}\dot{Z}_{u,rr}+F_{pfl}+F_{pfr}+F_{prl}+F_{prr} \end{aligned} \tag{1}$$

Pitching of the car body ($\theta$)

$$\begin{aligned} I_{yy}\ddot{\theta} = & \,2\left(aK_{s,f}-bK_{s,r}\right)Z_s+2\left(aC_{s,f}+bC_{s,r}\right)\dot{Z}_s \\ & -2\left(a^2K_{s,f}-b^2K_{s,r}\right)\theta-2\left(a^2C_{s,f}-b^2C_{s,r}\right)\dot{\theta} \\ & -aK_{sf}Z_{u,fl}-aC_{s,f}\dot{Z}_{u,fl}-aK_{sf}Z_{u,fr}-aC_{s,f}\dot{Z}_{u,fr} \\ & +bK_{sr}Z_{u,rl}+bC_{s,r}\dot{Z}_{u,rl}+bK_{sr}Z_{u,rr}+bC_{s,r}\dot{Z}_{u,fr} \\ & -\left(F_{pfl}+F_{pfr}\right)l_f+\left(F_{prl}+F_{prr}\right)l_r \end{aligned} \tag{2}$$

Rolling of the car body ($\varphi$)

$$\begin{aligned} I_{xx}\ddot{\varphi} = & -0.5w^2\left(K_{s,f}+K_{s,r}\right)\varphi-0.5w^2\left(C_{s,f}+C_{s,r}\right)\dot{\varphi} \\ & +0.5wK_{s,f}Z_{u,fl}+0.5wC_{s,f}\dot{Z}_{u,fl}-0.5wK_{s,f}Z_{u,fr} \\ & -0.5wC_{s,f}\dot{Z}_{u,fr}+0.5wK_{s,r}Z_{u,rl}+0.5wC_{s,r}\dot{Z}_{u,rl} \\ & -0.5wK_{s,r}Z_{u,rr}-0.5wC_{s,r}\dot{Z}_{u,rr} \\ & +\left(F_{pfl}+F_{prl}\right)\tfrac{w}{2}-\left(F_{pfr}+F_{prr}\right)\tfrac{w}{2} \end{aligned} \tag{3}$$

Vertical Direction for each wheel

$$\begin{aligned} m_u\ddot{Z}_{u,fl} = & \,K_{s,f}Z_s+C_{s,f}\dot{Z}_s-aK_{s,f}\theta-aC_{s,f}\dot{\theta} \\ & +0.5wK_{s,f}\varphi+0.5wC_{s,f}\dot{\varphi}-\left(K_{s,f}+K_t\right)Z_{u,fl} \\ & -C_{s,f}\dot{Z}_{u,fl}+K_tZ_{r,fl}-F_{pfl} \end{aligned} \tag{4}$$

$$\begin{aligned} m_u\ddot{Z}_{u,fr} = & \,K_{s,f}Z_s+C_{s,f}\dot{Z}_s-aK_{s,f}\theta-aC_{s,f}\dot{\theta} \\ & -0.5wK_{s,f}\varphi-0.5wC_{s,f}\dot{\varphi}-\left(K_{s,f}+K_t\right)Z_{u,fr} \\ & -C_{s,f}\dot{Z}_{u,fr}+K_tZ_{r,fr}-F_{pfr} \end{aligned} \tag{5}$$

$$\begin{aligned} m_u\ddot{Z}_{u,rl} = & \,K_{s,r}Z_s+C_{s,r}\dot{Z}_s+bK_{s,r}\theta+bC_{s,r}\dot{\theta} \\ & +0.5wK_{s,r}\varphi+0.5wC_{s,r}\dot{\varphi}-\left(K_{s,r}+K_t\right)Z_{u,rl} \\ & -C_{s,r}\dot{Z}_{u,rl}+K_tZ_{r,rl}-F_{prl} \end{aligned} \tag{6}$$

$$\begin{aligned} m_u\ddot{Z}_{u,rr} = & \,K_{s,r}Z_s+C_{s,r}\dot{Z}_s+bK_{s,r}\theta+bC_{s,r}\dot{\theta} \\ & -0.5wK_{s,r}\varphi-0.5wC_{s,r}\dot{\varphi}-\left(K_{s,r}+K_t\right)Z_{u,rr} \\ & -C_{s,r}\dot{Z}_{u,rr}+K_tZ_{r,rr}-F_{prr} \end{aligned} \tag{7}$$

### *B. Vehicle Handling Model*

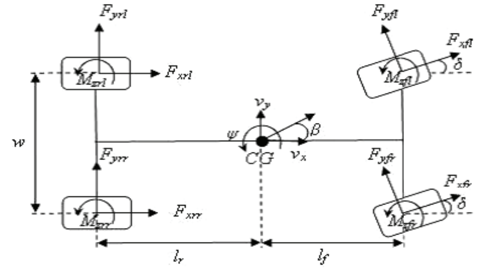

Fig.. 2. Vehicle Handling Model

Vehicle Handling Model represented as 3-DOF system which means it has 3 mathematical equations consisting of the equation of the movement of the car body laterally and longitudinally and yaw motion [10],[11]. 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 the lateral motion and longitudinal motion can be obtained by double integration of the lateral and longitudinal acceleration.

Lateral and longitudinal acceleration is expressed as follows:

$$a_y=\frac{F_{yfl}cos\delta-F_{xfl}sin\delta+F_{yfr}cos\delta-F_{xfr}sin\delta+F_{yrl}+F_{yrr}}{m_t} \tag{8}$$

$$a_x=\frac{F_{xfl}cos\delta-F_{yfl}sin\delta+F_{xfr}cos\delta-F_{yfr}sin\delta+F_{xrl}+F_{xrr}}{m_t} \tag{9}$$

Angular movement of the vehicle wheelbase vertical referred to as the yaw motion z (r) [12] which can be obtained by integration $\dot{r}$ dan $\ddot{r}$

$$\begin{aligned} \ddot{r} = & \frac{1}{J_z}\Big[\frac{w}{2}F_{xfl}cos\delta-\frac{w}{2}F_{xfr}cos\delta+\frac{w}{2}F_{xrl}-\frac{w}{2}F_{xrr} \\ & +\tfrac{w}{2}F_{yfl}sin\delta-\tfrac{w}{2}F_{yfr}sin\delta-l_rF_{yrl}-l_rF_{yrr} \\ & +l_fF_{yfl}cos\delta+l_fF_{yfr}cos\delta-l_fF_{xfl}sin\delta \\ & -l_fF_{xfr}sin\delta+M_{zfl}+M_{zfr}+M_{zrl}+M_{zrr}\Big] \end{aligned} \tag{10}$$

Based on the above equation then built a full vehicle model as a plant of active steering control system using MATLAB-SIMULINK software.

## III. SYSTEM CONTROL SIMULATION

Steering control system (active steer) vehicles built in this simulation using PID Control, where the settings are done in this simulation is setting the direction of the front wheels of vehicles which is the output of the plant model of the vehicle to match the plant is a reference to the input lookup tables x - y in the form of a line trajectory change and sine steer trajectory [15].

Plant output is expressed in the yaw rate and slip angle, where the slip angle is characteristic of the lateral and longitudinal relations of force, so that the function of the PID control system is used to suppress the error between the lateral motion (y) corresponding to the longitudinal motion (x) to the desired trajectory, whereas Tuning PID control is used accelerates ICA rise time, minimize errors and reduce overshot/undershot between the yaw motion of the setting point which is the output of the PID. Ideal conditions on the PID output are to have the removal or minimize error means the vehicle has not had a lateral motion (y), this gives the sense that the vehicle also has not experienced the yaw motion so that the output of PID is used as the setting point on the control yaw motion. To get the optimal control depends on the design of the composition on each parameter control system, in this paper the determination of the values of the parameters of both the PID control is done by tuning the values of these parameters to achieve optimal value by using ICA. Block diagram of the control structure used in the simulation of active steering control is shown in the following figure 3;

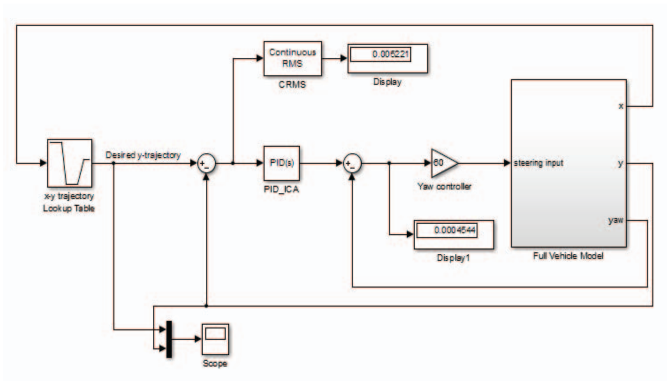


Fig. 3. The Proposed Control Structure

### *A. PID Control*

On The Proposed Control Structure control found the function enhance the control system. PID output is used as the setting point on the lateral motion. PID control is used as a control to eliminate the error between the setting points of the lateral motion. A control system known superior control measures, including Proportional Control (P) to speed up the system response rate (rise time), Integral Control (I) to minimize or eliminate the steady-state error of the system and control Derivative (D) to reduce the overshoot / undershoot [16]. Performance Control P, I, and D depend on the determination of the value of the constants Kp, Ki and Kd. This paper uses PID control where the value of the constants Kp = 12, Ki = 5, Kd = 8. This is necessary because if Kp is too large, will cause instability overshoot and even instability in the system. On the other hand, if the value of Kp is too small, will reduce the precision adjustment and make the system in a static state so that the loss of dynamic characteristics. At constant value Ki, if Ki is too big, it will cause response be overshoot, if Ki is too small, it is difficult to eliminate the steady-state error in the system, and affect the accuracy of the system, if Kd is too large, it will slow down the response and the ability of the system to be reduced [17].

### *B. Imperalist Competitive Algorithm (ICA)*

Recently a new meta-heuristic algorithm, so called Imperialist Competitive Algorithm (ICA) is proposed by Atashpaz et al. and applied to structural optimum design by the Kaveh and Talatahari. ICA is a socio-politically motivated optimization algorithm which is similar to many other evolutionary algorithms, and starts with a random initial population or empires. Each individual agent of an empire is called country and the countries are categorized into two types; colony and imperialist state that collectively form empires. Imperialistic competitions among these empires form the basis of the ICA. During this competition, weak empires collapse and powerful ones take possession of their colonies.

Imperialistic competitions converge to a state in which there exists only one empire and its colonies are in the same position and have the same cost as the imperialist Moving colonies toward imperialists are continued and imperialistic competition and implementations are performed during the search process. When the number of iterations reaches a pre-defined value, the search process is stopped. The pseudo-code of the ICA algorithm is presented:

Step 1: Initialization. Define the optimization problem; Select some random points as new position of colonies; Initialize the empires. Step 2: Colonies Movement. Move the colonies toward their relevant imperialist. Step 3: Imperialist Updating. If the new colony has lower cost than that of imperialist, exchange the positions of that colony and the imperialist. Step 4: Imperialistic Competition. Pick the weakest colony from the weakest empire and give it to the empire that has the most likelihood to possess it. Step 5: Implementation. Eliminate the powerless empires. Step 6: Terminating Criterion Control. Repeat Steps 2-5 until a terminating criterion is satisfied

## SIMULATION RESULTS AND DISCUSSION

The results of simulation is found that by using a PID control system on the lateral motion, and the yaw motion tuned to the ICA to control the plant in the form of a full vehicle model obtained from [16] as follows

TABLE I VEHICLE MODEL SIMULATION PARAMETERS [16]

| No | Parameter | 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 | Tire 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 $Nm^{-1}$ |
| 11 | Roll stiffness constant | 2400 $Nm^{-1}$ |
| 12 | Centre of gravity height | 0.55 m |
| 13 | Pitch moment of inertia | 425 kg $m^2$ |
| 14 | Roll moment of inertia | 425 kg $m^2$ |
| 15 | Yaw moment of inertia | 3125 kg $m^2$ |
| 16 | Wheel moment of inertia | 1.1 kg $m^2$ |
| 17 | Pitch damping constant | 170000 $Nm^{-1}s^{-1}$ |
| 18 | Roll damping constant | 90000 $Nm^{-1}s^{-1}$ |

ICA parameters can be shown in the table 3

TABLE II. PARAMETERS OF THE ICA

| | |
|---|---|
| Number of Countries | 50 |
| Number of Imperialists | 6 |
| Number of Colonies | 50-6=44 |
| Revolution rate | 0,3 |
| Assimilation Coefficient ( ) | 2 |
| Assimilation coefficient ( ) | 0,5 |
| Zeta | 0.01 |

Revolution rate is 0.3, it means 30% of the colonies in the empire would change its position randomly. Assimilation Coefficient (β) value is a number that is more than 1 so as to the make the colony moves closer to the imperial, the β value used is 2. Assimilation coefficient (γ) is the parameter that governs the deviation from the initial direction, the value of γ used 0.5. Selected values of β and γ reviews such that to produce good convergence towards the global minimum is positive values with values that are Considered less than 1 (small value) that causes total strength is influenced by the imperialist empire more than a colony

Optimizations performed by ICA is a simulation process repeated until 15 iterations on the control structure of the model vehicle with active steering input x-y trajectory plant double lane. The control system of the learning process with random parameters and ultimately to determine the values of the optimal parameters are converging to the size of the smallest lateral motion error. The results of the optimization of the 3 variables are: Kp = 80.015, Ki = 4.1046, Kd = 0.2014 and the yaw controller gain is 60. Computer simulation results that illustrate the accuracy of the controller can be seen in Figure 4 to 9

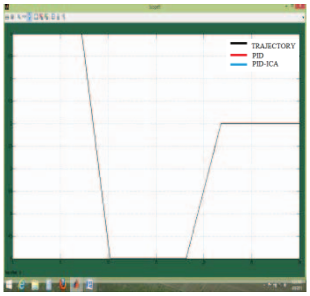

Fig. 4. Input Trajectory

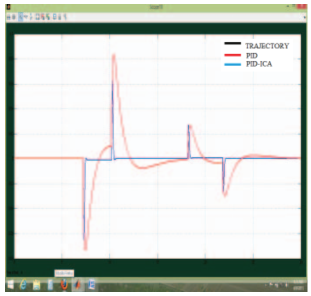

Fig. 5. Lateral Motion

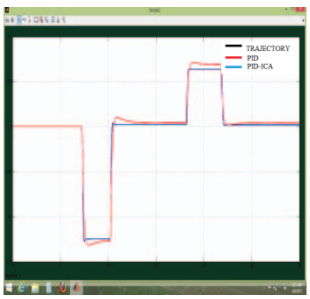

Fig. 6. Yaw Motion

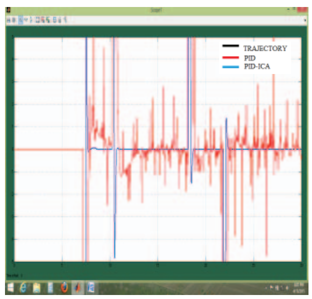

Fig. 7. Output Gain

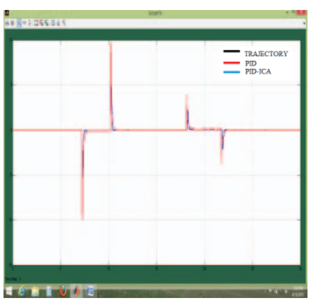

Fig. 8. Output PID

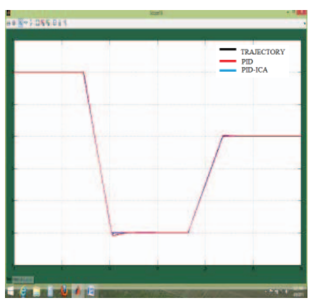

Fig. 9. Simulation Results

The results of simulation tests it was found that by using PID control system on the lateral motion and yaw motion tuned by ICA of the plant in the form of full vehicle model. Vehicle stability can be maintained in accordance with the desired trajectory (velocity maximum 29.978 m/s; CRMS error = 0.005221). These results represent the first stage in the form of simulated active steering control that further testing will be done through the HILS (Hardware in the Loop Simulations

## IV. CONCLUSION

This paper represents optimization of PID parameter using Imperialist Competitive Algorithm (ICA) to control lateral and yaw motion that applied to the simulation of vehicle models with 10 Degree Of Freedom (DOF) active steering control. The proposed optimization then compared with standard PID controller. The main advantage of proposed optimization is faster and more accurate compared with standard PID controller. And then the error of the controller is reduced too. The results obtained are of vehicle motion can be maintained in accordance with the desired trajectory with smaller error and was able to achieve higher speeds than with the control system using optimized without parameters. This paper only deals with software simulation to proof the effect of ICA-PID optimization. The hardware implementation will be investigated in the next future.

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