A Comparative Study of PID-PSO and Fuzzy Controller for Path Tracking Control of Autonomous Ground Vehicles

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Abstract: The work presented in this paper focuses on platonning navigation control (train of vehicles) according to different trajectories. As a first step we based our study on two vehicles. an kinematic model of the two vehicles is described followed by a PID multi-controller control approach based on conventional PID, PID optimized by Particle Swarm Optimization (PSO) technique and fuzzy controller applied to the longitudinal and lateral control of each vehicle. Controller parameters optimization is based on a fitness function time weight square error (ITSE). The communication between the two vehicles is ensured with the exchange of information, the speed and orientation angle, respecting the safety distance between the vehicles. To approve our approach we have use different reference trajectory in different simulations in matlab-simulink environment and v-rep 3D simulation. The simulation obtained results illustrate the efficiency of our control design and open the perspectives for future work.

1 INTRODUCTION

Today's transportation systems are increasingly complex systems with some difficulty in ensuring the control and security of these systems the number of vehicles is growing exponentially and the accomplishment of simple tasks really becomes a defeat with risk for the human being autonomous vehicles can solve this problem and act in the place of human beings. greasy to their capacity mobile robots (Car like vehicles or autonomous vehicles) are able to perform many tasks in dangerous places where humans cannot enter, those sites where harmful gases or high temperature are present in a harsh environment to humans and to ensure the delivery of goods at long distances in risky roads with autonomous vehicles we can save money by performing various routine tasks (Baturone et al., 2004). So that this goal is to ensure this means that it is necessary to upgrade and optimize autonomous vehicle controllers that solve complicated problems and tackle complicated in variable environments. in the literature different control approach are used to control the navigation of autonomous vehicles like fuzzy controller, controller based on networks of noodles, sliding mode control (Garcia et al., 2008; Bingyi et al., 2017; Fernandes, 2010). The simplest controller used in controlling the navigation of an autonomous vehicle being the PID controller. The traditional PID controller has been used to control the various industrial processes in the world (Bingyi et al., 2017). This controller has a major problem with a fixed choice of these parameters in a dynamic, complex environment and when there are variations in the installation parameters and operating conditions, which may cause the controller to not provide the parameters control performance required. There are different methods for adjusting the PID controller parameters according to the variation in the state of the environment and the system among these best-known methods, frequently used in industrial applications, the Ziegler-Nichols method, the genetic algorithm GA, fuzzy logic controller (Cao and Liu, 2017), etc. the PSO optimization technique was another very fashionable method of tuning. this technique (PSO) introduced by Kennedy and Eberhart (Campolo et al., 2015; Ploeg et al., 2014) is one of the modern heuristic algorithms, it was motivated by the behavior of organisms, such as fish farming and flocking of birds (Cao and Liu, 2017). Other modern heuristics algorithms are used as reinforcement learning (Q-learning) to optimize the parameters of the PID

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controllers. Unlike other heuristics (Campolo et al., 2015), PSO has a flexible and well-balanced mechanism to improve global and local exploration capabilities (Ploeg et al., 2014; Dumont, 2006; Bouibed, 2010). This technique is easy to implement and informally efficient. In this paper, a new control approach based on multi-PID-PSO controllers to optimally design a PID controller for tracking the trajectory of an autonomous vehicles train (platonning) is proposed (figure 1).

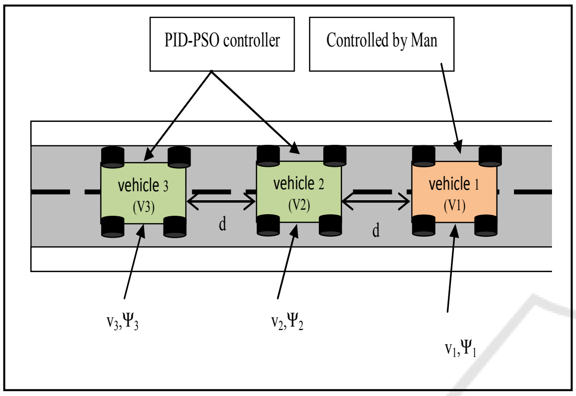

Figure 1: Architecture of Platonning system.

This article was organized as follows: in section 2, a kinematic model of the autonomous vehicle (mobile robot) is described. In Section 3, the method of optimizing the particle swarm is reviewed. Section 4 describes how PSO is used to design the PID controller optimally for the mobile robot to control the speed and angle of orientation of the vehicle. Section 5 simulation and results.

2 KINEMATIC MODLING

Different model of autonomous electrical vehicles existing in the literature (Baturone et al., 2014). this model more and less complex depend of the situation and the elements composed the vehicle. The model is more represent the vehicle when its take into account all the forces applied on the system. in this case the control results obtained are high efficient. Our work is based on the control study of two autonomous electric vehicles, that used four wheels driven by DC motor, the braking is done by electromagnetic brakes when the absence of current it also has dual front steering system and back. The simplified geometric model of vehicles is represented by the following figure :

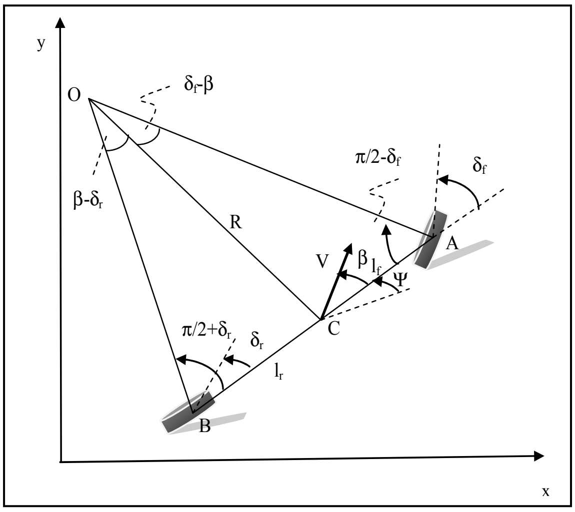

Figure 2: Geometric model of Electric vehicle (RobuCar) and kinematic model.

With :
O : is the instantaneous rolling centre for the vehicle
C : gravity centre of vehicle.
β : slip angle of the vehicle
Ψ : heading angle of the vehicle.
δf,δr : steering angles.
lr, lf :distance between gravity centre of vehicle and the wheels (AC and BC)
R : the radius (OC)

The course angle for the vehicle is γ=β+Ψ . Apply the sine rule to triangle OCA with same simplification, the kinematic model is described by the following formulary :

$$\dot{X} = V \cdot \cos(\Psi + \beta) \tag{1}$$

$$\dot{Y} = V \cdot \sin(\Psi + \beta) \tag{2}$$

$$\dot{\Psi} = \frac{V \cdot \cos(\beta)}{l_f + l_r} \cdot \left(\tan(\delta_f) - \tan(\delta_r)\right) \tag{3}$$

$$\beta = tan^{-1}\left(\frac{l_r \cdot \tan(\delta_f) + l_f \cdot \tan(\delta_r)}{l_f + l_r}\right) \tag{4}$$

In this model there are three inputs: δ_f , $\delta_r$and V. In our work we consider that our vehicle has a simple braking and the slip angle equal zero (β=0 and δr=0). The kinematic model in this situation is as follows :

$$\dot{X} = V \cdot \cos(\Psi) \tag{5}$$

$$\dot{Y} = V \cdot \sin(\Psi) \tag{6}$$

$$\dot{\Psi} = \frac{V}{L} \cdot \tan(\delta_f) \tag{7}$$

With : L=$l_f + l_r$

To keep the mobile robot on our desired trajectory it is necessary to design a regulator which will allow tracking of arbitrary trajectories (xr (t), yr (t)). The design of controller which we used is based on conventional PID controller it receives the values of distance and the robot location relative to the path as shown in Fig 3,

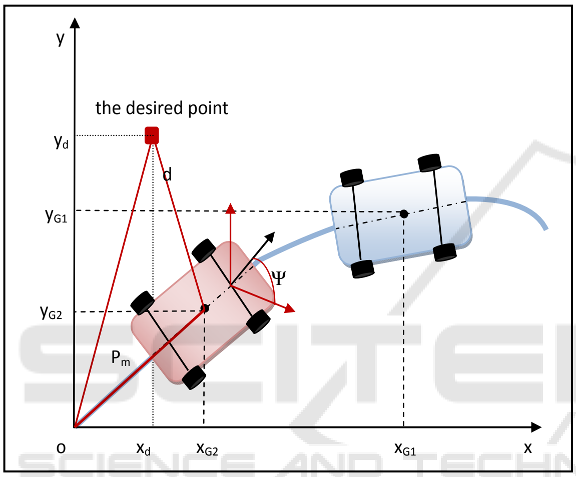

Figure 3: Technical diagram of the technique.

The error victor represents the distance between the vehicle and the desired position.

$$e_d = \sqrt{(x_d - x_G)^2 + (y_d - y_G)^2} \tag{8}$$

$$\Psi_d = \tan^{-1}\frac{y_d - y}{x_d - x} \tag{9}$$

$$e_\Psi = \Psi_d - \Psi \tag{10}$$

This model is used for the two vehicles. we described the architecture of multi-controller PID-PSO control approach in the following section.

3 PARTICLE SWARM OPTIMIZATION WITH PID

The Particle Swarm Optimization (PSO) is evolutionary computational technique based on the movement and intelligence of swarms looking for the most fertile feeding location; it was developed in 1995 by James Kennedy and Russell Eberhart. PSO is one of the optimization techniques and a kind of evolutionary computation technique. This algorithm is simple, easy to implement and few parameters to adjust mainly the velocity. It's inspired by social behavior of birds and fishes and it's combines self-experience with social experience and applies to concept of social interaction to problem solving (Al-Mayyahi, 2015) (Turki and Abdulkareem, 2012). The goal of Optimization is to find values of the variables that minimize or maximize the objective function while satisfying the constraints. The optimization needs the good mathematical model of the optimization problem and an algorithm that should have robustness (good performance for a wide class of problems), efficiency (not too much computer time) and accuracy (can identify the error). The optimization is based in population; it has been applied successfully to a wide variety of search and optimization problems. In this technique, a swarm of n individuals communicate either directly or indirectly with one another search directions (gradients) (Al-Mayyahi, 2014). PSO technique is not only a tool for optimization, but also a tool for representing socio cognition of human and artificial agents, based on principles of social psychology. A PSO system combines local search methods with global search methods, attempting to balance exploration and exploitation (Zoleikha et al., 2017). The Population-based search procedure in which individuals called particles change their position (state) with time. The Particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience, and according to the experience of a neighboring particle, making use of the best position encountered by itself and its neighbor. Suppose that the search space is D-dimensional, then the ith particle of the swarm can be represented by a D-dimensional vector $X_i = [x_{i1}x_{i2} \dots x_{iD}]^T$. The velocity of the particle can be represented by another D-dimensional vector $V_i = [Vi(1)Vi(2) \dots Vi(D)]^T$. The best previously visited position of the ith particle is denoted as $P_i = [p_{i1}p_{i2} \dots p_{iD}]^T$. Defining ''g'' as the index of the best particle in the swarm, where the gth particle is the best, and let the superscripts denote the iteration number, then the swarm is manipulated according to the following two equations (Zennir et al., 2017).

$$V_i\,(t+1) = w\,.V_i(t) + c_1.r_1\,(pbest_i\,(t) - x_i(t)) + c_2.r_2(gbest_i(t) - x_i(t)) \tag{11}$$

$$x_i(\,t+1) = V_i\,(t+1) + x_i\,(t) \tag{12}$$

where t = 1, 2, . . . , D; i= 1, 2, . . . , M, and M is the size of the swarm (i.e. number of particles in the swarm); c1, c2 are the positive values, called acceleration constants; r1, r2 are the random numbers uniformly distributed in [0, 1]. Typically w(t) is reduced linearly, from w_{start} to w_{end}, each iteration, a good starting point is to set w_{start} to 0.9 and w_{end} to 0.4.

$$w(t) = \frac{(T_{max}-t)\times(w_{start}-w_{end})}{T_{max}} + w_{end} \tag{13}$$

Thought V_{max} has been found not to be necessary in the PSO with inertia version, however it can be useful and is suggested that a $V_{max} = X_{max}$ be used. The original procedure for implementing PSO is as (Allou et al., 2017). In PID controller design methods, the most common performance criteria are integrated absolute error (IAE), the integrated of time weight square error (ITSE), integrated of squared error (ISE) and Mean Square Error (MSE) (Al-Mayyahi et al.,2015). In this work we use parallel PID, and the coefficients Kp, Ki, Kd are determined by the PSO algorithm using ITSE performance criteria (figure 4).

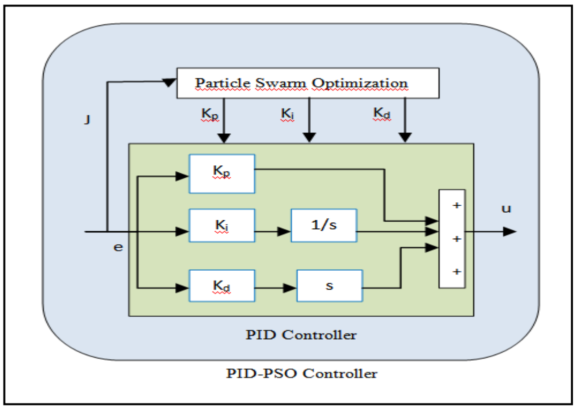

Figure 4: PID parameters based on PSO.

With: J: ITSE performance criteria (fitness function); u: law control; e: error.

4 DESIGN OF CONTROLLERS

In this paper we used two type of controller. in the first two PSO algorithm to find the optimal parameters for two PID controllers for the control of velocity and angle of orientation of vehicles. Figure 5 shows the block diagram of optimal PID controller for the vehicles. The design of our control approach used to control lateral and longitudinal position of vehicles is shown in the following figure:

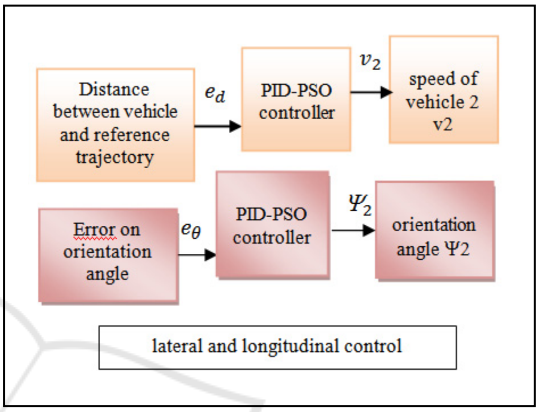

Figure 5: Optimal PID-PSO control structure.

The second controller based fuzzy controller applied in lateral and longitudinal control like in following figure:

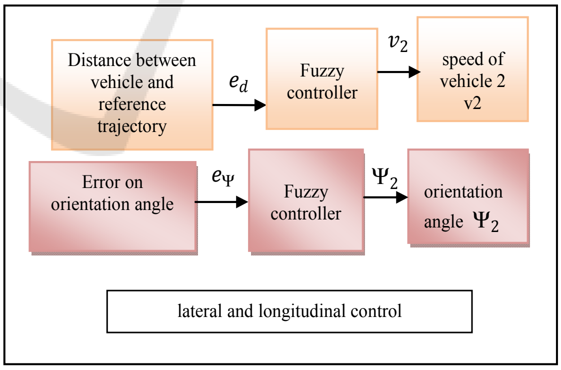

Figure 6: Control structure with Fuzzy controller.

The architecture of control for the controllers in simulink is illustrted in the following figures:

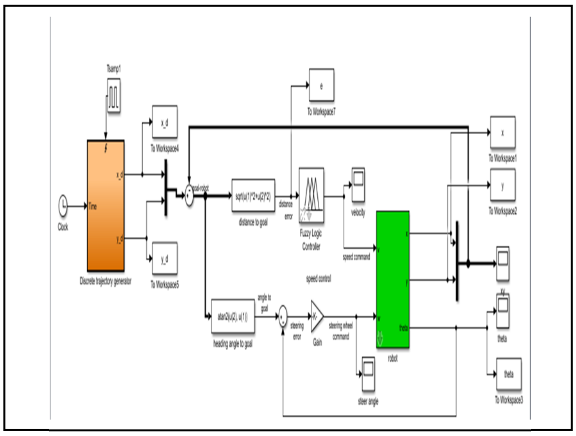

Figure 7: Control block diagram with fuzzy controller.

The Parallel PID controller parameters are extracted using the PID tool command. The following figure shows that our system is regulated by a parallel PID controller. We control the speed and orientation angle of vehicle. The transfer function of PID controller used to control orientation angle is as follows:

$$C_{PID} = Kp * e_{\Psi} \tag{14}$$

The transfer function of PID controller used to control speed of vehicle is as follows:

$$\mathrm{G_{PID}(s)} = \left(\mathrm{Kp} + \mathrm{Ki}.\frac{1}{\mathrm{s}} + \mathrm{Kd.s}\right) \cdot \mathrm{e_d} \tag{15}$$

5 SIMULATION

We have simulated our architecture control approach in continues time. The simulation aim is to approve the controller's efficiency on two types of controller (PID and PID-PSO controller) in five different trajectory in plan (triangle, rectangle, sinusoidal form, straight line form and trapezoidal form). The parameter of PID controller are:

- Controller for speed

$$K_p = 25\;;\; K_i = 0.1\;;\; K_d = 0.02$$

- Controller for orientation angle

$$K_p = 100$$

The obtained results without control are illustrated in the following figures:

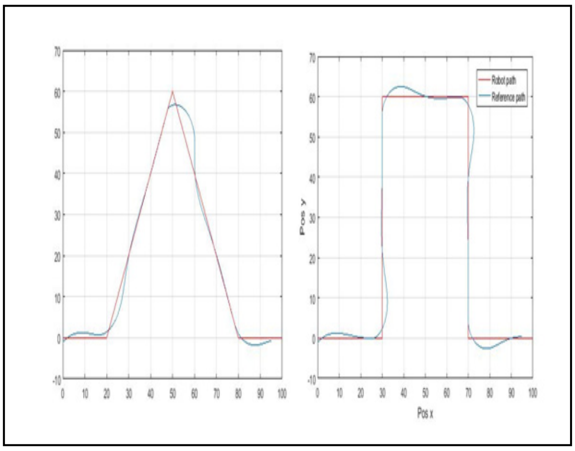

Figure 8: Rectangle and triangle trajectory without control.

The obtained results are illustrated in the following figures:

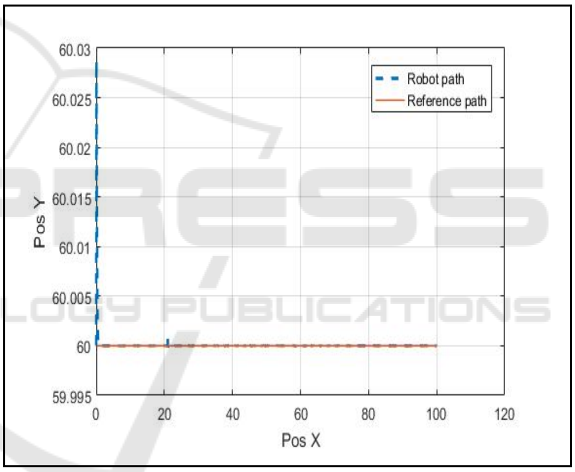

Figure 9: Straight line trajectory with PID-PSO.

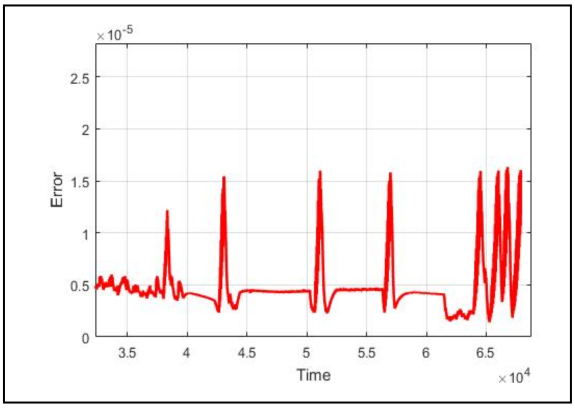

Figure 10: Error with straight line trajectory (PID-PSO controller).

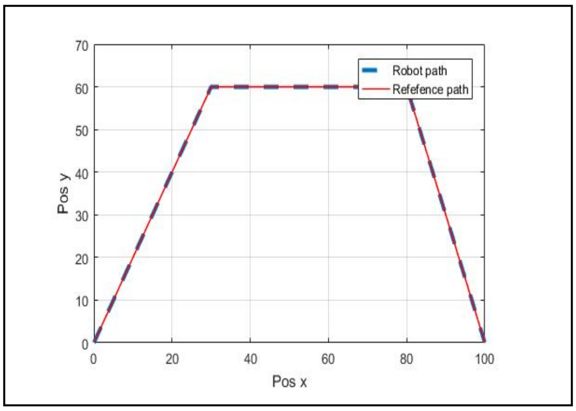

Figure 11: Trapezoidal trajectory with PID-PSO controller.

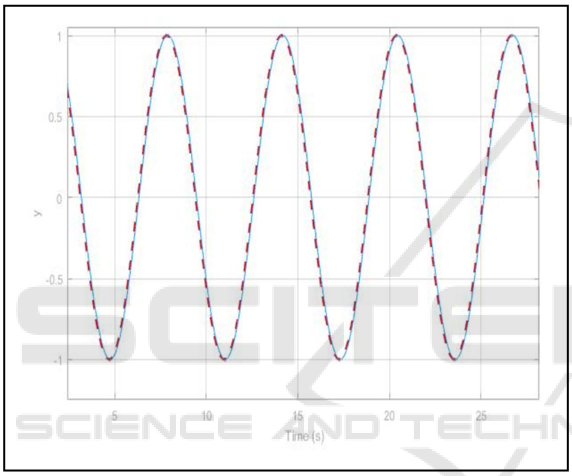

Figure 12: Sinusoidal trajectory with PID-PSO controller.

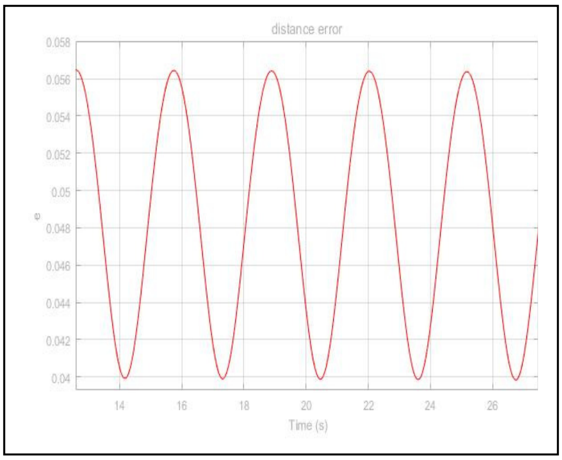

Figure 13: error with Sinusoidal trajectory (PID-PSO).

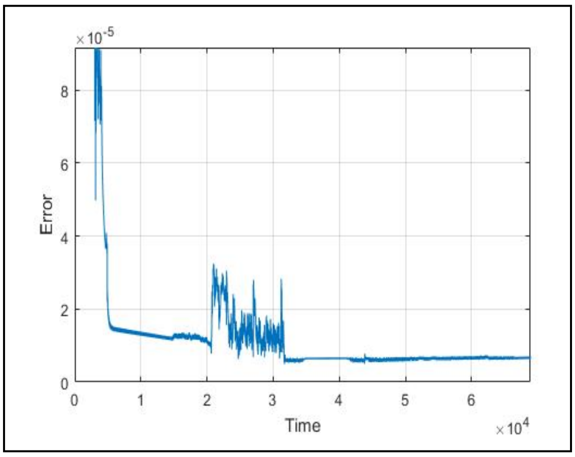

Figure 14: Error with rectangle trajectory PID-PSO controller.

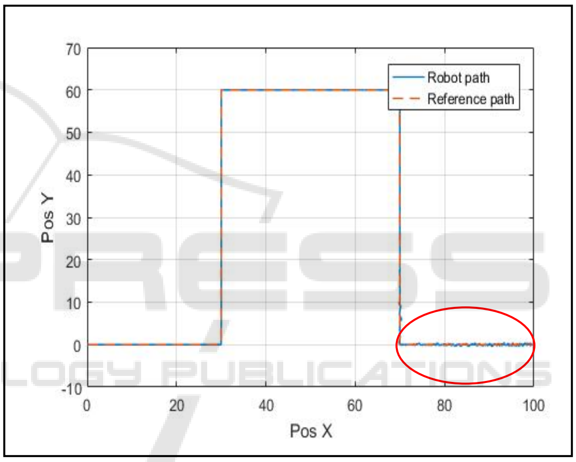

Figure 15: Rectangle trajectory with PID-PSO controller.

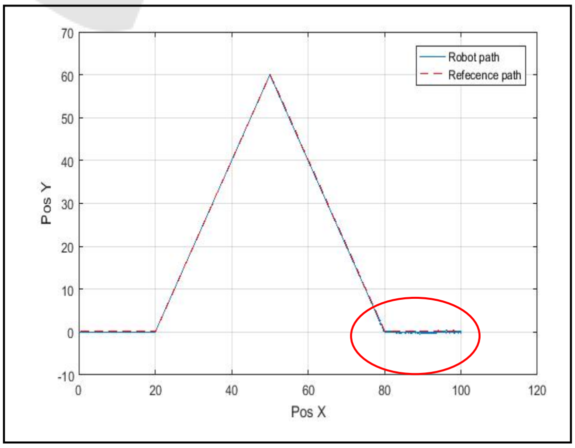

Figure 16: Curved triangle trajectory with PID-PSO controller.

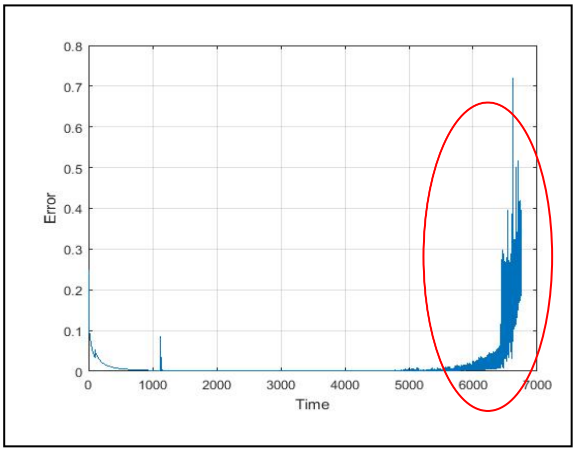

Figure 17: Error with triangle trajectory with PID-PSO controller.

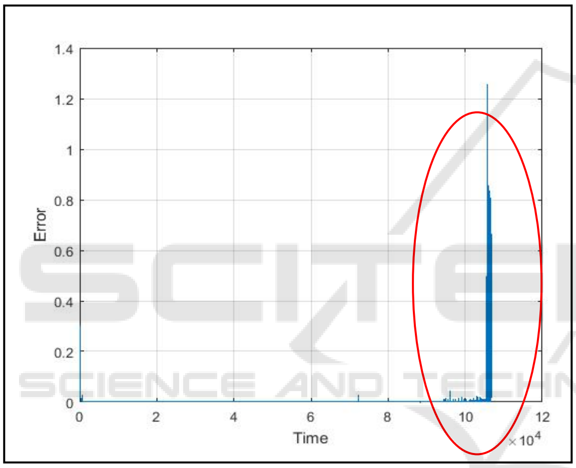

Figure 18: Error with rectangle trajectory with PID-PSO controller.

The obtained results obtained with fuzzy controller in different trajectory are illustrated in the following figures:

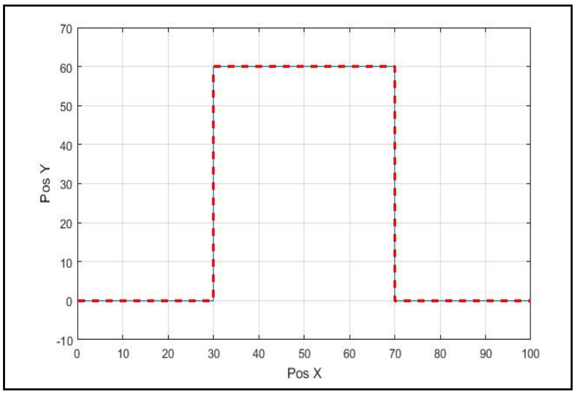

Figure 19: Rectangle trajectory with fuzzy controller.

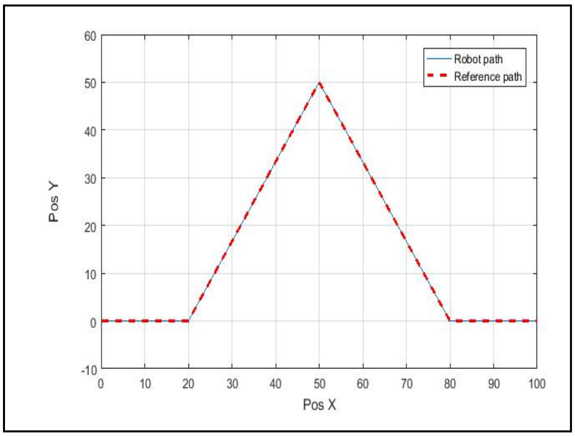

Figure 20: Triangle trajectory with fuzzy controller.

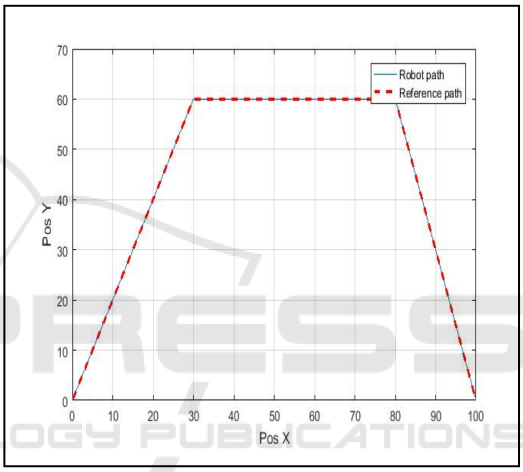

Figure 21: Trapezoidal trajectory with fuzzy controller.

Table 1: Error obtained with pid controller and fuzzy controller.

Trajectory	Error with PID controller	Error with Fuzzy controller
Triangle form	0.033-0.039	0.014-0.0175
Rectangle form	0.0315	0.0139
Sinusoidal form	0.015	0.007
Curved form	0.0095-0.0195	0.003-0.006
Trapezoidal form	0.03391	0.01395
Straight form	0.034	0.0137

The figures figure.8 show the tracking of the trajectory without optimization of PID controller. After adjusting the parameters of the controllers (PID) with PSO technique, the results are much improved and the tracking error is very small for all type of trajectory (figure.9-figure.18). But we have observed too that same error in the end of triangle or rectangle trajectory (figure.19 and figure.20). The tracking error with sinusoidal trajectory must be improved (figure. 13). The figures figure.19, figure.20 and figure.21 shows the tracking of the trajectory after adjusting the parameters of the controllers (PID and Fuzzy) the results are much improved and specially with the fuzzy controller as shown in the error table (table.I). This efficiency of the fuzzy controller is whatever the type of trajectory and specially in curved and sinusoidal trajectory. With obtained results we can observed that Fuzzy controller give very important stability and precision in the end of trajectory compared with PID and PID-PSO controllers. PSO-PID controller give high precision in all type of trajectory only in curved and sinusoidal trajectory. 3D simulation in v-rep in the following figure:

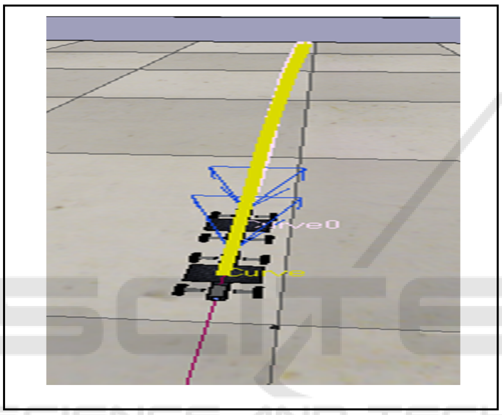

Figure 22: 3D simulation in v-rep with two vehicles.

6 CONCLUSION

In this paper we have proposed A comparative study with different controller design PID, PID-PSO and Fuzzy controller applied to control path tracking for platonning autonomous vehicles with four wheels. The controllers choses for able to offer more tracking flexibility and stability of our system. Different simulation has been realized in different trajectory with very interesting results in lateral and longitudinal control of vehicles with Fuzzy controller and PID-PSO controller. We can conclude that our approach of control gives high results in stability and precision but this approach must be more optimized where the platonning vehicles travel in curved trajectory and in the end of trajectory for PID-PSO controller. In the future works we plan, to improve our control approach with other optimization algorithm like Fractional PID controller (FOPID) optimizing by PSO algorithm, Genetic Algorithm and wolf Algorithm to optimize the parameters of controller in other trajectory with obstacle.

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