Path Tracking of Autonomous Ground vehicles Based on multi-PID controllers Optimized by PSO

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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 and PID optimized by Particle Swarm Optimization (PSO) technique 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. The simulation obtained results illustrate the efficiency of our control design and open the perspectives for future work.

Keywords— Mobile Robot, Particles Swarm Optimization, PID Controller, Kinematic and dynamic model,Trajectory tracking.

I. 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 [1]. 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 [2] [3] [4]. the simplest controller used in controlling the navigation of an autonomous vehicle being the PID controller.

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The traditional PID controller has been used to control the various industrial processes in the world [3]. 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 [3], the genetic algorithm GA, fuzzy logic controller [5-16], etc. the PSO optimization technique was another very fashionable method of tuning. this technique (PSO) introduced by Kennedy and Eberhart [6] is one of the modern heuristic algorithms, it was motivated by the behavior of organisms, such as fish farming and flocking of birds [5]. other modern heuristics algorithms are used as reinforcement learning (Q-learning) to optimize the parameters of the PID controllers. Unlike other heuristics [7], PSO has a flexible and well-balanced mechanism to improve global and local exploration capabilities [8-10]. 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).

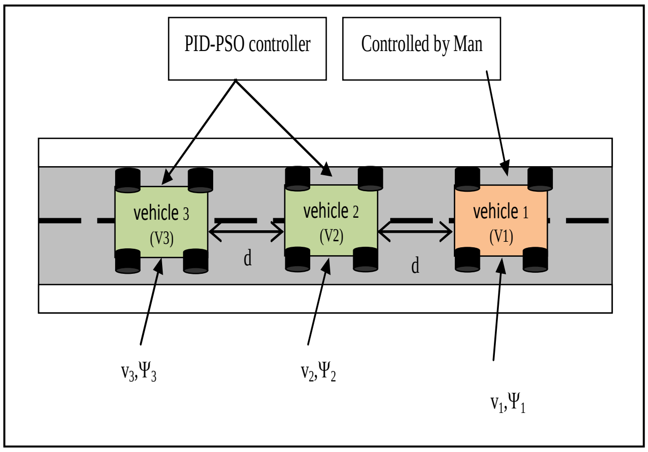

Fig. 1. Architecture of Platonning system

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.

II. CINEMATIC AUTOMOUS VEHICLES MODLING

Different model of autonomous electrical vehicles existing in the literature [1], [2]. 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. The first dynamic modeling of the autonomous electrical vehicle that we used are develop by [4] but he doesn't take on consideration all the forces, this model improved by adding some forces to consideration, we used the dynamic model improved proposed in [5][6] (figure 2). 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 mathematic model is illustrated by the following equations :

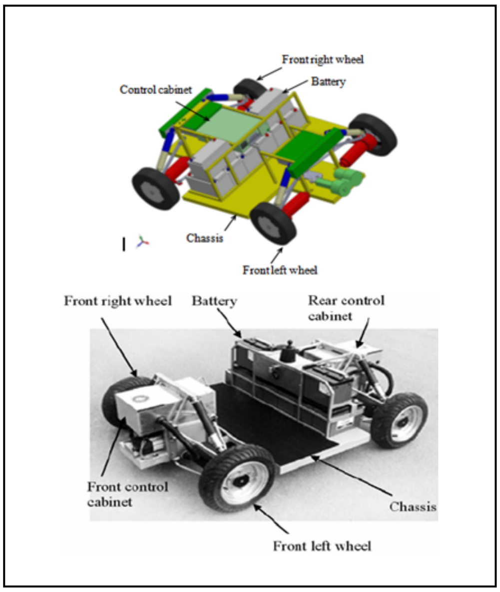

Fig. 2. Electric vehicle (RobuCar) and kinematic model [6-7]

The parameters of cinematic model are illustrated in the following table.

TABLE I. USED PARAMETERS IN THE MODELING

Ψ	Vehicle yaw angle
v_G	The velocity vector at the CG
v_x , v_y	The longitudinal and the lateral velocity
$\delta_f \delta_r$	Steering angle of wheel

The kinematic model of robucar [6] is given by:

$$\dot{x} = v_{moy} \cdot \sin(\Psi + 2\delta_r) \tag{1}$$

$$\dot{y} = v_{moy} \cdot \cos(\Psi + 2\delta_r) \tag{2}$$

$$\dot{\Psi} = v_{moy} \cdot \sin(2\delta_f)/L \cdot \cos(2\delta_f) \tag{3}$$

With : Ψ: Vehicle angle; δ_f, δ_r: Steering angle, x,y: ; v_{moy} : average speed. The given kinematic model with double steering system and takes into account three degrees of freedom, both longitudinal and lateral translation with a rotation around lace. In this work we used single steering modes of RobuCar The kinematic model become :

$$\dot{x} = v_1 \cdot \cos(\Psi) \tag{4}$$

$$\dot{y} = v_1 \cdot \sin(\Psi) \tag{5}$$

$$\dot{\Psi} = v_2 \tag{6}$$

Where: v_1: translation speed; v_2: rotation speed.

To keep the mobile robot on our desired trajectory it is necessary to design a regulator which will allow tracking of arbitrary trajectories (x_r (t), y_r (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, at the output of the controller, then we get the two parameters, the linear speed and the steering angle that will be needed so that the robot always stays on the desired trajectory.

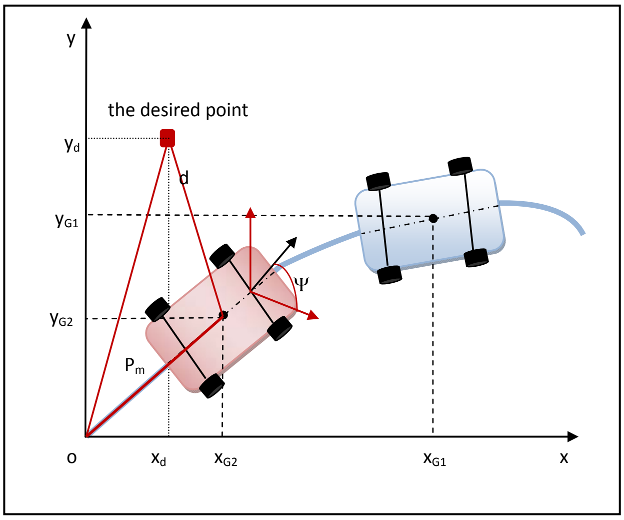

Fig. 3. Technical diagram of the technique

The vectors $\vec{r}_m$, $\vec{r}_r$, $\vec{r}_d$ et d, are: the position, the desired position, the angle of the orientation and the distance between the current state and the desired position. These vectors are given as follows:

$$\overrightarrow{p_m} = x\vec{i} + y\vec{j} \tag{7}$$

$$\overrightarrow{p_d} = x_d(t)\vec{i} + y_d(t)\vec{j} \tag{8}$$

$$\overrightarrow{p_e} = \cos(\Psi)\,\vec{i} + \sin(\Psi)\,\vec{j} \tag{9}$$

$$d = \overrightarrow{p_d} - \overrightarrow{p_m} = (x_d - x_G)\vec{i} + (y_d - y_G)\vec{j} \tag{10}$$

wtth : x_m, ym, Ψ are position and steering angle of the robot.

The *norm* victor represents the distance between the vehicle and the desired position.

$$e_d = \sqrt{(x_d - x_G)^2 + (y_d - y_G)^2} \tag{11}$$

$$\Psi_d = \tan^{-1}\frac{y_d - y}{x_d - x} \tag{12}$$

$$e_\Psi = \Psi_d - \Psi \tag{13}$$

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

III. 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 [11-12]. 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)[14-17]. 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[13]. 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[14].

$$V_i\,(t+1) = w\,.V_i(t) + c_1.r_1\,\big(pbest_i\,(t) - x_i(t)\big) + c_2.r_2\big(gbest_i(t) - x_i(t)\big) \tag{14}$$

$$x_i(\,t+1) = V_i\,(t+1) + x_i\,(t) \tag{15}$$

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.

$$w(t) = \frac{(T_{max} - t) \times (w_{start} - w_{end})}{T_{max}} + w_{end} \tag{16}$$

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 [13]. The original procedure for implementing PSO is as [16-17].

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) [14-17]. In this work we use parallel PID, and the coefficients K_p, K_i, K_d are determined by the PSO algorithm using ITSE performance criteria (figure 5).

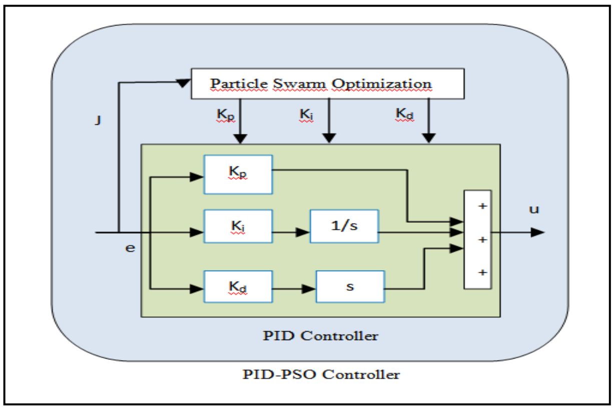

Fig. 4. PID parametrs based on PSO

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

IV. DESIGN OF CONTROLLERS

In this paper we used 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:

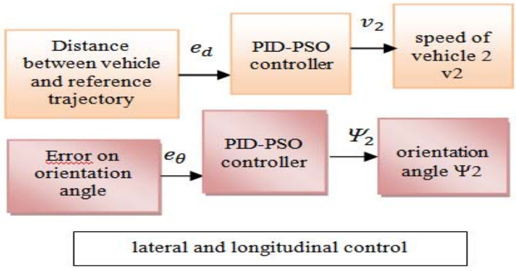

Fig. 5. Optimal PID-PSO control structure.

The architecture of controller in simulink is illustrted in the following figure :

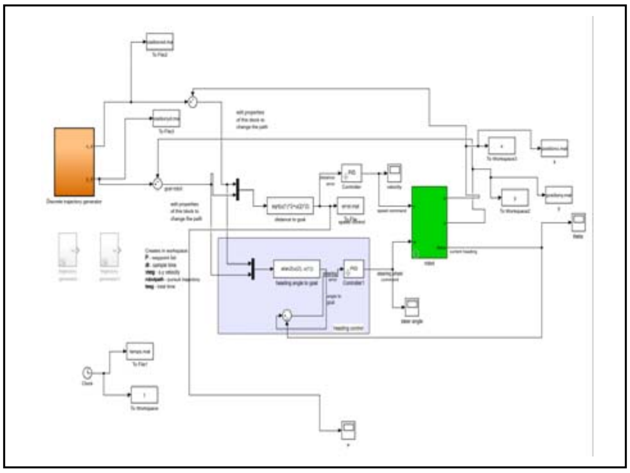

Fig. 6. Control block diagram with fuzzy controller

The Parallel PID controller parameters are extracted using the pidtool command. The following figure shows that our system is regulated by a parallel PID controller. The design of control block diagram is illustrated by the following figure :

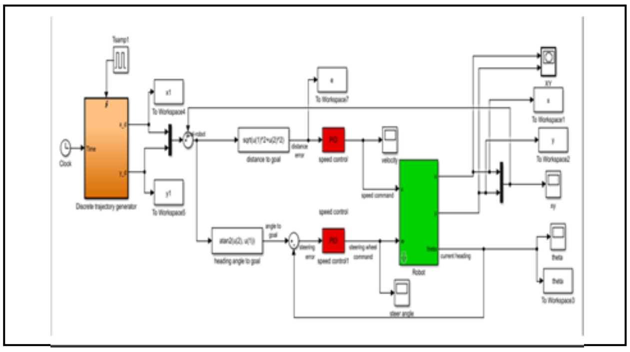

Fig. 7. Control block diagram with PID controller

We control the speed and orientation angle of vehicle. The transfer function of PID controller used to control orientation angle is as follows:

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

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

$$G_{PID}(s) = \left(Kp + Ki \times \frac{1}{s} + Kd \times s\right) \cdot e_d \qquad (17)$$

V. 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

$$K_p = 25\ ;\ K_i = 0.1\ ;\ K_d = 0.02 \qquad (18)$$

- Controller for orientation angle

$$K_p = 100 \qquad (19)$$

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

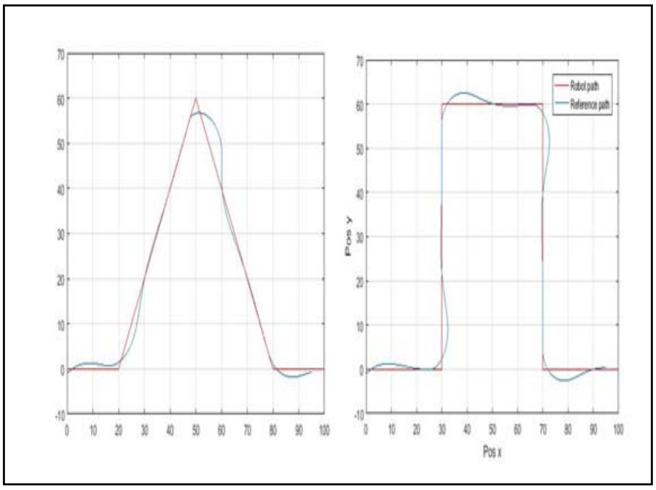

Fig. 8. Rectangle and triangle trajectory without control

The obtained results are illustrated in the following figures:

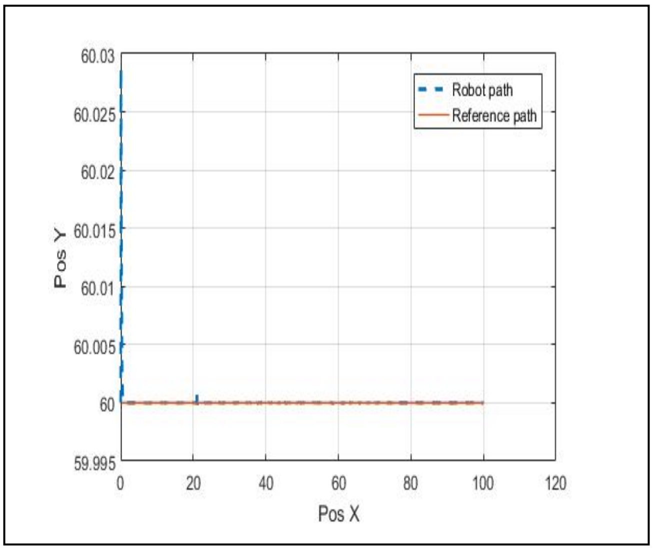

Fig. 9. Straight line trajectory with PID-PSO

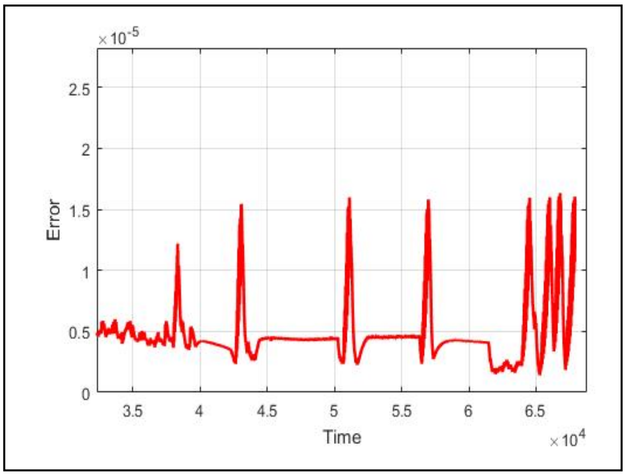

Fig. 10. Error with straight line trajectory (PID6PSO controller)

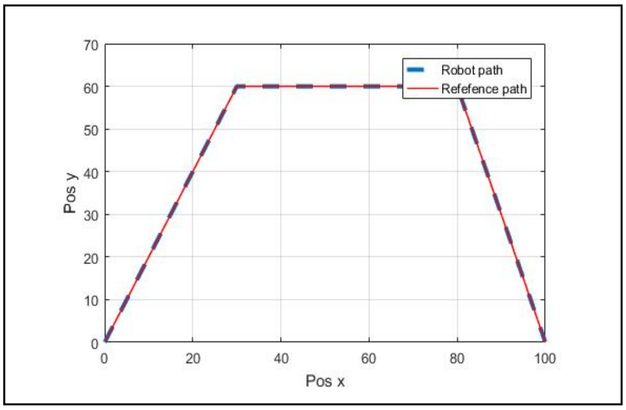

Fig. 11. Trapezoidal trajectory with PID-PSO controller

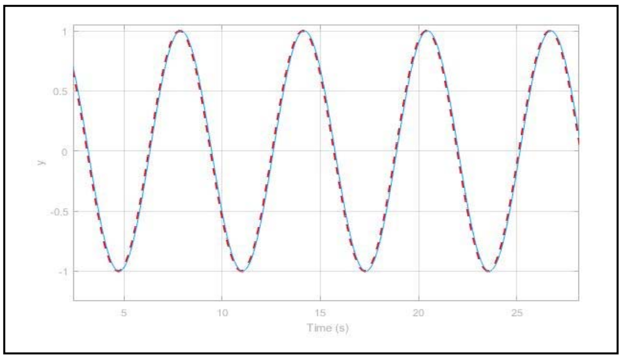

Fig. 12. Sinusoidal trajectory with PID-PSO controller

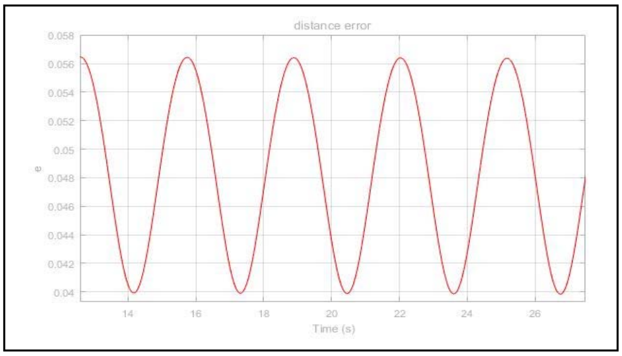

Fig. 13. error with Sinusoidal trajectory (PID-PSO controller).

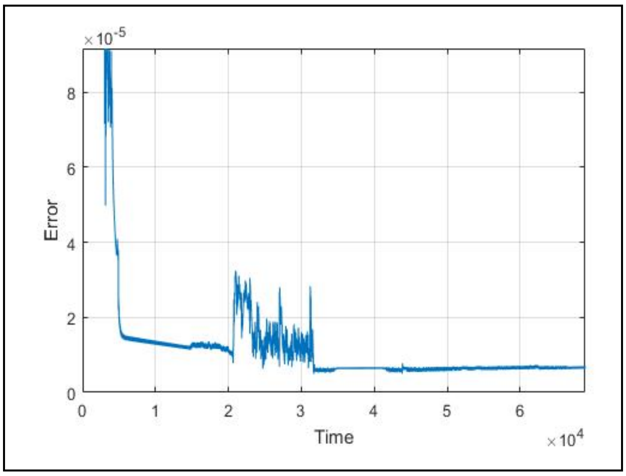

Fig. 14. Error with rectangle trajectory PID-PSO controller

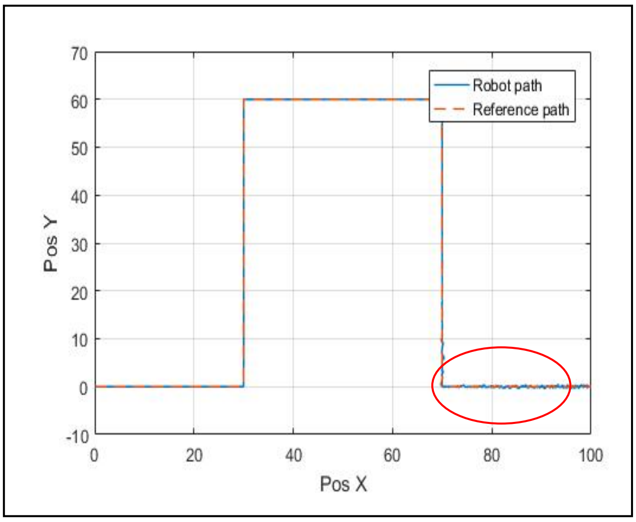

Fig. 15. Rectangle trajectory with PID-PSO controller

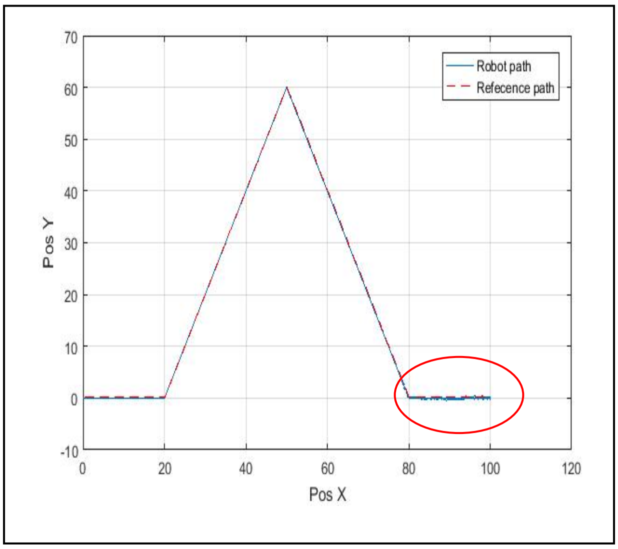

Fig. 16. Curved triangle trajectory with PID-PSO controller

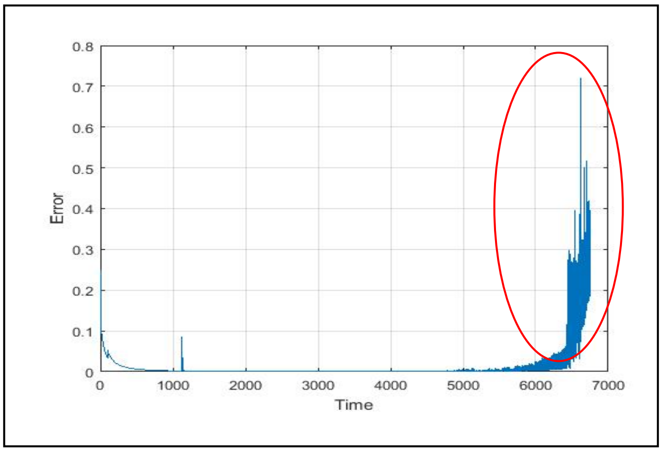

Fig. 17. Error with triangle trajectory with PID-PSO controller

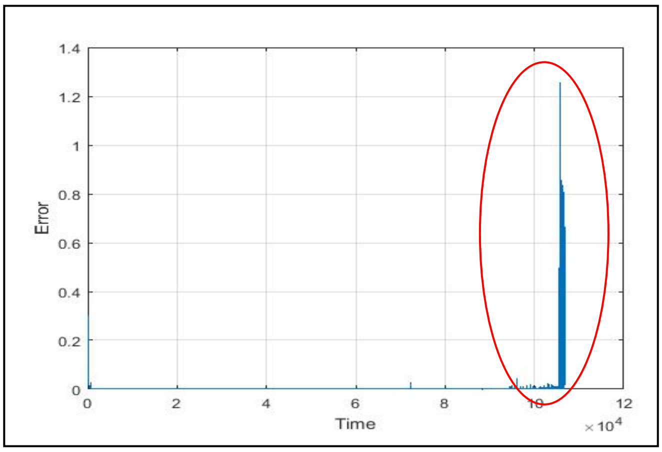

Fig. 18. Error with rectangle trajectory with PID-PSO controller

The figure fig.8 shows the tracking of the trajectory without control. 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 (fig.9-fig.16). But we have observed too that same error in the end of triangle or rectangle trajectory (fig.17 and fig.18). The tracking error with sinusoidal trajectory must bee improved (fig. 13).

VI. CONCLUSION

In this paper we have proposed path tracking controller for platonning autonomous vehicles with four wheels. The controller chose is based on the PID-PSO controller, it's able to offer more tracking flexibility and stability. different simulation has been realized in different trajectory with very interesting results in lateral and longitudinal control of vehicles with PID-PSO controller. we conclude that our approach of control must be more optimized where the platonning vehicles travel in curved trajectory. In the future works we plan, to improve our control approach with other optimization algorithm like Genetic Algorithm to optimize the parameters of controller in other trajectory with obstacle.

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