PSO APPLIED TO DESIGN OPTIMAL PD CONTROL FOR A UNICYCLE MOBILE ROBOT

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ABSTRACT

In this work, we propose a Particle Swarm Optimization (PSO) to design Proportional Derivative controllers (PD) for the control of Unicycle Mobile Robot. To stabilize and drive the robot precisely with the predefined trajectory, a decentralized control structure is adopted where four PD controllers are used. Their parameters are given simultaneously by the proposed algorithm (PSO). The performance of the system from its desired behavior is quantified by an objective function (SE). Simulation results are presented to show the efficiency of the method.).

The results are very conclusive and satisfactory in terms of stability and trajectory tracking of unicycle mobile robot

KEYWORDS

Particle Swarm Optimization (PSO), Proportional Derivative, Unicycle mobile robot, Optimization, Control

1. INTRODUCTION

Today mobile robots are a big hit on the side of the automatic control researchers, for their various applications in civilian and military tasks.

The control objective of a Unicycle robot can be position stabilization, trajectory tracking… Various controllers have been developed and adopted by researchers on controlling the differential drive robot, predictive control and fuzzy logic control **[1]** , A dynamic-model-based control scheme for balancing and velocity control of a unicycle robot **[2],** Fuzzy logic control (FLC) strategy **[3-4],** Based on both the kinematic and dynamic model of a unicycle an inner loop nonlinear controller with a dynamic model controller on the outer loop **[5] ,** back-stepping technique and the LaSalle's invariance principle **[6],** adaptive controller **[7] ,** An intelligent control approach was presented by **[8]** for a differential drive robot were a higher level navigation controller combined with a lower level fuzzy logic based controller, feedback linearization with PD control **[9].**

The PID control is relevant, due to the simplicity of this structure and its ease of implementation. However, it has limited performance because of its structure and the linear system and an opposite non-linear and complex system. In addition, an incorrect setting of these parameters will lead to a more performance degradation. Unfortunately, there are no systematic methods for setting parameters and the existing methods do not guarantee optimal operation such as Ziegler Nichols method **[10].**

In recent years, many heuristic evolutionary optimization algorithms have been developed. These include Genetic Algorithm (GA) **[11-12],** Ant Colony optimization (ACO) **[13-14],** Particle Swarm Optimization (PSO) **[15],** and Gravitational Search algorithm (GSA) **[16].** These methods have acquired a special interest in solving the problem of design of PD controllers.

The above listed methods are used for tuning PID controllers in case of SISO systems. In this paper, we suggest the use of PSO to solve the PD control design problem for control of Unicycle robot.

2. THE UNICYCLE MOBILE ROBOT

The robot considered in this paper is a unicycle mobile robot, reported by [**17**], and is described by the following equation of motion. A basic configuration of Unicycle mobile robot is shown in Figure 1.

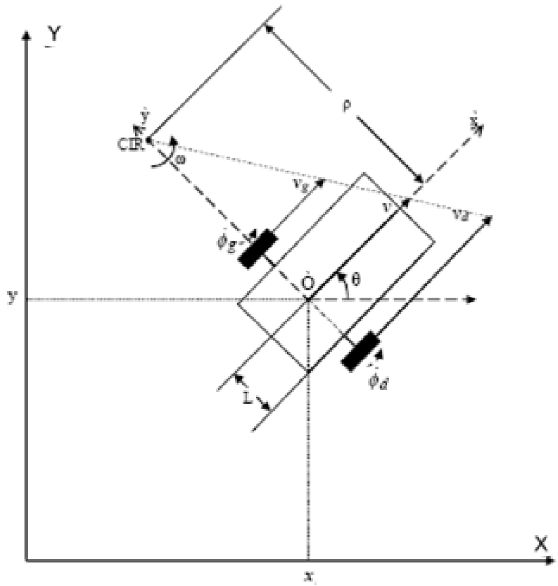

Figure 1. Unicycle mobile robot configuration

Let $\boldsymbol{q} = (\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{\theta})$ be the generalized coordinates of a unicycle, where $(\boldsymbol{x}, \boldsymbol{y},)$ is the Cartesian position of the unicycle in a world frame and $\boldsymbol{\theta}$ is its orientation with respect to the $\boldsymbol{x}$ axis. The kinematic model of the system is,

$$\begin{cases} \dot{\boldsymbol{x}} = \boldsymbol{v}\ \mathbf{cos}(\boldsymbol{\theta}) \\ \dot{\boldsymbol{y}} = \boldsymbol{v}\ \mathbf{sin}(\boldsymbol{\theta}) \\ \dot{\boldsymbol{\theta}} = \boldsymbol{w} \end{cases} \quad (1)$$

Where:

- $\boldsymbol{v}$ is linear velocity of the robot.
- $\boldsymbol{w}$ is the angular velocity of the robot.

The right and left wheel motor velocities can be expressed as $\boldsymbol{v_l} = \boldsymbol{r}\ \dot{\boldsymbol{\phi}}_{\boldsymbol{l}} = (\boldsymbol{\rho} - \boldsymbol{L})\boldsymbol{w}$ and $\boldsymbol{v_R} = \boldsymbol{r}\ \dot{\boldsymbol{\phi}}_{\boldsymbol{R}} = (\boldsymbol{\rho} + \boldsymbol{L})\boldsymbol{w}$ respectively.

Table 1. The unicycle mobile robot model parameter

Value	Parameter
L	0.2(m)
r	0.1(m)

3. THE PD CONTROL DESIGN USING

3.1. OVERVIEW OF THE PARTICLE SWARM OPTIMISATION

PSO is nature-inspired heuristic optimization method which first proposed by Kennedy and Eberhart **[15].** It belongs to the category of Swarm Intelligence methods. Its development was based on mimicking the movement of individuals within a swarm (i.e., fishes, birds, and insects) in an effort to find the optima in the problem space. It has been noticed that members of the swarm seem to share information among them. This communication fact leads to increase efficiency of the swarm. The PSO algorithm searches in parallel using a group of individuals similar to other population-based heuristic optimization techniques. PSO technique conducts search using a population of particles, corresponding to individuals. Each particle represents a candidate solution to the problem at hand. In a PSO system, particles change their positions by "flying" around in a multidimensional search space. Particle in a swarm adjust its position in search space using its present velocity, own previous experience, and that of neighboring particles.

Therefore, a particle makes use of best position encountered by itself and that of its neighbors to steer toward an optimal solution. The performance of each particle is measured using a predefined fitness function, which quantifies the performance of the optimization problem. The mathematical expressions for velocity and position updates are given by.

$$v_{ij}^{k+1} = w\, v_{ij}^{k} + c_1 r_1 \left(Pbest_{ij} - x_{ij}^{k}\right) + c_2 r_2 \left(Gbest_j - x_{ij}^{k}\right) \quad (2)$$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1} \quad (3)$$

Where:

$\mathbf{1 \le i \le I}$, $\mathbf{1 \le j \le J}$, $\mathbf{1 \le k \le K}$

$\boldsymbol{I}$. $\boldsymbol{J}$ and $\boldsymbol{K}$ are respectively the number of particles in the swarm, the dimension of particle, and the maximum iterations.

$\boldsymbol{x_{ij}^{k}}$ is the position of particle $\boldsymbol{i}$ in the dimension $\boldsymbol{j}$ at iteration $\boldsymbol{k}$

$\boldsymbol{v_{ij}^{k}}$ is the velocity of particle $\boldsymbol{i}$ in the dimension $\boldsymbol{j}$ at iteration $\boldsymbol{k}$, $\boldsymbol{pbest_{ij}}$ is a personal best of particle $\boldsymbol{i}$ in the dimension $\boldsymbol{j}$, $\boldsymbol{gbest_j}$ is a global best of all particles in the dimension $\boldsymbol{j}$, $\boldsymbol{w}$ is inertia weight factor , $\boldsymbol{c_1}$ and $\boldsymbol{c_2}$ are acceleration constants, $\boldsymbol{r_1}$ and $\boldsymbol{r_2}$ are random numbers in interval $[\mathbf{0 \cdot 1}]$.

3.2. THE PD PARAMETERS TUNING PROBLEM

The general function of Proportional Integral Derivative controllers (PDs) are given by:

$$u(t) = K_p e(t) + K_d \frac{de(t)}{dt} \tag{4}$$

The error $e(t)$ is defined as:

$$e(t) = y_r(t) - y(t) \tag{5}$$

Where :

u is the control signal, y_r is the reference signal and y is the controller output
The design parameters' vector is

$$P = [K_p \, K_d]^T \tag{6}$$

Without loss of generality, a squared error cost function (7) is used to quantify the effectiveness of a given PD controllers; it is evaluated at the end of desired input signal of the closed-loop system under control.

$$ISE = \int_{t_0}^{t_f} e(t)^2 dt \tag{7}$$

In the PD controller design problem using PSO, a particle is one value of the PD controller parameters vector.

A particle swarm is a group of parameters vector values which are manually or randomly initialized in search space defined by limits of the components of the tuning parameters vector. So, a the particle position x is the PD controller parameter value vector, $Pbest$ the best parameters values vector regarding the cost function, $Gbest$ is the global best parameters values vector of all particles.

4. APPLICATION TO THE CONTROL FOR THE UNICYCLE MOBILE ROBOT

The control objective is to control the mobile robot to achieve a desired point. That is, we use two decentralized PD controllers .

The design parameters' vector is composed of the parameters of the PD controllers:

$$PD = [K_{Px} \, K_{Dx} \, K_{Py} \, K_{Dy}]^T \tag{8}$$

The effectiveness of the PD controllers is evaluated at the end of the response of the entire control system to desired input signals by the squared error fitness function given by:

$$ISE = \sum_{i=1}^{2} \int_{t_0}^{t_f} e(t)^2 dt \tag{9}$$

In the simulations, we take the:

- The initial states : $x(0) = 0\ m$, $y(0) = 0\ m.$

- The desired point has the following coordinates $\boldsymbol{x(t_f) = 1\ m\ , y(t_f) = 1\ m}$
- The cost function spans from $\boldsymbol{t_0 = 0\ s\ , t_f = 25\ s}$
- For the PSO we take the parameters in Table 2.
- The initial parameters values are chosen randomly between the bounds given by Table 3.

Table 2. The algorithme parameters

PSO parameters
Number of particle in the swarm :20
$w = 0.9$
$c_1 = c_1 = 2$
dimension = 4
Number of iterations K: 50
Fitness function : ISE

Table 3. The initial parameters bounds

Parameters	Min	Max
$K_p^i, i = 1,2$	0	10
$K_D^i, i = 1,2$	0	10

4. Simulation Results

The final parameters values are given on Table 4.

The Figure 2 shows the evolution of the cost function with iterations. Figures 3, 4 and 5 show respectively the position in the x-axis, the position in the y-axis and the position in the plane with the tuned controllers.

Table 4. The final tuned parameters values

Controller	Parameter	Tuned value
PD_x	K_{px}	7.3136*10^5
	K_{dx}	0.0002*10^5
PD_y	K_{py}	0.0004*10^5
	K_{dy}	0.0014*10^5

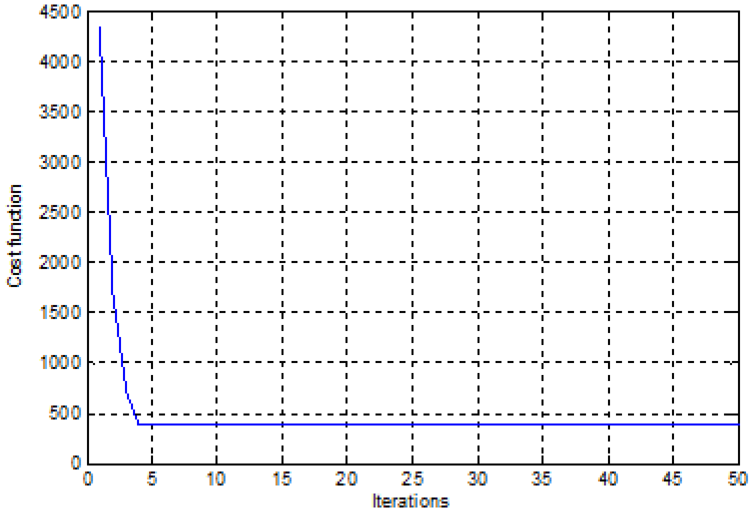

Figure 2. The Cost function

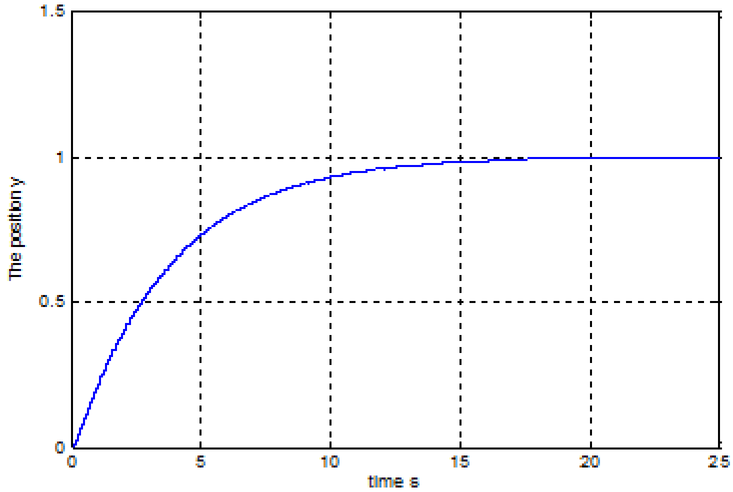

Figure 3. The position in the Y-axis

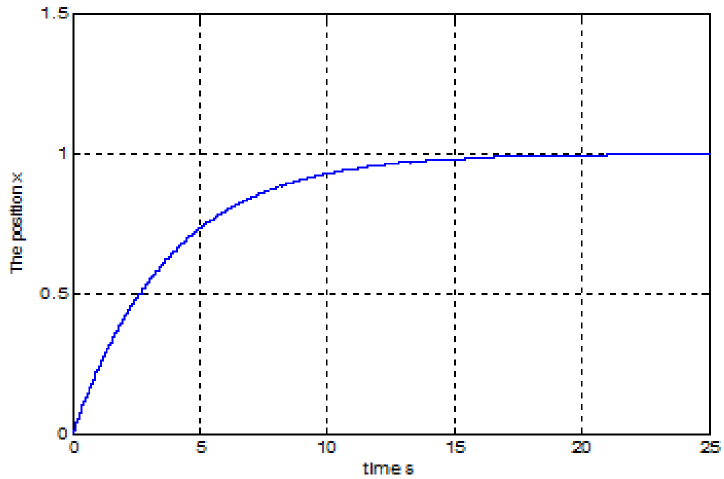

Figure 4. The position in the X-axis

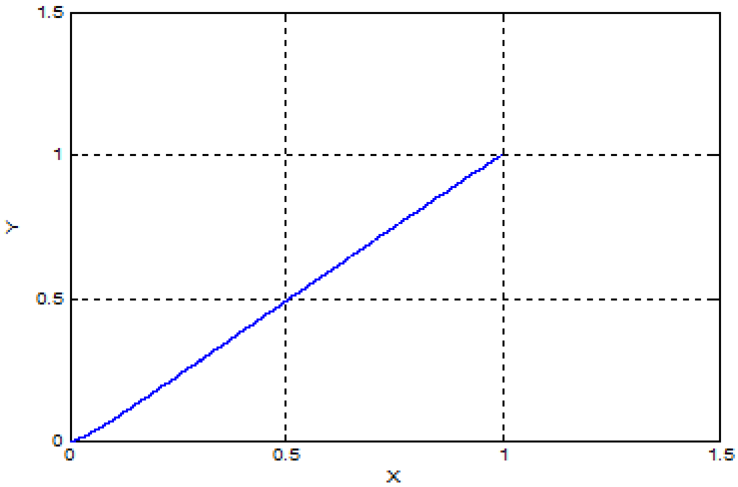

Figure 5. XY plot

From these figures, we can see well a good tracking of the desired values of the position in the X-axis and Y-axis and on the XY plane for the algorithms PSO Algorithm, (illustrated respectively by Fig. 3.4and 5).

After the results we can see that the proposed algorithm give us satisfactory results because it provide good trajectory tracking of unicycle mobile robot. The robot was able to follow its own way, we can simply say that PSO Algorithm has shown its effectiveness in terms of stability of unicycle mobile robot.

5. Conclusion

This paper has presented the performance of a intelligent synthesis of PD controller, using the praticle swarms optimisation algorithme (PSO) to control a unicycle robot . The intelligent controller was implemented and evaluated by simulating the system model in MATLAB environment. The controller gains have been optimised using PSO optimisation algorithm to minimise the mean square error of the robot system. The performance of the system with the optimised controller gains has been greatly improved proving a successful control and optimisation strategy. The simulation was able to yield results that showed good stability of the unicycle robot. The simulation results show the efficiency of the proposed methode.

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