Adaptive Fuzzy FOPID Control Scheme for Path tracking of Mobile Robot

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ABSTRACT

This paper present a new control method for path tracking of mobile robot based on using fuzzy logic and FOPID controller . Two FOPID controllers are used. Parameters of the two FOPID controllers are optimized offline using genetic algorithm.. These optimized FOPID controllers are used for speed control and azimuth control. Parameters of these controller are adjusted online via fuzzy system. Each FOPID controller is supported by a fuzzy controller for adjusting the parameters online. The adjusting mechanism in the designed control scheme work well when there are variations in the plant parameters and changes in operating conditions.

Keywords

Mobile Robot, Particles Swarm Optimization,fuzzy control, FOPID Controller, Trajectory tracking.

1. INTRODUCTION

Mobile robots have been used in many applications such as moving material in idustries . They can be found in wide areas such as industry, ports and agriculture [1]. A mobile robot is a wheeled vehicle capable of moving autonomously. Cleaning robots and cargo delivery can work automatically and are performing various routine tasks [2,3,4]. In cargo transport task, the robots move to the target location following their path. It is essential for these robots to precisely track the path from the starting location to the target location, carrying as much cargo as possible . Therefore, motion control is one of the most fundamental topics for mobile robots. Many types of controllers are used for controlling the mobile robot [5,6,7,8].

PID controllers have been used to control about 90% of industrial processes [3]. One of the ways to improve PID controllers is to use fractional-order controllers (FOPID) with non-integer derivation and integration parts[9]. FOPID is widely used and give good results when compared with PID controller in many applications[10]. The main problem of this simple controller is the correct selection of the values of gains and also values of fractions order. and the fact that by using fixed gains and order , the controller may not give the required control performance, when there are variations in the plant parameters and operating conditions[11]. An online adjusting mechanism must be performed to insure that the controller can deal with the variations of parameters of the system controlled and environment [4]. To tune the There are numbers of strategies, the most known, which is frequently used in industrial applications, is the Ziegler-Nichols method , genetic algorithm GA, PSO etc. [5,12,13]. In this paper, GA is used as an optimization tool for the parameters of FOPID controllers offline and fuzzy system is used for adjusting these parameters online. This paper has been organized as follows: in section 2 mathematical model of mobile robot is described. In section 3, FOPID controller is described , section 4 describes how GA is used for the optimization of the parameters of the FOPID controllers for mobile robot path tracking .Section 5 describe the method of using fuzzy controller for adjusting the parameters online. Simulation results are presented in section 6.

2. MATHEMATICAL MODEL OF MOBILE ROBOT

The mobile robot is shown in Figure 1. A robot must have a minimum of three wheels in order to work. Most mobile robots require two motorized wheels and at least one wheel for balance [14]. The system moves by driving the two independent wheels

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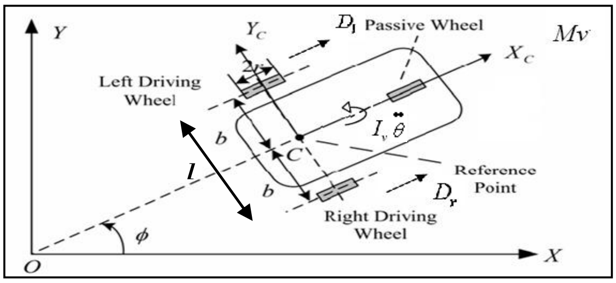


Figure 1: Model of mobile robot

Let us consider the kinematic model (motion without considering the forces that affect the motion , it use the geometric relationships) for an autonomous vehicle. The rotation angle of the wheel about its horizontal axle is denoted by $\varphi(t)$. Let $\varphi_r(t)$ be the rotation angle of the right wheel and $\varphi_l(t)$ be the rotation angle of the left wheel. The configuration of the mobile robot can be described as:[11, 12]:

$$q = (x_{c,} y_c, \theta, \varphi_r, \varphi_l) \quad (1)$$

where: x_c *and* y_c are the two coordinates of the origin C of the moving frame, θ is the orientation angle of the mobile robot (of the moving frame). The vehicle velocity v can be found as [3]:

$$\mathrm{v} = \frac{\mathrm{R}(\mathrm{w_r}+\mathrm{w_l})}{2} \quad (2)$$

w_r is the angular velocity of the right wheel and $w_l$is the angular velocity of the left wheel.The position and the orientation of the mobile robot are given as: [12, 3]:

$$\dot{x} = \mathrm{v}\cos(\theta) = (R\ (w_r + w_l)\cos\ (\theta))/2 \quad (3)$$

$$\dot{y} = (R\ (w_r + w_l)\sin\ (\theta))/2 \quad (4)$$

$$\dot{\theta} = R(w_r + w_l)/2b \quad (5)$$

Finally, the kinematics model can be represented by :

$$\begin{bmatrix} \mathrm{v} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \mathrm{R}/2 & \mathrm{R}/2 \\ \mathrm{R}/2\mathrm{b} & -\mathrm{R}/2\mathrm{b} \end{bmatrix} \begin{bmatrix} \mathrm{w_r} \\ \mathrm{w_l} \end{bmatrix} \quad (6)$$

The kinematic model has been used for motion control and this model is valid if the robot has low speed, low acceleration and light load [16]. Dynamic models consider the forces acting on the vehicle. Dynamic equation of wheeled mobile robot is described as in [17]:

$$Ms\,\dot{v} = F_r + F_l \qquad (7)$$

$$I_w\,\ddot{\theta}_i + c\,\dot{\theta}_i = ku_i - rF_i \qquad i = r, \text{ or } l \qquad (8)$$

Where ,

Ms : mass of robot , φ : azimuth of robot .

v : velocity of robot, I_w : moment of inertia of wheel.

c : viscous friction factor , k : driving gain factor.

r : radius of wheel, θ_i : rotational angle of wheel.

u_i : driving input, F_r ,F_l: right and left driving force.

I_v : moment of inertia .

l : distance between left and right wheel .

The geometrical relationships among variables φ, v , θ_i are given by:

$$r\dot{\theta}_r = v + l\dot{\varphi} \qquad (9)$$

$$r\theta_l = v - l\varphi \qquad (10)$$

The state model with manipulated variable as u=[u_r u_l] and the output variable as y=[v , θ] Yield the following equation:

$$\dot{x} = Ax + Bu \qquad (11)$$

$$y = Cx \qquad (12)$$

Where:

$$A = \begin{bmatrix} a_1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & a_2 \end{bmatrix}, \quad B = \begin{bmatrix} b_1 & b_1 \\ 0 & 0 \\ b_2 & -b_2 \end{bmatrix}, \quad C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

with,

$$a_1 = \frac{-2c}{(Ms * r^2 + 2I_w)}, \quad a_2 = \frac{-2cl^2}{(I_v r^2 + 2I_w l^2)}$$

$$b_1 = \frac{kr}{(Ms * r^2 + 2I_w)}, \quad b_2 = \frac{krl}{(I_v r^2 + 2I_w l^2)}$$

The relation between the controller output torques u_r and u_l with variables u_v and u_φ are given in equations (13) and (14.) below:

$$u_r = u_v + u_\varphi \qquad (13)$$

$$u_l = u_v - u_\varphi \qquad (14)$$

and error equations are:

$$e_v = v_d - v \qquad (15)$$

$$e_\varphi = \varphi_d - \varphi \qquad (16)$$

where v_d , φ_d are the desired velocity and the desired azimuth, respectively. v , φ are the actual velocity and the actual azimuth of the robot, respectively.

3. FRACTIONAL ORDER PID CONTROLLER

Classical proportional plus integral plus derivative (PID) controller has been widely used in process industries. It is so well known and applied in many applications. [9]. The PID controller is defined as:

$$u(t) = \left(k_p\, e + k_i \int e(\tau)d\tau + k_d \frac{de}{dt}\right) \qquad (17)$$

Where variables k_p, k_i, k_d represent the proportional, integral and differential gains respectively [10].

Fractional order PID controller (FOPID) is a generalization of the integer order PID controller. The (FOPID) controller is described as

$$u(s) = \left(k_p + k_i \frac{1}{s^\lambda} + k_d\, s^{\mu}\right) e(s) \qquad (18)$$

Wherek_p ,k_i,k_d are proportional gain, integration gain and differentiation gain respectively. λ is the fraction of integration and μ is the fraction of differentiation. PID controller is a special form of fractional order PID controller.

4. GA-BASED FOPID CONTROLLER OPTIMIZATION

As a mathematical means for optimization, GA can be applied to the optimization of PID or FOPID controllers. Optimization of FOPID controllers needs to know the optimization goal, and then encode the parameters to be searched. [18,19]. The decoding values of the best chromosome are the optimized parameters of the FOPID controller.

In this paper the GA is used offline to find the optimal parameters for two FOPID controllers used for the control of velocity and azimuth of mobile robot..

Each chromosome contains ten gens P_1, I_1 , D_1, λ_1 and μ_1 (parameters of velocity controller), and P_2 , I_2 , D_2 , λ_2 and μ_2 (parameters of azimuth controller). In this work The mean square error is used as a fitness function.

Mean Square Error (MSE)

$$MSE_{total} = \left(\frac{1}{n}\sum_{k=1}^{n}\left(e_\theta(k)\right)^2\right) + \left(\frac{1}{n}\sum_{k=1}^{n}\left(e_v(k)\right)^2\right) \qquad (19)$$

5. FUZZY CONTROLLER

Fuzzy logic controllers have been used in many applications . In the control systems, fuzzy logic is considered in the control of linear, nonlinear and complex nonlinear plants such as robotics power plants and induction motors[19 , 20,21,22,23,24]. Basics of a fuzzy model are explained in [25]:

5.1 Adjusting mechanism using Fuzzy system

In this section a fuzzy adjusting mechanism scheme that contain two fuzzy controllers is used for adjusting the parameters of the two FOPID controllers. Each fuzzy controller has two inputs and three outputs used to tune the three parameters *(Kp, Ki and Kd)* of the FOPID controller as shown in Figure 2 In this mechanism the order fraction values selected by genetic algorithm are fixed. This kind of controller is an online controller. Figure 2 represents the proposed control scheme. Each Fuzzy controller in this scheme has two inputs (the error and change of error of velocity or azimuth variable) and three outputs. (s_p, s_i , and s_d) which represent the values that used to change FOPID gains (K_p, K_i and K_d)[26,27]. The new values of the two FOPID parameters are found from the following equation[27].

$$K_h = K_{h_{min}} + (K_{h_{max}} - K_{h_{min}})\; s_h \qquad (20)$$

S_h is the output of the fuzzy controller with subscript *h* represents *p*, *i*, and *d* for each controller.

The maximum and minimum values appear in eq.(20) are determined offline using GA algorithm. Membership functions are chosen as shown in figure 3. Mamdani method is used in fuzzy inference system. Defuzzification method is center of area.

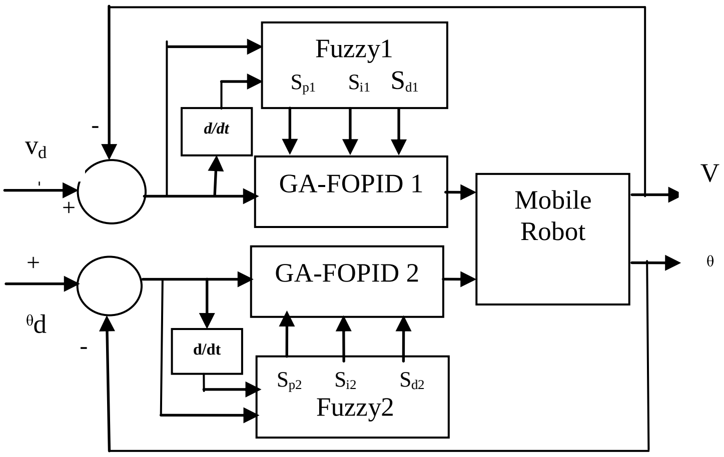
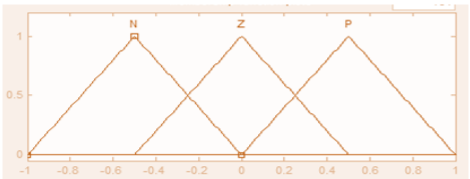
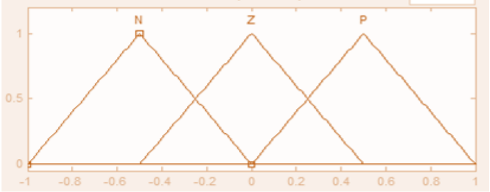


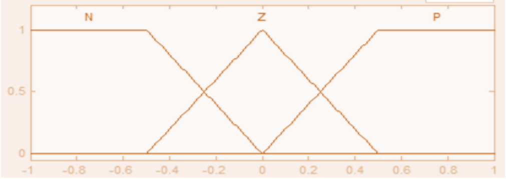
Figure2: The proposed control scheme



a) Input 1



b) Input 2



c) Output

Figure 3: Membership functions

Fuzzy rules used in FLC are shown in table 1.

Table 1: Fuzzy rules

S_h	e(t)			
ce(t)		P	Z	N
	P	P	P	Z
	Z	P	Z	N
	N	Z	N	N

6. SIMULATION RESULTS

Consider a mobile robot, the values of physical parameters shown in Table 2 are used [28].

Table 2: The physical parameters of mobile robot

Parameter	Value	Unit
I_v	10	kg.m^2
Ms	200	Kg
L	0.3	M
I_w	0.005	kg.m^2
C	0.05	kg/s
R	0.1	M
K	5	

The following GA parameters and operations are used to tain the optimal performance of the controller :

Number of generations=200, size of population=20, fitness function is mean square error, crossover method is scattered, mutation method is adaptive feasible, and termination is Number of generation.

By doing several experiment using different values .The following values for population size and number of generations are considered to be acceptable. Population size=20; Number of generation =200. The result obtained in 200 generations as [80, 96, 2.8, 0.6,0.4] and [97, 47, 0.5, 0.3,0.3] for the two FO PID controllers respectively. These values are considered as parameters of the two optimal FOPID controllers that give the lowest MSE.

The system is tested for two different cases as follows :

1) Circular trajectory given by a reference velocity v_d of 0.8 [meter/sec] and a reference azimuth θ_d given as :

$$\theta_d = \frac{(2*\pi)t}{5} \quad [\text{rad}]$$

with, $0 \leq t \leq 5$.

Figure 4 shows the velocity error, Figure 5 shows the azimuth error, Figure 6 shows the actual and desired path for circular trajectory

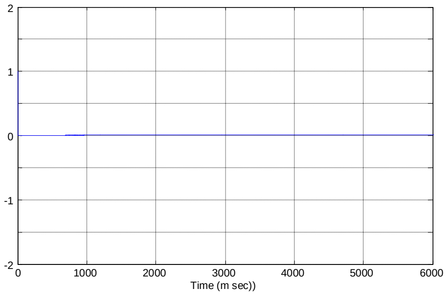


Figure 4: The error in velocity (circular)

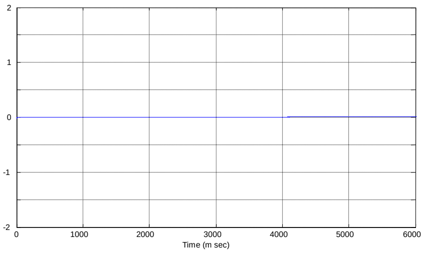


Figure 5: The error in azimuth (circular)

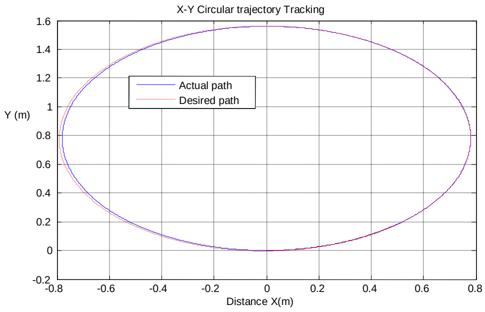


Figure 6: circular trajectory tracking

2) Sine trajectory.

Figure 7 shows the error in azimuth , Figure 8 shows the error in velocity and Figure 9 shows the desired and actual sine trajectory.

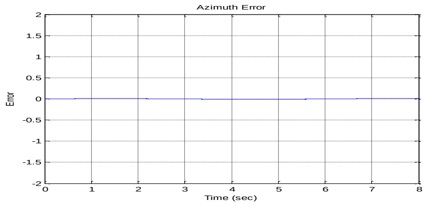


Figure 7: The error in velocity(sine)

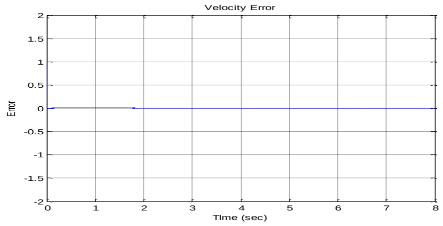


Figure 8: The error in azimuth (sine)

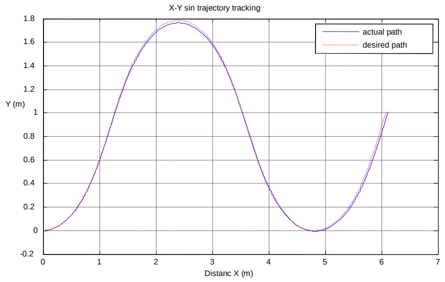


Figure 9: Sine trajectory tracking

7. CONCLUSION

The parameters of the two FOPID controllers are optimized offline using GA and further they are adjusted online using two fuzzy controllers. This proposed adaptive control scheme is applied for trajectory tracking of mobile robot . The online adjusting mechanism of the proposed control scheme gives acceptable robustness properties and solve efficiently the problems of disturbance , different load conditions and system parameters variations . Results show good tracking performance .

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