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Path Planning, Dynamic Trajectory Generation and Control Analysis for a Wheeled Mobile Robot Using Nonlinear PID Neural based on Optimization Algorithm

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ABSTRACT : Robot manipulators takes on ever more important roles on the factory floors around the world. They have been useful for relieving humans of simple repetitive and hazardous work. One of the problems with existing robot installations are limited flexibility. The robots must be reprogrammed by a human operator when the environment changes. The goal of this paper is to presents a trajectory tracking control algorithm for a nonholonomic wheeled mobile robot using optimization technique based nonlinear PID neural controller in order to follow a pre-defined a continuous path. Particle swarm optimization algorithm is used to tune the nonlinear PID neural controller's parameters to find best velocity control actions for the mobile robot. Nonlinear PID neural controller is built and implemented in MATLAB software package and it is succeeded to solve the trajectory tracking problem of mobile robot.
Simulation results show the effectiveness of the proposed nonlinear PID control algorithm; this is demonstrated by the minimized tracking error and the smoothness of the velocity control signal obtained
KEYWORDS - Nonholonomic Mobile Robot, Trajectory Tracking

I. INTRODUCTION

Robot is one of the most popular fields of automation techniques and artificial intelligence techniques. It also represents a new level of manufacturing technology development. Meanwhile, the development of robots asks for higher standard of automation control technology, intelligent technology, sensor technology and manufacturing technology. Basically, robots can be divided into two categories, fixed and mobile robots. Mobile robots have the capability to move around in their environment and are not fixed to one physical location
Mobility is the robot's capability to move from one place to another in unstructured environments to a desired target. These applications require mobile robots to have the ability to track specified path stably. During the past few years, many methods have been developed to solve mobile robot control problems which can be classified into three categories:
The first category is the sensor-based control.
The second category for navigation problems of the mobile robot is path planning.
The third category is designing and implementing the motion control that mobile robot needs to execute the desired path accurately and to minimize tracking error.
There are three reasons for increasing tracking error for mobile robot:
First reason for tracking error is the discontinuity of the rotation radius on the path of the differential driving mobile robot.
Second reason for increasing tracking error is due to the small rotation radius interferes with the accurate driving of the mobile robot.
The third reason for increasing tracking error is due to the rotation radius is not constant such as the complex curvature or randomly curvature, [2].
Many control algorithms were proposed in the path-tracking framework, such as PID [3], Lyapunov-based nonlinear controllers [4], adaptive controllers [1], model-based predictive controllers [5], fuzzy controllers [6–9], etc. Among several control methods, PID control is the most common one and used widely, also in robot field.
The article presented approach here can be understood considering the following points.
The analytically derived control law based on optimization algorithm.
Investigation of the controller robustness performance through adding boundary unknown disturbances.
Verification of the controller adaptation performance through change the initial pose state.
Validation of the controller capability of tracking continuous gradient trajectories.

Simulation results show that the proposed controller is robust and effective in terms of minimum tracking error and in generating best velocity control action despite of the presence of bounded external disturbances[11].

I. KINEMATICS MODEL OF MOBILE ROBOT

Let's consider the kinematics model for an autonomous vehicle. The position of the mobile robot in the plane is shown in Fig. 1. The inertial-based frame (Oxy) is fixed in the plane of motion and the moving frame is attached to the mobile robot. In this paper we will assume that the mobile robots are rigid cart equipped, with non-deformable conventional wheels, and they are moving on a non-deformable horizontal plane. The pose of mobile robot in the global coordinate frame [O, X,Y] and the pose vector in the surface is defined as: q =(x, y,θ)T where: x and y are the two coordinates of the origin P of the moving frame (the geometric center of the mobile robot), θ is the orientation angle of the mobile robot (of the moving frame)

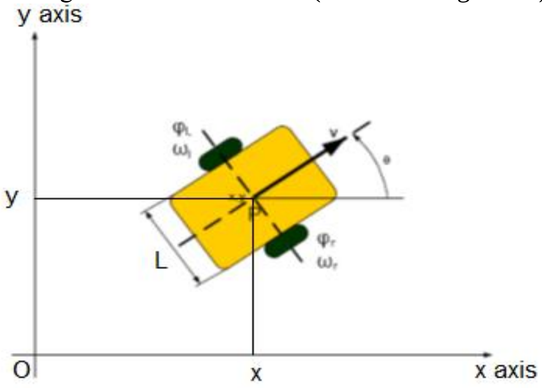

Fig.1 Nonholonomic mobile robot model

In this case, we now consider the mobile robot motion as a nonholonomic mechanical system, where three kinematics constraints exist:

$$-\dot{x}(t)\sin\theta(t) + \dot{y}(t)cos\theta(t) = 0 \quad (1)$$

Therefore, the kinematics equations in the world frame can be represented as follows

$$\dot{x}(t) = V(t)cos\theta(t) \quad (2)$$

$$\dot{y}(t) = V(t)sin\theta(t) \quad (3)$$

$$\dot{\theta}(t) = V_w(t) \quad (4)$$

By using Jacobi-Lie-Bracket of f and g to find [f , g] [12].

$$[\dot{q}] = [f]\omega_R(t) + [g]\omega_L(t) \quad (5)$$

$$rank\{f, g, [f, g]\} = rank\begin{bmatrix} 0.5cos\theta(t) & 0.5cos\theta(t) & \frac{1}{L}sin\theta(t) \\ 0.5sin\theta(t) & 0.5sin\theta(t) & \frac{1}{L}cos\theta(t) \\ {}^{1}/_{L} & -{}^{1}/_{L} & 0 \end{bmatrix} \quad (6)$$

The determent of the matrix in equation (6) is equal to (1/ L2) ≠ 0 , then the full rank of matrix is equal to 3, therefore, the system in equation (2, 3 and 4) is controllable.

II. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a technique used to explore the search space of a given problem to find the settings or parameters required to maximize a particular objective. PSO is one of the optimization techniques and a kind of evolutionary computation technique. The method has been found to be robust in solving problems featuring nonlinearity and non-differentiability, multiple optima, and high dimensionality through adaptation, which is derived from the social-psychological theory.

The modified velocity and position of each particle can be calculated using the current velocity and the distance from $Pbesti,d$ to $gbesti,d$ as shown in the following formulas(7):

$$v_{i,m}^{t+1} = w.v_{i,m}^{t} + c_1 * Rand(\ \ ) * \left(pbest_{i,m} - x_{i,m}^{(t)}\right) + c_2 * rand(\ \ ) * (gbest_m) \quad (7)$$

$$x_{i,m}^{t+1} = x_{i,m}^{(t)} + v_{i,m}^{(t+1)} \quad (8)$$

i = 1,2, …., n; m = 1,2, …., d

The nonlinear PID neural controller with nine weights parameters and the matrix is rewritten as an array to form a particle. Particles are then initialized randomly and updated afterwards according to equations (9, 10, 11, 12, 13 and 14) in order to tune the PID parameters:

$$\Delta Kp_{\gamma,m}^{k+1} = \Delta Kp_{\gamma,m}^{k} + c_1 r_1 \left(pbest_{\gamma,m}^{k} - Kp_{\gamma,m}^{k}\right) + c_2 r_{12}\left(gbest^{k} - Kp_{\gamma,m}^{k}\right) \quad (9)$$

$$Kp_{\gamma,m}^{k+1} = Kp_{\gamma,m}^{k} + \Delta Kp_{\gamma,m}^{k+1} \quad (10)$$

$$\Delta Ki_{\gamma,m}^{k+1} = \Delta Ki_{\gamma,m}^{k} + c_1 r_1 \left(pbest_{\gamma,m}^{k} - Kp_{\gamma,m}^{k}\right) + c_2 r_{12}\left(gbest^{k} - Ki_{\gamma,m}^{k}\right) \quad (11)$$

$$Ki_{\gamma,m}^{k+1} = Ki_{\gamma,m}^{k} + \Delta Ki_{\gamma,m}^{k+1} \quad (12)$$

$$\Delta Kd_{\gamma,m}^{k+1} = \Delta Kd_{\gamma,m}^{k} + c_1 r_1 \left(pbest_{\gamma,m}^{k} - Kd_{\gamma,m}^{k}\right) + c_2 r_{12}\left(gbest^{k} - Kd_{\gamma,m}^{k}\right) \quad (13)$$

$$Kd_{\gamma,m}^{k+1} = Kd_{\gamma,m}^{k} + \Delta Kd_{\gamma,m}^{k+1} \quad (14)$$

III. PROPOSED PSO-PID CONTROLLER

In this paper the PSO algorithm is used to find the optimal parameters for two PID controllers for the control of velocity and azimuth of mobile robot. Figure 2 shows the block diagram of nonlinear PID controller for the mobile robot. The feedback PID neural controller is very important because it is necessary to stabilize the tracking error of the system.

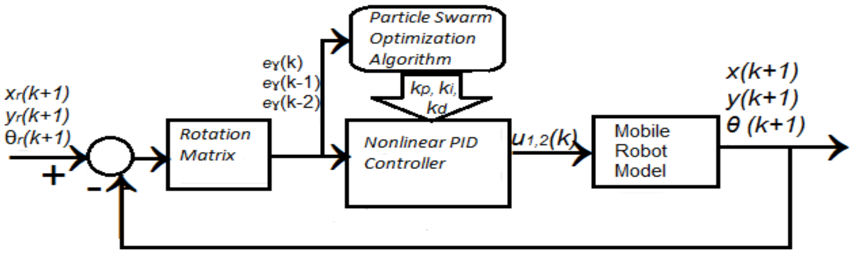

Fig.2. The structure of nonlinear PID neural trajectory tracking controller for mobile robot

The nonlinear PID neural controller for mobile robot system can be shown in Figure (3).

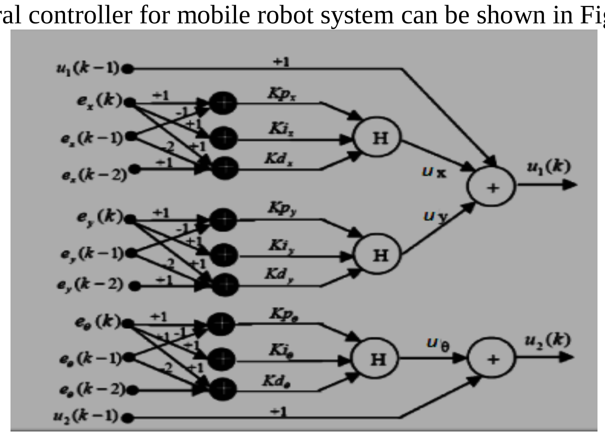

Fig.3. The nonlinear PID neural feedback controller structure

It has the characteristics of control agility, strong adaptability, good dynamic characteristic and robustness because it is based on that of a conventional PID controller that consists of three terms: proportional, integral and derivative where the standard form of a PID controller is given in the s-domain as equation (16) [9].

$$Gc(s) = P + I + D = K_p + \frac{K_i}{s} + K_d s \quad (16)$$

Where Kp, Ki and Kd are called the proportional gain, the integral gain and the derivative gain respectively. The proposed nonlinear PID neural controller scheme is based on the discrete-time PID as equation (11) [14].

$$u_{1,2}(k) = u_{1,2}(k-1) + Kp_{\gamma}\left[e_{\gamma}(k) - e_{\gamma}(k-1)\right] + Ki_{\gamma} e_{\gamma}(k) + Kd_{\gamma}\left[e_{\gamma}(k) - 2e_{\gamma}(k-1) + e_{\gamma}(k-2)\right] \quad (17)$$

Where □ = x, y, θ.

The proposed control law of the feedback right and left velocity (u_1 and u_2) respectively can be proposed as follows:

$$u_1(k) = u_1(k-1) + u_x + u_y \quad (18)$$

$$u_2(k) = u_2(k-1) + u_\theta \quad (19)$$

u_x, u_y and u_θ are the outputs of the neural networks that can be obtained from sigmoid function has nonlinear relationship

The control parameters Kp□, Ki□ and Kd□ of the nonlinear PID neural controller are adjusted using particle swarm optimization.

IV. CONCLUSION AND RESULT

In this article, continuous and non-continuous gradients desired trajectories are tracked from nonholonomic wheeled mobile robot. The trajectory tracking problem for nonholonomic vehicles is posed as follows.

$$\dot{x}_r(t) = V(t)cos\theta \quad (20)$$

$$\dot{y}_r(t) = V(t)sin\theta \quad (21)$$

$$\dot{\theta}(t) = V_w \quad (22)$$

The simulation results in this article are implemented using Matlab program.

The simulation is carry out by tracking a desired position (x,y) and orientation angle (θ) with circular,S-shape and line trajectories in the tracking control of the robot. The parameters values of the robot model are taken from [20,21], which are as follow: m=0.65 kg, I = 0.36 kg.cm2, L = 0.105 m, r =0.033 m, and tacking d = 0.01m for this mobile robot.

1. The circular trajectory was generated from the desired linear velocity $v_d = 0.1\ m/s$ and angular velocity $\omega_d = 0.1\ rad/s$.

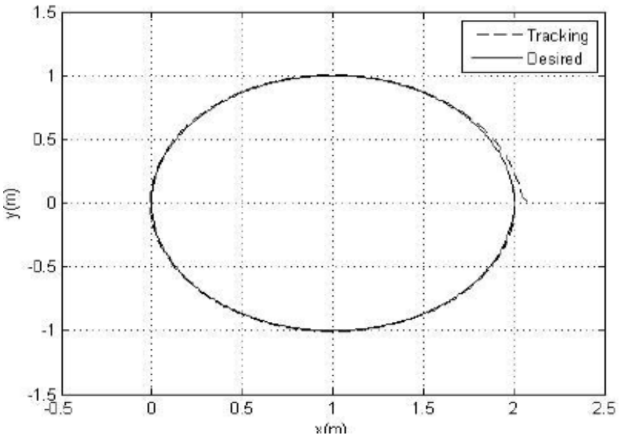

Fig.4 *Circular trajectory tracking*

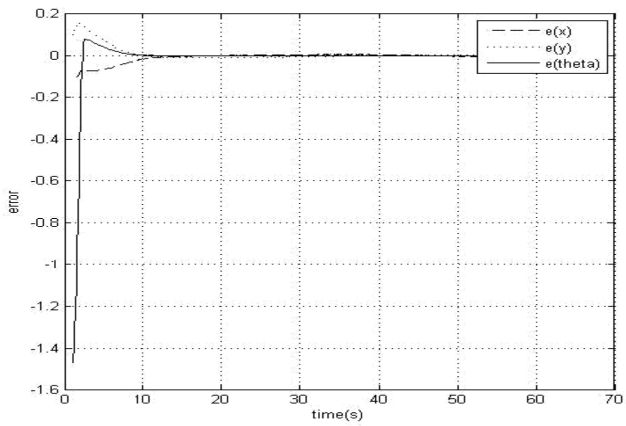

Fig.5 *Trajectory tracking error*

2. Simulation results of both trajectory tracking and the posture error curves for the S-shape trajectory.

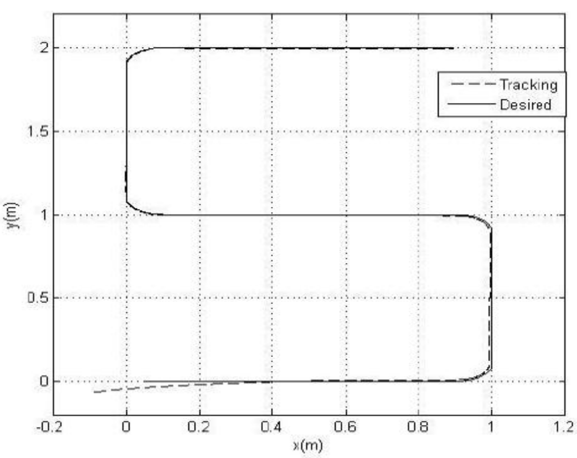

Fig.6 *S-shape trajectory tracking*

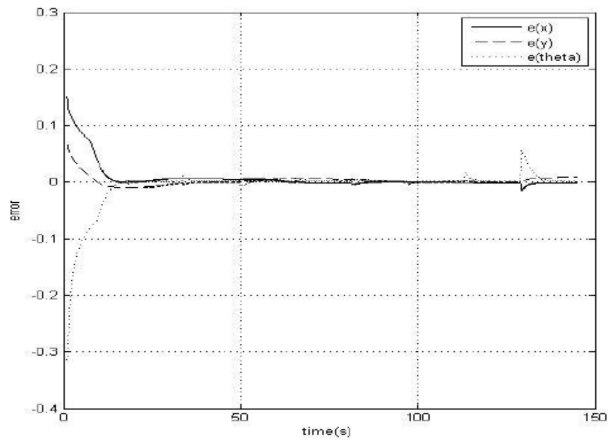

Fig.7 *S-shape trajectory tracking*

3. Simulation results of both trajectory tracking and the posture error curves for desired line trajectory.

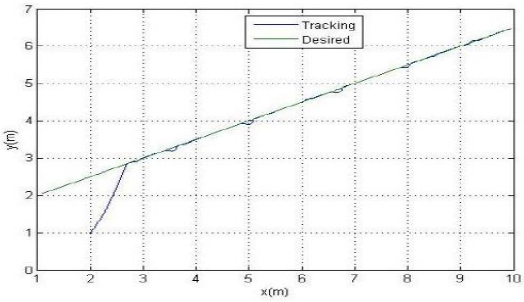

Fig.8 *Line trajectory tracking*

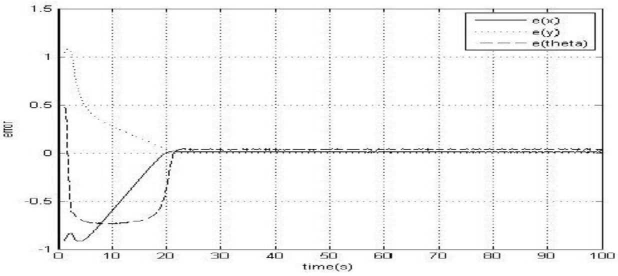

Fig.9 *Line trajectory tracking*

The proposed nonlinear PID neural controller scheme as in figure (2) is applied to the mobile robot model and it is used the proposed learning algorithm steps of PSO set parameters of the PSO algorithm. The resulting mobile robot trajectory tracking, obtained by proposed neural PID controller is show in figures(3) including trajectory tracking, tracking error and linear and angular velocity of mobile robot. The sampling period is set to T = 0.1s.
Circular trajectory tracking simulation and posture error curves are shown in Figures 4 to 5 respectively. It's very clear that good tracking performance that achieved by means of the proposed controller.
Although S-shape trajectory has sudden change in path, the proposed controller shows good trajectory tracking and the posture error goes to zero in short time.
Simulation results confirm the power full of the proposed controller in rejected external disturbance and return to desired trajectory in short time furthermore very good trajectory tracking in both cases.
Evolutionary Algorithm PSO used as optimization method for tuning nonlinear PID neural network controller.. The state outputs of the mobile model are position and orientation and they are followed the desired inputs because there are two control actions right and left velocities that are generated from the proposed controller with PSO algorithm.Simulation work demonstrates the effectiveness of the proposed algorithm with two-wheeled mobile robot and proved that this method is characterized by its robustness with disturbance and uncertainties in the system model with *MSE* (e_x,e_y,e_θ) is equal to (0.0455,0.0033,1.31) respectively, especially with regards to the external disturbances attenuation problem.

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