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Active Trajectory Tracking Control of AMR using Robust PID Tunning

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〈Abstract〉

Trajectory tracking of the AMR robot is one research for the AMR robot navigation. For the control system of the Autonomous mobile robot(AMR) being in non-honolomic system and the complex relations among the control parameters, it is difficult to solve the problem based on traditional mathematics model. In this paper, we presents a simple and effective way of implementing an adaptive tracking controller based on the PID for AMR robot trajectory tracking. The method uses a non-linear model of AMR robot kinematics and thus allows an accurate prediction of the future trajectories. The proposed controller has a parallel structure that consists of PID controller with a fixed gain. The control law is constructed on the basis of Lyapunov stability theory. Computer simulation for a differentially driven non-holonomic AMR robot is carried out in the velocity and orientation tracking control of the non-holonomic AMR. The simulation results of wheel type AMR robot platform show that the proposed controller is more robust than the conventional back-stepping controller to show the effectiveness of the proposed algorithm.

Keywords : AMR, Moving Trajectory, Kinematics, PID, Estimation

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1. Introduction

In the last decade years, mobile robot has been developed as industrial Autonomous Mobile Robot (AMR) with high nonlinearities that are often unknown and time-varying. Therefore, if we want to design a controller for mobile robot, we should consider that the exact path-following(PF) performance, which is concerned with the ability to drive a mobile robot autonomously as close as possible to a previously defined reference path [1].

Wheeled mobile robots have many application fields in industrial and service robotics, particularly when flexible motion capabilities are required on reasonably smooth grounds and surfaces [2]. They are especially necessary for tasks that are difficult and dangerous for men to perform. Many researchers have shown interest in mobile robots. Most of them have focused on trajectory tracking—to control the robot to follow a desired trajectory, and point stabilization—to stabilize a robot at a desired point[2].

Among the many control strategies that have been proposed for various non-holonomic systems, research results can generally be classified into two classes. The first class is kinematic control, which provides the solutions only at the pure kinematic level, where the systems are represented by their kinematic models and velocity acts as the control input. Based on exact system kinematic, different control strategies have been proposed [3-4].

In this paper, the adaptive following control is used as a following controller of mobile robot [5-6]. And also, a classical PID approach is applied for the path-following controller, which is the control strategy most frequently used in the industry. A very simple model of the mobile robot kinematics is used and thus a robust PID tuning is necessary. PIDs advantages include simplicity, robustness and their familiarity in the control community. Because of this, a great deal of effort has been spent to find the best choice of PID parameters for different process models.

2. Designing Controller

Contrary to the usual situation, tracking is easier than regulation for a non-holonomic AMR. An intuitive explanation of this can be given in terms of a comparison between the number of controlled variables (outputs) and the number of control inputs. For the two-wheel differential drive AMR robot of Section 2, two input commands are available while three variables (x_i, y_i and the orientation θ_i) are needed to determine its configuration. Thus, regulation of the AMR posture to a desired configuration implies zeroing three independent configuration errors. When tracking a trajectory, instead, the output p_e has the same dimension as the input and the control problem is square.

Let us denote the current position of the

AMR robot as p_m, the velocity as $\dot{p}_m$. The Cartesian velocity $\dot{p}_m$, is represented in terms of joint variables as (1). So, the kinematics model of the robot is as tracking;

$$\dot{p}_m = J(p_m)\dot{q}_m \tag{1}$$

$$\begin{bmatrix} \dot{x}_i \\ \dot{y}_i \\ \dot{\theta}_i \end{bmatrix} = \begin{bmatrix} \cos\theta_i & 0 \\ \sin\theta_i & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_m \\ \omega_m \end{bmatrix} = J(p_m)\dot{q}_m \tag{2}$$

Therefore, in order to obtain the real-time position of the AMR robot, we can control the control law as $\dot{q}_m = [v_m, \omega_m]^T$.

The tracking is the way to get the desired inputs of the AMR robot system mathematically. The issue of AMR robot trajectory tracking can generally be transformed into tracking one reference AMR robot. To assume the robot current position to be $p_m = [x_i, y_i, \theta_i]^T$, and

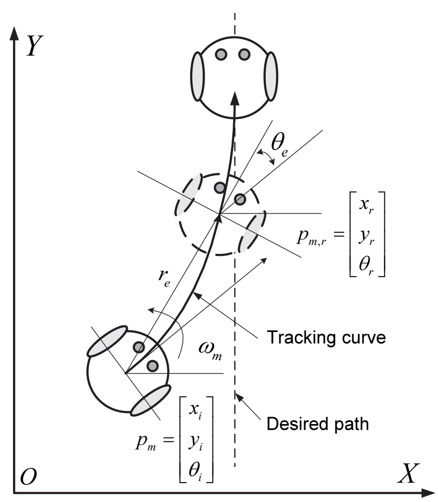

Fig. 1 Position error of mobile robot under Cartesian coordinate

the speed to be $\dot{q}_m = [v_m, \omega_m]^T$, the reference mobile robot position is $p_{m,r} = [x_r, y_r, \theta_r]^T$, and the speed to be $\dot{q}_{m,r} = [v_r, \omega_r]^T$, as shown in Fig. 1.

To order $p_e = [x_e, y_e, \theta_e]^T = [x_r - x_i, y_r - y_i, \theta_r - \theta_i]^T$, and the AMR robot position error equation (3) is obtained from the geometric relationship shown in Fig. 1. The reference state in the robot coordinate is expressed as follow by the transformation from the world coordinate to the robot coordinate.

$$\begin{aligned} p_e = \begin{bmatrix} x_e \\ y_e \\ \theta_e \end{bmatrix} &= \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \left(p_{m,r} - p_m\right) \\ &= T_e\left(p_{m,r} - p_m\right) \end{aligned} \tag{3}$$

Then the position error differential equation is as tracking:

$$\dot{p}_e = \begin{bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{\theta}_e \end{bmatrix} = \begin{bmatrix} y_e\omega_m - v + v_r\cos\theta_e \\ -x_e\omega_m + v_r\sin\theta_e \\ \omega_r - \omega_m \end{bmatrix} \tag{4}$$

Trajectory tracking of AMR robot based on kinematics model is to search the bounded input as $\dot{q} = [v_m, \omega_m]^T$, that causes position error vector, $p_e = [x_e, y_e, \theta_e]^T$ to be bounded, and $\lim_{t\to\infty} \left\| [x_e, y_e, \theta_e]^T \right\| = 0$, with arbitrary initial error and the equation (4) controlled by the control law.

By using the error vector $p_e = (x_e, y_e, \theta_e)$, the tracking curve in the robot coordinate can be calculated as follow;

$$\dot{r}_e = -v_m \cos\theta_e \tag{5}$$

$$\dot{\theta}_e = -\omega_m + \frac{v_m \sin\theta_e}{r_e} \tag{6}$$

$$\dot{\theta}_r = \frac{v_m \sin\theta_e}{r_e} \tag{7}$$

A Lyapunov candidate function is defined as in equation (8).

$$V = V_1 + V_2 = \tfrac{1}{2}\lambda\, r_e^2 + \tfrac{1}{2}(\theta_e^2 + h\theta_r^2) \tag{8}$$

where V_1 means the error energy to the distance and V_2 means the error energy in the direction. After differentiating both sides in equation in terms of time, we can acquire the result as in equation (9).

$$\dot{V} = \dot{V}_1 + \dot{V}_2 = \lambda r_e \dot{r}_e + (\theta_e \dot{\theta}_e + h\theta_r \dot{\theta}_r) \tag{9}$$

Therefore, using this controller for the AMR robot, $\dot{V}$ approaches to zero as $t \to \infty$; r_e and θ_e also approach almost to zero as shown in (10).

$$\dot{V} = -\lambda(\gamma \cos^2\theta_e) r_e^2 - k\theta_e^2 \le 0 \tag{10}$$

PID algorithm is proposed for controlling position and velocity of the AMR robot platform like shown in Fig. 2. Using the PID algorithm, we can control the important system characteristics, let say us, rising time, steady state error, system stability, etc. Each term in the control algorithm has a different effect on the system characteristics. In the PID control, the input for control of a standard PID controller in continuous time is stated as in equation (11).

$$\begin{aligned} m(t) &= K\left[e(t) + \frac{1}{T_i}\int_0^t e(\tau)\,d\tau + T_d \frac{d\,e(t)}{dt} \right] \\ &= K_p\, e(t) + K_i \int_0^t e(\tau)\,d\tau + K \frac{d\,e(t)}{dt} \end{aligned} \tag{11}$$

where $e(t)$ represents error signal that is the difference between desired input and output signal. For the digital control PID equation in discrete time is expressed as equation (11).

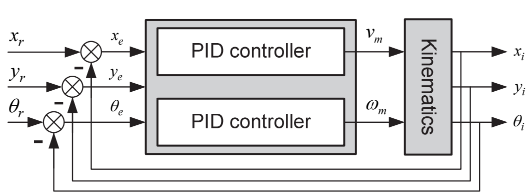

Fig. 2 Control system diagram

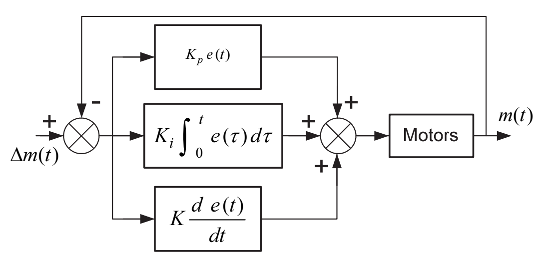

Fig. 3 PID controller diagram

3. Simulation Results

In order to test the method of this paper, the controller is simulated with the circular track as reference trajectory.

The reference track is as $x^2+y^2=1.25^2$, the reference velocity is as $v_r=0.2$, and the reference angular velocity is as $\omega_r=0.2$. While the initial velocity is as $v_m=0.4$, and the initial angular velocity is as $\omega_m=0.3$, the initial position is as . $p_m=(-3,0,2\pi/3)^T$.

The simulation results are shown in Fig. 4. and Fig. 5. From the results, it shows that

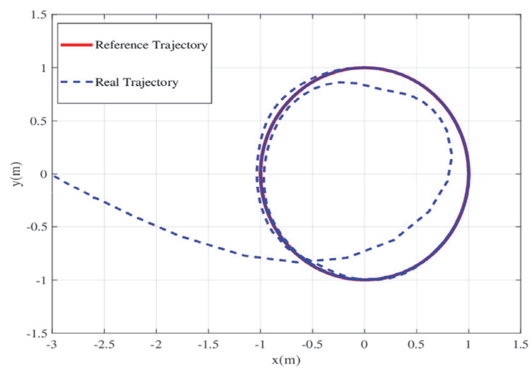

Fig. 4 Path following for the AMR robot

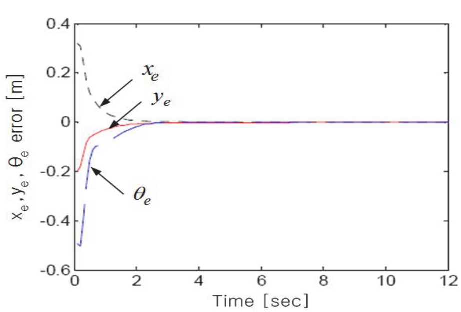

Fig. 5 Following error: x_e, y_e, and θ_e

the AMR robot starts from an initial position and then is trying to track the desired line. It takes a short time to follow up the desired line and land on the desired path smoothly.

4. Conclusion

This paper presents an adaptive tracking controller for AMR robot based on a robust PID method. The proposed controller has a parallel structure that consists of PID controller with a fixed gain. The principal advantage of the present methodology is that it uses a very simple model for the mobile robot which allows the tuning of a simple PID controller. The new method for the robust tuning of the PID controller is based on classical concepts and can be applied to integrative process plus a delay. The simple and clear control laws lead to simplicity of adjusting the parameters to achieve the desired performance including the tracking error and control signals. Stability of system has been guaranteed by appropriate choice of Lyapunov functions. Simulations have shown robustness and efficiency of this method. For the future work, robust tuning and position estimation should be considered to realize more accurate motions of AMR robots.

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