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Finite-time cascaded tracking control approach for mobile robots

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ABSTRACT

This paper develops a new control approach for trajectory tracking of mobile robots. For the purpose of tracking trajectory, the error dynamics of a mobile robot are divided into a first-order subsystem and a second-order subsystem by using a cascaded control design. Firstly, a global finite-time control law of the angular velocity is designed for the first-order system in order to stabilize the angle error of mobile robots. Subsequently, a finite-time sliding mode control law of forward velocity is synthesized, which guarantees the global stability of the second-order subsystem. Furthermore, the global uniform stability of the whole closed-loop system is analyzed by employing cascaded control theory, and some sufficient conditions are derived. Finally, the proposed control algorithm is applied to mobile robots, where simulation results demonstrate good convergence and performance.

1. Introduction

Over the past two decades, the mobile robots have been widely used in various industrial processes. One of the key challenges in mobile robots is the control system, which is known as a class of typical nonholonomic system [10,21,40]. One important topic in control system design of mobile robots is trajectory tracking. However, the tracking error system of mobile robots is a coupled nonlinear system, which fails to meet Brockett's necessary condition [1] and complicates the problem significantly.

In recent years, the tracking control problem for nonholonomic mobile robots has attracted more attentions. Kanayama et al. [11] proposed a tracking control law by using the Taylor linearization of the corresponding error model. To extend the trajectory tracking problem in Cartesian space, Samson and Ait-Abderrahim [25] developed a global tracking control law in 1991. A smooth controller presented in [31] achieved exponential stability for any initial condition, thus improved the convergence rate of the algorithm. A time-varying feedback control method was developed by using the chain form [26].

To further investigate the tracking problem, some important research efforts have been deployed. Sliding mode control methods were proposed for mobile robots [2,22], similar problem with bounded disturbances was considered in [34]. The smooth time-varying feedback control law was introduced in [28,29], which guarantees the global exponential convergence. By combining cascaded design and backstepping approach, a tracking controller was designed in [6]. In [7], under the consideration of input torque saturation and external disturbances, the authors derived a new adaptive control scheme. On the

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other hand, intelligent control theory was introduced to solve the tracking control problem of mobile robots [14,16,17,27,35,36,38]. The wide applications of these control methods promote the development of tracking control. Note that most of the aforementioned results only consider the asymptotic stability, which means that they achieve convergence in infinite settling time. In addition, the asymptotical stability [2,22,34] may not yield fast convergence for high-precision control. In fact, it is much more desirable to reach the target in finite time for practical mobile robots.

Finite-time tracking control method [19,32,33,37] is a fast control technique, which achieves the desired trajectory in finite time. A global finite-time tracking controller was given for the nonholonomic systems in [33]. For the uncertain nonlinear systems, Huang et al. [8] proved the global finite-time stabilization based on the finite-time Lyapunov stability theorem. The finite-time control techniques were employed for attitude control in [4,12]. However, the finite-time tracking control problem of mobile robots has rarely been studied till present, and only a few results have been reported [13,19,20]. Moreover, the low efficiency is still a problem of these methods, and the strong constraints on the desired velocities should be satisfied. To overcome these difficulties, in this paper, we propose a class of novel control laws based on cascaded control design. By using cascaded control design, we obtain two subsystems. One subsystem is stabilized by an improved global finite-time control law. To relax the strict constraints on the desired velocities, the other subsystem is stabilized by a finite-time sliding mode control law. By combining the finite time control technique and the sliding mode control approach, we improve the effectiveness of the converge rate of sliding mode control approach compared with [5,18,39,41].

The rest of the paper is organized as follows. The dynamical model of mobile robots and the tracking control problem are described in Section 2. In Section 3, the tracking control law is designed based on cascaded approach. Furthermore, the stability of the closed-loop system is analyzed. In Section 4, the simulation results by using the control laws are given. The conclusion is drawn in Section 5.

2. Problem description

In this section, we give the kinematic model of a mobile robot and the definition of tracking control problem.

2.1. Kinematic model

A mobile robot considered in this paper is made up of three wheels. Two driving wheels at the front of the mobile robot are parallel, driven by two independent motors. Another wheel is a driven wheel at the back of the mobile robot (see Fig. 1). Let D and r denote the length of the wheel axis and the radius of the driving wheels, respectively. The velocities v_L and v_R represent the velocities of the left wheel and the right wheel, respectively. The control variables v and w denote the forward velocity and the angular velocity of the mobile robot respectively, which can be described as [15]

$$\begin{bmatrix} v \\ w \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} \\ -\frac{1}{D} & \frac{1}{D} \end{bmatrix} \begin{bmatrix} v_L \\ v_R \end{bmatrix} \tag{1}$$

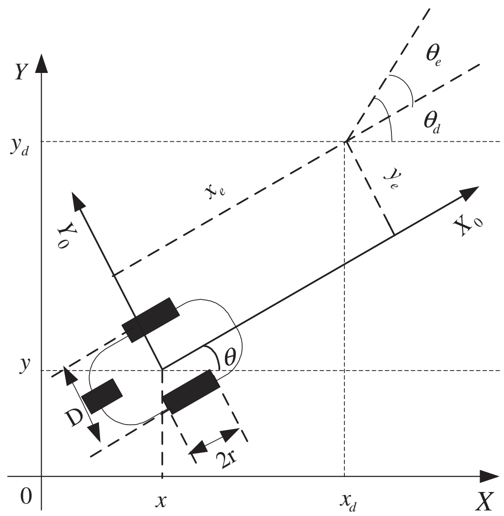

Fig. 1. Posture errors of the coordinate for a mobile robot.