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Robust adaptive tracking control for nonholonomic mobile manipulator with uncertainties

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ABSTRACT

In this paper, mobile manipulator is divided into two subsystems, that is, nonholonomic mobile platform subsystem and holonomic manipulator subsystem. First, the kinematic controller of the mobile platform is derived to obtain a desired velocity. Second, regarding the coupling between the two subsystems as disturbances, Lyapunov functions of the two subsystems are designed respectively. Third, a robust adaptive tracking controller is proposed to deal with the unknown upper bounds of parameter uncertainties and disturbances. According to the Lyapunov stability theory, the derived robust adaptive controller guarantees global stability of the closed-loop system, and the tracking errors and adaptive coefficient errors are all bounded. Finally, simulation results show that the proposed robust adaptive tracking controller for nonholonomic mobile manipulator is effective and has good tracking capacity.

1. Introduction

Tracking control for multi-joint robotic manipulators and mobile robots always is a challenging problem and has been given a lot of attention in the control field. Many powerful methodologies have been applied on robotic manipulators or mobile robots to achieve good tracking performances.

Robust adaptive control method combines the advantages of adaptive control and robust control methods [1–4], which have been widely used to control the robotic manipulators and mobile robots or other electromechanical systems. Slotine and Li [5] introduced a robust fixed gain based on the basic of adaptive control for controlling the manipulator, which enhanced the robustness of passive structure adaptive controller. Su and Leung [6] introduced an estimation algorithm of unknown parameters' upper bound based on the robust control structure, which can effectively reduce the robust gain conservatism. However, only parameter uncertainties were considered in the above works. By combining robust adaptive control and fuzzy logic control, Gueaieb et al. [7] proposed a decentralized robust adaptive fuzzy control strategy, which was specially for the parametric and non-parametric uncertainties, and the stability of system was proven by using the Lyapunov stability theory. González-Vázquez et al. [8] introduced a class of PD-type robust controllers for robotic manipulators by using the theory of singularly perturbed systems. Tomei [9] proposed a robust adaptive controller, which can maintain a high tracking accuracy and adjust system transient quality discretionarily under the circumstance that the unknown parameters of the system and the external interference coexist. However, the upper bound of system parameters should be known in the above works. Aiming at the system uncertainties, Wang et al. [10] proposed a robust adaptive tracking control for robotic manipulator, where the upper bound of system parameters was assumed to be unknown. However, the above works mainly focused on controlling for robotic manipulators or mobile robots only.

A mobile manipulator is a robotic manipulator mounted on a mobile platform, with the function of mobile and operation. It not only possesses the flexible function of manipulator's operation but also has mobile robot's extensity in workspace. The mobile manipulator shows its nonholonomic characteristics since the mobile platform is a typical nonholonomic system. In general, the tracking control methods of mobile manipulator are mainly divided into two categories: one is called centralized control strategy, the other is called decentralized control strategy [11]. In the centralized control strategy, the mobile platform and robotic manipulator are regarded as a whole. Seraji [12] established a unified dynamic model of mobile manipulators, the idea of configuration control was proposed. However, the control method that was based on the kinematics was difficult to implement in practice. Tan and Xi [13,14] established a dynamic model of mobile manipulators, and a hybrid force/position control method was proposed. In [15], the dynamic coupling was compensated by linearizing the dynamic model of mobile manipulators, however,

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the decoupling matrix was required to be full rank, that is, the initial states of system were restricted. Consider the dynamic coupling, Dong [16] designed a robust controller which is based on the Lyapunov theory to achieve system stable, however, the system structure was complicated due to the regression matrix was used. In the decentralized control strategy, the mobile manipulator is divided into nonholonomic mobile platform subsystem and holonomic manipulator subsystem. Evangelos and John [17] used computed torque control theory to implement the tracking control of mobile manipulator, which is subject to external disturbances. Liu and Lewis [18] took manipulator and mobile platform as two independent systems, the controllers for each system were designed, and the system dynamic couplings were regarded as external disturbances. Lin and Goldenberg [19] designed tracking controllers for mobile manipulator based on neural networks, which were used to estimate the system dynamic coupling and uncertainties online. Whereafter, they proposed a robust damping control algorithm as well [20], the control algorithm only needs a few control parameters. However, the above investigations cannot handle the varying parameter uncertainties well, because the adaptive parameters identification is generally not included in these methods. Wang and Wang [21] established the dynamic model of nonholonomic mobile manipulator based on Screw theory and designed a robust adaptive fuzzy controller of mobile manipulator. Andaluz et al. [22] proposed a kinematic controller of mobile manipulator with uncertainties. The controller was able to solve the problem, not only the point stabilization and the trajectory tracking, but also the path following. Shojaei et al. [23] proposed an input–output model of mobile manipulator, where a tracking controller was designed by using the dynamic surface control technique. Then, according to adaptive robust technique, the influence of parametric and non-parametric about the uncertainties in the mobile manipulators model was compensated. However, the upper bound of system parameters should be known from the above works.

In this paper, the decentralized control strategy is studied. The mobile manipulator is divided into nonholonomic mobile platform subsystem and holonomic manipulator subsystem. The kinematic controller of the mobile platform is derived. And considering that the dynamic model, Lyapunov functions of the two subsystems are derived, the couplings between the two subsystems are regarded as external disturbances. Then, the dynamic parameters and external disturbances are assumed to be unknown, a robust adaptive controller is proposed to achieve the closed-loop system stability. The proposed controller can eliminate interference of dynamic uncertainties and external disturbances as well. Simulation results show that the proposed robust adaptive controller is effective for controlling the mobile manipulator.

The rest of this paper is organized as follows. In Section 2, the mathematic models of nonholonomic mobile platform and holonomic manipulator are addressed respectively. In Section 3, the Lyapunov function for mobile platform is designed, which consists of the design of kinematic controller and Lyapunov function based on dynamic model. In Section 4, the design of Lyapunov function for manipulator is drawn. The design of robust adaptive control scheme is given in Section 5, as well as the robust stability is analysed. The simulation results are given in Section 6, and the conclusions are drawn in Section 7.

2. Model of nonholonomic mobile manipulator

A mobile manipulator system is depicted in Fig. 1, where a two-link manipulator is mounted on the centre C of a mobile platform. The two rear wheels of mobile platform are driven independently, and the two links of manipulator are also driven by motors independently. In addition, the manipulator is generally considered to be a holonomic system, while the mobile platform is subject to nonholonomic constraint, the mechanical system of mobile manipulator can be expressed as

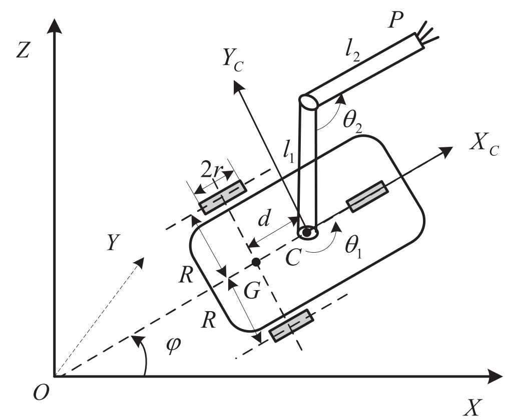

Fig. 1. System of a mobile manipulator.

$$M(q)\ddot{q}+C(q,\dot{q})\dot{q}+F(q,\dot{q})+\tau_d=B(q)\tau-A^T(q)\lambda \quad (1)$$

The nonholonomic constraint can be expressed as

$$A(q)\dot{q}=0 \quad (2)$$

where $q,\dot{q},\ddot{q}\in\Re^p$ are the state vectors of the mobile manipulator system, representing position, velocity and acceleration vectors respectively, $M(q)\in\Re^{p\times p}$ is the symmetric, positive definite inertia matrix, $C(q,\dot{q})\in\Re^{p\times p}$ represents the vector of centripetal and Coriolis forces term; $F(q,\dot{q})\in\Re^{p\times p}$ represents the gravity and friction term, $\tau_d\in\Re^p$ is the vector of unknown bounded external disturbances, $B(q)\in\Re^{p\times(p-r)}$ is the input transformation matrix, $\tau\in\Re^{p-r}$ is the input torque, $A(q)\in\Re^{r\times p}$ is the constraint matrix, $\lambda\in\Re^r$ is the constraint force.

Let $q=[q_v^T\ q_r^T]^T$, where $q_v\in\Re^m$ represents the position and direction of mobile platform, $q_r\in\Re^n$ represents the link position of manipulator, and $p=m+n$. Since the nonholonomic characteristics of mobile manipulator is caused by the movement of mobile platform, Eq. (2) can be simplified as follows:

$$A_v(q_v)\dot{q}_v=0 \quad (3)$$

where $A_v(q_v)\in\Re^{m\times p}$ is the constraint matrix of mobile platform. Therefore, Eq. (1) can be rewritten as

$$\begin{bmatrix}M_{11} & M_{12}\\ M_{21} & M_{22}\end{bmatrix}\begin{bmatrix}\ddot{q}_v\\ \ddot{q}_r\end{bmatrix}+\begin{bmatrix}C_{11} & C_{12}\\ C_{21} & C_{22}\end{bmatrix}\begin{bmatrix}\dot{q}_v\\ \dot{q}_r\end{bmatrix}+\begin{bmatrix}F_1\\ F_2\end{bmatrix}+\begin{bmatrix}\tau_{d1}\\ \tau_{d2}\end{bmatrix}=\begin{bmatrix}B_v(q_v)\tau_v\\ \tau_r\end{bmatrix}-\begin{bmatrix}A_v^T(q_v)\lambda\\ 0\end{bmatrix} \quad (4)$$

where $\tau_v\in\Re^{m-r}$ is the control torque of mobile platform, $\tau_r\in\Re^n$ is the control torque of manipulator, M_{11} and M_{22} represent the inertia matrices of mobile platform and manipulator respectively, $M_{12}\ddot{q}_r$ and $M_{21}\ddot{q}_v$ represent the interaction inertia between the manipulator and mobile platform, and $C_{12}\dot{q}_r$ and $C_{21}\dot{q}_v$ also represent the interaction centripetal and Coriolis forces between the two subsystems.

2.1. Subsystem of mobile platform

Select a full rank matrix $S(q_v)=[s_1(q_v),\ldots,s_{m-r}(q_v)]\in\Re^{m\times(m-r)}$ to be a basis of null space $A_v(q_v)$. Then, we have

$$S^T(q_v)A_v^T(q_v)=0 \quad (5)$$