A Sliding Mode Control based on Nonlinear Disturbance Observer for the Mobile Manipulator

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Abstract

A sliding mode control based on nonlinear disturbance observer is presented in this paper considering the tracking control of mobile manipulators. The proposed control strategy adopts the nonlinear observer to estimate the bounded external disturbances and overcome the effects. In addition, the stability of the controller is verified by Lyapunov theory. Finally, the simulation results verify the correctness and effectiveness of the proposed control strategy.

Keywords

Mobile manipulators, trajectory tracking, sliding mode control, nonlinear disturbance observer.

1. Introduction

Recently mobile manipulators have been widely used in the field of industrial and aerospace for mobility, adaptability and operational flexibility advantages[1]. In many practical tasks, the precise trajectory tracking control for manipulators is often necessary. However, strong coupling, model parameters uncertainty, external disturbances combined with inherent nonlinear dynamics makes the control of mobile manipulators more complicated and difficult.

The traditional control algorithm is often difficult to achieve the expected performance, so a variety of hybrid control strategies have been developed [2-7]. The procedure integrates several control techniques such as adaptive control, back-stepping, neural network, fuzzy logic, and sliding mode.

In [8], a robust adaptive control algorithm is proposed to addresses the trajectory tracking control of a nonholonomic wheeled mobile manipulator with parameter uncertainties and disturbances; the proposed algorithm consists of an adaptive sliding mode controller and two update laws, where parametric uncertainties are compensated and the disturbances are suppressed. In [9], the paper presents a sliding mode adaptive neural-network controller for trajectory following of nonholonomic mobile modular manipulators in task space. Sliding mode control and direct adaptive technique are combined together to suppress bounded disturbances and modeling errors caused by parameter uncertainties. In [10], a sliding-mode controller, composed of neural network control is proposed for the trajectory tracking problem of a dual-arm wheeled mobile manipulator subject to some modeling uncertainties and external disturbances. The significant features of the proposed controller hinge on no prior knowledge of the mobile manipulator’s dynamics, no limitations of the LIP and no persistent excitation (PE) conditions.

The above researches have advantages and disadvantages respectively. In this paper, a sliding mode control (SMC) strategy combined with nonlinear disturbance observer is proposed, considering the model uncertainties and external disturbances. The proposed control strategy can accurately estimate the external disturbance by the nonlinear disturbance observer, so as to eliminate the impact. The stability of the control system is proved by the theory of Lyapunov stability theory.

2. Mobile manipulator Modeling

Assuming that the mass of the mobile platform is m0, and the quality of the links is m1, m2 and the moment of inertia are J1, J2, respectively. The dynamic model of the mobile manipulator can be deduced with the Lagrangian equation and the nonholonomic Lodz equation [11].

According to the Lagrangian formulation the mobile manipulator system model can be described as:

$$M(q)\ddot{q}+C(q,\dot{q})+G(q)=\tau+d(t) \tag{1}$$

Where $M(q)$ is the symmetric bounded positive definite inertia matrix; $C(q,\dot{q})$ denotes the centripetal and Coriolis torques; $G(q)$ describes the gravitational torque vector; τ is the control input and $d(t)$ is the bounded disturbances.

3. Controller design

The model above is based on the accuracy of the parameters of the mobile manipulator. In order to eliminate the disturbances influence on the system performance, the disturbances observer is introduced to estimate the external disturbances in this paper. The system controller structure is shown in figure 2.

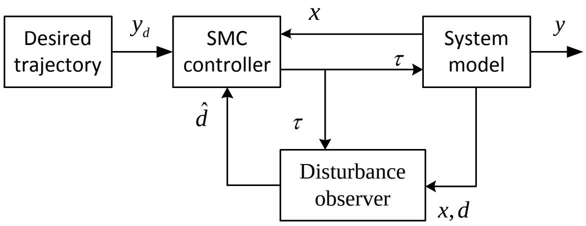

Fig.1 System controller structure

3.1 Nonlinear disturbance observer

We suppose the model uncertainties and external disturbances in the mobile manipulator system change slowly, that is $\dot{d}(t)=0$.

A nonlinear disturbance observer is designed in the following form:

$$\begin{cases} \hat{d}(t)=\xi+p(x) \\ \dot{\xi}=-L(x)\xi-L(x)\left[p(x)+\tau-M-C-G\right] \end{cases} \tag{2}$$

Where, $\hat{d}(t)$ is disturbance observations; ξ is observer internal variables; $p(x)$ is the nonlinear function to be designed; $L(x)$ is pending observation gain, and satisfied $L(x)\dot{x}_2=\dot{p}(x)$.

To prove the stability of the observer, define the observation error of the nonlinear disturbance observer is $\tilde{d}(t)=d(t)-\hat{d}(t)$, and then the dynamic characteristic of the observer error is:

$$\begin{aligned} \dot{\tilde{d}}(t) &= \dot{d}(t)-\dot{\hat{d}}(t) \\ &= \dot{d}(t)-\left[\dot{\xi}+\dot{p}(x)\right]=\dot{d}(t)-\left[\dot{\xi}+L(x)\dot{x}_2\right] \\ &= \dot{d}(t)+L(x)\xi+L(x)p(x)-L(x)d(t) \\ &= \dot{d}(t)-L(x)\tilde{d} \end{aligned} \tag{3}$$

Define the Lyapunov function $V_d = \frac{1}{2}\tilde{d}^T\tilde{d}$, its derivative can be obtained:

$$\dot{V}_d = \tilde{d}^T\dot{\tilde{d}} = -\tilde{d}^T L(x)\tilde{d} \tag{4}$$

From (16), the observation error of the observer can be exponentially converged by selecting the appropriate $L(x) > 0$.

3.2 Sliding mode control law

Assume the desired trajectory is y_d, the system state tracking error can be defined as follows:

$$z_1 = y - y_d \tag{5}$$

Then

$$\dot{z}_1 = \dot{y} - \dot{y}_d \tag{6}$$

And the stable coefficient of the mobile manipulator system can be taken as:

$$\alpha_1 = c_1 z_1 \tag{7}$$

where c_1 is the positive constant.

Define

$$z_2 = \dot{z}_1 + \alpha_1 = \dot{y} - \dot{y}_d + \alpha_1 \tag{8}$$

The Lyapunov function is selected as follows:

$$V_1 = \frac{1}{2} z_1^2 \tag{9}$$

Then,

$$\dot{V}_1 = z_1\left[\dot{y} - \dot{y}_d\right] = z_1\dot{z}_1 = z_1 z_2 - c_1 z_1^2 \tag{10}$$

The corresponding Lyapunov function can be taken as:

$$V_2 = V_1 + \frac{1}{2}s^2 \tag{11}$$

where, s is the switching function of the terminal sliding mode, and defined as:

$$s = kz_1 + z_2,\ k \ge 0 \tag{12}$$

Then,

$$\begin{aligned} \dot{V}_2 &= \dot{V}_1 + s\dot{s} = z_1 z_2 - c_1 z_1^2 + s\dot{s} \\ &= z_1 z_2 - c_1 z_1^2 + s\left(k\dot{z}_1 + \dot{z}_2\right) \\ &= z_1 z_2 - c_1 z_1^2 + s\left[k\left(z_2 - c_1 z_1\right) + \ddot{y} - \ddot{y}_d + \dot{\alpha}_1\right] \end{aligned} \tag{13}$$

All available above, we can get $\dot{V}_2 \le 0$. Therefore, the mobile manipulator system is proved to be stable.

4. Simulation

Among the control system, we assume that $f = 5 + 0.15\sin t$, nonlinear disturbance observer is (2) and the initial state is zero. The simulation results are presented in Figure.2 – Figure.4

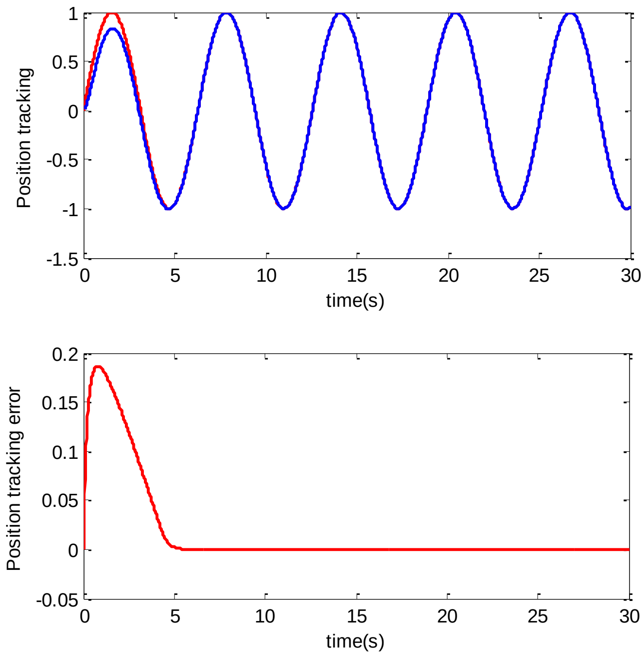

Fig.2 Position tracking and position tracking error

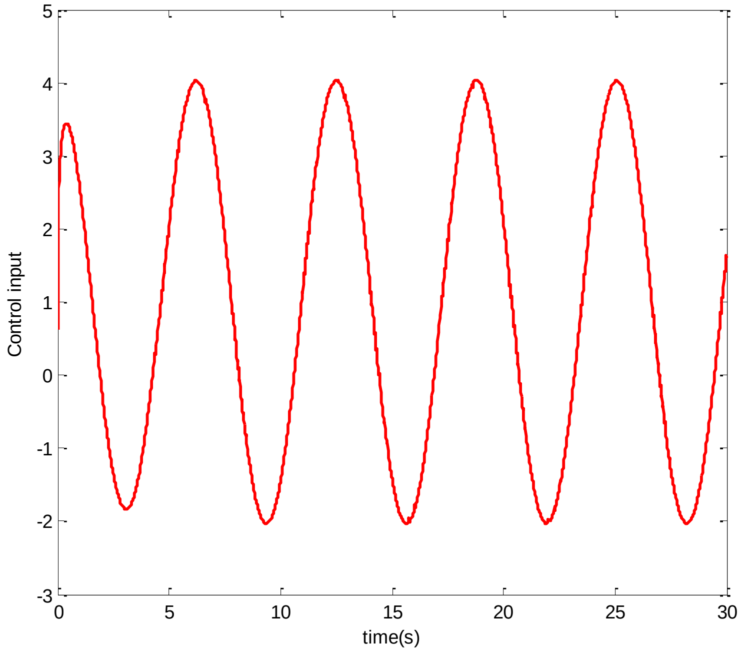

Fig.3 Control input

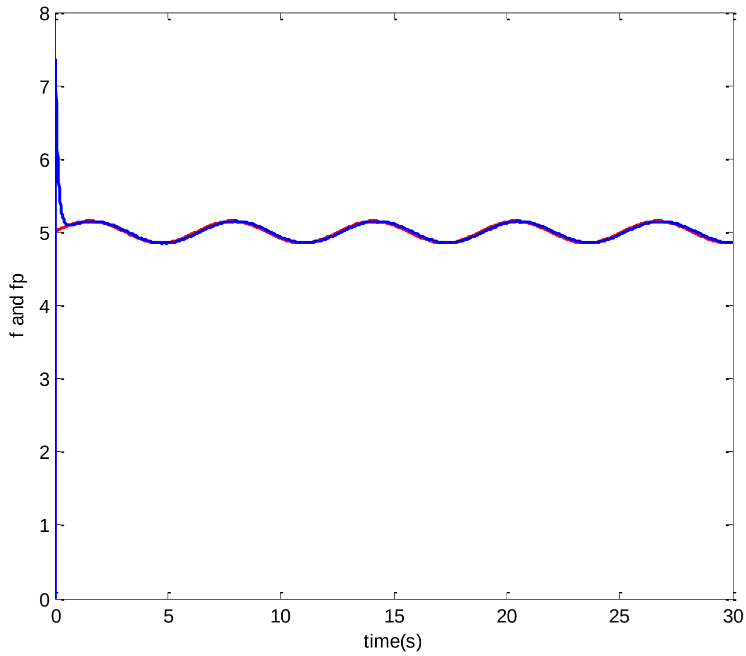

Fig.4 External disturbances and observed result

5. Conclusion

Based on the mathematical model of the mobile manipulator, this paper designed a nonlinear disturbance observer to observe the external disturbances. And a sliding mode-based control strategy is proposed to realize the accurate tracking of the position. The simulation results show that the controller is robust to bounded external disturbances and has good tracking performance.

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