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Robust adaptive sliding-mode control of condenser-cleaning mobile manipulator using fuzzy wavelet neural network [☆]

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Abstract

This paper presents a robust adaptive sliding-mode control (RASMC) scheme for a class of condenser-cleaning mobile manipulator (CCMM) in the presence of parametric uncertainties and external disturbances. The development of control system is based on the fuzzy wavelet neural network (FWNN). First, a dynamic model is obtained in view of the practical CCMM system. Second, the FWNN is used to identify the unstructured system dynamics directly due to its ability to approximate a nonlinear continuous function to arbitrary accuracy. Using learning ability of neural networks, RASMC can coordinately control the condenser-cleaning mobile platform and the mounted manipulator with different dynamics efficiently. The implementation of the control algorithm is dependent on the adaptive sliding-mode control. Finally, based on the Lyapunov stability theory, the stability of the whole control system, the boundedness of the neural networks weight estimation errors, and the uniformly ultimately boundedness of the tracking error are all strictly guaranteed. Moreover, simulation results validate the superior control performance of the proposed adaptive control method.

Keywords: Mobile manipulators; Fuzzy wavelet neural networks; Robust adaptive control; Sliding-mode control; Condenser-cleaning

1. Introduction

The tracking control of mobile robots have received increasing attention owing to its wide applicability in various fields, such as mining, waste management, forestry, planetary exploration and military [1,2]. It is well known that mobile manipulators possess strongly coupled dynamics of mobile platforms and manipulators. The mobile platform extends the manipulators workspace, whereas the manipulators offer much operational functionality. Therefore, the control design for these systems has attracted much attention and is a challenging problem in the nonholonomic mobile robots [3–6].

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Generally, the condenser-cleaning mobile platform has closed chain mechanism with redundant actuation. The redundant actuation provides an effective means for eliminating singularities, and improving the performance such as Cartesian stiffness and homogeneous output forces. At the same time, a major difficulty, which prevents vast control strategies from applying in redundant actuated systems, is the lack of an efficient dynamic model and control method. However, without dynamic control, it is difficult to perform coordinated motion of the mobile platform and the dynamically controlled manipulator. Hence, there are many researches about dynamic modeling and control of omnidirectional wheeled mobile manipulators with redundant or nonredundant actuation [7–9].

Recently, several results about dynamic modeling and control of holonomic systems were published [10–13], which provided effective means for such problems of CCMMs. The major components of well-known control methods are robust control, adaptive control, sliding-mode control, robust Lyapunov stability-based control, combination of adaptive and sliding-mode control. For example, in [14], the authors consider multiple mobile manipulators grasping a rigid object in contact with a deformable working surface, whose geometric and real physical parameters are unknown but boundedness of physical parameters is known. They proposed a neuro-adaptive robust force/motion tracking controller for coordinated mobile manipulators. Tsai et al. [15] present methodologies for dynamic modeling and trajectory tracking of a nonholonomic wheeled mobile manipulator with dual arms. In [16], the authors propose a novel control law based on sliding-mode theory in order to drive mobile robots to a target location, which is specified by a previously acquired reference image. However, the robust control schemes for these uncertain system dynamics are not fully explored. In practical applications, environmental uncertainties arise in mobile manipulator applications which can affect the system stability and performance. It is well known that the main advantage of using sliding-mode control is strong robustness with respect to system uncertainties and external disturbances. In this paper, to handle unknown dynamics of mobile robot systems, robust adaptive sliding-mode controls have been extensive investigated for mobile robot manipulators systems.

FWNN, one of the most popular intelligent computation approaches, has an inherent learning ability and can approximate a nonlinear continuous function to arbitrary accuracy. This property is crucial in the controller design for complex model identifying and unstructured uncertainties compensating. Therefore, the development of FWNN control in mobile manipulators has attracted considerable interest [17–20]. The FWNN can be represented by a linear combination of fuzzy wavelet basis functions. Different from wavelet neural networks, fuzzy wavelet basis functions can be specified by experts as traditional fuzzy systems. Furthermore, the architecture of wavelet networks and fuzzy wavelet networks can provide at least the same order of approximation error as neural networks. This is the reason why we choose the fuzzy wavelet network as the approximator in the proposed controller.

Moreover, the large-scale condensers are the crucial equipments of various industry fields, such as thermoelectricity plant, nuclear power plant, chemical plant, pharmaceutical factory and so on [9,10]. It is made up of tens of thousands of condenser pipes used for the cooling of heat-transport in turbogenerator (see Fig. 1). When the condensers are in motion, for the squalor of the cooling water and chemical reaction in heat-change, there exists a great deal of dirt which is harmful to the heat-transport, reduces the efficiency of turbogenerator and even causes rusty of the pipe wall. Therefore, it is important to pay attention to the cleaning of condensers.

Motivated by the discussions and observations above, in this paper, a new adaptive sliding-mode control approach is proposed for the condenser-cleaning mobile manipulators in the presence of uncertainties and disturbances. In the controller design, the FWNN is utilized to approximate the unknown functions and to transform the considered uncertain nonlinear system into an uncertain parameterized system with unmodeled dynamics. Based on the Lyapunov stability theory, a new adaptive sliding-mode control is therefore developed. It is shown that the proposed control approach can guarantee that the whole control system is stable, and the tracking error is uniformly ultimately bounded. Compared with the existing results, the main contributions of this paper can be summarized as follows: (i) Based on the Lyapunov stability theorem and the backstepping design technique, the proposed adaptive sliding-mode control method not only ensure the stability of the control system, but also has the robustness to the unmodeled dynamics, which cannot be solved by the existing results in [9]; (ii) by using the combination of adaptive backstepping and sliding-mode control, a new robust adaptive sliding-mode controller can coordinately control the mobile platform and the manipulator with different dynamics effectively; and (iii) by estimating the norms of parameter vectors rather than each element of the parameter vectors, the proposed control scheme contains fewer adaptive parameters to be tuned on-line than the previous results in [14,21], which makes the computational burden significantly alleviated. The remainder of this paper is organized as follows. The dynamic model of the CCMM is derived, and some preliminaries are given in Section 2. The main results of control design are presented in Section 3. Simulation result is given to