Mechanical Systems and Signal Processing 118 (2019) 623–644

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Experimental study on active vibration control for a kind of two-link flexible manipulator

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ARTICLE INFO

Article history:
Received 16 March 2018
Received in revised form 28 August 2018
Accepted 1 September 2018

Keywords:
Two-link flexible manipulator
Active vibration control
Generalized minimum variance self-tuning control
T-S model based fuzzy neural network controller

ABSTRACT

This paper presents experimental investigations on active vibration control of a two-link flexible manipulator (TLFM), utilizing a generalized minimum variance self-tuning control (GMVSTC) and Takagi-Sugeno model based fuzzy neural network control (TS-FNN) schemes. The GMVSTC algorithm consists of an on-line identifier in the form of controlled autoregressive moving average model and a vibration control signal generator, and the TS-FNN control algorithm generates control actions taking full advantages of fuzzy logic controller and a neural controller. Experimental setup of the two-link flexible manipulator is constructed. Experimental comparison research on vibration attenuation is conducted during and after the motor motion, to verify the designed controllers. The effectiveness of the designed controllers is evaluated in terms of vibration suppression as compared to that of the classical PD control. The experimental results demonstrate that the designed controller can damp out both the large and the small amplitude vibration of a two-link flexible manipulator more quickly than that the traditional linear PD controller, especially for the small amplitude residual vibration.

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1. Introduction

The most common construction of a flexible manipulator consists of flexible beams attached to rigid actuator such as motors. Compared with the conventional heavy and bulky rigid robots, flexible link manipulators have the potential advantage of lower cost, higher operational speed, greater payload-to-manipulator-weight ratio, smaller actuators, lower energy consumption, better maneuverability, better transportability and safer operation due to reduced inertia [1,2]. However, the greatest disadvantage of these manipulators is the vibration problem due to low stiffness [2]. The oscillatory behavior of the flexible manipulator needs to be considered especially during the operation due to the flexibility of their links. Due to the flexible nature of the system, the dynamics are highly nonlinear and complex. The complexity of the problem increases dramatically for a two-link flexible manipulator where several other factors such as coupling between both links have to be considered [3].

Numerous theoretical analyses were carried out in various ways for modeling the two-link flexible manipulator (TLFM) system. Generally, three methods are mainly used for mathematical modeling of flexible manipulators. These are finite element method (FEM), assumed modes method (AMM) and lumped parameter methods used for truncation of the system [4]. The most widely used method for modeling of flexible manipulators is AMM. Book et al. [5] studied two methods of mod-

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https://doi.org/10.1016/j.ymssp.2018.09.001
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eling a TLFM in time domain and frequency space, incorporating transfer matrices and numerical techniques. A dynamic model of a planar two-link flexible manipulator moving in a horizontal plane is developed using the AMM [6]. Also, experiments have been performed for validation of the dynamic model. For dynamic behavior, Abdollahpouri et al. [7] implemented the moving horizon estimation algorithm to observe the dynamic states and parameter variations of an active cantilever beam in real time. The practical behavior of this algorithm has been investigated in various experimental scenarios.

It is difficult to design high-performance controllers for flexible manipulators, due to the coupling dynamics between the rigid and the flexible modes [8]. The control strategies for flexible manipulator systems are mainly classified into two categories: feedforward and feedback control schemes. Feedforward control involves developing the control input through consideration of the physical and vibrational properties of the system. Feedback control techniques use measurements and estimates of the system states and changes the actuator input accordingly for control of rigid body motion and vibration suppression of the system [9]. Generally, motors were used as the actuators for driving the joint, while the piezoelectric patches were used as vibration actuators to reduce the vibration amplitudes of flexible manipulators. Shin and Choi established a nonlinear model including inertial effects using Lagrange's equation, and designed a sliding mode controller (SMC) for the position control of a two-link flexible manipulator with PZT actuators and sensors [10]. Mirzaee et al. [11] investigated active vibration control of a two-link manipulator with PZT actuator and sensor, using a hybrid variable structure and Lyupunov based controller for maneuver tracking. Input preshaping controller is also applied for a two-link flexible manipulator [12]. An improved recursive least square-based adaptive input shaping is investigated for zero residual vibration control of flexible system [13]. A hybrid control scheme was designed to simultaneously suppress the excited and the residual vibration during and after the motor motion, for a macro-micro manipulator [14]. The hybrid control strategy is composed of a trajectory planning approach and an adaptive variable structure control. Experiments on an inner/outer loop controller for a two-link flexible manipulator are conducted [15].

Sometimes the model of a two-link flexible manipulator system is hard to formulate properly or is not known accurately. In addition, even if a relatively accurate model of the flexible robot can be developed, it is often too complex to be used in controller development [16]. Thus, non-model based intelligent control algorithms are considered for vibration suppression of two-link flexible manipulators. Moudgal et al. [16] proposed a rule-based fuzzy model reference learning controller for the tip position control and vibration suppression of a TLFM. Although FLC was successful used in control of FLM, the drawback, such as the establishment of fuzzy control rules is highly dependent on the experience and to achieve a smooth control response. Therefore, the number of rule bases rises exponentially, which increases the design difficulty. To deal with these problems, the fuzzy neural network (FNN) controller is proposed. FNN inherits the reasoning ability of FLC and the learning ability of artificial neural networks [17]. It is able to deal with nonlinearities and uncertainties of the control systems in the control fields. New fuzzy and neuro-fuzzy approaches to tip position regulation of a flexible link manipulator are presented in [18], and the proposed adaptive neuro-fuzzy controller (NFC) can tune the input and output scale parameters of the fuzzy controller on-line. Caswara and Unbehauen [19] used the neuro-fuzzy controller as a nonlinear compensator for a flexible four-link manipulator and achieved a tradeoff between the tracking accuracy and manipulator link vibration control. Fuzzy logic and artificial neural network have some similar properties. Both of them may be able to map the typical nonlinear relation of the input-output without a precise mathematical formula or model between the input and output variables [20]. An improved Takagi-Sugeno (T-S) fuzzy neural network has a compact structure, high training speed, good simulation precision, and generalization ability [20,21]. For limiting the transient amplitude of payload deflection transferred by crane and minimizing the residual vibration in the presence of system's parameters variation, Smoczek [22] investigated a generalized predictive control and linear parameter varying based approaches, with the recursive least squares method and P1-TS interpolator of model's parameters. Niu et al. [23] enhanced the classical filtered-x least mean square control algorithm to adaptively suppress the vibration of time-varying structures, such as the vertical tail of aircraft.

During operation of two-link flexible manipulators, the configuration changes and the analyses become very complicated, due to the flexibility of each link [4]. Self-tuning is an important branch of control. The objective of self-tuning is to control systems with unknown constant or slowly varying parameters, as a method for controlling time-varying or nonlinear plant over a range of operating points [24]. A nonlinear adaptive model predictive control is designed for tip position control of a flexible manipulator. And experiments are conducted, compared the effectiveness with that of a self-tuning control and a nonlinear adaptive controller [25]. A self-tuning controller is designed for the case in which a two-link flexible manipulator carries an unknown payload at the end point of the second link [26].

In consideration of the aforementioned advantages of the T-S FNN control and the self-tuning control, two adaptive control algorithms are developed controller for the vibration control of a two-link flexible manipulator. A two-link flexible manipulator experimental setup is constructed, using two AC servo motors with high-ratio speed reducer as actuators. PZT patch sensors are bonded on two flexible links to detect the vibration. Experiments are conducted, utilizing the designed T-S fuzzy model with neural networks and self-tuning controller. The GMVSTC control algorithm is made up by an online identifier in the form of controlled autoregressive moving average model and a vibration control signal generator. Also, the parameters identification is implemented by applying the recursive augmented least square estimation (RELS).

The rest of this article is organized as follows. System description is presented in Section 2. Controller design including the T-S FNN algorithm and the GMVSTC is described in Section 3. Section 4 presents the experimental results on vibration suppression of the two-link flexible manipulator using the T-S FNN algorithm and the GMVSTC strategies. Finally, the concluding remarks are presented in Section 5.

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