



Contents lists available at ScienceDirect

## Journal of Sound and Vibration

journal homepage: [www.elsevier.com/locate/jsv](http://www.elsevier.com/locate/jsv)

# Active vibration control of Flexible Joint Manipulator using Input Shaping and Adaptive Parameter Auto Disturbance Rejection Controller

W.P. Li, B. Luo, H. Huang

School of Astronautics, Beihang University, 37 Xueyuan Road, Beijing 100191, China

## ARTICLE INFO

## Article history:

Received 21 September 2014

Received in revised form

13 August 2015

Accepted 1 November 2015

Handling Editor: J. Lam

## ABSTRACT

This paper presents a vibration control strategy for a two-link Flexible Joint Manipulator (FJM) with a Hexapod Active Manipulator (HAM). A dynamic model of the multi-body, rigid-flexible system composed of an FJM, a HAM and a spacecraft was built. A hybrid controller was proposed by combining the Input Shaping (IS) technique with an Adaptive-Parameter Auto Disturbance Rejection Controller (APADRC). The controller was used to suppress the vibration caused by external disturbances and input motions. Parameters of the APADRC were adaptively adjusted to ensure the characteristic of the closed loop system to be a given reference system, even if the configuration of the manipulator significantly changes during motion. Because precise parameters of the flexible manipulator are not required in the IS system, the operation of the controller was sufficiently robust to accommodate uncertainties in system parameters. Simulations results verified the effectiveness of the HAM scheme and controller in the vibration suppression of FJM during operation.

© 2015 Elsevier Ltd. All rights reserved.

## 1. Introduction

Manipulators mounted on a space vehicle can perform various tasks, such as the building or operation of the International Space Station (e.g., inspection, logistic support, and rescue from orbit) and lunar or planetary explorations. However, the structural flexibility of manipulators may induce detrimental vibrations [1,2]. For large manipulators, joint flexibility is often considered to be more important than link flexibility, especially when considering the operation range [3]. For instance, in the remote manipulator system (RMS) of the Space Shuttle, approximately 1/3 of the time spent in RMS operation is used to wait for vibrations to decay to negligible values (e.g. for every 6 h of operation of the RMS during a space flight, the astronauts spend 2 h waiting for the vibrations to decay) [4]. Therefore, the elimination of the vibration caused by joint flexibility is an important issue for a Flexible Joint Manipulator (FJM). There have been extensive studies on control strategies for FJMs, including a Fuzzy Logic control [5], an adaptive control [6], neural network controls [7,8,9], robust controls [10,11], and a linear quadratic regulator [12].

Input Shaping (IS) is an effective technique for the vibration control of flexible structures. This method works by altering the shape of input commands to reduce the oscillation of the system response. The input command is convolved by a sequence of impulses, or the input shaper, to produce a shaped command that reduces vibration. Smith [13] first proposed a posicast control. Because of the sensitivity to frequency uncertainties, the original IS method was not widely used until more robust methods were developed by Singer et al. [14], who obtained promising simulation results in controlling the RMS of the Space Shuttle. Singhose et al. [15] developed an IS controller for slewing a flexible spacecraft. Song et al. [16] studied the

<http://dx.doi.org/10.1016/j.jsv.2015.11.002>

0022-460X/© 2015 Elsevier Ltd. All rights reserved.

application of the IS method for the vibration reduction of a flexible spacecraft with modulated thrusters. Banerjee and Singhose [17,18] proposed IS controllers for the minimum-time control of a two-link flexible manipulator. The effectiveness of IS method has also been demonstrated via large space-based antennae [19], cranes [20], flexible manipulators [21,22], and flexible spacecraft [23–25].

There are different input shapers in common use, such as a zero vibration (ZV) shaper, a zero vibration derivative (ZVD) shaper, a zero vibration derivative derivative (ZVDD) shaper [14], a specified insensitivity shaper [26], and an extra-insensitive shaper [24,27]. During the implementation of an input shaper, the main challenge is to account for system uncertainties due to model errors or changes of system parameters. If the system has a large range of varying or unknown frequencies, large residual vibration would result. One approach is to use adaptive input shapers. Tzes and Yurkovich [28] used a fast Fourier transform on a portion of a residual vibration to improve an estimate of the flexible system frequency. Bodson [29] used a recursive least squares technique to tune input shaper parameters. Pereira et al. [30] designed an adaptive input shaper for single-link flexible manipulators using an algebraic identification.

While IS is effective in preventing vibrations induced by input commands due to its feedforward feature, it is unable to suppress residual vibrations and vibrations elicited by outside disturbances. Multiple prior works have indicated that the IS deficiency could be overcome if the feedback controller is incorporated. Kong and Yang [31] proposed a control strategy that integrates IS with a PD feedback control for a vibration reduction of a flexible spacecraft. In their research, a feedback control is designed according to system performance requirements. Then, a robust multimode input shaper is fabricated based on the eigenvalues of the closed-loop system. Ahmad investigated an IS with an optimal state feedback [32] and a fuzzy logic law [33] for FJM vibration control. IS has also been combined with other controllers, such as a variable structure control [34] and a positive position feedback [35,36].

In this paper, a new hybrid controller is proposed for reducing FJM vibrations, which combines an IS technique with an Adaptive-Parameter Auto Disturbance Rejection Controller (APADRC) as a feedback controller. The prototype of the APADRC is an ADRC which was first proposed by Han [37] in the 1990s. Commonly, an ADRC includes a tracking differentiator, an extended state observer and a nonlinear feedback and is based on a traditional Proportion-Integral-Derivative (PID) and modern control theory. ADRC has been applied in solving control problems, such as nonlinear and inaccurately modeled systems [38,39] and the active vibration control of an intelligent truss [40]. For APADRC, an adaptive law is added to adjust feedback parameters. A linear extended state observer (LESO) and a linear feedback (LF) replace the corresponding parts of an ADRC. With this hybrid controller, IS is used to shape the FJM input command to minimize the flexible vibration induced by manipulation, while both residual and external vibrations are suppressed by the APADRC.

A Hexapod Active Manipulator (HAM), located at the bottom of the FJM, serves as a vibration control module (Fig. 1). The HAM includes 6 degrees of freedom (6-dof) and provides movement, large loading capabilities, a high stiffness and pose accuracy, a powerful architecture, and is configurable [41]. It can be used for the multi-axial vibration control of a structure even under a relatively large payload. There have been extensive studies on HAMs to vibration control, such as passive vibration isolation [42], active/passive vibration isolation/suppression with piezo-electric actuator [43,44] and active/passive vibration isolation/suppression/steering with voice-coil actuator [45]. In addition, ADRC controller is applied to the control of the Stewart platform by the scholars, and achieved good results, such as [46,47]. Literature [46] studied the experiments of active vibration control for flexible beam, with a HAM employed as an active equipment at the bottom of the beam. Experimental results show the rate of amplitude attenuation using ADRC is almost 10 times faster than the free attenuation. At the same time, the results verify the effectiveness of the control conducted by HAM. In this paper, HAM and FJM joint motors are utilized for vibration control and motion control, respectively. Under this control scheme, the controller design is simpler and clearer than the common scheme in which joint motors are used for both vibration control and motion control. In addition, the vibration control effect will be enhanced because the control force produced by the 6 parallel struts of the HAM is greater than those of the joint motors.

Compared with the aforementioned research efforts, though the IS and APADRC in our proposed design are without inside explicit interconnection, there are three advantages: (1) the hybrid controller can effectively suppress joint vibrations induced by the rigid motion of the FJM motors and external disturbances; (2) APADRC parameters can be adaptively adjusted to ensure the closed loop system with certain system characteristics to be a given reference system, that provides a

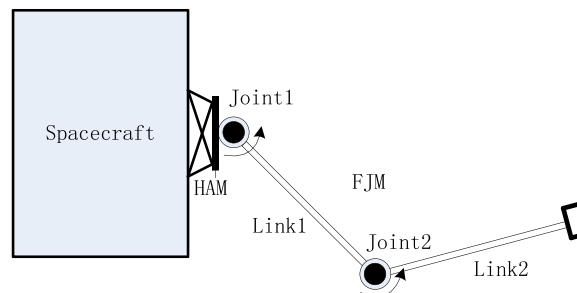


Fig. 1. Schematic of FJM System on free-floating base.

Download English Version:

<https://daneshyari.com/en/article/6754840>

Download Persian Version:

<https://daneshyari.com/article/6754840>

[Daneshyari.com](https://daneshyari.com)