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Trajectory control of a two DOF rigid–flexible space robot by a virtual space vehicle

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ABSTRACT

Model based control schemes use inverse dynamics of the robot arm to produce the main torque component necessary for trajectory tracking. For a model-based controller one is required to know the model parameters accurately. This is a very difficult job especially if the manipulator is flexible. This paper presents a control scheme for trajectory control of the tip of a two arm rigid–flexible space robot, with the help of a virtual space vehicle. The flexible link is modeled as an Euler–Bernoulli beam. The developed controller uses the inertial parameters of the base of the space robot only. Bond graph modeling is used to model the dynamics of the system and to devise the control strategy. The efficacy of the controller is shown through simulated and animation results.

1. Introduction

The flexible space robot will be useful for space application due to their light weight, less power requirement, ease of maneuverability and ease of transportation. Because of the light weight, they can be operated at high speed. For flexible manipulators flexibility of the manipulator have a considerable influence on its dynamic behaviors. It is observed by many researchers that fixed-gain linear controllers alone do not provide adequate dynamic performance at high speeds for multi-degrees-of-freedom robot manipulators. Out of various schemes studied so far, those involving the calculation of the actuator torque (force) using an inverse dynamics model (the computed torque methods), and those applying adaptive control techniques have been extensively studied, and show the greatest promise. In literature inverse dynamics models based on the trajectory pattern method have been reported [1]. Model based control schemes generally use the inverse dynamics of the robot arm to produce the main torque component necessary for trajectory tracking [2]. Thus, the nonlinearities are effectively compensated, and a linear controller, usually PD or PID, is used to provide any additional corrective torque needed for tracking. The inverse dynamics based control schemes have proven to be very effective in reducing tracking errors in robot manipulators [3]. The real time implementation of the model based control schemes has been possible in a powerful computational environment, especially when lightweight manipulators and high speed motions are involved. In order to reduce the computational delays associated with the model based control schemes, researchers have focused firstly on the development of methods allowing efficient and high speed use of the inverse dynamics model [2], and secondly on customization of the dynamics equations [4]. The customized nonlinear dynamic models are specific to a given manipulator; therefore the controllers using such models require significant modification when it is used with different robots.

The model based computed torque method, also known as nonlinear feedback control is based upon exact knowledge of the dynamic model of a robot manipulator, and therefore it may not be robust enough in the presence of modeling/parameter errors and external disturbances [5,6]. Zhu et al. [7] used an additional model-based parallel-compensator with a conventional model-based computed torque controller which is in the form of a serial compensator to enhance the robustness of robot manipulator control. Reyes and Kelly [8] described the experimental comparison among four model-based control algorithms on a direct-drive robotic arm. Fawaz et al. [9] presented a model based real-time virtual simulator of an industrial robot in order to detect the eventual external collision. The implemented method concerns a model based Fault Detection and Isolation. It is used to determine any lack

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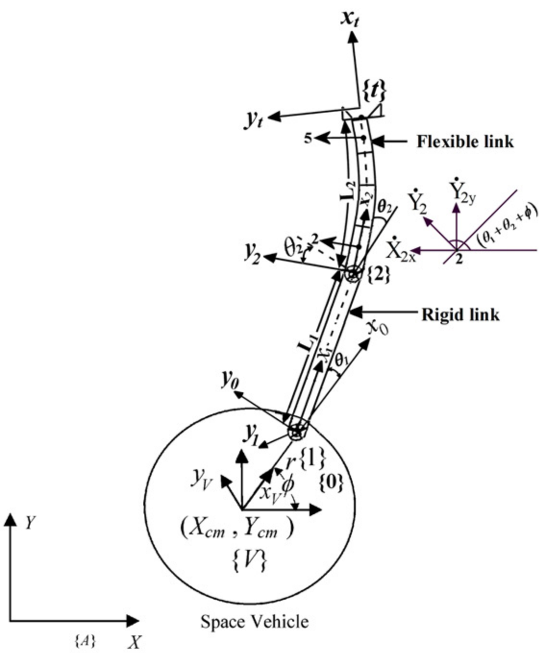

Fig. 1. Schematic representation of two arm rigid–flexible space robot.

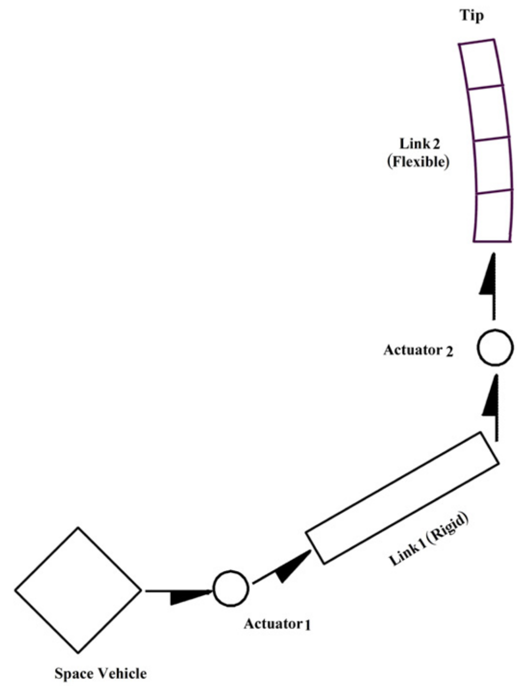

Fig. 2. Word bond graph of two arm rigid–flexible space robot.

of motion from an actuated robot joint after contact with static obstacles.

Researchers [10] have reported the inverse dynamics model-based control for flexible-link robots, based on model analysis. It is based on the assumption that the deformation of the flexible-link can be written as a finite series expansion containing the elementary vibration modes [10]. However, this inverse dynamics model-based control may result in unsatisfactory performance when an accurate model is unavailable, due to parameters uncertainty or truncation of high order vibration modes. Rigatos [11] presented a comparative study on representative methods for model-based and model-free control of flexible-link robots. Sueur and Dauphin-Tanguy [12] have elaborated the bond-graph modeling of flexible robots. They proposed a solution for improvement of the slow subsystem. Tso et al. [13] worked on a model-based control scheme for robot manipulators employing a variable structure control law in which the actuator dynamics is taken into consideration. Ho-Hoon Lee [14] developed a new trajectory control of a flexible link robot based on a distributed parameter dynamic model. Majda et al. [15] have provided a good comparison of different formulations of 2D beam elements based on the Bond Graph technique. Masoudi and Mahzoon [16] studied a free-floating space robot with four linkages, two flexible arms and a rigid end-effector that are mounted on a rigid spacecraft. Touati et al. [17] developed a procedure of fault detection and isolation by considering the presence of both parameter and measurement uncertainties for all linear time invariants and some classes of nonlinear systems using the bond graph approach. Borutzky and Dauphin-Tanguy [18] studied the incremental bond graph process as a starting point for setting up symbolically the canonical form as well as the standard interconnection form of state equations used for robustness.

The work is motivated with the aim of designing a controller for a rigid–flexible space vehicle, where the controller does not requires the flexible or rigid link parameters information. This paper presents the control of a rigid–flexible space robot with the help of a virtual space vehicle. The controller requires the information of the base of the space robot and tip velocity information of the manipulator. A robust overwhelming controller is used along with a virtual space vehicle to control the tip velocity of the rigid–flexible space manipulator. To illustrate the methodology, an example of a two DOF rigid–flexible space robot is considered. Bond graphs are used to represent both rigid and flexible body dynamics of the link in a unified manner.

2. The two arm rigid–flexible space robot

The modeling of the space robot involves the modeling for linear and rotational dynamics of the links and the base of the space robot. For modeling it is assumed that the space robot system has a single manipulator with revolute joints and is in an open kinematic chain configuration.

Fig. 1 shows the schematic sketch of a two arm rigid–flexible space robot. In this figure $\{A\}$ represents the absolute frame, $\{V\}$ represents the vehicle frame, $\{0\}$ frame is located in the space vehicle at the base of the robot, $\{1\}$ frame is located in the first arm at the first joint, and $\{2\}$ frame is located in the second joint. The frame $\{t\}$ locates the tip of the robot. Let L_1 be the length of the first rigid link, L_2 be the length of second flexible link and r is the distance between the frame $\{0\}$ and frame $\{V\}$. The flexible link is divided into four segments of equal length (i.e., each segment length is $L_2/4$). Let ϕ represent the rotation of the vehicle frame with respect to an absolute frame $\{A\}$, and θ_1, and θ_2 be the joint rotation of the first and second joint at any instant as shown in Fig. 1. It is further assumed that cross section areas of the second links be A_2, and the density be ρ_2.

The flexible link has uniform cross section and it has flexible–rigidity EI where E is the modulus of elasticity of the link material and I is the moment of inertia of the cross section of the link.

3. Bond graph modeling

The word bond graph of the two arm rigid–flexible space robot is shown in Fig. 2. The kinematic analysis of flexible and rigid links is performed in order to draw the bond graph as shown in Fig. 3(a). From the kinematic relations the different transformer moduli used in the bond graph are derived. The flexible link of