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Extended Multiple Impedance Control of a Space Robot with Flexible Members

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ABSTRACT

Dynamics and control of a space robotic system with flexible members during an object manipulation task is studied here. Flexible members such as solar panels of space free flying robotic systems and their flexible joints during a manoeuvre may get stimulated and vibrate. Therefore, such vibrations will cause some oscillatory disturbance forces on the moving base and manipulated object, which in turn produces error in the position and speed of the manipulating end-effectors. In this paper, considering a multiple arm space robotic system with flexible joints and flexible solar panels, the system dynamics is partitioned into two rigid and flexible bodies' motion, and a concise model for control implementations of compounded rigid-flexible multi-body systems is developed. Then, based on a designated path/trajectory for a space robotic system, the multiple impedance control is extended to perform an object manipulation task by such complicated rigid-flexible multi-body systems. Finally, a space free flying robotic system is simulated which contains two manipulators with flexible joints, and a rotating antenna and a camera as its third and fourth arms, appended with two flexible solar panels. Obtained results reveal the merits of the proposed controller to successfully perform the manipulation task and effectively suppress the vibration of flexible elements.

KEYWORDS

Space Robot, Multiple Impedance Control, Flexibility, Object Manipulation.

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1- INTRODUCTION

Robotic manipulators are widely used in unsafe, costly, and repetitive boring tasks. Most available robotic manipulators are designed such that they can provide essential stiffness for end-effectors to reach their desired position without any vibration. This stiffness is usually attained by massive links. Consequently, the design and use of weighty rigid manipulators may be deficient in energy consumption and the speed of operation, particularly in space applications. On the other hand, existence of flexible components on robots requires considering their effect. The needed settling time for vibration of such parts can delay the operation and thus conflicts with time limitations. This conflict of high speed and high accuracy in operations makes a challenging research problem, [1-5].

Controller design for multi-body systems with flexible members requires development of a proper dynamics model of such systems. Such models are also required to be as concise as possible for implementation of model-based control algorithms. In most researches on dynamics analyses, the modelling approach introduces an accumulation in the dynamics of rigid-flexible multi-body systems, [6-7]. Thus, a variety of methods are used in these dynamics modelling approaches, while the modelling approach does not affect their non-model based control design. To study the dynamics of a rigid-flexible multi-body space system, an inertia frame is used as a universal reference frame. Moreover, an intermediate reference frame is attached to each flexible or rigid body which is usually called the floating frame. The motion relative to this intermediate frame for flexible parts occurs because of the body deformation only. This selection simplifies the calculations of internal forces since the magnitude of the stress and strain does not vary under the rigid body motion. To develop a dynamics model of such systems, various approaches have been used, including the Lagrange method, [5,8], Hamilton principal, [9], Newton-Euler equations, [10], the virtual work principal, [11], and Kane method [12].

On the other hand, control of flexible multi-body systems is currently an attractive research subject because of its application in the flexible robot manipulators and the articulated space structures [13]. This depends on determining the actuator torques such that they can produce the desired motion of such a complicated multi-body system. In other words, the inverse dynamics become part of controller design, though the controller can be directly applied on a physical system without using a numerical model [3]. Also, in modelling flexible systems, accuracy of an obtained analytical dynamics model depends on the bodies deformation. In addition, deformation of the robots with flexible joints and links are certainly different from the robot with rigid joints and flexible links. So, we study these type of robots.

In this paper, after expressing the dynamics model of a space robot with rigid links and flexible joints, the dynamics model of flexible solar panels is appended. Then, the total dynamics equations of motion are studied. Next, in order to perform an object manipulation operation along a designated path/trajectory by this flexible-rigid multi-body system, the Multiple Impedance Control (MIC) is extended. Finally, using comprehensive simulation routine, obtained results of the implementation of this controller on the space robot will be discussed.

2- DYNAMICS MODELLING

In fact, the Rigid-Flexible Interactive Modelling (RFIM) approach for dynamics modelling decouples motion equations of rigid members from those of flexible members. Therefore, simpler sets of dynamics equations will be achieved so that the obtained model can be used for model-based controllers. Thus, this approach can be developed for two subsections. First, the usage of this approach for modelling bulk flexible members in a multiple rigid body system such as flexible joints in a robotic system with rigid links will be detailed. Next, this approach can be extended for modelling continuous flexible members such as flexible appendages. To this end, using floating frames under the assumption of large displacements and rotations, the situation of each flexible body in the multi-body system is specified by two sets of reference and elastic variables. The reference variables define the situation and the orientation of the considered body while the elastic coordinates describe the body deformations relative to the body reference. To avoid computational difficulties associated with infinite-dimensional spaces, the latter is introduced using classical approximation techniques such as the Rayleigh–Ritz method. Thus, the kinetic energy of a flexible body is developed and the inertia coupling between the reference motion and the elastic deformation is determined.

Hence, the dynamics equations of a space robot with rigid components were previously obtained. Considering joint flexibility, the dynamics model of the rigid space robot is modified and expressed as:

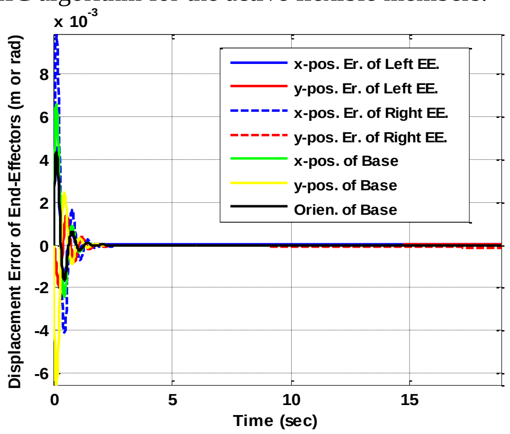
$$\begin{aligned}&\mathbf{H}(\boldsymbol{\beta}_0,\boldsymbol{\theta})\,\ddot{\mathbf{q}}+\mathbf{C}_1(\boldsymbol{\beta}_0,\dot{\boldsymbol{\beta}}_0,\boldsymbol{\theta},\dot{\boldsymbol{\theta}})\,\dot{\mathbf{q}}+\mathbf{C}_2(\boldsymbol{\beta}_0,\dot{\boldsymbol{\beta}}_0,\boldsymbol{\theta},\dot{\boldsymbol{\theta}})=\\&\qquad\mathbf{Q}(\boldsymbol{\beta}_0)+\mathbf{K}(\boldsymbol{\alpha}-\boldsymbol{\theta})+\mathbf{Q}_{\text{flex.}}(\boldsymbol{\beta}_0)\\&\mathbf{J}\ddot{\boldsymbol{\alpha}}+\mathbf{K}(\boldsymbol{\alpha}-\boldsymbol{\theta})=\mathbf{Q}(\boldsymbol{\theta})\end{aligned}\qquad(1)$$

where $\mathbf{Q}_{\text{flex.}}(\boldsymbol{\beta}_0)$ is the generalized resultant forces/torques applied on the main body of the space robot due to vibrating motion of the flexible solar panels.

3- MULTIPLE IMPEDANCE CONTROL

Three main issues that make the control problem of flexible multi-body systems more complicated than control of rigid systems should be mentioned here. First, the number of degrees of freedom is much larger than the number of actuators. The second issue is related to wave propagation delays. An action at one end of a flexible

beam takes time to propagate to its tip. The third one is reversal action. This effect can be observed in a rotating flexible beam. When a torque is applied to the beam in one direction, its tip position initially moves in the opposite direction. On the other hand, there are two main requirements for a flexible multi-body system controller. These are fast and precise response in following the desired trajectory. These two requirements are usually in conflict. The faster the controller the less accurate it is, and vice versa. Several types of control laws have been proposed each offering benefits under some conditions. So, more than one type of control law is often used.
By noting some considerations in path planning such as constant velocity path for the robot base, or at least not inducing on-off impact disturbances for passive members or flexible solar panels, this controller can successfully perform the object manipulation task. As shown in the figure below, these control methods can perfectly control the object motion along the designated circular path for an operation. Where these flexible members will possibly have an effect on this operation, they may even result in its failure. In addition, we note that although the MIC law has shown a more reliable performance compared to other object manipulation algorithms for the same controller's gains, in the case of flexible-rigid systems, this algorithm may face crucial difficulties. However, the object manipulation operation can be done by noting the mentioned considerations in path planning for the passive flexible members, and introducing some modifications to the MIC algorithm for the active flexible members.



4- CONCLUSIONS

In this article, after expressing the dynamic equations of the rigid subsystem with flexible joints, those of the flexible solar panels and appendages were developed. Then, these two sets of equations were combined to obtain a practical dynamic model for the whole compounded space robotic system. Next, considering the planned trajectory for an object manipulation operation, the extended MIC algorithm was implemented on the whole system. Finally, the obtained results were studied by a comprehensive simulation routine. It was shown that vibration of the flexible solar panels and the flexible joints results in generalized forces that disturb the robot, and may produce undesirable errors of the end-effectors. These effects were eliminated by taking some considerations into account in path planning for the passive flexible members, also introducing some modifications to the MIC algorithm for the actuated members.

5- REFERENCES

[1] Peggy, P., and Dubowsky, S.,"Coordinated Control of Space Robot Teams for the On-Orbit Construction of Large Flexible Space Structures", Journal of Advanced Robotics, 24(3), pp. 303-323, 2010.

[2] Wasfy, T. M., and Noor, A. K. ,"Computational strategies for flexible multi-body systems", Applied Mechanic Review, 56(6), pp. 553-613, 2003.

[3] Dwivedy, S. K., and Eberhard, P. ,"Dynamic analysis of flexible manipulators, a literature review", Mechanism and Machine Theory, 41, pp. 749–777, 2006.

[4] Korayem, M. H., and Basu, A. ,"Dynamic load carrying capacity of mobile-base flexible joint manipulators", The International Journal of Advanced Manufacturing Technology, 25(1–2), pp. 62–70, 2005.

[5] Liu, S., Wu, L., and Lu, Z. ,"Impact dynamics and control of a flexible dual-arm space robot capturing an object", Applied Mathematics and Computation, 18(5), pp. 1149–1159, 2007.

[6] Ebrahimi, A., and Moosavian, S. Ali A. ,"Dynamics of Space Free-Flying Robots with Flexible Appendages", Iranian Journal of Science and Technology, 4(4), pp. 29-36, 2008.

[7] Jiang, Z. H. ,"Impedance Control of Flexible Robot Arms with Parametric Uncertainties", Journal of Intelligent and Robotic Systems, 42(2), pp. 113-133, 2005.

[8] Boscariol, P., Gasparetto, A., and Zanotto, V., "Model Predictive Control of a Flexible Links Mechanism", Journal of Intelligent and Robotic Systems,58(2), pp. 125-147, 2010.

[9] Lippiello, V., Siciliano, B., and Villani, L. ,"A Position-Based Visual Impedance Control for Robot Manipulators", IEEE International Conference on Robotics and Automation, Italy, 2007.

[10] Kilicaslana, S., Ozgörenb, M. K., and Iderb, S. K., "Hybrid force and motion control of robots with flexible links", Journal of Mechanism and Machine Theory, 45(1), pp. 91–105, 2010.

[11] Kasai, Sh., and Kojma, H. ,"Input-Shaped Link Motion Control of Planar Space Robot Equipped with Flexible Appendage", Transactions of the Japan Society for Aeronautical and Space Sciences, 55(4), pp. 205-213, 2012.

[12] Sabatinia, M.,Gasbarrib, P., Montib, R., and Palmerinia, G. B. ,"Vibration control of a flexible space manipulator during on orbit operations", ActaAstronautica, 73, pp. 109-121 , 2012.

[13] Bascettaand L., Rocco P. ,"End-point Vibration Sensing of Planar Flexible Manipulators Through Visual Serving", Mechatronics, 16(3-4), pp. 221-232 , 2006.