OPTIMAL FEEDBACK LINEARIZATION CONTROL OF A FLEXIBLE CABLE ROBOT

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Abstract — In this paper the flexible cable robot tracking is controlled using optimal feedback linearization method. Feedback linearization is used to control the robot within a predefined trajectory while its controlling gains are optimized using LQR method to achieve the maximum payload of the end-effector in presence of flexibilities. Required motors’ torque and tracking error caused by flexibility uncertainties are calculated for a predefined trajectory of an under constrained cable robot with six Degrees of Freedom (DOF) and six actuating cables while its cables are considered elastic. Robust controller is also designed and added to the controller to ensure the accuracy and stability of the system and cancel any disturbing effects of the uncertainties. A series of analytic simulation study is done for the mentioned spatial cable robot to show the flexibility effect on dynamic performance of the robot and also prove the superiority of the proposed optimal control strategy to compensate these flexibilities. Finally the results are compared and verified with experimental results of the cable robot of ICarShot to verify the proposed controlling strategy for controlling the mentioned flexible robot and also prove the correctness of the simulations.

Keywords — Cable Robot, Flexible Cables, Optimal Feedback Linearization Control

I. INTRODUCTION

Cable suspended robots provide lighter manipulators which can carry higher loads compared to their weight (Albus et al., 1993). Considering parallel nature and non linear dynamics of this kind of robots and positive tension restriction of the cables, the control procedure of them is more challenging. On the other hand cable robots cannot always be considered as a rigid system (Williams and Gallina, 2001; Alp and Agrawal, 2002) while parametric uncertainties like elasticity at the joints and also cables can make considerable effect on its performance. In order to predict the behavior of the robots with flexible cables, it is highly significant to model and simulate these elasticities and design suitable controller to compensate their probable uncertainties.

Optimal control of rigid cable robots, is performed (Korayem et al., 2012a) using open loop approach i.e. Hamilton-Jacobi-Bellman Method and in another research (Korayem and Tourajizadeh, 2011) using closed loop approach i.e. LQR. Korayem et al. (2010a) considered flexibility of the motors and dynamics of this flexibility is modeled. Then the optimal path of this flexible joint cable robot is obtained for the open loop condition. Elasticity of the cables and controlling this elasticity has become one of the most challenging studies recently. Flexible dynamics of a cable robot is coupled with the dynamics of the end-effector (Zhang et al., 2006). Also a workspace study of this kind of robots is conducted by Korayem et al. (2007). A different method to control a flexible cable robot is presented by Baicu et al. (1996) using active boundary control. State Dependent Riccati Eq. (SDRE) is used to optimal control of a flexible cable robot with variable length (Zhang et al., 2005). Zhang (2004) has used H-infinity and delta flatness method to damp the vibrating response of the flexible cables. LQG is used to perform the optimization process here. Optimal force distribution is considered for a crane with flexible cables (Shiang et al., 2000). Also optimal control of cable robot is studied in an open loop way using Iterative Linear Programming (ILP) which is not robust against flexibility uncertainties and its performance is not suitable since its controller is not closed loop (Korayem et al., 2010b). Korayem et al. (2012b) implemented optimal sliding mode controller for cable robot, however, the uncertainties and flexibility of the cables were not considered in their study.

In this paper the control of closed loop rigid cable robot which acts based on optimal feedback linearization theory is extended for robots with flexible cable. Flexibilities are modeled and proper optimal controlling strategy is proposed to increase the accuracy and stability. Converting the system to linear states makes it possible to use LQR as the optimizer tool. While the system is supposed to be flexible, the states of the system increases and vibrating equation of the flexible parts needs to be coupled with the dynamics of the main system. Because of existence of flexibility, the system might be faced to parametric uncertainties since the exact value of the stiffness is not always exactly available. While these uncertainties can cause instability in the system, additive robust control is added to the system to cancel the effects of mentioned uncertainties or external disturbances. Thus, in this paper not only the flexibilities are modeled, but also their parametric uncertainties are compensated using robust feedback linearization. Feedback linearization is extremely applicable in experimental applications, since other possible nonlinear controllers have heavy calculation processes which are not suitable for online applications. By the aid of modeling the flexibilities and also using the proposed robust feedback linearization method, not only the large displacement of the end-effector can be controlled fast and in an...