Dynamic Analysis and Control Synthesis of a Space Tethered Robot System

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Dynamic modeling and control of a tethered space robot is studied in this paper. The librational motion of the tether as well as all the dynamic interactions between the tether and the robot are considered in the analysis. A hybrid computed torque method (CTM) and model predictive control (MPC) are used to control both the librational motion of the tether as well as the robot motion. The CTM part regulates the robot actuators and is used to control the robot motion, while the MPC part is used to change the tether length in order to suppress the tether librational motion. Performance of the proposed controller is analyzed by simulating the controlled system numerically.

Key Words: Tethered space robot system, Model predictive control, Hybrid control system

Nomenclature

a	:	Link center of mass position
I	:	Moment of inertia about center of mass
K		Controller gain matrix
m	:	Mass
R_c	:	Orbital motion radius
T	:	Kinetic energy
V	:	Potential energy
x, y	:	x and y coordinates
ℓ	:	Length
$\hat{\ell}$	:	Non-dimensional length (ℓ / R_c)
α	:	Tether liberation
θ	:	Link relative rotation
ρ	:	Tether mass per unit length
σ	:	non-dimensional time
τ	:	Actuating torque
Ω	:	Orbital motion angular velocity
ν	:	Non-dimensional mass
$()_1$	:	Link 1
$()_2$	:	Link 2
$()_d$	:	Desired value
$()_e$	:	endeffector
$()_\alpha$	:	Corresponding to liberational motion
$()_\theta$	:	Corresponding to manipulator motion
$\overline{()}$	:	Value at equilibrium configuration
$()'$	:	Time derivative w.r.t. non-dimensional time

1. Introduction

Tethered space robot (TSR) is a new concept in space robotic applications. The main objective of using a TSR is to increase the workspace of the space robot. Generally speaking, tethered robot systems can be divided in to two types: tethered space robots and tethered terrestrial robots. Underwater marine rovers are a type of tethered terrestrial robot [1]. Space tethered autonomous robotic satellite (STARS) [2], tether-net space [3] and tethered space manipulators [4] are some examples of the TSRs proposed. Although tethered underwater robots have been used for several decades, the concept of tethered space robots is relatively new and no such robot has been used in practice yet.

The literature on terrestrial tethered robots is extensive. On the other hand, that on tethered space robots is quite limited. Although there is some similarity between the dynamics and control of the two types of tethered robots, there is also a large number of differences, and one cannot directly transfer the control methods from the terrestrial case to the TSR. Nohmi etal. [5] were probably the first to study the control of a tethered space robot that involved a spacecraft mounted manipulator. A year after that, they extended their study to a tethered compact body with a massless and variable length tether [6]. Woo and Misra [4] studied kinematics and dynamics of tethered space manipulators. They studied planar motion of a TSR and determined a possible trajectory of the system in the joint space for given initial and final positions of the end-effector, using convergent Newton's method.

Although the TSRs have certain advantages such as larger accessible area, they also suffer from some disadvantages, especially the librational motion of the tether. Control of the librational motion of tethered systems has been studied extensively during the last three decades. Stability and control of in-plane and out-of- plane librational motion of a system consisting of two point masses connected by a massless and constant length tether in three dimensional space have been studied in [7]. In [8] control of tether librational motion in an elliptical orbit was analyzed considering constraints in the tether tension.