Chapter 17

Kinematics and Dynamics Modeling of a New 4-DOF Cable-Driven Parallel Manipulator

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ABSTRACT

This paper addresses the kinematics and dynamics modeling of a 4-DOF cable-driven parallel manipulator with new architecture and a typical Computed Torque Method (CTM) controller is developed for dynamic model in SimMechanics. The novelty of kinematic architecture and the closed loop formulation is presented. The workspace model of mechanism’s dynamic is obtained in an efficient and compact form by means of natural orthogonal complement (NOC) method which leads to the elimination of the nonworking kinematic-constraint wrenches and also to the derivation of the minimum number of equations. To verify the dynamic model and analyze the dynamical properties of novel 4-DOF cable-driven parallel manipulator, a typical CTM control scheme in joint-space is designed for dynamic model in SimMechanics.

DOI: 10.4018/978-1-4666-3634-7.ch017
INTRODUCTION

Cable-driven parallel manipulator is a special class of parallel manipulator in which the moving platform is driven by cables, instead of rigid links. In recent years, these manipulators have been researched extensively (Ebert-Uphoff & Voglewede, 2004; Kawamura, Kino, & Won, 2000; Albus, Bostelman, & Dagalkisi, 1993; Mustafa, Yang, Yeo, Lin & Chen, 2008; Homma, Fukuda, Sugawara, Nagata, & Usuba, 2003; Takemura, Enomoto, Tanaka, Denou, Kobayashi, & Tadokoro, 2005). Because of their advantages to provide a light-weight structure, low inertial properties, and large reachable workspace. A cable robot has a light-weight structure with low moving mass because the actuators are always mounted onto the base and the driving cables have negligible masses. Large workspace is achievable for a cable robot since the cables can be wound onto drums to provide infinite length, unlike the rigid cables with fixed lengths. These advantages make the cable manipulator a promising candidate for applications requiring high speed, high acceleration, and high payload but with moderate stiffness and accuracy (Ming & Higuchi, 1994; Ebert-Uphoff & Voglewede, 2004; Kawamura, Kino, & Won, 2000; Albus, Bostelman, & Dagalkisi, 1993; Mustafa, Yang, Yeo, Lin & Chen, 2008). Other advantages of these robots include their scalability, adaptability, and safety. As results, cable robots have been employed for long-range position measurement devices (Takemura, Enomoto, Tanaka, Denou, Kobayashi, & Tadokoro, 2005), service robots (Takahashi & Tsubouchi, 2000; Mustafa, Yang, Yeo, Lin, & Chen, 2008), and rehabilitation systems (Homma, Fukuda, Sugawara, Nagata, & Usuba, 2003). It is noted that the unilateral driving property of cables makes the well-developed modeling and analysis methods for conventional rigid-cable parallel manipulators not applicable to cable robots.

There is much prior work in kinematic, static, and dynamic analysis of cable robotic systems. Analysis, simulations and detail hardware implementation of cable-driven robots provided in (Williams & Gallina, 2001). Dynamic analysis of cable array robotic cranes is presented in Shiang, Cannon, and Gorman (1999) in the case of rigid cables and in Shiang, Cannon, and Gorman (2000) for flexible cables. The governing equations of motion for the parallel manipulators could be derived by Newton-Euler method (Fattah & Kasaei, 2000), Lagrange formula (Guo & Li, 2006) and screw theory (Kong & Gosselin, 2005). Other work in design and control of fully constrained cable driven robots includes the WARP (Maeda, Tadokoro, Takamori, Hiller, & Verhoeven, 1999) and FALCON (Kawamura, Choe, Tanaka, & Pandian, 1995) systems. Prior art in trajectory control of under-constrained cable robots is somewhat limited. The authors of Yamamoto, Yanai, and Mohri (2004) employ inverse dynamics and feed-forward and feedback control method to provide trajectory control of an incompletely constrained wrench-type cable robot with mobile actuators. Control is achieved through a PD controller and a pre-compensator. The authors of Alp and Agrawal (2002), Basar and Agrawal (2002), and Oh and Agrawal (2005) provide simulation and experimental results of two closed-loop asymptotic control mechanisms based on Lyapunov design techniques and feedback linearization respectively. Moreover, isotropic design of spatial cable robots, particularly a 6-6 cable-suspended parallel robot is studied in Hadian and Fattah (2008). Dexterity analysis of a 3-DOF cable-driven parallel manipulator with a new architecture based on distribution of tension among cables as well as robot stiffness is conducted in Hadian and Fattah (2009).

However, to the best knowledge of the authors, the proposed novel cable-driven manipulator in this paper has not been presented elsewhere. In this paper we address the kinematics and dynamics modeling of a cable-driven parallel manipulator with a new architecture supposed to be used for the moving mechanism of a flight simulator. The merits of this type of architecture, as compared with conventional type like Stewart platform, are independent and low degrees of freedom (DOF),
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