Chapter 18

Kinematic Isotropic Configuration of Spatial Cable-Driven Parallel Robots

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ABSTRACT

In this paper, the authors study the kinematic isotropic configuration of spatial cable-driven parallel robots by means of four different methods, namely, (i) symbolic method, (ii) geometric workspace, (iii) numerical workspace and global tension index (GTI), and (iv) numerical approach. The authors apply the mentioned techniques to two types of spatial cable-driven parallel manipulators to obtain their isotropic postures. These are a 6-6 cable-suspended parallel robot and a novel restricted three-degree-of-freedom cable-driven parallel robot. Eventually, the results of isotropic conditions of both cable robots are compared to show their applications.

INTRODUCTION

Cable robots are typically of a kinematic structure similar to parallel manipulators. The key difference, however, is that while the legs of a parallel manipulator impose bidirectional constraints, the cables of a cable robot impose unidirectional constraints, since a cable can only pull, not push. This difference makes it impossible to transfer many of the more advanced analysis tools used for parallel manipulators to cable robots. Instead, many tools from grasping are more suitable, since the fingers of a grasp are also unidirectional (each finger can only push, not pull). This mathematical connection has been pointed out by several researchers (Voglewede & Ebert-Uphoff, 2005).

However, Cable robots are a kind of parallel manipulators that consists of a MP connected in parallel to a base by light weight cables and driven actuators that enable controlled release of cables.
The motors and pulleys are mounted on the base platform and positioned in the extremities of the robot workspace. The motors can control the moving platform by extending or retracting the cables around the pulleys. Cable robots have several advantages in comparison with conventional parallel manipulators: 1) low inertial properties and high payload-to-weight ratio due to few moving parts, 2) potentially large workspace, since the cables may support a wide range of motion of MP, 3) reconfigurability because of remote location of motors and controls, 4) rapid deployability for their simple components, 5) economical construction and maintenance.

Due to these characteristics, cable robots are ideal for many applications, such as locomotion interface using two cable-driven parallel mechanisms (Perreault & Gosselin, 2007), handling of hazardous materials and disaster search and rescue efforts (Bosscher, Williams, & Tummino, 2005), a balloon cable-driven robot for information collection from sky and search strategy at a major disaster (Takemura et al., 2005), ultra-high-speed cable robot for pick-and-place applications (Dekker, Khajepour, & Behzadi, 2006), radiotelescope application by using workspace optimization of a very large cable-driven mechanism (Bouchard & Gosselin, 2007), gait rehabilitation that deploys a fully-constrained cable robot consists of eight cables (string-man) (Surdilovic & Bernhardt, 2004), and a 5 degrees-of-freedom wire-based robot (NeRe-Bot), designed for the treatment of patients with stroke-related paralyzed or paretic upper limb during the acute phase (Rosati, Gallina, Masiero, & Rossi, 2005).

There are many research works in optimal design and synthesis of rigid-link mechanisms and cable manipulators (Alici & Shirinzadeh, 2004; Li & Xu, 2006). Isotropic design of two types of spatial parallel manipulators: a three-degrees-of-freedom and the Stewart-Gough platform has been studied (Fattah & Ghasemi, 2002), a geometrical approach for the study and design of cable parallel robots are presented in (Behzadipour & Khajepour, 2004), best design for planar cable-direct-driven robot and haptic interfaces with one degree of actuation redundancy has been studied in Williams and Gallina (2002), complete kinematic and manipulability analyses for a planar 4 wire driven 3-DOF mechanism are presented in Gallina and Rosati (2002), analysis of the best kinematic performance for a 6-6 cable-suspended parallel robot is conducted in Hadian and Fattah (2008). Recently, there are some important investigations on the workspace of cable robots (Brau, Gosselin, & Lallemand, 2005; Gouttefarde & Gosselin, 2006; Bosscher & Riechel, 2006; Diao & Ma, 2007; Bruckmann, Mikelsons, Hiller, & Schramm, 2007; Gouttefarde, Merlet, & Daney, 2006; Verhoeven & Hiller, 2002). However, to the best knowledge of the authors, there is not any research work on the isotropic posture of cable robots. The kinematic isotropic configuration deals with Jacobian matrix which relates the input and output velocity of a system, i.e., a manipulator with kinematic isotropic configuration has the best kinematic performance and does not have any singularity configuration in its entire workspace. Isotropicity of a robotic manipulator is related to condition number of its Jacobian matrix, which can be obtained using singular values.

The key contribution of this paper is investigation of kinematic isotropic posture of cable robots. This can be done using the following four techniques: a) symbolic computation to obtain the isotropic and cable tension conditions, b) geometric workspace to determine the range of motion of MP without singularity, c) numerical workspace and GTI as objective functions to optimize the design parameters of robot, and d) numerical scheme to calculate the isotropic configuration of cable robots. Although first two techniques have already reported in the literature (Fattah & Ghasemi, 2002; Bosscher, Riechel, & Ebert-Uphoff, 2006), however in this research work, we intend to apply these methods to two
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