Analytical Workspace Delineation of a Translational Underconstrained Cable-based Robot

S. J. Torres-Mendez, J. R. Mendoza-Vazquez, V. Ramirez-Palacios, I. D. Rojas-Cuevas
Mechanical Engineering
Technological Institute of Puebla
Puebla, Puebla, Mexico
serm7007@yahoo.com.mx

***Abstract*— This paper presents the analytical controllable workspace boundaries of a crane-type cable-based robot with purely translational motions. The underconstrained cable robot is composed of eight cables which support the weight of a mobile platform, restricting its motions into the vertical plane of a static platform. The analytic equations are developed so that its workspace fulfills the tensionable condition for a given set of minimum and maximum tension limits. The all-tensionable workspace is obtained by analyzing slackness conditions with constant orientation of the mobile platform and by solving the all-positive cable tension redundancy. The minimum two-norm cable tension formulation results in a quadratic equation which admits a minimum value by equaling its derivative to zero.**

Keywords—cable-based robots; analytical workspace; controllable workspace; design

I. Introduction

Cable-based robots consist of a suspended mobile platform connected via flexible links (cables, wires) to a surrounding static platform. Cables reduce the robot weight because they are almost massless and also eliminates the use of revolute and prismatic joints. Thus, cable-based robots are characterized by their low-inertia and large-workspace attributes, which make them suitable for reconfigurable, huge-space, high load/power ratio, and high-speed applications. Based on the classification proposed by Yamamoto [1] and Bosscher [2], underconstrained robots need gravity in order to determine their position. The NIST robocrane [3] and the SkyCam [4] are examples of these robotic devices. Although cable-based robots are similar in structure and architecture to rigid-link parallel manipulators, their design development and mechanical analysis are quite different because of the elastic properties of cables.

Underconstrained robots can be distinguished from the rigid ones because the motion and force generation of the mobile platform is accomplished by controlling both the cable lengths and the positive cable tensions, respectively. The designs of cable-based robot manipulators reported in the literature are less frequent than those for parallel robots with rigid links. Among the first designs of cable-based robots are the NIST Robocrane [3]. The NIST Robocrane, also called by Yanai et al. [5] a Crane type manipulator, has a suspended mobile platform connected by six cables to a fixed platform. Based on the NIST Robocrane, the patented device SkyCam was developed by Brown [4] with a camera suspended from a four-cable-driven system with manual control. It is used in indoor locations such as stadiums and arenas.

In general, a cable-based robot losses tensionability (positive tension cannot be exerted on all cables at the same time) when the mobile platform falls into the neighborhood of a singular configuration. Consequently, the control of the mobile box is impossible; that is, the mobile box makes only ineffectual shaking motions, even though the length of each cable has not changed, Hiller et al. [6]. Su et al. [7] recommend changes in the cable-based robot design when there are near-singularity configurations that affect a system's controllability: rearrangement of the attached point on the mobile box and modification of the location of the anchor points in the static box. Lahouar et al. [8] adapt the path planning methods of serial manipulator by modeling singularities as obstacles in an under-constrained spatial four-cable driven robot. Qiu et al. [9] eliminate the force singularity of a large-scale cable robot by adding one more cable to the lower part of a large-scale crane design for radio telescope applications.

Several methods have been proposed for evaluating whether a given design meets all-positive cable tension requirements. Force-closure method gives conditions in which a given configuration can support any arbitrary wrench applied to the mobile platform if unbounded positive cable tensions are allowed [10] and [11]. Supposing a non-singular pose, Ming and Higuchi [12] solved the force equation by using the pseudoinverse formulation and determine the force-closure condition if the nullspace of the structure matrix (a transpose of the Jacobian matrix) is always positive. Workspace analysis methods can be identified by the inclusion of the following criteria: kinematic and force singularities, external wrenching applied to the mobile box, stiffness, interference, and gravitational force. Thus, several shapes and sizes of workspaces can be identified and depicted. The process of selecting an appropriate criterion may be reduced by identifying the existing correlation between the workspace with the type of cable-based robot and the task to be accomplished. Moreover, depending on the type of criterion selected, it is possible to propose changes in the configuration of a cable-based robot in order to expand its workspace. Bruckmann et al. [13] suggest starting the workspace analysis with the force singularity condition (force-closure workspace); that is, the identification of all possible mobile-box poses where cable

This work was supported in part by the National Institute Technology of Mexico under Grant 5835.16-P.