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ScienceDirect

Procedia CIRP 70 (2018) 290–295

www.elsevier.com/locate/procedia

28th CIRP Design Conference, May 2018, Nantes, France

Design of a Cable-Driven Parallel Robot with Grasping Device

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Abstract

Cable-Driven Parallel Robots (CDPRs) are composed of a base frame and a moving-platform. A set of cables actuated by winches and guided by pulleys on the base frame are attached to the moving-platform. Those cables are used to generate motions or to apply forces to the moving-platform throughout its workspace. CDPRs are being increasingly used in industry due to several advantages provided by the cables such as a large translational workspace, a high payload-to-weight ratio and high velocities and accelerations. However since the cables can only pull the moving-platform, the latter cannot go out of the robot base frame bounded by the pulleys. An example is the treatment of large structures by using a CDPR. The structure itself can be used to hold the pulleys of the CDPR and the moving-platform would therefore need to go out of the robot volume to reach it. To overcome this issue a grasping device is mounted onto the moving-platform to grab the structure. It should be noted that when the structure is grabbed, the model of the overall system changes as the motions of the moving-platform is not only controlled by cables anymore, but the contact between the grasping device and the structure should be considered. This paper deals with the conceptual design of a grasping device for CDPRs and the definition of two workspaces. The first workspace characterize the area covered by the moving-platform when the latter is free of contact with the environment. The second workspace is the region that the gripper can follow during gripping phase. It turns out that the robot workspace increases while considering the structure grasping into the system modeling.

Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.

Keywords: Cable-Driven Parallel Robots, Grasping, Design, Modeling, Workspace

1. Introduction

Because of their large workspace, Cable-Driven Parallel Robots (CDPRs) seem well suited for the maintenance of large structures such as bridges or buildings. Several workspaces have been studied in the literature, such as the *Wrench Closure Workspace* [1,2] or *Wrench Feasible Workspace* [3] for the static equilibrium of CDPR. In most cases, those workspaces are included inside the volume enclosed by the pulleys guiding the cables. Indeed the cables can only pull and not push the moving-platform, therefore limiting the pose it can reach outside of the volume of the pulleys. One technique for the moving-platform to go out from the area delimited by the pulleys is to take advantage of the dynamic behavior of the CDPR [4]. Accordingly, Barrette *et al.* defined the *Dynamic Workspace* [5] of CDPRs. However, it is not realistic from an industrial viewpoint to use this approach to make the moving-platform move along tubes outside the CDPR wrench-closure workspace.

To the best of the author's knowledge, two solutions exist to operate along large structures. The first one consists on the discrete reconfiguration of CDPRs [6,7] to cover the entire structure to treat. Gagliardini *et al.* defined a reconfiguration strategy to find a way to cover the entire structure with the smallest number of reconfigurations in [8]. However, some manual operations are still required to change the robot from one configuration to another. The second approach aims at embedded a serial manipulator onto the moving-platform to extend the workspace locally [9,10].

To avoid those drawbacks, a multi-link CDPR, namely, a CDPR with poly-articulated moving-platform, can be used. This concept was studied through the analysis of the *Force-Closure Workspace* in [11] or the *Tensionable Workspace* in [12], but there are still few applications [13]. The main one is the modeling of the human neck by Lau et al. who developed a generalized model of multi-link CDPR in [14,15].

This paper introduces a planar CDPR with a two-link

Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.
10.1016/j.procir.2018.03.105

moving-platform, which is used as a gripper. The contact between the grasping device and the structure modifies the model of the robot, which increases the part of the structure covered by the robot. The mechanism under study and its targeted applications are described in Sec. 2. Section 3 deals with the geometrico-static modeling of the mechanism at hand in both free phase, i.e, non grasping phase, and grasping phase. The manipulator workspace is analyzed in Sec. 4. Finally, some conclusions are drawn in Sec. 5.

2. Mechanism under study

Fig. 1. represents a planar CDPR with six cables, which come out of winches placed on the corner of a rectangle represented in blue. Those cables are attached to a four degree-of-freedom moving-platform. The latter is a grasping device composed of two jaws, the upper one in red and the lower one in blue. Those jaws are linked together by a revolute joint. This revolute joint gives a fourth degree-of-freedom to the gripper, in addition to the two usual translation and the rotation of the planar moving-platform. The grasping device should grab the guide and translate it along the rib.

The static workspace of CDPR is usually contained in the volume defined as the convex hull of the pulleys. In the case where those pulleys are fixed to the external structure to be treated, one need to ensure that the moving-platform can reach it even if it is located outside of this volume. To do so, the solution studied here consists of grasping the structure. It should be noted that the geometrico-static model of the robot differs from the free phase to the grasping phase.

A guide is placed inside this rib and is connected to it with a prismatic joint along the direction of the rib. The goal is to manage to move the guide along the entire rib by using the CDPR. To do so, two phases are considered. The first one, called *free phase*, corresponds to the motion of the moving-platform when it is only actuated by the cables. In this phase, the moving-platform is moved in the workspace of the CDPR to reach the guide and grasp it. The model of the robot changes since not only the cables generate forces on the moving-platform, but also the reaction forces between the guide and the jaws of the gripper. In the second phase, named *grasping phase*, the robot should be able to grab and move the guide all along the rib.

3. Geometrico-static modeling of a planar CDPR with an articulated moving-platform

3.1. Free phase

The moving-platform consists of a grasping device presented in Fig.2. It is composed of two jaws, the upper one is red and the lower one is blue, linked together in a point P by a revolute joint. The cables are attached to each jaw. The exit point (anchor point, resp.) of the ith cable connected to the upper jaw is named A_{ui}, (B_{ui}, resp.) $i = 1, \ldots, 3$. The exit point (anchor point, resp.) of the jth cable connected to the lower jaw is named A_{lj}, (B_{lj}, resp.) $j = 1, \ldots, 3$.

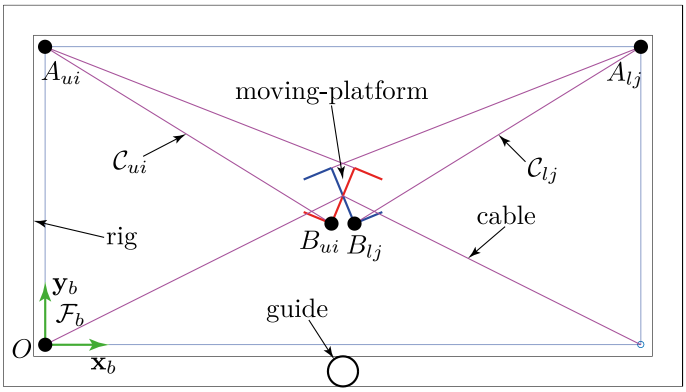

Fig. 1. Planar CDPR with an articulated gripper

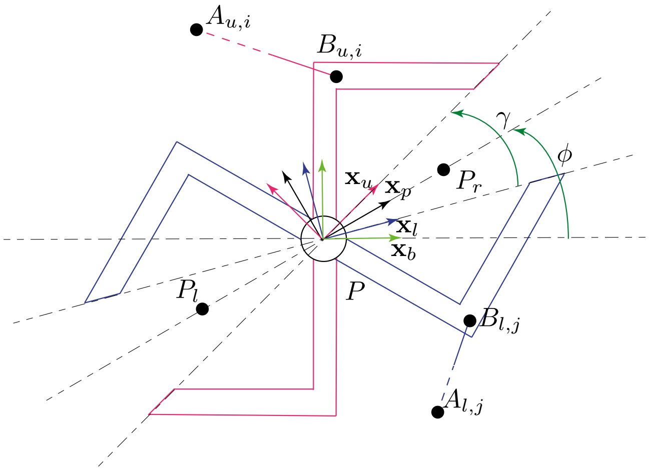

Fig. 2. A one degree-of-freedom gripper

Therefore the moving-platform has four degrees of freedom in this planar case, the two usual translations and one rotation along with the opening/closing of the jaws. The frame attached to the moving-platform is denoted $\mathcal{F}_p = (P, \mathbf{x}_p, \mathbf{y}_p)$ and ϕ is the rotation angle between axis x_b and axis x_p. $\mathcal{F}_u = (P, \mathbf{x}_u, \mathbf{y}_u)$ is the frame attached to the upper jaw and $\mathcal{F}_l = (P, \mathbf{x}_l, \mathbf{y}_l)$ the one attached to the lower jaw. The angle between axis x_l and axis x_u is denoted γ and the frame $\mathcal{F}_p$ is chosen so that each jaw is placed symmetrically around it. Therefore the angle between $\mathcal{F}_p$ and $\mathcal{F}_u$ or between $\mathcal{F}_p$ and $\mathcal{F}_l$ is $\frac{\gamma}{2}$. The loop-closure equations associated to the cables attached to the upper and lower jaws are the following:

$$ {}^b\mathbf{c}_{ui} = {}^b\mathbf{a}_{ui} - {}^b\mathbf{p} - \mathbf{R}\,{}^p\mathbf{b}_{ui} \tag{1a} $$
$$ {}^b\mathbf{c}_{lj} = {}^b\mathbf{a}_{lj} - {}^b\mathbf{p} - \mathbf{R}\,{}^p\mathbf{b}_{lj} \tag{1b} $$

$\mathbf{u}_{ui}$ and $\mathbf{u}_{lj}$ are the unit vectors of cables $\mathcal{C}_{ui}$ and $\mathcal{C}_{lj}$, respectively:

$$ \mathbf{u}_{ui} = \frac{\mathbf{c}_{ui}}{||\mathbf{c}_{ui}||_2} \tag{2a} $$
$$ \mathbf{u}_{lj} = \frac{\mathbf{c}_{lj}}{||\mathbf{c}_{lj}||_2} \tag{2b} $$