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A Storable Tubular Extendible Member (STEM) parallel robot: Modelization and evaluation

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ABSTRACT

Parallel robots have important benefits where speed, lightness and accuracy are concerned. A peculiar type of parallel robots is called vertical Cable Direct Driven Robot (CDDR). In this paper we discuss an innovative type of planar parallel 2-link, 2-d.o.f. robot which is conceptually similar to CDDRs; in place of using cables, this robot uses Storable Tubular Extendible Member (STEM) actuators, one of which is also capable to actively rotate. STEMs are lightweight mechanisms used mainly in the space industry.

We devise a complete model for the behavior of the robot. The kinematics of robot is defined analytically, whereas the structural model is based on numerical and empirical considerations as well. A working prototype of a STEM actuator is presented.

The robot is evaluated via the analysis of force polytopes inside the workspace envelope. This allows us to define some useful indexes: maximum force, maximum admissible weight, out-of-plane stiffness.

Results show that the robot outperforms Cable Direct Driven Robots (CDDRs). The robot's workspace reaches above the link anchor points and the system can eliminate configuration singularities. Out-of-plane stiffness is indeed computed to be within an acceptable range.

1. Introduction

The purpose of this paper is to present an innovative type of robot that unites the concept of vertical planar cable parallel robot to the concept of Storable Tubular Extendible Members, or STEMs. In the following, we will cover these two distinct aspects of our work.

In the field of Robotics, two general sets of robots exist: parallel and serial manipulators. Parallel manipulators are robots which are constituted by a number of links arranged in parallel; the synchronized motion of these links produces the desired motion of the end-effector. Serial manipulators, on the other hand, are robots where the links are arranged serially. In general, parallel manipulators tend to be lightweight, stiff and accurate, while the biggest disadvantage normally consists in a small workspace and limited manipulability indexes inside its envelope; serial robots, instead, tend to be heavy and less stiff, leading to less accurate positioning and motion, while, on the other hand producing larger workspaces and considerably higher manipulability indexes.

A peculiar type of parallel robot is the Cable Direct Driven Robot (CDDR), or Cable Driven Parallel Robot (CDPR). This class of machines is characterized by a system of cables that supports and maneuvers the end-effector. A general description is given by Lamaury et al. [1]. Many variations exist in literature; Gallina et al. [2] show a possible application of CDDRs to haptic interfaces; Tadokoro et al. [3] employ a 3D parallel CDDR for a virtual acceleration base; furthermore, Albus et al. [4] describe the NIST (National Institute of Standards and Technology) *Robocrane* setup which exploits a CDDR and Campbell et al. [5] show a cable robot for space

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and terrestrial applications. Another popular example is *SkyCam* [6], a robotic camera system widely used in stadiums around the world.

As Williams et al. [7,8] point out, the CDDR's major advantage lies in the fact that, since their primary structure is made out of light-weight, high load-bearing cables, the resulting system can be lighter, safer, stiffer, and more economical than traditional parallel robots. Additionally, the workspace can be much larger. Furthermore, as Trevisani et al. [9] remark, a peculiar benefit of some of these robots is the fact that they efficiently exploit gravity to keep their correct configuration; in fact, gravity can be made to act on the mechanism in the same way a cable pulling towards the ground would.

On the other hand, as the very same Trevisani [10], Williams [7,8] and Pigani [11] et al. point out, these features are achieved through often severe limitations in manipulability; in fact their manipulability indexes vary considerably inside the boundaries of their reachable, kinematic or dynamic workspace. The reason for this behavior lies chiefly in the inability of cables to sustain compressive loads; this ultimately translates in the major constraint that some degree of positive tension must be present in the cables at all times. When gravity stabilized robots are considered [6,9,12,13], this has the effect of causing the end-effector to be unable to deliver downwards forces other than its own weight, thus greatly limiting practical applications.

In the present case, we focus on a subset of these robots: *planar vertical CDDRs*. For example, Pigani et al. [11] describe a vertical planar CDDR robot to be used in industrial spray-painting processes; these types of robots tend to have an additional drawback, which is out-of-plane instability. As Pigani [11] and Trevisani [9] et al. point out, the structure of these robots does not explicitly constrain the end-effector in the direction orthogonal to the workspace plane; this invariably causes some degree out-of-plane sag. Some solutions are given by these authors, in the form of passive serial manipulators applied to a state-of-the-art planar vertical CDDR. These, however, present some drawbacks as well; the workspace can become irregular as a consequence of adding a complex system on top of the robot, and the overall inertia is bound to increase.

The planar parallel 2 d.o.f. robot that we propose, takes advantage from the CDDR's structure, while at the same time exploiting a special type of actuator in place of the cables, to increase the workspace and the manipulability indexes, and to increase stability along the normal to the workspace plane, thus avoiding out-of-plane motions. This actuator is based on the Storable Tubular Extendible Member (STEM) technology first described by Groskopfs in his patent [14]. A STEM is a type of component which is based on two distinct concepts. The first is the structural stability and stiffness of a curved sheet of material, albeit thin. In fact, thin sheets generally tend to offer low stiffness values when compression or bending is concerned. In the case of STEM, this is overcome thanks to the increase in the area moment due to the curving nature of the thin section; this is the same concept which is applied with hollow tubes, which the extendable STEM mimics. The second aspect is that, by using thin sheets the structure can be un-bent and rolled up. An illustration of the STEM founding concepts is shown in Fig. 1.

Normally these types of structures are used in the aerospace and space industry; they are exploited in deployable booms and masts aboard space-faring apparati [15,16]. Typical uses regard deployment of solar panels, large antennae and detectors. Another less common use is for artificial satellite gravity-gradient stabilization [17].

A few examples of similar applications that regard actuators are available in literature, for example Blanchard et al. [18] exploit spread-band actuators for deployable telescopes; similarly, Aridon et al. [19] show a deployable Steward–Gough platform for space applications, as do Guinot et al. [20]. However it is generally not a common solution, especially in the field of planar robots.

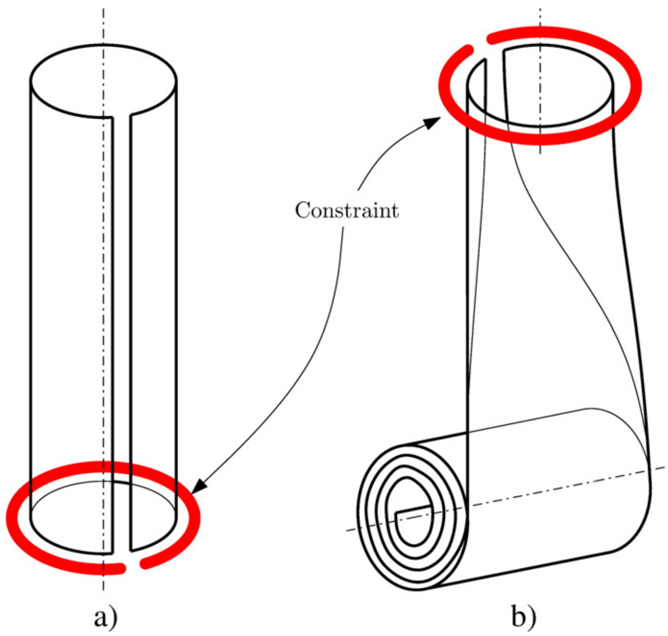

Fig. 1. Storable Tubular Extendible Member (STEM). In a) the extended structure is visible, whereas in b) the folded or rolled-up configuration is shown. The constraint shown in the figure shows the “connection” of the structure in a) and in b).