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Effect of Orientation on the Wrench-Feasible Printable Workspace of an Over-Constrained Cable-Driven Parallel Robot

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Abstract
This paper proposes a methodology to determine the wrench-feasible printable workspace of a cable robot considering the orientation of the mobile-platform. This workspace has a characteristic feature of preventing the lower cables from interfering with the preceding layers of the object being printed while maintaining the cable tensions within the prescribed positive tension bounds. The positive minimum tension bound avoids cable sagging while the maximum tension bound takes care of mechanical limitation of actuators, cables, etc. Additionally, cable-platform collision constraint has been considered for the workspace analysis as the change in the orientation of the mobile-platform may cause the interference of cable with the mobile-platform. The proposed methodology is validated on a planar redundant over-constrained CDPR and the results show a significant improvement in the printable workspace of the robot with the consideration of orientation.

1. Introduction

Cable-driven parallel robots (CDPRs) belongs to the class of parallel robots in which rigid links are replaced by flexible cables. Since cables are lighter in weight and can be extended to much larger lengths (with the application of spool), CDPRs have a characteristic feature of large workspace, high payload to weight ratio, high portability and are easy to assemble, disassemble and transport. Thus, making them appropriate for on-site 3D printing/construction. Since the application requires large stiffness, redundant over-constrained mechanism is suitable. However, CDPRs possess some potential challenges. One such challenge is unilateral tension constraints, i.e., cables can only transmit force when the tension in the cable is kept positive. Another challenge associated with over-constrained mechanism is the interference of lower cables with the preceding layers of the object being printed. The approach to obtain the printable workspace has been presented in [2]. However, the orientation of the mobile-platform has not been considered in this work. Therefore, this paper proposes a methodology to determine the wrench-feasible printable workspace of a cable robot considering the orientation of the mobile-platform. Considering orientation of the mobile-platform can significantly improve the printable workspace of the robot.

2. Methodology

Consider a planar redundant cable-driven parallel robot consisting of a mobile-platform/ nozzle held by four cables in crossed configuration at the corner of the mobile-platform, as shown in Figure 1. The other ends of the cables are anchored to the corners of the rectangular frame of length l_b and height h_b.The geometric parameters of the mobile-platform include platform length l_p, platform height h_p and nozzle tube height n_p. The wrench-feasible workspace includes the poses at which the mobile-platform can be statically balanced such that tensions in the cable are within the prescribed positive tension bounds. The approach to determine wrench-feasible workspace is well known and can be referred in detail from [1].

Wrench-feasible printable workspace (WFPW) represents the subset of wrench-feasible workspace in which 3D printing can be done, i.e., no interference of cable with the preceding layers of the object being printed occurs. WFPW can be obtained by first identifying the line of symmetry for the object to be printed. For no external wrench (except the weight of the platform), the line of symmetry will be parallel to z direction and in the middle of the workspace. The symmetry line will result in a symmetrical printable zone which can be obtained by maximizing the dimension of the object along the line. For a symmetrical object and the cable arrangements for the proposed robot, cable-object interference can only happen between the lower cables and the object on the other side of the symmetry. Thus, in order to determine the printable workspace, the following procedure has been proposed:

1. The mobile-platform is kept at zero orientation and each pose on one side of the line of symmetry (inside wrench-feasible workspace) is checked for the cable-object interference (i.e., when the

mobile-platform is at $\hat{Q}$, then Q must be below cable 1, as shown in Figure 2). If no cable-object interference is detected, the pose is in the printable workspace.

2. Otherwise, the orientation of the mobile-platform is changed by tilting it towards the line of symmetry by a small increment (as shown in Figure 2) and the cable-object interference is rechecked. If no cable-object interference is detected, the pose is in the printable workspace.
3. Otherwise, condition 2 is repeated with further increment in orientation until one of the below-mentioned criteria is satisfied:
   - No cable-object interference is detected: the pose is in the printable workspace.
   - Cable-platform interference (i.e., cable interference with the mobile-platform) is observed for any cable: the pose is outside the printable workspace.

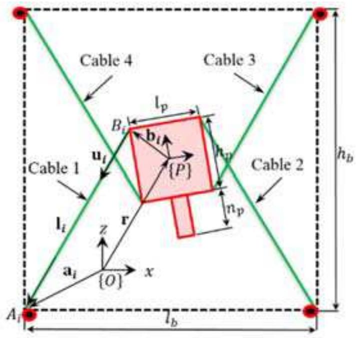


Figure 1: Schematic diagram of CDPR

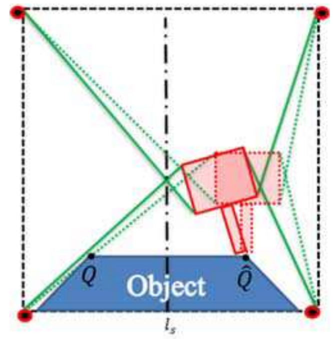
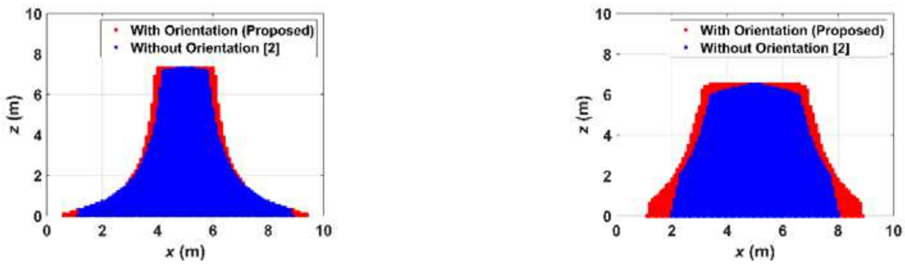


Figure 2: Methodology to obtain printable workspace

The tilting of the mobile-platform towards the line of symmetry prevents cable-object interference. Since the line of symmetry is in the middle of the wrench-feasible workspace, the tilting may also cause the mobile-platform pose to become wrench-feasible, which may otherwise not be wrench-feasible at zero orientation. Therefore, the proposed methodology has the advantage of improving the printable workspace.

3. Results and Discussion

The proposed approach is validated on a planar redundant over-constrained robot for the mobile-platform of mass $m = 50$ kg with minimum tension bound $t_{min} = 100$ N and maximum tension bound $t_{max} = 700$ N. The frame of length $l_b = 10$ m and height $h_b = 10$ m is considered. The workspace is obtained for two sets of platform geometric parameters, i.e., case 1: $[l_p, h_p, n_p] = [1, 1, 1]$ m and case 2: $[l_p, h_p, n_p] = [2, 2, 2]$ m, as shown in Figure 3. The obtained results show that the consideration of orientation resulted in a 10.65% and 20.47% increase in the workspace for case 1 and case 2, respectively. A large increase is observed for large mobile-platform. The improvement in the workspace is significant and encourages to test the proposed methodology for 6 DOF spatial robot in the future.



(a) (b)

Figure 3: Effect of orientation on the printable workspace for (a) case 1 and (b) case 2

References

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