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# Mobile Attachment Points on a Reconfigurable Cable-Driven Parallel Robot : A Study of Workspace

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## 1 Introduction

Cable-driven paralell robots (CDPR) offer a superior alternative to traditional rigid link parallel robots with their advantages [2]. These robots possess high payload capacity, large workspace, low inertial, and easy reconfiguration abilities, making them the ideal solution for a vast range of industrial applications, including heavy payload handling, warehouse operations and construction [5].

More recently, they are being explored for challenging applications such as pick and place in cluttered work environments due to which the research community is working on new CDPR designs with reconfiguration capabilities.

Several studies are available on reconfigurable CDPR (RCDPR) designs. One of the earliest work was the NIST RoboCrane project by NIST. Planar RCDPR has been presented by [6]. One of the popular spatial RCDPR is the ReelAx developed by Izard et al. for different industrial application [4]. A RCDPR for sand blasting and painting application was developed by Gagliardini et al. [1]. It was possible to place the connection points of the cables on the base platform at different set of discrete locations. A RCDPR relocating the cable drawing points using extra cables was proposed by Zhang et al.[7].

In this contribution, we present the study of the workspace of a RCDPR where the attachment points on the moving platform are mobile [3]. The prototype of the proposed design is shown in Fig. 1. The attachment points on the moving platform are made to move on an inclined plane at an angle of 20°.

## 2 Mathematcial model

The mathematical model for calculating the static equilibrium workspace, considering the position (x,y,z) and orientation ($\alpha$, $\beta$, $\gamma$), of the RCDPR can be formulated using the classical kinematics and statics equation of the CDPR found in [5].

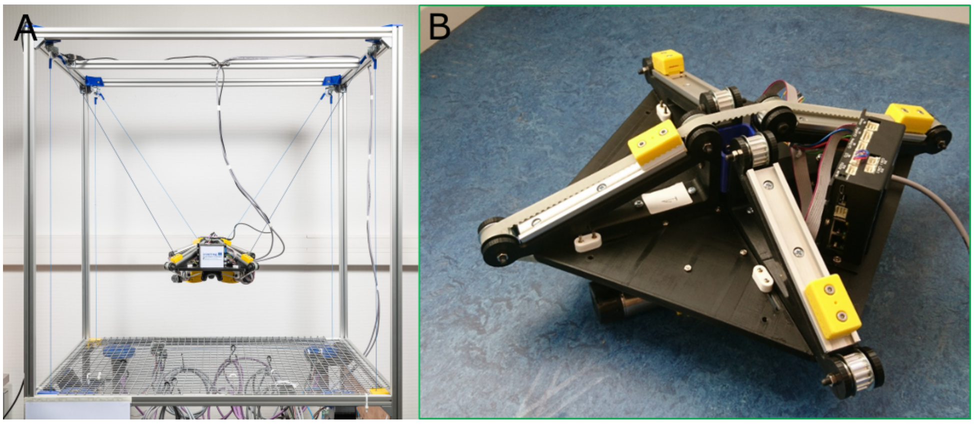

FIG. 1 – In A, the prototype of the reconfigurable cable-driven parallel robot can be observed. It consists of four cables and four attachment points, which can move on an inclined plane with the aid of two motors. The static equilibrium workspace of this reconfigurable robot is larger than that of a robot with fixed attachment points. In B, the picture depicts a photograph featuring the four inclined attachment points on the platform.

However, for the reconfigurable design, in addition to the classical parameters (the platform orientation angles ($\alpha$, $\beta$, $\gamma$) and cable lengths ($l_{1-4}$)), we also have four additional parameters $r_{1-4}$ (the distance along which the attachment point can move on the inclined plane. This converts the problem of tension calculation into an optimization problem with redundant number of equations. This will enable the platform to have the desired platform orientation angle which is not possible in case of a classical spatial CDPR with four cables [5].

To solve the optimization problem, we have used the $Levernberg - Marquardt$ algorithm in MATLAB to solve for the static equilibrium conditions. We have used the following conditions to calculate the corresponding cable tension for maintaining the static equilibrium workspace.

$$\begin{aligned} \underline{\tau} \leq \tau_1, \tau_2, \tau_3, \tau_4 &\leq \overline{\tau} \\ \underline{\tau} = 1N, \quad \overline{\tau} &= 500N \\ \underline{\alpha} = -5^\circ, \quad \overline{\alpha} &= 5^\circ \\ \underline{\beta} = -5^\circ, \quad \overline{\beta} &= 5^\circ \\ \underline{\gamma} = -5^\circ, \quad \overline{\gamma} &= 5^\circ \end{aligned} \tag{1}$$

where, $\underline{\tau}$, $\underline{\alpha}$, and, $\underline{\beta}$ denotes the lower-limit on cable tensions, orientation about $x$-axis and orientation about $y$-axis respectively, and $\overline{\tau}$, $\overline{\alpha}$, and, $\overline{\beta}$ denotes the upper-limit on cable tensions, orientation about $x$-axis and orientation about $y$-axis respectively. The objective function of the optimization problem is to

$$obj = min(\alpha - \alpha_{des})^2 + min(\beta - \beta_{des})^2 + min(\gamma - \gamma_{des})^2 \tag{2}$$

## 3 Results

The calculation of the workspace has been done by considering the dimensions of the CDPR used in the earlier works to show the comparison of the static equilibrium workspace. The simulation is done assuming a cuboid shape for the base platform having a length of 5 $m$, a breadth of 5 $m$, and a height of 3 $m$. Taking into account the length and width of the room and the MP, the searching region was restricted between 0.3 $m$ and 4.7 $m$ for the $x$ and $y$ axis, while different heights were selected for the $z$ axis (0, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 1.8). The step size for the simulation was fixed at 0.1 $m$. The limits for point to be considered inside the static equilibrium workspace is given in eq. 1.

The workspace of the proposed design for the dimensions considered is shown in the fig. 2.

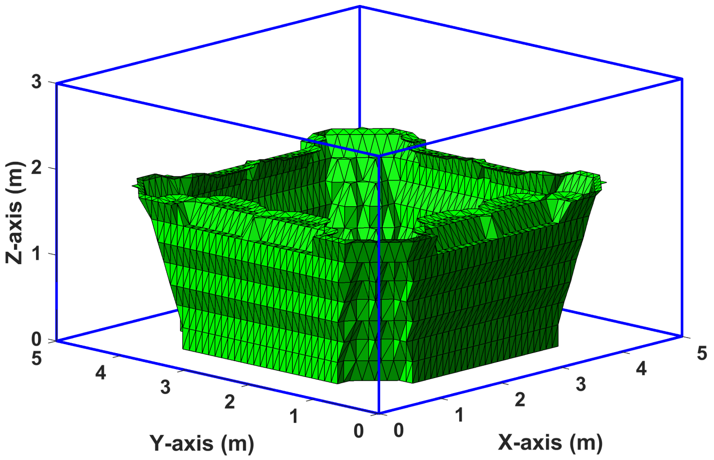

FIG. 2 – Static equilibrium workspace of the RCDPR prototype

It can be seen that the workspace for the prototype is larger than the workspace of a CDPR with four cables whose attachment points on the moving platform are fixed [5]. Additionally, the performance of the design in terms of achieving the desired values of the platform orientation angles are also better than the CDPR developed before by the same authors [5].

## 4 Conclusions and perspectives

This work presented the static equilibrium workspace of a reconfigurable cable-driven robot with augmented maneuverability. The prototype has a larger workspace than the conventional CDPR with 4 cables but with fixed attachment points. Future work will involve the energy consumption study and the formulation of the dynamic model to implement a robust and effcient control algorithm for the prototype.

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