



HAL
open science

Four Cables-Suspended Parallel Robot with Reconfigurable platform

El-Golli Hanene, Atal Anil Kumar, Jean François Antoine, Gabriel Abba

► **To cite this version:**

El-Golli Hanene, Atal Anil Kumar, Jean François Antoine, Gabriel Abba. Four Cables-Suspended Parallel Robot with Reconfigurable platform. 25e Congrès Français de Mécanique (CFM 2022), Centrale Nantes; Université de Nantes; ENSAM d'Angers; Ecole Navale de Brest; Université de La Rochelle, Aug 2022, Nantes, France. hal-04280101

HAL Id: hal-04280101

<https://hal.science/hal-04280101v1>

Submitted on 13 Nov 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Four Cables-Suspended Parallel Robot with Reconfigurable platform

H. EL GOLLI^a, A.-A. KUMAR^c, J-F ANTOINE^b, G. ABBA^a

- a. Ecole Nationale d'Ingénieurs de Metz, Université de Lorraine, LCFC, F-57000 Metz, France ; e-mails : hanene.el-golli@univ-lorraine.fr , gabriel.abba@univ-lorraine.fr
- b. IUT Nancy-Brabois, Dépt. GMP, Université de Lorraine, LCFC, F-54000 Nancy, France ; e-mail : jean-francois.antoine@univ-lorraine.fr,
- c. University of Luxembourg, 6, rue Richard Coudenhove-Kalergi, L-1359, Luxembourg; e-mail : atal.kumar@uni.lu

Résumé

Avec la progression scientifique des systèmes automatisés, les robots parallèles à câbles présentent des excellentes performances grâce à leur faible coût et de leur capacité à effectuer plusieurs tâches nécessitant un grand espace de travail. Malgré un espace de travail étendu en translation, la conception des robots parallèles suspendus à quatre câbles ne permet qu'un mouvement de rotation incontrôlé ou limité. Outre le sous-actionnement, ces problèmes peuvent être causés par les caractéristiques des câbles ou/et les positions des points qui maintiennent la plateforme mobile. De plus, cette contrainte peut affecter l'équilibre statique de l'organe terminal lors de son déplacement. Afin d'assurer le contrôle de la position et de l'orientation de ce dernier, un robot parallèle reconfigurable à quatre câbles avec une structure compacte est développé. Par conséquent, cet article propose un algorithme d'optimisation qui se base sur le gradient (méthodes sans-dérivés) pour sélectionner la configuration optimale associée à chaque point de la trajectoire souhaitée. Cette solution optimale peut être déterminée à travers plusieurs critères tels que l'équilibre statique de l'organe terminal du robot et l'orientation souhaitée. La simulation numérique est réalisée et analysée pour assurer 6-ddl avec ce robot parallèle reconfigurable à quatre câbles.

Abstract:

The design of manipulators has progressed within few last decades. Recently, Cable-Suspended/Driven Parallel Robots are progressively used in industrial applications due to their large payload capacity, low cost, and good ability to perform several tasks requiring a large workspace. For these applications, the main objective is to pursue imposed trajectories.

However, despite the advantage of the considerable workspace, the design of the suspended four-cables parallel robots provides an uncontrolled or limited rotational motion.

In order to ensure control over the end effector's position and orientation, a self-reconfigurable four-Cable parallel robot with a compact structure is developed. For this purpose, the typical fixed anchor points will be translated on an inclined guide rail.

Accordingly, this proposed work aims to select the appropriate anchor points which will be associated with each position of the desired trajectory. This suitable solution can be performed by an optimization approach by considering several criteria such as the robot equilibrium, cables tension, and the desired orientation.

Eventually, the numerical simulation of a reconfigurable robot is performed and analyzed. The results verify the feasibility of a 6-DoF for the parallel reconfigurable robot with four suspended cables.

Keywords : *Reconfigurable Cable Parallel robot, Modulization, Optimization, Derivative-free method,*

1 Introduction

Cable-Driven Parallel Robots (CDPR) are parallel robots where the mobile platform is suspended by flexible cables instead of rigid elements [1]. This feature gives CDPR excellent performance in terms of large payload capacity, expanded workspace, accelerations, and speeds compared to conventional parallel robots [2].

Recently, several CDPRs have been proposed and developed by the robotics community. These robots have been used in many engineering fields such as for urban construction tasks [3], video recording applications [4], and for radio telescopes [5]. Similarly, cable robots have demonstrated their adaptation for medical tasks such as haptic applications, mini-invasive surgery [6], and physical rehabilitation exercises [7], and for industrial tasks such as motion simulators [8], and manipulating parts in the manufacturing process [9]. However, most of these applications need single operation tasks which lead to the use of several CPRs with different configurations. Therefore, in the last few years, some research dealt with CDPRs which are modular and reconfigurable [10], [11] to be used in various situations.

In this context, several works have dealt with manual reconfigurable robots such as reconfigurable cable-driven parallel robots (RCDPRs) ReelAx [11] and the NIST Robocrane [12]. Other research deals with self-RCDPRs like SEGESTA prototype [13], and the CoGiRo prototype [14].

Nevertheless, all previous works, investigate RCDPRs by moving the attachment points associated to the fixed base's pulley. Therefore, to improve the mobility of this kind of CDPR without the need for more cables or multiple actuators, the self-reconfiguring task will be dependent on the anchor points attached to the moving platform.

In this work, we are interested in modeling the static behavior of the RCDPRs, then searching for a suitable position for the anchor point to have a secure motion during the process.

The rest of the paper is structured as follows: Following this introduction, the description of the RCDPR is presented. The kinematic and static models of this type of parallel robot are formulated in section 3. Section 4 is dedicated to formulating and discussing the optimization results of the robot. Finally, the conclusion is presented in section five.

2 Structure Design

The proposed suspended CDPR is composed of a moving platform connected to a fixed base by four cables of variable lengths, used to control the pose of the end-effector.

The cables are attached to the fixed structure of the robot at points A_i which represents the center of the attachment points, and connected to the moving platform at the anchor points B_i .

Referring to **Fig.1.a**, $\mathcal{R}_0(O, X_0, Y_0, Z_0)$ and $\mathcal{R}_p(P, X_p, Y_p, Z_p)$ are the fixed frame attached to the robot base and the local frame attached to the moving platform, respectively. **Fig.1.b** represents part of the moving platform where C_i is the platform's corners, and B_i is the moving anchor points.

The position and orientation of the platform are defined by the vector $\chi = [P \ \theta]^T$ with respect to the fixed frame \mathcal{R}_0 where $P = [x \ y \ z]^T$ is the position vector and $\theta = f(\alpha, \beta, \gamma)$ represents the orientation angle where α around X , β around Y and γ around Z .

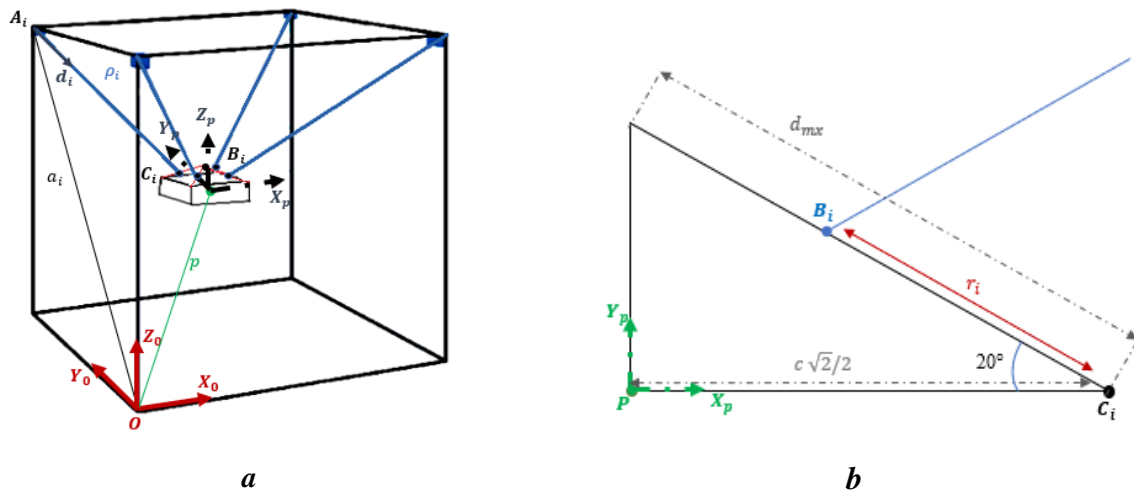


Fig. 1: a. Geometric Parameters of the Ludic design b. Geometric Parameters of the platform

3 Kinematic and static Model

3.1 Inverse Kinematic Model

The Inverse Kinematics model of the RCDPR determines the lengths of the cables, for a given pose χ and a given configuration of the moving platform.

The expression for calculating the cable length (l_i) which are considered as a straight-line segment is given by:

$$l_i = \|A_i B_i\| = \rho_i d_i = \|\mathbf{p} - \mathbf{r}_i - \mathbf{a}_i\| \quad (1)$$

Where

$\mathbf{r}_i = r_i \mathbf{B}_i \mathbf{C}_i$ is the displacement vector of the anchor points.

3.2 Static Model

During the motion, external forces $\mathbf{W}_p = [0 \ 0 \ -m_p g \ 0 \ 0 \ 0]^T$ are exerted on the platform due to its weight with payload and forces produced on task execution.

Moreover, each cable produces forces on the platform proportional to its tension $\mathbf{T} = [T_1 \ T_2 \ T_3 \ T_4]^T$ (cable weight is neglected).

According to Newton-Euler formulation, the static equilibrium is denoted by:

$$\mathbb{W} \mathbf{T} + \mathbf{W}_p = \mathbf{0} \quad (2)$$

Where $\mathbb{W} = [W_1 \ W_2 \ W_3 \ W_4]$

$$W_i = \left[\begin{array}{c} d_i \\ (\mathbf{B}_i / R_0 - \mathbf{P}) \times \mathbf{d}_i \end{array} \right]$$

4 Reconfiguration Method

4.1 Planning Method

To reach the desired position, a new configuration is realized by translating two or more cables from their first anchor points to new locations. Accordingly, a scheme (Fig.2) of a RCDPR control is given, to determine the optimal reconfiguration.

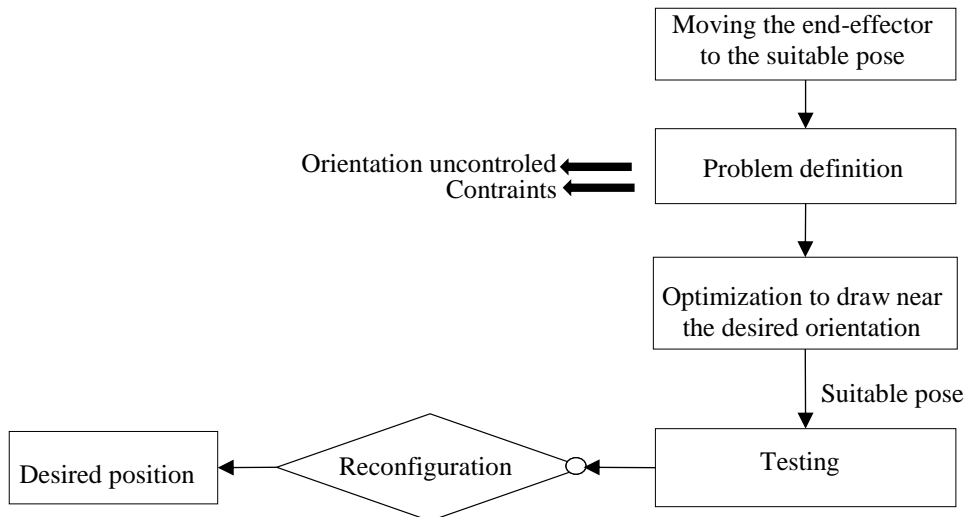


Fig. 2: Scheme of the optimal reconfiguration planning method

4.2 Optimization

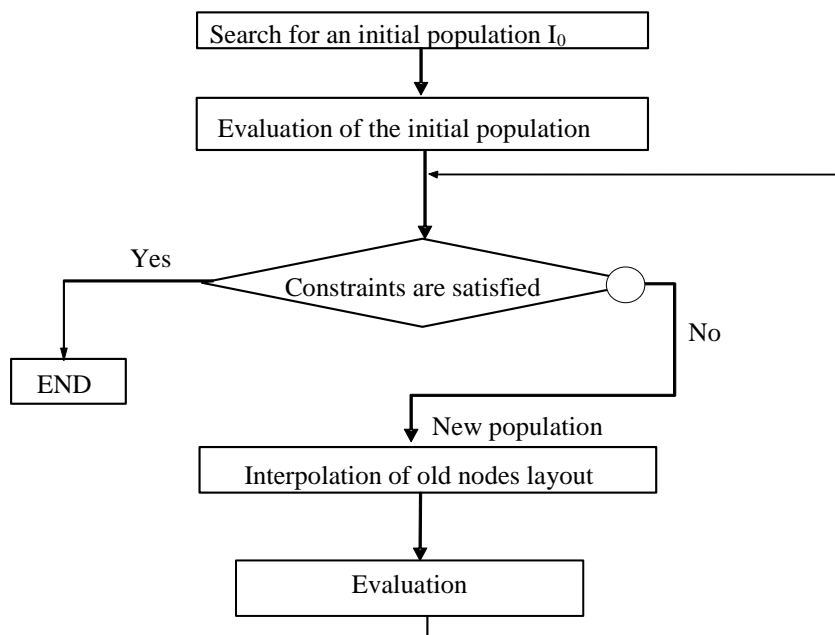


Fig. 3: Flow chart of the proposed optimization method

An optimization approach for mechanism reconfiguration is proposed in Fig.3. It aims to expand the Derivative Free Method allowing the search for the suitable configuration in each position.

Starting from searching initial population I_0 , the individuals are evaluated and then operators are applied to interpolate and evaluate the new population.

4.2.1. Design variables I

The design vector of the proposed approach is composed of three parts, cables tensions T , to avoid slacking during the displacement process, anchor points' displacement r_i , to select appropriate configuration, and orientation of the moving platform θ to improve pose control.

Therefore, the design vector is written as:

$$\mathbf{I} = [T_1, T_2, T_3, T_4, r_1, r_2, \alpha, \beta, \gamma]$$

Where $r_3 = d_{mx} - r_1$ and $r_4 = d_{mx} - r_2$ and

$$(r_{min} = 0) \leq r_i \leq (r_{max} = d_{mx})$$

And, the constraint imposed to guarantee better performance of the robot is to have always positive cables tension to avoid sagging cables.

$$0 < T_{min} \leq \mathbf{T}(i) \leq T_{max}$$

Then, to examine if the desired orientation has occurred, the function to minimize error is used as follows

$$f = \min_i \sqrt{\frac{1}{3} \left((\alpha_i - \alpha_{req})^2 + (\beta_i - \beta_{req})^2 + (\gamma_i - \gamma_{req})^2 \right)} \quad (3)$$

4.2.2. Objective function

The criterion used in this approach aims to enhance the static equilibrium of the robot during its motion over the entire workspace. This criterion is mathematically formulated by the expression presented in section 3.2:

$$F_1(I) = \mathbb{W} \mathbf{T} + \mathbf{W}_p \quad (4)$$

5 Results

The feasible robot reconfigurations have been identified by mapping all the workspace. For each position, a configuration is selected, aiming to minimize the error between the calculated orientation of the platform and the required one.

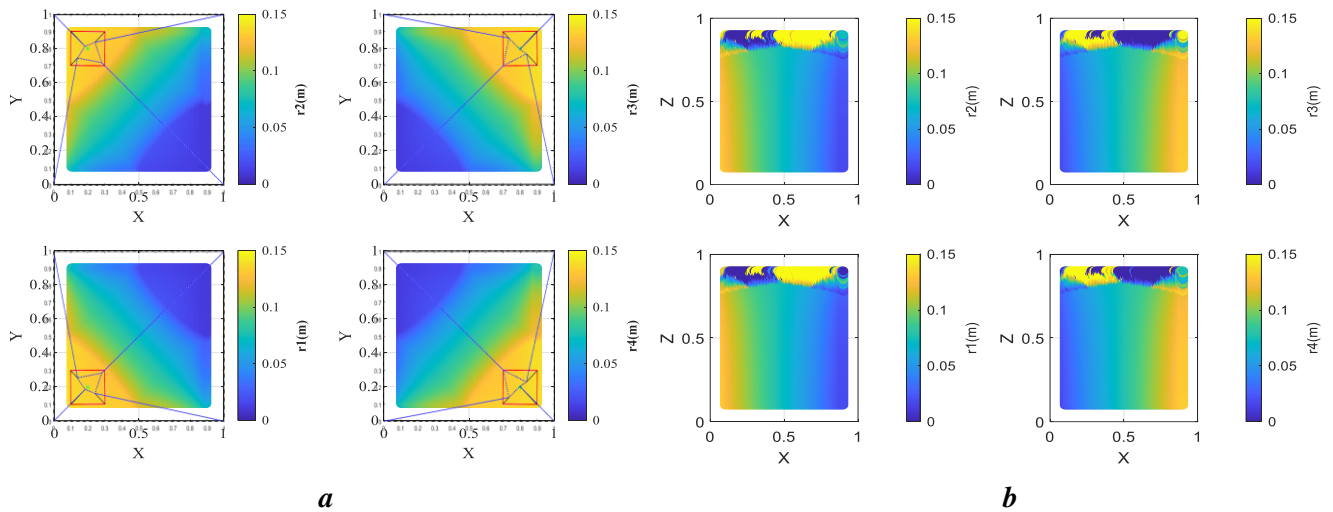


Fig. 4 : Anchor points positions *a.* on the plan (X, Y) *b.* on the plan (X, Z)

These optimal solutions are determined using MATLAB software. The algorithm was implemented with a function having a tolerance of $1e-16$, and a maximum number of iterations equal to 10000.

Fig. 4 shows the suitable position of the anchor points \mathbf{B}_i . This figure presents a mapping value going from r_{min} to r_{max} along the plane (X, Y) for $z = 0.5\text{m}$, and (X, Z) for $y = 0.5\text{m}$.

It should be noted that the anchor point position is near the center of mass of the platform, if the cable is the shortest length, inversely, the anchor point position is close to the border if the cable is of the maximum length.

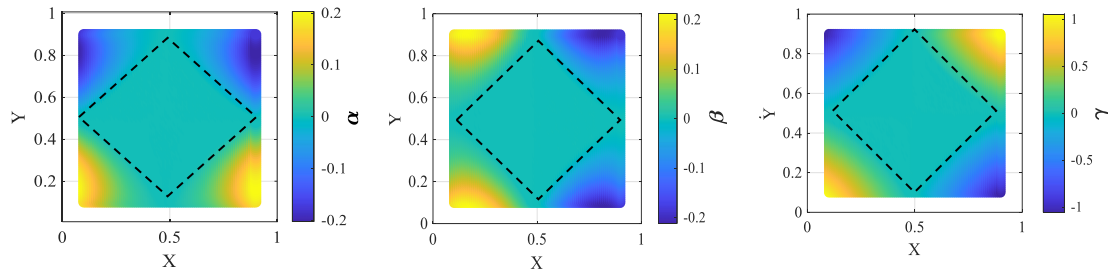


Fig. 5 : Platform Orientation on the plan (X,Y)

Fig. 5 illustrates that the orientation of the platform is almost equal to the required orientation in the center of the workspace and the error of 0.2° on the boundary near the base’s pulley.

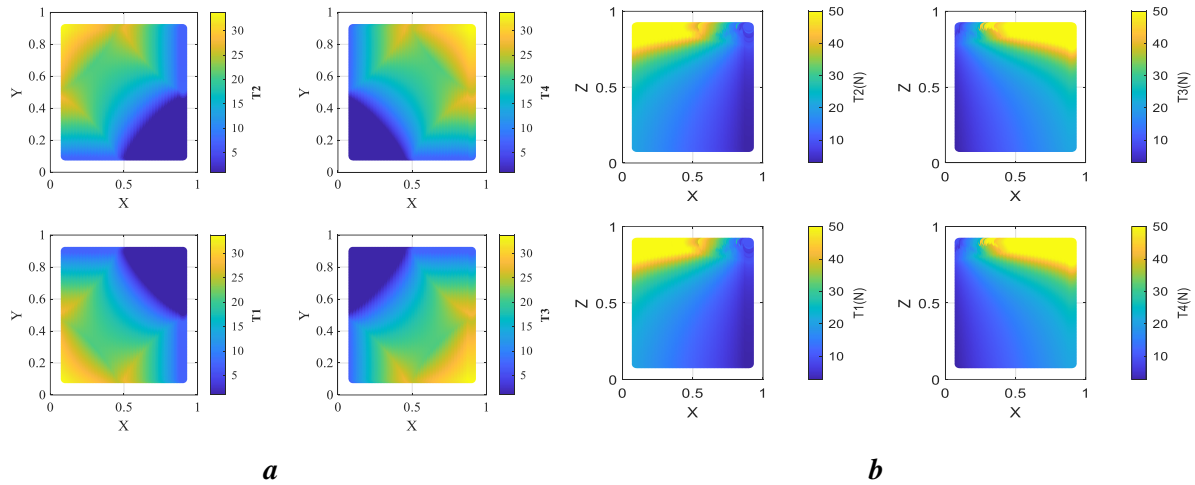


Fig. 6 : cable tension a. on the plan (X,Y) b. on the plan (X,Z)

The motion of the robot is demonstrated by positive cable tension which is represented in Fig. 6 where the maximum tension can achieve 50N near the attachment point for that cable.

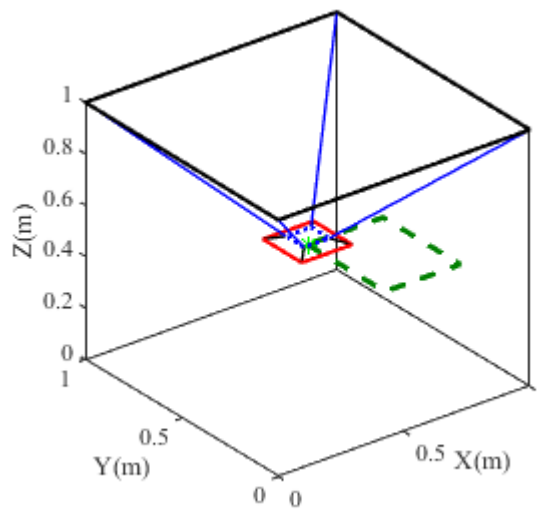


Fig. 7: Desired trajectory

In order to validate this optimization, a comparison between CDPR and RCDPR is executed in quasi-static mode. This comparison is made for the same rectangular trajectory, which is given in Fig.7, that starts from the center of the robot ($x = 0.5, y = 0.5, z = 0.5$) with a null desired orientation.

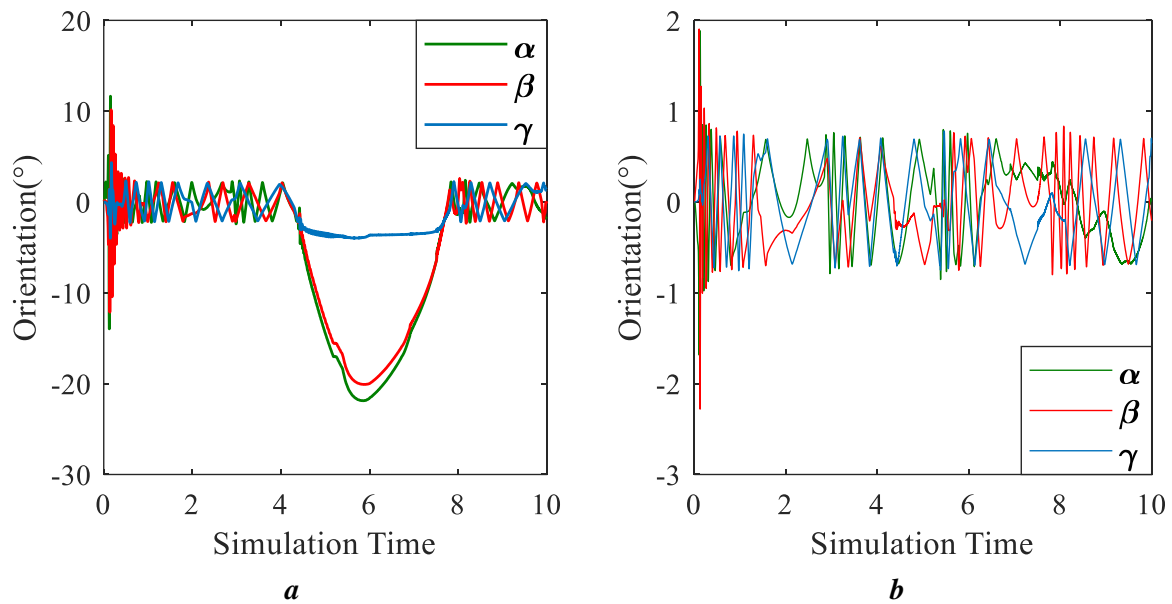


Fig. 8: comparison between trajectory with **a.** CDPR and **b.** RCDPR

Fig. 8 presents the orientation of the moving platform in the three directions, whereas the first figure **Fig. 8.a** introduces the orientation of the CDPR without reconfiguration, thus, this orientation affects the inclination of the moving platform which can reach 22° while considering the RCDPR this orientation doesn't exceed 1.8° in **Fig. 8.b**.

6 Conclusion

The first part of this work focuses on the fundamental characteristics related to the kinematic and static modeling of the new RCDPR. Then, an optimization approach specific to the position of the anchor points of the RCDPR is proposed in order to ensure stability and the maximum accuracy of the end-effector. This has allowed identifying the desired optimal solution.

Results demonstrate that the new reconfigurable robot is most effective in terms of minimizing the inclusion of the end-effector during the displacement process with positive cable tensions and user safety.

Références

- [1] M. Newman, A. Zygielbaum, and B. Terry, "Static analysis and dimensional optimization of a cable-driven parallel robot.," in *Cable-Driven Parallel Robots - Proceedings of the 3rd International Conference on Cable-Driven Parallel Robots*, 2018, pp. 152–166.
- [2] C. Gosselin, "Cable-driven parallel mechanisms: state of the art and perspectives," *Mechanical Engineering Reviews*, vol. 1, pp. 1–17, 2014.
- [3] A. M. Pinto, E. Moreira, J. Lima, J. P. Sousa, and P. Costa, "A cable-driven robot for architectural constructions : a visual-guided approach for motion control and path-planning," *Auton. Robots*, vol. 41, no. 7, pp. 1487–1499, 2017.
- [4] L. L. Cone, "Skycam: An Aerial Robotic Camera System," *Byte*, vol. 10, no. 10, pp. 122–132, 1985.

- [5] R. Nan et al., “The five-hundred-meter Aperture Spherical radio Telescope (FAST) project,” *Int. J. Mod. Phys*, vol. 20, no. 6, pp. 989–1024, 2011.
- [6] G. Boschetti, G. Rosati, and A. Rossi, “A haptic system for robotic assisted spine surgery,” in *Proc. IEEE Int. Conf. Control Appl*, 2005, pp. 19–24.
- [7] D. Zanotto, G. Rosati, S. Minto, and A. Rossi, “Sophia-3: A semi adaptive cable-driven rehabilitation device with a tilting working plane,” *IEEE Trans. Robot*, vol. 30, no. 4, pp. 974–979, 2014.
- [8] P. Miermeister et al, “The CableRobot simulator large scale motion platform based on Cable Robot technology,” in *IEEE International Conference on Intelligent Robots and Systems*, 2016, pp. 3024–3029.
- [9] A. A. Kumar, “Design and Control of an underactuated cable-driven robot for agile handling of parts in a manufacturing line.” [Online]. Available: <https://hal.univ-lorraine.fr/tel-03284822>
- [10] L. Gagliardini, S. Caro, M. Gouttefarde, and A. Girin, “A Reconfiguration Strategy for Reconfigurable Cable-Driven Parallel Robots A Reconfiguration Strategy for Reconfigurable Cable-Driven Parallel Robots,” pp. 1613–1620, 2015, doi: 10.1109/ICRA.2015.7139404.
- [11] U. Mishra, S. Caro, M. Gouttefarde, and U. A. Mishra, “Optimizing Cable-Routing for Reconfigurable Cable-Driven Parallel Robots Optimizing Cable-Routing for Reconfigurable Cable-Driven Parallel Robots. 5th IEEE/IFTOMM International Conference on Reconfigurable Mechanisms and Robots Optimizing Cable-Routing for Reconfigurable Cable-Driven Parallel Robots,” 2021. [Online]. Available: <https://hal.archives-ouvertes.fr/hal-03338563>
- [12] T. Zhao, B. Zi, S. Qian, Z. Yin, and D. Zhang, “Typical configuration analysis of a modular reconfigurable cable-driven parallel robot,” *International Journal of Advanced Robotic Systems*, vol. 16, no. 2, Mar. 2019, doi: 10.1177/1729881419834756.
- [13] T. Bruckmann, L. Mikelsons, M. Hiller, and D. Schramm. “A new force calculation algorithm for tendon-based parallel manipulators”. *Proceedings of the IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM '07)*, pages 1–6, 2007. Cited pages 4, 5, and 6.
- [14] J. Lamaury, M. Gouttefarde. “Control of a Large Redundantly Actuated Cable Suspended Parallel Robots”. *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, 2013. Cited pages 4, 5, 9, 61, 85, and 93.