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Numerical modelling of Hybrid Cable-Driven Parallel Robots

INTRODUCTION

Cable robots have a wide-ranging applicability in different areas, such as rehabilitation, surgery, agriculture, entertainment and manipulation for industrial means. Health researchers developed a surgical robot which is able to do a minimally invasive laparoscopic surgery (GAO, *et al.* , 2019) and robot-aided rehabilitation robots like NeReBot and MariBot for arm active-assisted exercises (ROSSI, ROSATI, 2007). Agriculture professionals have also seen usefulness in cable robots and improved strawberry picking robots (FROM, ISLER and XIONG, 2018). In 1980s the August Design Company created the SkyCam, a recorder system driven by cables commonly seen in the transmission of soccer matches. At the industry field, Fraunhofer IPA conceived the IPAnema system family of Cable-Driven Parallel Robots (POTT, *et al.* , 2014).

Cable-Driven Parallel Robots (hereinafter CDPR) became a trend research subject because it stands out from other classes of robots (including the anthropomorphic class) in topics that are usually required in day-to-day use, such as: heavy payloads capabilities (ALBUS, BOSTELMAN and DAGALAKIS, 1992), large workspace (MARQUEZ-GAMEZ, *et al.*, 2018), reconfiguration capabilities and relatively light weight of the manipulator can result in a fast motion of the end-effector (ZANOTTO, ROSATI and AGRAWAL, 2011).

Following this global research trend, Trevisani (2010) proposed an unique design of planar CDPR by adding a passive 2-link support. From then on the Cable-Direct Driven Robot (hereinafter CDDR) emerged bringing on the following advantages (TREVISANI, 2010):

1) it can load much more than its own weight;
2) a large working area;
3) a high capability of keeping a planar trajectory;
4) refusal to accept moment at the end-effector, not seen commonly in CDDRs;
5) by inserting encoders to the SCARA passive arm its provided additional metrological control, avoiding trajectory failures as a result of cable elasticity;
6) feasibility of upgrading the planar model to a special by adding an active axis normal to the trajectory seen in the 2D model.

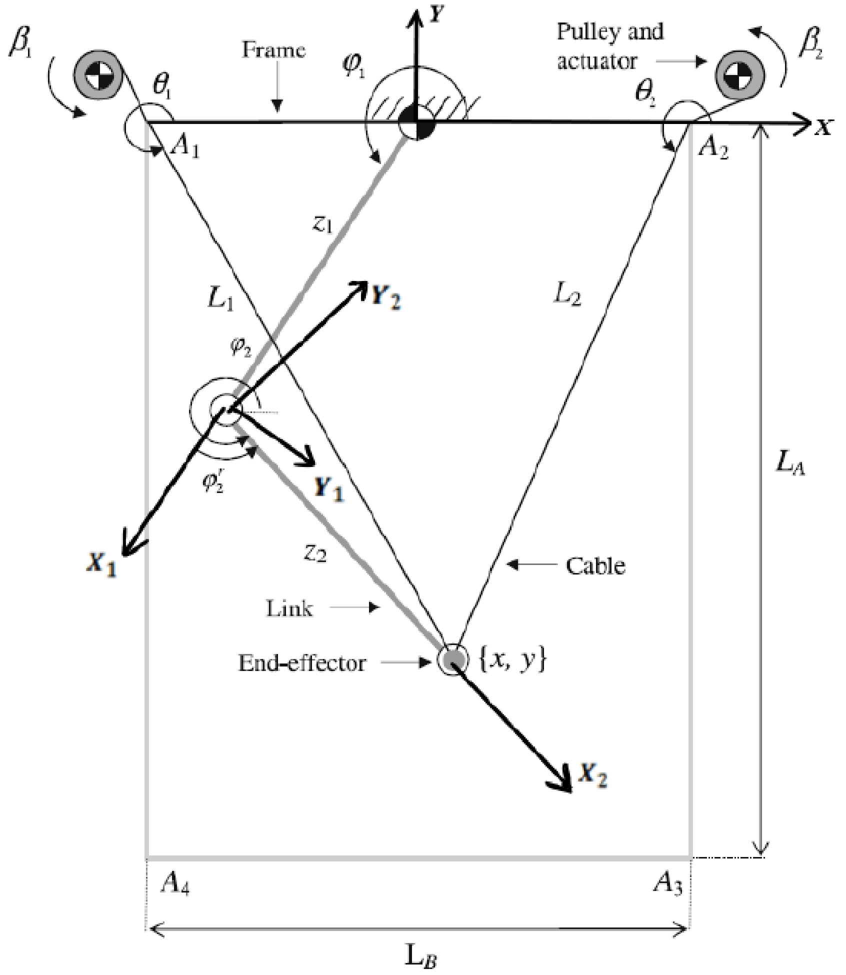
Besides Trevisani’s (2010) proposed model there are many other possibilities of Hybrid Cable-Driven Parallel Robots, such as a very similar configuration but adding two extra actuators in the edge of workspace and putting the same 2-link serial manipulator connecting the bottom part of workspace to the end-effector (TREVISANI, GALLINA and WILLIAMS II, 2006). In order to provide a bigger workspace comparing to 2-link serial manipulators, this was substituted by a 3-link manipulator (PIGANI and GALLINA, 2013). Afterwards, studies were made to improve the trajectories (kinematics and dynamics) of these robots (ISMAIL, LAHOUAR and ROMDHANEA, 2016) (TREVISANI, 2010) (TREVISANI, 2013) and an applied situation inspired in an industrial task, aiming the optimization of its workspace to paint an area (SERIANI, SERIANI and GALLINA, 2015).

MATERIALS AND METHODS

Since the objective of this work is calculate the arm angles and make the end-effector follow a given trajectory, inverse kinematics was used. To this end Rigid Bodies and Manipulators Theories, besides the Planar Kinematics and Dynamics Theory described by Santos (2001) will be also employed to solve the proposed situation in this report.

Analyzing the mechanism as a SCARA arm subdivided in two links (z_1 and z_2), the global system is defined by the X and Y axes. A first local system is tied to the link z_1 when X_1 axis is parallel to z_1 axis and the Y_1 axis is orthogonal to it. A second local system is tied to the link z_2 when X_2 axis is parallel to it and the axis Y_2 is orthogonal to it. These systems of coordinates are described in Figure 1.

Figure 1: Employed coordinate systems on Trevisani's proposed robot.



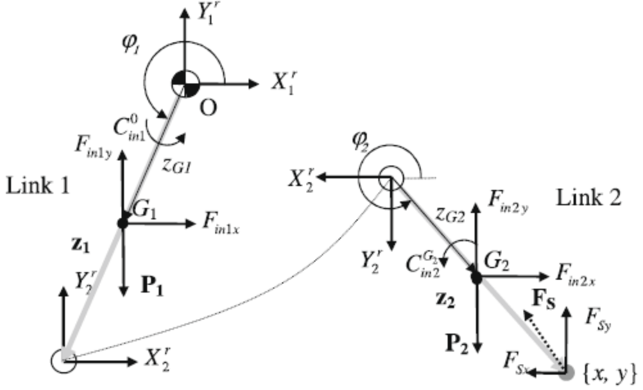
Source: Spaulonci (2020).

Knowing the position, velocity and acceleration in the multibody dynamics analysis its possible to calculate the system dynamics, in other words to determine the necessary forces to build up this work movement.

When studying articulated arms usually its imposed a previous known movement to the end-effector, in this case the position $\boldsymbol{P}_{\boldsymbol{z}_2}$. Therefore the unknowns are φ_1 e φ'_2. It was adopted a trapezoidal speed profile, commonly applied in industrial cases (TREVISANI, 2010). Hence the angular velocities $\dot{\varphi}_1$ and $\dot{\varphi}'_2$, angular accelerations $\ddot{\varphi}_1$ and $\ddot{\varphi}'_2$ and the scalar accelerations $\ddot{\boldsymbol{P}}_{\boldsymbol{z}_1}$ and $\ddot{\boldsymbol{P}}_{\boldsymbol{z}_2}$. The results of this section are plotted in the results section of this report (**IV.a**).

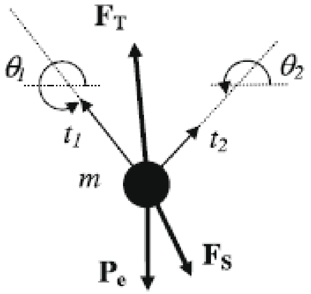
From the obtained kinematics data, the dynamics calculus of this mechanism is performed analyzing the free-body diagrams proposed by Trevisani (2010) in Figures 2, 3 and 4 and applying the Newton-Euler Method, having the equations 1, 2 and 3. The results of this section are plotted in the results section of this report (**IV.b**).

Figure 2: Serial links free-body diagram.



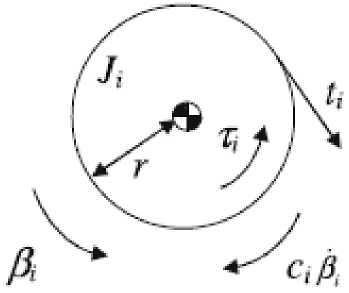
Source: Trevisani (2010).

Figure 3: End-effector free-body diagram.



Source: Trevisani (2010).

Figure 4: Actuator free-body diagram.



Source: Trevisani (2010).

$$\boldsymbol{F_T + F_S - P_E = m\ddot{X}}\ . \quad \text{(Equation 1)}$$

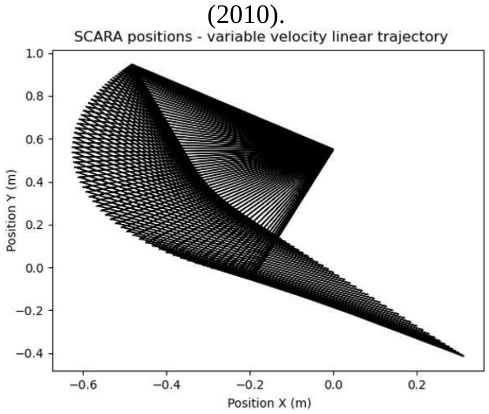
$$\boldsymbol{F_S = M_S\ddot{X}_{G2} + I_{NS}\ddot{\varphi} + P_M}\ . \quad \text{(Equation 2)}$$

$$\tau_i - rT_i - c_i\dot{\beta}_i = \ddot{\beta}_i J_i\ . \quad \text{(Equation 3)}$$

RESULTS

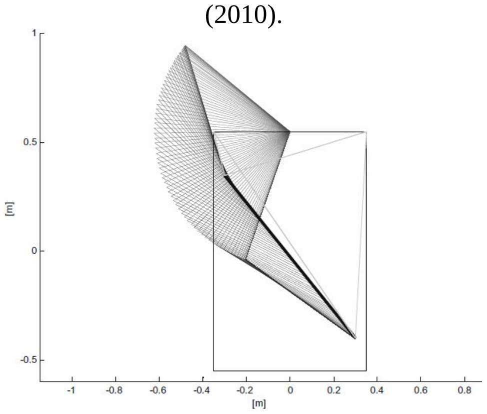
IV.a KINEMATICS

Figure 5: SCARA positions based on Trevisani (2010).



Source: Author (2020).

Figure 6: SCARA positions obtained by Trevisani (2010).

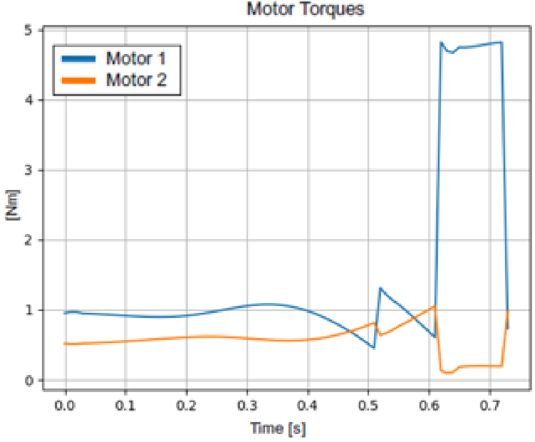


Source: Trevisani (2010).

IV.b DYNAMICS

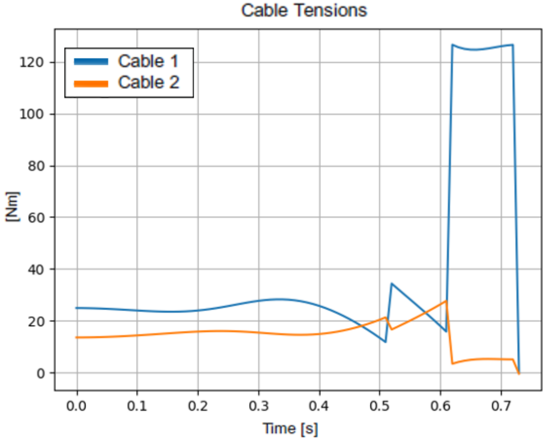
The linear trajectory was studied in order to obtain the motor torques and cable tensions. The reason why this data is necessary is to command the motors actuation in the following project. Figures 7 and 8 refer to its motor torques and cable tensions obtained by the author and Figures 9 and 10 the same data obtained by Trevisani (2010).

Figure 7: Linear trajectory motor torques.



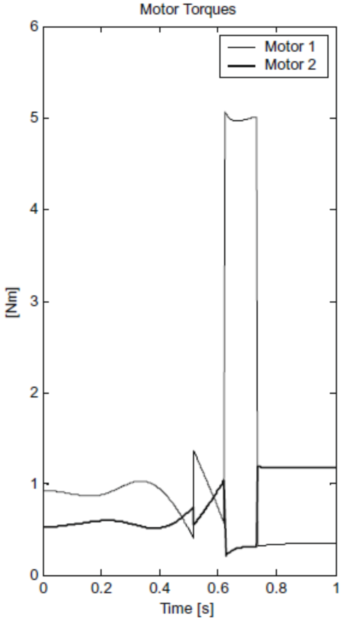
Source: Author (2020).

Figure 8: Linear trajectory cable tensions.



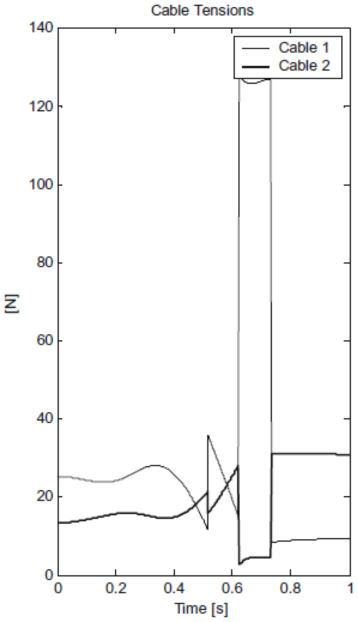
Source: Author (2020).

Figure 9: Trevisani (2010) linear trajectory motor torques.



Source: Trevisani (2010).

Figure 10: Trevisani (2010) linear trajectory cable tensions.



Source: Trevisani (2010).

CONCLUSIONS

By the results comparison, principally by the linear trajectory motor torques and cable tensions, the proposed model here in this report is validated with Trevisani (2010) model. The development of the numerical model of Hybrid Cable-Driven Parallel Robot was well-succeeded, the torques for both motors can now be calculated and stored. Having this tool, the development of a 3D printer based in a Hybrid Cable-Driven Parallel Robots is much more feasible.