Cable-Driven Parallel Robots with Large Translational and Rotational Workspaces

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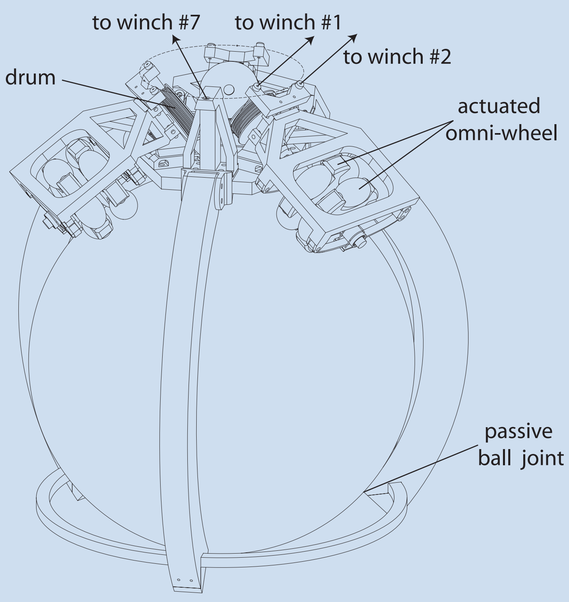
Abstract

Cable-Driven Parallel Robots (CDPRs) draw interests towards industry thanks to their fundamental advantages and capabilities, such as high payload-to-weight ratio, large translational workspace and high-speed motion. However, most of the CDPRs provide only limited rotation of the platform due to the collision between the cables. The objective of this research work is to design, analyze and build a CDPR linked in series to a Parallel Spherical Wrist for ensuring unlimited rotational workspace in addition to the large translational workspace provided by CDPR. The robot has 6-DOF with modular motion system, namely, translational and rotational motion modules.

Parallel Spherical Wrist

The Parallel Spherical Wrist (PSW) was designed at LS2N. The idea was to design a PSW that is actuated by omni-wheels and to provide a large orientational workspace.



Wrist Kinematics:
Rotational jacobian matrix, $\mathbf{J}_\omega$, maps the angular speed of the omni-wheels, $\dot{\boldsymbol{\varphi}}$, to the required angular velocity, $\boldsymbol{\omega}$, of the sphere:

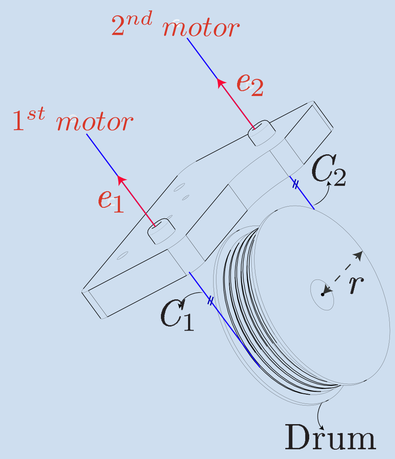
$$\boldsymbol{\omega} = \mathbf{J}_\omega \dot{\boldsymbol{\varphi}} \Leftrightarrow \boldsymbol{\omega} = \frac{1}{r_o}\mathbf{J}_\omega \begin{bmatrix} \dot{l}_1 - \dot{l}_2 \\ \dot{l}_3 - \dot{l}_4 \\ \dot{l}_5 - \dot{l}_6 \end{bmatrix}$$

$$\boldsymbol{\omega} = \frac{1}{r_o}\begin{bmatrix}\mathbf{J}_\omega & -\mathbf{J}_\omega & 0_{3\times1}\end{bmatrix}_{3\times7} \begin{bmatrix} \dot{l}_a \\ \dot{l}_b \\ \dot{l}_7 \end{bmatrix}_{7\times1}$$

$$\boldsymbol{\omega} = \frac{1}{r_o}\mathbf{J}_r\ \dot{l}$$

$\mathbf{J}_r$ maps the cable velocities to the required platform rotation.

Double-Actuated Cable Module (DACM)



DACM is coupled with two actuators and will generate:

- Translational motions if the cables move in the same direction
- Rotational motions if the cables move in opposite directions

Kinematics of the Cable-Driven Parallel Robot

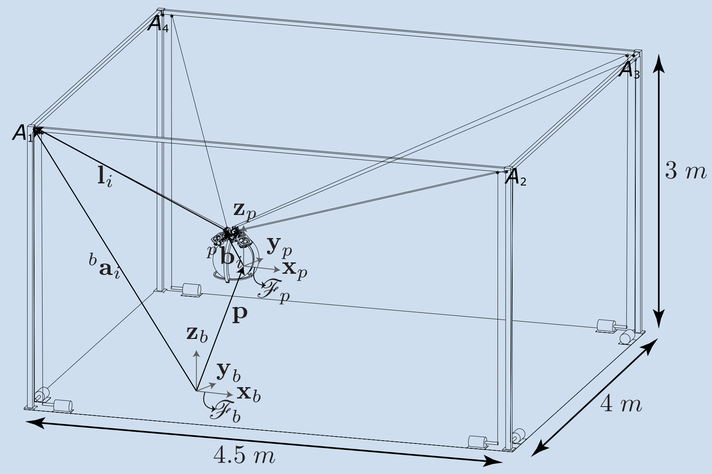
$$\mathbf{J}_t = -\mathbf{W}^T = -\begin{bmatrix}\mathbf{e}_1^T & \mathbf{e}_2^T & \mathbf{e}_3^T & \mathbf{e}_4^T & \mathbf{e}_5^T & \mathbf{e}_6^T & \mathbf{e}_7^T\end{bmatrix}^T$$

Translational Jacobian matrix, $\mathbf{J}_t$ maps the required platform linear velocities $\dot{\mathbf{p}}$ to cable velocities, $\dot{\mathbf{l}}$.

$$\dot{l} = \mathbf{J}_t\ \dot{\mathbf{p}} \Leftrightarrow \begin{bmatrix}\dot{l}_a^T & \dot{l}_b^T & \dot{l}_7^T\end{bmatrix}^T = \begin{bmatrix}\mathbf{J}_{t1}^T & \mathbf{J}_{t2}^T & -\boldsymbol{e}_7^T\end{bmatrix}^T \dot{\mathbf{p}}$$

$\mathbf{J}_{t1}$ relates end-effector velocity with cable 1, 3 and 5 velocities while $\mathbf{J}_{t2}$ relates end-effector velocity with cable 2, 4 and 6 velocities. $\dot{l}_i$ is the magnitude of the i^{th} cable velocity.

Kinematics of CDPR with large orientation workspace



Inverse-Kinematics of the Robot:

$$\begin{bmatrix} \dot{l}_a \\ \dot{l}_b \\ \dot{l}_7 \end{bmatrix}_{7\times1} = \begin{bmatrix} \frac{1}{3}\mathrm{I}_{3\times3} & \frac{2}{3}\mathrm{I}_{3\times3} & \frac{1}{3}\mathrm{I}_{3\times3} & 0_{3\times1} \\ -\frac{1}{3}\mathrm{I}_{3\times3} & \frac{1}{3}\mathrm{I}_{3\times3} & \frac{2}{3}\mathrm{I}_{3\times3} & 0_{3\times1} \\ 0_{1\times3} & 0_{1\times3} & 0_{1\times3} & 1_{1\times1} \end{bmatrix}_{7\times10} \begin{bmatrix} r_0\mathbf{J}_\omega^{-1} & 0_{3\times3} \\ 0_{7\times3} & \mathbf{J}_t \end{bmatrix}_{10\times6} \begin{bmatrix}\boldsymbol{\omega} \\ \dot{\mathbf{p}}\end{bmatrix}_{6\times1}$$

LS2N prototype

Conclusion

This project is focuesd on a Cable-Driven Parallel Robot with a novel Concept of exploiting a parallel Spherical Wrist modeled earlier at LS2N. The 6-DOF prototype is composed of two mechanisms which are connected in series to provide large translational and orientation workspaces. The following subjects are also in the context of this research:

- Workspace analysis
- Parasitic motion analysis
- Design of reconfigurable CDPRs

References

[1] Saman Lessanibahri, Marc Gouttefarde, Stéphane Caro, and Philippe Cardou. Twist feasibility analysis of cable-driven parallel robots. In *Cable-Driven Parallel Robots*, pages 128–139. Springer, 2018.