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DYNAMICS OF CABLE – DRIVEN ROBOTS

INTRODUCTION

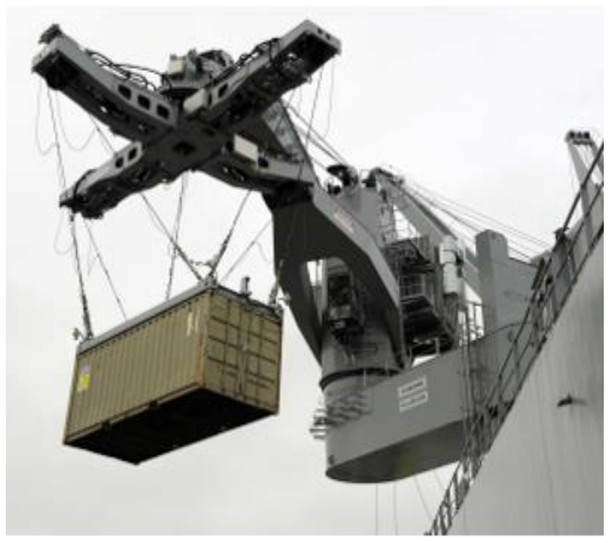
Cable–Driven Parallel Robots (CDPRs) are a class of **parallel robots** where the end effector (EE) is moved by **cables** that are coiled and uncoiled on cable winches. Thus, they work like multiple Degree–Of–Freedom (DOF) cranes controlled by several cables.

Due to this peculiar architecture, CDPRs provide interesting advantages such as:

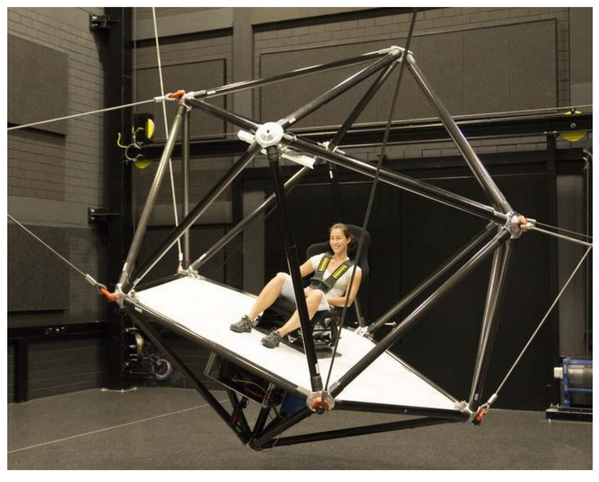
- **very large workspaces**, especially if compared to standard parallel robots;
- high **payload–to–robot–weight** ratio and low **inertia**;
- **high dynamic performances** with smaller and cheaper actuators;
- ease of **assembly**, **disassembly** and **manufacturing,** with **reduced costs**;
- excellent **ease of transport** and superior **modularity** and **reconfigurability**.

APPLICATIONS

Research on CDPRs started in the early '90s. CDPRs overcome the usual limits of parallel robots (such as a limited **workspace** and reduced **dexterity**) while keeping their traditional strength of **high dynamics**. This expands the range of potential applications.



Large workspaces The Skycam (left) records sport or music events in stadiums from above. Other proposed applications are in shipyards and hangars, for assembling, loading and maintaining ships and airplanes (right), or for large scale 3D printing and scanning.

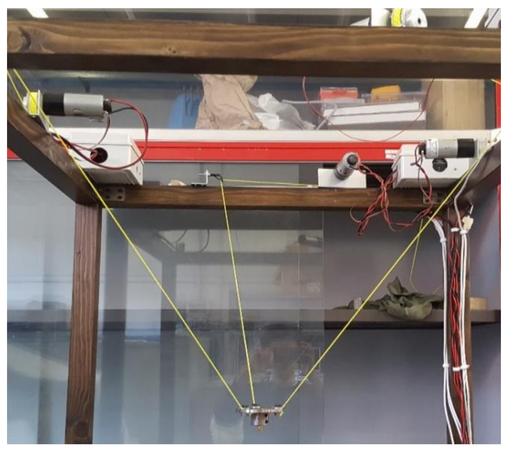


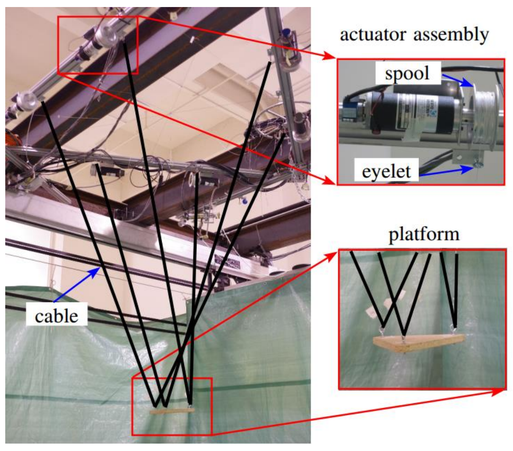
Human interaction CDPRs are intrinsically safe to operate with humans: this has been used for haptic interfaces (left), post-stroke rehabilitation or VR simulation (right).

CHALLENGES

Cables have a major limit: they can only provide **tensile** forces, that is, they cannot **push**. This raises challenges in the design process, which have been tackled in two ways:

- **Over-constrained robots** use more cables than the required number of DOFs, so that all cables are under tension (by pulling each other). This allows all DOFs to be controlled in the entire workspace, but limits application in crowded environments.
- **Under-constrained robots** use a reduced number of cables. This makes the robot easier, cheaper and quicker to deploy; it also increases accessibility, with fewer cables being all located above the EE. However, dexterity and workspace are limited.



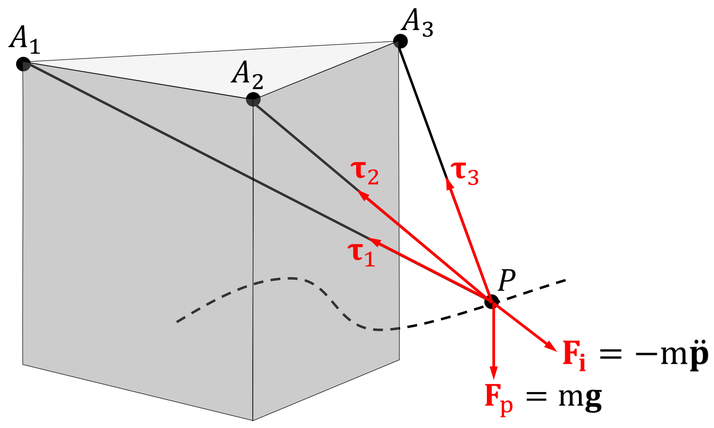


Underconstrained prototype at DIN (left) and fully-constrained robot from ULaval (right)

A third option is to take advantage of robot **dynamics**, so as the inertial forces on the EE help to keep cables in tension. In this way, we might use as many cables as DOFs (**fully-constrained robots**), with all cables above the EE in a **cable-suspended** architecture.

DYNAMIC MODEL

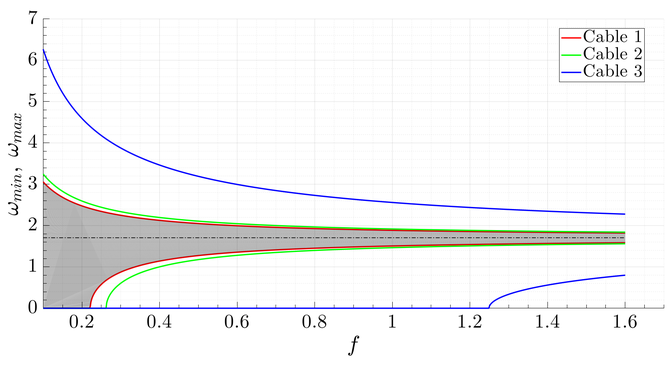
The **statics** of fully-constrained CDPRs have been extensively studied, while the **dynamic** problem has received less attention.

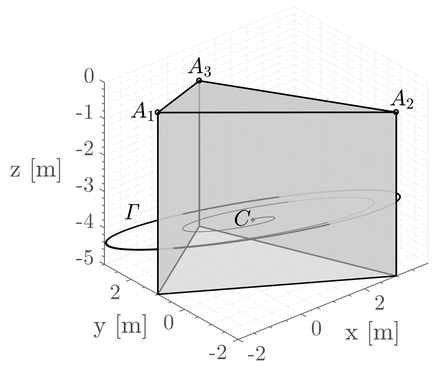


The **Static Equilibrium Workspace** (SEW) is the set of static equilibrium positions (shown in gray above) where cable tensions $\tau_i = \|\boldsymbol{\tau}_i\|$ are positive. For a 3-cable robot with point-mass EE, $\boldsymbol{\tau}_1 + \boldsymbol{\tau}_2 + \boldsymbol{\tau}_3 = m(\ddot{\mathbf{p}} - \mathbf{g})$, with $\ddot{\mathbf{p}}$=acceleration of the EE, m=mass and $\mathbf{F}_p$ =weight. The inertia force $\mathbf{F}_i$ keeps the τ_i's positive even as the EE moves beyond the SEW. The workspace is far larger than the SEW; this expands potential applications.

OUR RESEARCH

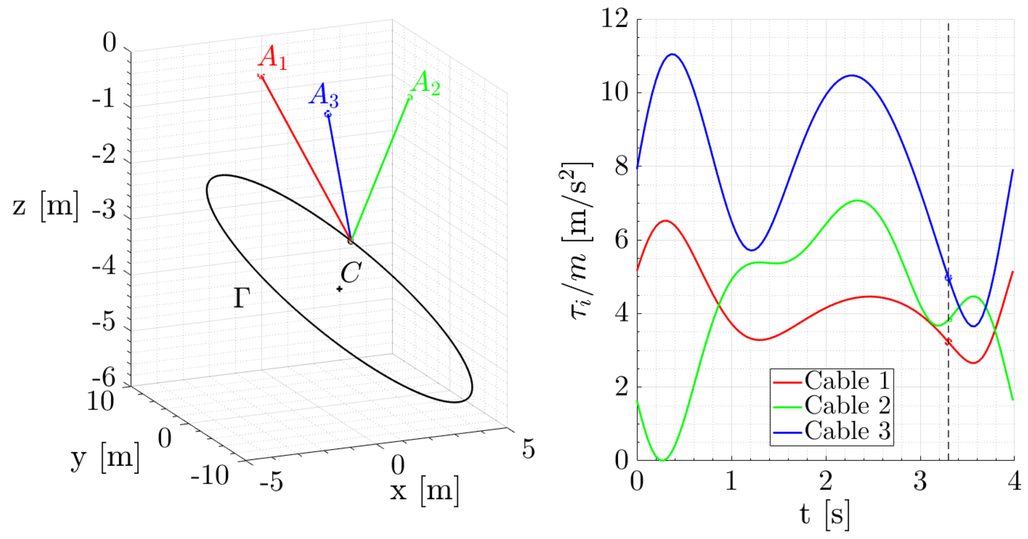
We studied a general class of spatial periodic motions (e.g.: straight lines, circles or ellipses), for a 3-cable robot with general architecture (cable exit points A_i are arbitrarily placed). We found strict feasibility conditions that don't require to integrate the dynamic equations: the trajectory planning can thus be done online in real-time applications.





Left: the EE moves with frequency ω. For the i-th cable (i = 1,2,3), a range of ω is found, that guarantees positive τ_i; the intersection of the 3 ranges (in gray) is the admissible range. A special frequency ω_n allows arbitrarily large motions with positive tensions.

Right: we also studied transition motions where the robot starts from rest in the SEW and moves with growing oscillation amplitudes (or viceversa slows down within the SEW).



Left: an example trajectory. Right: cable tensions remain positive along the motion.

This research topic has produced a paper for the main conference in this sector:

- G. Mottola, C. Gosselin and M. Carricato, "Dynamically Feasible Elliptical Trajectories for Fully Constrained 3-DOF Cable-Suspended Parallel Robots," in *Proceedings of the 3rd International Conference on Cable-Driven Parallel Robots*, Québec, 2017.

A journal paper with further developments is currently under review.

CURRENT ACTIVITIES

The student is currently at the Robotics Laboratory of Laval University in Québec (Canada), a leading institution on robotics with many papers on the dynamics of CSPRs, under the supervision of prof. Clément Gosselin. The expected outcomes are journal papers to complete and expand previous work on the topic. Potential applications are the dynamic recovery of cable robots after a cable failure, a fundamental issue for safety.

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