Design of a cable driven parallel robot for additive manufacturing

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Introduction

Cable driven parallel robots are robots for which the fixed base and the mobile platform are connected by cables. There are no guiding elements except those of the pulleys used to wind and unwrap the cables.

The **main advantages** of this technology are:

- **reduction of the moving masses** resulting in a large acceleration capacity of the moving platform;
- **reconfigurability and modularity**: the robot can be reconfigured easily by changing the anchor points of the actuators and adapting its geometric control model;
- **reduction of the production costs**.

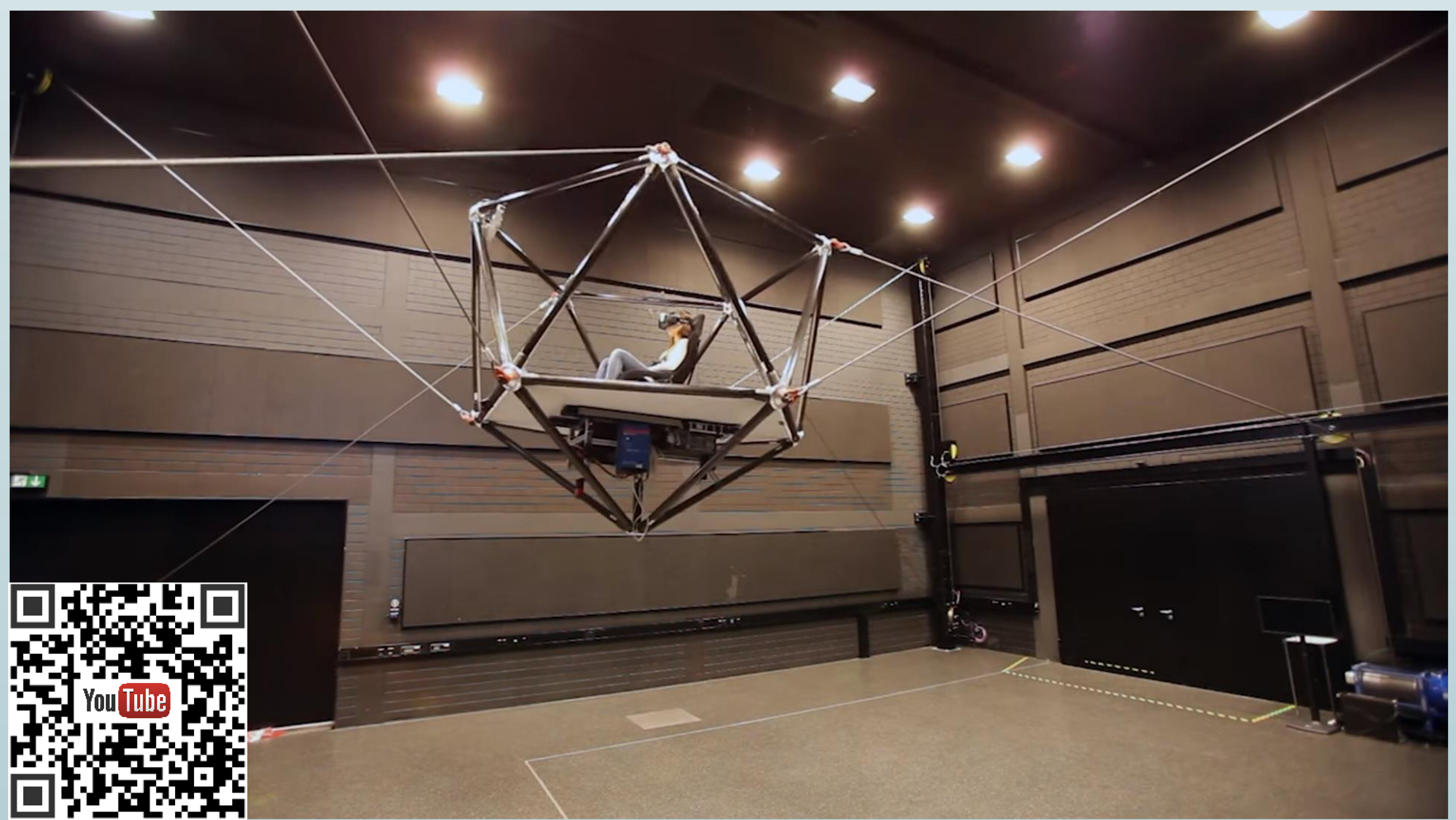

Fig 1: Completely constrained cable driven parallel robots simulator from Max Plank Institute [2]

Additive manufacturing is a manufacturing process by adding material. As opposed to subtractive manufacturing commonly used in the industry to machine parts by removing material from a crude. The vast majority of these solutions use a Cartesian robot, a horizontal plane 2D motion for the movement of the head and a linear 1D movement for the support table, which corresponds to 3 degrees of freedom(DoF) machines.

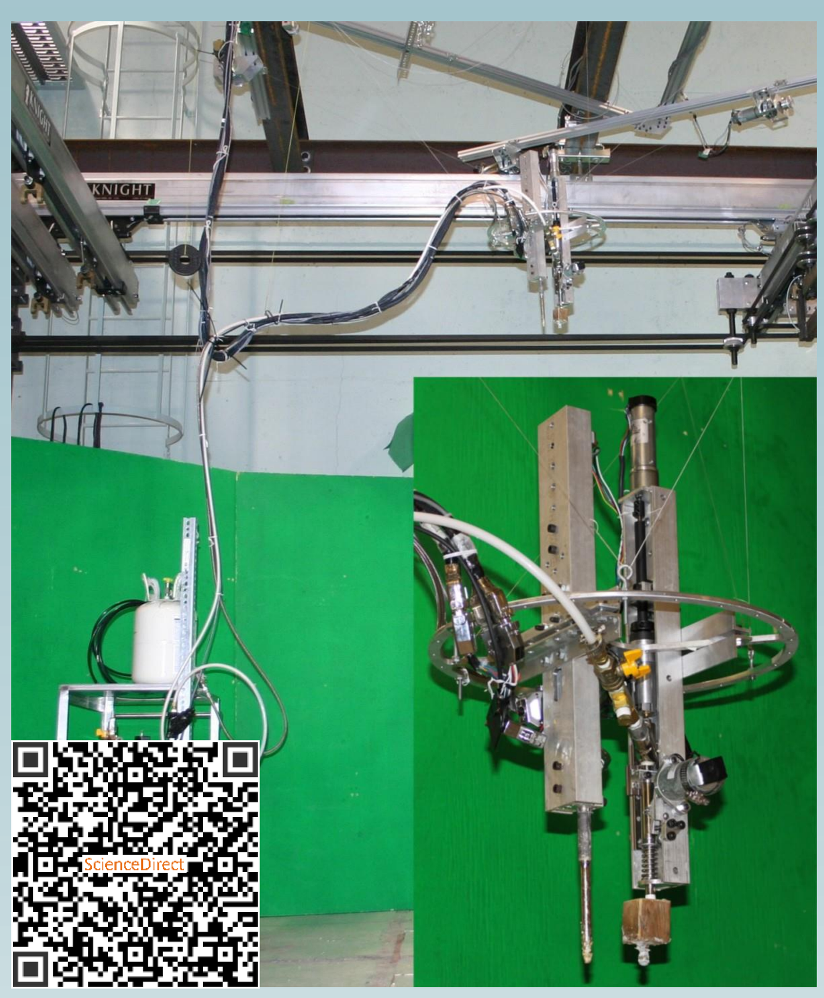

Fig 2: Suspended cable driven parallel robots for large-scale 3D printing from University of Laval [3]

The manufacturing process which need more than 3 DoF are **Fused Deposition Modeling** and **electron-beam melting**. This will enable more complex parts to be produced. This can decrease the manufacturing cost by using less material and a less expensive architecture. But this can also increase the production speed, and propose a modular architecture to adapt to the size of the part. These different approaches to innovation can be satisfied by a cable architecture.

The use of cable robots for additive production in a short term is conceivable. Unlike a use for subtractive production, where the mechanical stresses are stronger, and the rigidity of the cable solutions being too weak.

Problematics

- Design of a high dynamic cable robot for accurate position control for large-scale printing;
- Dimensional synthesis maximizing the workspace and the rigidity of the robot.

Objectives

- **Preliminary design:**
  Structural synthesis, geometric and kinematic-static of a 6 DoF cable robot having a guaranteed level of rigidity in a workspace optimized in terms of accessibility in position and orientation.
- **Modeling:**
  Dynamic modeling of the robot taking into account the elasticity of the cables and the behavior of the drive chain. Static and dynamic performance evaluation by model simulation.
- **Design:**
  Realization of a demonstrator and evaluation of its static and dynamic performances by experimental characterization.
- **Model adjustment and design optimization.**

Kinematics

The inverse kinematics model can be easily defined by the equation [4]:

$$l_i = \left\| \overrightarrow{A_iB_i}\Big|_O \right\|_2 = \left\| -\overrightarrow{OA_i}\Big|_O + \overrightarrow{OC}\Big|_O + R_C\,\overrightarrow{CB_i}\Big|_C \right\|_2$$

Where:

- l_i is the length of the i^{th} cable.
- $\overrightarrow{OC}\Big|_O$ is the position vector of the effector on the origin frame;
- R_C is the rotation matrix from the origin frame to the effector frame which contains the orientation of the effector;
- $\overrightarrow{CB_i}\Big|_C$ is the fixed vector of the attachment point B_i on the effector frame;
- $\overrightarrow{OA_i}\Big|_O$ is the fixed vector of the attachment point A_i on the origin frame;

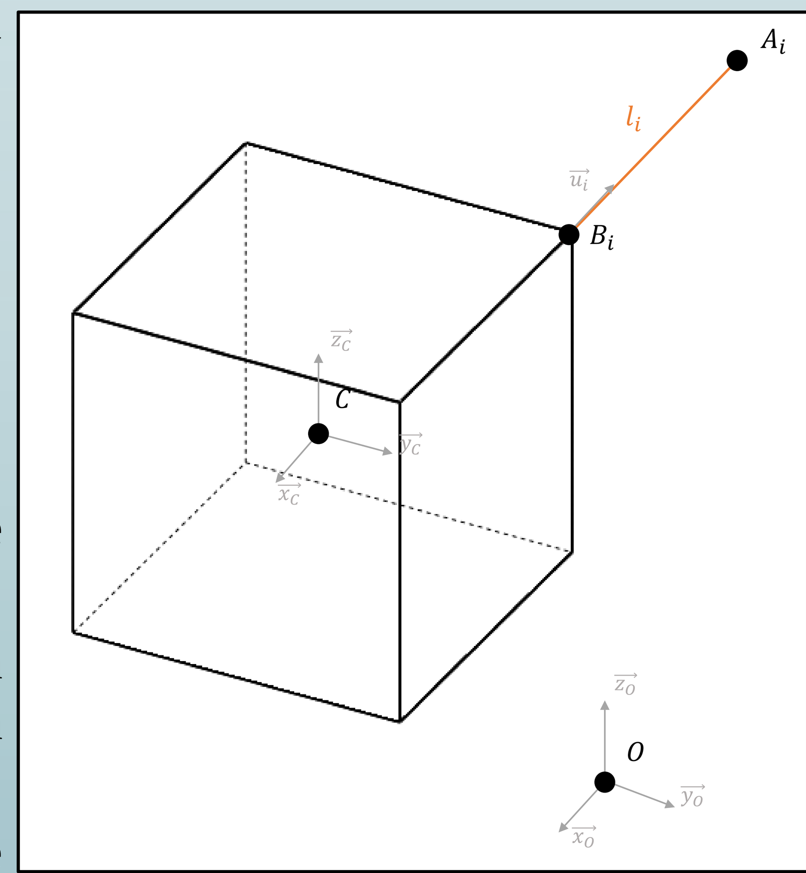

Fig 3: Kinematics of a cable driven parallel robot

Prospect

The prospect is to **analyze the dynamic behavior of the robot**. To this end we need to implemented a dynamic model with elastic wire **by using Lagrange equations**. There are 6+n generalized coordinates $x_C, y_C, z_C, \psi, \theta, \varphi, q_1, \dots, q_n$. n multiplicator of Lagrange are introduced with n holonomic constraints :

$$f_i(x_C, y_C, z_C, \psi, \theta, \varphi, q_i) = \overbrace{R_{reduc}(q_i - q_0) + l_0}^{l_i} - \left\| -\overrightarrow{OA_i}\Big|_O + \overrightarrow{OC}\Big|_O + R_C\,\overrightarrow{CB_i}\Big|_C \right\|_2$$

The Lagrange equations of the dynamics can be defined by 6+n equations for a robot with 6 DoF and n wires:

$$\mathcal{L}_{p_i}:\ \frac{d}{dt}\frac{\partial T}{\partial \dot{p}_i} - \frac{\partial T}{\partial p_i} = P_{p_i} + \sum_{k=1}^{n} \lambda_k \frac{\partial f_k}{\partial p_i}$$

Where p_i is the generalized coordinate, T is the kinetic energy of the robot, P_{p_i} is the generalized force, λ_k is a Lagrange multiplicator, R_{reduc} is the reduction ratio between the cable length and the drum angle, q_0 is the drum angle at 0 and l_0 is the wire length at 0.

Bibliography

1. C. Gosselin, "Cable-driven parallel mechanisms: state of the art and perspectives," *Mech. Eng. Rev.*, vol. 1, no. 1, pp. DSM0004-DSM0004, 2014.
2. 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, vol. 2016–Novem, pp. 3024–3029.
3. E. Barnett and C. Gosselin, "Large-scale 3D printing with a cable-suspended robot," *Addit. Manuf.*, vol. 7, pp. 27–44, 2015.
4. T. Bruckmann, L. Mikelsons, T. Brandt, M. Hiller, and D. Schramm, "Wire Robots Part I: Kinematics, Analysis & Design," *Parallel Manip. New Dev.*, vol. 1, no. April 2008, 2008.

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