Cable-Suspended Parallel Robot CoGiRo

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I. CoGiRo CSPR prototype

LIRMM and Tecnalia have built a demonstrator of a 6-DOF large-dimension CDPR driven by 8 cables. Contrary to most redundantly actuated CDPRs (more cables than mobile platform DOFs), it is a cable-suspended robot (crane-like configuration), i.e., all its cable drawing points are located above its workspace, gravity being used to keep the cables tensed. Such a cable-suspended configuration is relevant in many applications since no cable clutters the lower part of the workspace. This prototype has been constructed in the framework of the ANR project CoGiRo (2010-2013).[1] It is shown in Fig. 1. In the following, it will be referred to as the CoGiRo prototype. The mobile platform of the CoGiRo prototype can move in a significant part of the volume occupied by its supporting structure thanks to an efficient cable layout which has been selected by maximizing the acceptable horizontal distance between the mobile platform reference point and the platform center of mass [1]. The CoGiRo prototype has a payload carrying capability of more than 300 kg over all its workspace and of 500 kg nearby the center of the workspace.

Demonstration videos:

- https://youtu.be/2b4YwFZhtIE
- https://youtu.be/An_i8xoMXDc
- https://youtu.be/-CmjXwXEZJA

A. Supporting structure

The supporting structure of the CoGiRo prototype is an aluminum structure of overall dimensions 15.24 m x 11.24 m x 5.93 m (length x width x height). A CAD view of the structure, the winches, and the mobile platform of the CoGiRo prototype is shown in Fig. 2. In this figure, the fixed reference frame, referred to as the *base frame*, is also shown. The base frame is located on the ground in the center of the workspace, its z-axis being vertical.

Each cable is routed from the winch drum to the mobile platform by means of a swiveling pulley of diameter 100 mm located near the top of the supporting structure (Fig. 3). The rotation axis of this swiveling pulley is vertical and practically coincident with the cable segment going to the drum (part of the cable located between the swiveling pulley and the drum). The point where the cable segment extending from the winch drum enters the swiveling pulley is fixed in space. This point is chosen to be the so-called cable exit point A_i. In the base frame, the coordinate vectors $\boldsymbol{a}_i$ of the points A_i are given in Table I. These values have been obtained by (almost) direct measurements of the swiveling pulley locations with a laser tracker.

TABLE I: Coordinates of the cable exit points A_i in the base frame and of the cable platform attachment points B_i in the mobile frame (November 2015)

	x (m)	y (m)	z (m)		x (m)	y (m)	z (m)
$\boldsymbol{a}_0$	-7.1775	-5.4361	5.3911	$\boldsymbol{b}_0$	0.5032	-0.4928	0.0
$\boldsymbol{a}_1$	-7.4594	-5.1504	5.3999	$\boldsymbol{b}_1$	-0.5097	0.3508	0.9976
$\boldsymbol{a}_2$	-7.3911	5.1940	5.3976	$\boldsymbol{b}_2$	-0.5032	-0.2700	0.0
$\boldsymbol{a}_3$	-7.1026	5.4753	5.4094	$\boldsymbol{b}_3$	0.4960	0.3561	0.9996
$\boldsymbol{a}_4$	7.2398	5.3759	5.4093	$\boldsymbol{b}_4$	-0.5032	0.4928	0.0
$\boldsymbol{a}_5$	7.5208	5.0851	5.4200	$\boldsymbol{b}_5$	0.4998	-0.3404	0.9991
$\boldsymbol{a}_6$	7.4461	-5.2539	5.3874	$\boldsymbol{b}_6$	0.5021	0.2750	-0.0007
$\boldsymbol{a}_7$	7.1608	-5.5342	5.3973	$\boldsymbol{b}_7$	-0.5045	-0.3463	0.9976

B. Winches

Each of the 8 winches of the CoGiRo prototype consists essentially of a three-phase synchronous motor (B&R 8LSA85), a timing belt, and a drum collecting the cable, as illustrated by the CAD view shown in Fig. 4. The motor drives the drum by way of the timing belt in order to wound or unwound the cable. The gear ratio of the timing belt is equal to 3. The drum radius is equal to 0.0675 m. The inertia of the set motor (with brake) - timing belt - drum is approximately equal to 0.03 $\mathrm{kg.m}^2$ at the motor axis while it is equal to 0.27 $\mathrm{kg.m}^2$ at the drum axis.

[1] http://www.lirmm.fr/cogiro/

Fig. 1: LIRMM/Tecnalia CoGiRo suspended CDPR prototype

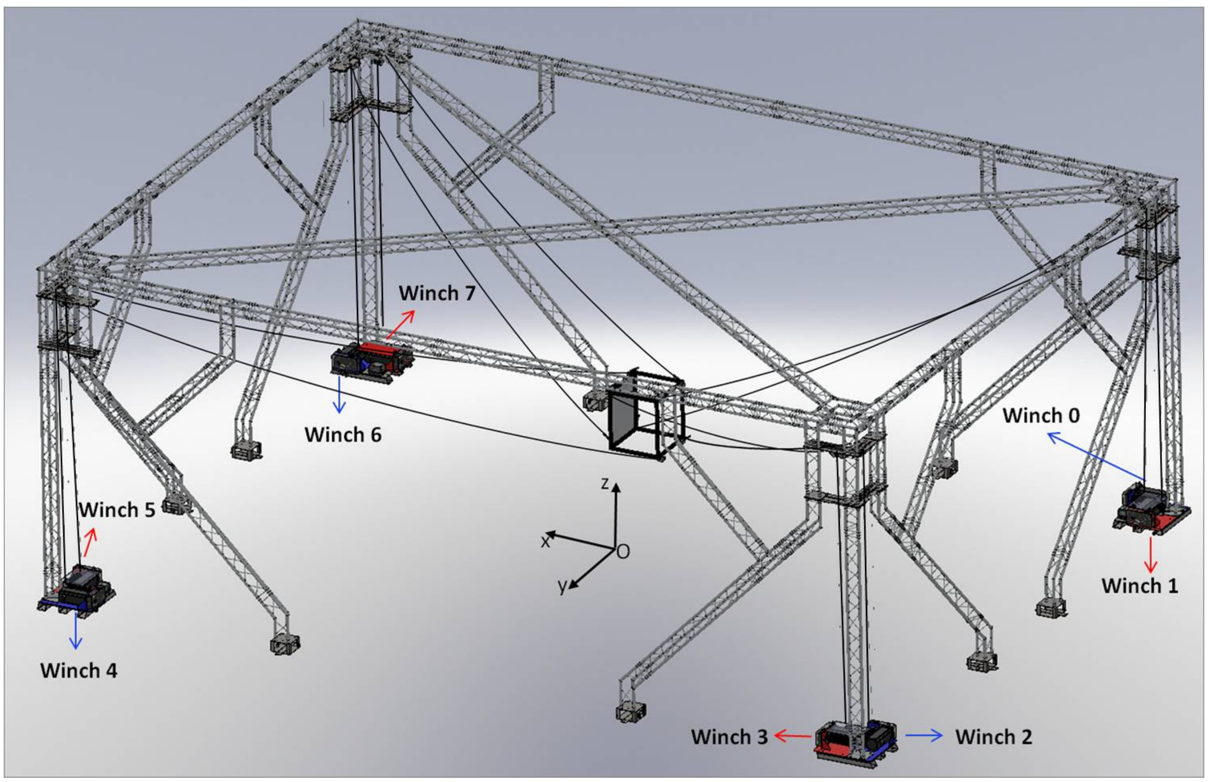

Fig. 2: CoGiRo ANR project prototype—A large parallel robot driven by eight cables in a crane-like configuration

C. Cables

Eight non-rotating steel cables with metallic core (DIN 3069) are used to drive the mobile platform of the CoGiRo prototype. Each cable has a diameter of 4 mm and an unstrained linear density of 0.064 kg/m. The unstrained cross-sectional area is estimated to be 8.2051e-06 m^2 while the actual value of the Young's modulus remains uncertain. In various contexts, different values of the Young's modulus have been used ranging from 17 GPa to 120 GPa. The minimum breaking force of the cable is about 10 kN and the maximum admissible cable tension has been set to 5000 N.

D. Mobile platform

A CAD view of the currently used CoGiRo mobile platform is shown in Fig. 5. This cube-shaped mobile platform is made of steel. The reference frame attached to the mobile platform (*platform frame*) is also shown together with the cable attachments B_i. Each cable is connected to the mobile platform by means of a swiveling hoist ring which (roughly) realizes a universal joint (cardan joint) between the cable and the mobile platform. The cable attachment point B_i is considered to correspond

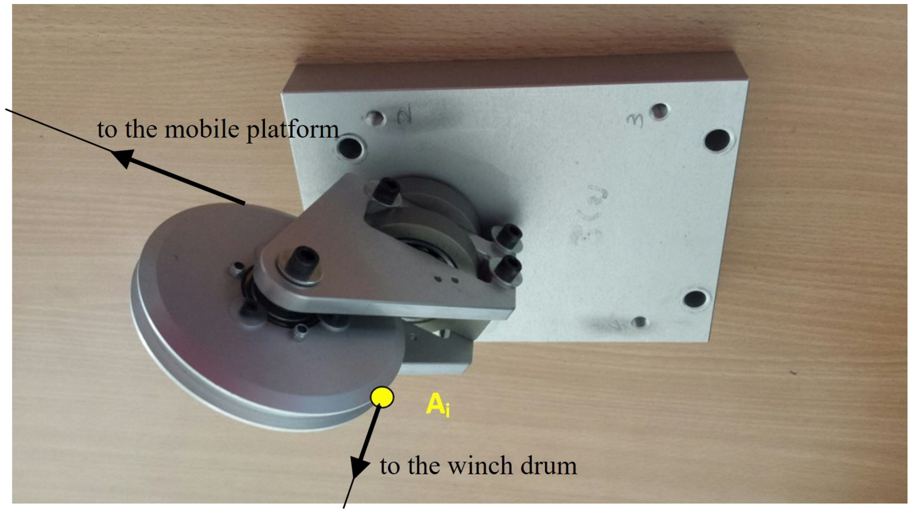

Fig. 3: Swiveling pulley routing the cable toward the mobile platform

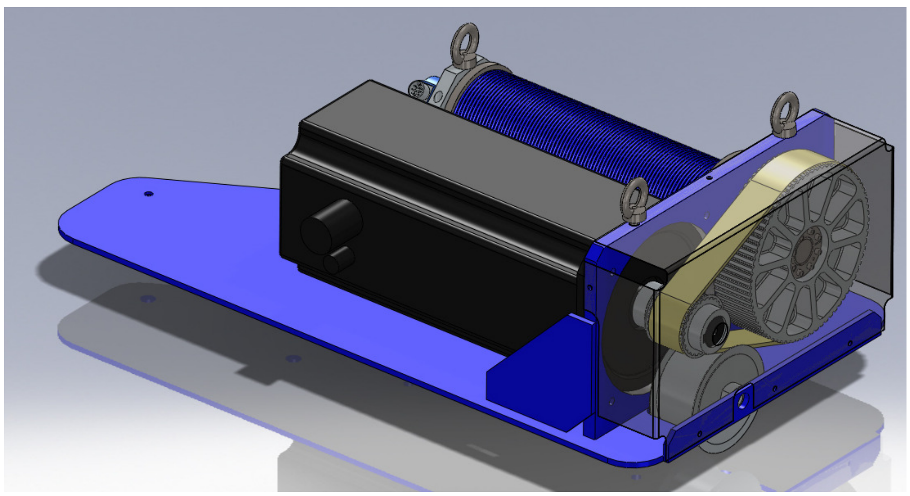

Fig. 4: CAD view of a winch of the CoGiRo prototype

to the center of rotation of this universal joint. The coordinate vectors $\boldsymbol{b}_i$ of points B_i in the platform frame are given in Table I. These coordinates have been obtained by (almost) direct measurements with a laser tracker. From the CAD modeling, the mobile platform mass is 91.058 kg and the coordinates of its center of mass in the platform frame are $x = -0.034$ m, $y = -0.013$ m, and $z = 0.264$ m. The inertia matrix of the mobile platform in a frame having the same orientation as the platform frame but whose origin is coincident with the platform center of mass G is (units: $\mathrm{kg.m}^2$)

$$\mathbf{I}_G = \begin{bmatrix} 36.598 & -0.453 & 3.012 \\ -0.453 & 35.982 & -1.539 \\ 3.012 & -1.539 & 25.439 \end{bmatrix} \tag{1}$$

In the platform frame shown in Fig. 5, this frame origin being denoted by P, the inertia matrix is (units: $\mathrm{kg.m}^2$)

$$\mathbf{I}_P = \begin{bmatrix} 42.955 & -0.414 & 2.205 \\ -0.414 & 42.427 & -1.849 \\ 2.205 & -1.849 & 25.557 \end{bmatrix} \tag{2}$$

References

[1] M. Gouttefarde, J.-F. Collard, N. Riehl, and C. Baradat, "Geometry selection of a redundantly actuated cable-suspended parallel robot," *IEEE Trans. on Robotics*, vol. 31, no. 2, pp. 501–510, 2015.

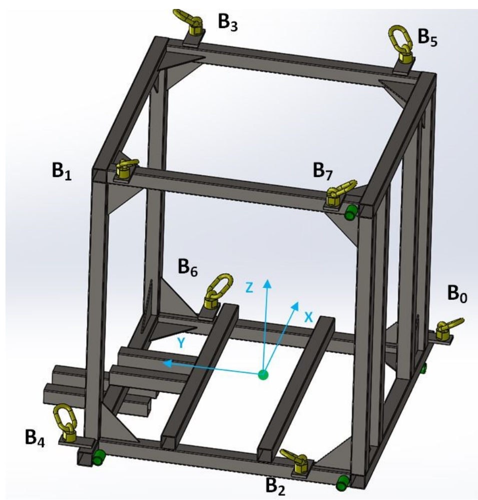

Fig. 5: CAD view of the CoGiRo mobile platform and the reference frame attached to it.