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# Modeling and stabilization of a Cable-driven parallel platform suspended by an airship

Fida Ben Abdallah<sup>1,2</sup>, Naoufel AZOUZ<sup>2</sup>, Lotfi BEJI<sup>2</sup>, Azgal ABICHOU<sup>1</sup>

**Abstract**—In this work, the modeling and control of a heavy-lift airship carrying a payload through a cable driven parallel manipulator were investigated. The vertical take-off and landing capabilities of the airships give them an additional advantage over other means of freight transport. This crane airship will operate as a mobile cable robot. However, during loading and unloading, the airship is very sensitive to wind gusts. Its motion will have a significant inertial impact on the load. In this study we will try to present a strategy to stabilize the load in the presence of a sudden shift in the airship. The dynamic model of the system is then developed taking into account the airship motion which was considered as a disturbance. This model is used to design an anti sway controller that reduces the effect of payload pendulation while respecting constraints on cables tension. Theoretical results are discussed in this paper and computer simulation are presented.

## I. INTRODUCTION

In the last few years, we have seen a mature technology to the point of allowing quadricopters to cooperate in order to maintain and move a load while stabilizing it. While these flying robots can maneuver in highly-constrained space, they are limited in term of their payload carrying capacity. In order to be able to transport, load and unload heavy loads in a precautionary way, the study and development of economical and environmentally friendly air vehicles has become a priority. This applies to the lifting by helicopters [1], [2] for specific loads, but also the lifting by airships. Indeed, the complexity and capability of airships are expanding recently due to the the latest technological advances in the field of aeronautics. This may represent a revolution, especially in freight transport.

The last ten years have seen a tremendous growth in the research focused on the development of large airships dedicated to freight transport [3]. Recent developments in lightweight materials, renewable energy technologies and embedded electronics have generated a renewed interest in an old concept. The complexity and capability of airships are expanding rapidly and the range of missions they designed to support is growing [4]. This may represent a revolution,

especially in freight transport. However, to reach this potential, significant technical issue must be overcome. A special focus is done on the computation of added masses on an conventional airship by Azouz et al. [5]. Beji et al. [6] studied the stabilization problem of an airship with an homogeneous time varying control law.

Amidst this astounding technological development, there are very few applications concerning the use of airships as cranes carrying heavy loads. In our study, we are interested in modelling and control of loading and unloading system of the heavy-lift airship by means of cable-driven parallel manipulator (CDPM). The airship is used for gross motion of the system, while the CDPM is used for fine manipulation of the load.

Cable robots are a special class of parallel robots in which the rigid links are replaced by cables. The choice of the CDPM for handling a heavy load is justified by its potential properties such as large workspace capability, reconfigurability and economical structure and maintenance. However, replacing the rigid links by cables, introduces many new challenges in the study. Unlike the rigid links, cables can only apply tensile forces and not compressive forces. In order to overcome this constraint while controlling all the degrees of freedom (dofs) of the platform, it is possible to design CDPMs with redundancy of actuation. The vast majority of the published works [7], [8], [9] use optimization algorithms in order to obtain an optimal tension distribution. In most studies of CDPM, a non-elastic massless cable model is used [10], [11], [12]. The cables are then considered as straight line segments.

Most of the research on payload manipulation via cables has been approached in two distinct ways : the first approach focuses on fixed bases and variable length cables, while the second focuses on the use of mobile bases without varying cable lengths. A promising alternative recently proposed by Zhou [13], attempts to merge these two approaches together. Thus, the variability of cable lengths is associated to the base mobility in order to provide a more flexible system. Although such a configuration has undeniable advantages, the motion of the base adds complexity to the modeling and control of the system.

In cargo handling operation, the transferred cargo always suffered from pendulation which is caused by wind gust. The pendulation brings a lot of troubles to the handling operation such as instability and hence must be avoided. In order to minimize the load swing, various methods have been implemented. Recently, Yongpan Hu et al [14] propose to determine the anti-pendulation workspace of the CDPM

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which represents the set including all pose (the position and the orientation) of the payload that guarantee strictly positive cable tension. Sung et al [15] propose a 3-D trajectory generation method to suppress unwanted payload oscillations of a 4-cable driven parallel robot. Furthermore, a study of a helicopter carrying a payload using a cable suspended robot was presented by Agrawal [16]. In order to control the helicopter and the cable robot independently, a two time scale control method is proposed where the helicopter motion is considered to be a disturbance in the control design of the cable suspended robot.

The modelling of this dual system composed of the airship and CDPM is difficult to elaborate. For this purpose, we limit ourselves in a first approach to study the loading and unloading phases. This paper addresses the development of a novel anti-sway control for a heavy-lift airship offering stability, safety and efficiency during handling.

The rest of the paper is structured as follows. First, the concept of the heavy-lift airship is introduced in section II. Then, the kinematic and dynamic model of the global system is presented in section III and IV respectively. Subsequently, a command of the global system is elaborated in section V.

## II. CONCEPT AND NOTATIONS

### A. Crane cable description

The heavy lift airship will operate as a cable crane with base mobility. The position and orientation of the platform corresponding to the suspended load depend on the cables length which can be adjusted by winches fixed on the CDPM base rigidly linked to the airship. The kinematic and dynamic analysis of the dual system consisting of the airship and the CDPM requires a representative parametrization which implies a significant benefit in the motion equations.

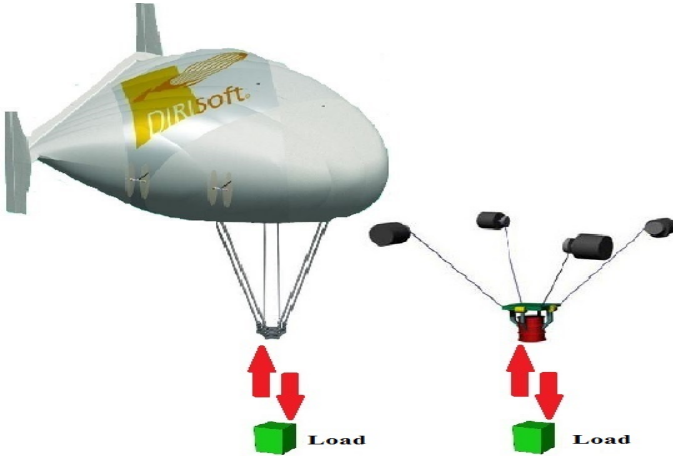


Fig. 1. Aerial cable crane

The analysis of the CDPM with base mobility is made with respect to three reference frames, namely an earth-fixed frame  $R_0(O, X_0, Y_0, Z_0)$ , a local frame fixed to the base  $R_b(G, X_b, Y_b, Z_b)$ , having as origin the inertia center of the base  $G$  and local frame attached to the platform

$R_p(P, X_p, Y_p, Z_p)$  having as origin the geometric center of the platform  $P$ . To describe the orientation of the base and the platform, we use a parametrization by the Euler angles: yaw, pitch and roll  $(\psi, \theta, \phi)$ .  $J_1$  and  $J_3$  are the rotation matrix between the inertial frame  $R_0$  and the local frame  $R_b$  and  $R_p$  respectively.

We denote by  $\eta^b = [x_b, y_b, z_b]^T$  the position vector of the local frame  $R_b$  expressed in the inertial frame  $R_0$ . The position vector of the local frame  $R_p$  is defined as  $\eta^c = [x_c, y_c, z_c]^T$  and  $\eta^p = [x_p, y_p, z_p]^T$  with respect to  $R_0$  and  $R_b$  respectively.

A CDPM with  $n_c$  cables, having the geometry illustrated in Figure 2, has  $n_c$  exit points denoted  $A_i$  on the base and  $n_c$  attachment points on the platform, denoted  $B_i$  and  $\mathbf{l}_i$  is the  $i^{th}$  driving cable connecting these two points. The coordinates of these points are collected respectively in the vectors  $a_i$  and  $b_i$ .  $a_i$  is expressed in the local frame fixed to the base  $R_b(G, X_b, Y_b, Z_b)$  while  $b_i$  is expressed in the local frame attached to the platform  $R_p(P, X_p, Y_p, Z_p)$ . We denote by  $J_4$  the rotation matrix between the two local frames  $R_p$  and  $R_b$ .

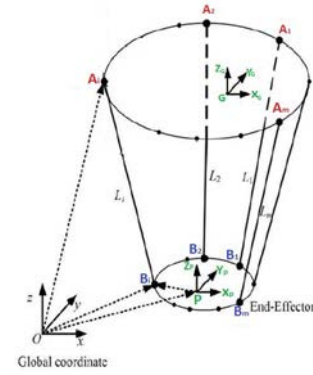


Fig. 2. Representation of a CDPM

### B. Nomenclature

$I_i$	Inertial matrix of the drums
$r_i$	Radius of the drums
$l_i$	Length of the cable $i$
$m$	Mass of the platform with the load
$I_P$	Inertial matrix of the platform with respect to $R_0$
$I_p$	Inertial matrix of the platform with respect to $R_p$
$\eta^b$	Position vector of the local frame $R_b$
$\eta^c$	Position vector of the local frame $R_p$ with respect to $R_0$
$\eta^p$	Position vector of the local frame $R_p$ with respect to $R_b$
$\omega_b$	Angular velocity of the local frame $R_b$
$\omega_c$	Angular velocity of the local frame $R_p$ with respect to $R_0$
$\omega_p$	Angular velocity of the local frame $R_p$ with respect to $R_b$
$u_i$	Engine torque
$t_i$	Cable tension at the point of attachment
$J_1$	Rotation matrix ( $R_0, R_b$ )
$J_3$	Rotation matrix ( $R_0, R_p$ )
$J_4$	Rotation matrix ( $R_b, R_p$ )

### III. KINEMATICS

For a parallel robot, there are  $n_c$  kinematic closures. The components of the vector  $\mathbf{l}_i$  are expressed in reference frame  $R_0$  as follow :

$$\mathbf{l}_i = \overrightarrow{A_i B_i} = -\eta^c - J_3 b_i + \eta^b + J_1 a_i \quad i \in \{1, 2, \dots, n_c\} \quad (1)$$

To obtain the Jacobian matrix, we only have to derive the cable length  $l_i$  with respect to time. We have then:

$$\dot{l}_i^2 = (-\eta^c - J_3 b_i + \eta^b + J_1 a_i)^t (-\eta^c - J_3 b_i + \eta^b + J_1 a_i)$$

$$l_i \dot{l}_i = \mathbf{l}_i^t (-\dot{\eta}^c - \dot{J}_3 b_i + \dot{\eta}^b + \dot{J}_1 a_i)$$

$$l_i \dot{l}_i = \mathbf{l}_i^t (-\dot{\eta}_1^c + \dot{\eta}^b - [\omega_c] J_3 b_i + [\omega_b] J_1 a_i)$$

$$-l_i \dot{l}_i + \mathbf{l}_i^t \dot{\eta}^b + (J_1 a_i \times \mathbf{l}_i)^t \omega_b = \mathbf{l}_i^t \dot{\eta}^c + (J_3 b_i \times \mathbf{l}_i)^t \omega_c$$

Where  $[\omega_c]$  and  $[\omega_b]$  are anti-symmetric tensors corresponding to the cross product associated with  $\omega_c$  angular velocities of the geometrical center of the mobile platform and  $\omega_b$  angular velocities of the inertial center of the base  $G$  respectively, such that :  $\dot{J}_3 = [\omega_c] J_3$  and  $\dot{J}_1 = [\omega_b] J_1$ . If we generalize for the  $n_c$  cables, the matrix writing becomes:

$$\underbrace{\begin{pmatrix} -l_1 & 0_{n_c-1} & \mathbf{l}_1^t & (J_1 a_1 \times \mathbf{l}_1)^t \\ \vdots & \vdots & \vdots & \vdots \\ 0_{n_c-1} & -l_{n_c} & \mathbf{l}_{n_c}^t & (J_1 a_{n_c} \times \mathbf{l}_{n_c})^t \end{pmatrix}}_B \begin{pmatrix} \dot{l} \\ \dot{\eta}^b \\ \omega_b \end{pmatrix} = \underbrace{\begin{pmatrix} \mathbf{l}_1^t & (J_3 b_1 \times \mathbf{l}_1)^t \\ \vdots & \vdots \\ \mathbf{l}_{n_c}^t & (J_3 b_{n_c} \times \mathbf{l}_{n_c})^t \end{pmatrix}}_A \begin{pmatrix} \dot{\eta}^c \\ \omega_c \end{pmatrix}$$

Thus the Jacobian matrix of the system is :  $J = B^+ A$  such as  $B^+ = B^T (B B^T)^{-1}$  is the pseudo-inverse of  $B$ . Due to the motion of the base,  $J$  is the Jacobian matrix of the CDPM which take into account the base mobility. In this case, the Jacobian matrix is defined as the relation between the velocity of the platform  $[\dot{\eta}^c, \omega_c]^t$  and the linear velocities of the cable-driven  $\dot{l} = [\dot{l}_1, \dot{l}_2, \dots, \dot{l}_{n_c}]$  as well as the velocity of the base  $[\dot{\eta}^b, \omega_b]^t$ . This relation is given by :

$$\begin{pmatrix} \dot{l} \\ \dot{\eta}^b \\ \omega_b \end{pmatrix} = J \begin{pmatrix} \dot{\eta}^c \\ \omega_c \end{pmatrix} \quad (2)$$

The angular velocity of the geometric center of the mobile platform expressed in the global coordinate system  $R_0$  is :

$$\omega_c = J_1 \omega_b + J_3 \omega_p$$

The angular acceleration in the global coordinate system is :

$$\dot{\omega}_c = J_1 \dot{\omega}_b + J_3 \dot{\omega}_p + \dot{J}_1 \omega_b + \dot{J}_3 \omega_p$$

$$\dot{\omega}_c = J_1 [\dot{\omega}_b + J_4 \dot{\omega}_p + (\omega_b \times J_4 \omega_p)]$$

### IV. DYNAMICS

Using the Newton-Euler approach, the general dynamic model of a CDPM can be divided into two expressions corresponding to the dynamics of the platform and the dynamics of the  $n_c$  winches. These dynamic equations that describe the motion of the CDPM will be directly used for control.

#### A. Dynamics of the actuators

Applying the Newton-Euler approach, the dynamic equation of the winch is:

$$I_i \ddot{\phi}_i - r_i \dot{\phi}_i = u_i \quad (3)$$

Where  $I_i$  is the inertia moment of the winch around the  $X_b$  axis,  $r_i$  is the radius of the winch and  $\phi_i$  is the rotation angle of the winch around the  $X_b$  axis. Using the rotation matrix  $J_1$ , the expression of the driving torque  $u_i$  expressed in the global reference  $R_0$  is :

$$U_i = J_1 \|u_i\| e_{X_b}$$

In which  $e_{X_b}$  is the unit vector along the  $X_b$  axis. If we generalize the expression (3) for the  $n_c$  winches, the dynamic model of the actuators (winches) which connects the vector of the engine torques  $u \in \mathbb{R}^{n_c}$  to the joint accelerations  $\ddot{\phi} \in \mathbb{R}^{n_c}$  and cables tension  $T \in \mathbb{R}^{n_c}$  is given by the following relation:

$$u = I_m \ddot{\phi} - R T \quad (4)$$

Where  $R$  is a diagonal matrix  $n_c \times n_c$  defined by  $\text{diag}(R) = [r_1, r_2, \dots, r_{n_c}]^t$ .

#### B. Dynamics of the platform

The tension  $\mathbf{t}_i$  exerted by the cables on the platform at different attachment points  $B_i$  have the same direction as the vector  $\overrightarrow{A_i B_i}$ . These tensions are collected in a force torsor applied at the geometric center  $P$  such that the vector  $T = [t_1, t_2, \dots, t_{n_c}]$  groups the  $n_c$  cable tensions  $t_i$ . The external forces, such as the weight of the platform and its loading, are represented by the vector  $mg$ . The platform dynamic is given by the following relation :

$$m \ddot{\eta}^c = mg - \sum_{i=1}^{n_c} t_i v_i$$

$$I_P \dot{\omega}_c + \omega_c \times I_P \omega_c = - \sum_{i=1}^{n_c} J_3 b_i \times t_i v_i$$

Where  $\eta^c$  represents the position vector of the platform expressed in  $R_0$  such that  $\eta^c = \eta^b + J_1 \eta^p$ ,  $\dot{\omega}_c$  is the angular acceleration,  $m$  is the mass of platform as well as its loading,  $I_P$  is the inertia moment expressed in the inertial frame  $R_0$  and  $v_i = \frac{\overrightarrow{A_i B_i}}{\|\overrightarrow{A_i B_i}\|}$  the unit vector along the  $i^{th}$  cable.

As already mentioned, the motion of the base (rigidly linked to the airship) acts as a disturbance  $\mathbf{D}_G$  to the platform. By choosing to express the preceding dynamics model in the local coordinate system  $R_p$ , the unknown disturbance from the motion of the base can be modeled as additive terms in the dynamics of the platform. Denoting by  $q_i = J_1^t v_i$  the

unit vector along the  $i^{th}$  cable expressed in  $R_p$ , the dynamics expression takes the following form :

$$m\ddot{\eta}^p + \underbrace{mJ_1^t(\ddot{\eta}^b + \ddot{J}_1\eta^p + 2\dot{J}_1\dot{\eta}^p) - J_1^t mg}_{D_{\eta^b}} = - \sum_{i=1}^{n_c} t_i q_i \quad (5)$$

$$J_4 I_p \dot{\omega}_p + J_4 \omega_p \times J_4 I_p \omega_p + D_{\omega_b} = - \sum_{i=1}^{n_c} J_4 b_i \times t_i q_i \quad (6)$$

With :

- $D_{\eta^b} = mJ_1^t(\ddot{\eta}^b + \ddot{J}_1\eta^p + 2\dot{J}_1\dot{\eta}^p) - J_1^t mg$
- $D_{\omega_b} = J_4 I_p J_4^t [\dot{\omega}_b + (\omega_b \times J_4 \omega_p)] + (\omega_b + J_4 \omega_p) \times J_4 I_p J_4^T \omega_b + \omega_b \times J_4 I_p \omega_p$

The two terms  $D_{\eta^b}$  and  $D_{\omega_b}$  are considered as a disturbance term on the platform's motion. We can combine both force and moment equations as :

$$\underbrace{\begin{pmatrix} mI_3 & 0_{3 \times 3} \\ 0_{3 \times 3} & J_4 I_p \end{pmatrix}}_{M_G} \underbrace{\begin{pmatrix} \ddot{\eta}^p \\ \dot{\omega}_p \end{pmatrix}}_{\dot{x}} + \underbrace{\begin{pmatrix} 0_{3 \times 1} \\ J_4 \omega_p \times J_4 I_p \omega_p \end{pmatrix}}_{C_G} + \underbrace{\begin{pmatrix} D_{\eta^b} \\ D_{\omega_b} \end{pmatrix}}_{D_G} = - \underbrace{\begin{pmatrix} q_1 & \cdots & q_{n_c} \\ J_4 b_1 \times q_1 & \cdots & J_4 b_{n_c} \times q_{n_c} \end{pmatrix}}_{W_G} T$$

in which,  $M_G$  is the mass matrix,  $C_G$  is the vector of Coriolis and centrifugal terms,  $D_G$  is the disturbance term and  $W_G$  the force transmission matrix. Knowing that  $\ddot{x} = [\ddot{\eta}^p, \dot{\omega}_p]$ , the compact dynamic model of the payload is given by the expression

$$M_G(x)\ddot{x} + C_G(x, \dot{x}) + D_G = W_G T \quad (7)$$

The control of this system composed of a platform suspended by winches rigidly linked to a mobile base is quite complicated. To make the task less arduous, we assumed that the base has only two degrees of freedom along the  $X_b$  axis and  $Y_b$  axis. Under this condition and referring to the dynamics equations, (5) and (6), the effect of the orientation motion of the base  $D_{\omega_b}$  on the cable robot vanishes and the effect of the position motion of the base  $D_{\eta^b}$  reduces to  $m(\ddot{\eta}^b - g)$ . Multiplying now the moment equation, (6) by  $J_4^t$ , the dynamic model of the platform is given by :

$$M(x)\ddot{x} + C(x, \dot{x}) + D(\eta^b) = WT \quad (8)$$

Where :

$$M(x) = \begin{pmatrix} mI_3 & 0_{3 \times 3} \\ 0_{3 \times 3} & I_p \end{pmatrix} \\ C(x, \dot{x}) = \begin{pmatrix} 0_3 \\ \omega_p \times I_p \omega_p \end{pmatrix}; D(\eta^b) = \begin{pmatrix} m(\ddot{\eta}^b - g) \\ 0_3 \end{pmatrix} \\ W = - \begin{pmatrix} q_1 & \cdots & q_{n_c} \\ b_1 \times J_4^t q_1 & \cdots & b_{n_c} \times J_4^t q_{n_c} \end{pmatrix}$$

## V. CONTROL

During critical loading or unloading phases, the airship may be subjected to wind acceleration. Due to the inertial coupling between the airship and the load, the load may swing with large amplitudes that may generate dangerous configurations to the system. For this purpose we have applied controls at the level of the winches in order to exert cable tensions which may attenuate the swinging of the suspended load to ensure the safety of the system. In this preliminary study, we limit ourselves to a translation motion of the airship along the  $X_b$  axis, and we suppose that the airship (base) follows this theoretical trajectory for a specific time  $t_f$ :

$$x_d(t) = \begin{cases} h_d \frac{t^5}{t^5 + (t_f - t)^5}, & \text{if } 0 \leq t \leq t_f \\ h_d, & \text{if } t > t_f \end{cases} \quad (9)$$

More realistic simulations of wind action on the airship will be studied in future papers. Based on this proposed simulation, it is essential to design a robust controller for the load to ensure efficient swing attenuation. For this purpose, we consider only the inverse dynamics of the suspended platform. In the following derivation, it is assumed that all cables must be kept in tension in the whole manoeuvre. Therefore, the components of the vector must remain strictly positives. A cable robot with an  $n$  dofs end effector requires at least  $n + 1$  cables to fully constrain the end-effector, leading to minimum limits of four cables for planar robots and seven cables for the spatial case [17]. A non-elastic massless cable model is used. The cables are then considered as straight line segments. The control states are measured by Inertial Measurement Unit attached to the mobile platform.

In order to integrate a robust control, we chose to apply a feedback controller based on Lyapunov function. The anti sway control of the payload with changing rope length is considered as follows :

$$T = W^+(D - K_p e - K_d \dot{x}) \quad (10)$$

where  $K_p$  and  $K_d$  are positive definite matrices,  $e = x - x_d$  the position error,  $W^+$  the pseudo-inverse of the force transmission matrix  $W$  and  $D$  is the effective disturbance on the payload's motion. The asymptotic stability of the payload can not only be provided by the adequate choice of the control law but also a cable tension distribution algorithm should be integrated to ensure that the control is capable to keep the CDPM cable tensions always positive. In this paper, the problem of tension distribution is formulated as a 1-norm linear programming method as follows:

Compute:  $\min(\|T\| = \sum_{i=1}^{n_c} t_i)$  such as  $WT = F$  and  $0 < t_{imin} \leq t_i \leq t_{imax} \quad i = \{1, \dots, n_c\}$

### Proof

A Lyapunov function candidate for the system is considered as follows :

$$V = \frac{1}{2} \dot{x}^T M \dot{x} + \frac{1}{2} e^T K_p e \quad (11)$$

in which,  $e = x - x_d$ . Although the dynamic equations of the global system are nonlinear and complex, they have some known properties which are necessary for the controller synthesis and stability analysis :

- *Property 1* The inertia matrix  $M(x)$  is symmetric and positive definite.
- *Property 2* The matrix  $\dot{M}(x) - 2C(x, \dot{x})$  is skew symmetric.

Based in property 1,  $M(x)$  is positive definite and  $K_p$  is chosen to be positive definite. Then we can conclude that  $\dot{V} \geq 0$ . Now, the time derivative of the Lyapunov function is given by :

$$\dot{V} = \dot{x}^T M \ddot{x} + \frac{1}{2} \dot{x}^T \dot{M} \dot{x} + \dot{e}^T K_p e \quad (12)$$

By substituting  $M \ddot{x}$  from the dynamic equation in the preceding equation :

$$\dot{V} = \frac{1}{2} \dot{x}^T (\dot{M} - 2C(x, \dot{x})) \dot{x} + \dot{x}^T (WT - D + K_p e) \quad (13)$$

According to property 2, the first term vanishes and therefore

$$\dot{V} = \dot{x}^T (WT - D + K_p e) \quad (14)$$

To ensure the payload asymptotic stability, we must choose a control law that satisfy the condition  $\dot{V} < 0$ . Hence, as already mentioned the control law is given by :

$$T = W^+(D - K_p e - K_d \dot{x}) \quad (15)$$

That leads to :

$$\dot{V} = -\dot{x}^T K_d \dot{x} < 0 \quad (16)$$

Our proposed idea consists of developing an anti-sway control in such a way that the time derivative of lyapunov function is negative definite. Therefore the asymptotic stability of the system is proved.

## VI. SIMULATION RESULTS

In this section, some numerical simulation are carried on to illustrate the performance of the proposed controller. Specifically, the payload swing is affected by the airship acceleration. In this simulation we highlight the effect of our feedback controller to prevent the payload from oscillations. Simulations concern a suspended CDPM with eight cables. This 6-dofs manipulator has the following characteristics.

- $5m \times 3m \times 6m$  ( $L \times l \times h$ ) overall dimensions.
- cubic mobile platform of side length  $0.4m$  in suspended configuration.
- 8 actuators with joint coordinates, each pair of winches is installed on the vertices of the rectangle base.
- $t_{min} = 50N$  in order to respect the non-negativity constraint in cable tension and  $t_{max} = 5000N$  according to the maximum admissible cable strain.

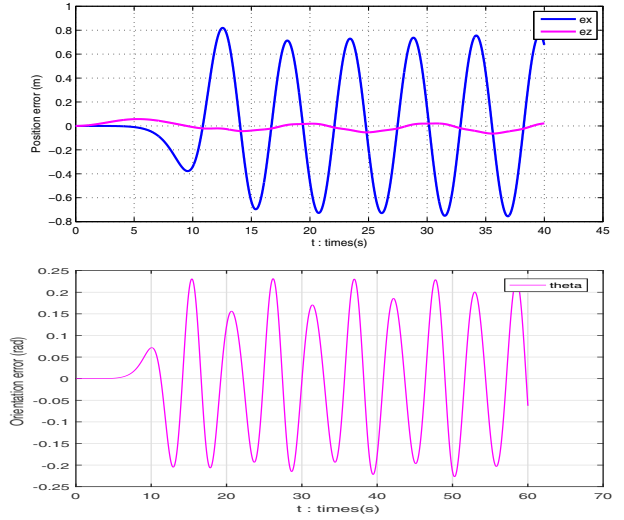


Fig. 3. Position and swing-angle errors without control

As it is shown in Figure 3, the airship acceleration leads to an oscillation with a peak up to  $0.25rad$ . In order to overcome the pendulum behaviour which may be inherent, a feedback controller is proposed.

The simulation results shows that the designed anti-sway controller prevent the payload from oscillations. In fact as can be seen in Figure 4, it is clear that thanks to the feedback controller the load swing amplitude has been considerably reduced compared to the free swing in Figure 3.

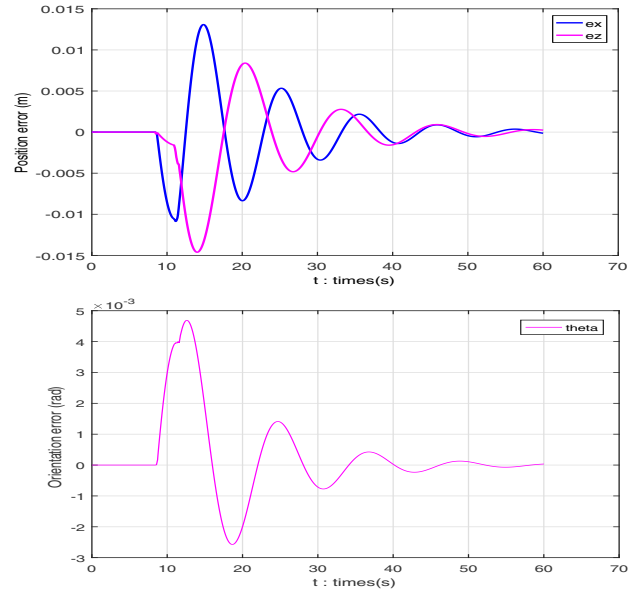


Fig. 4. Position and swing-angle errors with feedback control

As it is shown in Figure 5, the algorithm developed for the tensions distribution keeps cables in tension for the whole manoeuvre. We can conclude that our objective of stabilizing the load and minimizing its oscillations has been largely achieved through the application of our feedback controller.

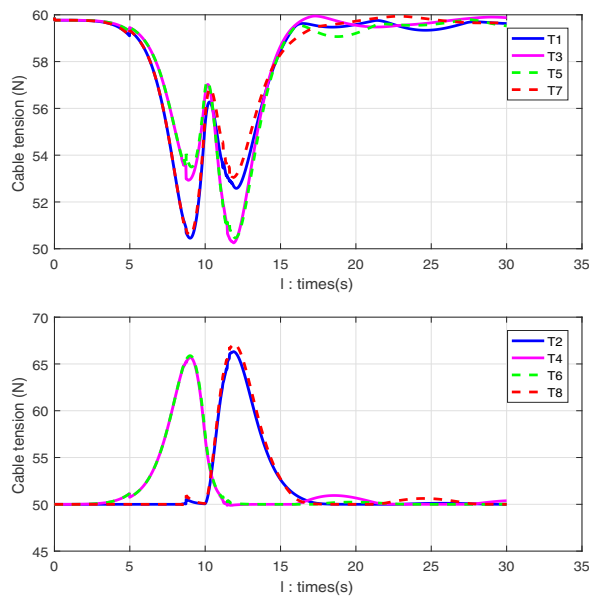


Fig. 5. Cable tensions

## VII. CONCLUSION

In this paper we have presented a preliminary analyses of a heavy lift airship carrying a load using a cable-driven parallel manipulator. The scenario studied in this paper corresponds to the critical phases of loading and unloading where the airship may be subjected to a gust of wind which will cause a sudden acceleration of the craft. By inertial effect this motion will generate the swinging of the suspended load which could be detrimental to the safety of the assembly. For this purpose a model of the CDPM with base mobility is derived using Newton-Euler approach. Further a robust controller based on Lyapunov function was developed to ensure asymptotic stability of the platform (load) where the effect of the airship acceleration was considered as a disturbance. In addition, the control design should integrate an optimal tension distribution because the cables must remain in tension for this class of robots. Finally the performance of the designed controller is highlighted through numerical simulations which have shown the power of this controller to attenuate the amplitudes of the platform swing.

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