Modeling and Control of a Multi-link Convertible Drone for Manipulation Operations

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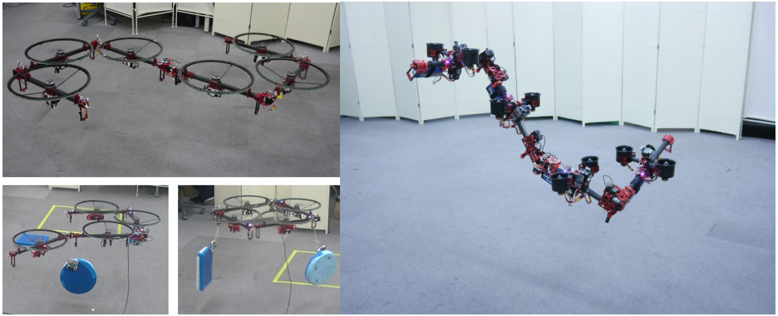
Journée Technique ²RM: Démarche de conception mécatronique de drones avec systèmes de préhension et main dextres.

Outline

Introduction

Related Work

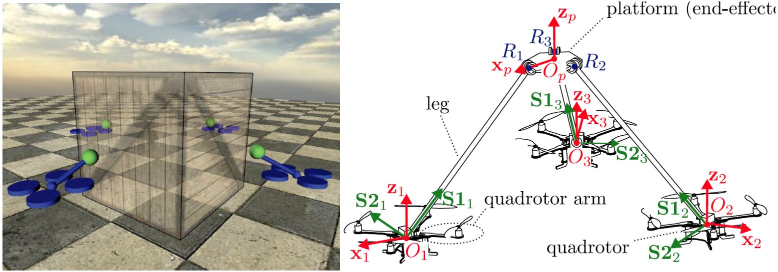


(a) (b)

Figure: (a) Single propeller kinematic chain, (b) DRAGAN Robot

Introduction

Related Work



(a) (b)

Figure: (a) 4 UAVs transportation, (b) Flying parallel robot

Outline

Single Link System
System Description

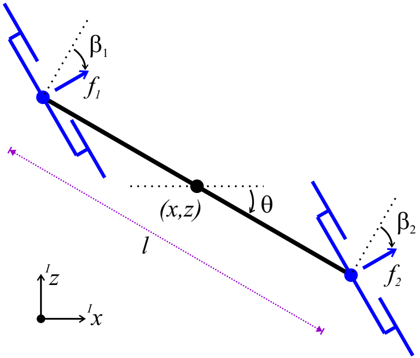


Figure: Single link system 2D representation

Where $m_1 = m_2 = m_0$ is the mass of the vehicles, m_a the mass of the link, $I_1 = I_2 = I_0$ the moment of inertial of the quadrotors and, finally, I_a that of the link.

Let the vector of generalized coordinates be $q_{l1} = [x \; z \; \theta]^T$, by applying the Euler Lagrange formalism, the dynamics of the system can be expressed as:

$$\mathbf{M}_{l1}\ddot{q}_{l1} + \mathbf{G}_{l1} = \tau_{l1}$$

with

$$\mathbf{M}_{l1} = \begin{bmatrix} 2m_0 + m_a & 0 & 0 \\ 0 & 2m_0 + m_a & 0 \\ 0 & 0 & \frac{m_0 l^2}{2} + I_a \end{bmatrix} \quad \mathbf{G}_{l1} = \begin{bmatrix} 0 \\ (2m_0 + m_a)\, g \\ 0 \end{bmatrix}$$

$$\tau_{l1} = \begin{bmatrix} S_{\theta+\beta_1} f_1 + S_{\theta+\beta_2} f_2 \\ C_{\theta+\beta_1} f_1 + C_{\theta+\beta_2} f_2 \\ \frac{l}{2}\left(C_{\beta_1} f_1 - C_{\beta_2} f_2\right) \end{bmatrix}$$

The quadrotor's rotational dynamics are described by $I_0\ddot{\theta}_i = \tau_i$ where $i = 1, 2$.

Single Link System

Control

For control purposes, we consider $\beta_1 = \beta_2 = \beta$ which allows us to establish the relations

$$\begin{aligned} f_1 + f_2 &= \sqrt{u_x^2 + u_z^2} \\ \theta + \beta &= \tan^{-1}\left(\frac{u_x}{u_z}\right) \end{aligned}$$

Moreover, to determinate each force, we find

$$\begin{bmatrix} f_1 \\ f_2 \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}\begin{bmatrix} \sqrt{u_x^2 + u_z^2} \\ (2u_\theta)\,/\,(lC_\beta) \end{bmatrix}$$

where u_x, u_z and u_θ are the control inputs given by PD controllers in the form:

$$u = K_p e_p + K_v e_v + G_d$$

Outline

Two Links system

System Description

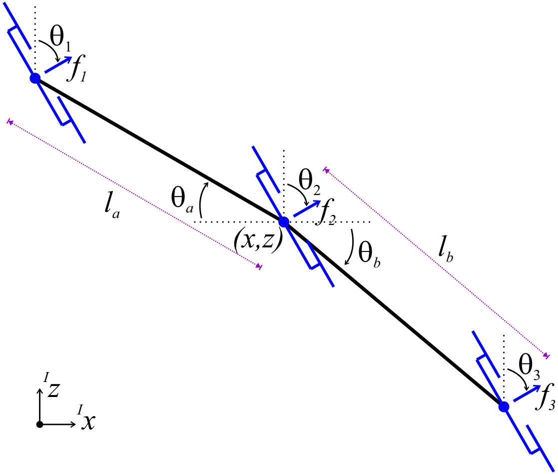


Figure: Two links system 2D representation

Two Links System

System Description and Modeling

As in the previous case we consider:

m_0	the mass of the vehicles
m_a	the mass of the links
I_0	the moment of inertia of the quadrotors
I_a	the moment of inertia of the links
l	the length of the links

To apply the Euler Lagrange formalism, let $q_{l2} = [x\ z\ \theta_a\ \theta_b]^T$ be the vector of generalized coordinates which leads to the equation:

$$\mathbf{M}_{l2}\ddot{q}_{l2} + \mathbf{C}_{l2}\dot{q}_{l2} + \mathbf{G}_{l2} = \tau_{l2}$$

Where:

$$\mathbf{M}_{l2} = \begin{bmatrix} 3m_0 + 2m_a & 0 & l\left(m_0 + 0.5m_a\right) S_{\theta_a} & -l\left(m_0 + 0.5m_a\right) S_{\theta_b} \\ & 3m_0 + 2m_a & l\left(m_0 + 0.5m_a\right) C_{\theta_a} & -l\left(m_0 + 0.5m_a\right) C_{\theta_b} \\ & & m_0 l^2 + \frac{m_a l^2}{4} + I_a & 0 \\ Symmetry & & & m_0 l^2 + \frac{m_a l^2}{4} + I_a \end{bmatrix}$$

$$\mathbf{C}_{l2}\dot{q}_{l2} = \begin{bmatrix} l\left(m_0 + 0.5m_a\right)\left(C_{\theta_a}\dot{\theta}_a^2 - C_{\theta_b}\dot{\theta}_b^2\right) \\ -l\left(m_0 + 0.5m_a\right)\left(S_{\theta_a}\dot{\theta}_a^2 - S_{\theta_b}\dot{\theta}_b^2\right) \\ 0 \\ 0 \end{bmatrix}$$

$$\mathbf{G}_{l2} = \begin{bmatrix} 0 \\ \left(3m_0 + 2m_a\right) g \\ gl\left(m_0 + 0.5m_a\right) C_{\theta_a} \\ -gl\left(m_0 + 0.5m_a\right) C_{\theta_b} \end{bmatrix} \quad ; \quad \tau_{l2} = \begin{bmatrix} S_{\theta_1} f_1 + S_{\theta_2} f_2 + S_{\theta_3} f_3 \\ C_{\theta_1} f_1 + C_{\theta_2} f_2 + C_{\theta_3} f_3 \\ \frac{l}{2}\left(C_{\theta_a - \theta_1} f_1 - C_{\theta_a - \theta 2} f_2\right) \\ \frac{l}{2}\left(C_{\theta_b - \theta_1} f_2 - C_{\theta_b - \theta 2} f_3\right) \end{bmatrix}$$

Two Links System
Control

For control purposes, we consider $\theta_1 = \theta_2 = \theta_3 = \gamma$ which allows us to establish the relations

$$
\begin{aligned}
f_1 + f_2 + f_3 &= \sqrt{u_x^2 + u_z^2} \\
\gamma &= \tan^{-1}\left(\frac{u_x}{u_z}\right)
\end{aligned}
$$

Moreover, to determinate each force, we find

$$
\begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 2 & 1 \\ 1 & -1 & 1 \\ 1 & -1 & -2 \end{bmatrix}\begin{bmatrix} \sqrt{u_x^2 + u_z^2} \\ (2u_{\theta_a}) / (lC_{\theta_a - \gamma}) \\ (2u_{\theta_b}) / (lC_{\theta_b - \gamma}) \end{bmatrix}
$$

where u_x, u_z, u_{θ_a} and u_{θ_b} are the control inputs given by PD controllers previously described.

Outline

Simulation Results

Single Link System

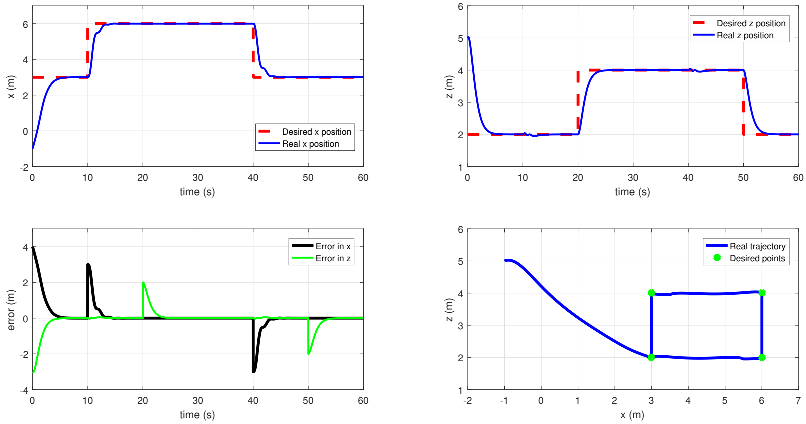


Figure: Translational behavior of the Single Link System

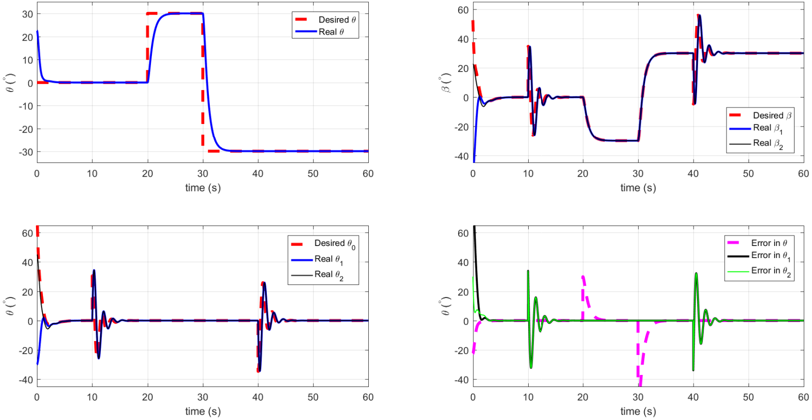


Figure: Rotational behavior of the Single Link System

Simulation Results
Two Links System

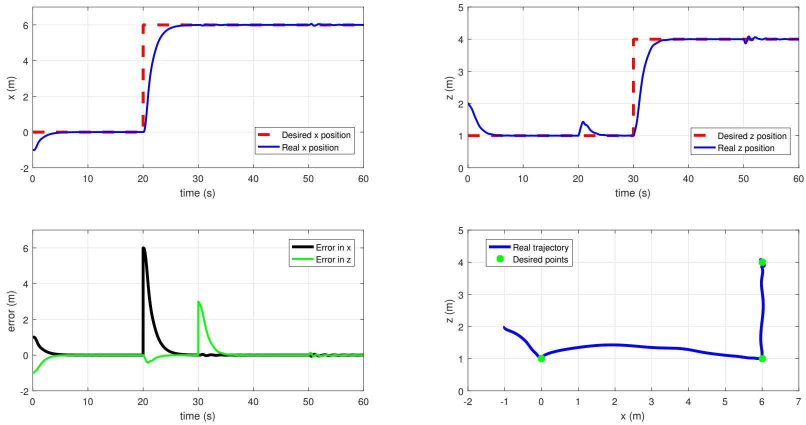


Figure: Translational behavior of the Two Links System

Simulation Results

Two Link System

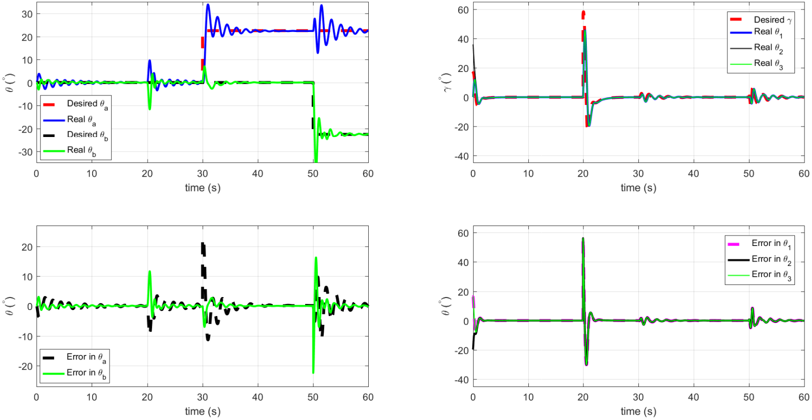


Figure: Rotational behavior of the Two Links System

Outline

Conclutions

Future Work

- Study of systems with more links in 2D
- 3D Modeling
- Implementation of a Convertible UAV
- Formation stability control
- Trajectory tracking control
- Implementation of Time-delay systems control theory

Conclutions
Future Work

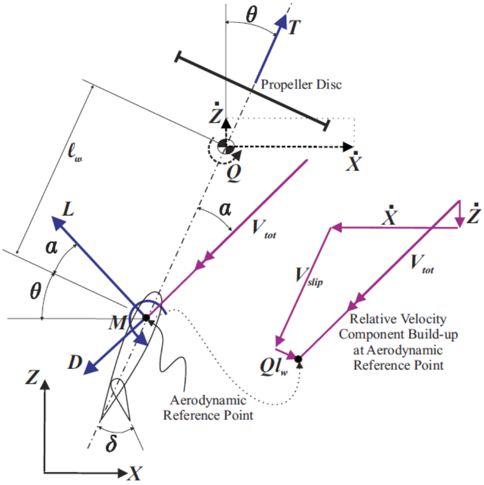


Figure: Proposed convertible aircraft

Thank You