Attitude and Position Control of a Quadcopter in a Networked Distributed System

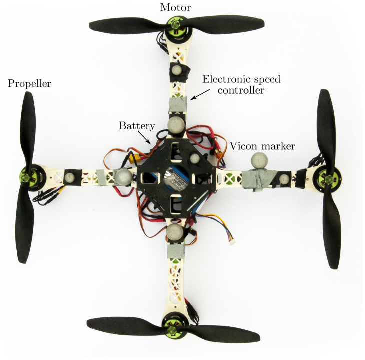
Alejandro Alonso García, Amalie Vistoft Petersen, Andrea Victoria Tram Løvemærke, Niels Skov Vestergaard, Noelia Villarmarzo Arruñada

Agenda

Introduction

- Surveillance and inspection
- Rescue
- Aerial photography
- ...

Introduction
Prototype



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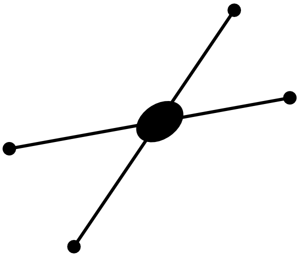
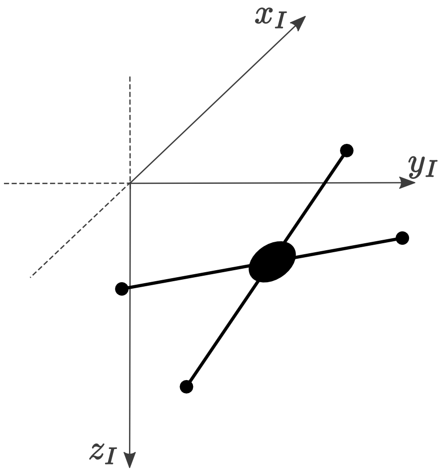
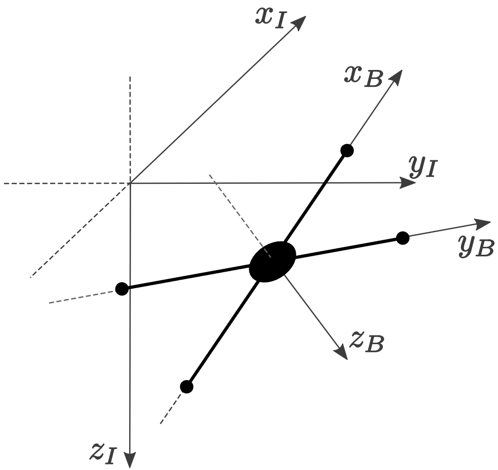
Model
Attitude Model

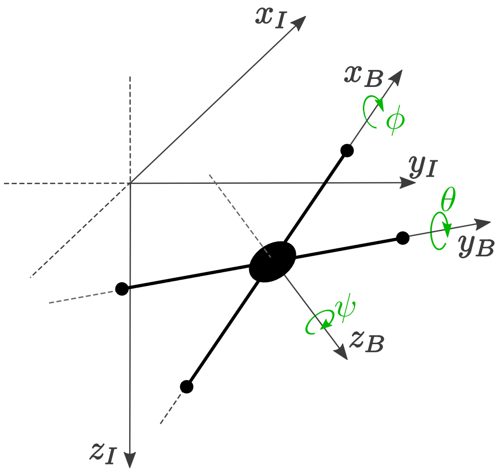


Model
Attitude Model

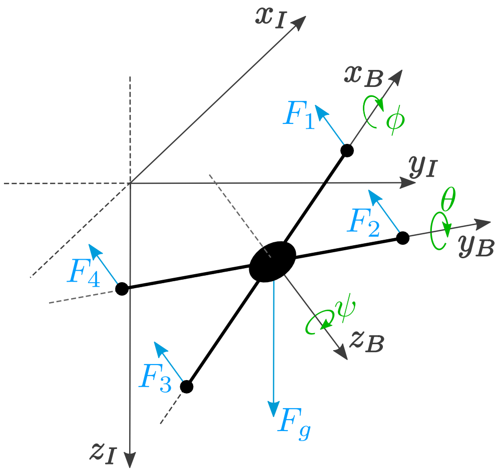


Model
Attitude Model

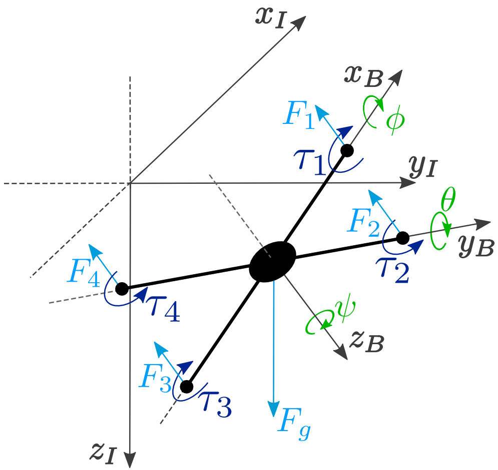




x_I
x_B
ϕ
y_I
θ
y_B
ψ
z_B
z_I



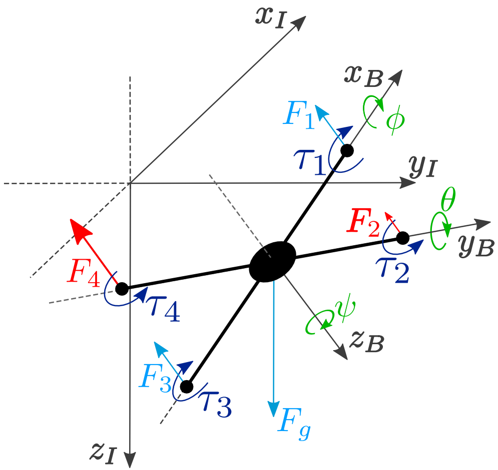
x_I
x_B
ϕ
F_1
y_I
θ
F_2
y_B
F_4
ψ
z_B
F_3
F_g
z_I



x_I
x_B
ϕ
F_1
τ_1
y_I
θ
F_2
y_B
τ_2
F_4
τ_4
ψ
z_B
F_3
τ_3
F_g
z_I

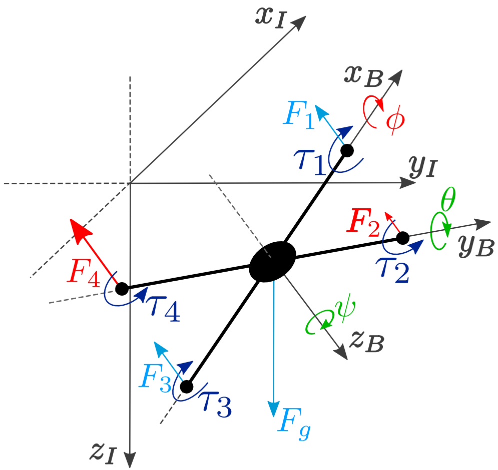
Model

Attitude Model



Model

Attitude Model



Model

Attitude Model

- Dynamic Equations

Model
Attitude Model

- Dynamic Equations

$$J\alpha = \sum \tau$$

- Dynamic Equations

$$J\alpha = \sum \tau$$

$$J_x\ddot{\phi} = (F_4 - F_2)L$$
$$J_y\ddot{\theta} = (F_1 - F_3)L$$
$$J_z\ddot{\psi} = \tau_1 - \tau_2 + \tau_3 - \tau_4$$

- Dynamic Equations

$$J\alpha = \sum \tau$$

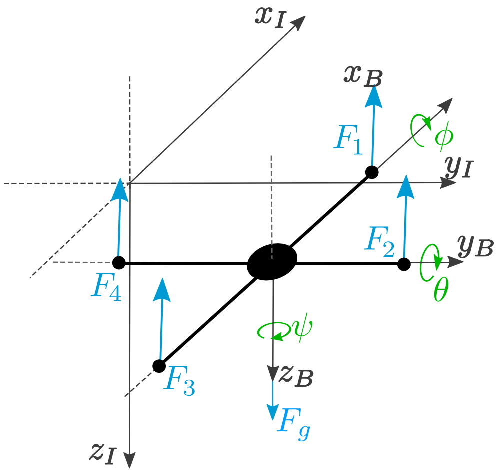
$$J_x\ddot{\phi} = (F_4 - F_2)L$$
$$J_y\ddot{\theta} = (F_1 - F_3)L$$
$$J_z\ddot{\psi} = \tau_1 - \tau_2 + \tau_3 - \tau_4$$

$$J_x\ddot{\phi} = k_{\mathrm{th}}(\omega_4^2 - \omega_2^2)L$$
$$J_y\ddot{\theta} = k_{\mathrm{th}}(\omega_1^2 - \omega_3^2)L$$
$$J_z\ddot{\psi} = k_{\mathrm{d}}(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2)$$

Agenda

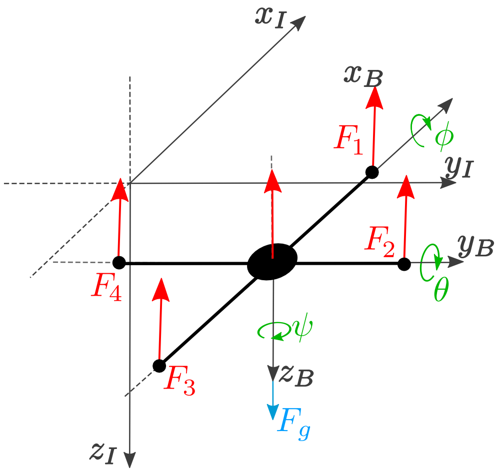
Model

Translational Model

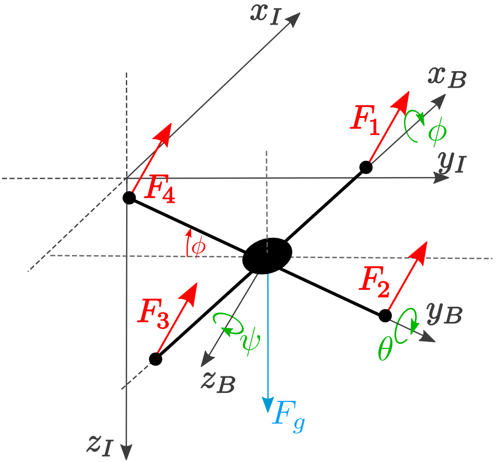


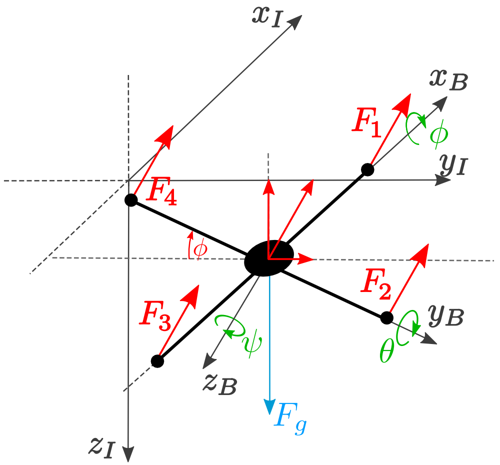
Model

Translational Model



Model
Translational Model





x_I
x_B
F_1
ϕ
y_I
F_4
ϕ
F_2
y_B
F_3
ψ
θ
z_B
F_g
z_I

Translational Model

- Rotation Matrix

$$R_X = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\phi & -s\phi \\ 0 & s\phi & c\phi \end{bmatrix} \quad R_Y = \begin{bmatrix} c\theta & 0 & s\theta \\ 0 & 1 & 0 \\ -s\theta & 0 & c\theta \end{bmatrix} \quad R_Z = \begin{bmatrix} c\psi & -s\psi & 0 \\ s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R = R_Z R_Y R_X$$

$$v_{\mathrm{I}} = R v_{\mathrm{B}}$$

Model
Translational Model

- Dynamic Equations

- Dynamic Equations

$$ma = \sum F$$

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$$m\ddot{x}_{\mathrm{I}} = -(F_1 + F_2 + F_3 + F_4)(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi)$$
$$m\ddot{y}_{\mathrm{I}} = -(F_1 + F_2 + F_3 + F_4)(\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi)$$
$$m\ddot{z}_{\mathrm{I}} = F_g - (F_1 + F_2 + F_3 + F_4)\cos\phi\cos\theta$$

- Dynamic Equations

$$ma = \sum F$$

$$\begin{aligned}
m\ddot{x}_{\mathrm{I}} &= -(F_1 + F_2 + F_3 + F_4)(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi) \\
m\ddot{y}_{\mathrm{I}} &= -(F_1 + F_2 + F_3 + F_4)(\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi) \\
m\ddot{z}_{\mathrm{I}} &= F_g - (F_1 + F_2 + F_3 + F_4)\cos\phi\cos\theta
\end{aligned}$$

$$\begin{aligned}
m\ddot{x}_{\mathrm{I}} &= -k_{\mathrm{th}}({\omega_1}^2 + {\omega_2}^2 + {\omega_3}^2 + {\omega_4}^2)(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi) \\
m\ddot{y}_{\mathrm{I}} &= -k_{\mathrm{th}}({\omega_1}^2 + {\omega_2}^2 + {\omega_3}^2 + {\omega_4}^2)(\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi) \\
m\ddot{z}_{\mathrm{I}} &= F_g - k_{\mathrm{th}}({\omega_1}^2 + {\omega_2}^2 + {\omega_3}^2 + {\omega_4}^2)\cos\phi\cos\theta
\end{aligned}$$

- First order Taylor approximation

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$$m\bar{\ddot{z}}_{\mathrm{I}} = F_g - k_{\mathrm{th}}({\overline{\omega}_1}^2 + {\overline{\omega}_2}^2 + {\overline{\omega}_3}^2 + {\overline{\omega}_4}^2)\cos\overline{\phi}\cos\overline{\theta}$$

- First order Taylor approximation

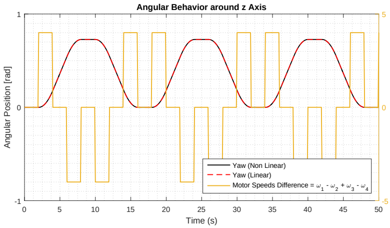
$$m\ddot{\bar{z}}_{\mathrm{I}} = F_g - k_{\mathrm{th}}({\overline{\omega}_1}^2 + {\overline{\omega}_2}^2 + {\overline{\omega}_3}^2 + {\overline{\omega}_4}^2)\cos\overline{\phi}\cos\overline{\theta}$$

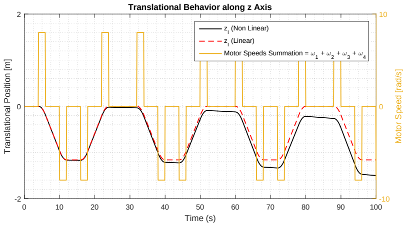
$$\overline{\omega}_i = \sqrt{\frac{F_{\mathrm{g}}}{4k_{th}}}$$

- First order Taylor approximation

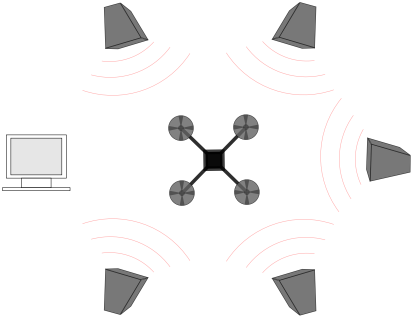
$$m\ddot{\overline{z}}_{\mathrm{I}} = F_g - k_{\mathrm{th}}(\overline{\omega}_1{}^2 + \overline{\omega}_2{}^2 + \overline{\omega}_3{}^2 + \overline{\omega}_4{}^2)\cos\overline{\phi}\cos\overline{\theta}$$

$$\overline{\omega}_i = \sqrt{\frac{F_{\mathrm{g}}}{4k_{th}}}$$

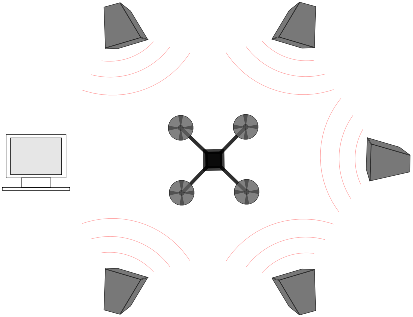




Network

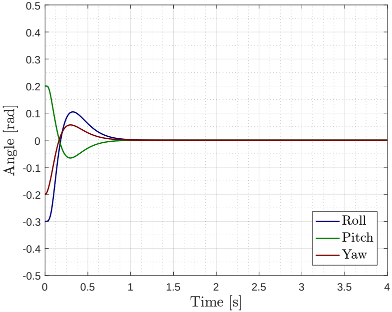


Network

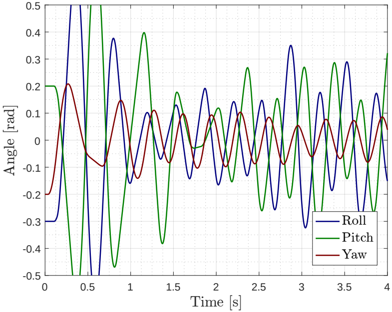


- Delay
- Missed packets

Network



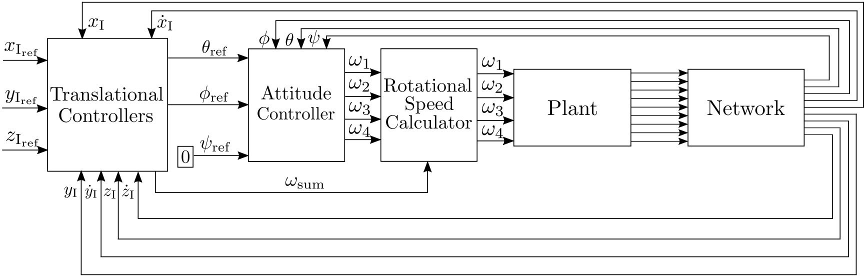
Control design only taking the model into account



Same controller with the effect of the network

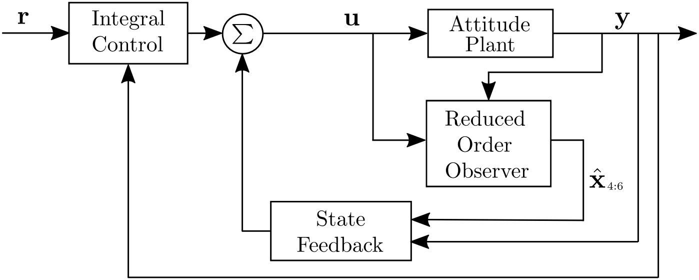
Agenda

Control Solution



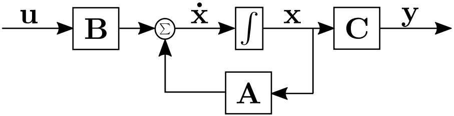
Control Solution

Attitude Controller



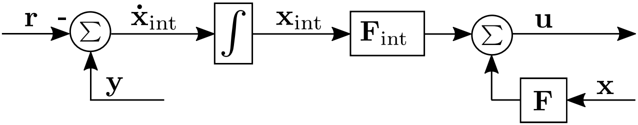
- System Representation

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t)$$
$$\mathbf{y}(t) = \mathbf{C}\mathbf{x}(t)$$



$$\mathbf{x} = \begin{bmatrix} \phi \\ \theta \\ \psi \\ \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} \qquad \mathbf{u} = \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} \qquad \mathbf{y} = \begin{bmatrix} \phi \\ \theta \\ \psi \end{bmatrix}$$

- State Feedback with Integral Control



$$\dot{\mathbf{x}}_{\text{Int}}(t) = \mathbf{y}(t) - \mathbf{r}(t)$$

$$\mathbf{u}(t) = \mathbf{F}\mathbf{x}(t) + \mathbf{F}_{\text{Int}}\mathbf{x}_{\text{Int}}(t)$$

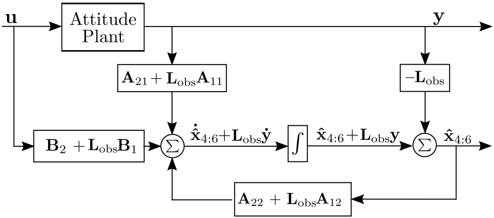
- LQR

$$\mathcal{J} = \int_0^\infty \mathbf{x}^T \mathbf{Q} \mathbf{x} + \mathbf{u}^T \mathbf{R} \mathbf{u} \, dt$$

- Bryson's Rule

$$Q_{ii} = \frac{1}{\text{maximum acceptable value of } [x_i^2]}$$
$$R_{ii} = \frac{1}{\text{maximum acceptable value of } [u_i^2]}$$

- Reduced Order Observer



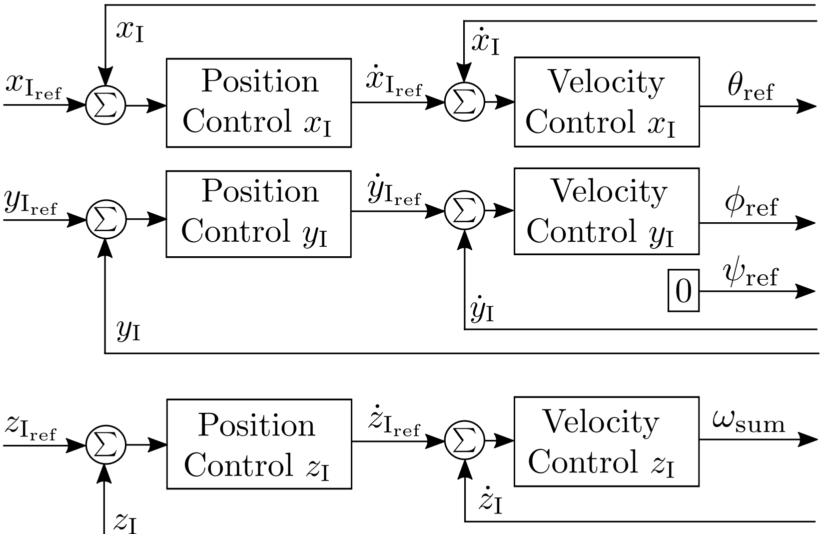
$$\mathbf{x}_{4:6} = \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

$$\mathbf{A}_{22} + \mathbf{L}_{\text{obs}}\mathbf{A}_{12}$$

Agenda

Control Solution

Translational Controller



Control Solution
Translational Controller

transfer functions with block diagram

Control Solution
Translational Controller

put three root locus

consideration of bandwidth equations for velocity controllers
equations for position controllers

Implementation

FreeRTOS, tasks

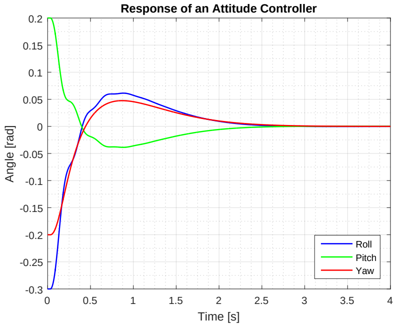
old 35ms

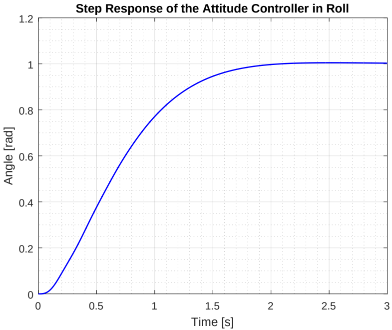
new, 25ms, less sampling freq.

comparison oscilloscope

Agenda

Results
Attitude Controller Simulations

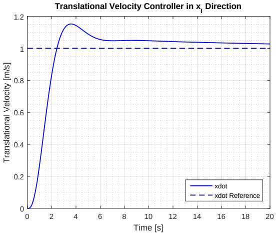


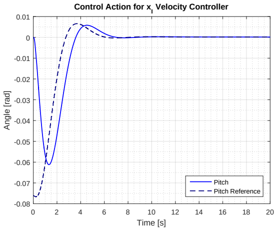


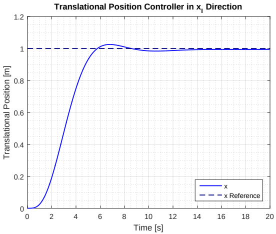
Results

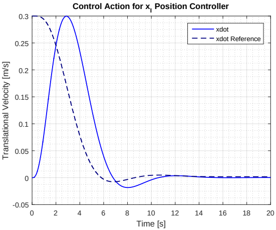
Translational Controllers Simulations

- x_I (and y_I) controllers for velocity and position





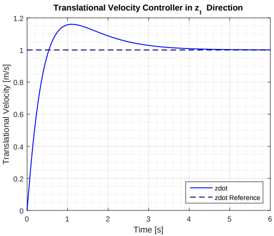


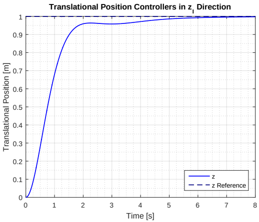


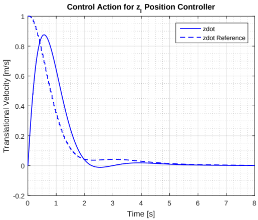
Results

Translational Controllers Simulations

- z_{I} controllers for velocity and position

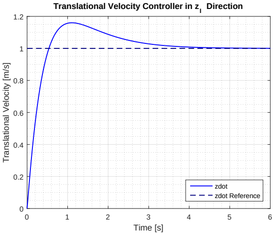


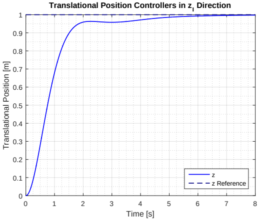


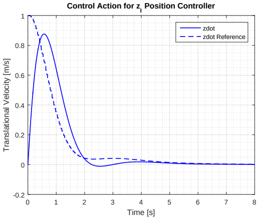


Results

Attitude Controller Functional Tests







Final Statements

- Limited bandwidth of controllers due to sampling.
- Control design working in simulation for attitude and translational controller.
- Implementation/Hardware issue when testing the translational controllers.
- Attitude controller tests carried out successfully.

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