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

Introduction

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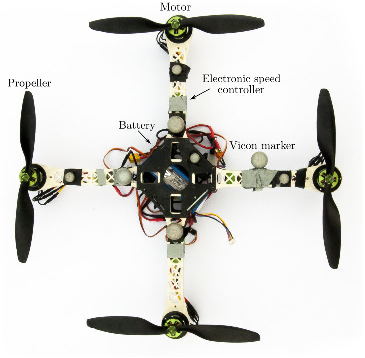
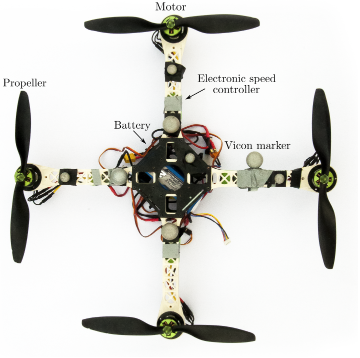
Prototype



Introduction

Prototype



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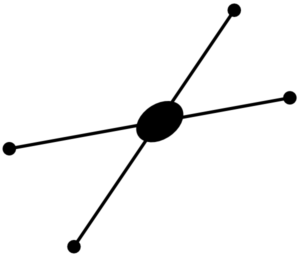
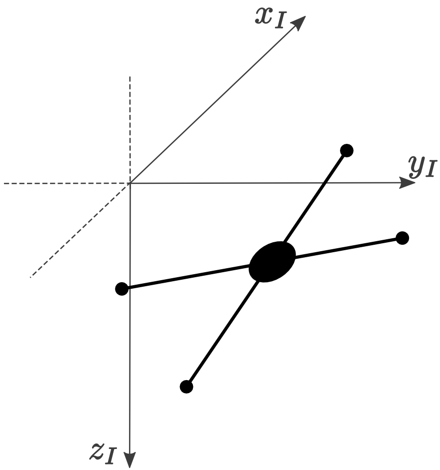


Model
Attitude Model



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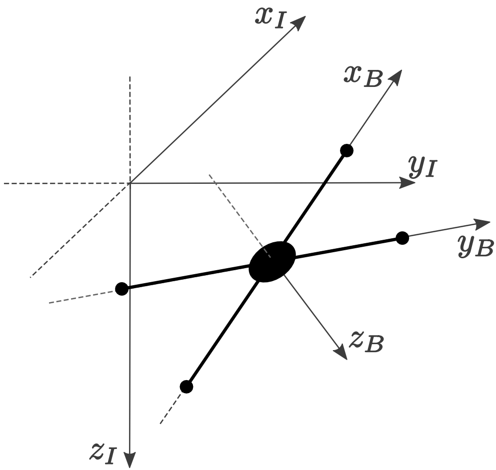

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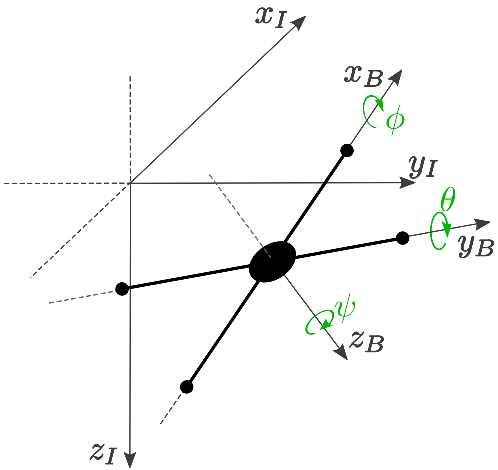

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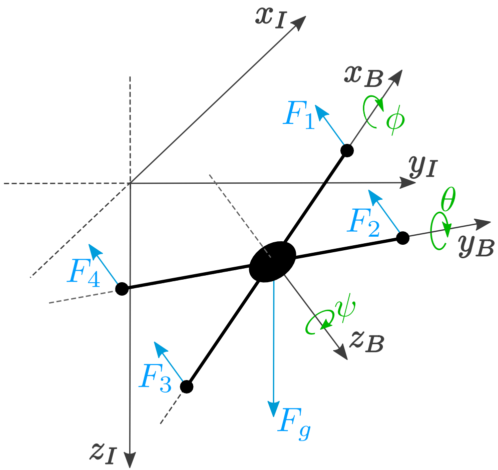
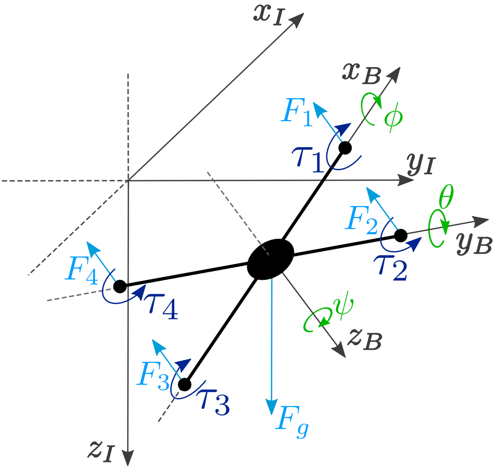
Attitude Model

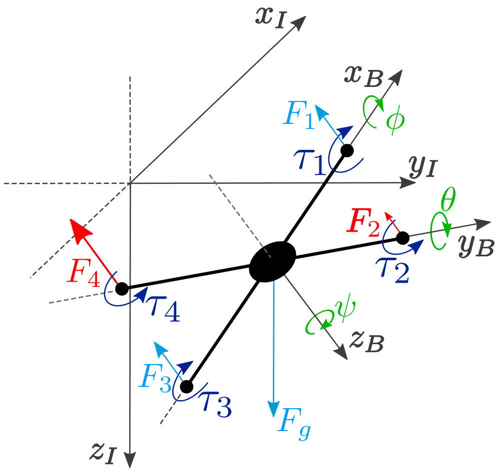


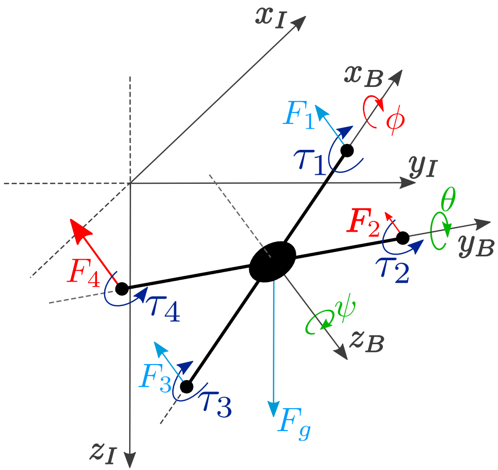


x_I
x_B
F_1
ϕ
τ_1
y_I
θ
F_2
y_B
τ_2
F_4
τ_4
ψ
z_B
F_3
τ_3
F_g
z_I

Model

Attitude Model





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

- Dynamic Equations

- Dynamic Equations

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

- Dynamic Equations

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

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

- Dynamic Equations

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

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

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

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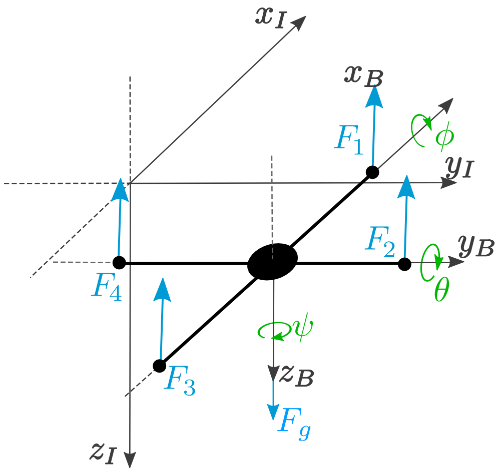
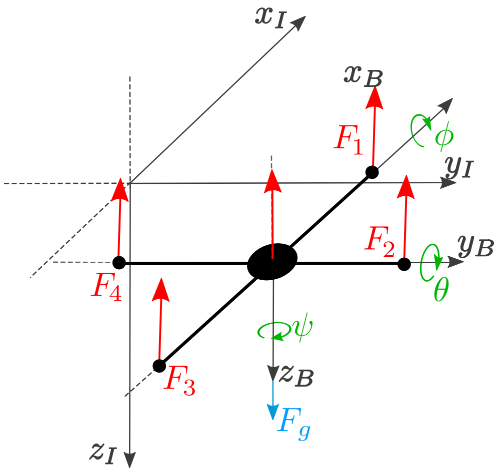
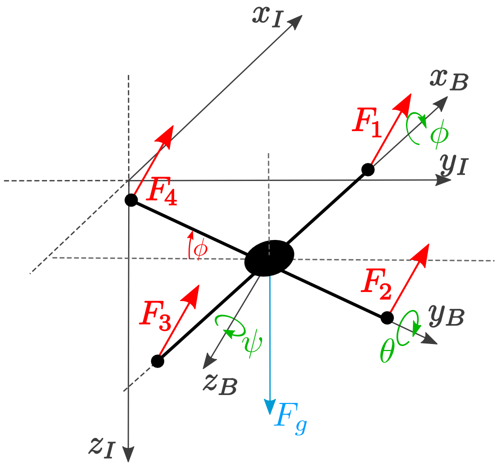
Model
Translational Model



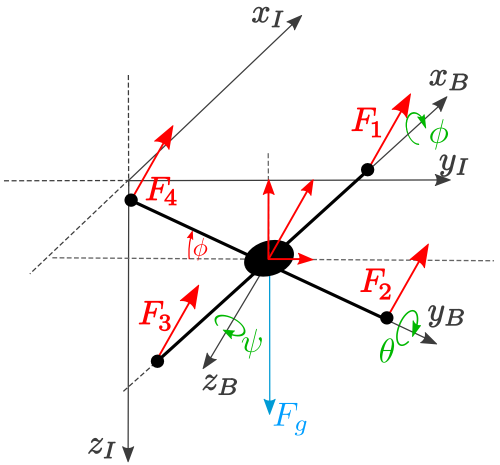
Model

Translational Model





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



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

Translational Model

- Rotation Matrix

$$R = R_Z R_Y R_X$$

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

- Dynamic Equations

- Dynamic Equations

$$ma = \sum F$$

- Dynamic Equations

$$ma = \sum F$$

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

- Dynamic Equations

$$ma = \sum F$$

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

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

Model
Linearization

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

Model
Linearization

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

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

Network

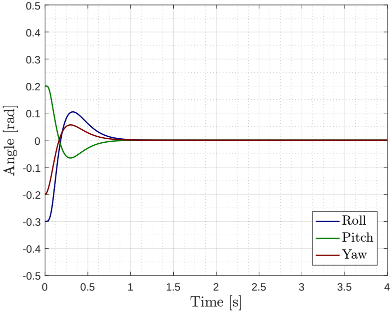
Network

- Delay
- Missed packets

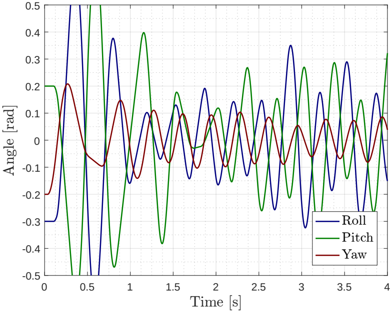
Network

- Delay
- Missed packets

Network



Control design only taking the model into account



Same controller with the effect of the network

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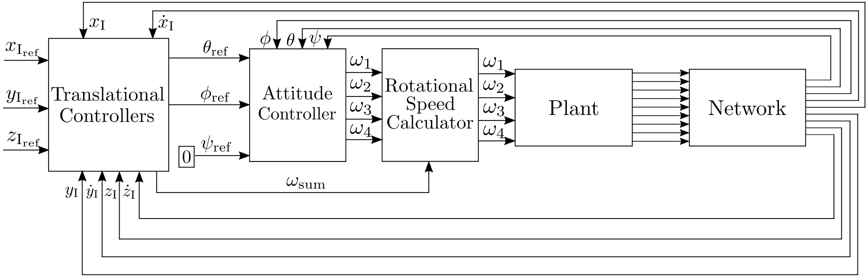
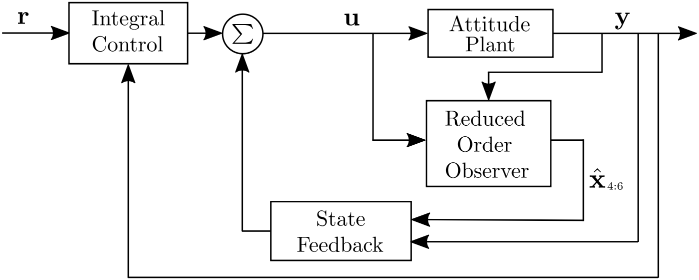
Control Solution



Control Solution

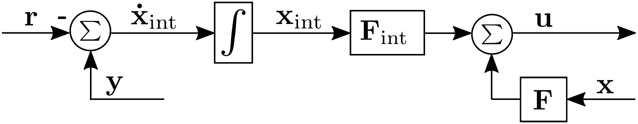
Attitude Controller



Control Solution
Attitude Controller

- System Representation

- State Feedback with Integral Control



extended

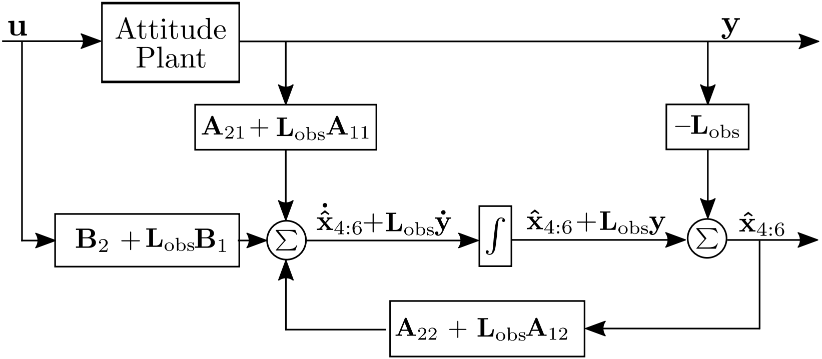
- LQR

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

- Bryson's Rule

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

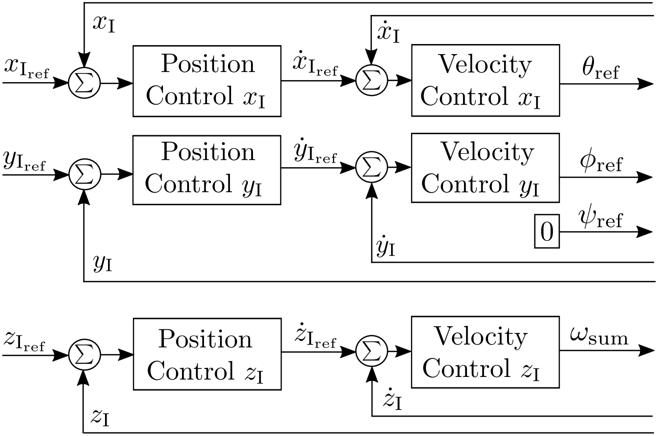
- Reduced Order Observer



equation what are the states we estimate

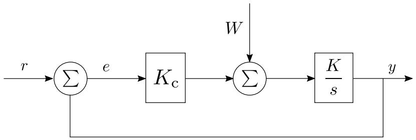
$$\mathbf{A}_{22} + \mathbf{L}_{\mathrm{obs}}\mathbf{A}_{12}$$

Agenda

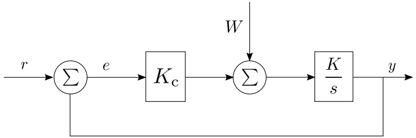


x_{I}
$\dot{x}_{\mathrm{I}}$
$x_{\mathrm{I_{ref}}}$
Position Control x_{I}
$\dot{x}_{\mathrm{I_{ref}}}$
Velocity Control x_{I}
θ_{ref}
$y_{\mathrm{I_{ref}}}$
Position Control y_{I}
$\dot{y}_{\mathrm{I_{ref}}}$
Velocity Control y_{I}
ϕ_{ref}
0
ψ_{ref}
$\dot{y}_{\mathrm{I}}$
y_{I}
$z_{\mathrm{I_{ref}}}$
Position Control z_{I}
$\dot{z}_{\mathrm{I_{ref}}}$
Velocity Control z_{I}
ω_{sum}
$\dot{z}_{\mathrm{I}}$
z_{I}

Control Solution
Translational Controller

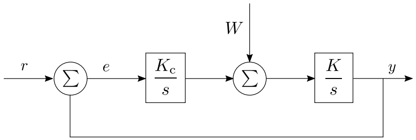


Control Solution
Translational Controller



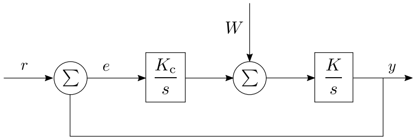
$$\frac{y}{W} = \frac{\frac{K}{s}}{1 + K_c \frac{K}{s}} = \frac{K}{s + K_c K} \Rightarrow \lim_{s \to 0} \frac{K}{s + K_c K} = \frac{1}{K_c}$$

Control Solution
Translational Controller



$$\frac{y}{W} = \frac{\frac{K}{s}}{1 + K_c\frac{K}{s}} = \frac{K}{s + K_cK} \Rightarrow \lim_{s\to 0}\frac{K}{s + K_cK} = \frac{1}{K_c}$$

Control Solution
Translational Controller



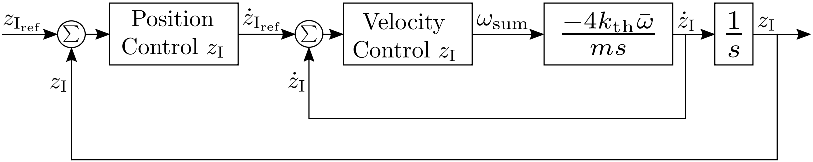
$$\frac{y}{W} = \frac{\frac{K}{s}}{1 + \frac{K_c}{s}\frac{K}{s}} = \frac{Ks}{s^2 + K_c K} \Rightarrow \lim_{s \to 0} \frac{Ks}{s^2 + K_c K} = 0$$

$$\frac{\dot{x}_{\mathrm{I}}}{\theta} = \frac{-k_{\mathrm{th}} 4\overline{\omega}}{ms} \qquad \frac{\dot{y}_{\mathrm{I}}}{\phi} = \frac{k_{\mathrm{th}} 4\overline{\omega}}{ms} \qquad \frac{\dot{z}_{\mathrm{I}}}{\omega_{\mathrm{sum}}} = \frac{-2k_{\mathrm{th}}\overline{\omega}}{ms}$$

Control Solution

Translational Controller

$$\frac{\dot{x}_{\mathrm{I}}}{\theta} = \frac{-k_{\mathrm{th}} 4\overline{\omega}}{ms} \qquad \frac{\dot{y}_{\mathrm{I}}}{\phi} = \frac{k_{\mathrm{th}} 4\overline{\omega}}{ms} \qquad \frac{\dot{z}_{\mathrm{I}}}{\omega_{\mathrm{sum}}} = \frac{-2k_{\mathrm{th}}\overline{\omega}}{ms}$$



put three root locus

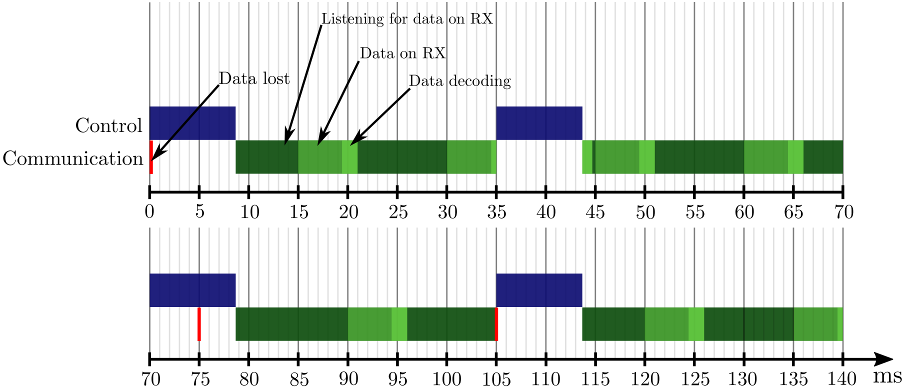
consideration of bandwidth equations for velocity controllers
equations for position controllers

Implementation

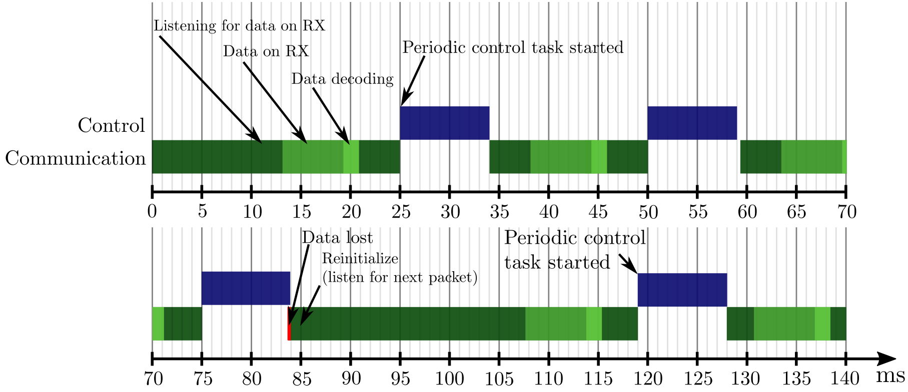
FreeRTOS, tasks

Implementation

Schedule



Implementation
Schedule



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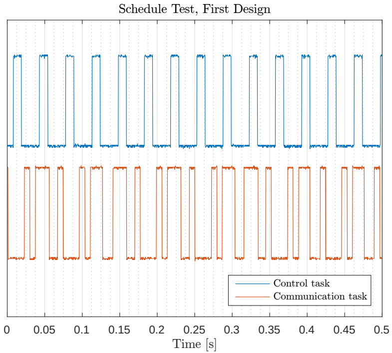
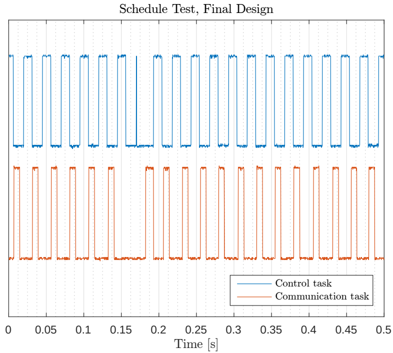
Schedule





Agenda

Results

Attitude Controller Simulations

Results

Translational Controllers Simulations

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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