ROS-Based **M**ulti-**A**gent **S**ystems **CO**ntrol Simulation **T**estbed (MASCOT)

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Indian Control Conference (ICC-8)
14-16 December 2022, Chennai, India.

INDIAN CONTROL CONFERENCE

॥ सा विद्या या विमुक्तये ॥

भारतीय प्रौद्योगिकी संस्थान धारवाड
Indian Institute of Technology Dharwad

Overview

Multi-Agent Systems

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Multi-Agent Systems:

A system consists of multiple co-operative agents interacting with each other.

Distributed Control:

- Control is distributed among multiple agents.
- Each agent with it's own local control algorithm.
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Applications:

Robotics, space missions, search and exploration, surveillance, agriculture etc.

Simulation Platform for Multiagent System

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- Test the performance of robot before it is built.
- Evaluate different control laws.
- Train in safe and controlled environment.
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Existing MAS Simulation:

- MATLAB based simulators.
- Limitation of no. of agents.
- Not readily deployable of hardware.

MASCOT

- Developed using open source tools.
- ROS and Gazebo.
- Supports low level driver.
- Simple user interface.
- In this version Quadcopter as an agent.
- Multiagent system with double integrator.
- Easy to setup with Docker Support.

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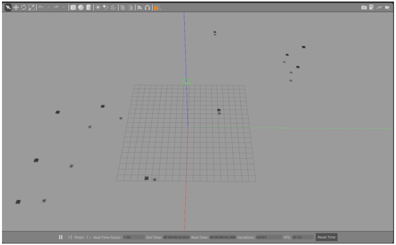


Figure: Initial Position of Drones

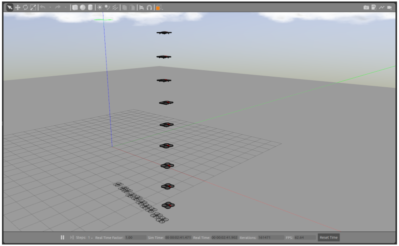
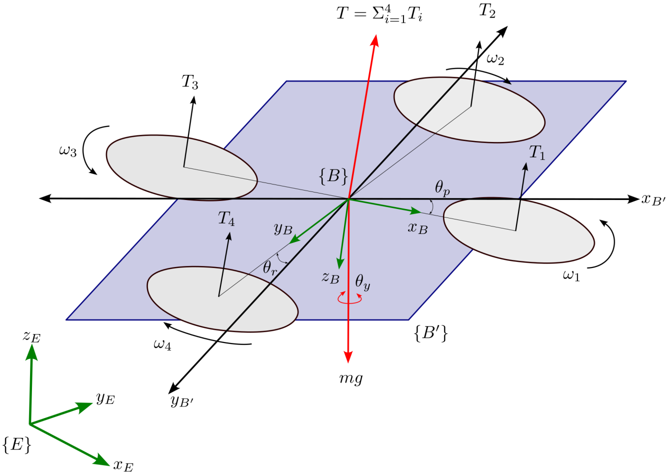


Figure: Final Position

Preliminaries

Frame of Reference



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Quadcopter Dynamics

- The total upward thrust along the $-z^B$ axis is given by

$$\mathbf{T} = \Sigma(b\omega_i^2) \tag{1}$$

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$$m\dot{\mathbf{v}}^E = \begin{bmatrix} 0 & 0 & mg \end{bmatrix}^T - \mathbf{R}_B^E \begin{bmatrix} 0 & 0 & T \end{bmatrix}^T - B\mathbf{v} \tag{2}$$

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- Overall quadcopter motion equation

$$\begin{bmatrix} \mathbf{T} & \boldsymbol{\Gamma} \end{bmatrix}^T = A \begin{bmatrix} \bar{\omega}_1^2 & \bar{\omega}_2^2 & \bar{\omega}_3^2 & \bar{\omega}_4^2 \end{bmatrix}^T \tag{7}$$

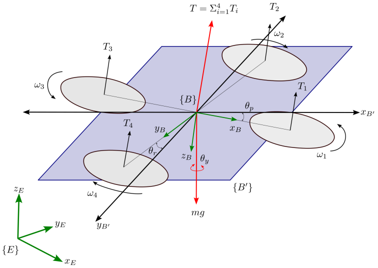
Quadcopter Dynamics as Double Integrator

- Total force on quadcopter

$$\mathbf{f}^{B'} = \mathbf{R}x\left(\theta r\right)\mathbf{R}y\left(\theta p\right)\begin{bmatrix}0 & 0 & T\end{bmatrix}^{T}$$

- Thus we get $\mathbf{f}^{B'}$ as

$$\mathbf{f}^{B'} = \begin{bmatrix} T\sin\theta_p \\ T\sin\theta_r\cos\theta_p \\ T\cos\theta_r\cos\theta_p \end{bmatrix}$$



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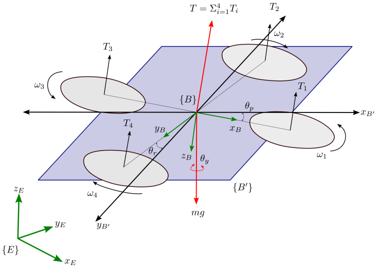

Figure: Quadcopter Dynamics

- For small θ_p and θ_r the $\mathbf{f}^{B'}$ can be approximated by

$$\mathbf{f}^{B'} \approx \begin{bmatrix}T\theta_p & T\theta_r & T\end{bmatrix}^T$$

- With this assumption the Quadcopter can be assumed as a double integrator system where θ_p and θ_r are given by

$$\theta_p = \frac{m}{T}a_x^{B'}, \quad \theta_r = \frac{m}{T}a_y^{B'}$$

MASCOT:Structure and Features

Tools Used

ROS:

- Open source robotics framework.
- Distributed architecture with intercommunication between different nodes.
- Support for various programming language Python, C++, Java.
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TUM Simulator Package:

- Uses the AR Parrot drone model.
- Low level plugin is modified as per the Double integrator dynamics.
- Added the required topics and controls.

Control Block

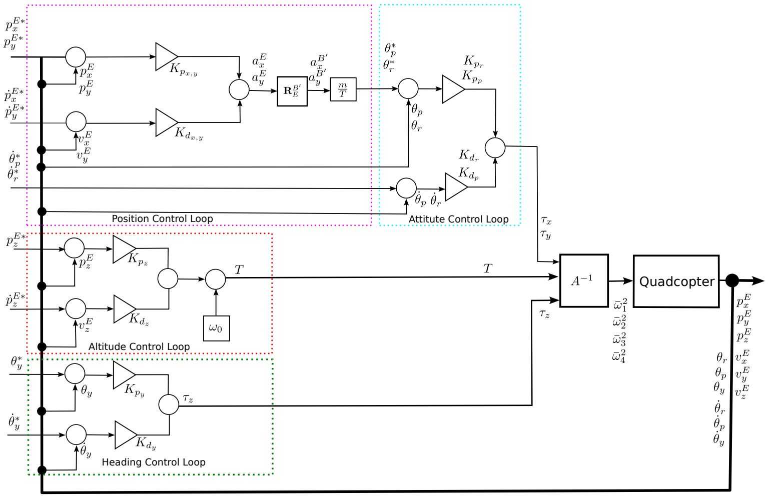

Figure: Control Block

Architecture

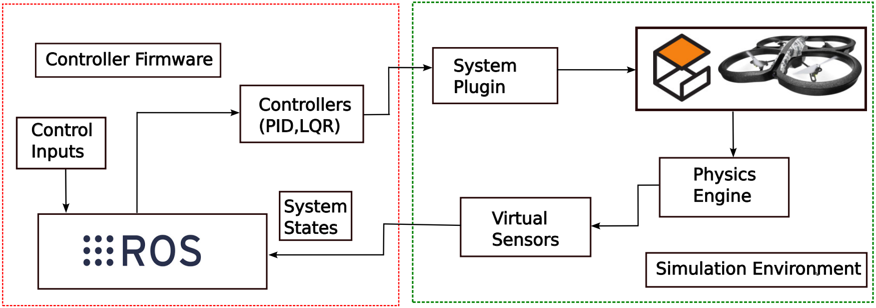

Figure: System Architecture

- Gazebo internal scheduler provides the ROS interface.
- ROS works as middleware which runs independent controller for each agent.
- The intercommunication uses TCPROS protocol.

Feature and Configuration of Simulation Testbed

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Configuration

- **Robot:** Details of the Robots to be simulated
  - **Number:** No. of Agents.
  - **IntialPosition:** Enable initializer.
  - **Position:** Initial Position.
- **Output:** Output config
  - **Velocity :** Generate Vel plot.
  - **Position :** Generate Vel plot.
  - **Save-plot :** Save plots.
  - **Show-plot :** Show plots.
  - **Save-data :** Save Numpy
- **Control:** Controls laws
  - **Custom-Control:**
  - **Tutorial Examples:**
  * **Waypoint Navigation:**
    - **P-Gain:** Default = 1.0
    - **D-Gain:** Default = 1.0
  * **Consensus:**
    - **Leader:** Robot index to be leader, 0-for leaderless.
    - **Communication Graph:**
    - **L-mat:** Laplacian Matrix.
  * **Min-max Consensus:**

Examples

Way-Point Navigation

- The position of the quadcopter in $x^{B'}y^{B'}$ plane is controlled independently by the proportional-derivative controller for each axis.

$$a_x = K_{p_x}\left(p_x^* - p_x\right) + K_{d_x}\left(\dot{p}_x^* - \dot{p}x\right)$$
$$a_y = K_{p_y}\left(p_y^* - p_y\right) + K_{d_y}\left(\dot{p}_y^* - \dot{p}y\right)$$

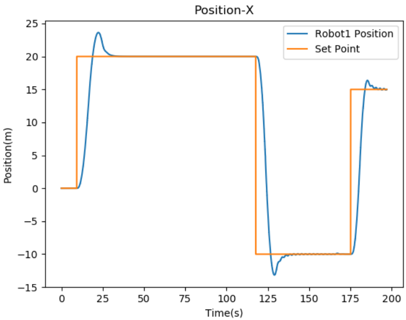

Figure: X-axis Position plot of Waypoint Navigation

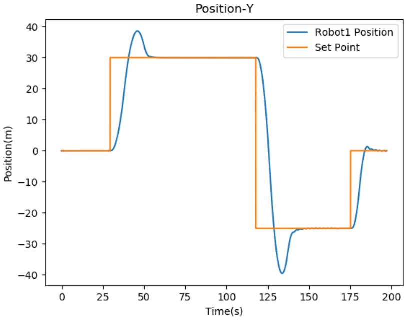

Figure: Y-axis Position plot of Waypoint Navigation

Consensus Algorithm (Linear)

- A leaderless asymptotic consensus and leader follower is implemented.
- The control algorithms used is as follows:

$$\mathbf{f}_i^E = \begin{cases} \sum_{j=1}^{n} a_{ij} \left(\mathbf{p}j^E - \mathbf{p}i^E \right) - \beta \mathbf{v}_i^E \text{ if } \alpha_i \in \mathbf{F} \\ 0 \text{ if } \alpha_i \in \mathbf{L} \end{cases}$$

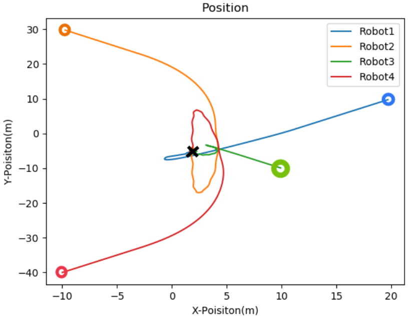

Figure: Leaderless Control plot

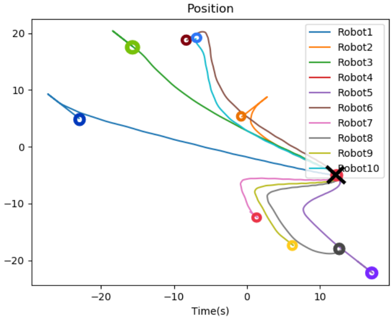

Figure: Leader Follower plot

Min-Max Time Consensus

- A non linear Min-Max time consensus Algorithm is implemented.
- The Control Law used is

$$\mathbf{f}_c^E = \beta_c \text{sign}(2(\beta_c - \beta_p)(\mathbf{p}_c - \mathbf{p}_p) + (\mathbf{v}_c - \mathbf{v}_p)^2 \text{sign}(\mathbf{v}_c - \mathbf{v}_p))$$

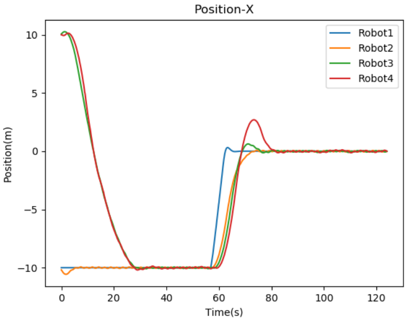

Figure: Position in X axis

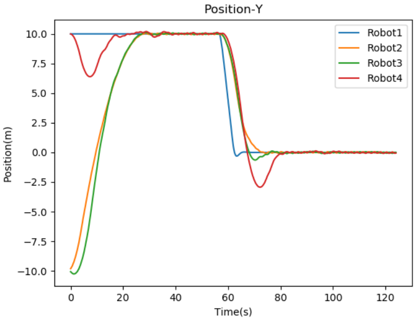

Figure: Position in Y axis

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Future Work

- System is Open-source and expandable.
- UGVs and different UAVs can be deployed.
- Human In the loop control.
- Deployment on real hardware.

Thank You

Figure: https://github.com/Avi241/mascot