UNIVERSITÀ DEGLI STUDI DI NAPOLI
FEDERICO II

itee PhD
information technology
electrical engineering

DIETI. UNINA

PhD student Salvatore Marcellini

Motion planning for autonomous unmanned aerial vehicles

Tutor: Prof. Vincenzo Lippiello

co-Tutor: Prof. Fabio Ruggiero

Cycle: XXXVI

Year: Third

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information technology
electrical engineering

My background

- M.Sc. in Automation Engineering, University of Naples Federico II
- Group: PRISMA Lab
- PhD start date: 1/11/2020
- Scholarship type : Company-funded by Leonardo S.p.A
- Period abroad: 6 months at INRIA Rennes

Summary of study activities

- Some courses attended in these 3 years:
  - Neural Networks and Deep Learning
  - Complex systems
  - Scientific visualization with Python
  - Academic entrepreneurship

- Summer school:
  - IEEE RAS Summer school on multirobot system

    Czech technical university in Prague

Summary of study activities

- Some seminars attended in these 3 years:
  - Robot Manipulation and Control
  - Quadruped Robotics on the Rise
  - Introduction to Underwater robotics
  - Adaptive and learning controllers for high accuracy trajectory tracking in changing environments
  - Design, Learning, and Control for Safe Human-Robot Collaboration
  - PX4 Developer Summit

Research area

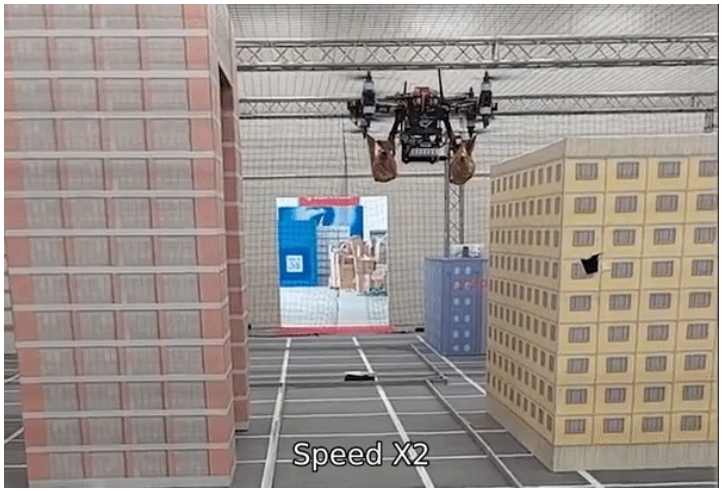
- A key trait of an autonomous robot is the ability to plan its own motion to accomplish specified tasks

- Once the robot has been stabilized thanks to a dedicated controller, the following question that comes to mind is

How can I make the robot move as I would like?

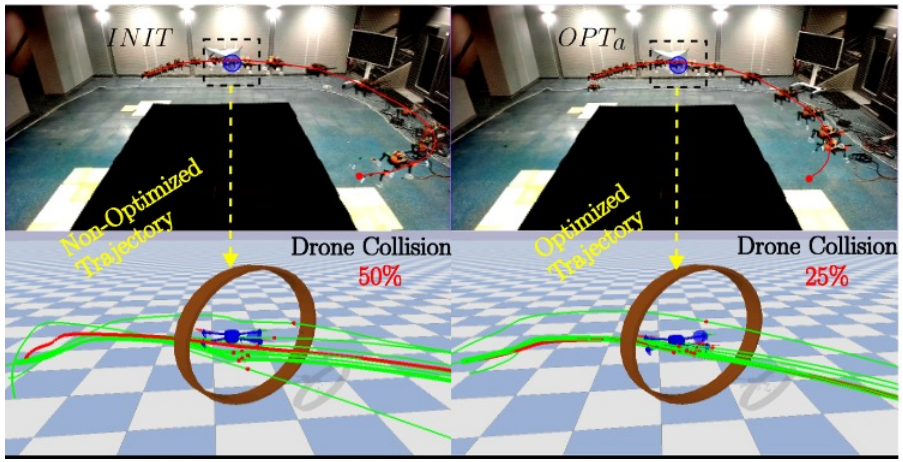
Research area

- To this purpose, scientists have devised various methods to enable robots to navigate and
  - Avoid obstacles
  - Complete a desired task
  - Perform precise movements
  - Explore diverse environments

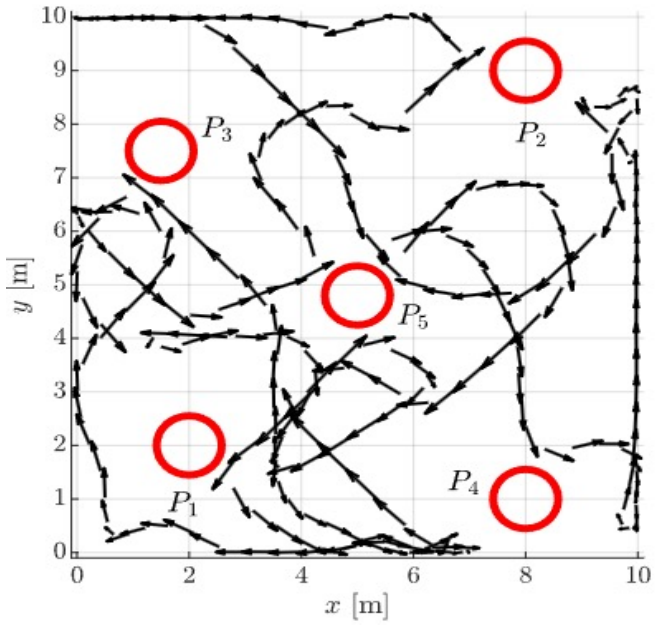


Research results

- **Precise movements:**
  - Planning of trajectories robust to parameters uncertainties



- **Task based motion:**
  - Repetitive area reconnaissance with UAV



Research products

[P1]	S. Marcellini, F. Ruggiero and V. Lippiello *Nonlinear Model Predictive Control for Repetitive Area Reconnaissance with a Multirotor Drone* **2023 International Conference on Unmanned Aircraft Systems (ICUAS),** Warsaw,Poland, 2023, pp. 1089-1096, doi: 10.1109/ICUAS57906.2023.10156642
[P2]	S. Marcellini, J. Cacace and V. Lippiello *A PX4 Integrated Framework for Modeling and Controlling Multicopters with Til table Rotors* **2023 International Conference on Unmanned Aircraft Systems (ICUAS),** Warsaw,Poland, 2023, pp. 1089-1096, doi: 10.1109/ICUAS57906.2023.10156642
[P3]	S. Marcellini, S. D'Angelo, M. Marolla, A. De Crescenzo, V. Lippiello and B. Siciliano *Development of a semi-autonomous framework for NDT inspection with a tilting aerial platform* **18th International Symposium on Experimental Robotics (ISER 2023)**, Chiang Mai, Thailand, 2023,
Under review	A. Srour, S. Marcellini, T. Belvedere, M. Cognetti, A. Franchi and P.Robuffo Giordano *Experimental Validation of Sensitivity-Aware Trajectory Planning for a Quadrotor UAV Under Parametric Uncertaint* **2024 IEEE International Conference on Robotics and Automation (ICRA2024)**, Yokohama, Japan

PhD thesis overview

- **Problem statement:**
  Planning trajectories to allow a drone to complete a task autonomously and safely
- **Objective:**
  1. Design motion planning algorithm that takes into account the system's parameters uncertainties
  2. Design motion a planning algorithm to perform autonomous repetitive area surveillance with an UAV

- **Methodology**
  - Exploit the closed-loop sensitivity function to plan optimal trajectories that are robust to system's parameter uncertainties
  - Leverage on model predictive control to adapt to the environment evolution

PhD thesis: Robust trajectories

- Every real system is affected by parametric uncertainties

- Usually, this problem can be solved by :
  - Parameters estimation
  - Robust controllers (customized, adaptive, ecc…)

PhD thesis: Robust trajectories

- In 2018, Robuffo Giordano and Franchi proposed a new solution based on the ***closed-loop sensitivity function***

- This function gives information about the uncertainty accumulated along the trajectory, by the closed-loop system (robot+control)

PhD thesis: Robust trajectories

- Untill now, it has been used to find optimal trajectories/movements for the robot, capable of minimizing the sensitivity

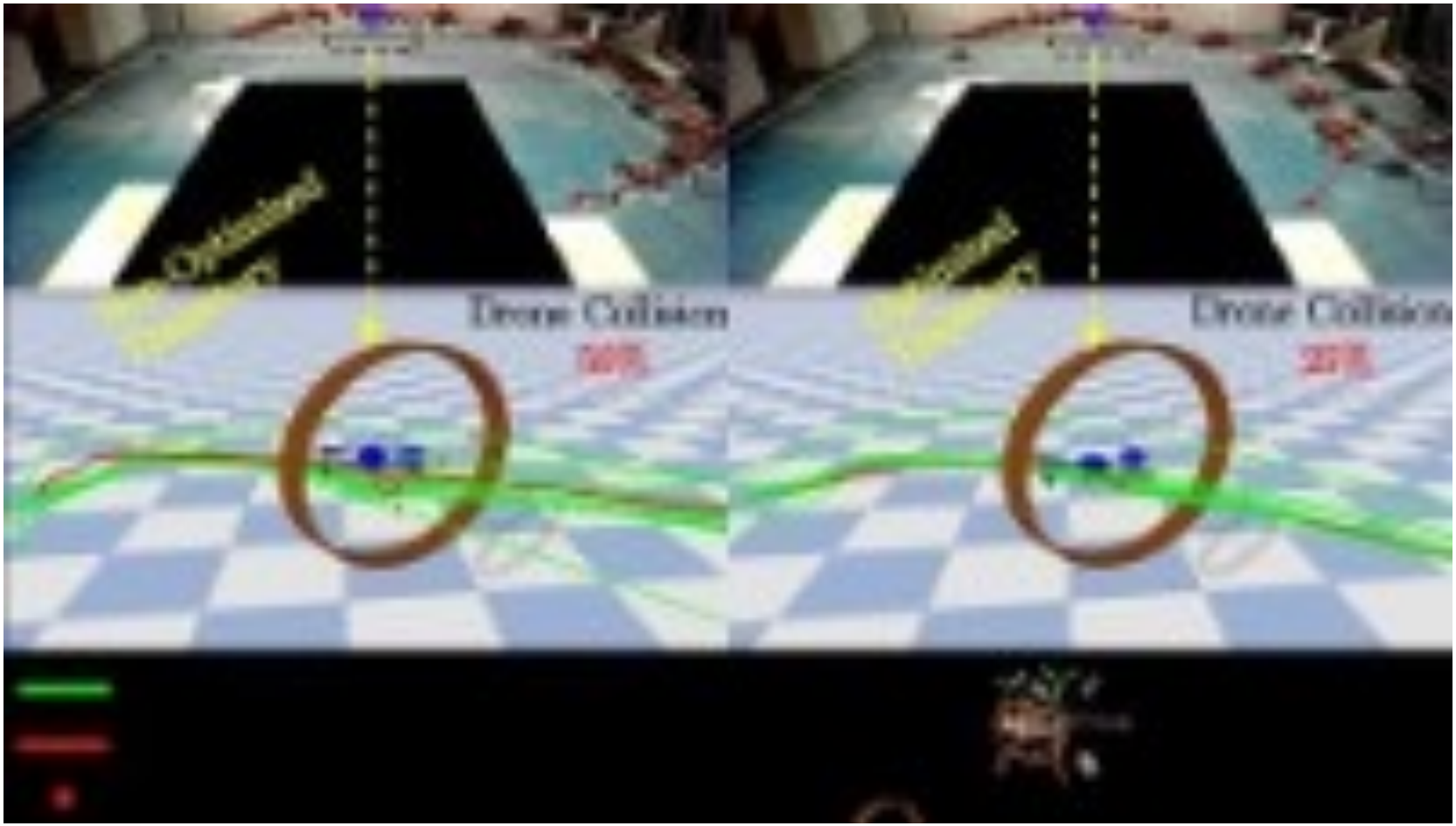
- Despite promising results in simulation, it has not been applied on real drones, if not just on one customized platform (no papers published)

PhD thesis: Robust trajectories

- **Contribution:**
  - We applied this theory on a commercial drone, controlled with the well-known autopilot firmware PX4
  - To show the improved accuracy, we planned a high-speed trajectory that pass through a window

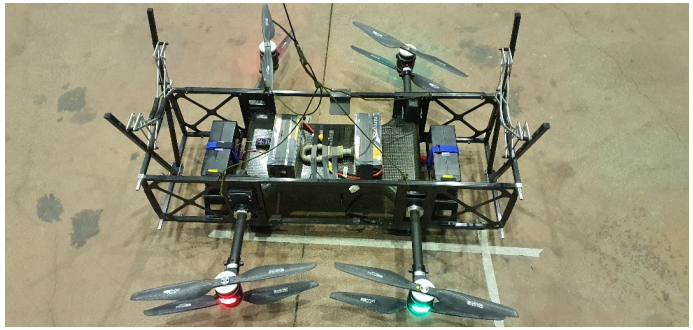
PhD thesis: Robust trajectories

- **Contribution:**



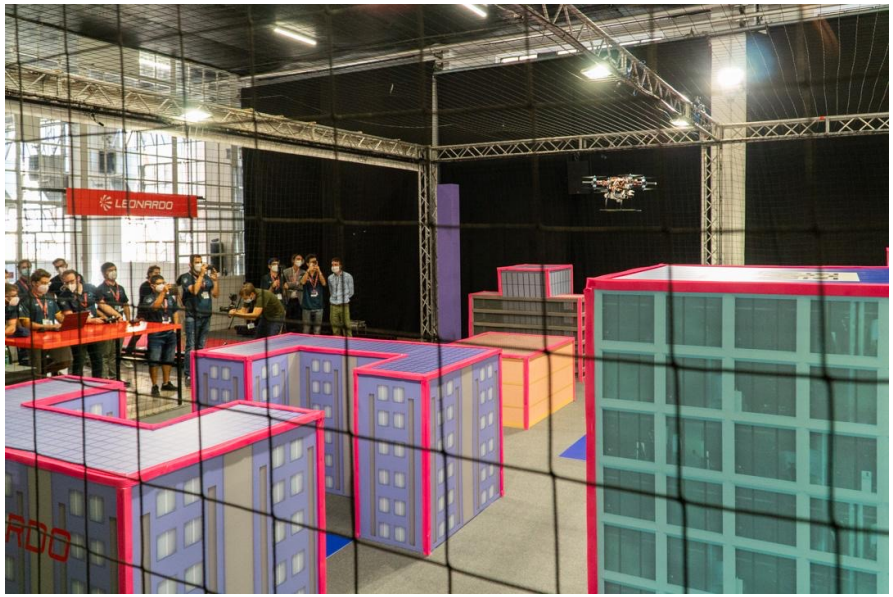
PhD thesis: Robust trajectories

- **Working on application to tilting multirotors:**
  - these platforms are affected by several uncertainties related to the dynamic of the motors, servomotors, and their combination
  - these are usually used in tasks that requires the interaction with the environment, which require high movement precision



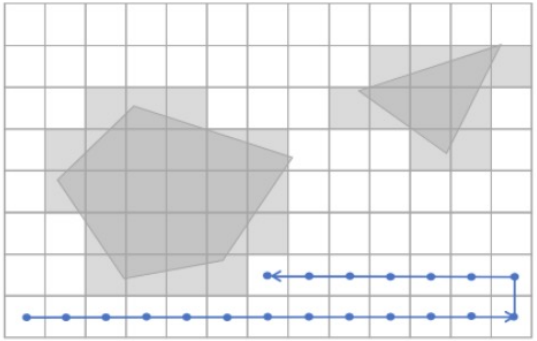
PhD thesis: Reconnaissance

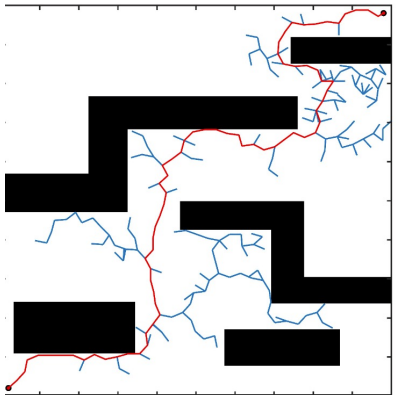
- Leonardo drone contest:
  - Build an autonomous drone capable of navigating in an indoor environment, while looking for an intruder

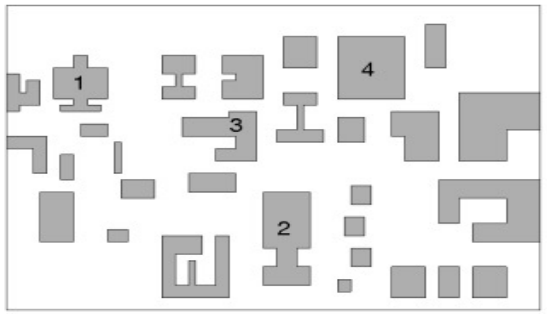


PhD thesis: Reconnaissance

- How to discover the moving intruder?
  - Map coverage algorithms would be too slow
    (we don't need to cover the entire map)
  - Online planners like RRT would be hard to execute at each time the environment evolve/change
  - The best fit would be a planner for **regional surveillance**



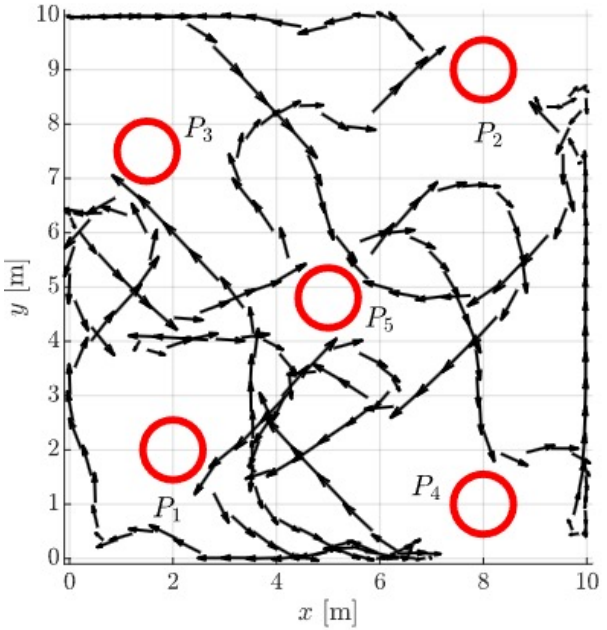




PhD thesis: Reconnaissance

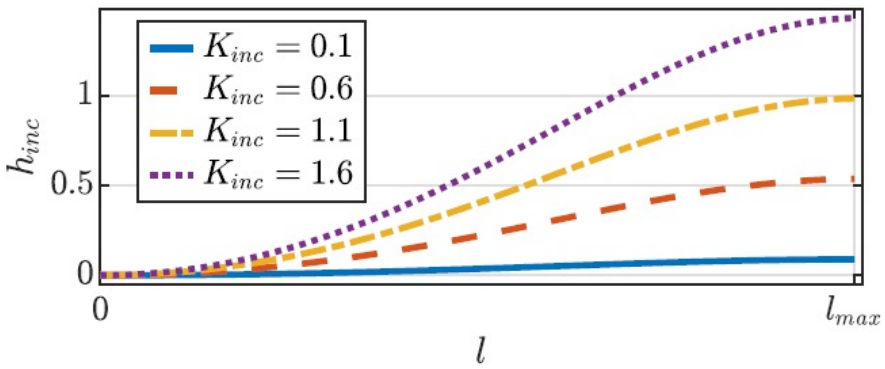
- Regional surveillance:
  - *defining a mission to scan specific isolated swaths at designated locations*

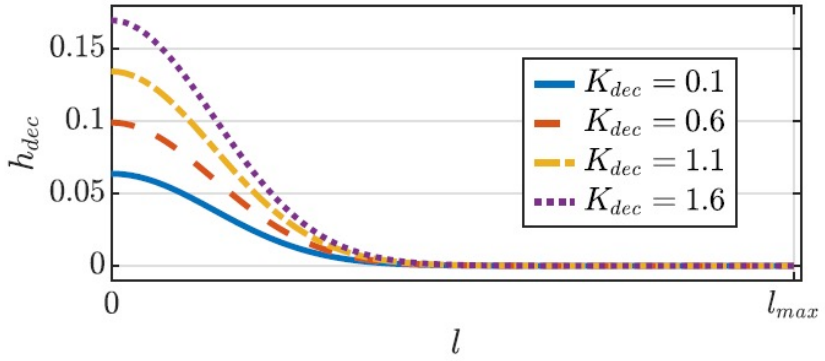
- **Proposed solution:**
  - *To adapt to the environment evolution, we exploited the capabilities of the Model Predictive Control (MPC) theory*



PhD thesis: Reconnaissance

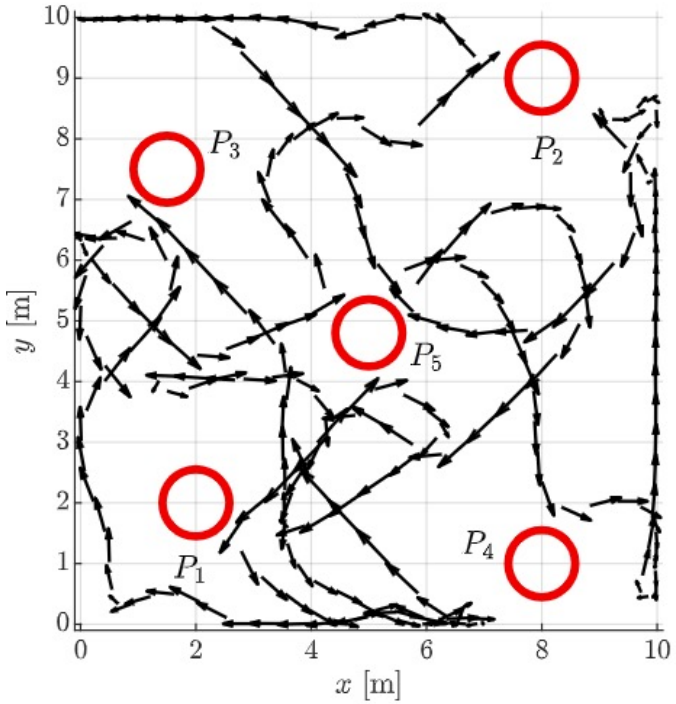
- **Proposed solution:**
  - We consider a heat value for each region that evolves during time, and respect to the distance from the drone

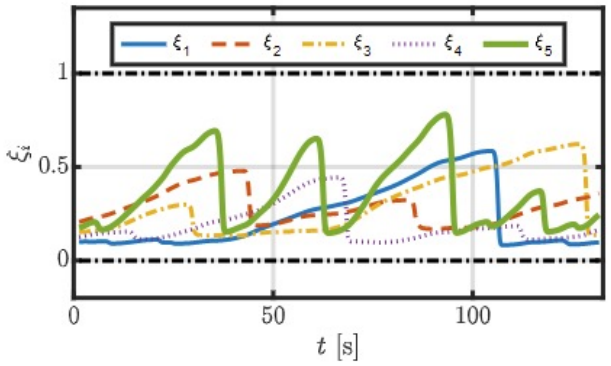




PhD thesis: Reconnaissance

- **Proposed solution:**
  - The optimization problem aims to find the optimal movements of the drone, to minimize the sum of all heat values





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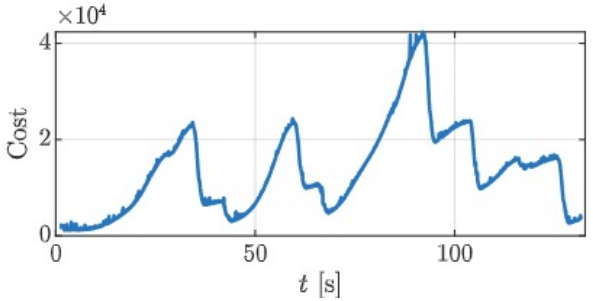

PhD thesis: Reconnaissance

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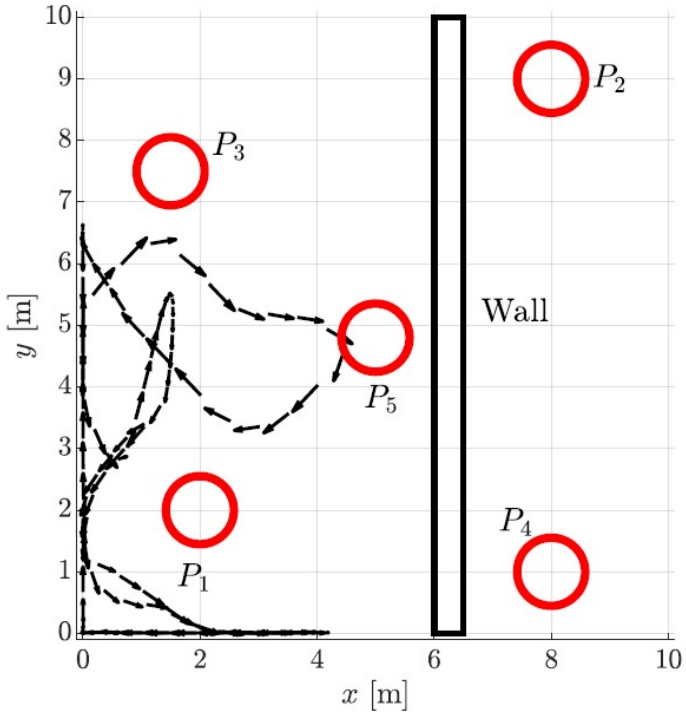
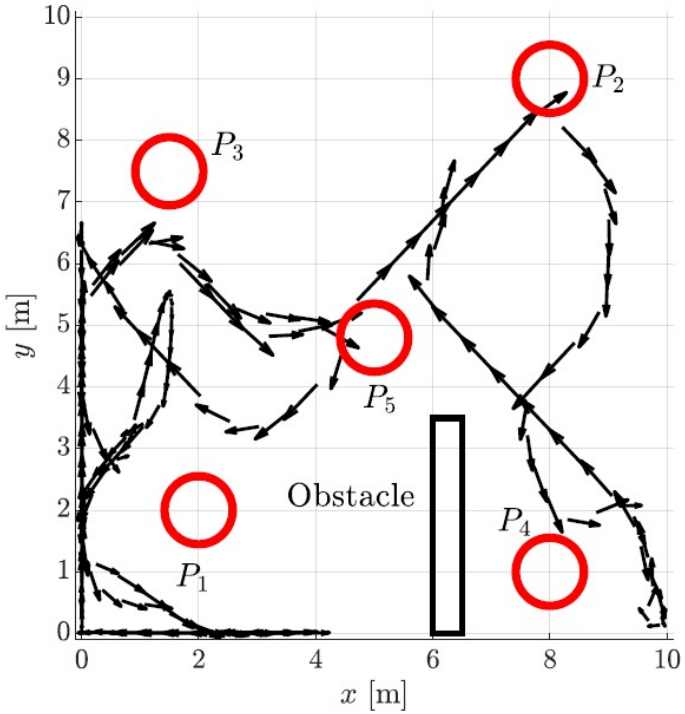
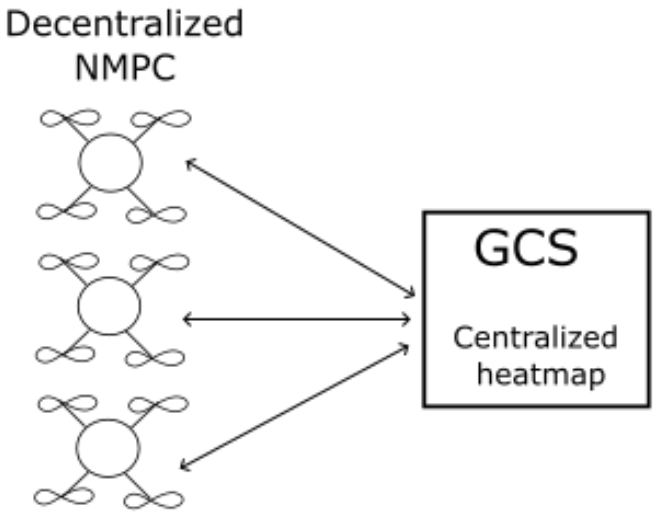




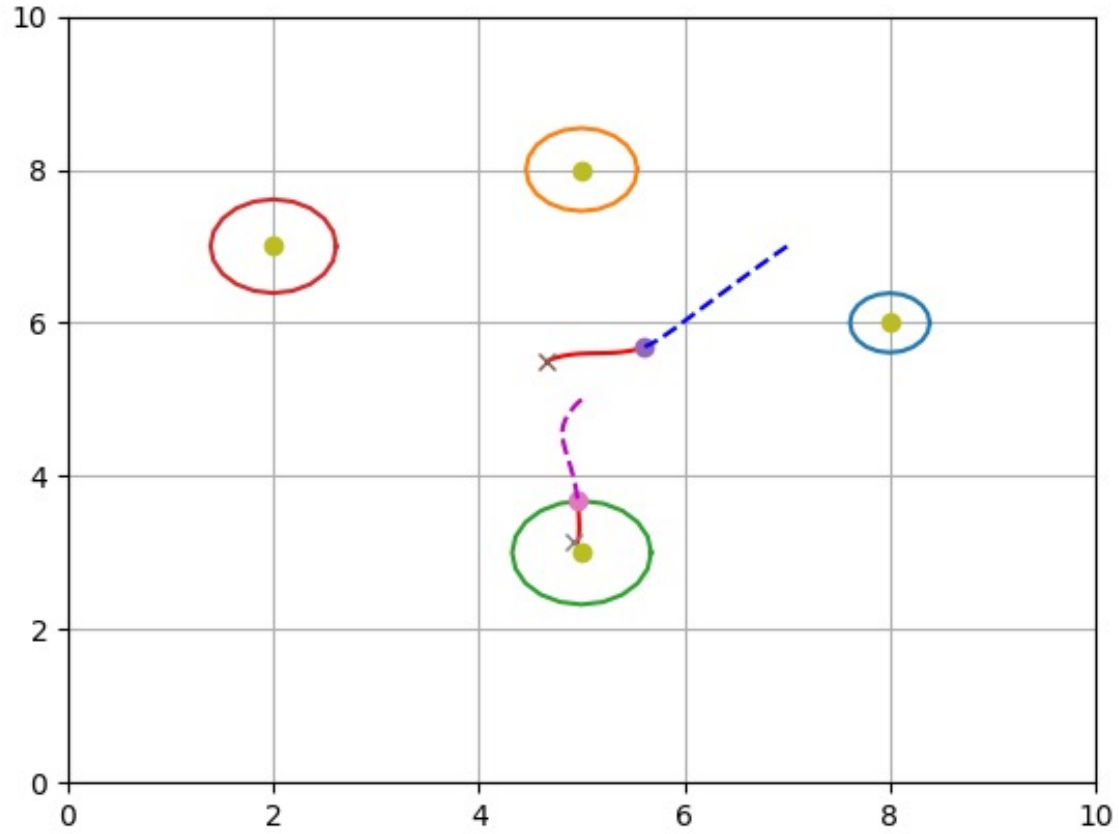
PhD thesis: Reconnaissance

- **Working on multirobot extension:**
  - Considering N drones with N decentralized MPC that communicate with a ground control station that store a centralized heatmap, updated with the information coming from all the agents
  - Each drone sends the predicted solution to the ground station and its position to all the agents
  - The optimization problem now consider the avoidance between the agents instead of the obstacles



PhD thesis: Reconnaissance

- **Working on multirobot extension:**



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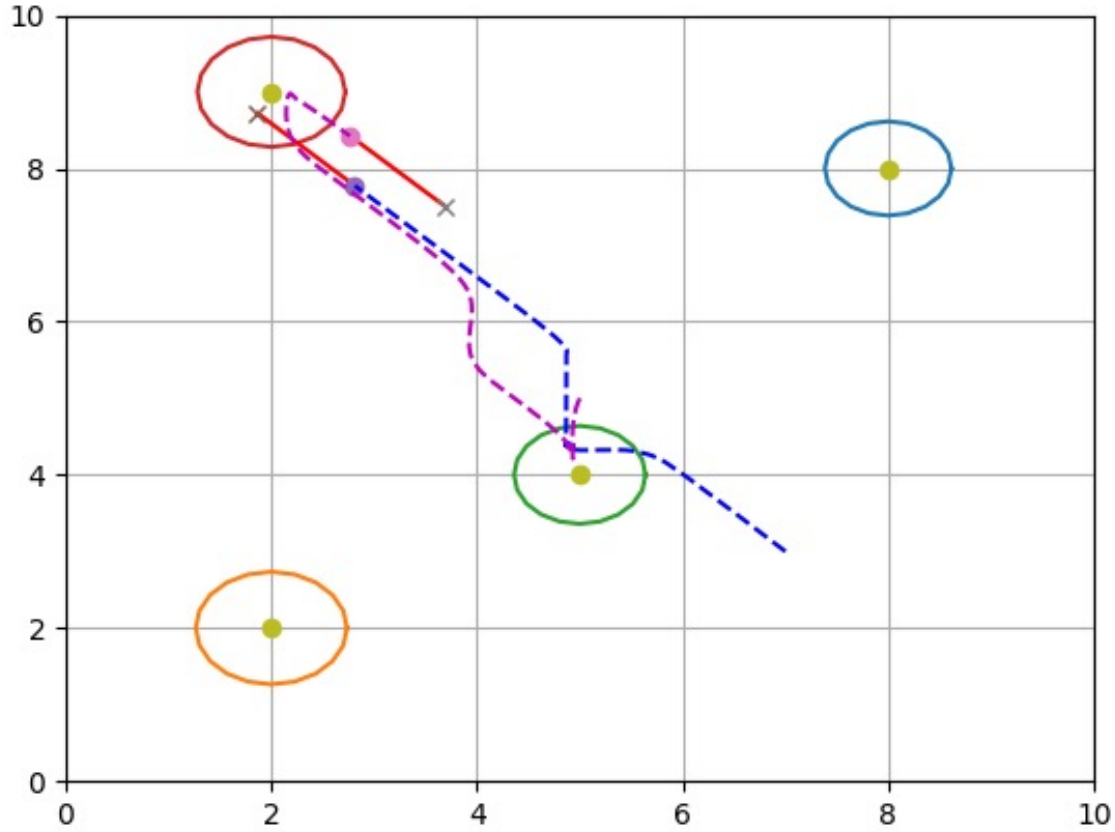

PhD thesis: Reconnaissance

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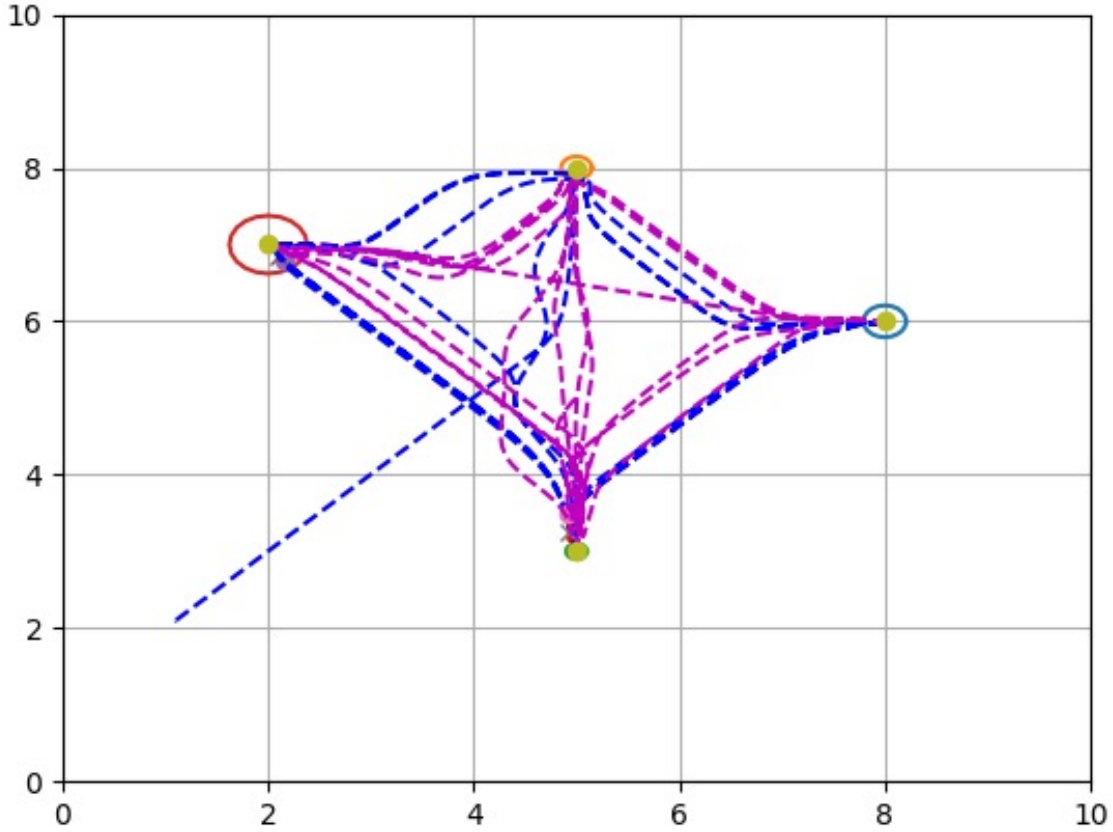

Any questions?