



UNIVERSITÀ DEGLI STUDI DI NAPOLI
FEDERICO II

itee^{PhD}
information technology
electrical engineering



DIE
TI

UNI
NA

PhD Francesca Pagano

Multi-robot persistent field monitoring

Tutor: Prof. Vincenzo Lippiello

Cycle: XXXVII

Year: Second

My background

- *BSc and MSc degree* in Automation Engineering
University of Naples “Federico II”
- *Research group*: PRISMA Lab – Aerial Robotics
- *PhD start date*: 01/01/2022
- *Scholarship type*: PON-Green
- *Partner company*: Società Agricola “Lenza Lunga”
dei F.lli Cacciapuoti



Research field of interest

- *Robotics* applied to remote sensing and crop monitoring, will play a key role in meeting rising food demands and improving environmental sustainability

**9.7 billions
people by 2050**

- Multi robot teams can reduce time, costs and improve efficiency in real world applications.
- Aerial and ground robotic platforms can be employed in agricultural applications as
 - coordinate remote sensing,
 - crop monitoring,
 - persistent surveillance.
- Challenges
 - Long-term autonomy
 - Multi-robot coordination

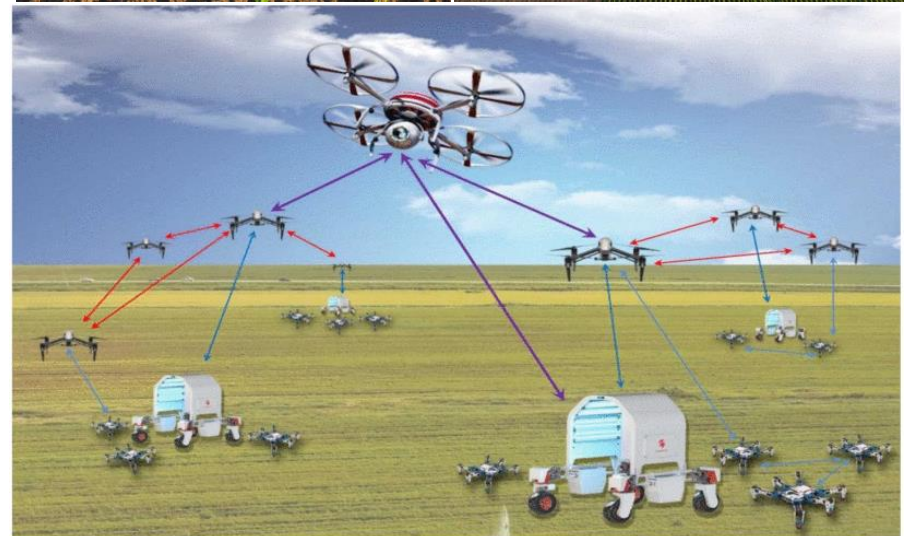


Image from: J. Hu, P. Bhowmick, I. Jang, F. Arvin and A. Lanzon, "A Decentralized Cluster Formation Containment Framework for Multirobot Systems," in *IEEE Transactions on Robotics*, vol. 37, no. 6, pp. 1936-1955, Dec. 2021, doi: 10.1109/TRO.2021.3071615.

Summary of study activities

- Ad hoc PhD courses:
 - **Model Predictive Control** – Prof. A. Bemporad, Scuola IMT Alti Studi Lucca
 - Main topics: General concepts of Model Predictive Control (MPC) and general Stability properties. Linear, explicit, hybrid and stochastic MPC. Selected applications of MPC in various domains.
 - **2023 Spring School in Transferable Skills** – SIpEIA
 - Main topics: team management, public engagement, gender equality and communication in academia and research
 - **Ethics and AI** – University of Naples Federico II
 - Overview of the main ethical issues concerning AI from an interdisciplinary perspective
- Conference attended
 - *2023 International Conference On Unmanned Aircraft Systems - ICUAS 23 - Warsaw*
 - Presented paper: *Development of a Control Framework to Autonomously Install Clip Bird Diverters on High-Voltage Lines*
- Seminars
 - organized by ETHZ, ITEE, INRIA, SSM...

Research activity: Overview

- Problem

- Multi-robot persistent area reconnaissance for points of interest's inspection.
- Persistent active sensing for unknown field estimation.
- Handle energy constraints.

- Objective

- Device online motion planning and multi robot coordination strategies.
- Develop control techniques to enable the coordinated execution of multiple prioritized tasks by a team of robots.

- Methodology

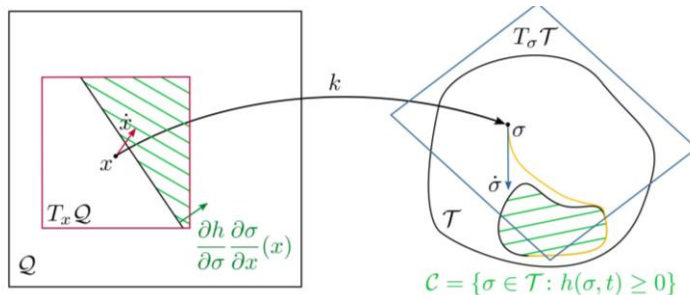
- Optimization-based frameworks
 - Nonlinear Model Predictive Control (NMPC)
 - Convex constrained QP - Constraint driven execution of tasks through CBFs
- PX4 Autopilot testing

Research activity:

Execution and prioritization of Extended set-based tasks

- Problem

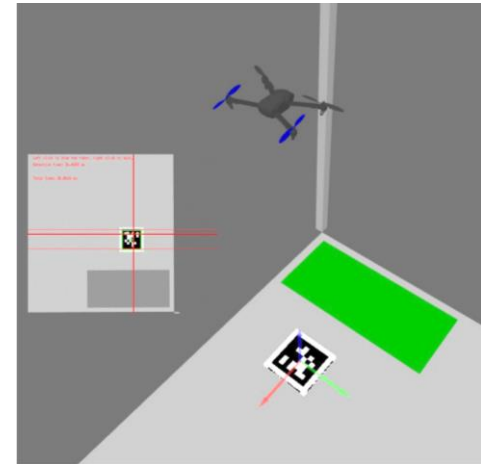
- Execute multiple tasks simultaneously exploiting system's redundancy.
- Ensure system safety requirements while executing a nominal task.
- Allow for a time-varying, online, eventually user driven, insertion and removal of tasks
- Dynamic switching of task priorities, i.e. tasks hierarchy



$$\underset{u, \delta, v}{\text{minimize}} \|u\|^2 + l_\delta \|\delta\|^2 + l_v \|v\|^2$$

$$\text{subject to } \frac{\partial h_i}{\partial t} + \frac{\partial h_i}{\partial \sigma_i} \frac{\partial \sigma_i}{\partial x} f(x) + \frac{\partial h_i}{\partial \sigma_i} \frac{\partial \sigma_i}{\partial x} g(x) u + \gamma_i (h_i(\sigma_i, t)) \geq -\delta_i, \quad \forall i \in \{1, \dots, M\}$$

$$K\delta \leq Vv.$$



- Methodology

- Convex constrained quadratic problem
- Tasks encoded as constraints through CBFs
- Experimental validation

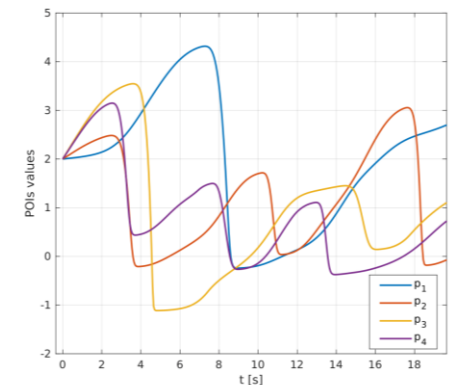
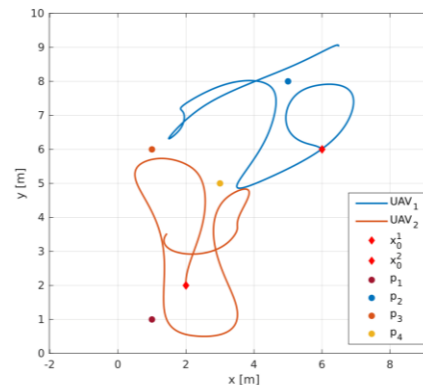
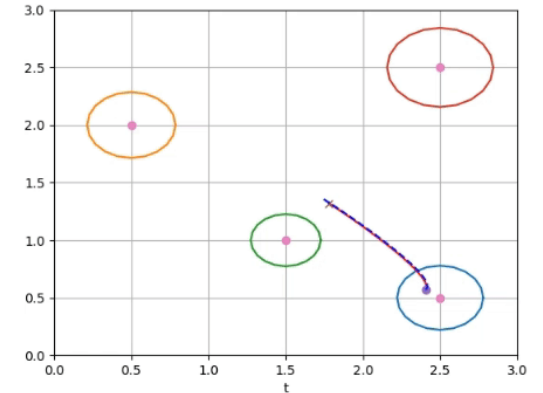
[J1] Beyond Jacobian-based tasks: Extended set-based tasks for multi-task execution and Prioritization

Authors: G. Notomista, M. Selvaggio, M. Santos, M. Siddharth, F. Pagano, V. Lippiello, C. Secchi

Research activity:

Multi-robot persistent area reconnaissance

- **Problem:**
 - Monitor persistently some points of interests with a team of agents
 - Applications: repetitive measurements and intruder detections (e.g., wild boars)
- **Objective**
 - Online coordinated motion planning
- **Methodology**
 - Decentralized Nonlinear Model Predictive Control (NMPC)
 - Global map update
 - Cubic Bézier parametrization of the reference trajectory
 - Agents kinematic model
 - POIs dynamics

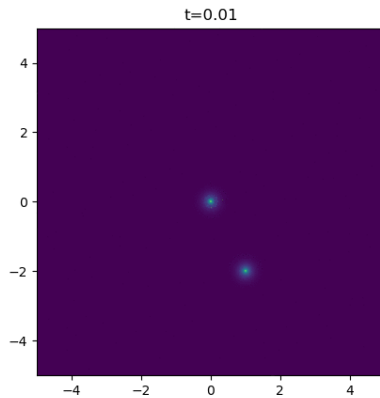


Work in progress with Eng. S. Marcellini, Prof. F. Ruggiero

Research activity:

Multi robot persistent environmental monitoring

Active sensing using High Order Control Barrier Function



Research activity at

- INRIA, Rainbow Team, Rennes (France)
- Supervisor: Dr. Paolo Robuffo Giordano



- Application:
 - Diffusive source seeking and field estimation
- Objectives:
 - Heterogeneous multi-robot system
 - Distributed implementation
 - Optimize estimation executing informative trajectories
 - Drone's battery constraints

- Methodology:

- *Model Based*: 3D Continuous/Instantaneous diffusive source model

$$y = h(r, q, t) = \frac{q}{4\pi Dr} \left[1 - \frac{2}{\sqrt{\pi}} \int_0^{\frac{r}{2\sqrt{Dt}}} \exp(-\eta^2) d\eta \right]$$

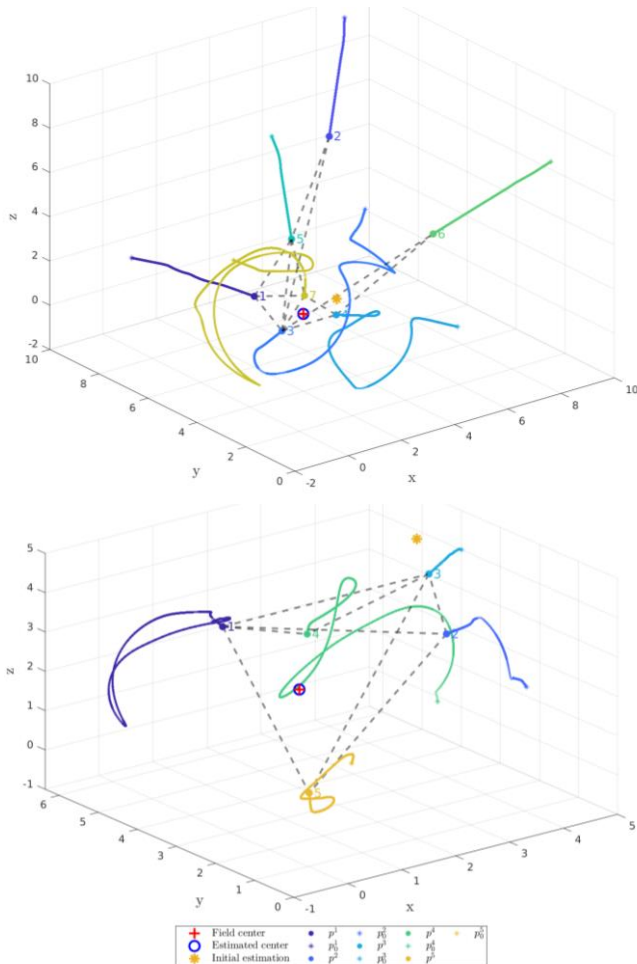
$$y = h(r, q, t) = \frac{q}{8(\pi Dt)^{3/2}} \exp\left(-\frac{r^2}{4Dt}\right)$$

- Distributed Estimation with Extended Kalman Consensus Filter

Research activity:

Multi robot persistent environmental monitoring

Active sensing using High Order Control Barrier Function



- Methodology:

- Gramian-based information measure and optimality criterion

$$\mathcal{G}_o(t_0, t_f) \triangleq \int_{t_0}^{t_f} \Phi(\tau, t_0)^T \mathbf{H}(\tau)^T \mathbf{W}(\tau) \mathbf{H}(\tau) \Phi(\tau, t_0) d\tau$$

- Constrained **QP** optimization with Higher Order Control Barrier Functions (HOCBFs)

$$\begin{aligned} \min_{\delta, \mathbf{u} \in \mathcal{U}} \quad & \frac{1}{2} \|\mathbf{u} - \mathbf{u}^d\|_2^2 + \frac{1}{2} l_\delta \delta^2 \\ \text{s.t.} \quad & \sum_{i=1}^N L_{g_i} \psi_1(\boldsymbol{\zeta}) \mathbf{u}_i + L_f \psi_1(\boldsymbol{\zeta}) + \alpha_2^\psi \psi_1(\boldsymbol{\zeta}) + \delta \geq 0 \end{aligned}$$

Research activity at

- INRIA, Rainbow Team, Rennes (France)
- Supervisor: Dr. Paolo Robuffo Giordano



Products

[J1]	Beyond Jacobian-based tasks: Extended set-based tasks for multi-task execution and Prioritization Authors: G. Notomista, M. Selvaggio, M. Santos, M. Siddharth, F. Pagano, V. Lippiello, C. Secchi <i>Submitted to International Journal of Robotics Research - IJRR</i> Status: under review
[C1]	Development of a Control Framework to Autonomously Install Clip Bird Diverters on High-Voltage Lines Authors: <i>S. D'Angelo, F. Pagano, F. Ruggiero, V. Lippiello</i> Conference: <i>The 2023 International Conference On Unmanned Aircraft Systems - ICUAS 23</i> Current state: published

Tutorship

Lecturer assistant: Teoria dei Sistemi, (ING-INF/04), Prof. Fabio Ruggiero

Next Year

Inria



Thank you
for your attention