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PROPOSITION DE SUJET DE THESE

Intitulé : Robust dynamic planning and control for interacting large-scale multi-agent systems: application to exploration and containment missions with heterogenous teams of robots.

Référence : **TIS-DTIS-2025-27**
(à rappeler dans toute correspondance)

Début de la thèse : octobre 2025	**Date limite de candidature :**

Mots clés

Automatic control ; multi-agent and large-scale systems ; learning ; constraints ; planning.

Profil et compétences recherchées

MSc (M2) / last year of Engineering School in automatic control or related field.
Good knowledge in control theory, learning, multi-agent systems, Python and/or Matlab.
Good written and spoken English is mandatory.

Présentation du projet doctoral, contexte et objectif

We are interested in developing a flexible architecture for guiding, controlling, and navigating a class of autonomous agents tasked with exploring restricted areas to locate and monitor targets of unknown positions. Applications include target detection in security missions (e.g., tracking an intruder), search and rescue operations (e.g., locating and escorting a victim), monitoring goods in industrial warehouses, and mapping extensive areas like agricultural fields or pollution hotspots. Numerous approaches have been developed in the literature for control design of multi agent systems in relation to these missions, see eg. [Franchi10, Hu21, Zahroof23, Ibenthal23].

In this PhD work, the agents are assumed to be organized into different heterogeneous teams, including: i) those responsible for locating the target(s) and, if mobile, subsequently contains and monitors it; ii) those focused on continuously monitoring the boundaries of the unexplored area to detect any potential escape by the target(s). For example, this mission may involve mobile robots navigating obstacles for ground exploration and drones conducting aerial surveillance of the perimeter. Our approach focuses on real-time planning and task updates for the agents, allowing for: i) trajectory reconfiguration to optimize time and energy efficiency, ii) connectivity constraints to maintain communication and cooperative visibility of area boundaries, and iii) hierarchical containment constraints [Ji06] to keep exploring agents within the zone defined by the monitoring team. Management of these coupled, time-varying constraints at the interface of hierarchical layers between teams of agents is therefore crucial and is at the heart of the proposed research project. Although the mission of interest, as described above, involves only two teams of agents, generalization to hierarchical architectures with multi layers will be considered in the PhD work to be able to deal with large-scale systems.

Different methods have been investigated in the literature to deal with distributed control of interacting network systems [Doan-11, Jilg13, Zheng18, Liu21]. However, many of these studies tend to overlook the role of uncertainties and disturbances within individual layers, as well as their coupling effects at the interfaces between layers. Moreover, little attention has been given to how faults or the loss of agents could affect these coupling dynamics or constraints.

The main objective of the PhD work is therefore to develop optimization-based dynamic planning and control algorithms for hierarchical and heterogeneous teams of agents, accounting for these coupling dynamics and constraints in a robust manner. Possibilities offered by learning techniques will also be investigated to train reconfiguration policies for the system in response to perturbations and faults.

The work envisaged during the PhD is described through the following items:

- *Formalization of the coupling dynamics and convolutive constraints.*
Complex constraints are to be considered since not only depending on agents' states (eg. relative positions) and environment (eg. occlusions due to obstacles in case of connectivity) but also on inter layer descriptions. Effective representations such as polytopic/zonotopic inner/over-approximations and/or neural networks PWA descriptions [Do24] will be investigated.

- *Analysis of the effect of perturbations / uncertainties / faults and their propagation to other layers.*

For instance, if an agent has a fault or suffers from a perturbation, it is necessary to identify the possible impacts in its own team but also on other layers, and characterize the effects in terms of the formalization developed in the previous item.

- *Development of hierarchical optimization-based dynamic planning and reconfiguration algorithms.*
Robust algorithms will be developed to mitigate the effects of the perturbations / uncertainties / faults previously mentioned accounting for inter layers coupling effects. Computation time concerns will be addressed, especially for dealing with large-scale systems. To that end, mixed offline-online strategies will be studied, such as offline planification of bundles of trajectories / reconfiguration strategies and determination of an online selection policy. Use of Reinforcement Learning techniques will be investigated to train such selection policies to be applied online.

- *Implementation and validation.*
Validation in simulation will be done on different scenarios with increasing levels of complexity (e.g. two layers architecture, no uncertainties, uncertainties related to one layer only, multiple layers, etc.). Implementation on robotic platforms available at ONERA and LCIS labs will also be considered for validation on experimental benchmark scenarios.

<u>References:</u>

[Do24] H. -T. Do and I. Prodan, "On the Constrained Feedback Linearization Control Based on the MILP Representation of a ReLU-ANN," in *IEEE Control Systems Letters*, vol. 8, pp. 1445-1450, 2024.

[Doan11] M. D. Doan, T. Keviczky and B. De Schutter, "A distributed optimization-based approach for hierarchical MPC of large-scale systems with coupled dynamics and constraints," *50th IEEE Conference on Decision and Control*, Orlando, FL, USA, 2011.

[Franchi10] A. Franchi, P. Stegagno, M. Di Rocco, G. Orlio, “Distributed Target Localization and Encirclement with a Multi-Robot System”, *7th IFAC Symposium on Intelligent Autonomous Vehicles*, Lecce, Italy, 2010.

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[Jilg13] M. Jilg, O. Stursberg, “Optimized Distributed Control and Topology Design for Hierarchically Interconnected Systems”, *European Control Conference*, Zürich, Switzerland, 2013.

[Liu21] Z. Liu, O. Stursberg, “Distributed Control of Networked Systems with Nonlinear Dynamics and Coupling Constraints”, *European Control Conference*, Rotterdam, Netherlands, 2021.

[Zahroof23] R. Zahroof, J. Liu, L. Zhou, V. Kumar, “Multi-Robot Localization and Target Tracking with Connectivity Maintenance and Collision Avoidance”, *American Control Conference*, San Diego, CA, USA, 2023.

[Zheng18] Y. Zheng, Y. Wei, S. Li, “Coupling Degree Clustering-Based Distributed Model Predictive Control Network Design”, IEEE Transactions on Automatic Control, vol. 15, no. 4, pp. 1749-1758, 2018.

Collaborations envisagées

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