M2 Research Internship 2024

Title: **On large-scale networks of multi-agent systems (MAS): A PDE-based approach for control of Autonomous Vehicles**

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Context and objectives

This research internship will be at the interface of Automatic Control and Computer Science and falls within the framework of the scientific Axis – Autonomous Mobility: Control and Planification of the FR TTM CNRS. It will be carried out at the CRIStAL laboratory (in conjunction with the LAMIH laboratory) and within the PRETIL platform (plate-forme de recherche Robotique et Transports Intelligents de Lille).

Substantial research efforts have been put into the problem of cooperative and formation control of Multi-Agent Systems (MAS). This problem has gained much importance because of MAS's vast practical applications, such as Unmanned Aerial Vehicles (UAV) formation, moving sensor networks, robot deployments, swarm dynamics, and autonomous vehicles' coordination, among many others. The modeling and control of such systems still represent a challenge due to the associated scalability and complexity. Most of the studies in this framework have been conducted by modeling with Ordinary Differential Equations (ODEs) with limitations in terms of scalability. Nowadays, there is a need of new scalable solutions to control multiple cooperative vehicles.
Recent and highly inspiring contributions propose a fresh way to address the abovementioned applications. It is about modeling and control by a partial differential equations (PDEs) approach. This viewpoint is supported by the fact, among others, that in large-scale networks, as the number of agents of the network increases, the computational complexity to simulate, analyze, and control the overall behavior of the network does as well. To overcome this issue, a continuum modeling approach (PDE-based modeling) offers a powerful way to deal with a large number of components in large networks. It has been proved that important global characteristics of large network agents can be captured by a PDE continuum model, where basement features are the diffusion and the transport phenomena (thus captured by parabolic and hyperbolic PDEs, respectively). A PDE setting allows not only the study of the communication topology after discretizing but also a faster simulation using existing tools for PDEs and allows a suitable model to be handled for control and estimation purposes. Although similarities between multi-agent systems and PDEs have been noted, they remain largely unexplored. This project aims to investigate the potential of employing PDEs for modeling, designing, analyzing, and controlling multi-agent systems.

From the theoretical point of view, this internship aims at studying control-oriented models using a PDE setting of network agents in which leaders and followers communicate with each other and

perform some collaborative tasks: e.g.; agents are required to move to the desired positions on a given deployment, for instance, on 2D planar curves or 3D manifolds.
Once we have a model, we expect to develop controllers under centralized/decentralized configurations. All information about the states of the agents (in particular of those being leaders and followers while deploying) is to be used for control and estimation design, which may also account for delays and sampling.

From the practical point of view, in this internship, we expect to apply the theoretical results on an experimental setup at the PRETIL platform, more precisely: a swarm of Tello Edu Drones. While counting on several drones, which have to perform predefined flight paths or be deployed to for instance planar curves, we require to obtain full or partial information of the state of each agent (e.g., position, velocity, history of the flight path, trajectories of agents,...) which are needed for control and estimation purposes. This requires to: a) handle the existing software for Tello Edu drones, and review the research literature - in particular concerning Swarm flights and reliability of the existing system and improvement of the software quality (automation of the configuration of drones by script, development of tests, integration of sources on a repository of GitLab codes, documentation) ; b) development of a swarm flight application: flight data, states of the agents, communication among agents to establish the software specifications of the application; and c) interfacing of Tello Edu with ROS (Robot Operating System) Drones localization by motion capture (via Optitrack system).

The candidate is expected to:
1) develop a PDE model approximating a set of ODEs which represent the fleet of autonomous vehicles
2) determine a control law based on the PDE model
3) handle the existing software for the PRETIL drone platform
4) implement the proposed control law.

References:

[1]. *Freudenthaler, G. & Meurer, T.. PDE-based multi-agent formation control using flatness and backstepping: Analysis, design and robot experiments, Automatica, Vol 115, 2020*
[2]. *Frihauf, P. & Krstic, M. Leader-Enabled Deployment Onto Planar Curves: A PDE-Based Approach IEEE Transactions on Automatic Control, 2011, 56, 1791-1806*
[3]. *Selivanov, A., & Fridman, E. (2022). PDE-Based Deployment of Multiagents Measuring Relative Position to One Neighbor. IEEE Control Systems Letters, 6, 2563-2568.*

The required skills: We are looking for a candidate with a solid background on applied mathematics and Automatic control. Knowledge in python, Matlab and ROS2 will be appreciated.

Duration and salary: 5 months with a salary of 584 euros per month.