2EL1130 – Dynamical Multi-Agent Systems. Application to drones formation control

Instructors: Cristina-Nicoleta Maniu
Department: DÉPARTEMENT AUTOMATIQUE
Language of instruction: FRANCAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 60
On-site hours (HPE): 35,00
Elective Category : Engineering Sciences
Advanced level : Yes

Description

Numerous applications involve formation of several autonomous systems, capable of cooperation in a specific environment and of reconfiguration for the mission achievement. In particular, formation flying (Unmanned Aerial Vehicles - UAVs, satellites, etc.), car traffic control or pedestrians behavior in a crowd highlight the notion of a dynamic Multi-Agent System (MAS).

In the context of rescue missions (large-scale fire extinguishing missions, search for avalanche victims or black boxes in a large environment, etc.), the coordination and the control of a fleet of autonomous vehicles becomes key elements. These multi-agent missions relay on several MAS concepts such as tasks assignment, trajectory/path planning, and induce control problems in real time under constraints etc. The topics covered in this course will allow students to understand the basic concepts and challenges related to dynamic multi-agent systems via several experimentations on UAVs formations.

Experiments in the flight arena of CentraleSupélec on Crazyflie UAVs and onTurtleBot ground autonomous vehicles (GAVs), and on the Robotarium remote platform are planned as part of this course.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Control Theory (ST5)

Syllabus

This course is based on a **collaboration with ONERA and the Heudiasyc laboratory** and has the following structure:

- Introduction: a brief history, industrial and academic context;
- Dynamic modeling of multi-agent systems (MAS);
- Specific tools for MAS: notions of vehicles fleet/swarm, communication graph, consensus;
- Modeling and handling of Crazyflie drones and ground vehicles;
- Control techniques of multi-agent systems;
- Taking into account constraints in the cooperative control law;
- Refinement of control laws and analysis of results;
- Multi-agent systems in space missions.

A tutored case study is envisaged as a guideline throughout this course in order to validate the proposed control techniques both in simulation and on an indoor experiment of a fleet of Crazyflie UAVs and/or Turtlebot mobile robots.

Experiments are planned in the indoor flight arena of CentraleSupélec.
See experiments en 2022:
https://twitter.com/centralesupelec/status/1535211296240685057

Class components (lecture, labs, etc.)
This course is composed of **interactive lectures, tutorials** and a **case study** (*carried out by team on a subject proposed by the students*) that will serve as a guideline throughout this elective module and will lead to indoor experimentations on UAVs formations and mobile robots formations. The case study will follow the progress of the course and will allow acquiring practical skills. Active learning methods such as *Problem-Based Learning (PBL)* in small tutored groups are envisaged for the case studies on UAVs formations.
Students will discover dynamic multi-agent systems through various examples, exercises, discussions, and theoretical and practical guidance. An estimate of the hourly volume (35h) is as follows: 18h for interactive lectures, 6h for tutorials, 9h for the case study and 2h for the evaluation of interactive posters and peer assessment.

Grading
The evaluation procedure is designed to respect the alignment of objectives - activities - evaluations. A report (containing a state-of-the-art, the analysis of the results obtained during the case study, etc.) will be delivered and evaluated. The results will be presented using an interactive poster in front of a committee and with a cross-examination of the other groups (peer assessment). The final grade is computed from the report evaluation (40%), the interactive poster evaluation, both poster design and presentation (40%) and the simulation & experimentation validation (20%). A skill-based assement is also envisaged.

Course support, bibliography
References

- *A Massive Open Online Course on Drones and Aerial Multi Robot Systems* (*DroMOOC*), www.onera.fr/dromooc, University Paris-Saclay, 2018.
- K.K. Oh, M.C. Park, H.S. Ahn, "A survey of multi-agent formation control", *Automatica*, vol. 53, pp. 424-440, 2015.
- J.A. Guerrero, P. Castillo, S. Salazar, R. Lozano, "*Mini Rotorcraft Flight Formation Control Using Bounded Inputs*", *Journal of Intelligent & Robotic Systems*, vol. 65, pp. 175-186, 2012.
- J. Guerrero, R. Lozano, "*Flight Formation Control*", John Wiley & Sons, 2012.
- I. Prodan, "*Commande des systèmes dynamiques Multi-Agents en présence de contraintes*", PhD thesis, Supélec, 2012.
- M.T. Nguyen, "*Commande prédictive sous contraintes de sécurité pour des systèmes dynamiques Multi-Agents*", PhD thesis, Université Paris-Saclay, 2016.
- G. Rousseau, C. Stoica Maniu, S. Tebbani, M. Babel, N. Martin, "Quadcopter-performed cinematographic flight plans using minimum jerk trajectories and predictive camera control", *European Control Conference*, Limassol, Cyprus, 12-15 June 2018.
- Y. Rochefort, H. Piet-Lahanier, S. Bertrand, D. Beauvois, D. Dumur, "Model predictive control of cooperative vehicles using systematic search approach", *Control Engineering Practice*, vol. 32, pp. 204-217, 2014.
- N. Michel, S. Bertrand, G. Valmorbida, S. Olaru, D. Dumur. "Design and parameter tuning of a robust model predictive controller for UAVs", *IFAC World Congress*, Toulouse, France, 2017.
- Wilson, S., Glotfelter, P., Wang, L., Mayya, S., Notomista, G., Mote, M., & Egerstedt, M. The Robotarium: Globally Impactful Opportunities, Challenges, and Lessons Learned in Remote-Access, Distributed Control of Multirobot Systems. IEEE Control Systems Magazine, 40(1), 26-44, 2020.
- C. Stoica Maniu, C. Vlad, T. Chevet, S. Bertrand, A. Venturino, G. Rousseau, S. Olaru, "Control systems engineering made easy: motivating students through experimentation on UAVs", 21th IFAC World Congress, Demonstrator Late Breaking Results, Berlin, Germany, 12-17 July, 2020.

Examples

- https://www.youtube.com/watch?v=hyGJBV1xnJI

- https://www.youtube.com/watch?v=YQIMGV5vtd4
- https://www.youtube.com/watch?v=fdrmahUPwaI
- http://www.asctec.de/en/uav-uas-drones-rpas-roav/asctec-hummingbird/

Resources

Pedagogical team: Cristina Maniu, Cristina Vlad, Sorin Olaru

Teaching staff (to be confirmed): Gauthier Rousseau, Sylvain Bertrand (ONERA), Pedro Castillo (UTC Heudiasyc), Cristina Maniu, Cristina Vlad, Sorin Olaru.

Funding via the project MEECOD – *Moderniser l'Enseignement par l'Expérimentation sur la Coordination de Drones*, *with the support of UPSaclay on « Initiatives Pédagogiques – Oser ! » 2018, N°FOR-2018-070*, was obtained for the purchase of the necessary equipment (flight arena equipement, numerous Crazyflie UAVs and TurtleBot GAVs, etc.) for this course and the construction of an indoor space at CentraleSupélec dedicated to UAVs flight tests (room VI.003, Eiffel building).

Funding via the project DAReTeach – Drone Arenas-based Remote International Teaching with the support of *FACE Fondation – French-American Cultural Exchange in Education and the Arts* allowed to complete the fleet of Crazyflies UAVs.

Learning outcomes covered on the course

After completion of this course, students will be able to:

- Describe and recognize the behavior of a multi-agent system (state-of-the-art on the subject);
- Model a multi-agent system via a state-space representation;
- Analyze time-domain or frequency specifications and propose a control law for a multi-agent system in order to fulfill the considered specifications;
- Design a control law for the multi-agent system and validate it in simulation;
- Validate the proposed control law on an available experimental testbed (a UAVs/GAVs formation).

Description of the skills acquired at the end of the course

- C1.2 – Modeling: using and developing the appropriate models, choosing the right modeling scale and the relevant simplifying assumptions
- C1.4 – Design: specify, implement and validate all or part of a complex system
- C2.3 – Identify and independently acquire new knowledge and skills
- C5.3 – Analyze global and / or local issues internationally and adapt projects or solutions to them
- C7.1 – Know how to convince basically: Structure your ideas and arguments, be synthetic (assumptions, objectives, expected results, approach and value created)
- C7.3 – Know how to convince about yourself: Being comfortable and being convinced, showing empathy and managing your emotions
- C8.1 – Build the collective to work as a team
- C8.2 – Mobilize and train a collective by showing leadership