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Modernizing Teaching through Experimentation on UAVs Formations

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Abstract: In the context of innovative control laboratories, this paper presents a new engineering course applying basic automatic control and optimization concepts to the cooperative control of Unmanned Aerial Vehicles (UAVs) formations. Innovatory methods of active learning such as Problem-Based Learning (PBL) in small tutored groups are proposed, as well as a peer assessment of the results. Indoor experiments on UAVs formations, as well as interactive presentations of the results such as interactive posters and videos are envisaged.

Keywords: General control laboratories, university-industry cooperation in control engineering, pedagogy in control engineering.

1. INTRODUCTION

Collaborations university-industry are beneficial both to develop new high quality technological products as well as to better form the engineering students to be innovators and leaders. In this context, CentraleSupélec [1] proposes a new curriculum with an original structure, novel pedagogical approaches and a strong coherence of the students' knowledge and skills with the industrial requirements. The new course on "Analysis, optimization and control of dynamical multi-agent systems. Experimentation on UAVs Formations" fits this framework, allowing students to familiarize with complex engineering questions related to UAVs formation control. Inspired by several top universities which have already built UAVs flight arenas (e.g. University of Pennsylvania, ETH Zürich, EPFL, MIT, KTH, TU München, Concordia University), an indoor flight testing area will be designed especially for this course, with the financial support of University Paris-Saclay via the MEECOD Project (2019). This project is issued from a collaboration between education and research institutions (CentraleSupélec/Laboratoire des Signaux et Systèmes, ONERA - the French AerospaceLab), with the industrial participation of Parrot Drones and MathWorks.

This course relies on previous research work of the involved participants on control techniques applied to a single UAV (Rousseau et al. (2018), Rousseau et al. (2019), Michel et al. (2017), Prodan et al. (2013)) or to UAVs formations (Chevet et al. (2018), Nguyen et al. (2015), Rochefort et al. (2014)), as well as the recent MOOC (Massive Open Online Courses) teaching experience on UAVs (Bertrand et al. (2018)). The challenges (and at the same time original elements) mainly arise from: (*i*) applying Problem-Based Learning (PBL) pedagogical approaches (Evensen and Hmelo (2000)) in the context of experiments for the control of UAVs formations; (*ii*) teaching Multi-Agent Systems (MAS) control techniques to students with a basic level of automatic control and optimization. To this aim, several open-ended scenarios for UAVs formation control are envisaged, allowing students to acquire solid knowledge in MAS control together with team working and communication skills.

The remaining part of this paper is organized as follows. Section 2 synthesizes the theoretical notions taught during this course and gives the curriculum structure. The pedagogical approach, the skills acquired during the course and the evaluation procedure are presented in Section 3. Conclusion remarks are drawn in Section 4.

2. CURRICULUM STRUCTURE

The course "Analysis, optimization and control of dynamical multi-agent systems. Experimentation on UAVs Formations" enhances theoretical knowledge, practical and team working skills of the second year students of CentraleSupélec, allowing them to innovate within a dynamic scientific and technological environment.

Numerous applications involve formation of several autonomous systems, capable of cooperation in a specific en-

[1] CentraleSupélec is one of the French 'Grandes Écoles', i.e. a graduate engineering school, with a three-year curriculum, preceded by two years of higher education.

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vironment 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 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.

This elective course of 35 hours is initially intended for a maximum of 40 students. The workload is estimated to 60 hours, which represents the time a student needs to efficiently learn the course curriculum and complete course activities. The course will be held on one month and a half from end April to June (starting from 2020).

Prerequisites of this elective course are the core courses on "Automatic Control" and "Optimization" (taught at CentraleSupélec) and the DroMOOC (Bertrand et al. (2018), DroMOOC Project (2018)).

The theoretic content of this course focuses on: (*i*) proposing a dynamical model of a quadcopter drone and analyzing it; (*ii*) modeling a multi-agent system composed of several heterogeneous UAVs and analyze the interaction between its agents via a simulator; (*iii*) proposing a scenario for a UAVs formation mission; (*iv*) designing a basic control technique for the considered formation mission; (*v*) validating the proposed control technique in simulation and on a formation of several Parrot quadrotors (e.g. Mambo, Bebop).

The course is based on a collaboration with Parrot Drones and ONERA and contains the following modules:

- 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 Parrot drones;
- 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 validate the proposed control techniques both in simulation and on an indoor experiment of a fleet of Parrot drones.

The experiments are carried out on Parrot Mambo and Bebop 2 drones (and also Anafi drones in the future). To this end, a new drone testing facility is currently under construction. The enclosed 10mx5mx3m flight arena will be provided with *OptiTrack Prime 13* tracking cameras, which are used for closed-loop control of vehicles. Each group of students will handle several drones to conduct experimental trials.

Therefore, the course framework is situated at the frontier between control and robotics as long as it deals with path/trajectory planning and navigation, enhancing students with transverse skills in these domains.

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;
- Control techniques of multi-agent systems;
- Validate the proposed control law on an experimental testbed (a UAVs formation).

This course is composed of lectures/conferences and a case study that serves as a guideline throughout this elective module and leads to indoor experimentations on UAVs formations. The case study is meant to follow the progress of the course and allows acquiring practical skills. 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: 15h for lectures/conferences, 18h for the case study and 2h for the evaluation of interactive posters and peer assessment.

3. PEDAGOGICAL APPROACH AND SKILLS

The main contributions of this engineering course to students knowledge and skills acquisition are the following: (*i*) developing their ability to work effectively as part of a team on a complex subject ranging from mathematical modeling to the analysis and implementation of control techniques on a real multi-agent system; (*ii*) developing transverse knowledge and skills offering an opening towards both theoretical and applicative domains (e.g. control engineering, optimization, computer science, flight mechanics) currently at the forefront of research and development; (*iii*) being proactive, taking initiatives and proposing solutions to open-ended problems of significant industrial interest such as the coordination of a fleet of drones used to search for objects in an area with limited accessibility and resources. More precisely, this course will allow students to develop the following core skills of the new curriculum of CentraleSupélec (2018):

- C1.2 – Select, use and develop modelling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem;
- C1.3 – Apply problem-solving through approximation, simulation and experimentation/Solve problems using approximation, simulation and experimentation;
- C1.4 – Design, detail and corroborate a whole or part of a complex system;

- C2.3 – Rapidly identify and acquire the new knowledge and skills necessary in applicable/relevant domains, be they technical, economic or others;
- C2.4 – Create knowledge within a scientific paradigm;
- C3.1 – Be proactive and involved;
- C3.5 – Put forward new tools with either continual progress or disruptive solutions as the goal;
- C3.6 – Evaluate the efficiency, feasibility and strength of the solutions offered/proposed solutions;
- C7.1 – Persuade at core value level; be clear about objectives and expected results; apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematize the ideas themselves; highlight the added value;
- C8.1 – Work collaboratively in a team;
- C9.3 – Act ethically, with integrity and respect for the others.

During this elective course on the coordination and management of dynamic multi-agent systems, the students are encouraged to use the theoretical concepts to propose solutions to different open-ended scenarios (e.g. Baillard et al. (2018)) for UAVs formation control, which are then applied on experimental testbeds for validation. Using a Problem-Based Learning (PBL) pedagogy, this course allows students to increase their knowledge and skills by working in small teams of 5-6 students.

The students are evaluated based on a report containing a state-of-the-art and the analysis of the results obtained during the case study. Each team of students presents their results using an interactive poster (or video) in front of a committee and with a cross-examination of the other groups. A peer assessment using the Peeramid tool (Peeramid Project (2017), Galtier (2016)) is envisaged, allowing students to think critical and to persuade by working on communication techniques. The real-time feedback gathered by teachers (during the case study and via interactive MCQs during lectures/conferences) is also a tool for assessing the students' skills and knowledge. The final grade is computed from the report evaluation, the interactive poster evaluation (both design and presentation), the evaluation of the results obtained for the case study, the supervisors feedback on the students involvement during the case study and evaluation of the activities (e.g. interactive MCQs, exercises) during lectures.

4. CONCLUSION

This paper focuses on a new course on "Analysis, optimization and control of dynamical multi-agent systems. Experimentation on UAVs Formations" allowing the second year students of CentraleSupélec to acquire transversal knowledge and skills, using a Project-Based Learning approach, benefiting from the expertise of industrial partnerships (Parrot Drones and MathWorks) and research institution (ONERA). Future work consists in developing an advanced level of this course for Master and PhD level.

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