Control Systems Engineering made Easy: Motivating Students through Experimentation on UAVs

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Abstract: This paper focuses on a new elective course on modeling and control of multi-agent systems, with experimentation on Unmanned Aerial Vehicles (UAVs). The module is taught for students with basic knowledge in Automatic Control and Optimization and it intends to increase their interest in applying advanced control techniques on UAVs in an enjoyable framework favorable to develop creativity, practical and team working skills, together with a solid and persistent theoretical background.

Keywords: Control education, multi-agent systems, university-industry cooperation, Problem Based Learning

1. INTRODUCTION

In rescue missions (extinguishing forest fire, searching for victims/black boxes in a large environment, evacuating buildings, etc.) or surveillance/maintenance missions (inspecting road traffic, solar plants, wind turbines), the coordination and control of a fleet of Unmanned Aerial Vehicles (UAVs) becomes crucial. In the drone-related industrial market there is an increasing request of pluridisciplinary engineers, with excellent knowledge in flight mecanics, control systems, robotics, computer science, etc. and experimental, team working and proactiveness skills. Thus a university-industry close cooperation is needed to better train the engineering students. A balanced teaching curriculum between theoretical notions and practical training is necessary in order to lead to highly qualified engineers. Numerous worldwide universities (e.g. University of Pennsylvania, MIT, ETH Zürich, EPFL, KTH, TU München, Concordia University) or French education institutions (e.g. UTC, ENAC, ISAE, LAAS) offer courses related to UAV control, with experiments in their own flight arenas.

In the context of a new curriculum of CentraleSupélec (Jankovic et al. (2019)), with an original structure and strong coherence with the industrial requirements, a new elective course has been proposed on the *Analysis, optimization and coordination/control of dynamic multi-agent systems. Application to the formation of drones.* This course is part of the MEECOD Project (2019) (see Stoica Maniu et al. (2019) for more details) issued from a collaboration between education and research institutions (CentraleSupélec/Laboratoire des Signaux et Systèmes, ONERA - the French AerospaceLab) and industrial partenerships (Parrot Drones and MathWorks). A close collaboration with Université de Technologie de Compiègne will allow students choosing this elective course to benefit from the expertise of accomplished researchers in UAVs control. The module (35h) is divided in lectures, tutorials and a case study organized as a Problem Based Learning (PBL) and its first occurrence will take place between April 20 and June 3, 2020. The main challenge is that the 40 students following this module have only basic notions of Automatic Control and Optimization [1]. The objectives of the course are ambitious: make students with basic notions on control systems discover advanced control techniques via simulations and experiments on quadrotor UAVs. Indeed, students have only notions about P/PI/PID, phase-lead, feed-forward, cascaded and state-feedback control (coupled with a Luenberger observer). The challenge is to introduce the notion of multi-agent system (MAS) and the simplest suitable control laws for MAS, within an agreeable (yet difficult) framework of experimentation on quadrotor formations. In this context, a flight arena of 50m^2 is on progress at CentraleSupélec and it will be the playground for the quadrotor experiments. Pedagogical approaches such that PBL, interactive MQCs, peer assessment, interactive poster session will be used to motivate the students, to develop their creativity and team work skills, to perpetuate the learning process, etc. Existing

[1] All the students followed two core modules on Automatic Control and Optimization, respectively.

MOOCs (e.g. DroMOOC Project (2018), Bertrand et al. (2019)) on UAVs, as well as previous research work of the involved participants to a single quadrotor (Rousseau et al. (2019), Michel et al. (2017)) or UAVs formations (Chevet et al. (2020), Nguyen et al. (2015), Nguyen and Stoica Maniu (2016), Rochefort et al. (2014), Prodan et al. (2013), Prodan et al. (2012)) will be referred as starting point for this module. The main contribution of this demonstrator late breaking results paper is related to the impact that the elective course will have on students motivation to choose the Control Engineering option during their last year at CentraleSupélec. This analysis will be done at the end of the course (in June 2020). An analysis of the acquired hard and soft skills during this module will also be performed. A survey will also be considered in order to allow students to self-evaluate their skills before and after the module.

The remaining part of this paper is organized as follows. Section 2 details the module content and structure. Section 3 focuses on the students' evaluation procedure. Section 4 briefly presents how the first occurence of the module was adapted to online teaching during the Coronavirus pandemic. Conclusion remarks are drawn in Section 5.

2. MODULE OUTLINE

The module *Analysis, optimization and coordination/control of dynamic multi-agent systems. Application to the formation of drones* is organized as follows:

(1) Introduction: brief history, industrial and academic context
(2) Dynamic modeling of a quadrotor UAV
(3) Introduction to multi-agent systems
(4) Elements for dynamic modeling of multi-agent systems
(5) Consensus-based control laws
(6) Simulation: UAV control techniques, multi-UAV control laws via consensus
(7) Multi-UAV control (notions of fleet, swarm and formation, swarm control based on behavioral rules [2])
(8) Simulation: multi-vehicle control, possible tests using the GeorgiaTech's Robotarium platform [3] (see Wilson et al. (2020) for more details)
(9) Feedback linearization control
(10) Backstepping control
(11) Trajectory generation and trajectory tracking/path following
(12) Control by saturation functions
(13) Multi-agent systems coordination strategies
(14) Problem Based Learning - Phase I
(15) Problem Based Learning - Phase II
(16) Finalizing the results : simulations (exemples are provided in Fig. 1 and Fig. 2), possibly tests [4] on UAVs
(17) Poster design
(18) Interactive poster session

[2] Multi-agent systems control based on *nearest neighbors* rules and Reynolds rules will be proposed.

[3] http://www.robotics.gatech.edu/robotarium

[4] When the flight arena of CentraleSupélec will be available, the implementation of the proposed control techniques on UAVs is envisaged. In the meantime, simulations will be considered.

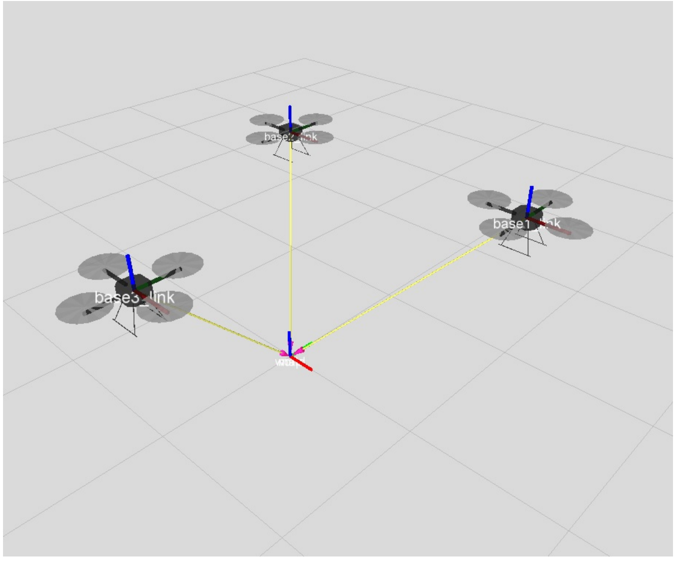

Fig. 1. 3D RViz visualization of three UAVs in the ROS simulator developed for the module

The Problem Based Learning will focus on taking into account constraints in the synthesis of the multi-agent cooperative control law. During the Phase I of the PBL the students will discover an open problem that will allow them to choose an appropriate control technique for taking into account constraints and to apply it on a multi-vehicle formation. They will plan the work strategy (scenario, optimization problem formulation, simulation, etc.) in order to elaborate an answer to the proposed problem and allocate the tasks to each group member. During the one week between the Phase I and Phase II sessions, each student will work autonomously on the tasks according to their plan. During the Phase II session, the students will share what they have studied/prepared/developed with the other students of the same group and they will then start preparing the simulations and the poster. They still have one session to finish the simulations and the poster. Then, during the interactive poster session each group will present the developed results. For most of the students, this will be the first time they design and present a poster, which represents a valuable addition to their skill set.

3. EVALUATION

The evaluation procedure is designed to respect the alignment between the *objectives* - *activities* - *evaluation* of the elective course. Both the team work and individual contribution are evaluated. The final grade is obtained from the report evaluation, the interactive poster evaluation, the evaluation of the results obtained during the case study, the supervisors' feedback on the students involvement during the case study and evaluation of the activities (e.g. via interactive MCQs) during lectures and tutorials. The interactive poster session will take place in a dedicated room, as illustrated in Fig. 3. Concerning the interactive poster evaluation, a survey will be filled by the evaluation committee and by all the groups of students (peer assessment). The following criteria will be evaluated:

(1) Oral presentation:

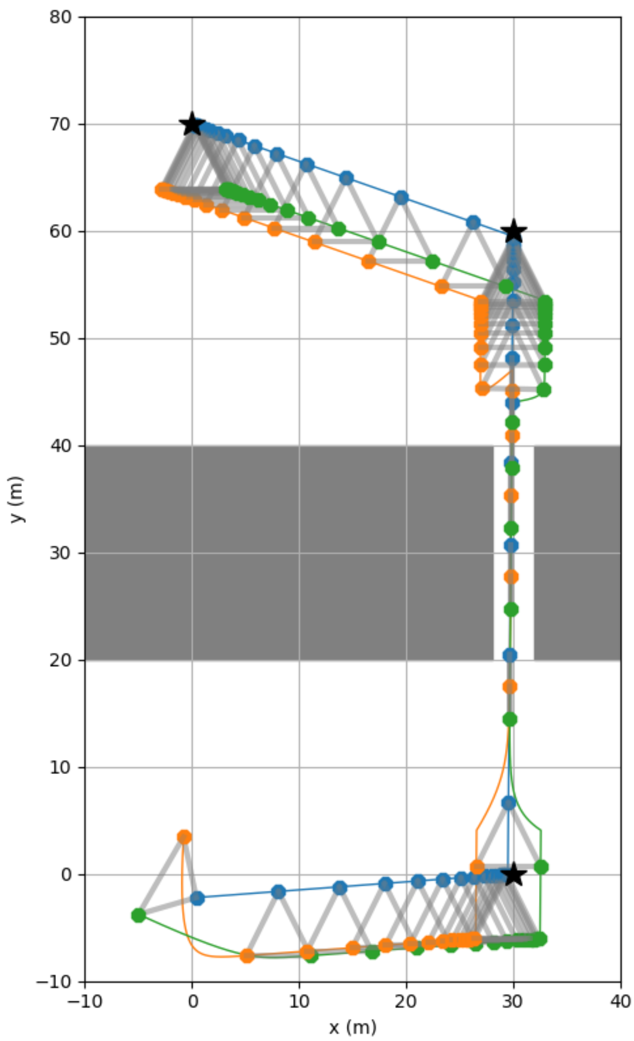

Fig. 2. Leader-follower control of a 3-agent formation (blue, green and orange dots), using waypoints (black stars) for guidance with obstacle (grey rectangles) avoidance

- Elocution quality (speech quality, dynamics, speech based on the interactive poster, etc.);
- Structure of the speech (common thread, catching the audience attention, concise summary of the poster);

(2) Poster design:
- Poster layout (readability, structure, relevant illustrations, easy to follow, etc.);
- Self-contain poster (template, title, captions, poster flow, etc.);

(3) Poster content:
- Scientific quality and contribution (focused content, results, originality, etc.);
- Objectives, methods, results, conclusion and main references;

(4) Interactions during the poster session:
- Storyboard poster (message to take home);
- In-depth discussions (motivating presentation, answer quality, relevance for the audience, etc.).

Fig. 3. Interactive poster session room

4. ONLINE TEACHING DURING THE CORONAVIRUS OUTBREAK

The first occurence of this module started during the lockdown in April 2020. Microsoft Teams made possible the online teaching for all the activities of CentraleSupélec. Several adjustements were done with respect to the initial schedule in order to take into account several constraints. During the Coronavirus lockdown period, the number of teaching activities of all the elective courses of CentraleSupélec was descreased by 6h, thus leading to a total number of 29h (instead of 35h). Twenty nine students regularly followed the teaching activities, divided in five groups of five students and one group of four students. To encourage online interactions during this period, the pedagogical team suggested students to choose their group [5] .

The teaching activities mainly took place in the general chanel of the team created for this elective course in Microsoft Teams. Several members of the pedagogical team were connected online during the lectures. Interactions with all the participants (both students and involved professors) were facilitated by using the Chat option and also encouraging discussions, adapting the lecture to take into account students interest in specific points etc. Part of the teaching activities have required individual work and online interactions at the classroom level. Each team of students also had a specific chanel used for group activites. Working in small groups with four tutors for six groups was highly appreciated by students. After each group activity, the groups explained their solutions in a classroom-type discussion, which was fruitful for all the participants.

Concerning the evaluation, the interactive poster session is also scheduled online, as most of the conferences during this particular time period.

Practical experimentations via the Robotarium platform was a key solution (highly appreciated both by students and professors) for the teaching of this module during the Coronavirus outbreak. These remote experiments have definitely played a crucial role in the motivation of our students.

[5] The Edunao (2019) platform was used for forming groups.

Overall, during the elective course the pedagogical team received encouraging feedback from the students. Mathilde Laune sent us her feedback about this module: "As a second year student at CentraleSupélec, I followed this introduction course to multi-agent systems as a complement to the [Automatic Control] course. Currently heading a project in which I work on the design and control of a fully automated sailboat, some notions associated to the control of multi-agent systems actually gave me new ideas to develop it, such as a way to take obstacles into account while implementing the navigation system. Plus, the application to drones formation flight accurately materializes all the concepts progressively introduced in the lessons. Last but not least, the teaching team is passionate and the lessons are both clear and synthetic, it's a pleasure!".

5. CONCLUSION

This paper proposed an overview of a new elective course at CentraleSupélec on advanced control techniques applied to Unmanned Aerial Vehicles formations taught for students with basic control skills with the aim of increasing the students' motivation, creativity, team work, technical and practical skills using experimentation on UAVs. The activities during this module can be seen as a first research experience in Control Systems Engineering.

Current work focuses on the impact that this course will have on students, with the intention of motivating them to continue their studies within the Control Engineering option, with the aim of a career in the field of Control Systems. In addition, an analysis of the acquired skills during this module will be done. A survey will be considered in order to allow students to self-evaluate their skills before and after the module. A comparison of the results of the peer assessment during the poster session with the evaluation provided by the teaching team is also envisaged.

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