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Feedback on Drone Arenas-based Remote international Teaching – DARETeach

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Abstract: This paper presents the lessons learned from a Collaborative Online International Learning (COIL) project in Control engineering, involving Rutgers University (USA) and CentraleSupélec (France). Students from both universities collaborated on advanced control design for fleets of aerial and ground vehicles for mission-specific algorithms, encompassing scenarios like search and rescue, building inspections, and artistic drone shows. The project employed active learning methods, with small, tutored groups working on projects. A unique aspect of this COIL involved a 3-step relay structure: 1/ The French students' teams proposed several theoretical case studies involving advanced control techniques for drones formations. 2/ Co-working activities between French and American students were possible during common online tutorship leading to adapt the initial scenarii. 3/ The American students continued the case studies proposed by the French students, completing the work with experiments on real drones. The international component of this COIL set a higher expectation from the students and motivated them to work harder to represent themselves and their respective universities as well.

Keywords: Control Education, multi-agent systems, autonomous systems, project-based education, teaching and learning experiences, Collaborative Online International Learning (COIL) on Control.

1. INTRODUCTION

Drones and mobile robots are used for teaching STEM topics at different academic levels ranging from primary school to graduate programs, see e.g., Yeppes et al. (2022). Numerous and various pedagogical approaches involving drones have been developed (see e.g., the review proposed in Yeung et al. (2024)), to teach different subjects such as Aerospace, Control Systems, Mechatronics, Robotics, Artificial Intelligence, etc. Some of these pedagogic approaches are:

- Hands-on experiments and labs (Stoica Maniu et al. (2019); Giurato et al. (2020); Bertrand et al. (2023); Takács et al. (2023)),
- MOOCs (DroMOOC Project (2018); Bertrand et al. (2019)) and online open access materials for tutorials and labs (Cañas et al. (2020)),
- Active Learning (Lobo et al. (2021)) and Project Based Learning (Castaldi and Mimmo (2019); Hoople et al. (2019)),

- Competition Based Active Learning (Abichandani et al. (2022)),
- Flipped classrooms (Schuchter (2021)).

Notice that the COVID period has witnessed a significant development of online resources, MOOCs and MOOLs. For in-presence pedagogical activities, group work is most of the time adopted both to save resources (hardware drone equipment, computers) by sharing them between students and promote exchanges of ideas between them. Most of the time, groups of students from the same curriculum are considered.

An interesting experience of courses mixing students from two schools with two different domains has been reported in Hoople et al. (2019): students from a School of Engineering and a School of Peace Studies, with the objective of designing a drone accounting for its social implications. Mixing different cultures and countries has also been identified as a good opportunity for the students to improve their motivation, develop intercultural competences and extend their networks. To this end, Collaborative Online International Learning initiatives have been developed, with positive feedback (see e.g., Hackett et al. (2023)).

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This paper presents an innovative Collaborative Online International Learning (COIL) project designed and implemented by CentraleSupélec (France) and Rutgers University (USA), where students collaborated remotely on developing and implementing control algorithms for multi-agent systems. The main contribution is related to co-working activities between American and French students, with experimentations on real drones and mobile robots. Setting up these activities has been a great challenge for the pedagogic teams, having to adapt and coordinate the content of the two curricula, design a mutual pedagogic approach and a collaboration flow, as well as organize on-site and online synchronized work sessions, and mutual evaluations. The content and pedagogic approach of this COIL initiative are described in this paper, as well as feedback from the professors and the students involved in it.

The paper is organized as follows. The next section presents the content of the French and the American courses. The pedagogic approach and organizational aspects are detailed in Section 3. Section 4 proposes an example of one case study imagined and developed by the students during this COIL experience. The students assessment is presented in Section 5. Feedback from students and lessons learned by the pedagogic teams are finally provided in Section 6 before concluding remarks.

2. BRIEF DESCRIPTION OF THE FRENCH AND AMERICAN COURSES

The new curriculum of CentraleSupélec (implemented between 2018-2021) supported creativity and new pedagogical approaches in engineering courses in CentraleSupélec (see Jankovic et al. (2019)). In addition, the Covid'19 pandemic period (together with the post-Covid period) was an amazing source of innovation in teaching in all the domains, all around the world.

In this context, in April 2020, at CentraleSupélec a new elective course (see Stoica Maniu et al. (2019, 2020) for details) on multi-agent systems for the *second year students* (undergraduate level) was taught *online* in a Problem-Based Learning (PBL) format, including *remote experimentations* on the GeorgiaTech Robotarium (see Wilson et al. (2020)).

Inspired from this experience and with the support of the FACE Foundation, a *new COIL* has been proposed between CentraleSupélec and Rutgers on *advanced control* of multi-agent systems with *on-site* implementation on real drones and mobile vehicles (see timeline of the courses implemented in the respective universities in Fig. 1). In 2020-2021, this COIL mainly involved 32 third year students (graduate level) in CentraleSupélec and 12 undergraduate students from Rutgers.

At CentraleSupélec, the following courses were taught:

- Winter-Spring 2021 (Graduate students): “Control architectures of complex systems” Bertrand et al. (2021). The objective of this teaching module is to propose decentralized/ distributed/ hierarchical/ consensus-based control techniques together with the conditions to achieve the performance level of centralized control taught in other courses, while keeping

a reasonable computation load. This was the first occurrence of this course (in 2021). This module is part of the “Control Engineering” specialization of the last year students of CentraleSupélec (equivalent to Master level).

- Spring 2021 (Undergraduate students): “Dynamical Multi-Agent Systems. Application to drones formation control”. The topics covered in this course allow students to understand the basic concepts and challenges related to dynamic multi-agent systems via several experimentations on Unmanned Aerial Vehicles (UAVs) formations. The first occurrence of this course was during the Spring 2020, and it was developed under the auspices of the MEECOD (“Moderniser l’Enseignement par l’Expérimentation sur la Coordination de Drones”), with the support of Univ. Paris-Saclay on “Initiatives Pédagogiques – Oser!” 2018.

At Rutgers the following courses were taught:

- Spring 2021: “Special topic: Drones II: control and coordination”. It is an extension to the course “Drones fundamentals” introduced by another professor. This course was made possible thanks to the DARETeach project and most of its content was designed in close collaboration with CentraleSupélec. Rutgers is the only university offering an aerospace degree in New Jersey and this new course is a terrific extension to the existing portfolio.
- Fall 2021: “Autonomous vehicle dynamics and control”. Previously the course “Vehicles dynamics” was taught and focused on traditional car kinematics and dynamics textbooks. The project DARETeach enabled to revisit its content and to propose some exciting projects to the students about autonomous vehicles / self-driving cars.

The scientific content of the courses was ready before starting this project. However, both in France and USA, the learning outcomes, scientific content and scientific level were adapted to allow a common basis for the French and American students, despite the heterogeneity of their backgrounds.

3. SETTING UP A NEW JOINT FRENCH-AMERICAN ONLINE COURSE

The preparation of these courses had to address both pedagogical approach and organizational/administrative tasks, e.g., common agenda i.e., organizing common sessions at CentraleSupélec and Rutgers.

3.1 Pedagogical innovation

In the context of the Covid'19 pandemic, all the courses were taught online. Appropriate pedagogical approaches for online teaching were used, allowing interactions between professors and students (e.g., interactive questions using Wooclap) and in-between students via Problem-based Learning methods (e.g., using Microsoft Teams, using the interactive wall MIRO, etc.). To increase the motivation of the students, each group of French students¹

¹ There were 8 groups of 4 French students.

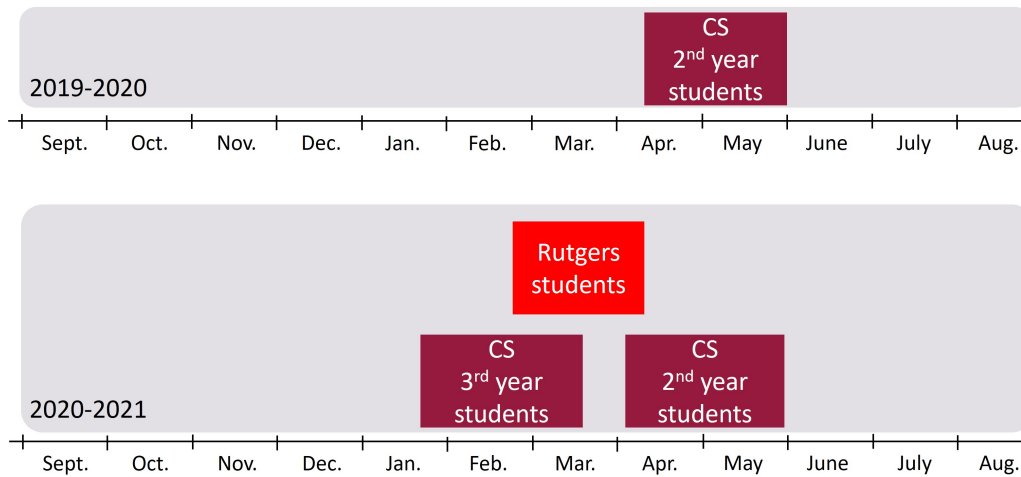


Fig. 1. Timeline during the scolar year in CentraleSupélec (denoted by CS) and Rutgers

proposed a case study on multi-agent systems inspired by their own interest, and then solve it. The assessment of the course consisted in evaluating the case study (poster presentation, report, code deliverables). Each case study received double evaluation: from the professors committee (involving the French and American participants) and a peer review evaluation (involving the French and American students). The main pedagogical innovation consists in the 3-step relay structure of the case studies:

- (1) theoretical case studies involving drones' formations and Matlab simulations proposed by the French students;
- (2) common working activities between French and American students;
- (3) completing the case-studies by the American students with experiments on real drones.

Due to numerous curriculum constraints, it was impossible to have all the course slots simultaneously for the American and French students. In addition, the French course finished before the end of the American course (see Fig. 1).

3.2 Organizational/administrative tasks

Organizing common sessions for the students in Centrale-Supélec and Rutgers to allow fruitful exchanges was the main objective of this COIL. However, the courses were already scheduled for both universities and it was complicated to have more common slots for synchronous co-working.

Asynchronous activities were also proposed by the teaching team for the Problem-based Learning setup. An example of an international exchange session between Rutgers and CentraleSupélec, together with the progress of one common co-work session on March 12, 2021, is provided below:

- (1) Microsoft Teams general channel: Brief introduction and flash presentation of each case study by the French students.
- (2) Microsoft Teams dedicated channel for each case study: Working in small groups. Each US student has chosen one case study proposed by the French students.

- (3) Microsoft Teams dedicated channel for each case study: After 30min visit of one group, US students may visit another case study channel, or they can continue within the same channel.
- (4) Microsoft Teams general channel: Concluding remarks and feedback.

An example of one common activity using MIRO is provided in Fig. 2. The following elements were highlighted for each case study: title, context, objective, theoretical approaches and possible extension to drone formations for the case studies involving only ground robots.

4. EXAMPLE OF A JOINT CASE STUDY

This section briefly describes one case study proposed by the French students and completed by the American students.

4.1 French students' project

Group 2 studied a multi-agent formation control with one leader and 4 followers. The leader tracks the desired trajectory using Model Predictive Control (MPC) and the followers are controlled by a consensus control law. This case study has potential applications in tasks like filming a moving object (the leader) from different angles using cameras mounted on the follower drones. Numerical simulations using the integrator dynamical model were conducted by the French students to verify the performance of the algorithms.

Therefore, on the French side, this project ended with 2D simulations in Matlab.

4.2 Continuation of the project at Rutgers

Subsequently, one group of American students extended the French case study. The extensions included:

- 3D control of multiple agents;
- use of Python;
- implementation of a collision avoidance algorithm (based on potential fields) on the followers;

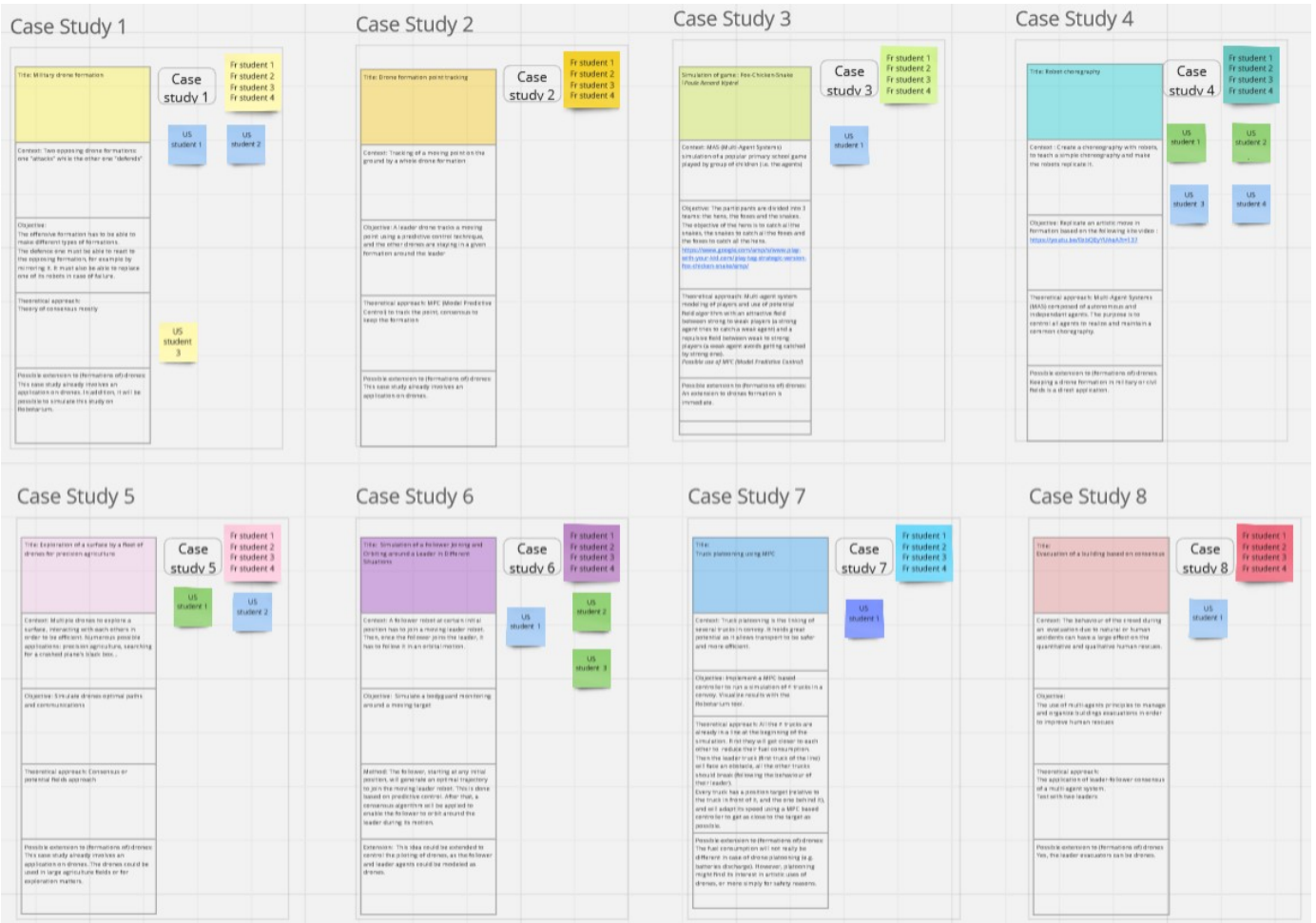


Fig. 2. MIRO wall developed by the French students.



Fig. 3. Crazyflie drone

- some real-life experiments using Crazyflie (Fig. 3) nano-drones (2 actual and 3 virtual drones) in one American student's apartment (N.B. the campus was closed at that time due to the Covid'19 pandemics).



Fig. 4. Two Crazyflies flying in the apartment of one American student

To fly the Crazyflies at home, two HTC Vive Lighthouse Base Stations (V1) were used as a motion capture system. The experiments were run within an indoor area with dimensions 2 meters x 2 meters x 1.5 meters. The control

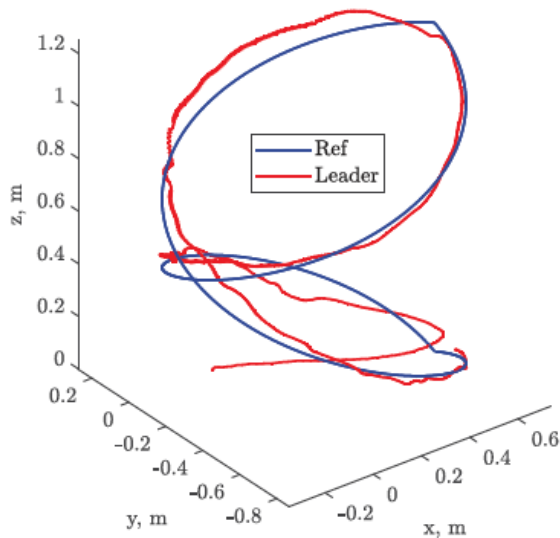


Fig. 5. Experimental results: leader and reference trajectories

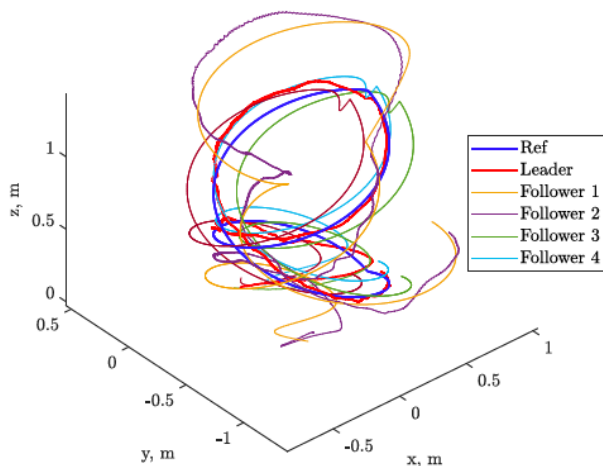


Fig. 6. Experimental results: leader, followers and reference trajectories

velocities were sent from a laptop to the actual drones using a PA USB radio dongle. Example of experimental results including the trajectories of the leader and the followers, together with the reference trajectory are plotted in Fig. 5 and Fig. 6. Notice that virtual agents were used for followers 2, 3 and 4.

5. STUDENTS' ASSESSMENT

An innovative assessment process has been conducted for the students' assessment.

Each group of students had first to prepare an interactive poster, by following a proposed template, in order to present a summary of their work in an interactive way. The posters included a presentation of the context and objectives of the case study chosen by the students, a description of the proposed scenario, problem formulation, results analysis, conclusions and perspectives. Video of experimental and/or simulations results were also included.

Oral presentations of the posters were organized on MS Teams. Each group had to present its own poster in a 5 minutes slot. After presentation by all the groups, a dedicated MS Teams canal was open for each group for questions and answers.

Peer evaluation was organized, each group of students being in charge to evaluate two other groups, from their oral presentation and answers to questions, together with the poster form and content. To this end, a survey with evaluation criteria was provided to the students.

The French students' projects were peer-reviewed both by the French and the American students. The French course finished earlier than the American course. During the defence of the American students, the French students started their internship (mainly in industry or research laboratories). Therefore, not all the French students participated to the peer review of the American students.

Each group was also evaluated in a same way by a joint committee of both US and French professors.

The final mark for each group of students resulted from a weighted average of the marks corresponding to the poster and the report assessments, taking into account the difficulty level of the proposed approaches and the quality of the simulation/experimentation results.

6. FEEDBACK ON THIS COLLABORATIVE ONLINE INTERNATIONAL LEARNING

6.1 Students' feedback

CentraleSupélec organized an evaluation of each course by the students. The 3rd year course on Control architectures of complex systems received excellent evaluations from the French students:

- Overall, I enjoyed the course: 100%.
- The objectives of the course were achieved: 100%.
- The organization of the course was clear: 100%.
- The coherence between the course, the pedagogical activities and the assessments: 100%.
- The pace of the course is: adequate 92%; too fast 8%.
- The scientific level of the course in relation to my initial level: ok 100%.
- The documentary resources (slides, videos, bibliography, etc.): agree 84%, no opinion 16%.

Rutgers organized an evaluation of the course taught.

- Overall quality of the course: 80%.
- The students recognized the teaching effectiveness of their professor: 80%.
- The students learnt a great deal in this course: 86%.
- The course workload was manageable: 74%.

6.2 Lessons learned

Both the American and French pedagogical teams involved in this COIL enjoyed this innovative international co-teaching activity. As this kind of pedagogical innovation is time demanding, it is recommend to apply for a grant supporting additional teaching charge and experimentation hardware. The obtained results were appreciated both

by Rutgers and CentraleSupélec. In addition, Rutgers University recognized the value of this COIL by rewarding their professor with the *Provost Award for Excellence in Teaching Innovations*.

7. CONCLUSION

This paper reports implementation details and lessons learned from a Collaborative Online International Learning project on advanced control of multi-agent systems with on-site implementation on drones, involving students from CentraleSupélec (France) and Rutgers University (USA). In a Project-Based Learning approach, a 3-step relay structure was implemented in 2021. First, the French students' teams proposed several theoretical case studies involving advanced control techniques for drones formations. Then, during the online co-working activities between French and American students, the initial case studies scenarii were adapted considering the American students' suggestions. Finally, the French students (those course was finished earlier) developed Matlab simulators for the proposed case studies and the American students completing the work of the French students with experiments on real drones.

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