Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 54-12 (2021) 68–73

Group Design Project in Control Engineering: Adapting to COVID-19 Pandemic

Dmitry I. Ignatyev*. Hyo-Sang Shin, Argyrios Zolotas, Antonios Tsourdos

School of Aerospace, Transport and Manufacturing, Cranfield University, Cranfield MK43 OAL, UK (e-mail: d.ignatyev@cranfield.ac.uk).

Abstract: Group Design Project (GDP) is a common education strategy in engineering. However, due to the COVID-19 pandemic, GDP cannot be fulfilled in a typical lab condition. The paper describes an example of delivering intensive hands-on, group project-based engineering course Autonomous Vehicle Dynamics and Control at Cranfield University. The project was designed to be implemented using modern simulation tools. As a result, students have not only obtained a better understanding of the engineering areas but also learned the usage of essential engineering and IT tools. The students obtained skillsets useful in modern engineering applications, where a simulation environment could improve the quality of the system before deployment and reduce a development cost.

Keywords: Group Design Project, COVID-19, Unmanned Aerial Systems, Swarm of Drones

1. INTRODUCTION

Group work is proven to be a very efficient strategy to motivate students, enhance their learning and develop their skills, including soft skills (Ayres, 2014). It is built upon the constructivism model of learning, where students construct their own knowledge and comprehension through active learning, namely, obtaining experience built upon their existing knowledge. The main advantage of such type of learning is that students take responsibility for their own learning. By undertaking a variety of learning activities in a group work (e.g. problem solving, experimentation, discussion, learning from others), students develop their higher-order thinking skills, such as analysis, synthesis and evaluation.

Traditionally, group projects in Aerospace and Aerospace Control Engineering are hands-on oriented (Castaldi & Mimmo, 2019; Giurato et al., 2020; Hong et al., 2019; Kim et al., 2014). Furthermore, group work requires a forum, which facilitates communication and a collaborative environment.

However, the COVID-19 pandemic has challenged engineering education (Daniel, 2020), especially in highly interactive, hands-on and group design classes (Liu et al., 2021). The new environment required novel methods of implementing Group Design Project. The main goal of the current paper is to demonstrate that group design project in Control education and Aerospace Control Education, in particular, can be successfully conducted online or in hybrid mode. This is demonstrated with Master Course in Autonomous Vehicle Dynamics and Control held at Cranfield University (*https://www.cranfield.ac.uk/courses/taught/autonomous-vehicle-dynamics-and-control*, n.d.).

2. MSc in Autonomous Vehicle Dynamics and Control (AVDC)

The MSc in AVDC includes eight taught compulsory modules, which are generally delivered from October to March. The course begins with the fundamentals of autonomous vehicle dynamics and control, and progresses to the core subjects of guidance and navigation, sensor fusion, advanced control, decision making and AI for autonomous systems.

The intended learning outcomes (skills and knowledge) of AVDC are the following

- Distinguish the primary engineering challenges of Unmanned Aircraft Systems (UAS) analysis and design.
- Formulate, analyse and simulate dynamic models of an air vehicle.
- Analyse and design control systems for the autonomous operation of an air vehicle.
- Relate sensor fusion and Artificial Intelligence in the context of autonomously operating vehicles.
- Appraise and utilise fundamental guidance and navigation techniques for UAS.
- Examine and relate advanced control systems and their applications to UAS.
- Design, build and fly an unmanned aerial vehicle by working in a group environment.
- Exhibit independent learning by planning, conducting and critically evaluating an individual programme of extended research into some aspect of UAS.
- Communicate effectively, verbally or in writing, to suit a range of audiences.

10.1016/j.ifacol.2021.11.011

3. Group Design Project (GDP)

The GDP follows the taught modules and it facilitates the design, assembly and operation of autonomous vehicles, thus integrating and applying the knowledge students acquire in the taught modules. The GDP also aims to provide students with experience of working on a collaborative engineering project, within an industry structured team, developing transferable skills that include working in a team with members having diverse backgrounds and expertise, project management and technical presentations.

Before COVID-19, GDP was implemented in the form of multi-university competition (*https://www.cranfield.ac.uk/press/news-2019/bae-competition-challenges-students-to-counter-threat--from-uavs*, n.d.). The topic "The operation of UAV swarms" was dictated by an extraordinary interest to the collaborative platforms for both military and civil applications. Despite this potential, there are key challenges to be addressed to enable UAV swarm operations (Shin & Segui-Gasco, 2014). Unlike operations of a small number of aerial vehicles, the onboard decision-making responsibility may be more favorably distributed across the UAV swarm taking into account their scalability and sustainability. This project addressed the main issues of UAV technologies enabling onboard decision-making: Situation Awareness (SA), Task Allocation (TA), Communication network connectivity, and Guidance, Navigation and Control (GNC) in UAV swarm operations.

The teams of students were challenged to develop the most effective solution to take control of unauthorized UAVs in a restricted area, known as a 'swarm attack'.

The scenarios were developed based on the real and emerging threats that exist to protect urban spaces, airfields and airports from such incidents. Increasingly capable, UAVs are becoming more affordable, so there is a need to counter these systems in a robust and affordable manner using innovative solutions. Attacks could cause damages to aircraft and infrastructures so the scenarios created the perfect challenge for students.

The students used a combination of technologies including artificial intelligence (AI) and automation, together with innovative thinking and close co-operation between UAVs.

On successful completion of this module a student should be able to (Intended Learning Outcomes (ILOs)):

1. Demonstrate originality in the application of knowledge and skills.
2. Collaborate as a member of a team to solve a defined problem.
3. Self-direction in practical problem solving.
4. Plan, manage and execute work effectively in a team environment.
5. Communicate and present both orally and in writing in a team environment

4. GDP in COVID-19 Pandemic

Due to restrictions introduced by the University as a result of the COVID-19 pandemic, the format of real lab work during the GDP was not available. As a response to that situation, the GDP was transformed into distance and hybrid delivery modes. The introduction of the project was done during Face-to-face mode in November 2020 (see Fig. 1). Restrictions were imposed during most of the project duration. However, a hybrid mode, when part of the students and a teaching team participated remotely and part of the students and a teaching team participated in person, became available at the end of the GDP. It should be noted that, as the project matured, more intensive communication and collaboration between different subgroups and supervisors were required. Fortunately, for this stage, usage of the hybrid mode facilitated project progress.

The student cohort was quite diverse, namely, the students had a background in aerospace, mechanical, electrical engineering and computer science. The students were divided into two groups based on their background to produce a balanced distribution of knowledge and skills across the groups. Each group had the same target, namely, create a novel and innovative swarm solution either to demonstrate its values in persistent monitoring scenario or to counter threats imposed by a swarm of UAVs. By completing the task students built upon the knowledge and skillset of the sub-team. Group project considered a significant element of choice in the topic/task and the activities to be undertaken. Each group is supposed to select its own scenario, goals, system requirements etc.

Each group supervisors and mentors were assigned. Formative feedback was provided to students by mentors and professors during Group discussions and System Requirement Review. In addition, students got formative and summative feedback from the combined teaching team at the design review meetings, namely, at PDR – preliminary design review, CDR – Critical Design Review, and TRR – Technology Readiness Review. In the end, students delivered the final presentations and prepared reports and obtained formative and summative feedback.

Due to the COVID-19 situation, the nature of the project is adapted to a simulation environment. Students were able to develop simulation scenarios where a UAV swarm counters the UAV swarm threat and defends the critical area. For a realistic result, integration of Gazebo, ROS, and Ardupilot was proposed.

Students of each group were allowed to use their own preferences to self-organize within the team. However, to facilitate the project shaping we proposed the following subdivision of each group corresponding to the tasks: Interface and integration sub-team, Modelling and "Guidance, Navigation and Control" sub-team, Mission and task control sub-team, Situation Awareness sub-team. The example of interactions between different subsystems is provided in Fig. 2.

Breaking up the students into different groups supported motivation for students, by allowing them the opportunity to focus on an area of particular interest.

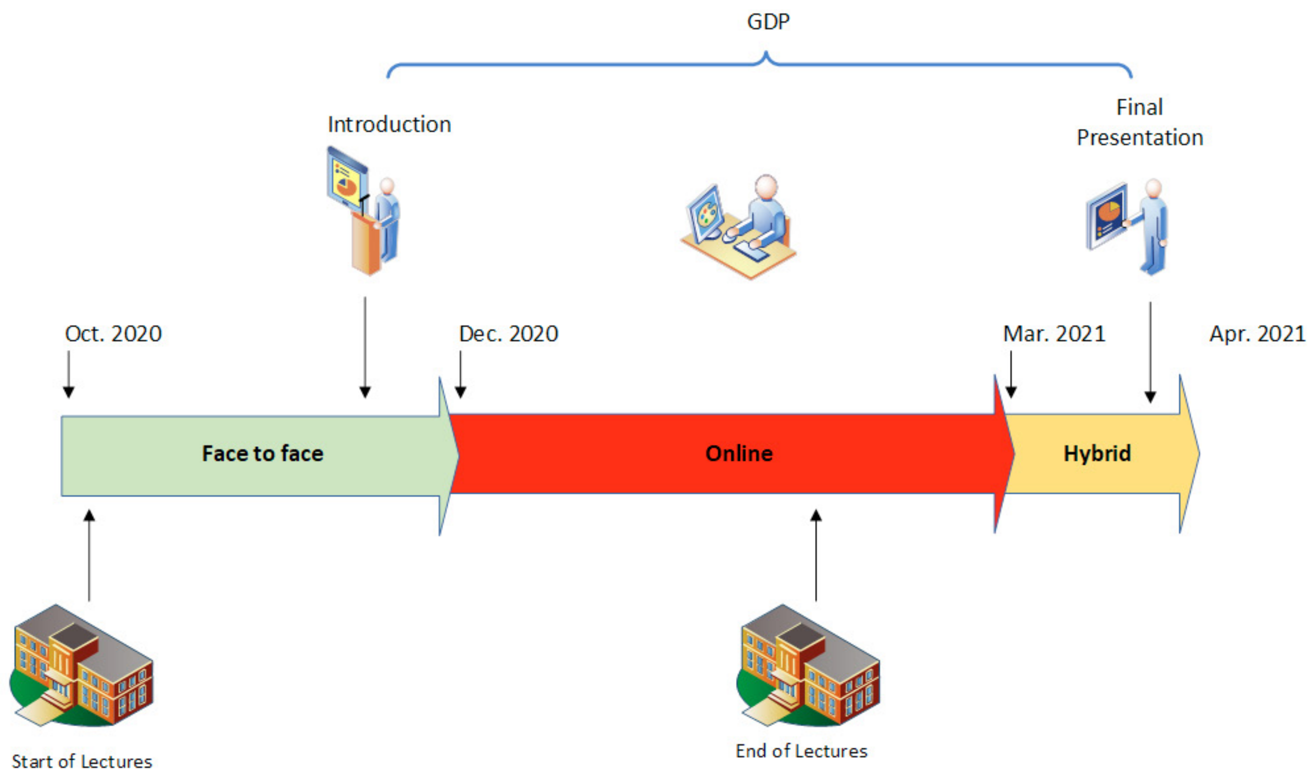

Figure 1. The course timeline

As a result of the project, students built up their technical skills in the following areas, corresponding to the mentioned tasks. They developed and implemented systems capable to detect, track, localize enemy UAVs, allocate tasks to different defending/attacking drones, perform proper guidance and navigation of the drones and implementation of the task allocation and automatic decision making in the challenging dynamic environment.

Students of the first team aimed to design, develop and simulate a swarm of UAVs, counteracting a swarm of UAVs and defending the critical area. The system operated in the cylindrical space with a perimeter of 500 m and a height of 120 m in a rural environment. The goal of the attacking swarm was to enter the defended area for more than a specific period, whereas the defending swarm should avoid it by effectively neutralizing enemy drones.

A hybrid architecture between centralized and decentralized has been developed with a task allocation algorithm based on Extended Gale-Shapley algorithm, which combines a near optimal solution with a quick computation. Situational awareness network is designed as centralized architecture which is able to provide global track information to the drone team. The localization is based on computer vision based technologies, i.e. YOLO and DeepSort. Moreover, DBSCAN, GCI and GNN are adopted to cluster and fuse the local tracks and formulate global tracks. The GNC subsystem is based on a 3D potential field guidance algorithm integrated with the EKF sensor fusion for navigation purposes and the Ardupilot software for control. Communication between the different instances involved (drone, ground station, sub teams, software) is done using MAVlink and MAVROS protocols. Software-in-the-Loop Testing were performed in Gazebo simulation environment.

The second team selected another scenario, where the goal of the mission was to design a swarm of UAVs in a simulated environment that would be able to counter threats imposed by another swarm, defend its zone, as well as to attack the enemy's zone. This scenario might be considered as a variant of drone team game (see Fig.3).

The second team developed centralized task allocation algorithm that utilizes modified Kuhn–Munkres algorithm with backtracking. GNC used weight-based, real-time algorithm for obstacle avoidance. Situation awareness and Integration teams used the approaches similar to the ones proposed by first group.

5. Lessons learned

5.1 Student feedback

According to the student feedback, during the project, students have not only obtained a better understanding of the engineering areas and algorithms but also learned the usage of essential engineering and IT tools, such as ROS, Gazebo and Linux Operating System. They gathered skills of creating a simulation environment using different software and models

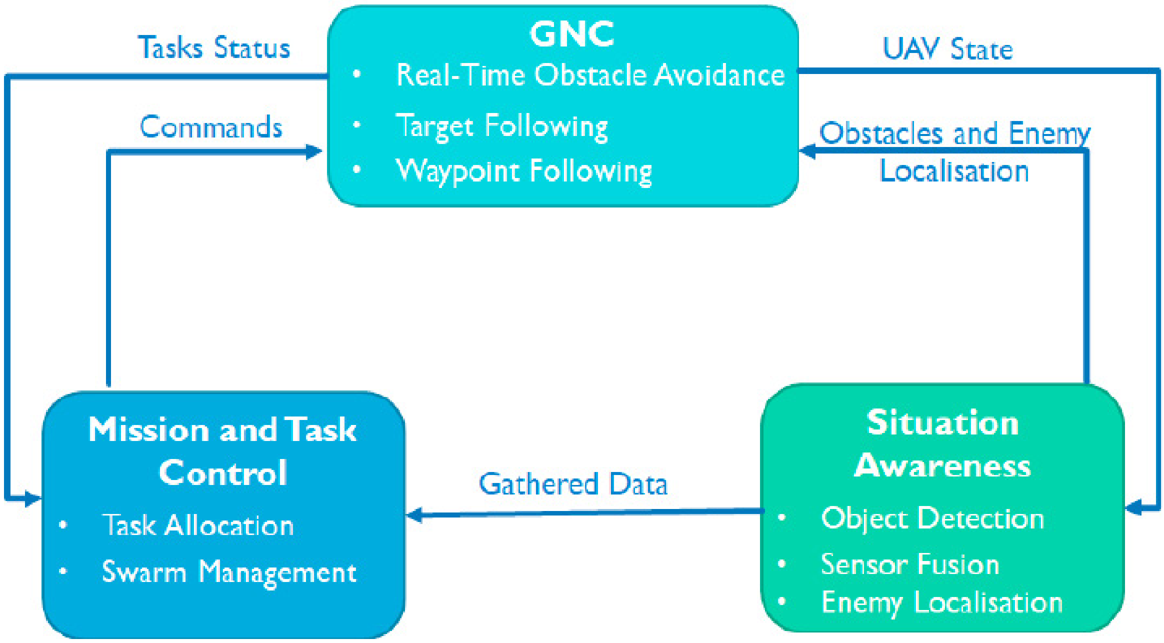

Figure 2. Interaction between different subsystems

corresponding to the pre-defined problem.

A conducted student experience survey manifested that before GDP most of the students did not have experience in using both Gazebo and ROS – only 7% of the students were somehow familiar with these software, and most of them were either uncomfortable or extremely uncomfortable with using these tools. However, 57 % of the students responded that they were comfortable to work with Gazebo and 43 % - with ROS as a result of the GDP. It is also worthwhile to mention that confidence in using Gazebo and ROS increased the confidence in using these tools in their future career thus increasing the technical skill box. Namely, before GDP 93% and 71% of the cohort did not expect to use Gazebo and ROS in their future careers, however, after the GDP, 43 % and 71% correspondingly expected to use these tools.

The simulation environment was of high fidelity since it included the dynamics of the drones, environment, different sensors and communication. We believe that these skillsets are useful in modern engineering applications, where a simulation environment like Gazebo could improve the quality of the system before deployment and reduce development cost. Furthermore, while dealing with dangerous robots, the usage of simulations tools such as Gazebo is usually preferred. In this way, untaught users can perform safe simulations instead of running experiments.

Beyond that, valuable project experience has been acquired by the students from the perspective of system engineering.

The students appreciated well-designed system architecture and understood that it was critical to the success of project development.

It is well established that the most efficient learning is achieved when students are challenged enough (Fry et al., 2015). According to the conducted survey, 71% of the students found the GDP challenging.

According to this survey 57% of cohort responded that they had improved they knowledge and skills during GDP.

5.2 Challenges

Implementation challenged teaching GDP project. We would like to stress the following main challenges we faced.

1. Students can work with different paces since progress of learning from home depends not only on access to technology and Wi-Fi, but on physical space, family support, and emotional bandwidth for learning. According to our survey, 50% of the students experienced difficulties in finding a quiet study environment and 21% experienced internet connectivity problems. Similar issues were identified in other studies (*https://www.gensler.com/blog/how-education-can-build-an-optimistic-equitable-future*, n.d.; Means & Neisler, 2020).

2. Despite the prevalence of social media among students and availability of online communication tools (Zoom, MS Teams, etc.), we find out a disconnection between different group of people. According to the survey, 64% of the students highlighted a lack of opportunities to meet and network with team mates. To stimulate discussion was one of the challenges in such conditions.

3. The pandemic actually elevates the importance of human interaction, further underscoring place and community as a core value proposition (*https://www.gensler.com/blog/how-education-can-build-an-optimistic-equitable-future*, n.d.). 86% of the students responded that the face-to-face meetings were helpful to increase a level of communication

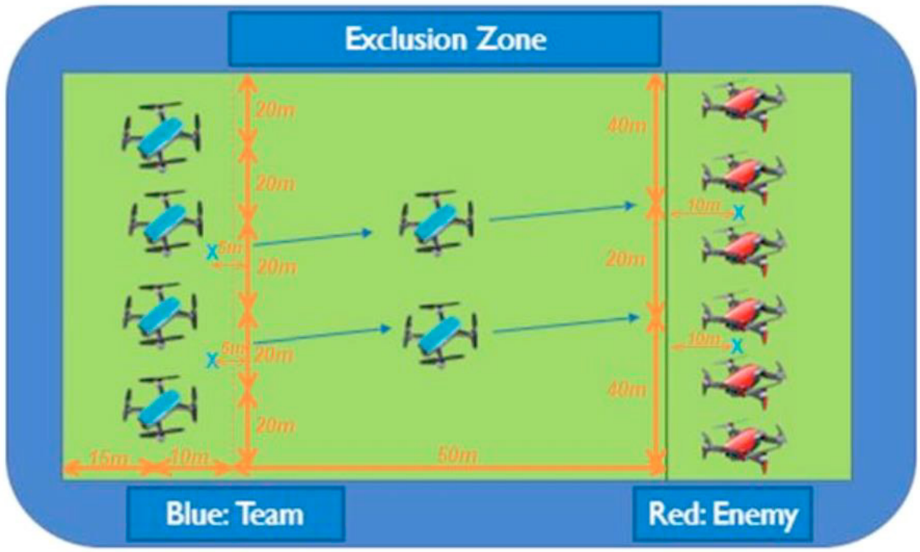

Figure 3. Drone swarm scenario

within a subgroup; 76% of them responded that the face-to-face meetings were helpful to increase a level of communication within the whole team and 65% responded that the face-to-face meetings were helpful to increase a level of communication with the supervisory team.

4. Availability of powerful computing resources. Since the GDP was fully simulation, it was required to provide access to high-performance computing capabilities.

As the response to these challenges, we find that having regular face-to-face or blended meetings facilitating the communication between students within the group and also between sub-teams. It was proposed that a hybrid faculty support programme might be quite efficient (Brooks, 2010). Due to COVID-19 restrictions, it was not possible to held real lab work, however, regular face-to-face meeting of students with mentors and supervisors while keeping safety measures significantly improved the progress of the project. During the meetings, supervisors stimulated discussions between students improving bonds both within the sub-teams and between them. From our own experience and also from the student feedback, we can conclude that even with significant progress of tools for online learning such as Zoom, MS Teams, the depth and strength of interactions between students are still lower the level corresponding to the face-to-face discussion.

The constructivist learning philosophy formulates knowledge as generated through interaction with others, through engagement with one's environment, and as existing in a constant state of renewal. In other words, learning and knowledge generation are social processes that are negotiated through interaction (Vygotsky, 1962). Thus, the more efficiently interaction is implemented, the more efficiently learning is organized. That is why we believe that even for group projects that can be held remotely the possibility to have face-to-face or blended meetings facilitates learning.

6. CONCLUSIONS

We consider the implementation of the GDP successful because all ILOs were achieved. Furthermore, even under the pressure of remote learning and lack of time students produced relevant engineering solutions and learned new software and IT skills. Fully simulation GDP manifested the effectiveness of modern simulation tools for deployment of complex systems.

REFERENCES

Ayres, R. L. (2014). Lecturing, working with groups and providing individual support. In *S. Marshall, H. Fry, & S. Ketteridge (Eds.), A Handbook for Teaching and Learning in Higher Education: Enhancing academic practice* (4th ed.). Routledge. https://doi.org/10.4324/9781315763088

Brooks, C. F. (2010). Toward "hybridised" faculty development for the twenty-first century: Blending online communities of practice and face-to-face meetings in instructional and professional support programmes. *Innovations in Education and Teaching International*, *47*(3), 261–270. https://doi.org/10.1080/14703297.2010.498177

Castaldi, P., & Mimmo, N. (2019). An experience of project based learning in aerospace engineering. *IFAC-PapersOnLine*, *52*(12), 484–489. https://doi.org/10.1016/j.ifacol.2019.11.290

Daniel, S. J. (2020). Education and the COVID-19 pandemic. *Prospects*, *49*(1–2), 91–96. https://doi.org/10.1007/s11125-020-09464-3

Fry, H., Ketteridge, S., & Marshall, S. (Eds.). (2015). *A handbook for Teaching and Learning in Higher Education: Enhancing academic practice* (4th ed.).

Routledge.

Giurato, M., Invernizzi, D., Panza, S., & Lovera, M. (2020). The role of laboratory activities in aerospace control education: two case studies. *IFAC-PapersOnLine*, *53*(2), 17162–17167. https://doi.org/10.1016/j.ifacol.2020.12.1711

Hong, J. H., Shin, H. S., & Tsourdos, A. (2019). A design of a short course with COTS UAV system for higher education students. *IFAC-PapersOnLine*, *52*(12), 466–471. https://doi.org/10.1016/j.ifacol.2019.11.287

https://www.cranfield.ac.uk/courses/taught/autonomous-vehicle-dynamics-and-control. (n.d.). 19/06/2021.

https://www.cranfield.ac.uk/press/news-2019/bae-competition-challenges-students-to-counter-threat--from-uavs. (n.d.). 19/06/2021.

https://www.gensler.com/blog/how-education-can-build-an-optimistic-equitable-future. (n.d.). 19/06/2021.

Kim, S., Oh, H., Choi, J., & Tsourdos, A. (2014). Using Hands-on project with lego mindstorms in a graduate course. *International Journal of Engineering Education*, *30*(2), 458–470.

Liu, Y., Vijay, A., Tommasini, S. M., & Wiznia, D. (2021). Hands-on engineering courses in the COVID-19 pandemic : adapting medical device design for remote learning. *Physical and Engineering Sciences in Medicine*, *44*(1), 195–200. https://doi.org/10.1007/s13246-020-00967-z

Means, B., & Neisler, J. (2020). Unmasking Inequality: STEM Course Experience During the COVID-19 Pandemic. *Digital Promise Global*, *August*. https://digitalpromise.dspacedirect.org/handle/20.500.12265/102

Shin, H.-S., & Segui-Gasco, P. (2014). UAV Swarms: Decision-Making Paradigms. *Encyclopedia of Aerospace Engineering*, 1–13. https://doi.org/10.1002/9780470686652.eae273

Vygotsky, L. S. (1962). *Thought and language* (A. Kozulin (Ed.)). MIT Press.