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Work in Progress: Development of UAS Module in Laboratory Class for a Senior Engineering Core Course

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Work in Progress: Development of UAS Module in Laboratory Class for a Senior Engineering Core Course

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Abstract

Designing a senior-level course that involves problem-based learning, including project completion task, is laborious and challenging. A well-designed project motivates the students to be self-learners and prepares them for future industrial or academic endeavors. The COVID-19 pandemic brought many challenges when instructions were forced to move either online or to a remote teaching/learning environment. Due to this rapid transition, delivery modes in teaching and learning modalities faced disruption making course design more difficult. The senior level Flight Controls course AME - 4513 is designed with Unmanned Aerial Systems (UAS) related projects for the students to have a better understanding of UAS usage on various applications in support of Advanced Technological Education (ATE) program. The purpose of this paper is to present the UAS lab modules in a junior level robotics lab, AME - 4802, which preceded the Flight Controls course in the school of Aerospace and Mechanical Engineering at the University of Oklahoma.

Successfully completing the course project requires independent research and involves numerical simulations of UAS. The Robotics Lab course focuses on hands-on projects of robotic systems with an emphasis on semi-autonomous mobile robots, including an UAS introduction module.

- The UAS module in the Robotics Lab class is introduced in Spring 2020. Therefore, most of the students enrolled in the Spring 2020 Robotics Lab course have introductory knowledge about the UAS system when taking the Fall 2020 Flight Control course. In addition, Spring 2020 Robotics Lab was affected due to COVID-19.
- The UAS module was not introduced in 2019 Spring Robotics lab. Thus, the students enrolled in Fall 2019 Flight Controls course did not have prior knowledge on the UAS system.
- We thus present the implementation of UAS module in a junior level robotics lab which preceded the senior level Flight Controls course in following Fall semester, when the same instructor taught the course.

1. Introduction

According to industry demands, training a specialized workforce faces unique challenges, considering UAS as a smaller aircraft. One of the significant advantages of UAS is that they are unmanned, and hence are not regulated as conventional aircraft. The industry demands and the lack of tight regulations permit the UAS market to evolve promptly. In August 2016, the Federal Aviation Administration (FAA) issued the Small Unmanned Aircraft Rule (Part 107) concerning the use of UAS for research, educational, and commercial purposes. These regulations will mature over the years. Thus, it is beneficial to train the future workforce to be fully well informed of the current regulations on using UAS with the capabilities of complying with the future ones [1].

Globalization [2] has put engineering education [3], [4] and the profession at a challenging crossroad. We envision a UAS workforce engaged at a higher-level cognitive skill (Analyzing, Evaluating, and Creating in Bloom's Taxonomy [5]–[9]) working together to design, develop, operate and advance UAS industry. A UAS education program for technicians and engineers needs to provide the necessary technical background in multiple aspects. In addition to technical skills, next-generation technical professionals and engineers need to be adaptive enough to address changing demands and challenges [10]–[12]. Education systems for engineering education need to hold up instigation of technical aptitude that enable students to communicate effectively, work in teams, and operate in complex organizations, to new challenges or tasks [13].

Previous research efforts [14], [15] discuss analyses conducted to enhance student participation and performance in courses amidst all the changes and adjustments during the COVID-19 pandemic. We consider the impact of sudden interruption and transition to learning in Spring 2020 and at Fall 2020. Student data from Fall 2019, when the courses were offered in the usual face-to-face setting, is compared to the Fall 2020 semesters. This section provides a brief overview of Flight Controls and Robotics Lab taught during Fall 2019, Spring 2020 and Fall 2020.

Flight Controls class (AME-4513) course was designed with a project completion task on Fall 2019 and Fall 2020 for better hands-on understanding among the students for UAS uses on various applications. Group projects aim to deepen students' knowledge on specific topics not covered in class. Successfully completing the course project requires some independent research and performing numerical simulations. The class was divided into 4 groups (Group A, B, C, D) in alphabetical order. All groups utilized the MATLAB toolbox CAD-Based Simulator for Quadrotors, which is a Simulink toolbox that allows to compare and contrast the performance of two control architecture for quadrotors, namely, the proportional-integral-derivative (PID) and the model reference adaptive controls (MRAC). One of the learning objectives of Flight Control class is able to design the control laws needed to achieve assigned mission objectives.

The Robotics Lab class (AME-4802) was redesigned in Spring 2020 by introducing a UAS module. In contrast, Spring 2019 Robotics Lab students were not introduced to such a UAS module. Majority of the Robotics Lab students who enrolled later enrolled in Flight Controls during Fall 2020 had introductory knowledge about UAS systems, which could be applied to their UAS project. Students enrolled in Flight Controls in 2019 did not have previous UAS introduction. On the other hand, Spring 2020 Robotics Lab class has been negatively impacted by COVID-19 pandemic, as the delivery method of that class moved to online from face-to-face in the middle of the semester. The course heavily relies on hands-on and in-person activities. However, due to the pandemic, students had to attend the class remotely (online) for half of the semester. Thus, it was difficult for the students to understand all the concepts clearly. Also, the instructor needed time to manage the abrupt remote learning environment. Over time, as people adjusted to the situation, the negative impacts were reduced. Inclusion of the UAS module in the Robotics Lab on Spring 2020 assisted students to overcome the COVID-19 negative effects on

Flight Controls project during Fall 2020. We hypothesize that the basic knowledge of UAS system students received in the Robotics Lab is reflected in their Flight Controls project grades when compared to the class taught in 2019. Fall 2019 and Fall 2020 Flight Controls class was taught by the same instructor. The students enrolled in this course are primarily from the Aerospace and Mechanical Engineering.

This study aims to develop and understand the students' performance on the Flight Controls course project after they receive the introductory UAS module in Robotics Lab class from the same perspective. The implementation is made based on group project final reports during Fall semesters. Additionally, this paper considers the impact of COVID-19 on student learning for instructions that were primarily experiential during this pandemic.

2. UAS student project description – Flight Controls

After gaining fundamental knowledge in the control of linear dynamical systems, students are assigned group projects to better understand the applications of various control methods to deal with aircraft dynamical systems. Students were instructed to record all steps and contributions for each group member in the project.

Flight Controls (AME-4513) from Fall 2019 and 2020 respectively, follow the Robotics Lab (AME-4802) during Spring 2019 and 2020. Flight Controls has a class size with an average of 36 students. Most of the students enrolled in Robotics Lab in Spring semester usually enroll in the Flight Control class 4513 the following Fall semester. Few students enroll in the two courses in the reverse sequence. This study is interested to see the student's enrollment data with Flight Controls, which follows the Robotics Lab. The enrollment in Spring 2020 Robotics Lab class was 39 students, and in Fall 2020 Flight Controls class enrollment was 36, of which 20 students were from Robotics Lab (Spring 2020). The enrolment data shows that in Fall 2020 Flight Controls 55.55% students enrolled from Spring 2020 Robotics Lab. Therefore, most of the students enrolled in Spring 2020 Robotics Lab had introductory knowledge about the UAS system when they took Flight Control. Table 1 represents the Flight Controls Projects description during Fall 2019 and 2020.

Table 1 - Flight Controls Projects for AME 4513/AME 5513 (Fall 2019 and 2020)

Fall 2019	Fall 2020
Group A project Study the Ziegler–Nichols method (a heuristic method of tuning a PID controller) and tune the PID control in the Simulink toolbox through this method. Then pick the ’square’ reference path and apply the PID control law in the CAD-Based Simulator and compare it with the MRAC control used in the simulator.	**Group A project** Implement the LQR control law (refer to LQR document uploaded to Canvas) and replace MRAC control in the Simulink toolbox with your control law. Check if the quadrotor in the simulator can hover at a given position that is different from the initial position with your control.
Group B project Modify the ‘Reference Path’ in the Simulink toolbox so that the quadrotor can track a figure-8 trajectory (one example of figure-8 is $x = \cos(t)$, $y = \sin(2t)/2$, it can be changed (shift/enlarge/reduce) as seen fit) in the horizontal plane with the PID control. Tune the PID parameters if necessary.	**Group B project** Modify the ‘PID Controller’ block in the Simulink toolbox and implement PID control to φ and θ. Then tune the PID parameters and pick one reference trajectory to check if the quadrotor manages to track the trajectory with your control.
Group C project Implement the LQR control law taught in the class and replace MRAC control in the Simulink toolbox with your control law. Check if the quadrotor in the simulator can hover at a given position that is different from the initial position with your control.	**Group C project** Modify the ‘Reference Path’ block in the Simulink toolbox so that the quadrotor can track a figure-8 trajectory (one example of figure-8 is $x = \cos(t)$, $y = \sin(2t)/2$, it can be changed (shift/enlarge/reduce) as seen fit) in the horizontal plane with the PID control. Tune the PID parameters if necessary.
Group D project Implement the LQG control law (see Sec. 3.6 of reference book) and replace MRAC control in the Simulink toolbox with your control law. Then pick any reference trajectory and check if the quadrotor in the simulator manage to track the trajectory with your control.	**Group D project** Study the Ziegler–Nichols method (a heuristic method of tuning a PID controller) and tune the PID control in the Simulink toolbox through this method. Then pick the ’square’ reference path and apply the PID control law in the CAD-Based Simulator and compare it with the MRAC control used in the simulator.

Project grading and evaluation

To evaluate the implementation of UAS module in the project outcome of the Flight Controls courses 4513 in Fall 2019 and Fall 2020, when the course was taught by the same instructor, a common rubric is used. It was developed by correlating the project related challenges and grouping them under related topics as explained. One major challenge is Group/Individual project evaluations. Overall grading is difficult to do for group work such as projects. It is difficult to judge the individual students' contribution in a group. The reports were graded using a scale from 0-2 on multiple criteria, which included report organization, formatting, graphics, mechanics citations, calculations, introduction section, problem solution and individual contribution. Distribution of grades for Fall 2019 and Fall 2020 are shown in Tables 2 and 3. As shown in Figure 1, there is not much grade difference between 2019 and 2020 projects.

Table 2: Fall 2019 AME 4513 Flight Controls class project grades for all four groups

Group	**Organization**	**Formatting**	**Figures, tables, and**	**Graphics**	**Mechanics**	**Citations**	**Calculations**	**Introduction**	**Solution**	**Individual Contribution**	**Total points (out of 20)**	**Grade (100%)**
A	1	2	1	2	2	2	2	2	1	2	17	85
B	2	2	2	2	2	1	2	2	2	0	17	85
C	2	2	1	2	2	2	2	1	1	2	17	85
D	2	2	1	2	2	2	2	2	1	2	18	90

Table 3: Fall 2020 AME 4513 Flight Controls class project grades for all four groups

Group	**Organization**	**Formatting**	**Figures, tables, and**	**Graphics**	**Mechanics**	**Citations**	**Calculations**	**Introduction**	**Solution**	**Individual Contribution**	**Total points (out of 20)**	**Grade (100%)**
A	2	2	1	2	2	2	2	2	1	2	18	90
B	1	2	1	2	2	0	2	2	2	1	15	75
C	2	1	1	2	2	2	2	1	2	2	17	85
D	2	2	2	1	2	1	2	2	1	2	17	85

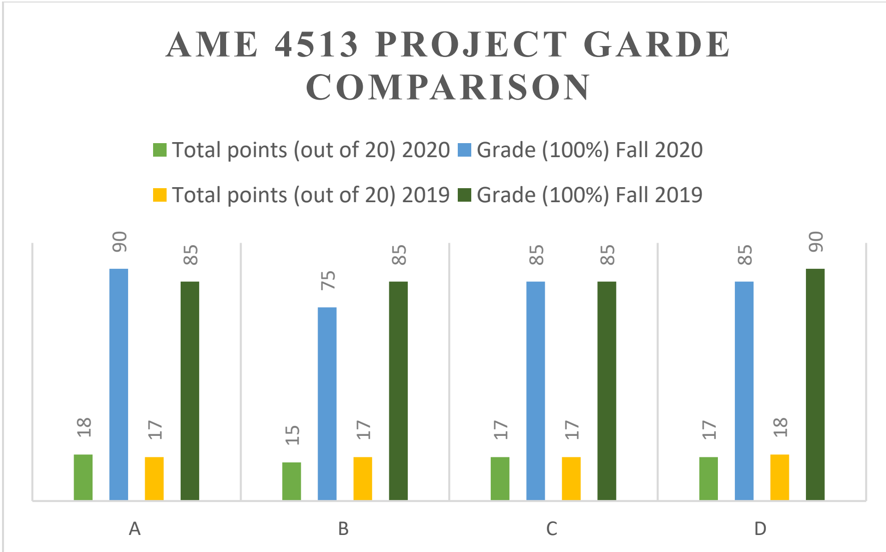

Figure 1: AME 4513 Project Garde Comparison between Fall 2019 and Fall 2020 semester UAS project.

3. Discussion

The inclusion of the UAS module in the Robotics lab positively impacted the UAS project results in the Flight Controls class. However, the COVID-19 had adverse effects on the students taking the Robotics course in Spring 2020, which negatively impacted the UAS project deliverables in the Fall 2020 Flight Controls class. We hypothesize that the combination of these two impacts led to the close performance in the Flight Controls projects between Fall 2019 and Fall 2020. In the future, we plan to extend the evaluation to additional years with the same methodology. A few recommendations to enhance teamwork for project-based learning are: (i) The project report may be submitted in multiple stages based on the progress; (ii) Team-mate evaluation could be implanted to ensure the involvement of the all-group members; (iii) Accountability could be achieved by dividing the work among the members and by providing necessary materials on project management.

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