122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #13485

Engaging Students in Multidisciplinary Projects in Unmanned Vehicles Technologies for Enhanced Learning Experience

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Abstract

This paper talks about innovative multidisciplinary projects on unmanned vehicles technologies at California State Polytechnic University at Pomona (Cal Poly Pomona) that are designed to increase students' interest, involvement, retention, and performance. Many aspects of unmanned systems are not or cannot usually be taught in classroom settings. Students and/or research projects are effective ways of exposing students to the state-of-the-art in unmanned vehicles technologies. Moreover, multidisciplinary projects provide students opportunities to learn real-world problems in a team environment. The projects include many aspects of unmanned vehicles technologies such as Sense & Avoid, Computer Vision, Path Planning, Autonomous Routing and Dynamic Rerouting, Geolocation Techniques, et cetera, and involve more than 90 students from Aerospace, Electrical & Computer, Mechanical, and Industrial Engineering, and Computer Science Departments. The projects have been found to effectively engage students in learning and help develop new understanding, knowledge, and skills. The students get ample opportunity to develop theoretical understanding, by means of hands-on learning, and apply the knowledge to designing, building, modeling, simulation, and experimental testing of real-world engineering problems. It has been found, based on industry feedback, that with the involvement in multidisciplinary and real-world projects, students demonstrate increased readiness for career in the industry. Students have also shown increased interest to graduate degrees.

The paper also describes the strategies to retain, recruit, and train lower level students for the multidisciplinary project, which is expected to continue for several years into the future with funding support from the Northrop Grumman Corporation. The project has succeeded in retaining the students from previous years with the retention rate being more than 90% among non-graduating students. The returning students usually assume leadership roles and help train the lower level students. The paper also talks about the outreach activities that include presentations at minority student clubs, community colleges, and high school for recruiting purposes as well as for motivating them to STEM fields. The student diversity has increased significantly compared to the first year of the project, which is currently in its fourth year.

I. Introduction

UAVs offer solutions to many high value military and civilian missions. Military applications of UAVs include intelligence, surveillance, and reconnaissance (ISR), battlefield damage assessment, and force protection. Civilian applications include remote sensing, scientific research, search and rescue missions, border patrol, surveillance of disaster-affected areas, aerial photography, aerial mapping for geotechnical survey, vegetation growth analysis, crop dusting, precision agriculture, and assessment of topographical changes, etc.

The UAV industry is the fastest growing sector of the aerospace industries and the use of UAVs has been growing significantly for civilian applications[1]. It is estimated that UAV spending will double over the next decade from current worldwide expenditures of $5.2 billion annually. Once the technology matures to integrate the UAVs into the National Airspace System (NAS), the domestic UAV market is expected to increase rapidly and that will not only create tens of thousands of jobs, but also save money for federal, state, and local governments and taxpayers by dramatically reducing the need for expensive manned airplane and helicopter for a number of missions.

UGVs also extend operators' capabilities in many applications, especially in dangerous and hazardous situations. They are easy to deploy, fast to respond, and have a closer and more detailed observation of the environment. Military and civilian applications include surveillance, ordnance disposal, localization, teleoperation, construction, target detection, target tracking, etc. Thus, ground and aerial robots help humans in accomplishing difficult and dangerous tasks[2].

Recently, the collaboration between UAVs and UGVs has received increased attention from industry and research community. The teaming between the two can tackle a task with increased robustness through redundancy and efficiency through task distribution[3]. The main problem is to efficiently distribute payloads and coordinate the actions so that each vehicle performs its task at appropriate time and location without much human intervention[4]. Due to the challenges in many missions, such as visibility constraints posed by high-rise buildings and unreliable GPS data in urban environments, UAV-guided navigation of ground robots is becoming increasingly important as the UAVs provide better view. A typical teaming scenario can be: UAVs detect a target of interest on the ground, the UAVs guides the UGVs to the area, the UGVs provide on-the-scene and close-up evaluation and assessment, and the team of UAVs and UGVs execute the appropriate level of response for various missions such as search and rescue, target identification and tracking, etc[5].

Though the role of unmanned vehicles in our national defense and economy is increasing, there is a lack of professionals entering the workforce for UAV-related jobs. Many students may not yet be aware of the existence of UAVs or their importance in our society. The ongoing projects at Cal Poly Pomona are designed to expose our students to the state-of-the-art in unmanned vehicles technologies in a multidisciplinary environment and better prepare them for future assignments in industry and academia. This is particularly important as the aerospace industry is facing an aging workforce, and there is a need to prepare well-trained engineers and scientists who can take higher level of responsibilities than entry level graduates usually do. Given the growing importance of UAVs in economy and defense, there is definitely a need to prepare a student body that can fulfill the future requirements.

The multidisciplinary project at Cal Poly Pomona involves collaboration between two UAVs and one UGV. The extracurricular project is designed to educate our students, by means of hands-on learning, on many topics in the areas of flight dynamics and control, artificial intelligence, computer vision, UAV autonomy, collision and obstacle avoidance, avionics systems, and other topics that are not taught in typical classroom settings. The project that is a replication of the real-world problems used in industry settings gives students an opportunity to design, analyze, build, integrate, and test, both in simulation and experimentally, a system of systems. The project also gives students first-hand research experience with faculty members and helps better prepare them in their writing, communication, collaboration, and time management skills. Lack of strong written and oral communications has been identified as deficiency in STEM education, resulting in poor success rate. The students from several departments in the Colleges of Engineering, Science, and Business are advised by four faculty advisors from Aerospace Engineering, Electrical & Computer Engineering, and Computer Science Departments. Research shows an extended participation in research results in an increase in the students' GPAs and their overall success[6].

The project is funded by Northrop Grumman Corporation on an annual basis. The funding support is used primarily for equipment, materials & supplies, and travel. The project also uses the extensive collection of UAVs and other resources already available in the Colleges of Engineering and Science at Cal Poly Pomona including a UGV Lab, Microcontroller Lab, Computer Programming Lab, Communications Lab, Machine Design Lab, CNC Machine Lab, Software Engineering Lab, and Intelligent Robotics Lab.

The rest of the paper is organized as follows. Section II talks about the project elements that the students are being involved in and that the students investigate, design, analyze, build, integrate, and test. Multidisciplinary environment is presented in Section III. Evaluation of learning outcomes is presented in Section IV. Section V presents the strategies for recruiting, outreach, and diversity. Lessons learned are presented in Section VI followed by the conclusion in the last section.

II. Project Elements

As discussed above, the project involves work on many areas that are important for collaboration between UAVs and UGVs. Through these projects, students get an opportunity to apply their knowledge to practical problems, design and conduct experiment, design a component, system, or system of systems, and identify and solve engineering problems. Some of the key areas that require multidisciplinary teaming are discussed in the following paragraphs. A sub-team of multidisciplinary students works on each of these topics. Work from each sub-team is integrated to form the whole system.

A. UAV Autonomous Navigation

For the autonomous navigation, the UAVs are either equipped with commercial off-the-shelf autopilots[7] or with the custom autopilots that are developed at Cal Poly Pomona[8]. The integration or development of autopilot requires expertise in Aerospace and Electrical & Computer Engineering and Computer Science disciplines. Figure 1 shows an autopilot in the simulation environment for testing the performance of the autopilot in the lab prior to flight testing[7]. Students from Aerospace Engineering, Electrical & Computer Engineering, and Computer Science Departments have been working on this element of the project

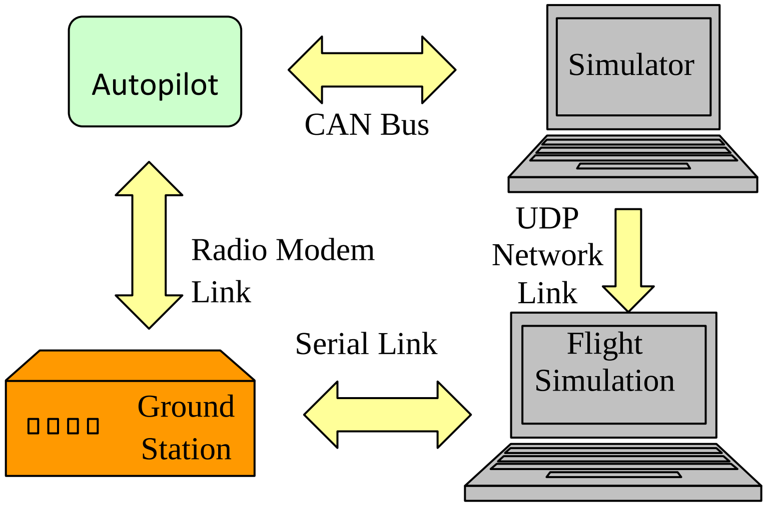

Figure 1: Simulation Block Diagram

B. UAV Collision and Obstacle Avoidance System

Since the project involves more than one UAV, they must be able to avoid collision with each other. The collision avoidance system must be able to detect obstacles or other aircraft well ahead of collision, perform collision avoidance maneuver, and plan an alternate path for the continuation of the mission. This requires an adequate sensor that rapidly detects obstacles. For obstacle detection, sensors such as ADS-B transponders, laser scanners, camera, and sonars are being used[9, 10, 11, 12]. The students have developed and implemented collision and obstacle avoidance algorithm on flight computer and have tested it in simulation.

Students from Aerospace Engineering, Electrical & Computer Engineering, and Computer Science Departments have been working on this element of the project. Figures 2 and 3 show the two airplanes being used for the project.

Figure 2: Sig Kadet Senior Airplane

Figure 3: 8′ Telemaster Airplane

Figure 2 shows the Sig Kadet Senior airplane in the flight range with a water bottle that serves as a rescue package.

C. Ground Vehicle Navigation, Path Planning, and Obstacle Avoidance

One of the major responsibilities of the UGV is to navigate to the target location. To do that, the UGV needs the capability to follow a series of waypoints, which can either be manually generated by a human operator or automatically generated by a path planner[13]. To avoid local obstacles, the UGV uses its laser range finder and sonars to identify the obstacles and keep itself a safe distance away from the obstacles[14].

Students from Mechanical Engineering, Computer Science, and Electrical & Computer Engineering departments are working on this element of the project. Figure 4 shows the UGV under development, and Figure 5 shows the electronics suite for the UGV.

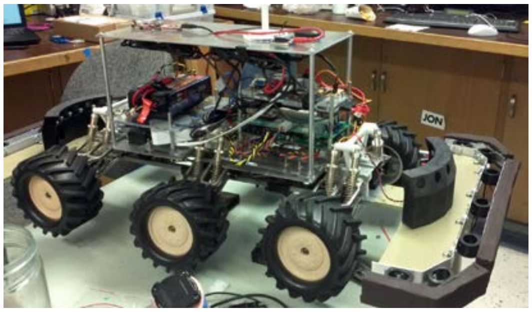

Figure 4: Unmanned Ground Vehicle

Figure 5: UGV Electronics Suite

D. Computer Vision for Target Identification

The computer vision systems onboard the UAVs and UGVs are used to identify the targets and determine their geographical location autonomously[15, 16]. The vision system is also used in developing collision and obstacle avoidance capabilities[12]. For target identification and tracking, OpenCV Computer Vision Library, an open source library for target identification and tracking is used[17]. OpenCV is also used for detecting obstacles using optical flow method[12]. Students from Aerospace Engineering, Electrical & Computer Engineering, and Computer Science Departments are working on the computer vision.

Potential targets are identified by a UAV and their locations are communicated to the UGV and Ground Control Station (GCS). Once the UGV navigates to the vicinity of the target location, it activates its own target identification process to confirm the target. The UGV is also in a search mode for the potential target.

E. Modeling and Simulation

This project entails the use of a computer aided design (CAD) model in conjunction with mathematically derived flight dynamics model to create a development and simulation environment for testing autonomous UAVs. Although no amount of software simulation can replace flight testing, this testing process can be greatly augmented through the use of various software tools. In addition to traditional Hardware-in-the-Loop (HIL) simulation, software-in-the-loop (SIL) testing of the algorithms is also performed[7]. SIL simulations greatly reduce both the time required for testing as well as reduce the development time by facilitating debugging and troubleshooting. Figure 6 shows a UAV in FlightGear simulation, which is used for both SIL and HIL simulations[8].

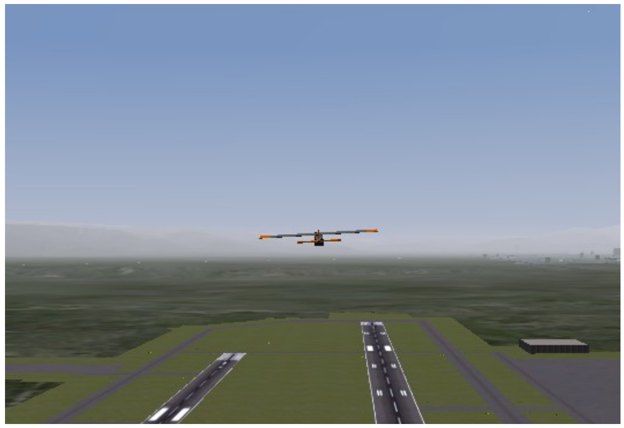

Figure 6: UAV in FlightGear Simulation

F. Command and Control of Multiple Unmanned Vehicles

When multiple vehicles are involved, operating each vehicle separately increases cost and number of operators required. The objectives for developing the custom Ground Control Station (GCS) is for the command and control of multiple vehicles. In addition, there is a goal to build a GCS that is low-cost, enables interoperability between vehicles without putting a heavy load on the operator, and provides the operator notification of possible hazards. The GCS displays operator specified and mission critical data from all the vehicles in the coordination[18]. Figure 7 shows the graphical user interface, which is displaying one UAV and one UGV. Works on this subtask requires the knowledge of Aerospace Engineering, Mechanical Engineering, and Electrical & Computer Engineering, and Computer Science disciplines.

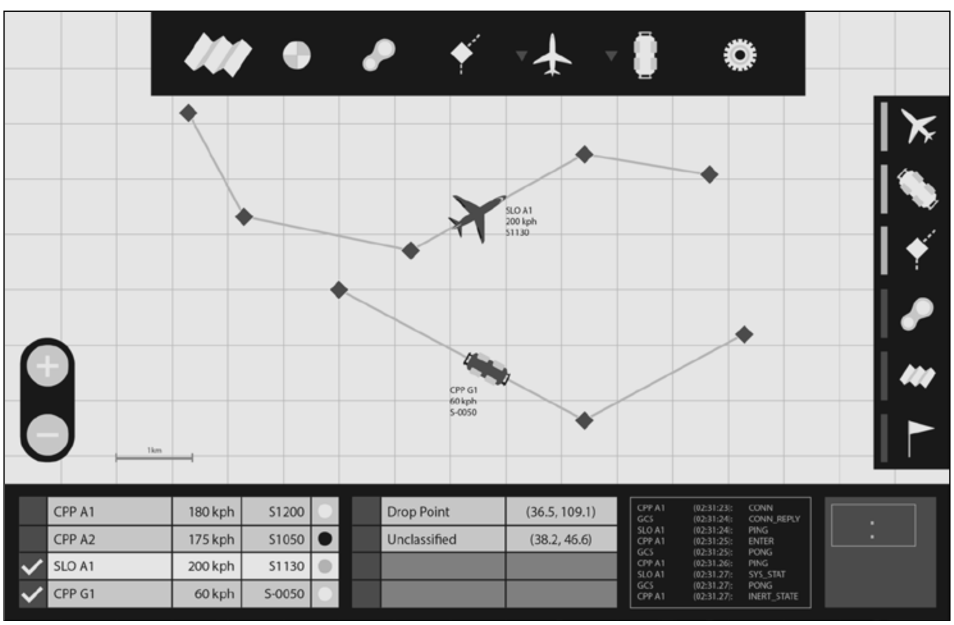

Figure 7: Graphical User Interface for UAV and UGV Display

G. Integration and Testing

At the end of each project year, all the elements of the project from the sub-teams are integrated, simulated, debugged, and made ready for the demonstration. Figure 8 shows the students preparing a UAV and the UGV for the project demonstration on the demo day. Some Executives and Engineers from the Northrop Grumman Corporation have been witnessing the yearly project demonstration.

Figure 8: Students Preparing the UAV and UGV for Demonstration

Figure 9 shows the overall concept of operation. As can be seen in the figure, all the vehicles in the team communicate with the GCS.

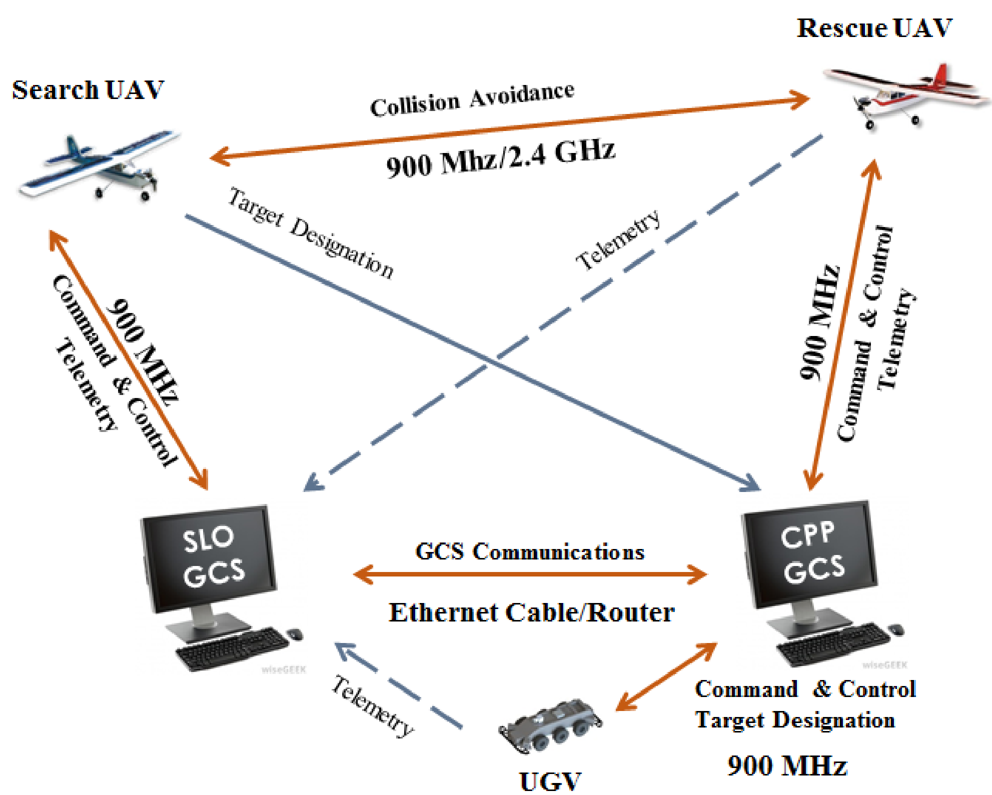

Figure 9: Concept of Operation

Figure 10 shows the water bottle dropped near the target (big red ball) by the UAV. The inaccuracy is attributed to the poor quality of the GPS used.

Figure 10: Dropped Water Bottle near the Target

In Figure 11, the UGV is seen navigating autonomously to the target location after the water bottle was dropped by the UAV.

Figure 11: UGV Navigating Autonomously to the Target Location

The students are trained on the safety of the vehicle operation. Prior to the demonstration, the students are required to perform a safety inspection, which includes performing a visual inspection as well as fail-safe check. The safety of the team, spectators, vehicles, and systems are also taken into account. To address these issues, the students use and strictly follow the preflight checklists and the flight test cards. Also, the autopilot ground station allows the creation of airspace boundaries that the airplanes will not leave during the demonstration, which has been taking place in an area that is away from residential and populated areas.

III. Multidisciplinary Environment

As previously mentioned, the goal of the project is to expose the students to the state-of-the-art technologies in unmanned vehicles technologies and enhance their learning experience through involvement in a multidisciplinary environment. The project is supervised by four faculty members from Aerospace Engineering, Electrical & Computer Engineering, and Computer Science Departments. The students also frequently get advice from the experts in the industry, mainly from Northrop Grumman Corporation, which has been providing funding support for the project for the past four years.

The project, in its fourth year, currently involves more than 90 students from Aerospace Engineering (ARO), Electrical Engineering (EE), Computer Engineering (CPE), Mechanical Engineering (ME), Engineering Technology (ET), Industrial Engineering (IE), Computer Science (CS), Business (BUS), Technology and Operations Management (TOM), Physics (PHY), and Computer Information System (CIS) departments. Figure 12 shows the percentage of students from each discipline for the fourth year of the project. In the first year, there were students from four disciplines. In the third year of the project, number of disciplines increased to six.

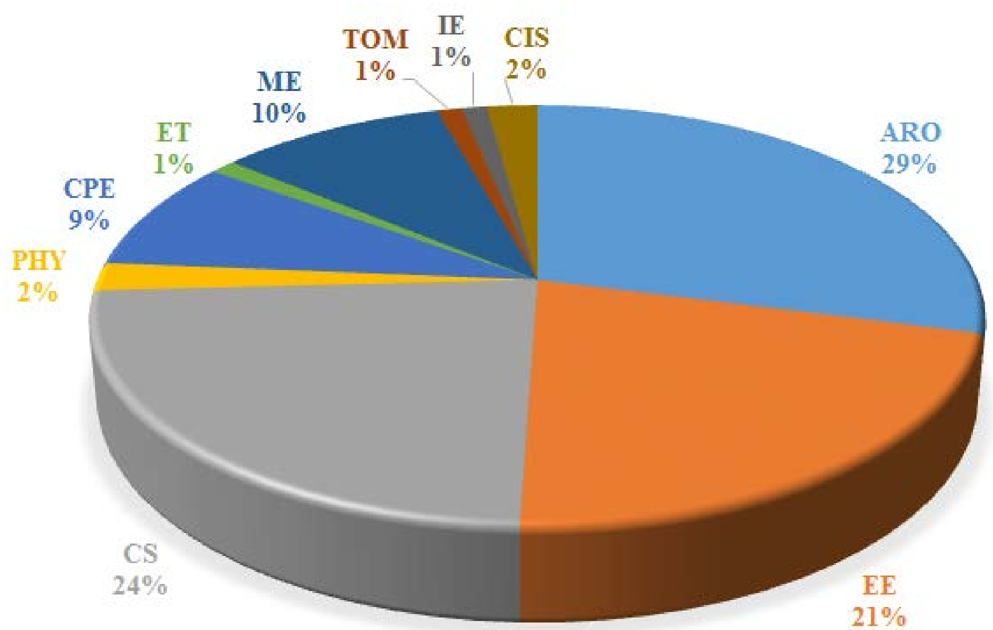

Figure 12: Percentage of Students by Discipline (2014-2015 AY)

IV. Assessment of Learning Outcomes

The project has been found to be very effective in enhancing student learning experience. Some of the key findings are presented in the following paragraphs.

A. Development of New Skills and Knowledge

The involvement of students in this multidisciplinary project has helped students learn, by means of hands-on learning, other disciplines that are not taught in classroom settings of individual disciplines. Students are exposed to the state-of-the-art in unmanned vehicles technologies and industrial trends. For example, students from Aerospace Engineering major have learned or have opportunity to learn computer programming, computer vision, electronics, avionics system, communication, etc. The students in the GCS group must be able to understand the problem of command and control of a group of unmanned vehicles and design the interface accordingly to satisfy the requirements. This is evidenced by the students from Aerospace Engineering and Computer Science majors being co-authors on the papers on GCS and Search and Rescue that were presented to AIAA's Infotech@Aerospace Conference[18, 19]. This is also evidenced by a number Aerospace Engineering majors getting employment for the industry careers that have traditionally required Computer Science or Electrical & Electronics Engineering graduates.

B. Increased Ability to Apply Knowledge to Real-World Problems

Involvement in the project has increased the students' ability to apply the knowledge and skills to the real-world engineering problems. The students have been successful in identifying, formulating, and solving engineering problems with an understanding of engineering and science fundamentals, and decide on appropriate methods of solution. The students have also been successful in designing a system, component, and system of systems, designing and conducting experiments, and collecting and interpreting the experimental data. This is evidenced by the successful demonstration at the end of each project year, which is also attended and witnessed by some Engineers, Executives, and support staff from Northrop Grumman Corporation[20].

C. Increased Ability to Function in Multidisciplinary Teams

Studies have found that, despite many advantages, students either prefer not to work in groups or prefer to work in groups that they are comfortable with. However, when they graduate and join the workforce, they no longer have that choice. They have to work with any group they are assigned to. Not only has this project taught the students to work in groups, but also in a multidisciplinary environment. Different majors work closely in subgroups that are formed according to the needs of the project. They get to learn from each other's specialty and apply their knowledge together to solve real-world problems.

D. Improved Written and Oral Communication Skills

The project has been helpful in improving the students' written and oral communication skills. One of the indicators is the number of presentations made by the students to the student and professional conferences. The number of students attending and presenting at both the student and professional conferences has consistently increased over the period of four years. Also increased is the number of students who are willing to present during the conferences. In the second year of the project, there was only one presentation by a student at a local conference. That number increased to four in the third year at student or local conferences and to eight so far at student conference and two national level conferences[18, 19].

Moreover, the students have been presenting their work to the Engineers, Technical Experts, Management, and Executives of Northrop Grumman Corporation during Midterm and Final Project Reviews, and other occasions. These presentations have proved to be very helpful in sharpening their presentation skills as the students get feedback and comments on their written and oral communication skills, technical expertise and skills, ability to work in a team environment, ability to understand multidisciplinary problems, understanding of ethical and professional responsibility, etc[20]. The students are also required to document their work and prepare a report at the end of each project year.

E. Increased Readiness for Industry Career

The students involved in this project have shown increased readiness for the industry career. Industry in general and aerospace industry in particular is looking for graduates who possess multidisciplinary knowledge and skills. Graduates with these skills have better chances of getting employed sooner than the students without these skills. The participants' career in industry or academia is an important indicator of the success of the project in terms of enhanced learning experience. Many students involved in the project have been successful in getting employed immediately after the graduation and/or have pursued their studies for graduate degrees. The industry feedback is also important indicator of the success of the program. According to industry feedback, the students who were part of the project are ready to work on the project without much training, and are able to take a higher level of responsibility than the entry level graduates usually do[20, 21]. Over 60% of the graduated students who were part of the project have been hired by the companies that are involved in unmanned vehicles technologies. Also, many non-graduating students have been selected for internship opportunities at these companies.

We have been using various methods to track the students after graduation such as E-mail, Facebook, and LinkedIn. These methods are also valuable in measuring their success in industry and academia.

F. Development of Lifelong Learning Skills

This project has taught and motivated students to become lifelong learners. Due to involvement in highly multidisciplinary and complex problems, students have developed positive attitude towards learning. The project has motivated the students to pursue their studies for graduate degrees, both at Master's and PhD levels. Some undergraduate and graduate students showed interest in and have been working on other ongoing research projects in unmanned vehicles technologies. Participation and presentation during the student and professional conferences has also helped the students in developing lifelong learning skills.

G. Increased Retention Rate

The project has been very successful in retaining the students. The retention rate has been increasing over the years. Figure 13 shows the percentage of new and returning students for the 2014-2015 academic year. In the previous year, the percentage of the returning students was 21%. The main motivation for students to return to the project is the opportunity to enhance their knowledge and skills, assume leadership roles, continue working on more advanced problems, increase the chances for job opportunities, etc. The returning students are also helpful in training, mentoring, and guiding incoming students.

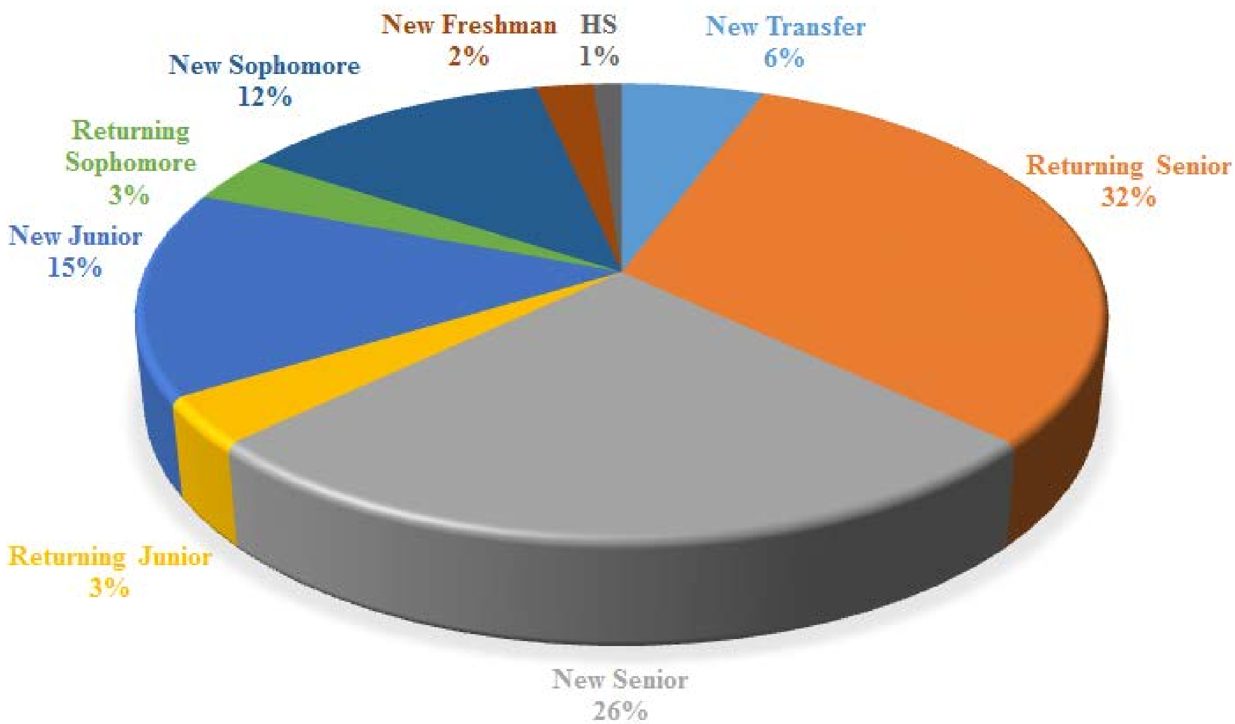

Figure 13: Incoming and Returning Students (2014-15 AY)

V. Outreach, Recruiting, and Diversity

Various recruiting strategies are adopted in order to make sure that there is a constant pipeline of students for the continuation of the project. This is important as the project is expected to continue for several years into the future with increased level of complexity. Students are recruited by faculty advisors primarily from their classes based on students' motivation, academic success, availability, willingness to work in a multidisciplinary environment, etc. The students involved in the project are a great source for recruiting new students through the word of mouth. The outreach activities are also helpful in recruiting the students. The total number of students has increased from 25 in the first year to 94 in the current year. In the second year, the number of students was 45 followed by 70 in the third year.

Every effort is made to increase the diversity of students involved in the project. One of the main goals of the project is to improve the participation of minority and underrepresented students including women, Hispanics, and first generation students. The outreach activities include presentations by the faculty advisors and student leadership team to the meetings of student clubs such as American Institute of Aeronautics and Astronautics (AIAA), Society of Women Engineers (SWE), National Society of Black Engineers (NSBE), Society of Hispanic in Science and Engineering (SHSE), etc. These avenues are helpful in recruiting students from underrepresented groups.

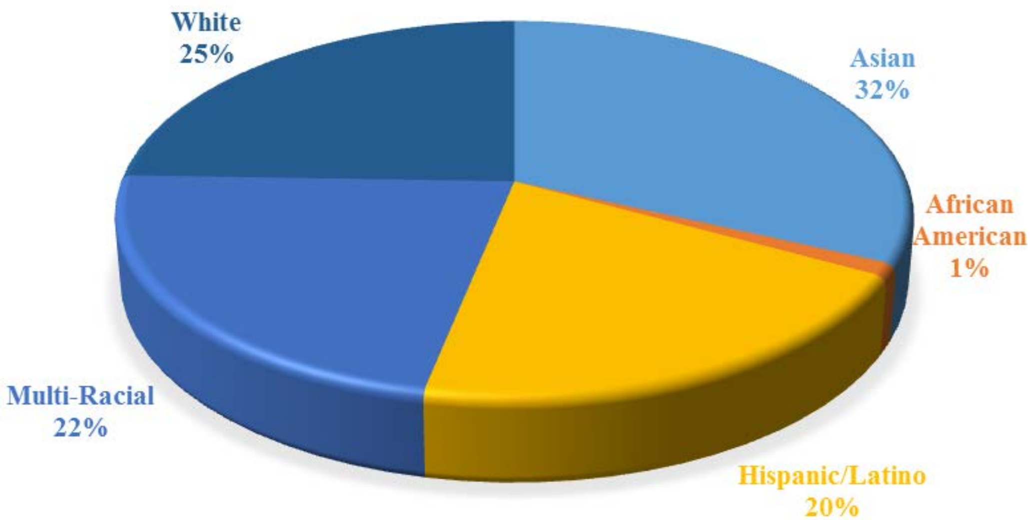

Figure 14: Percentage of Students by Ethnicity (2014-2015 AY)

Figure 14 shows the diversity of students by ethnicity in the current academic year. The student diversity has almost consistently increased after the first year of the project. In the first year, the percentage of Hispanic students, for example, was 9. That increased to 18% and 20% in the second year and the current year, respectively.

Currently, 27% of the students are female and 73% are male. In the 2011-12 academic year, percentage of female students was 6%. Participation of female students increased to 14% in the 2012-13 academic year and to 23% in the 2013-14 academic year.

VI. Lessons Learned

Since the project for each year begins in the fall quarter and culminates with a demonstration at the end of spring quarter, it is important to enforce planning and scheduling tools to avoid last minute integration and other errors. Since it's a large team of faculty and students from several departments, effective management of the team is another important aspect, and therefore, a well-defined organization structure is required. We have come up with an organizational structure that emulates the management structure exercised in the industry. Figure 15 shows the management structure, which shows the Project Manager for overall project management. The Project Manager works with the UAV and UGV Chief Engineers as well as with the team leads that include UAV Lead, Communication System (Comms Lead), GCS Lead, Project Management Office (PMO) Lead, etc. The management team is also highly interdisciplinary, and includes a student from Technology and Operations Management Department. The leadership team helps in delegation and distribution of the leadership responsibilities across sub-teams, and monitors budget issues (purchases, travel, equipment, supplies, etc.), schedule issues (milestones, deliverables, contingencies, etc.), and reporting. The focus is on how the interdisciplinary work by the students and sub-teams is integrated to meet the overall project goal.

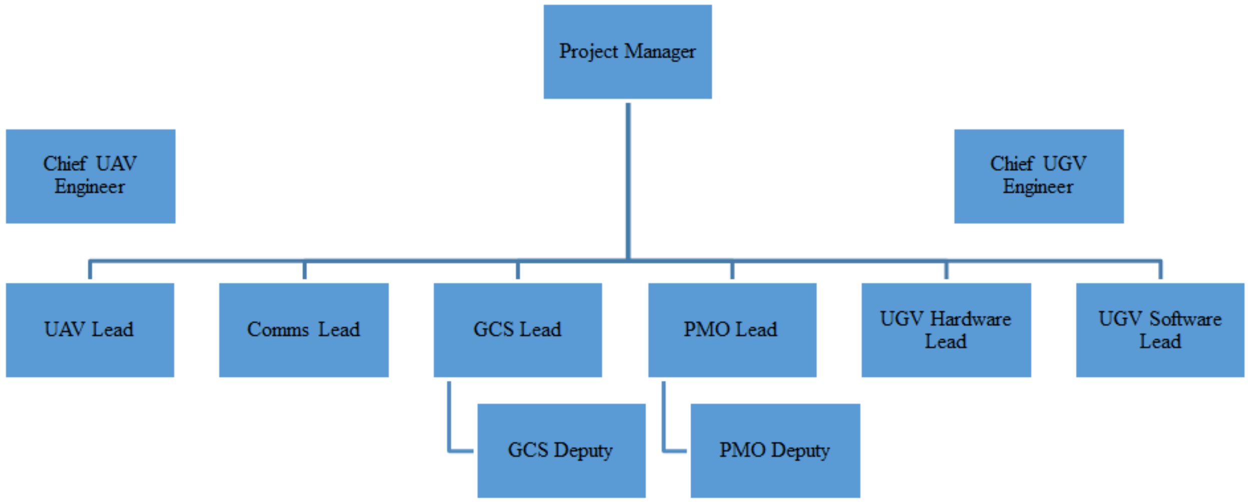

Figure 15: Team Management Structure

Another lesson we have learned is that prior to recruiting, students must be screened for their motivation, commitment towards the project, and required set of skills and knowledge. Though the goal of the project is to make it as much accessible as possible, screening is required for the success of the project.

Documentation of work done and progress made is another important aspect for this multidisciplinary and multi-year project. The students have been asked to prepare well-documented reports during and at the end of each project year. Also, since this project requires significant amount of software development, the software version control is another important aspect. We are coming up with effective ways for version control so that the students do not have to rewrite the software or use the version of the software that has already been updated. The methods used so far include Bitbucket revision control system[22].

VII. Conclusion

Many students are being involved in a multidisciplinary and multi-year project that emulates the real-world problem typically exercised in the industry settings. The students get opportunity to apply their knowledge to real-world problems, design, build, simulate, test system and system of systems, learn other disciplines, work in a team environment, and improve oral and written communication skills via presentation and technical writing. The enhanced learning experience has been found to better prepare them for assignments in the industry and academia, with the students involved in the project getting higher level of responsibilities at work than their peers. The project has been helpful for the students in developing new knowledge and skills, enhancing the ability to work in group settings, improving written and oral communication skills, and becoming lifelong learners. The project has also been helpful in retaining the students not only for the project, but also in the STEM disciplines.

Acknowledgement

We would like to thank Northrop Grumman Corporation for their continued funding support for the project. We would also like to thank Cal Poly San Luis Obispo for their partnership and collaboration on the project.

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