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Summer Research Program to Motivate Undergraduates for Careers in Unmanned Aerial Systems

Dr. Subodh Bhandari, California State Polytechnic University, Pomona

Dr. Subodh Bhandari is a professor in the Department of Aerospace Engineering at Cal Poly Pomona and the Director of its Unmanned Aerial Vehicles (UAV) Lab. He received his PhD from University of Kansas in 2007. His current research emphasis is on increased autonomy of unmanned aerial vehicles (UAVs), UAV-UGV collaboration, robust and intelligent control, collision and obstacle avoidance system for UAVs, and developing capabilities for widespread use of unmanned vehicles including precision agriculture and 3-D mapping. Dr. Bhandari leads a multi-disciplinary team of faculty and students from several departments within the Colleges of Engineering and Science at Cal Poly Pomona for research on unmanned systems. He has obtained several external grants for research on UAVs including from National Science Foundation, Northrop Grumman Corporation, AERO Institute/NASA Armstrong, and California's Agriculture Research Institute. He is a senior member of American Institute of Aeronautics and Astronautics (AIAA) and a member of American Helicopter Society (AHS), Association for Unmanned Vehicles International (AUVSI), and American Society of Engineering Education (ASEE).

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Abstract

The use of unmanned aerial systems (UASs) has been increasing rapidly for widespread applications including for precision agriculture, search and rescue, infrastructure monitoring, and powerline inspection. Because of their cheaper cost, UASs can also be used as the entry point for many advanced concepts in aerospace engineering. However, academia and industry have not seen proportionate increase in the number of students pursuing studies for advanced degrees or entering the workforce in the area of UAS technologies. This paper talks about the summer research program at Cal Poly Pomona that is designed to motivate students to advanced degrees and/or career path in UAS technologies. Students from Community Colleges and High Schools are also involved in the program. The students have been supported by funding from NSF, NASA, Department of Education, and industry.

The Program exposes the students to many aspects of research including literature review, designing and conducting flight test experiments, data collection, data processing, algorithm development, and implementation. The students get opportunities to learn other disciplines including Computer Science and Electrical & Electronics Engineering that are important for the successful research in UAS technologies. The students involved in the program have shown increased interest in advanced degrees in the area of UAS technologies including for PhD degrees. Many of the graduates have joined the companies involved in the unmanned aerial systems. More than 50% of the Community College Students who were involved in the Program transferred to Cal Poly Pomona and continued their interest in unmanned aerial systems.

I. Introduction

Unmanned aerial systems or unmanned aerial vehicles (UAVs) have been used or have potential to be used for many applications such as search and rescue missions, remote sensing, surveillance of disaster-hit areas, aerial photography, aerial mapping for geotechnical survey, crop dusting, precision agriculture, assessment of topographical changes, and power line inspection. UASs have also been used in conjunction with other unmanned vehicles such as unmanned ground vehicles (UGVs)[1] and unmanned underwater vehicles (UUVs). The UAV industry is the fastest growing sector of the aerospace industries and the use of UAVs has been growing significantly for civilian applications.[2]

Also, because of their cheaper costs, UASs can also be used as the entry point for many advanced concepts in aerospace and other engineering disciplines. For example, UASs can be used for testing many advanced control concepts such as neural network based adaptive controllers.[3]

Many universities and R&D organizations have been conducting research on UASs in many areas ranging from dynamics and control, obstacle and collision avoidance, multi-vehicle coordination, and precision agriculture. However, there has not been a proportionate increase in the number of students pursuing graduate or undergraduate level research in the area of unmanned aerial systems.

The Department of Aerospace Engineering at Cal Poly Pomona is currently engaged in several UAV research projects. Current research focus is on increasing the UAS autonomy. The ongoing research projects include development and validation of flight dynamics models of UAVs,[4] modeling and simulation,[5] development of obstacle and collision avoidance capabilities[6,7,8], vegetation growth analysis using UAVs,[9] and search and rescue using UAVs.[10] An excellent collection of UAVs and associated equipment at the university facilitates these projects. The UAV Lab at Cal Poly Pomona has more than 25 fixed- and rotary-wing UAVs of various sizes and payload capacities. Some of the UAVs are shown in Figure 1. Also available for the research projects are autopilots, inertial measurement units (IMUs), differential GPS, stabilized camera gimbal, multispectral and hyperspectral sensors, LIDAR, and infrared cameras.

Figure 1. Cal Poly Pomona UAV Fleet.

This paper presents the summer research program being offered at the UAS Lab at Cal Poly Pomona. The goal is to motivate them to research, graduate degrees, and industry career in UAS technologies. The summer research program started in 2009 with 3 students, and has grown in number of students and projects ever since. It the summer of 2016, the number of students participating in the program was 16. The program has been involving community college and high school students as well. The number of students is expected to increase in future. The author has recently received a funding from NSF for summer research program in UAV Technologies.

Figure 2 shows the number of students involved in the Summer Research Program at Cal Poly Pomona since 2009. As can be seen, the number of students has consistently increased over the years. Since 2012, we started involving community college students.

Most of the students selected for the Summer Research Program are sophomores and juniors. The students are required to have background in Engineering, Math, Physics, and/or Computer Programming. Preferences are given to the students who have completed Differential Equations and College-Level Physics. High-school students are involved just to give them exposure to the research environment and research topics.

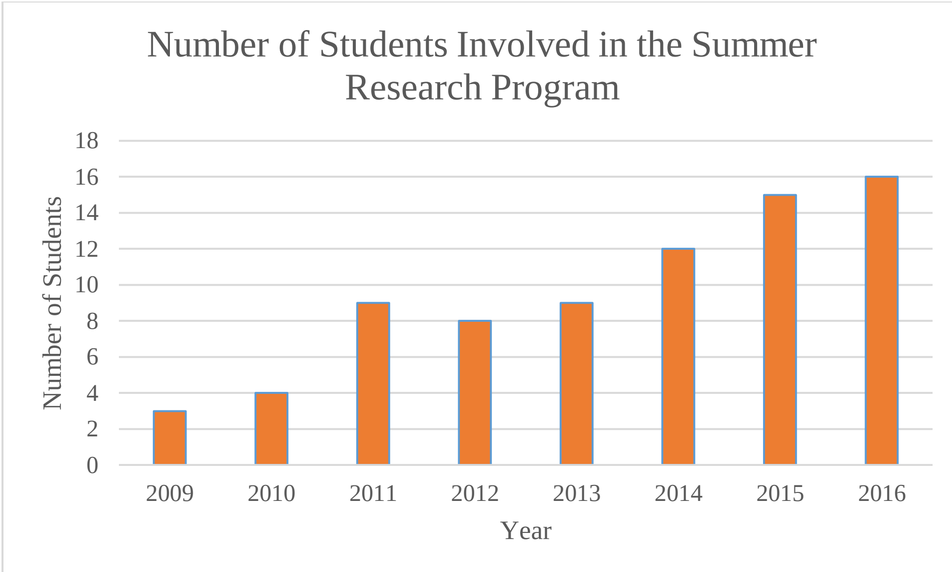


Figure 2. Number of Students Involved in Summer UAV Research Program

The rest of the paper is organized as follows. Section II presents some sample projects that students are involved in. Student activities during the period of the summer program is presented in Section III. Section IV talks about the support that the students receive for their involvement in the research program. Outcome of the research program and its impact on students is discussed in Section V followed by the conclusion in the last section.

II. Sample Projects

The projects for summer research program are designed to give undergraduates a comprehensive research experience including introduction to the research environment, research topics, literature survey, experiments, flight testing, validation, and presentation. Often times, a multidisciplinary team of students work on these projects. The students are encouraged to present their work to student and professional conferences. The research projects range from flight dynamics and control, intelligent control, and advanced control topics to the application of UAVs for search and rescue, 3-D mapping, and precision agriculture. The paragraphs below describe some of the research projects.

A. Aircraft System Identification

Aircraft system identification involves identifying parameters of flight dynamics model using flight data. Figure 3 shows a multicopter used for the project. The vehicle is flown for frequency sweep and doublet inputs. The collected data is post processed to remove any noise present in the data. The processed data is then used for the identification of transfer function and state-space models using frequency- or time-domain techniques.[11,12]

Figure 3. X8 Multicopter from 3D Robotics.

The multicopter is equipped with a PixHawk autopilot from 3DR, which is shown in Figure 4. It comes with a 10 degrees-of-freedom inertial measurement unit (IMU), Pitot-static pressure sensors, and an Extended Kalman Filter (EKF) algorithm that better estimates the quadcopter's velocity, position, and angular orientation based on all the available measurements from the various sensors. The autopilot is primarily used in this project for data collection required for the system identification in open-loop and stabilized modes.

Figure 4. Pixhawk Autopilot.

The multicopter was flown for both frequency sweep and doublet input. The frequency sweep data was used for the identification of the model parameters, both transfer function and state-space models using CIFER (Comprehensive Identification from FrEquency Reponse) software.[12] The identified model response was compared with the flight data as shown below for verification. It is seen that the model responses compare well with the flight data, validating the identified model.

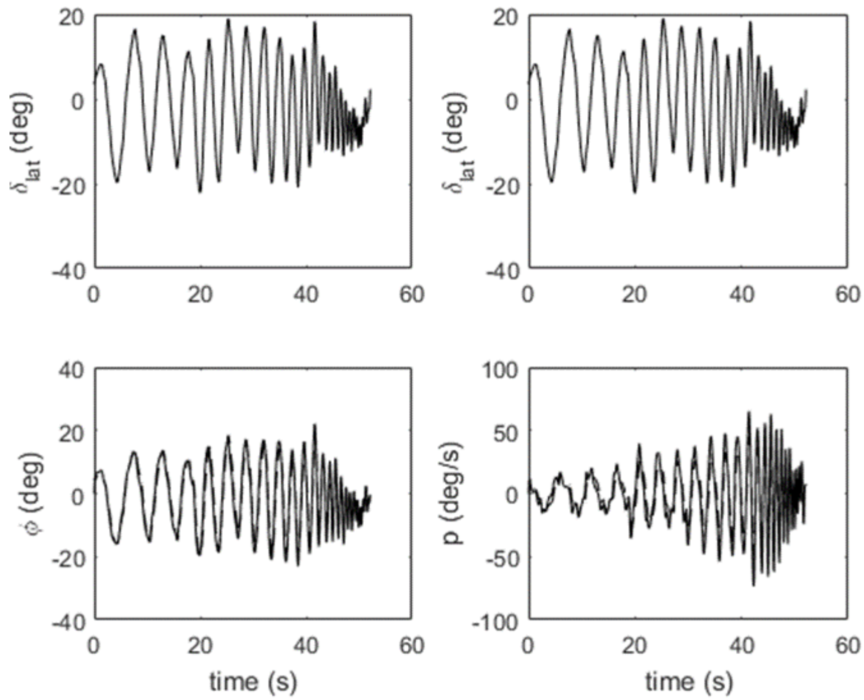


Figure 5. Identified Model Response (Dashed) vs. Roll Angle (ϕ) and Roll Rate (p) Flight Data for Lateral Input (δ_{lat}).

Figure 6 shows the identified model response compared with the flight data for roll doublet input.

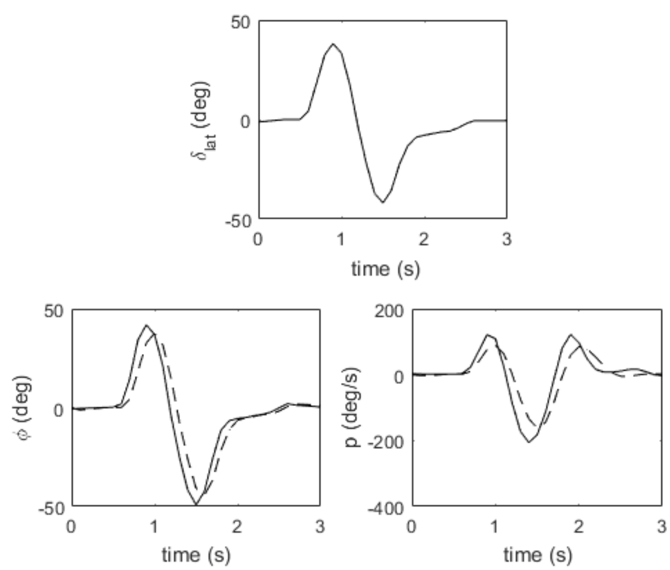


Figure 6. Identified Model Response (Dashed) vs. Flight Data for Lateral Doublet Input.

The students involved in this project presented their work during a student conference and AIAA's SciTech 2017 conference.[13] The students also presented their work at another student conference.

B. Collision Avoidance using Stereoscopic Vision

For the mass integration of unmanned aerial systems in the National Airspace System (NAS), these vehicles must be able to sense and avoid static and dynamic obstacles including other aircraft. Methods for obstacle detection include LIDAR, ADS-B sensors, and laser range finders.[14] Our undergraduate students have been using these sensors for research on UAS collision detection and avoidance.[15,16] However, LIDAR and ADS-B can be very expensive and are not suitable for use with small UASs because of size and weight limitations. Optical sensor such as camera can be used effectively using stereoscopic vision or optical flow for collision detection.[6,17] Stereoscopic vision based obstacle avoidance can be advantageous because of low cost and light weight of cameras. However, one of the main problems is to be able to process the images sufficiently faster in real-time to detect the objects and distance to the objects from the vehicles.

Stereoscopic vision technique uses two images together to find the depth of the correlating images and generate a depth map, similar to how human perceive depth using two eyes.[18] The distance to the object is found using an algorithm utilizing the baseline distance between the cameras and the focal lengths. The depth map is then fed to a PixHawk autopilot to correct the course of the UAS to avoid an impending collision.

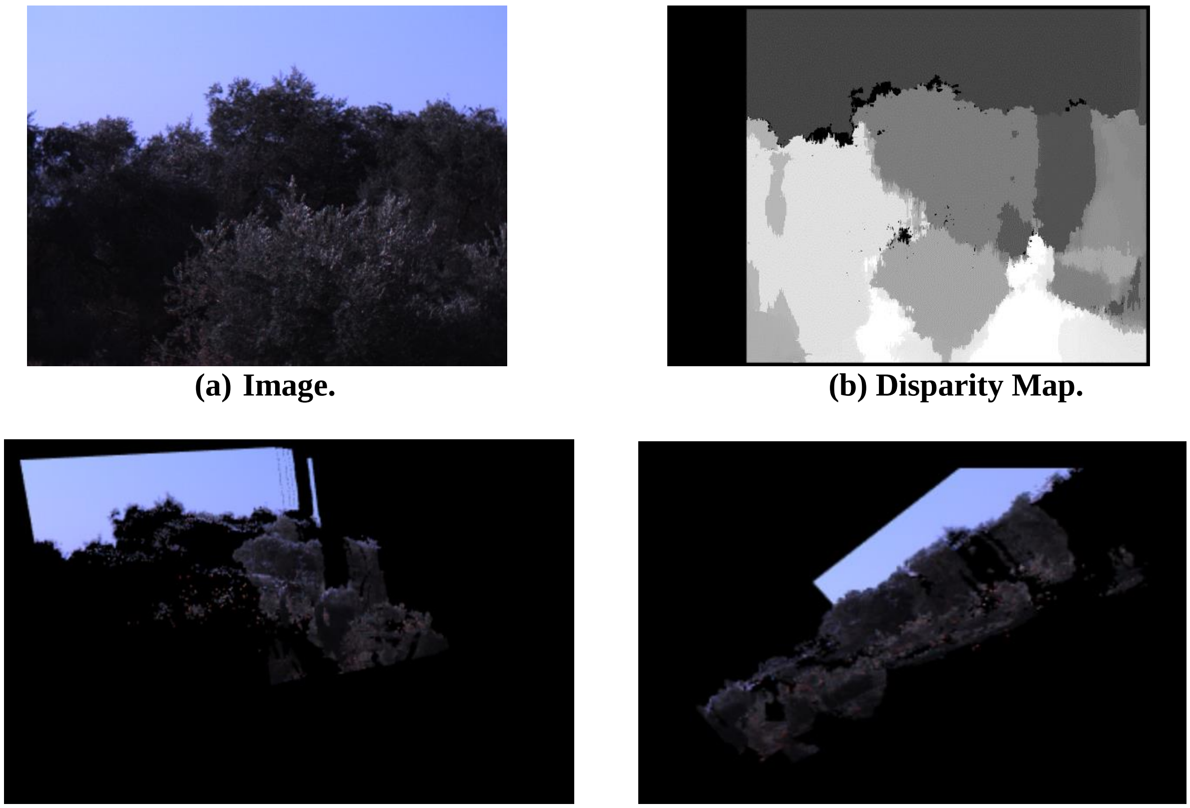
The undergraduate students working on this project have used Sig Kadet Sport UAS as well as DJI's S900 multicopter as shown Figure 7. They have been working on developing methods to eliminate noise from the sensing part of the algorithm so that it does not affect the avoidance algorithm, decrease processing power needed for the vision code to decrease the time to process each disparity map, increase the range so that the objects at longer distances can be detected, and test the algorithms in flight tests.

Figure 7. Sig Kadet Senior Sport (Left) and DJI S900 Multicopter.

Two Point Grey Chameleon3 cameras are mounted on the UAVs while using an Intel NUC for onboard processing. The NUC communicates with the PixHawk autopilot, which transmits data to the ground control station via Xbee radios. The NUC generates a disparity map using an algorithm that uses OpenCV library to process the images into the map. The algorithm generates the disparity map that is provided to the collision avoidance algorithm, which guides the UAS to the location within the map with the least dense area.

The students used different cameras for the project. Currently, they are using Point Grey Chameleon3 cameras, which can capture color images at 1.3 MP using USB 3.0 with resolutions up to 1280x1024 and up to 149 FPS.

Figure 8 (a) shows the images taken during flight. Figure 8 (b) shows the disparity map and Figure 8 (c) shows the 3-D view of the image. As can be seen in the figure, the disparity map is clear, although the depth of the image is not very far. The images could be processed around 20 disparity maps per second. The research is ongoing to increase the range and quality of detection.



(a) Image. **(b) Disparity Map.**

(c) 3-D View of the Image

Figure 8. Disparity Map and 3-D View of the Scene.

The students presented their work at student conferences as well as at the AIAA's SciTech 2017 conference.[19]

C. Search and Rescue using UAVs

UAVs can cost-effectively be used for search and rescue missions in both indoor and outdoor environments. Because of their small sizes and agility, they offer many advantages for indoor search and rescue during disasters such as earthquake, flood, and fire. Deploying manned aircraft may pose a significant threat to the pilot and the aircraft, and is impossible for the indoor missions. Multicopters show an enormous potential for search and rescue missions in the indoor environments. Many undergraduate students have been involved at Cal Poly Pomona for research on using UAVs for search and rescue missions. The challenges and limitations in using these in indoor environments include the size of the vehicles, the amount of the payload they can carry, the lack of GPS signal and map of the environment, and the obstacles such as walls.

One research project uses two small multicopters for search and rescue missions in the indoor environment. One of the multicopters is used as a search vehicle, and the second is used as a rescue vehicle. The vehicles are shown in Figure 9. The main advantage using two vehicles is that the agility of small-sized vehicles can be utilized without compromising the mission through payload distribution.

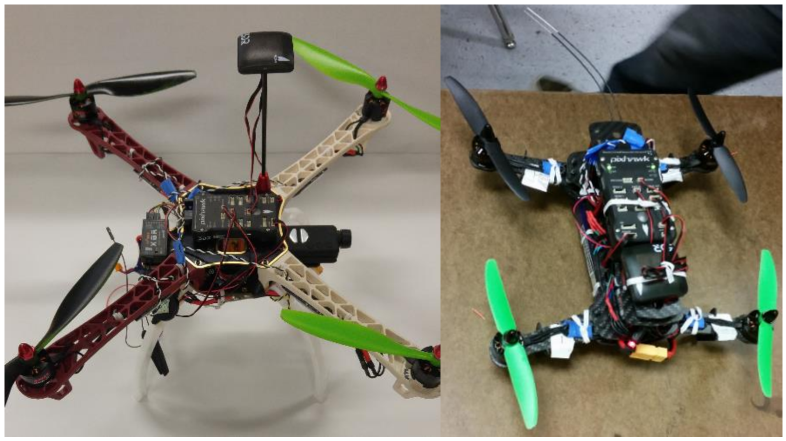


Figure 9. Search Quadcopter (Left) and Rescue Quadcopter.

The search quadcopter utilizes different types of sensors to provide collision avoidance abilities such as sonars, and is equipped with a Pixhawk autopilot. The sonar data is processed using a Raspberry Pi 2 processor. A forward facing camera is used to visually detect potential survivors. A spinning LiDAR is used to map the indoor environment. A position encoder is used to record the direction the LiDAR is facing when the distance is measured which is then plotted using polar coordinates, essentially creating a 2-D map. The map is then used by the rescue copter to find and deliver relief packages.

The rescue quadcopter also uses a Pixhawk as the flight controller to allow for easier communication with the search quadcopter. The sensors and technologies used on the rescue quadcopter are similar to that of the search quadcopter. The main difference was that an electro permanent magnet is utilized in this system to hold and release the rescue package to be delivered to the survivor (s).

Figure 10 shows the collision avoidance system being tested for the search quadcopter. The first flight test was conducted by hovering the quadcopter roughly 3 feet above the ground and activating the altitude hold flight mode. The copter was then slowly pitched forward towards a wall until the safety zone was breached and the Arduino took over the pitch control.

The students presented their work both at student conferences and a professional conference.[20]

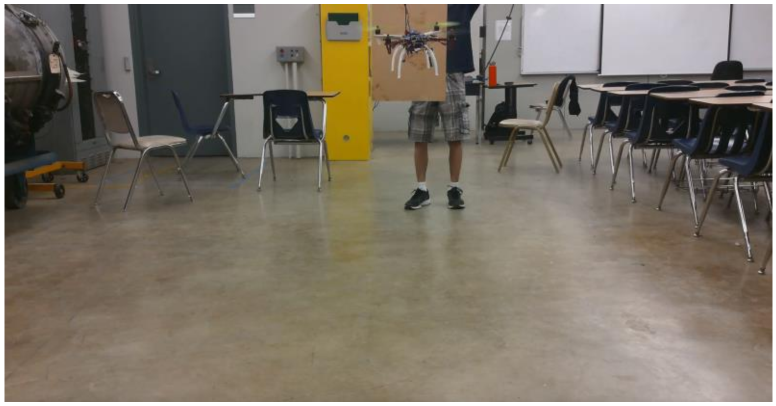


Figure 10. Testing of Collision Avoidance in Indoor Environment.

D. 3-D Mapping using Unmanned Aerial Vehicles

Recently, unmanned aerial vehicles have seen increased use for remote sensing applications such as remote sensing of ice sheets, vegetation, soil moisture content, and 3-D mapping. One of the project that the undergraduate students are being involved at Cal Poly Pomona is the 3-D mapping using a UAV and a LIDAR for topographical changes. This is helpful in assessing the topographical changes due to earthquake, landslide, and other factors. The information can be used by Department of Transportation, Metropolitan Water Districts, Cities, Law Enforcements, and others. In the case of a natural disaster such as tsunamis and earthquakes, 3-D models of the affected areas before and after the events can be used for scientific assessment and could be of great benefit for rescue missions. 3-D models can also be used for infrastructure development and monitoring. 3-D mapping using small size LIDAR and UAV will be equally useful in mapping the surface of Mars.

The project uses a puck size LIDAR and DJI 900 multicopter UAV which is shown in Figure 11. The LIDAR can also be used for collision detection and avoidance so that the UAVs takes the terrain data more autonomously without colliding with the obstacles.[16,21] Additional equipment on the UAV include an external GPS, Bullet M transmitter, and a PixHawk autopilot.

Figure 11. DJI S900 Hexacopter Equipped with a LIDAR.

Figure 12 shows the concept of operation. The LIDAR collects the data points capturing all of its surrounding environment while the vehicle is flying autonomously. The algorithm in the Intel NUC Processor executes and converts the raw data from hexadecimal to decimal and then into XYZ points, and transfers them over into the PointCloud Software. The results automated by this software is portrayed in the ground control station through the Bullet M Transmitter.

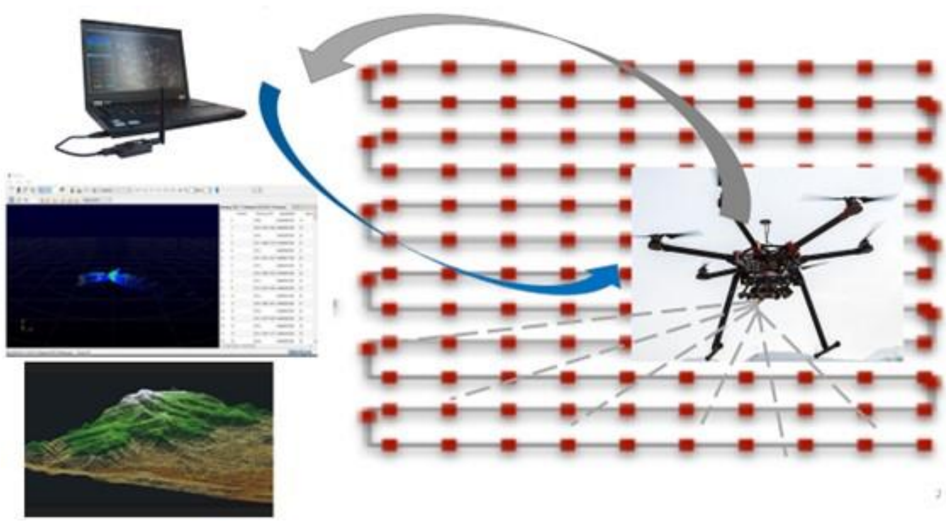


Figure 12. Concept of Operation.

For the collision detection, the LIDAR dual return function as shown below is used. It detects the strongest return and last return to keep track of objects in the flight path at all times in the 3-D space.

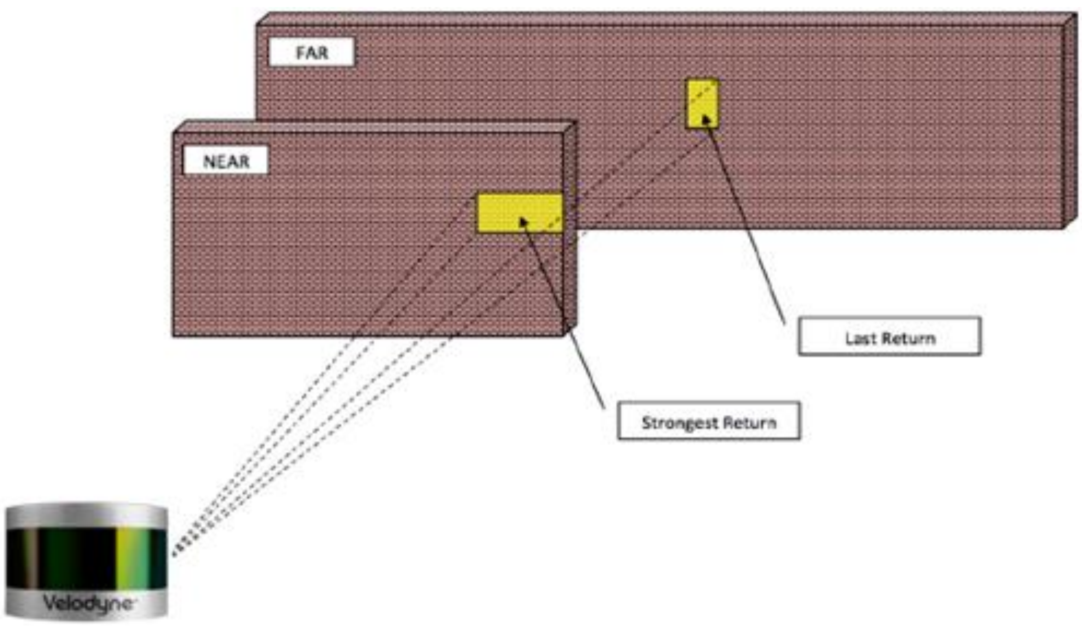


Figure 13. LIDAR Dual Return System.

The algorithm takes as inputs the strongest and last return distances only from the field of view angle, which is the vertical orientation of +15˚ to -15˚. The LIDAR accuracy is +/- 3cm, and its optimum detection range is 100 meters.

The students working on this project presented their work at student conferences and the AIAA's SciTech 2017 conference.[16]

III. Student Activities and Student Involvement

In the beginning of the summer program, the students are introduced to the research environment and research projects that they will be involved with by the research supervisor. The students are usually teamed up in a group of 2 or more. The students are asked to do literature review, and come up with a solution for the problems that need further development and maturation. During the program period, the students work on sensor and processor selection and integration, algorithm development, flight testing, data collection, data processing, and validation. The students are highly encouraged to present their work during student and professional conferences. All this provides an intensive research environment where the students learn, by means of hands-on learning, state-of-the-art in UAV technologies. The students also attend weekly research seminars held at Cal Poly Pomona. Often times, the undergraduate students work with graduate students. The students attend a weekly meeting with the research supervisor.

The projects usually address or try to address the problems that the UAV operations is currently facing such as integration of the UAVs into the National Airspace System, Collision and Obstacle Avoidance, Navigation in GPS-Denied Indoor Environments, and Modeling and Simulation.

The students are highly encouraged to present their work during student and professional conferences. All this provides an intensive research environment where the students learn, by means of hands-on learning, state-of-the-art in UAV technologies.

IV. Support for the Summer Research Program

The students for the summer research program work closely with the faculty supervisor to meet the goals and objectives of the projects as well as the overall program. The students are hired as research assistants or receive stipends for their involvement in these projects. Funding comes from various external and internal grants including from National Science Foundation, NASA, aerospace industry, McNair Scholarship Program, and the institutional programs such as support for Research, Scholarship, and Creative Activities. The students from the Community College have been supported by the College's Program to encourage their students to research and STEM education, and is supported by a grant from Department of Education.

As discussed above, the number of students in the summer research program has been increasing with more than 15 undergraduate students from the Cal Poly Pomona and Citrus Community College involved in the program during the summer of 2015 and 2016 each. The research projects also involved a high-school student.

V. Outcomes and Evaluation of Outcomes

Involvement in the summer research program has been found very effective in the students' intellectual growth, motivation for continued involvement in research projects, and motivation for advanced degrees. Some of the key outcomes are presented in the following paragraphs. Student feedback obtained through a post completion survey are also discussed. The survey questionnaire asked the students whether the projects were helpful for them in learning other disciplines, improving their written and oral communication skills, motivating them for graduate degrees, finding jobs and internships, etc.

A. Motivation for Undergraduate and Graduate Degrees

Study has shown that participation in research projects motivates undergraduate students for graduate degrees.[22] The students who were part of the summer research program are pursuing or have shown interest in pursuing their studies for graduate degrees, both at Master's and PhD levels. Most of the community college students who were involved have transferred to 4-year engineering programs at Cal Poly Pomona and other institutions. Four community college students from 2013 and 2014 summer programs transferred to the Aerospace Engineering Department alone, and have been continuing research in unmanned aerial systems. All three community college students from 2016 Summer Program have shown interest in transferring to Cal Poly Pomona for 4-year degree in aerospace engineering and continued involvement in the UAS research projects. At least four students are pursuing or are planning to pursue their studies for PhD degrees in the area of unmanned aerial systems and related areas. About 60% of the students who have already graduated are pursuing or planning to pursue their studies for a Master's degree.

B. Presentation at Student and Professional Conferences

The students involved in the summer research program are highly encouraged to present their work at student and professional conferences. The community college students are required to present their research at the end of summer research program during the Research Symposium organized at Cal Poly Pomona.

The students have been presenting at the annual Southern California Conference for Undergraduate Research (SCCUR) and Student Research, Scholarship, and Creative Activities (SRSCA) Research Conference organized every year at Cal Poly Pomona in the month of March. Almost all the students involved in the summer research program have been presenting at these conferences.

The students have also been presenting at professional conferences such as AIAA's SciTech Conference and AUVSI's Xponential Conference. This year alone, three students or student teams involved in the summer research program presented their work during the AIAA's SciTech 2017 conference. They also prepared and submitted papers for publication in the conference proceedings.

Figure 14 shows the number of students presenting at the student and professional conferences for the past six years. This number is significantly higher than the number of students who were not part of the Summer Research Program. For example, only 2 students who were not part of the Summer Research Program presented at Student Conferences and only 1 student presented at a Professional Conference during 2015-2016 academic year compared.

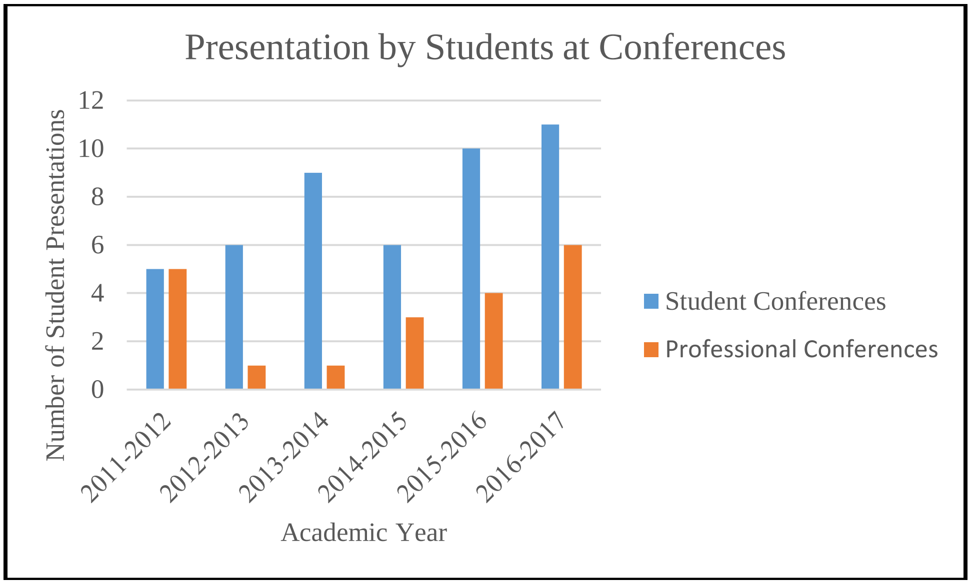


Figure 14. Number of Student Presentations at Conferences.

The presentations at student and professional conferences and publication of their work help in improving the students' written and oral communication skills. This is necessary and important as the lack of strong written and oral communications has been identified as deficiency in STEM education, resulting in poor success rate. Study has found that presenting and publishing at conferences significantly improves students' communication skills, both oral and written, as compared to the presentations and writing as part of the curriculum alone.[23,24]

Most of the students who responded to the survey questionnaire said that the involvement in the project helped them improve their written and oral communication skills.

It has also been observed that the students who presented and published their work at conferences had higher success rate in getting employment offers. The students also are more motivated for graduate degrees at Master's and PhD levels.

C. Exposure to Multidisciplinary Environment

These research projects have been helpful in exposing the students to multidisciplinary environment. The research program involves students from Aerospace and Electrical & Electronics Engineering and Computer Science disciplines. These students usually work in teams for a common task such as collision avoidance system that involves computer programming, data and algorithm processing, and aircraft dynamics and control. This is helpful for the students in developing new skills and knowledge in the disciplines other than their major. The students get opportunity to learn other disciplines that are not taught in classroom settings of individual disciplines. For example, students from Aerospace Engineering major have learned or have opportunity to learn computer programming, computer vision, electronics, and communication system. Similarly, the students in the Computer Science and Electrical & Computer Engineering departments get opportunity to learn about the application of these disciplines to the Aerospace Engineering and unmanned aerial systems.

80% of the students who responded to the survey questionnaire said that the project was helpful for them in learning disciplines in engineering and science other than their major discipline. Most of the students also said that the projects helped them acquire new skills.

Also, a number of Aerospace Engineering have been getting employment for the industry careers that have traditionally required Computer Science or Electrical & Electronics Engineering graduates such as in Jet Propulsion Laboratory, and Unmanned Systems Division of Northrop Grumman Corporation.

D. Continued Involvement in UAS Research Projects

Most of the students involved in the summer research program have continued working on the same or other research projects after the end of summer research program. Some of the students chose UAS research projects as their Senior Projects. Other students continued or have been continuing as undergraduate research assistants or as individual studies. The continued involvement has helped the students get employment for the career in UAS technologies in various industry and R& D organizations involved with UAS research as discussed below.

It has been observed that those students who were part of the UAS projects for a prolonged period of time had more success in getting employment and were more motivated for graduate degrees.

E. Increased Opportunities for Industry Career

The students involved in the summer research program and beyond have increased opportunities for industry career. Many students involved in these projects have been successful in getting employed immediately after the graduation in the areas of unmanned aerial systems. This information is based on the information provided by the students or the information gathered from the methods used for student tracking that include E-mail, Facebook, and LinkedIn.

Students' involvement in these projects, and presentation at student and professional conferences enhances their resumes, increases their visibility, and attracts the employers. Some students get offer of employment during professional conferences after the presentation of their work.

Also, many non-graduating students have been selected for internship opportunities at the companies and Government organizations including Northrop Grumman Corporation, The Boeing Company, and NASA to work in the areas of unmanned aerial system.

Another noteworthy observation is that the students who have acquired skills via involvement in the UAS research projects for an extended period of time are likely to get employed after gradaution even with low GPAs (GPA between 2 and 3).

60% of students who responded to survey questionnaire said the involvment in these projects was helpful in securing a full-time employment

VI. Conclusion

Many undergraduate students including from community colleges and high schools have been involved in the summer research program on unmanned aerial systems at Cal Poly Pomona. The students are exposed to extensive research environment over the period of 10 weeks. The research activities include literature survey, research on the topical areas, sensor selection and integration, experiment design, algorithm development ground and flight testing, data collection, data analysis, and verification. The students work in multidisciplinary environment on the research projects that need knowledge in multiple disciplines. At the end of the summer program or after the summer program, students present their work at student and professional conferences. This has helped them in improving their written and oral communication skills.

Students involved in these projects have been found to be motivated for advanced degrees. Most of the community college students have transferred to Cal Poly Pomona. Undergraduate students already in 4-year program have been pursuing or plan to pursue their studies for graduate degrees, both at MS and PhD levels. Also, the students have increased chances of getting employed after graduation, both at aerospace industry and research labs.

Acknowledgement

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