ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #37977

Integrated multidisciplinary capstone projects of an underwater robot and a quadcopter for building structural analysis

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Abstract

Research and teaching are two crucial aspects of faculty responsibilities for some Engineering Technology and Multidisciplinary Engineering Programs. It would be worth discussing how faculty can manage a research project and engage with students through capstone projects. As a case study, a building structural analysis project is presented in this paper. This building structural analysis project can be broken down to several components. One of the sub-components is a quadcopter platform, and the other one is an underwater robot platform for a building analysis. These two components were managed as two capstone projects. Two capstone projects were carried out as a part of this building structural analysis research project at Texas A&M University. The first capstone team designed and built a custom quadcopter that could fly close to the building to find potential damage to the building. The second capstone team designed and built an underwater robot to inspect the portion of a building structures that are submerged such as bridges. For this multidisciplinary project, three faculty members from two departments of Engineering Technology and Construction Science formed a team and advised the students. The Engineering Technology department at Texas A&M University has an Electronics Systems Engineering Technology (ESET) program and Multidisciplinary Engineering Technology (MXET) program. For the second capstone project team, students have created an underwater robot for a building analysis. These four students are from the Multidisciplinary Engineering Technology (MXET) program. This second capstone started in Fall 2020, and it was concluded in Spring 2021. In this paper, the details of the second capstone project will be provided. Moreover, the details of the integration of the two capstone projects will be introduced and discussed in this paper.

I. Introduction

Research and teaching are two crucial aspects of faculty responsibilities for some Engineering Technology and Multidisciplinary Engineering Programs. As these Engineering programs have strived to increase research productivity, it is worth discussing how faculty can manage a research project and engage with students through capstone projects. As a case study, a building structural analysis project is presented in this paper. This building structural analysis project can be broken down to several components. Two of the sub-components can be executed by engineering students as two separate capstone projects. One of the sub-components is a quadcopter platform, and the other one is an underwater robot platform for a building analysis. These two capstone projects are integrated for this building analysis project.

The capstone project experience in the Engineering Technology Department at Texas A&M University is managed by two courses for two semesters. During this capstone period, students can learn practical skill and knowledge via experiential learning by building a prototype that may have a potential to be a product. While capstone projects are typically industry sponsored, faculty members in the Electronics Systems Engineering Technology (ESET) Program can also create their own faculty sponsored capstone projects, and they can support the capstone teams given the condition that the project can meet the capstone project requirements. In this way, it is possible for faculty members to extend their research project effort to a capstone project to engage with the students. In applied research, it is important to have a working prototype that can be used to collect data to validate research ideas.

This arrangement can provide a chance for faculty members to engage with students via capstone projects. If needed, the sponsoring faculty members would use the developed prototype to conduct more advanced research such as with graduate students. The engineering technology department at Texas A&M University offers a Master of Science degree in Engineering Technology (MSET). There can be graduate students who would continue to conduct research with the faculty in this master's program.

The faculty members in this paper have sponsored several capstone projects as a part of their research projects. To support capstone projects from a faculty's funded research project, one of the main challenges is that the research project itself is usually more complex than the scope of a capstone project. This is the reason that the work for the research project needs to be broken down to several components and some portions can be covered by multiple capstone projects. This requires careful planning because the capstone course has its unique requirements, which may not be consistent with that of the research project.

In this paper, two capstone projects were carried out as a part of the building structural analysis research project [1-3]. The first capstone team designed and built a custom quadcopter that could fly close to the building to find potential damage to the building [4][5]. The second capstone team designed and built an underwater robot to inspect the portion of a building structures that are submerged such as bridges. This capstone project approach for a faculty research project has its limitations, for example, it may take multiple semesters to complete. This means it would take some additional time to build up and educate the team. And, capstone project schedules are dependent on academic semesters, which may not be necessarily in sync with the needs of the timing of the research project milestones.

For this multidisciplinary project, three faculty members from two departments of Engineering Technology and Construction Science formed a team and advised the undergraduate students. The Engineering Technology department at Texas A&M University has the Electronics Systems Engineering Technology (ESET) program and Multidisciplinary Engineering Technology (MXET) program [6][7]. The second capstone project team created an underwater robot for a building analysis. Four students from the Multidisciplinary Engineering Technology (MXET) program carried out this capstone project. This second capstone project started in Fall 2020, and it was concluded in Spring 2021. In this paper, the integration of the two capstone projects will be introduced. Moreover, the details of the second capstone project will be provided.

II. Integrated Multidisciplinary Capstone Project Management

The Engineering Technology Department at Texas A&M University includes Manufacturing Engineering Technology (MMET) program and Electronics Systems Engineering Technology (ESET) program. For the Multidisciplinary Engineering Technology (MXET) program, students may need to take the courses from both the MMET and ESET programs. For instance, currently, students from the MXET program take selected core courses offered by the MMET and ESET programs.

There are two focuses available in the MXET program. They are mechatronics focus and STEM (Science, Technology, Engineering, and Mathematics) educator focus. As of now, a majority of students in the MXET program have been pursuing the mechatronics focus. Two authors in this paper, Dr. Hur and Dr. Zhan, have been teaching embedded system and control courses [8][9]. In Fall 2020, four students from the Multidisciplinary Engineering Technology (MXET) program decided to work on the underwater robot capstone project. This is about the second capstone team for the building analysis project. In addition to the capstone project courses, students have taken the faculty members' embedded system and control courses. The name of this team is LUX mechatronics. This second capstone team completed the project in Spring 2021.

For the first team, a quadcopter project team for the building analysis, was started in Fall 2019 and completed this capstone project in Spring 2020 [4]. The name of this team was CRANE Tech. In short, there were two multidisciplinary capstone projects for four academic semesters from Fall 2019 until Spring 2021. The first capstone team was started in Fall 2019 and completed in Spring 2020, and the second capstone team was started in Fall 2020 and completed in Spring 2021. These two capstone projects were integrated for the project theme of the quadcopter and underwater platform development for a building analysis. The first capstone team's quadcopter platform was previously published [4]. In this paper, the second capstone team's effort will be presented in more detail. Also, the details of the integration of these two capstone projects for a building analysis have been presented.

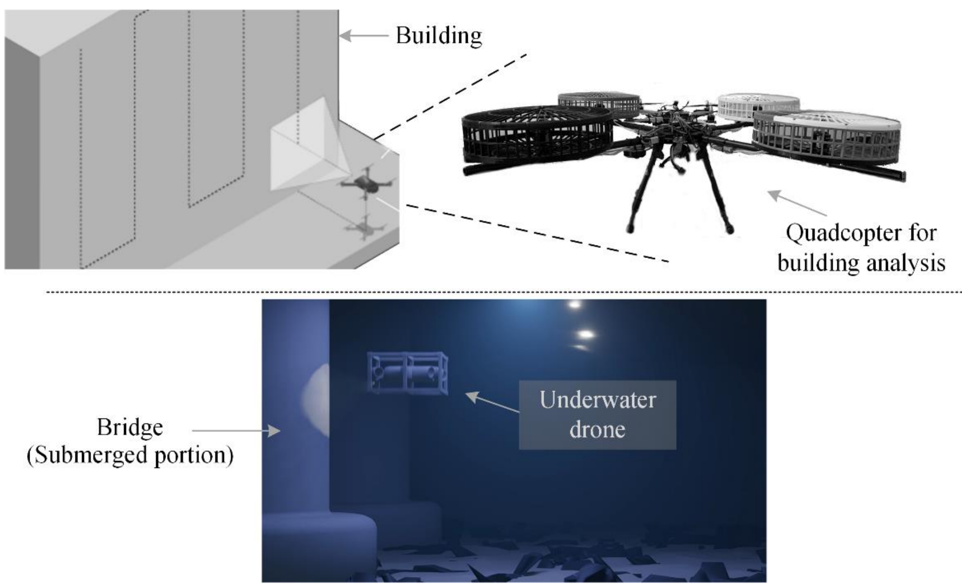

Figure 1. Quadcopter and Underwater robot platforms for building analysis.

Figure 1 shows the quadcopter and underwater robot platforms for a building analysis. A custom quadcopter can be used for the survey and inspection missions for buildings. The images and videos can be obtained for the detection of cracks of the building surface. On the left side, it shows an example scanning pattern. On the right, it shows the fabricated custom quadcopter via the first capstone project. In addition, there are some of the building structures that are submerged under water. For instance, a portion of a bridge can be submerged. For the detection and inspection tasks, they can be dangerous at times for humans to perform due to the unpredictable nature of the weather and water current. Thus, an underwater robot that can be used in the detection and inspection task can be useful and the development of this task was given to the second capstone project team. In the following section, the details of this second capstone project team will be presented.

The capstone project management of these two teams suddenly turned out to be a challenging task due to the COVID-19 interruptions and restrictions [12]. For the first team, there was a forced remote during the first semester of their capstone project. It was the beginning of the COVID-19 impact. For the second team, the mode of operation was still effective, and it caused the zoom online meetings and limited use of the development tools. Despite the challenges, both capstone teams were capable of delivering functional prototype devices successfully, and they could complete their capstone projects.

III. Underwater Robot Platform for Building Analysis via a Capstone Project

The submerged building structure such as a part of a bridge may need inspection for damages to avoid a potential catastrophic event [13][14]. Divers can perform the inspection tasks [15]. In some cases, it might be dangerous for the divers due to unexpected changes of weather or water current. In this aspect, the use of an underwater robot is an alternative choice [2]. An underwater robot system for a building analysis was designed, fabricated, and tested via this second capstone project.

A. System Design and Implementation.

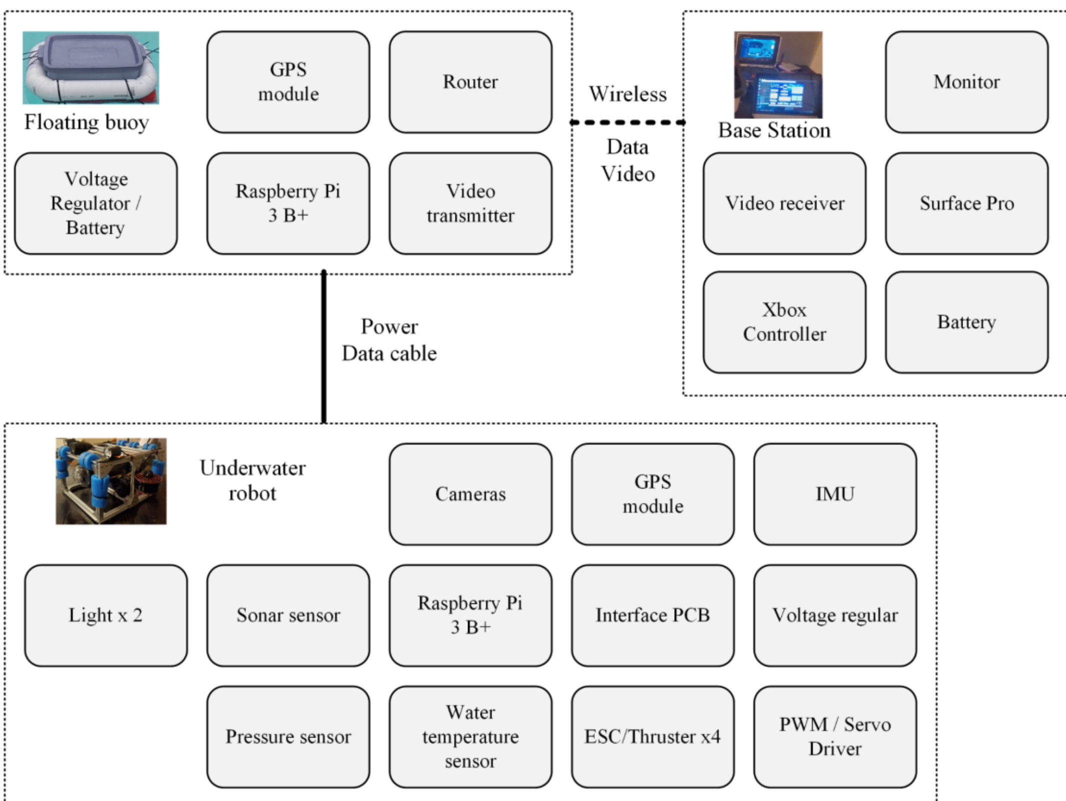

Figure 2. System Block Diagram of the Underwater Robot System.

Figure 2 shows a system block diagram of the underwater robot system for a building analysis. On the bottom of the figure, it shows an underwater robot. This underwater robot has a camera for navigation. Moreover, this underwater robot has a second camera to capture the videos and images for the building analysis. Furthermore, it has lights for a dark underwater environment.

Moreover, this underwater robot has sensors such as sonar sensor, pressure sensor, water temperature sensor, and IMU (Inertial Measurement Unit) sensor. It also has a GPS (Global Positioning System) module to obtain the location information when it could be on the water surface. This underwater robot is connected to the power/data cable bundle. The cable bundle is also connected to a floating buoy. The floating buoy is shown on the top left side of the figure. The floating buoy can communicate with both the underwater robot and the base station. This floating buoy contains a battery to supply power to the underwater robot. It has a GPS module to obtain the location of the buoy. On the top right side of the figure, it shows the base station, the data and the video signals can be sent to the base station. This is assumed to be located remotely. The base station can receive the data and the video and can control the underwater robot using an Xbox controller. A surface pro PC is used as the main controller unit for the base station.

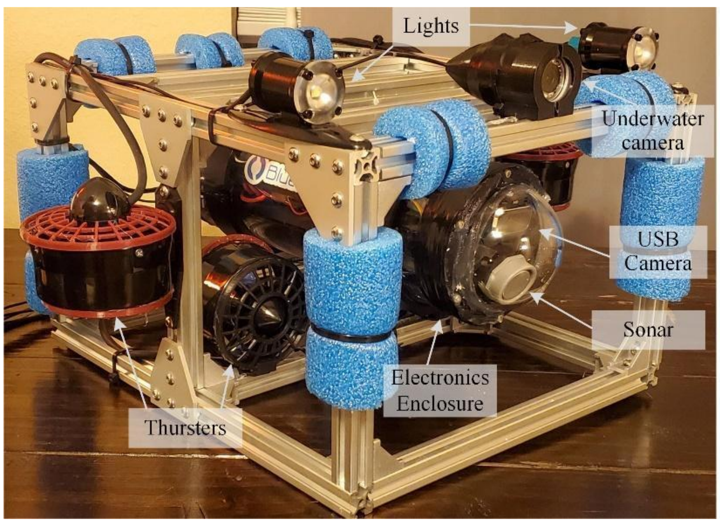

Figure 3. Fabricated Underwater Robot.

The underwater robot was implemented as shown in Figure 3. This underwater robot has four thrusters for the movement freely under the water. The underwater robot has two cameras for navigation and to store the videos and images. The underwater robot has a sonar sensor to detect the object in front of the underwater robot. These electronics parts are contained in a waterproof enclosure. The frame of the underwater robot consists of aluminum extrusions.

The assembled underwater robot system is placed on the floor in Figure 4. On the left side, it shows the underwater robot. In the middle, a floating buoy is shown. The cover and the buoyant ring components were removed for testing. On the right side, a base station set with the surface pro and camera screen is shown.

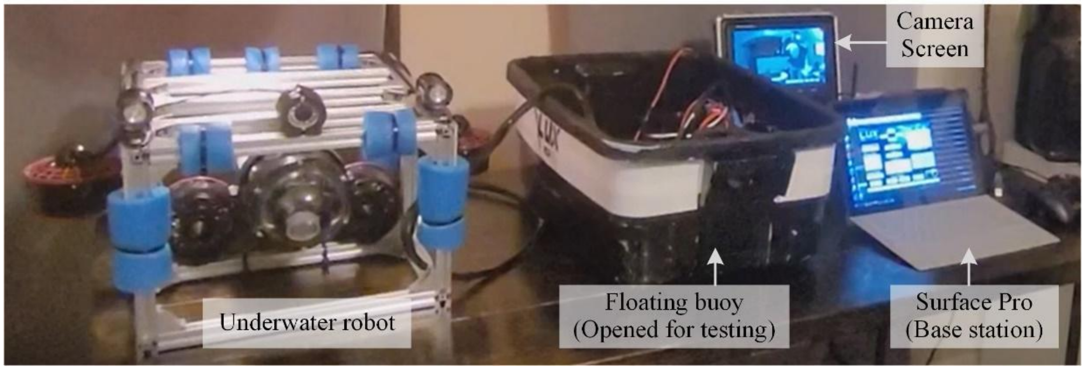

Figure 4. Assembled Underwater Robot System.

The electronics and the underwater robot control board components are shown in Figure 5. On the left side, it shows the top view of the underwater robot. The electronic enclosure can be found inside of the robot. On the right side, it shows the electronics components. They are placed inside of a waterproof enclosure. As an intelligence of the controller unit, a Raspberry Pi 3 B+ is used. It can be mounted on the custom interface board. This interface board was designed to hold the other various components such as PWM/Servo driver, various sensors, and GPS module. The electronics parts can communicate with the base station through the electronics system in the floating buoy.

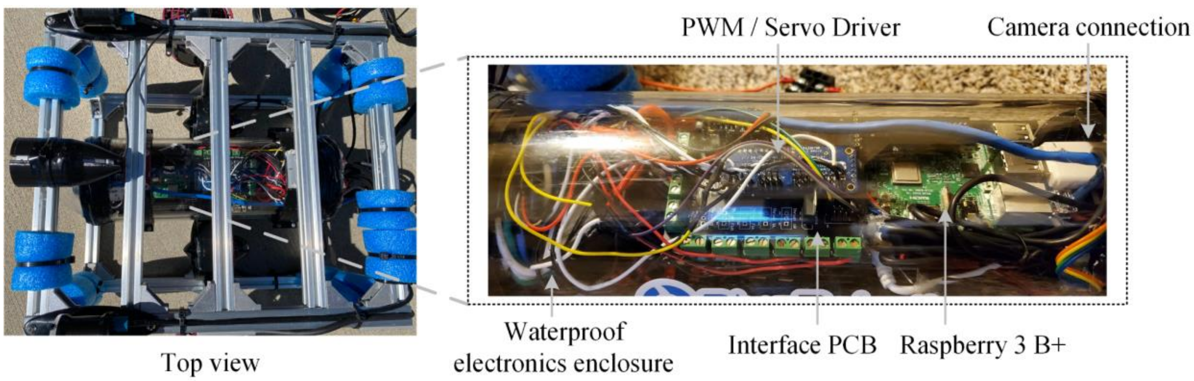

Figure 5. Electronics and Underwater Robot Control Board.

B. Test and Measurements

This underwater robot system was tested, and the display of the measured data is shown in Figure 6. On the right side, it shows the base station of the systems. The surface pro PC is used as a main unit for the base station. The captured image of the surface pro PC screen is shown on the left side. The custom designed GUI (Graphical User Interface) screen shows temperature, pressure, sonar, pressor, and IMU data. The GPS data was not shown in this GUI as it was tested in an enclosed space. A user can control the underwater robot using an Xbox controller. For instance, the joystick on the Xbox controller is manipulated to the right side, it shows the right on the GUI screen as shown in the figure, and the signals can be sent to the underwater robot to control thrusters for the movement to the right side.

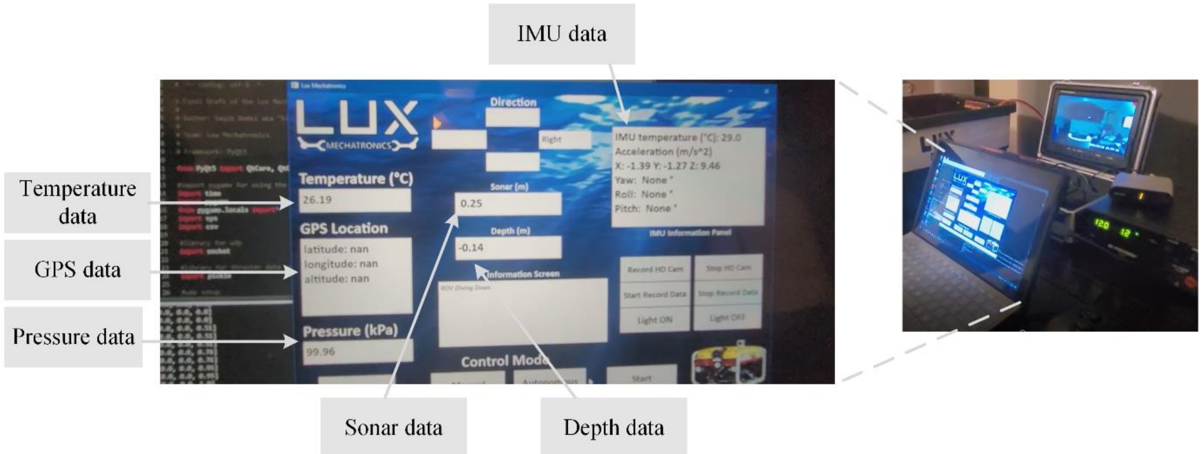

Figure 6. Sensor Measurements and the Control of the Underwater Robot.

As a part of the final testing as a capstone project, the underwater robot was deployed and tested in a swimming pool environment as shown in Figure 7. This underwater robot could dive and rise as well as navigate in the swimming pool by a user. Also, the user can turn on or off the lights. The video was displayed to the monitor on the base station. And, the sensor data was successfully transmitted to the base station. This capstone project team with a group of students from the MXET program has demonstrated and required functions in the water environment.

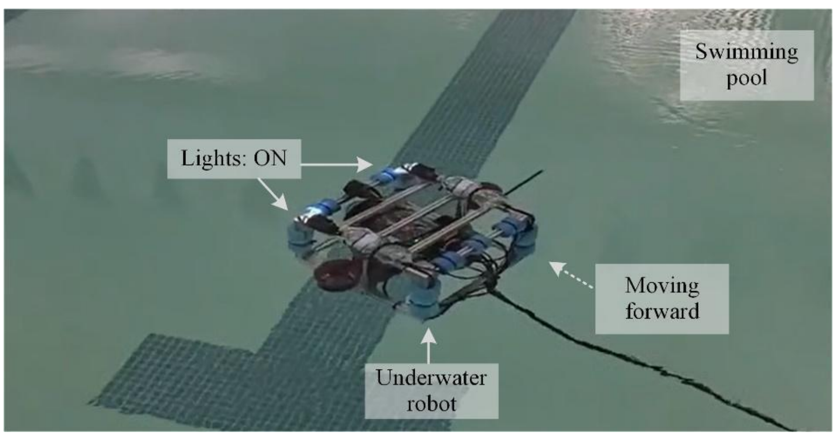

Figure 7. Operation and Testing in the Water

C. Educational value and evaluation

For the platform development for the building analysis project, two capstone project teams have worked on this building analysis platform research. For the first capstone project, the project started in Fall 2019 and concluded in Spring 2020. There were four undergraduate students. For the second project team, the project started in Fall 2020 and concluded in Spring 2021. There was a total of eight undergraduate students who have learned various aspects of the engineering skills through these two capstone projects. They graduated and they are in the industry. To gain understanding of students' learning via these capstone projects, a post-capstone survey was carried out using an on-line anonymous survey method in May 2022. The questions in the on-line survey are shown as follows:

1. Are you a member of CRANE Tech or Lux Mechatronics?

2. Did this capstone project enhance your learning about relevant technical skill sets?

Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**	**N/A**
5	4	3	2	1	0

3. Briefly state the technical skills that you learned during this capstone project.

4. Did this capstone project enhance your learning about working in a team environment?

Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**	**N/A**
5	4	3	2	1	0

5. In your experience and opinion, did COVID-19 affect your capstone project?

Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**	**N/A**
5	4	3	2	1	0

6. Briefly state the impact on your capstone experience due to COVID-19.

7. Do you think this capstone has been beneficial to your current or future career?

Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**	**N/A**
5	4	3	2	1	0

7. Briefly state the impact and/or influence of this capstone project related to your current or future career.

This survey was created and conducted using Qualtrics. This voluntary survey was designed to ask a few questions related to the educational impact and their feedback related to their capstone experience. "Anonymize responses" option in Qualtrics was used. The summary of this post capstone survey results is shown in Table 1. 87.5% of the capstone students have participated in this post capstone survey. The ratio between participating students for Crane Tech and Lux mechatronics teams is 43% to 57%. Participants have shown positive responses toward their capstone project related to technical skills (Q2, Average: 4.43), and teamwork (Q4, Average: 4.85).

Table 1. The post capstone survey results for the RAJA electronics team

Survey participation rate	87.5% (7/8)
1. Are you a member of CRANE Tech or Lux Mechatronics?	43% / 57% (Crane Tech / Lux Mechatronics)
2. Did this capstone project enhance your learning about relevant technical skill sets?	4.43 (Mean) (Std. deviation: 0.49)
3. Briefly state the technical skills that you learned during this capstone project. Summary of the selected answers: * PCB design * Mechanical design * Python * Testing * Analyzing data * Technical writing * Project management	

4. Did this capstone project enhance your learning about working in a team environment?	4.85 (Mean) (Std. deviation: 0.35)
5. In your experience and opinion, did COVID-19 affect your capstone project?	4.43 (Mean) Std deviation: 0.49)
6. Briefly state the impact on your capstone experience due to COVID-19. Summary of the selected answers: * Interruption/restrictions due to COVID-19 * Lack of in-person meetings * Lack of interactions with professors	
7. Do you think this capstone has been beneficial to your current or future career?	4.14 (Mean) (Std. deviation: 0.83)
8. Briefly state the impact and/or influence of this capstone project related to your current or future career. Summary of the selected answers: * Enhanced schematics and programming * Helped to become an independent learner * Helped to get hired * No impact	

The technical skills they learned were related to PCB design, Mechanical design, Python, Testing, Analyzing data, Technical writing, and Project management. For the question about the impact on their career, the response was still positive but lower than others (Q7, Average: 4.00). The impacts on their career include the enhancement of schematics and programming and this project helped a student to become an independent learner and this project helped a student to get hired. And, there was one student responded as no impact. For the COVID19 related question, COVID-19 has impacted the students (Q5, Average: 4.5). The impacts due to the COVID-19 include interruption and restrictions due to COVID-19, lack of in-person meetings, and lack of interactions with professors. This could be related to mode changes of operation and the COVID-19 restrictions. As an advisor for these capstone projects, despite the difficulties, students showed resilience and determination, and they were able to manage to complete the given tasks successfully.

V. Discussion & Concluding remarks

Two capstone projects were carried out for the development of platforms for a building analysis. A quadcopter platform was carried out via capstone and completed in Spring 2020. The second capstone was created in Fall 2020 for an underwater robot system development. This second capstone team completed the task in Spring 2021. The two capstone projects were integrated for the platform development tasks for building analysis. Three faculty members from two departments managed and advised two capstone projects with students from the Electronics Systems Engineering Technology (ESET) program and Multidisciplinary Engineering Technology (MXET) program. The authors plan to continue and to advance the quadcopter and the underwater robot platforms for the building structure analysis applications.

Acknowledgements

This work was supported by Texas A&M Triads for Transformation (T3) grant, and this work was also supported by Dr. B. Hur's Texas A&M research fund and resources.

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