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Educational Small Scale Underwater Robot Development via a Capstone Project in Engineering Technology

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Abstract

Remotely operated vehicles (ROVs) can be used for ocean explorations. ROVs are typically tethered underwater robots. For a survey task and explorations in shallow channels, a small scale ROV can be used. This small scale ROV can allow engineering students to gain understanding of the water property and various electrical and mechanical components. The development of a small scale ROV can be performed for an educational purpose. To build an underwater robot, a capstone project team was formed with four senior Engineering Technology (ET) students at Texas A&M University in Fall 2018. One graduate student from the Subsea engineering program was assigned to mentor the team. This ROV can be operated manually. Moreover, this ROV was designed to perform a dive mission autonomously using a sonar sensor that can measure the depth of the water. This ROV can be configured as tethered or tether-less like an autonomous operated vehicle. In this aspect, this is called Hybrid ROV. This Hybrid ROV can measure the water temperature. The ROV has IMU (Inertial measurement unit) and GPS (Global Positioning System) units for navigation. Moreover, it has an underwater camera and LED (Light-Emitting Diode) lights to identify objects in a dark environment. Two configurations of the manipulators are supported. The base frame of this underwater robot consists of aluminum extrusions. This dimension of the base frame of the underwater robot is 40 cm × 35 cm × 25 cm. This capstone was concluded in Spring 2019. This team participated in a regional Texas MATE (Marine Advanced Technology Education) competition in May 2019. In this paper, educational values and lessons learned via the capstone experience as well as the detail of the educational ROV will be presented.

I. Introduction

For Ocean exploration, a remotely operated vehicle (ROV) can be used, and it can be a form of an unmanned and tethered underwater vehicle. There are various sizes of the ROVs depending on the tasks and the depth of the explorations [1-3]. In order to dive a deep ocean floor, the size of the ROVs is large. But, for a survey task and explorations in shallow channels, a small scale ROV can be used [4-6]. This small scale ROV can allow engineering students to understand the water property, and the ROV has various electrical and mechanical components that allows them to build their engineering skill sets. This small scale ROV was developed for an educational purpose. In order to develop this ROV, a capstone team was formed with four Engineering Technology (ET) students at Texas A&M University in Fall 2018. In addition, one graduate student from a subsea engineering program was assigned to help the team as a mentor.

This educational ROV was designed to be operated manually, and the ROV can perform a dive mission autonomously using a sonar sensor that can measure the depth of the water. The ROV can measure the water temperature and the measured data is stored for further analysis. The ROV has IMU (Inertial measurement unit) and GPS (Global Positioning System) sensors for the navigation and movement control. Moreover, it has an underwater camera as well as two underwater LED (Light-Emitting Diode) lights to identify objects in a dark environment for navigation.

This ROV supports two configurations of the manipulators. One of them is to use a single manipulator to perform a relatively simple grip and release task. Another one is to use two 3-axis robot arms (3DOF) as the manipulators. The base frame of this underwater robot consists of aluminum extrusions. This dimension of this base frame of the underwater robot is 40 cm x 35 cm x 25 cm.

This ROV development capstone project was concluded in Spring 2019. This project was completed before COVID-19. This team participated in a regional Texas MATE (Marine Advanced Technology Education) competition in Spring 2019 [7][8]. Students have graduated and joined the industry. In this paper, educational values and lessons learned via the capstone experience and the MATE competition will be presented. Moreover, the details of the educational remotely operated vehicles will be presented.

II. Capstone project management

The underwater robot development in academic settings has been pursued by the faculty member in this paper, Dr. Hur. There have been several underwater ROV projects that were managed through capstone projects by the faculty member. One of the capstone projects for an underwater robot is introduced in this paper.

This capstone project was initially inspired by underwater robots that can detect navel subsea mines to avoid putting human divers into harm's way. The original target of this capstone project was to develop an underwater robot that can potentially be used for the mine detection task in the shallow channel in the long run. For this long-term goal, it was recognized that it would be beneficial to design an underwater ROV prototype that can be operated in either tethered or tether-less mode. This underwater ROV was named hybrid ROV for this capstone project in this paper. This hybrid ROV can be operated similar to the traditional ROV, and it also could be operated without the need of the tether similar to the autonomous underwater vehicle.

Moreover, there was another target considered in this capstone project. The faculty recognized the benefits of potential educational experiences for engineering students to obtain through a MATE (Marine Advanced Technology Education) competition. In order to conduct research on a hybrid ROV as well as to give students learning experiences through the MATE competition, this capstone project was created in Fall 2018. Four engineering students have formed a team, and one graduate from Subsea engineering program was assigned to help the team as a mentor.

The name of the capstone project team was ORCA (Ocean Robotics Centered Applications). This two-semester capstone project was concluded in Spring 2019. After the completion of the final demo as a capstone project, the modification of the ROV had to be made to meet the MATE competition requirement and some of the functions were not needed for the competition [10]. After the modification, this student team participated in the regional MATE competition in May 2019.

III. Small scale underwater robot development via a capstone project

The Hybrid ROV has a manual control option via a tethered connection to the base station. When in manual mode, it can activate all sensors available as well as a camera, lights, and a manipulator. The addition of the camera provides real-time video. Moreover, the HROV has an autonomous control option to scan areas by a pre-programmed pattern. The HROV can obtain sensor measurements at different depths of water autonomously. As described, this capstone project was planned as a part of a multiphase project, and in this first phase, it was focused on vertical autonomous navigation operation and the depth measurements.

A. System and the operation of the underwater robot

A system block diagram of the hybrid ROV is shown in Figure 1. On the left side, it shows the components in the ROV. A Raspberry Pi Zero W board is used as a main controller unit [11]. This board is mounted on the interface PCB. The interface PCB is a custom designed PCB that can hold the electronics components and provide proper connections to sensors, ESCs (Electronic Speed Controllers), thrusters, and manipulators. The sensors include IMU (Inertial Measurement Units), Pressure, Sonar, Water temperature sensors. On the right side, it shows the base station. It consists of a Raspberry Pi 3 B+, monitors, and an Xbox controller. A tether can be used to connect the ROV and the base station. This tether is detachable. If removed, the operation of mode will be switched to an autonomous mode. If needed, the ROV and the base station can communicate over Wi-Fi.

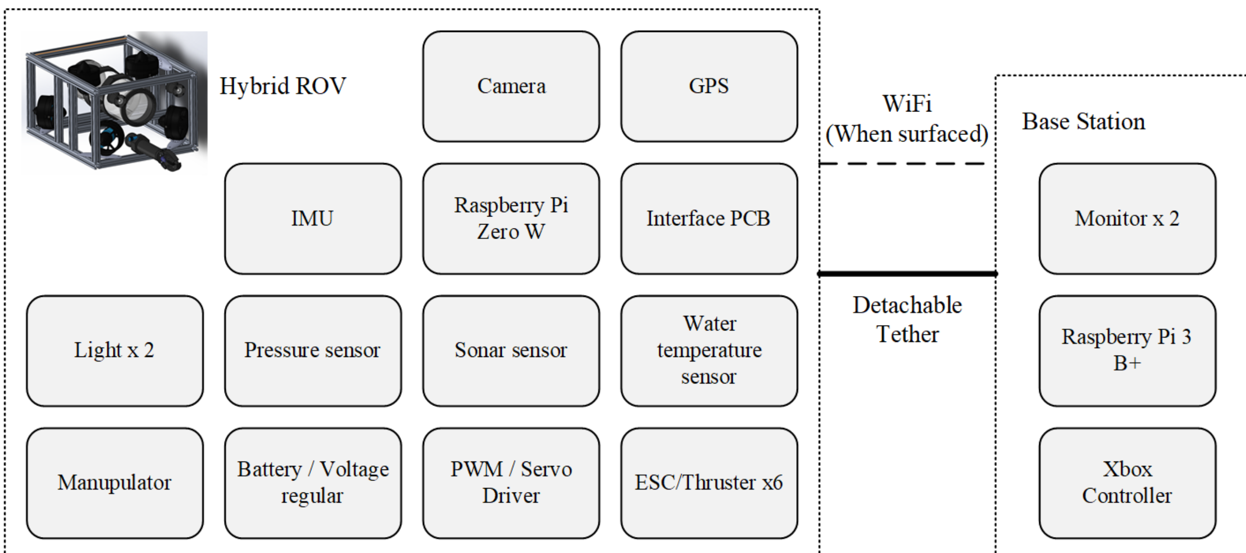

Figure 1. System block diagram of the hybrid ROV.

A functional block diagram of the hybrid ROV is shown in Figure 2. This functional block diagram provides the lower level and more details of the system connection. A Raspberry Pi 3 B+ on the base station can communicate with the Raspberry Pi Zero W in the ROV via the tether for tethered mode and via Wi-Fi for tetherless mode. The tether cable was bundled with data/communication and power cables.

The tether includes ethernet, 12V power, and video lines. The Raspberry Pi Zero W board can receive data from the sensors and provide control signals for ESCs via the UART and I^2C (Inter-Integrated Circuit) buses. The measured data and information can be sent to the base station. In autonomous mode, the hybrid ROV can be operated by a standalone 12V battery pack without the need of the base station.

For the autonomous task, the hybrid ROV initiated the task at the surface of the water as it could receive commands from the base station via IEEE 802.11n wireless protocol [12]. After receiving the commands, the hybrid ROV then can dive and collect data from its sensors by depth. The data can be stored on a SD card. The data can be retrieved by the user after the mission is completed. Once the predefined area was searched, the hybrid ROV can return to the surface of the water and await further commands from the base station.

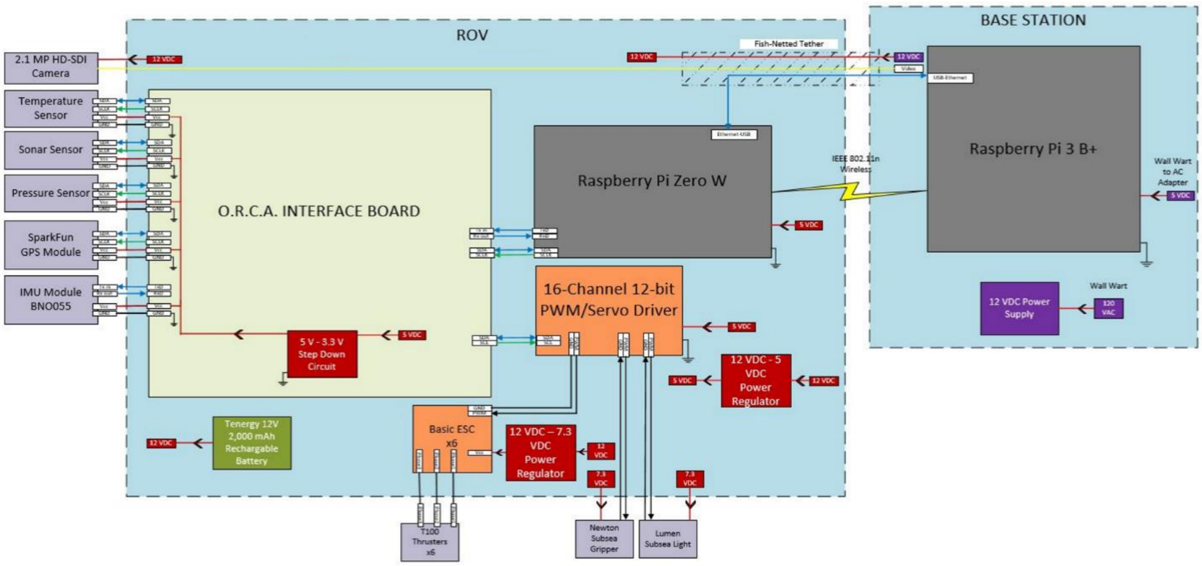

Figure 2. Functional Block Diagram of the hybrid ROV.

The fabricated and assembled hybrid ROV is shown in Figure 3. On the left side, the hybrid ROV constructed by aluminum extrusions is shown. In this implementation, there is a manipulator that can grip an object. The manipulator can also be extended by the function of a linear actuator. A total of six thrusters were used. Using this thruster configuration, it can freely navigate in the water. This ROV has two LED lights that can be used in a dark environment. On the right side, it shows a picture when the lights are turned on. On the top right side, the electronics in a waterproof enclosure is shown. This enclosure contains the electronic components including the interface PCB.

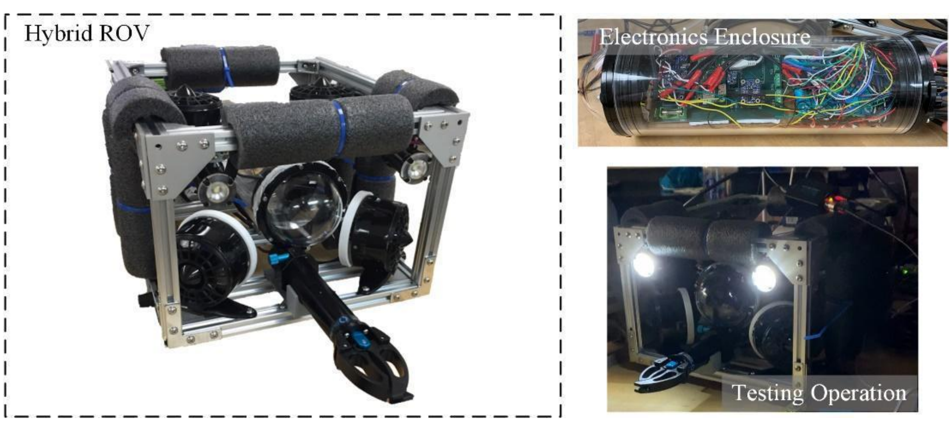

Figure 3. Fabricated and assembled hybrid ROV.

The interface PCB and the electronics modules are shown in Figure 4. A Raspberry Pi Zero W board can be mounted on the interface PCB. On the right, it shows a fuse, and the fuse can effectively protect the circuit components. 5V can be supplied through the power connector. The 5V can supply power to the PWM (Pulse-width modulation) drive and Raspberry Pi Zero W board. A voltage regulator on the interface module can take the 5 V and can generate 3.3 V. The PWM servo module is mounted on the right side. On the left side, IMU and GPS modules are mounted. The connections for the other sensors such as water temperature and pressure are also shown on the left side. This PCB is a 4-layer board. Top and bottom layers are used as signal layers. One of the middle layers is used as an internal ground plane for noise reduction and current cycle. The other middle layer is a split plane for power, featuring 5 V on the right side of the board, and 3.3 V on the left side of the board.

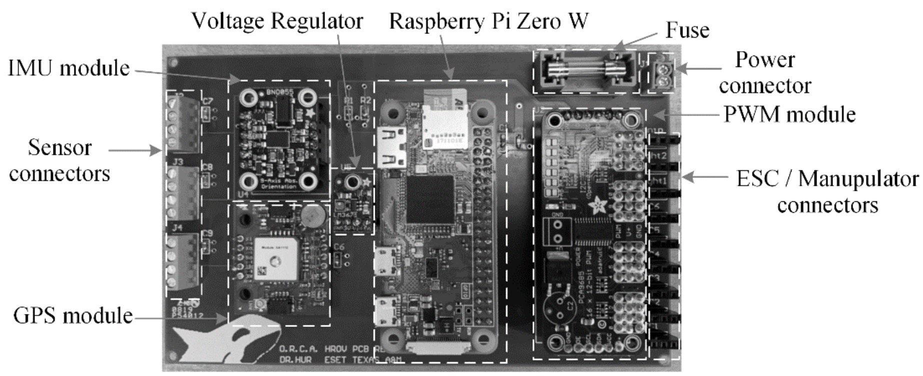

Figure 4. Interface PCB and Electronics modules

B. Test and Measurements

The testing of the hybrid ROV was performed, and the pictures of the test and measurements are shown in Figure 6. On the left side, it shows the ROV, and the base station is shown on the right side. The tether is shown in the middle. The tether or tetherless modes are tested as the cable bundle is attached or detached.

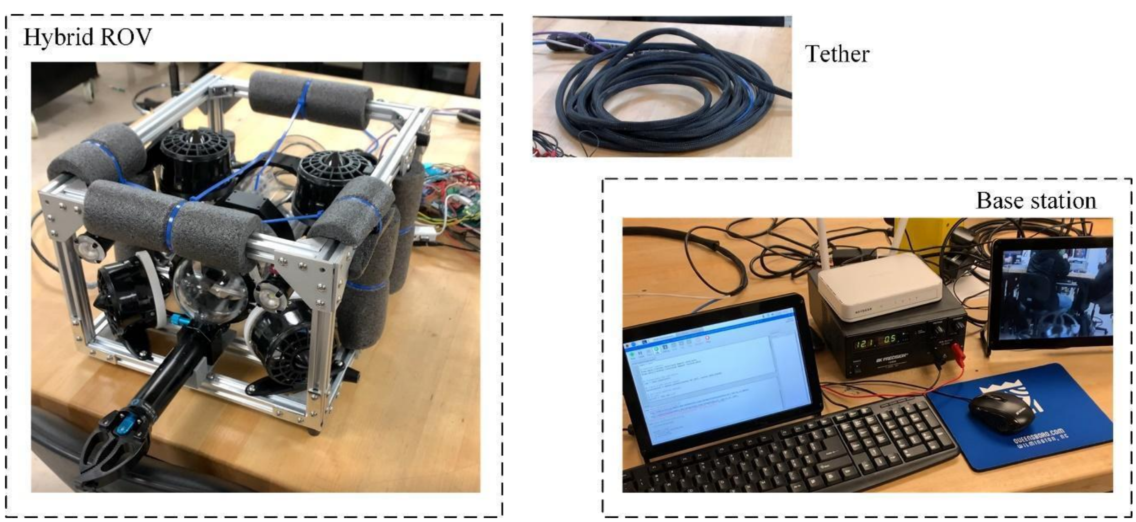

Figure 6. Tests and measurements of the hybrid ROV system.

The base station can display the camera screen and the test program can control the components such as manipulator, thrusters, and lights via an Xbox controller. The base station can receive data such as sonar sensor data to show the distance between the sensor and an object.

For the verification of functions, various tests were performed to validate the ROV prototype. Figure 7 shows the test matrix for the hybrid ROV system. The test matrix identifies tests needed to validate selected core functions. The blue squares in the matrix indicate a test that was done to validate the functions.

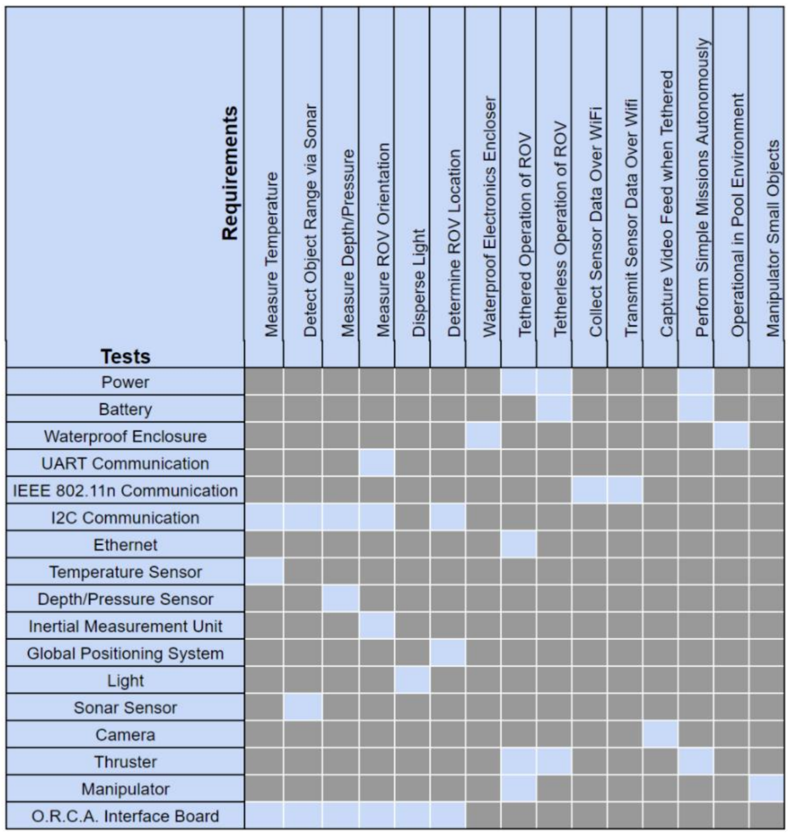

Figure 7. Test matrix for the hybrid ROV system.

C. Capstone project schedule

In order to manage the team's deliverables and deadlines, a timeline was created to visualize the order in which each deliverable needs to be completed. As an example, the second semester capstone project schedule is shown in Figure 8. The deliverable timelines are managed as software, hardware, mechanical, and documentation deliverable components. The second semester started in January 2019. One of the major milestones in the second semester was a critical design review. That was carried out on February 27, 2019. The final demonstration was carried out on April 23, 2019. The capstone project was almost completed as the team could meet all required milestones on May 1, 2019, except the MATE competition. As the last requirement, the student team participated in the MATE competition on May 4, 2019.

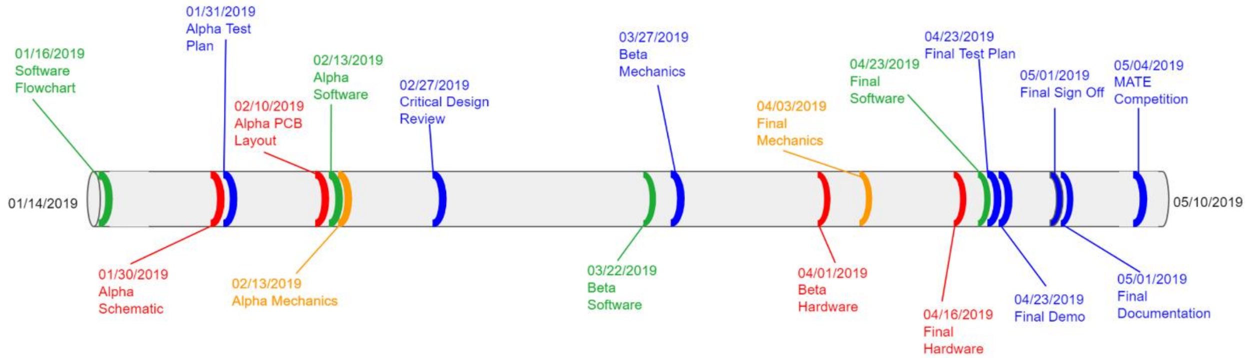

Figure 8. The second semester Capstone project schedule.

D. MATE Competition

The student team participated in the regional Texas MATE competition in May 2019 after the team had passed the final demonstration. This capstone project was not primarily targeted for the MATE competition. This means the team needed to spend extensive additional effort in modifying the ROV for the given MATE competition missions. Figure 9 shows the picture of the team and the modified ROV. One of the major modifications was to replace a single gripper to two-gripper platform. Two-gripper platform was the strategy to tackle the given missions. The best effort with a limited short amount of time did not result in a successful mission score but the team could earn a decent engineering score. The student team and the faculty could be able to gain the knowledge and learn about the educational ROV competition.

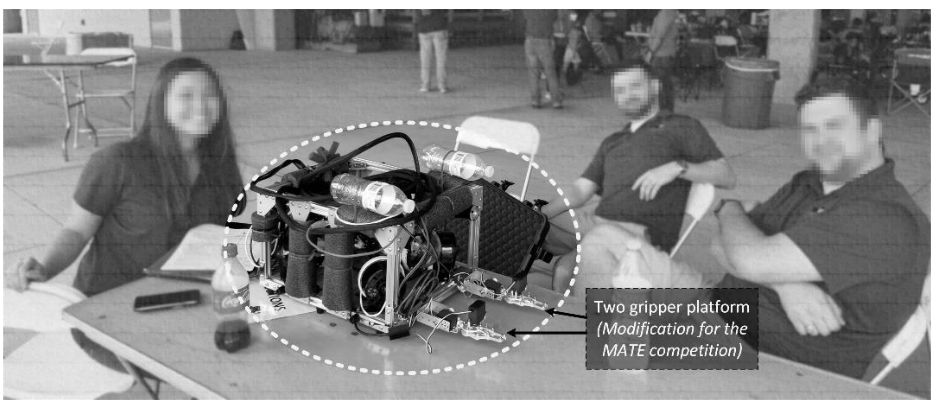

Figure 9. MATE competition and the modified Hybrid ROV.

E. Educational value and evaluation

This group of capstone project team members made constant progress during the capstone project period and met the expected millstones. Students learned various aspects of the engineering skills as well as about underwater robots. In order to gain more understanding of an educational impact, a retrospective post-capstone survey was performed via an on-line anonymous survey in May 2022. The questions in the on-line survey are shown as follows:

1. Did this capstone project enhance your learning about relevant technical skills?

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

2. Briefly state technical skills and/or tools learned through this capstone project?

3. Did this Capstone project enhance your learning about soft skills in engineering?

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

4. Briefly state soft skills learned through this capstone project.

5. Did the participation experience of your MATE ROV competition enhance your learning about technical or soft skills?

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

6. Briefly state the lessons or skills learned thorough your MATE ROV competition experience.

7. Do you think that this capstone project was beneficial, influenced, or relevant to your current or future career?

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

8. Briefly state the influence or relevance 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. All the students have participated in this post capstone survey. Participants have shown positive responses toward their capstone project related to technical skills (Q1, Average: 4.75), and soft skills (Q3, Average: 4.75), and the impact on their career (Q7, Average: 4.50).

Table 1. The post capstone survey results for the ORCA team

Survey participation rate	100% (4/4)
1. Did this capstone project enhance your learning about relevant technical skills?	4.75 (Mean) (Std. deviation: 0.43)
2. Briefly state the technical skills that you learned during this capstone project Summary of the selected answers: * Altium designer and PCB layout * Software design, System design * Mechanical design and 3D printing * ROV design	
3. Did this Capstone project enhance your learning about soft skills in engineering?	4.75 (Mean) (Std. deviation: 0.43)

4. Briefly state soft skills learned through this capstone project. *Summary of the selected answers:* * Project management * Financial planning * Communication and Teamwork * Presentation	
5. Did the participation experience of your MATE ROV competition enhance your learning about technical or soft skills?	4.25 (Mean) (Std. deviation: 0.43)
6. Briefly state the lessons or skills learned through your MATE ROV competition experience. Summary of the selected answers: * MATE competition gave us specific requirements and kept the team on track * Lessons learned from trying	
7. Do you think that this capstone project was beneficial, influenced, or relevant to your current or future career?	4.50 (Mean) (Std. deviation: 0.50)
8. Briefly state the influence or relevance of this capstone project related to your current or future career. Summary of the selected answers: * Benefits: Project management, Communication, Program-solving, Organization, Teamwork, Increased electrical hardware knowledge	

The technical skills they learned include Altium software, software tools, system design, 3D printing, and ROV design. The soft skills they learned include project management, financial planning, communication, teamwork, and presentation. Moreover, for the lessons related to the MATE competition, this competition has given specific requirements that helped keep the team on track. Since the robot was operated as they expected in the competition, there seem to be lessons learned from trying. Furthermore, for the benefits and the relevance to their career, students have shown the impact on project management, communication, problem-solving, organization, teamwork and increased electrical hardware knowledge. As a faculty member, during their capstone project period, I have observed these students' dedication to their given challenging capstone projects. They have completed their capstone successfully in Spring 2019.

V. Discussion & Concluding remarks

A capstone team created a hybrid ROV system that can be operated in either tethered or tetherless mode. This development task was carried out by four undergraduate students as a capstone project. This capstone project started in Fall 2018, and it was concluded in May 2019. This educational ROV project was able to help students to apply what they have learned in class and extend their knowledge. The functions of the hybrid ROV had been tested and verified. After the completion of their final demonstration, the capstone team put their additional effort in participating in the MATE competition. The faculty member, Dr. Hur, plans to advance the hybrid ROV research and continue to associate with new educational ROV development.

Acknowledgements

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