Small-scale Underwater Robotics Development for Underwater Archaeological Applications

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Andres Fly

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Grace Tsai graduated with bachelor degrees in Psychology and Anthropology from the University of California, San Diego in 2011. She is currently a Ph.D. candidate in the Department of Anthropology, Nautical Archaeology Program at Texas A&M University. She served as an industry advisor and stakeholder in the capstone team, Submersible Exploration Aquatic Labs (SEAL), given her nautical archaeology background, and guided the team by explaining archaeologists' needs in the field, desirable ROV specifications, and current technology used during field work. She has also led students as a business mentor for water monitoring systems, and guided and tracked students' progress collecting customer interviews through the NSF I-Site program.

Her personal research focuses on understanding post-medieval seafaring life through analysis of diet and physical labor on sailors' health. Her most recent field work includes the Gnaliç Project, an excavation of a sixteenth-century Venetian galley that sank off the coast of Croatia, the Burgaz Harbor Project, an excavation of Hellenistic harbors in Turkey, and the Shelburne Steamboat Project, an excavation of a steamboat graveyard in Vermont. She has also helped catalogue lead fishnet weights from Uluburun, a late Bronze Age shipwreck, in Turkey. In her free time, she works as the co-founder and CDO of Bezoar Laboratories LLC, a R&D company focusing on probiotic supplements.

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Erika Davila is a Molecular Biology and Neuroscience student in Texas A&M University and graduated in 2017. Erika oversaw the chemical analysis and science behind the project. Now Erika is pursuing a Ph.D. program in Neuroscience in hopes of doing research on neurodegenerative diseases.

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Abstract

Nautical archaeologists explore bodies of water around the world to survey wrecks and artifacts. If a worthy site is discovered and appropriate funding is acquired, a site is excavated to extract artifacts and sometimes the entire wreck. Divers physically swim over the site to record and excavate remains, and in many cases remove artifacts. After objects are lifted from the water, archaeological conservation methods are used to keep the artifacts intact, and the proper conservation method often depends on the chemical makeup of the water in which the artifact was submerged. For the divers' safety and the conservation of the artifacts, underwater environmental data are critical to collect prior to and during the excavation. No device specifically for this purpose currently exists, as such, a customized small-scale underwater robot was developed for underwater archaeological applications. In this paper, a small-scale underwater robot developed for underwater archaeological applications through an Engineering Technology Capstone project is presented. This underwater vehicle can measure temperature, pH, dissolved oxygen, pressure, and salinity levels. Moreover, it can collect water samples for further lab testing during the conservation process.

I. Introduction

Nautical archaeologists explore waters around the world to survey for wrecks and artifacts. When worthy sites are discovered, they dive in them and proceed to extract the artifacts. Diving into unfamiliar conditions introduces potential risks especially if environmental factors go unchecked, and currently no method to conveniently track the chemical composition of the water in dive sites exists. Although divers do not blindly dive into the wrecks, their methods for scoping out the site are primarily visual and tactile, and no means of easy chemical tracking exists. In the past, nautical archaeologists have unwittingly dived into waters that contained dangerous levels of lead, arsenic, and other chemical pollutants. Furthermore, artifacts are often delicate and require careful conservation with chemicals to reverse damage and prevent further degradation, which require conservation plans for each specific artifact [1][2]. As such, technology that can track environmental data for underwater missions is needed because there are no convenient or affordable methods to track the chemical composition of the water at these sites available in the market at the moment. To solve this issue, a multidisciplinary group was formed to create a small-scale underwater robot for underwater archaeological applications [3][4]. This work was carried out through an Engineering Technology Capstone project at Texas A&M University. This underwater robot control system consists of an underwater robot, a communications buoy at the surface, and a command center PC at the ship. The underwater robot contains temperature, pH, dissolved oxygen, pressure, and salinity sensors that are used to take measurements at different depths, along with the ability to collect water samples for further laboratory testing.

II. Capstone Design Experience

The Electronic Systems Engineering Technology (ESET) Program in the Engineering Technology Department at Texas A&M University provides a rigorous undergraduate educational program and Capstone project classes. The emphasis includes electronics, device communication, embedded systems, testing, instrumentation and control systems. Through this program, students obtain a wide range of engineering and industrial knowledge and various methods to develop, design, and implement potential products. During the two semester capstone period, students form a group and create a mock business entity with set roles per individual. Faculty members and stakeholders guide them to perform at a professional level, which is very useful in helping students as it creates a working environment similar to that of a real internship in a firm.

Six ESET students from Engineering Technology, one graduate student mentor from Nautical Archaeology and one Entomology undergraduate student formed a team to create this platform under the guidance of Dr. B. Hur. The two students from different disciplines were essential and provided valuable insights into the scientific approach and the chemical analysis for the project. Together they formed the team SEAL (Submersible Exploration Aquatic Labs) [5]. Their underwater robot system was nicknamed PUPS (Portable Underwater Probe System),

Through this project, part of the learning experience for students was to expand their horizons to perform the interdisciplinary underwater robotics research and development. They completed their Capstone project successfully in the Fall of 2018, and the underwater robot system is presented in this paper. For learning evaluation, a customized capstone exit survey was created to gauge the students' progress and learning. It revealed that the capstone experience was positive and valuable in helping them prepare for a career in this industry, and also in technical learning of engineering skills.

III. Underwater Robot Control System

The underwater robot control system, PUPS, can be divided into three subsystems: an underwater robot, buoy, and remote command center. The conceptual block diagram is shown in Figure 1. Typically, a remotely operated vehicle (ROV) is controlled by the user on a ship and the tether is also attached to the ship. In this project, instead of a tether to a ship, the ROV was tethered to a floating buoy. The floating buoy contained the battery and communication unit, providing the power to the underwater robot. The tethered buoy also works as a broker between the underwater robot and the command center on the ship [6]. This subsystem setup makes it possible to navigate the underwater robot more freely compared to traditional ROVs.

Figure 1 shows the methods of communication between the three subsystems. Between the underwater robot and buoy, an orange tether cable connects the two subsystems. Inside the tether, there are two separate cables: a Cat6 Ethernet cable for the live video feed and sensor/control data, and a power cable to power the underwater robot between the buoy and the command center. There are two separate wireless systems to communicate between the two subsystems. The first is a 2-way, 2.4 GHz frequency that is used to send and receive data from both subsystems. The second channel is a 1-way, 5.8 GHz frequency that is used to transmit the video feed from the buoy communication system to the Command Center.

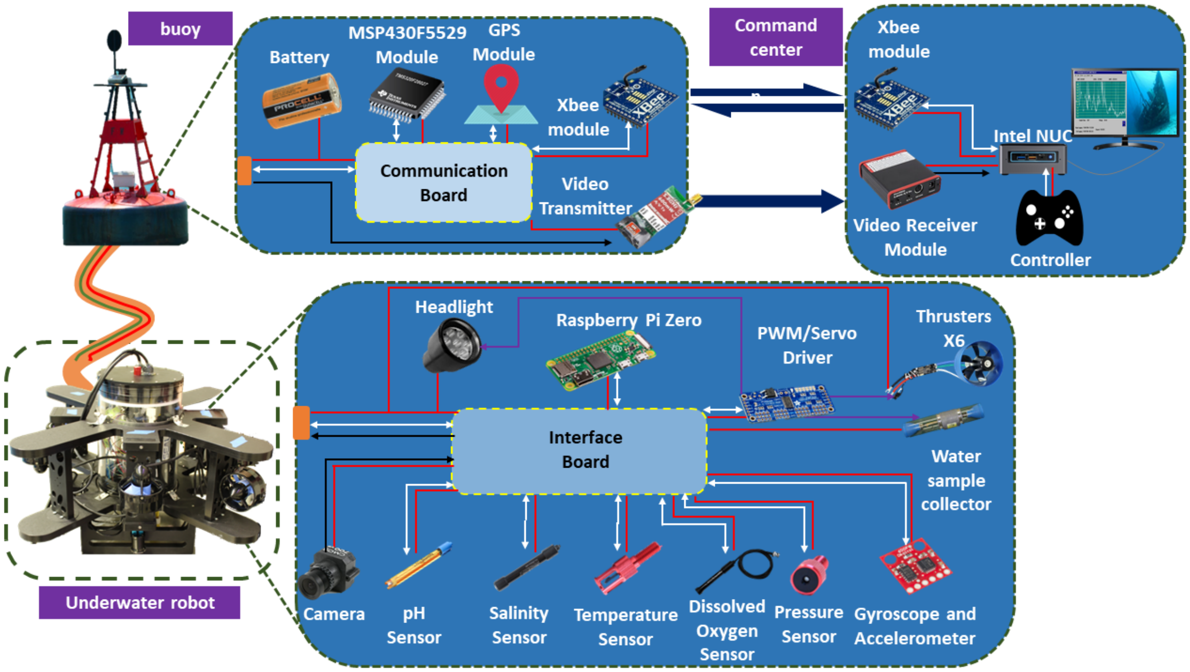

Figure 1. Block Diagram of the underwater robot control system, PUPS

Inside the underwater robot, the interface board was used to put the electronic components together. The board includes a power regulator circuit and provides the power to sensors such as pH, salinity, temperature, dissolved oxygen, pressure, gyroscope and accelerometer. It also provides the power for a driver board which sends the motor speed control data. This driver board controls six electronic speed controls (ESC) units, one pump motor for the water sample collection apparatus, and the intensity of headlights. To have enough power for the propeller motors, the ESCs are individually powered directly from the battery through a fuse box, which provides power to the thrusters. A Raspberry Pi Zero was used as an intelligence, and controls the peripherals. Camera signals were also routed through the board.

On the buoy, the battery set was placed in a waterproof enclosure. The battery supplied the power to the communication board on the buoy and to the interface board on the underwater robot. The communication board included a power regulator circuit which provided power to the video transmitter module and received a direct connection from the customized Cat6 Ethernet cable and transmitted the live video feed using a 1-way 5.8 GHz signal to the command center. The communication board also provided the power to a data transmitter/receiver module which transmitted the sensor and location data packets using a 2-way, 2.4 GHz signal to the command center. Along with sending data, this signal also receives packets of control data that come from the command center so that the user can control the movement of the underwater robot. This communication board also powered a GPS (Global Positioning System) module that determines the location of the buoy. A custom MSP430F5529 module, BH5529 module, was designed, and it was used to control the components on the buoy and process the data being collected and transmitted [7].

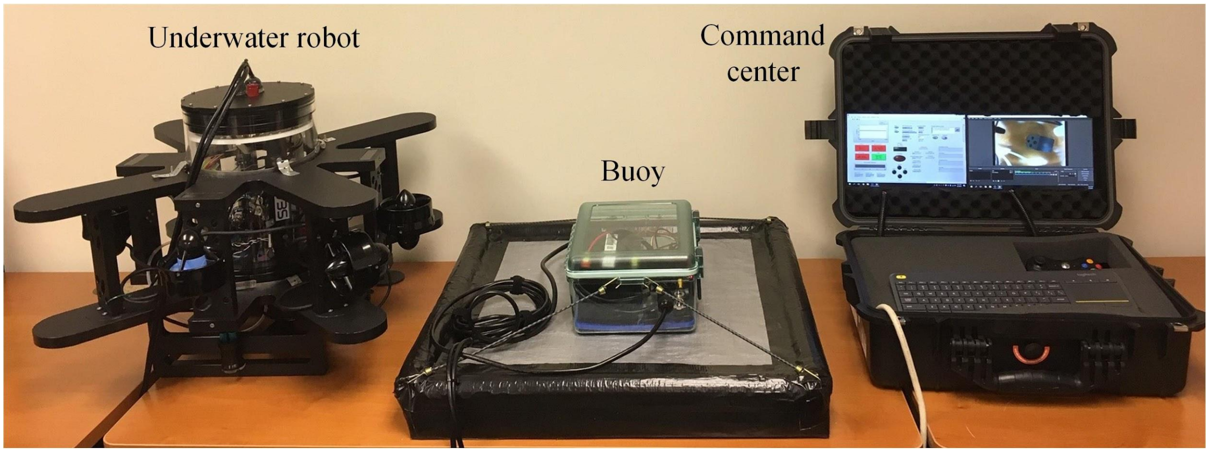

Figure 2. Implementation the underwater robot control system

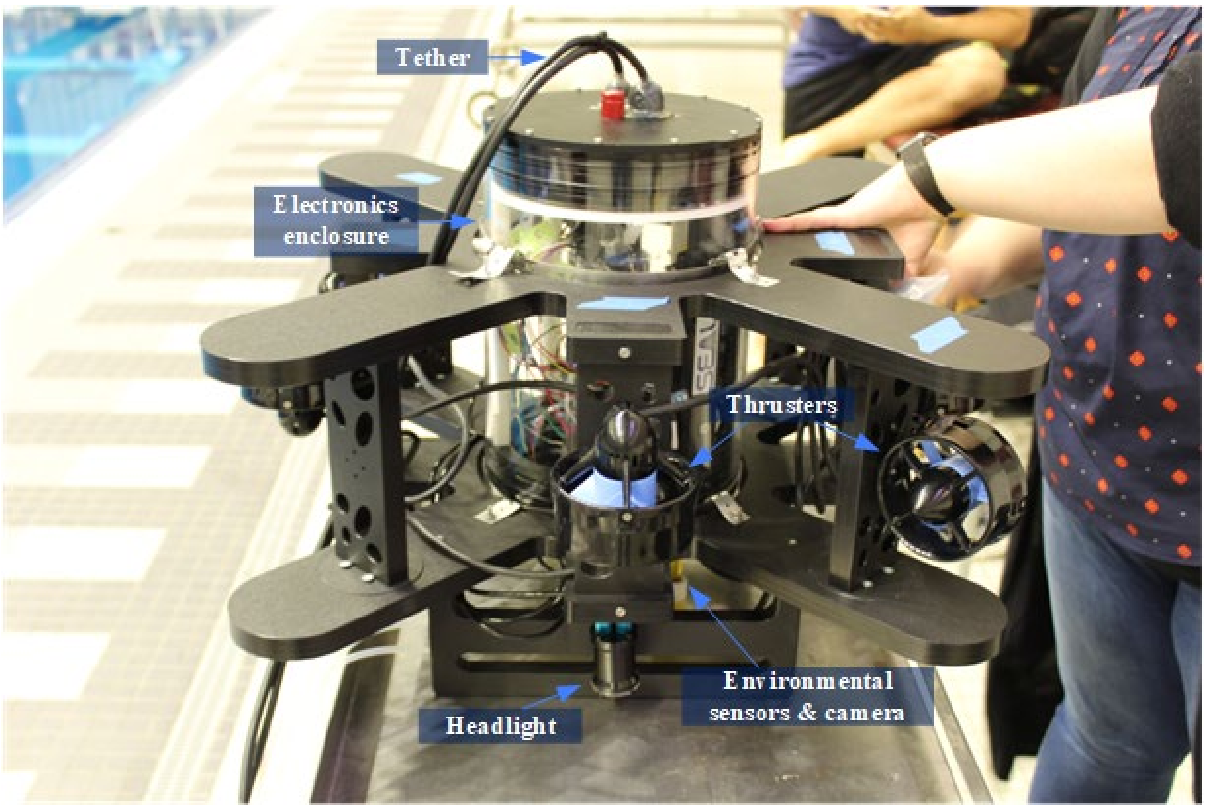

Figure 3. The underwater robot showing its tether, electronics enclosure, headlight, sensors, camera, and thrusters.

To communicate with the buoy, there is a data transmitter/receiver module on the remote command center. This module receives the packets of sensor and location data sent from the buoy and transmits the controller data from the user. In order for the 1-way 5.8 GHz signal to be picked up, there is a video receiver module on the command center. This video receiver module receives live video feed sent from the camera on the underwater robot and is processed through a USB capture card to digitize the signal for viewing. A compact PC, Intel Next Unit of

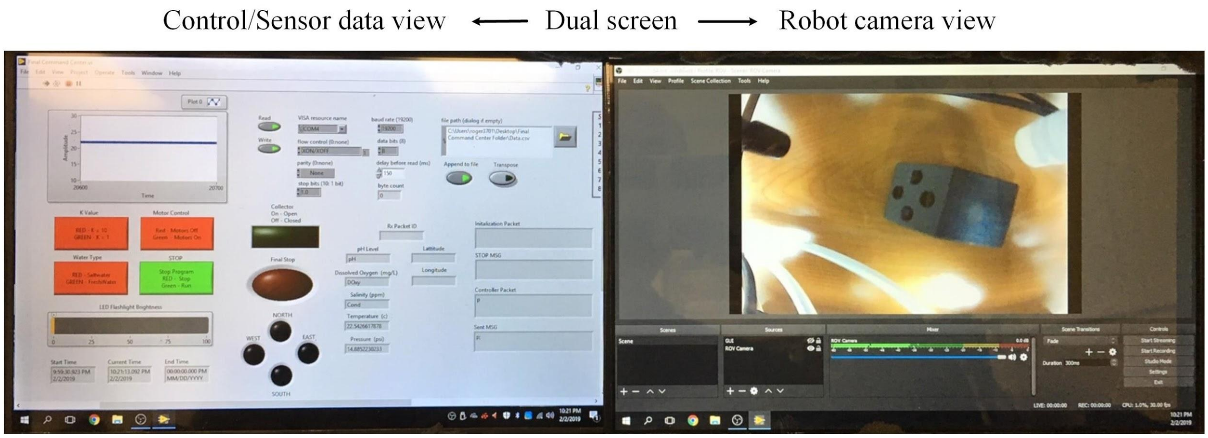

Figure 4. GUI screen (left) and video screen (right)

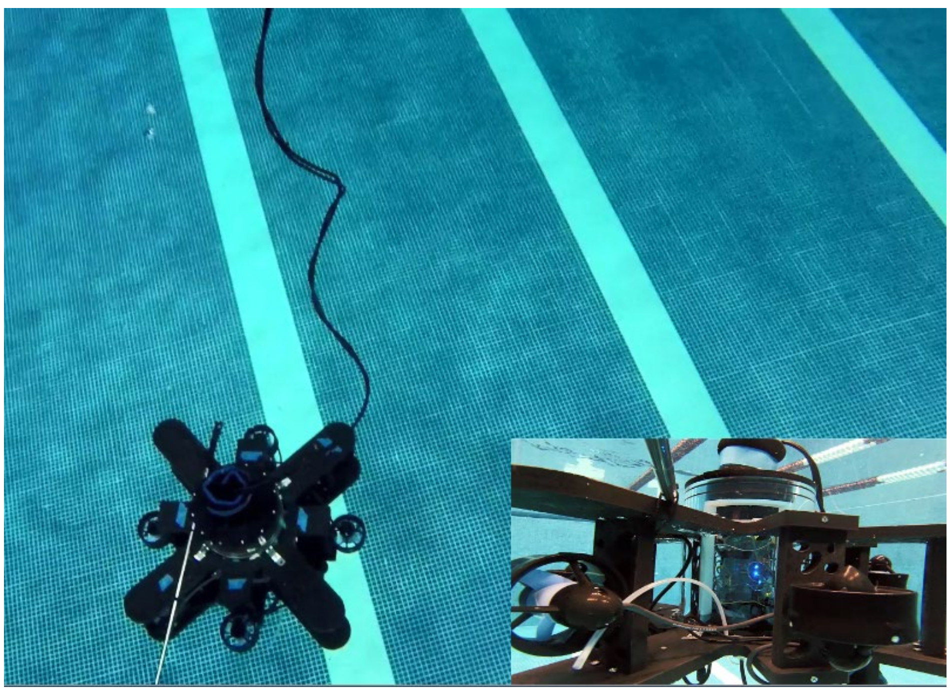

Figure 5. The ROV being tested in a pool.

Computing (NUC), was used as an intelligence for the command center. The Intel NUC displays the data on one screen and the live video feed on the other screen.

The implementation of the underwater robot control system is shown in Figure 2. On the left, is the underwater robot, in the middle, the buoy, and the command center on the right. This system has been tested in a pool environment. Further testing and measurements at different sites are expected to be performed through 2019.

Figure 3 shows a detailed view of the underwater robot. The ROV has a total of six thrusters. Four thrusters are oriented laterally for upwards and downwards movement, while two thrusters

Figure 6. A photo of the team members during their final Capstone presentation.

are oriented vertically for lateral movement. This underwater robot was purposefully designed to put more emphasis on diving, which is the reason more thrusters are added for descent and ascent, rather than lateral movement, although it can also rotate sideways with ease. The ROV's movement is similar to that of an aerial drone, with the exception that this device works under water. The center of the robot has an electronics enclosure that is watertight as it contains the electronic boards, parts, and camera. In addition, headlights were attached at the bottom of the ROV, in order to capture video in a dark environment. The tether that connects to the buoy is attached at the top.

Figure 4 shows the status picture of the remote command center. The captured sensor and the control data were shown on the left side and the real-time video was shown on the right side. The graphical user interface (GUI) screen shows the sensor data including pH, salinity, dissolved oxygen, pressure, water temperature, gyroscope/accelerometer, the remote-control data, and GPS information.

The submersion testing at a pool was carried as shown in Figure 5. It was tested in the student recreation center at the authors' University. Additional GoPro cameras were mounted to capture another view of the underwater robot under water. When running a test in the pool environment up to 6 feet of depth, the ROV did not have any leakage into the enclosure. However, when pushed to the bottom of the pool, the ROV's enclosure sprung a small leak. It needs further investigation; however, the team figured it might be from the pump system that collects water samples. This underwater robot system was tested and successfully demonstrates the functionality of the communications, sensor data collection, video display, and the movement of the underwater robot as intended.

IV. Educational assessment and benefits

The team members with teachers and mentors were shown in Figure 6. This photo was taken during the final Capstone project presentation in the laboratory where the students spent most of their time developing the underwater robot system in the Engineering Technology Department. The underwater robot can be found in the center. The controller and relevant electronics are on the workbench.

The Capstone course evaluation was performed by the University using its standard course evaluation. Since this information may not be directly relevant in giving insights to teachers to evaluate how this Capstone project was practically helpful for them, an anonymous Capstone post survey was designed as a self-study. It was conducted after completion of the capstone program and grade submission to prevent bias. The survey questions were shown as follows:

1. *Did this Capstone project enhance your learning on your relevant technical skill sets*

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

2. *Did this Capstone project enhance your learning about working in a group?*

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

3. *What was your grade from the first semester of Capstone?*

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

4. *What was your grade from the second semester of Capstone?*

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

<u>Additional Questions</u>

5. *Describe what should be improved in this Capstone experience; and/or, describe which lessons you have learned throughout this Capstone experience.*

6. *What tools, if any, did you use to manage your tasks and time effectively when working in the group?*

7. *Are there any activities or best practices you would recommend for other Capstone groups?*

8. *Do you think Capstone will be beneficial in your current or future career?*

9. Do you think having interdisciplinary members on the team helped the Capstone project? If so, how?

The summary of this post Capstone survey results is shown in Table 1. All team members participated in the survey despite the fact that the capstone students had already graduated and many are already employed in firms, indicating their continued dedication to the project. Students selected positive scores toward improvement in technical skills and their soft skills (e.g. teamwork). Students received good grades from the instructors in this project. Moreover, students provided constructive feedback through additional survey questions 5 to 9 as seen in Table 1. Overall feedback included useful management and communication tools, and tips for success in the capstone projects.

Survey participation rate	100% (7/7)
1. Did this Capstone project enhance your learning about relevant technical skill sets?	4.71 (Average)
2. Did this Capstone project enhance your learning about working in a group?	4.86 (Average)
3. What was your grade from the first semester of Capstone?	5.00 (Average) *(*Excluded N/A)*
4. What was your grade from the second semester of Capstone?	4.14 (average) *(*Excluded N/A)*
5. Describe what should be improved in this Capstone experience; and/or, describe which lessons you have learned throughout this Capstone experience. *Summary of the selected answers:* ** Importance on the communication between all members, * learned professional presentation skill, * implementation of project needs is a great experience, * option about the continuation of this project.*	
6. What tools, if any, did you use to manage your tasks and time effectively when working in the group? *Summary of the selected answers:* ** Gantt chart and RAM, * Time sheet, * Google calendar, * ProjectLibre*	
7. Are there any activities or best practices you would recommend for other Capstone groups? *Summary of the selected answers:* ** Learn to work well as a team, * Strong communication, * Start early, * Updating Gantt chart and RAM*	
9. Do you think having interdisciplinary members on the team helped the Capstone project? If so, how? *Yes: * different viewpoints of the project and the ideas, * valuable input*	

Table 1. Summary of the Capstone exit survey results.

V. Concluding remarks

This underwater robotics project was carried out in a multidisciplinary setting, and this Capstone project has successfully met the Capstone requirements and it showed high educational values. The ESET program Capstone course does not require the formation of a multidisciplinary team, but this was an extra effort and essential formation due to the nature of this project. Hence, it allowed the Engineering Technology students to be exposed to the knowledge from various fields including engineering, underwater archaeology, and chemical analysis. The underwater robot control system was completed according to this project's Capstone standard, and the robot has a decent level of the functionality. The customized anonymous survey results also indicate a positive attitude toward this project and the benefits of the multidisciplinary approach. In the near future, the authors plan to pursue more innovative underwater robot applications.

Acknowledgements

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