Submersible sensor device and remote aquatic environment system for monitoring shallow water pollution

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Abstract

Water is a vital natural resource for humans and living creatures. 97% of the Earth's water can be found in oceans. The water can be found to be polluted in many different ways. The pollution of an aquatic environment, particularly at a specific site, can be a highly relevant topic for scientists and engineers. In this paper, a submersible sensor device as a part of a remote aquatic environment pollution monitoring system is presented. The remote aquatic environment pollution monitoring system can be used to collect water property data locally. The data collected from multiple locations can be analyzed to create predictive decisions through the neural network and machine learning analysis. A submersible water property sensor device is attached to the floating object and sends the data wirelessly. The collected data can be sent over the Internet to a web server such as Amazon Web Services (AWS). This is a multidisciplinary project with two departments of Engineering Technology and Ocean Engineering at Texas A&M University. The research has been conducted by engineering students, including a graduate student from the Electrical Engineering Department. This is a pilot research and development effort for further expansion with the potential involvement of more students. The submersible sensor device can measure water temperatures and light conditions at different depths to analyze the turbidity and cleanliness. In this paper, the submersible sensor device and aquatic environment pollution monitoring system will be introduced, and the educational values and lessons will be presented and discussed.

I. Introduction

Water is a vital natural resource for humans and living creatures. 97% of the Earth's water can be found in oceans. The remaining 3% can be found in many areas like glaciers, ice, rivers, lakes, and underground [1]. A wide variety of living creatures and ecosystems can be found in shallow water and coastal water. For humans, some of us access the ocean water through a sandy or rocky shore, which is a beach. The pollution of the body of water is becoming a more serious problem. The water can be found to be polluted in many different ways, including the infusion of dirty water from yards and fields, discharges and debris from ships and boats, trash, and harmful chemicals, which affect aquatic ecosystems [2].

The health of humans can be affected by polluted water. The picture that can be found in the article [3] shows children playing around the sewage pipe, which can be harmful to their health. Besides, the picture that can be found in the news article [4] shows a man swimming in polluted, murky water. These examples imply that the polluted water could affect human health. It is desirable to monitor the contamination of water and process it properly. The monitoring and analysis of water bodies have been regularly conducted, and data have been collected, such as by the National Oceanic and Atmospheric Administration (NOAA), and satellite images and coastal data can be obtained [5]. However, the pollution of an aquatic environment, particularly at a specific site, can certainly be a point of interest for scientists and engineers. In this paper, a remote aquatic environment pollution monitoring system is introduced, and it is used to obtain micro-climatology data at the test sites of interest. The educational and multidisciplinary approach will be introduced, and the remote aquatic environment system will be presented. And, the educational values and the lesson will be presented.

II. Educational effort and Multidisciplinary research

This research project in this paper has been derived from the continued research and development by multiple generations of capstone project teams. The first author in the Engineering Technology department has been working with engineering students on underwater robots and surface water robot platforms [6-9]. The first author's research group has been working with undergraduate and graduate students to create educational underwater robots and surface water robot platforms. And, the research effort has expanded to involve researchers in the Ocean Engineering department. As of Spring 2026, a graduate student in the Electrical Engineering department has also been involved in the research project.

One of the relevant capstone teams for the work shown in the paper is the ManateeTech capstone team with four undergraduate engineering students. This capstone team developed a floating buoy and published their effort at the ASEE GSW conference in 2022 [8]. Capstone project courses in the first author's Engineering Technology department are managed as two-semester courses. Students develop, design, and fabricate prototype systems during the two semesters. This paper presents a remote aquatic environment system, and the work became a preliminary work of the remote aquatic environment system. The remote aquatic environment system has been matured by other Capstone teams and further research efforts.

III. Submersible sensor device and remote aquatic environment system

A remote aquatic environment system to monitor shallow water pollution is introduced and shown in Figure 2. This remote aquatic environment system is used to obtain micro-climatology data at the test sites of interest.

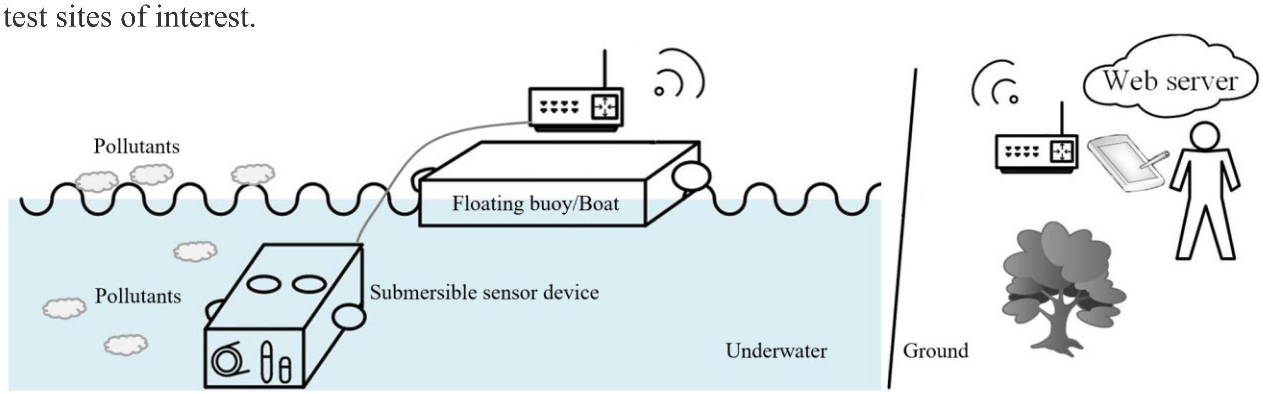

Figure 2. A conceptual diagram of a remote aquatic environment system for monitoring shallow water pollution

A submersible sensor device is placed in the water as shown in Figure 2. It can be deployed where there are pollutants or where it needs to be monitored. The submersible sensor device can perform the survey missions at different depths. The submersible sensor device has a water temperature sensor, a pressure sensor, and a light sensor. In addition, the submersible sensor device has an underwater camera that can be used to monitor the level of pollution or analyze the objects and pollutants in the water.

A tether from the submersible sensor device was connected to a floating buoy or a boat. The floating boat includes a communication unit to exchange data and control packets between the control station at a remote location. The control station can be located in a ground location, as shown in Figure 2. The transmitted data can be uploaded to a web server over the Internet. The control station can serve as a lightweight messaging server or a broker by using MQTT (Message Queuing Telemetry Transport). MQTT is one of the efficient technologies in IoT (Internet of Things) systems [10-12].

AWS (Amazon Web Services) can be used in aquatic environment pollution monitoring systems. AWS IoT Core can connect IoT devices using the MQTT protocol [13][14]. The data in AWS can be analyzed and processed using cloud-based machine learning (ML). AWS offers Amazon ML services such as Amazon SageMaker and AWS IoT Greengrass. Using the collected camera and sensor data, engineers and scientists can perform analysis to monitor and analyze the pollution levels for the site. The data collected from multiple sensors and from multiple locations can be used in analysis to create predictive decisions and models associated with pollutants and pollution through neural network analysis and machine learning (ML) analysis.

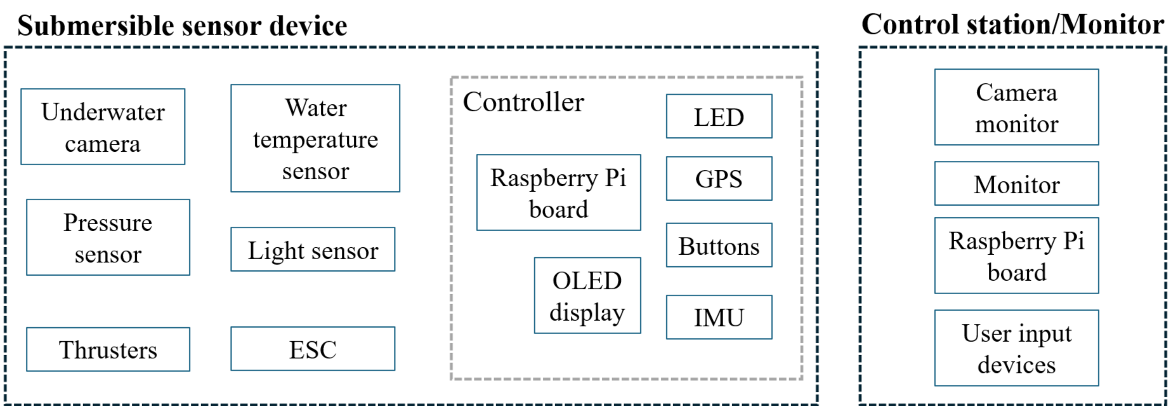

Figure 3. Block diagram of the components in a remote aquatic environment system for monitoring shallow water pollution.

A block diagram of the components in an aquatic environment pollution monitoring system presented in this paper is shown in Figure 3. A submersible sensor device is shown on the left side. And, it has thrusters that can be used in ascending (rising) and descending (diving) of the device in the water. This controller unit has an embedded Linux system built on a Raspberry Pi board [15][16]. A submersible sensor device includes an underwater camera, a water temperature sensor, a pressure sensor, and a light sensor.

A control station and monitor are shown on the right side. The control station can control the submersible sensor device and receive data. The control station can be configured to be an MQTT broker to send the data to a web server, such as AWS. A separate monitor was used to show the video from the submersible sensor device.

Figure 4 shows a fabricated prototype of the submersible sensor device. This prototype was created by repurposing the floating buoy frame and sensor parts that were previously used in the ManateeTech Capstone team. This submersible sensor device is constructed to be relativity sturdy by using aluminum extrusions. For a submersible device, it is desired to have the buoyancy to be slightly positive. The buoyance can be easily adjusted by adding more buoyancy materials on the buoy frame. A lightweight anchor can be loosely attached additionally to the bottom to sustain the orientation of the submersible sensor device in the water during the operation.

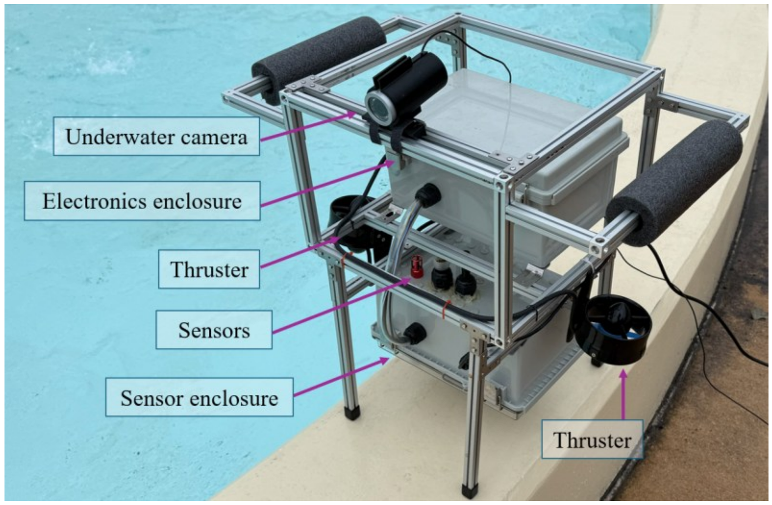

Figure 4. Fabricated prototype submersible sensor device.

A controller electronics unit in a submersible sensor device is shown in Figure 5. A custom PCB (Printed Circuit Board) was designed and fabricated. A Raspberry Pi board is used as an intelligence unit. On this PCB, a buzzer, LED, IMU (Inertial Measurement Unit), OLED (Organic Light-Emitting Diode) display, GPS (Global Positioning System), and button components were mounted. Figure 5 shows the placement of these components on the PCB. This controller electronics unit is designed to be controlled by an embedded Linux, and rich development tools, such as programming languages such as C++ and Python [7], are available for users and developers.

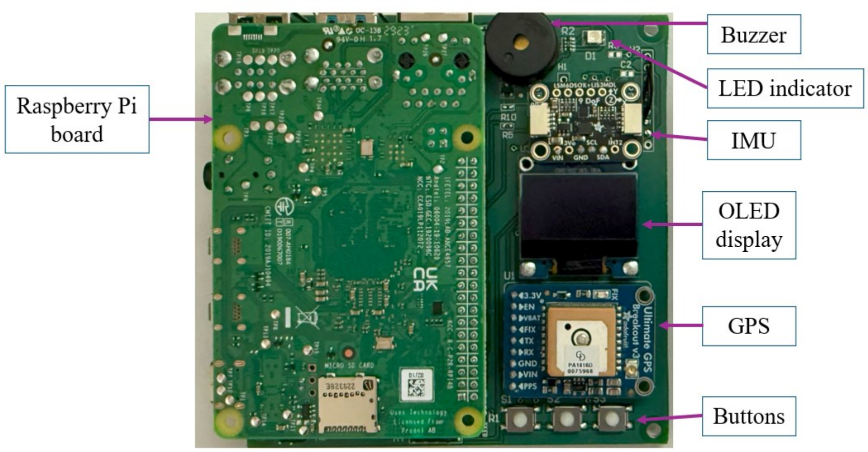

Figure 5. A controller electronics unit in a submersible sensor device.

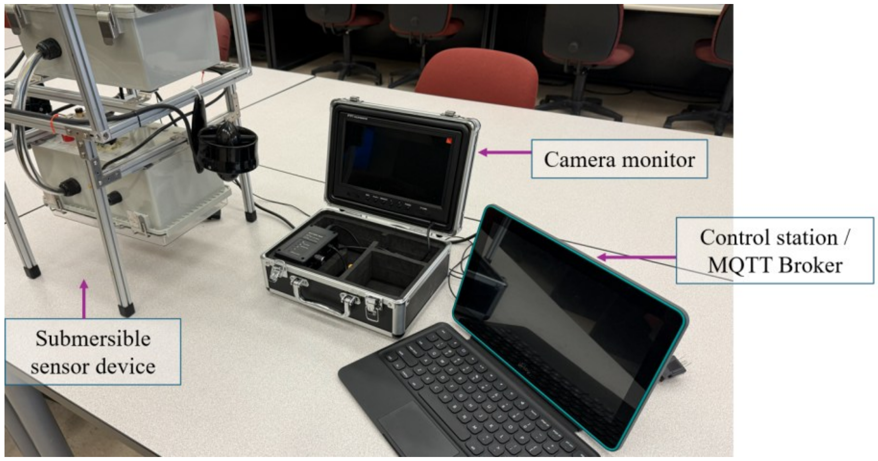

Figure 6. Control station and camera monitor.

The prototype control station and camera monitor are shown in Figure 6. The control station is implemented using an additional Raspberry Pi Embedded Linux system. In this Raspberry Pi Embedded Linux system, the system is configured to support MQTT and works as an MQTT broker. It can access and communicate with the Raspberry Pi unit in the controller unit of the submersible sensor device. This paper presented a remote aquatic environment system for monitoring shallow water pollution and demonstrated the fabricated system. The authors plan to present further research progress in future publications. In the following section, the educational values and lessons will be presented and discussed for this multidisciplinary project through multiple capstone projects.

V. Educational values and lessons

The remote aquatic environment system in this paper has been derived from the multidisciplinary efforts involving three departments of Engineering Technology, Ocean Engineering, and Electrical Engineering. This project is relevant to the prior capstone project efforts for the first author's side of the Engineering Technology department. For the ManateeTech capstone [8], four undergraduate engineering students were educated and involved in 2021−2022, and their work contributed as a preliminary device and system.

There are other relevant capstone project teams. One of them is the CRANE Tech capstone team [6]. They created an underwater robot for building structural analysis. Four undergraduate engineering students were educated and involved in 2020−2021. Another capstone team is the ORCA capstone team [7]. They created a hybrid underwater robot that can be operated with a tether or tetherless. As an extra effort, this team participated in a regional Texas MATE competition. Four undergraduate engineering students were educated and involved in 2018−2019. For the ORCA team, a post-capstone survey was conducted [7]. For reference, selected questions and the answers from the survey by the ORCA team are listed as follows:

> *(Question 1) 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

(Question 2) 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

(Question 3) Do you think that this capstone project was beneficial, influenced, or relevant to your current or future career? (Likert chart 5 ~ 0)
Response: 4.50 (Mean) (Std. deviation: 0.50)

Another capstone team is the SEAL capstone team [7]. They created a small-scale underwater robot for underwater archaeological applications. Six undergraduate engineering students were educated and involved in 2018. Overall, through these four capstone projects, a total of 18 undergraduate engineering students were involved. Two students were female engineering students (11.1%). These capstone projects impacted the remote aquatic environment system for monitoring shallow water pollution in this paper.

Moreover, the lessons learned from the first author's side through this remote aquatic environment system project are followed. First, the capstone teaching efforts for instructors can contribute to research, as they can be used in creating new devices or systems for research. This is related to the integration of teaching and research efforts. Faculty members who teach or are involved in capstone projects may generate new research projects by using their knowledge and experience learned through the capstone projects.

Second, this project was expanded to involve students and faculty members from multiple departments. In this project, two faculty members in the Engineering Technology department and one faculty member in the Ocean Engineering department were involved. And, one graduate student from the electrical engineering department was involved. For the capstone teams, a total of 18 undergraduate engineering students through multiple generations of four capstone teams in the Engineering Technology Department were involved. Considering only the most relevant capstone team, four undergraduate engineering students in the Engineering Technology Department were educated and involved.

Third, the importance and the popularity of machine learning have increased. Engineering projects may need to incorporate machine learning components to solve the given problems. For IoT devices and systems, cloud-based machine learning tools or embedded Linux systems may be more suitable to meet the needs of complex functional requirements. Last, as the authors will continue to research and develop underwater and surface water robots associated with this technology, it is expected to see further expansion of this technology with the potential involvement of more engineering undergraduate and graduate students.

VI. Summary and Conclusions

A submersible sensor device and a remote aquatic environment system were presented in this paper. It can be used for monitoring shallow water pollution. The water can be found to be polluted in many ways. For certain sites of interest, it is important to monitor and process them accordingly for human health. The remote aquatic environment pollution monitoring system can be used to collect water property data locally. The data can be analyzed to create predictive decisions through the neural network and machine learning analysis. This research project was conducted as a multidisciplinary project and involved several undergraduate and graduate students. The prior effort includes the capstone team effort with four undergraduate students. For some institutions and certain departments, it is expected that faculty members be productive both in research and teaching. This research project was discussed as an example of the integration effort in teaching and research. The educational values and lessons were discussed. The authors plan to continue to pursue innovative underwater robotics, devices, and systems, and share the lessons learned through future publications.

References

1. R. W. Schmitt, (1995), *The ocean component of the global water cycle*, Reviews of Geophysics, 33(S2), pp. 1395-1409.
2. P. J. Landrigan, J. J. Stegeman, L. E. Fleming, D. Allemand, D. M. Anderson, L. C. Backer, & P. Rampal, (2020). *Human health and ocean pollution*, Annals of global health, 86 (1).
3. S. Hu, (2020), *Beach Pollution 101*, Online: https://www.nrdc.org/stories/beach-pollution-101#whatis
4. D. Markowitz, (2014), Punch Shots: *Murky waters await sailors in Brazil*, Online: https://www.delcotimes.com/2014/05/19/punch-shots-murky-waters-await-sailors-in-brazil
5. NOAA, Satellites, Online: https://www.noaa.gov/satellites
6. Hur, B., Zhan, W., Ryoo, B. Y., Perea, A., Davila, C., Burciaga, C. Domki, S., Bustos, C., Orozco, L., Consuelo, G., Vazquez, R. (2022), *Integrated multidisciplinary capstone projects of an underwater robot and a quadcopter for building structural analysis*, 2022 ASEE Annual Conference.
7. Hur, B., Goins, D., Allen, J., Proksch, B., Wood, C., Alvi, M., Goulart, A. E. (2022), *Educational Small Scale Underwater Robot Development via a Capstone Project in Engineering Technology*, 2022 ASEE Annual Conference.
8. Hur, B., Castro, S., Carrillo, O., Villegas, R., Ruepprich, C., Myles, K., Adelman, Z. (2022), *Capstone project progress on the floating buoy IoT device development for mosquito research*, 2022 ASEE Gulf Southwest Annual Conference.
9. Hur, B., Casas, R., Cervantes, D. A., Comer, J. R., De Anda, B. R., Ledbetter, L. J., Fly, A., Davila, E. L. (2019), *Small-scale Underwater Robotics Development for Underwater Archaeological Applications*, 2019 ASEE Annual Conference.
10. Pan, Z., Hur, B., Myles, K., Adelman, Z. (2022), *Development of Raspberry Pi 4 B and 3 B+ Micro-Kubernetes Cluster and IoT System for Mosquito Research Applications*, Computation, 10 (12), pp. 221.
11. Mishra, B., Kertesz, A. (2020), *The use of MQTT in M2M and IoT systems: A survey*. IEEE Access, 8, pp. 201071-201086.
12. Wukkadada, B., Wankhede, K., Nambiar, R., & Nair, A. (2018), *Comparison with HTTP and MQTT in Internet of Things (IoT)*, 2018 International Conference on Inventive Research in Computing Applications (ICIRCA), pp. 249-253.
13. Kodali, R. K., Sabu, A. C. (2022), *Aqua monitoring system using AWS*, 2022 International Conference on Computer Communication and Informatics (ICCCI), pp. 1-5.
14. Pierleoni, P., Concetti, R., Belli, A., Palma, L. (2019), *Amazon, Google and Microsoft solutions for IoT: Architectures and a performance comparison* , IEEE access, 8, pp. 5455-5470.
15. Hur, B. (2025), *Machine learning and Vision Based Embedded Linux System Education*, 2025 ASEE-GSW Annual Conference.
16. Hur, B., Malawey, D., Morgan, J. A., Song, X., Langari, R. (2020), *Open-source embedded Linux mobile robot platform for Mechatronics Engineering and IoT Education*,
17. Hur, B. (2025), *Python-based Microcontroller Architecture and Microcontroller Application Education in Engineering Technology*, 2025 ASEE-GSW Annual Conference.