AC 2010-2117: EXPERIMENTAL PROTOTYPE OF A REMOTE-CONTROLLED PLATFORM TO MONITOR WATER QUALITY DATA

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Experimental Prototype of a Remote-Controlled Platform to Monitor Water Quality Data

Abstract

Eutrophication (nutrient-enrichment) leading to algal blooms is a serious threat to the coastal bays and the open oceans. As a consequence of this algal proliferation, changes in pH, salinity, dissolved oxygen, and turbidity could impact various marine and estuarine ecosystems in an adverse manner. This provided the motivation to develop a multisensory remote-controlled platform for applications in recording the water quality data from the coastal bays of the Delmarva Peninsula; as well as to analyze and compare the pH, salinity, and dissolved oxygen data trends from the platform to the multi-parameter YSI unit; and to map the sensor data using geospatial information technologies. A cost-effective Lego Mindstorm's NXT system in combination with a radio-controlled boat and Geographical Positioning System (GPS) was configured for this purpose as a summer (2009) experiential learning and research project for an undergraduate engineering student. Preliminary tests were done with the platform for recording data from the Assateague (Maryland) and Chincoteague (Virginia) Bays of the Delmarva Peninsula in areas where seagrass ecosystems are impacted by increased eutrophic conditions. The faculty members in the department of Natural Sciences and Engineering programs at the University of Maryland Eastern Shore (UMES) collaborated to initiate this effort in the summer. They have integrated project assignments related to enhancement, data collection, and data analysis utilizing the multi-sensor platform in Marine Botany and Instrumentation courses offered in the fall to undergraduate students in the environmental sciences and engineering majors respectively,. This paper highlights the summer efforts and the subsequent student learning experiences during the fall semester involving this experimental platform. Future educational and research efforts to develop and use an autonomous water quality data collection system for lakes, rivers, and bays are underway.

1.0 Introduction

The problem of water eutrophication has become very severe worldwide. The nutritive organic wastes resulting from land runoff, river inflow, or sewage discharged into the coastal areas with low rates of water exchange often could lead to proliferation of the growth of excessive amounts of both micro and macroalgae.[1] The water body impacted is termed "eutrophic" (nutrient enrichment), and the proliferated algal biomass in such bodies of water could lead to increased turbidity, and altering conditions of pH, salinity, and oxygen depletion. An increased turbidity results in light attenuation for photosynthesis in seagrasses, thereby, impacting the survival of these macrophytes along with those floras and faunas dependent on these beds.[2] The fluctuations in free carbon dioxide values vary with the algal populations. As the diversity and density of algae increase, the amount of free carbon dioxide for photosynthetic activity becomes limiting. The pH changes in these water bodies are governed by the amount of free carbon dioxide and bicarbonate, and could eventually be detrimental for the organisms sensitive to such changes. The algal masses consume the dissolved oxygen for respiration leading to anoxic conditions in the waters which in turn could result in massive fish kills and related organisms.[4] The algal blooms are a strong indication of the overall health of a body of water in any region, and through monitoring the water quality of a specific ecosystem it becomes much easier to devise a water quality management plan towards reversing or preventing the changes that are negatively affecting the region.[5]

The monitoring of water quality using remote sensing was initiated in the 1970's using earth resources technology satellite, later renamed Landsat1 (ERTS-1). Since then, the digital evaluation of remotely sensed data has been widely used to estimate the water quality parameters of surface waters. Through advancement in such technologies, more efficient and powerful technologies have surfaced.[6]

One such example is the observing system along the coastal ocean regions of Virginia, Maryland, and Delaware. New sensors are developed, tested, and deployed on platforms to support NOAA and NASA coastal ocean remote sensing activities. A Coastal Bio-Optical buoy (COBY) is deployed and maintained during biweekly cross-shelf surveys. This Ocean-Atmosphere Sensor Integration System (OASIS), comprising of a fleet (6-12) of solar-powered surface autonomous vehicles deployed offshore to measure surface ocean currents, meteorological measurements, surface ocean salinity and temperature, air-sea CO_2 fluxes, water leaving radiances, chlorophyll a and CDOM fluorescence, and algal bloom detection, is the template for the autonomous remote sensing in the coastal regions of the Delmarva Peninsula.[7]

The OASIS project in collaboration with the regional partners such as the University of Maryland Eastern Shore, inspired the development of an experimental prototype of a remote controlled platform referred to as "Aquabot", which is used to monitor selected water quality variables in lakes, rivers, and bays on a small scale. A cost-effective Lego Mindstorm's NXT system in combination with a radio-controlled boat and Geographical Positioning System (GPS) was configured for this purpose. The system measures salinity, pH, turbidity, and dissolved oxygen levels in a particular body of water. The prototype is a simple cost-effective solution for water quality data collection in these areas, and also provides insight for future improvements for developing autonomous water quality data collection systems in low-energy fresh water and estuarine environments.

The faculty in the Department of Natural Sciences, and Engineering and Aviation Sciences at the University of Maryland Eastern Shore (UMES) collaborated to initiate this effort of providing multidisciplinary experiential research activities to undergraduate engineering (exchange) and environmental sciences' students in the summer of 2009. For furthering the interdisciplinary collaboration and research experiences for undergraduate students in environmental sciences and engineering, mini projects involving the "Aquabot" were integrated in two courses in Fall 2009: BIOL 202 (Marine Botany), and ENGE 380 (Instrumentation).

Through the development of the Aquabot, and integration of this platform in summer research and courses in engineering and environmental sciences, the following objectives are met: 1) to develop, maintain, and improve a multi-sensor remote controlled platform that would have future applications in recording water quality data from the bays of the Delmarva Peninsula; 2) to analyze and compare the pH and salinity data (and subsequently surface temperature and dissolved oxygen data also) between fresh water and estuarine environments with the device; and 3) to represent the selected water quality attribute data in geo-referenced maps.

2.0 Research Experience in Summer 2009

During the summer of 2009, an exchange undergraduate student intern from Morgan State University spent 8 weeks at UMES, and worked under the supervision of two faculty; one from the Department of Engineering and Aviation Sciences, and the other from the Department of Natural Sciences. The exchange student was exposed to the OASIS project and worked as part of student team towards developing experimental prototype of a remote-controlled platform called the "Aquabot system" at UMES.

The core of the Aquabot system is the Lego® Mindstorms ® NXT[8], which is a robotics kit that allows the user to create, store, save, and run programs for performing different tasks. The NXT is a powerful platform, with connection ports for three motors and four sensors. In the current configuration of the Aquabot system, the four Vernier ® water quality sensors[9] occupy each of the available sensor ports. Four Vernier ® sensor adapters were used with the NXT for compatibility.

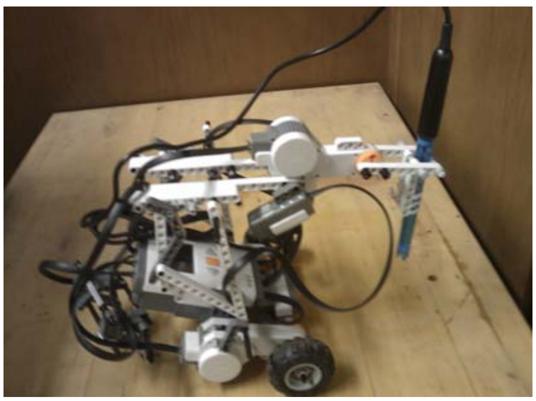


Figure 1a

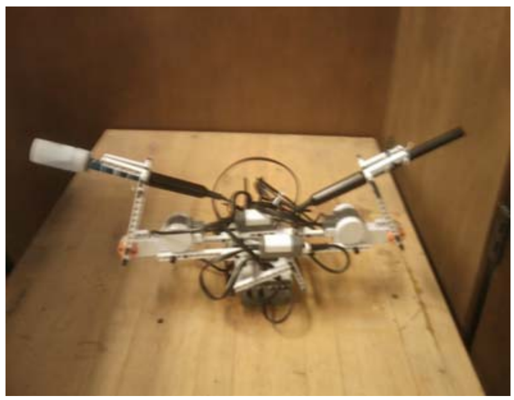


Figure 1b

Figures 1a and 1b – Initial test configurations with NXT- Vernier sensor systems.

The NXT unit is programmed using Lego ® Mindstorms ® Software powered by LABVIEW. In order to ensure that the use of the water quality sensors would be practical for Aquabot system, the NXT was tested in various ways. By assembling and testing the NXT in several different configurations (Figures 1a and 1b) with the sensors, the behaviors, response times, the overall operation and accuracy of the system proved to be acceptable for the purposes of developing the Aquabot prototype.

The NXT also serves as a data logging system, and the data can be easily downloaded to a laptop or desktop computer for further processing and analysis. As an additional component of the data logging process, a GPS unit[10] is integrated with the Aquabot, which allows for each of the sensor data to be linked to a location value. Since the GPS device is independent an appropriate mechanism was designed using Lego pieces to toggle the logging button of the GPS device. GPS unit acquired, uses a rocking selector button, thus a mechanism that would convert the rotary motion from a motor integrated at one of the motor ports of the NXT to linear reciprocating motion had to be developed. Alternative configurations using a rack and pinion and a worm and worm wheel drive mechanisms were constructed and tested. It was determined that the rack and pinion based system performed appropriately. This system allows proper transmission of forces to activate the GPS button for recording locations values subsequent to acquisition of sensor data under NXT command. Figure 2a shows the rack and pinion configuration used to activate the GPS button.

Figure 2 a. Mechansim to toggle GPS switch

Figure 2b. Aquabot in Chincoteague Bay

The project team integrated and adjusted additional components so that it would fit onto a remote controlled boat without adversely affecting the balance and floatation of the craft. A boat with a two propellers for forward motion and differential thrust capability for turning, and a large surface area was used (Figure 2b).

Figure 3 – YSI 6600

In order to assess the reliability of the system, the Aquabot sensor data were compared to that of the more sophisticated and expensive multi-parameter YSI 6600[11] sensor data. The YSI unit (Figure 3) has sensors that measure dissolved oxygen, turbidity, pH, chlorophyll a, temperature, and conductivity/salinity levels. The sensors have a very high level of accuracy, and the *in situ* data collected from this equipment can be a basis for accuracy check for the data collected from the Aquabot system. Preliminary data on salinity and pH from the two sites of the coastal bays of the Delmarva Peninsula, namely Chincoteague Bay and Assateague Bay were collected following the design and development of the "Aquabot" platform.

3.0 Implementation in BIOL 202 (Marine Botany Course)

Marine Botany (Biol 202) is a three-credit undergraduate course for environmental science majors. The course examines the theories and principles of marine plant environments, survey of marine and estuarine plants, energy flows and food webs, ocean color, remote sensing, mariculture, and the management of ecological communities in the Chesapeake, and the coastal bays of the Delmarva Peninsula. A one-credit laboratory is a co-requisite for this course. The course has evolved over the years to infuse more cross disciplinary research and experiential learning activities for students. The class was divided into 5 groups of three, and each group was assigned a research project based on the applications of technologies in marine and environmental sciences. The incorporation of "Aquabot" in laboratory was an integral part of the course and students were exposed to the principles of the geospatial information technologies including Geographical Information Systems, Global Positioning Systems, and Remote Sensing for the Marine Environments. The students also had a lab where they had hands-on experience with the multiparameter YSI unit and Aquabot and they collected mapped pH data from a UMES pond. Two of the five groups were involved with mini projects related to "Aquabot". One of the groups conducted a comparative analysis of collecting pH and salinity data with the "Aquabot" and multiparameter YSI unit, and the other group was involved with comparing data on salinity and pH from two bays of the Delmarva Peninsula; Chincoteague and Assateague. The selected sites of the bays are known for the decline of the seagrass beds due to the impact of phytoplankton and macroalgal blooms. The sensor data collected were then mapped using the ArcGIS 9.3 software. The projects were presented orally at the end of the semester along with submission of group reports, and contributed about 25% of the total grade.

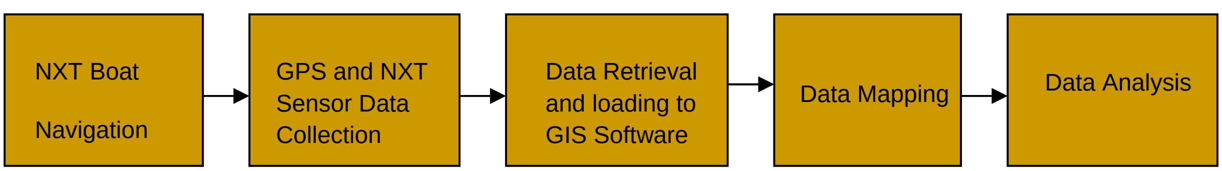
4.0 Implementation in ENGE 380 (Instrumentation Course)

Instrumentation (ENGE 380) is a 3-credit course for the engineering majors emphasizing on the principles of measurement and instrumentation including sensor selection to measure temperature, pressure, flow, level, force, and torque; transducers to measure translational displacement, velocity, acceleration, and vibration; rotational displacement, velocity, and acceleration measurement; and sensor application to measure different physical phenomena. A team based project requirement is integral to the course. One of the three member team in the course was assigned the "Aquabot" project. The student members of that team configured the "Aquabot" system to accommodate the dissolved oxygen and surface temperature sensors after appropriate calibration (Figure 4). The salinity and pH sensors were already calibrated and integrated to the Aquabot during the summer. Following calibration, the program that was developed on the NXT over the summer was modified to accommodate the additional sensors. After implementing the program and uploading it to the NXT brick, the entire arrangement was appropriately installed on the boat and prepared for the field trials. An UMES pond was selected for convenience. The salinity, pH, dissolved oxygen, and surface temperature were collected from the UMES pond. The point or vector data were plotted on ortho-rectified base maps of appropriate location of the campus and surface interpolated using Inverse Distance Weighting (IDW)[12] algorithm in Geographical Information System (ArCGIS 9.3)[13]. All the student teams gave power point presentations of their projects and also submitted written reports. The project contributed about 15% of the total course grade.

Figure 4: Calibration steps of Dissolved Oxygen Sensor at UMES Lab

5.0 Results and Discussion

The data collection and mapping followed the outline provided below both during the summer and subsequently in the fall semester by the student teams in Marine Botany and Instrumentation courses. Depending on the chosen body of water over which the Aquabot was to collect the data,



a navigation plan was outlined. The remote controlled boat was navigated to appropriate data collection locations in the plan with appropriate synchronization of timing with the software code so that the sensors and the GPS unit could record the attribute and location data successively, and log them in the NXT memory. At the completion of the planned navigation run, the recorded data were downloaded and appropriately tabulated on an EXCEL spreadsheet and loaded on the GIS software for mapping. Once the data maps were developed, the spatial variation of the data were observed and analyzed.

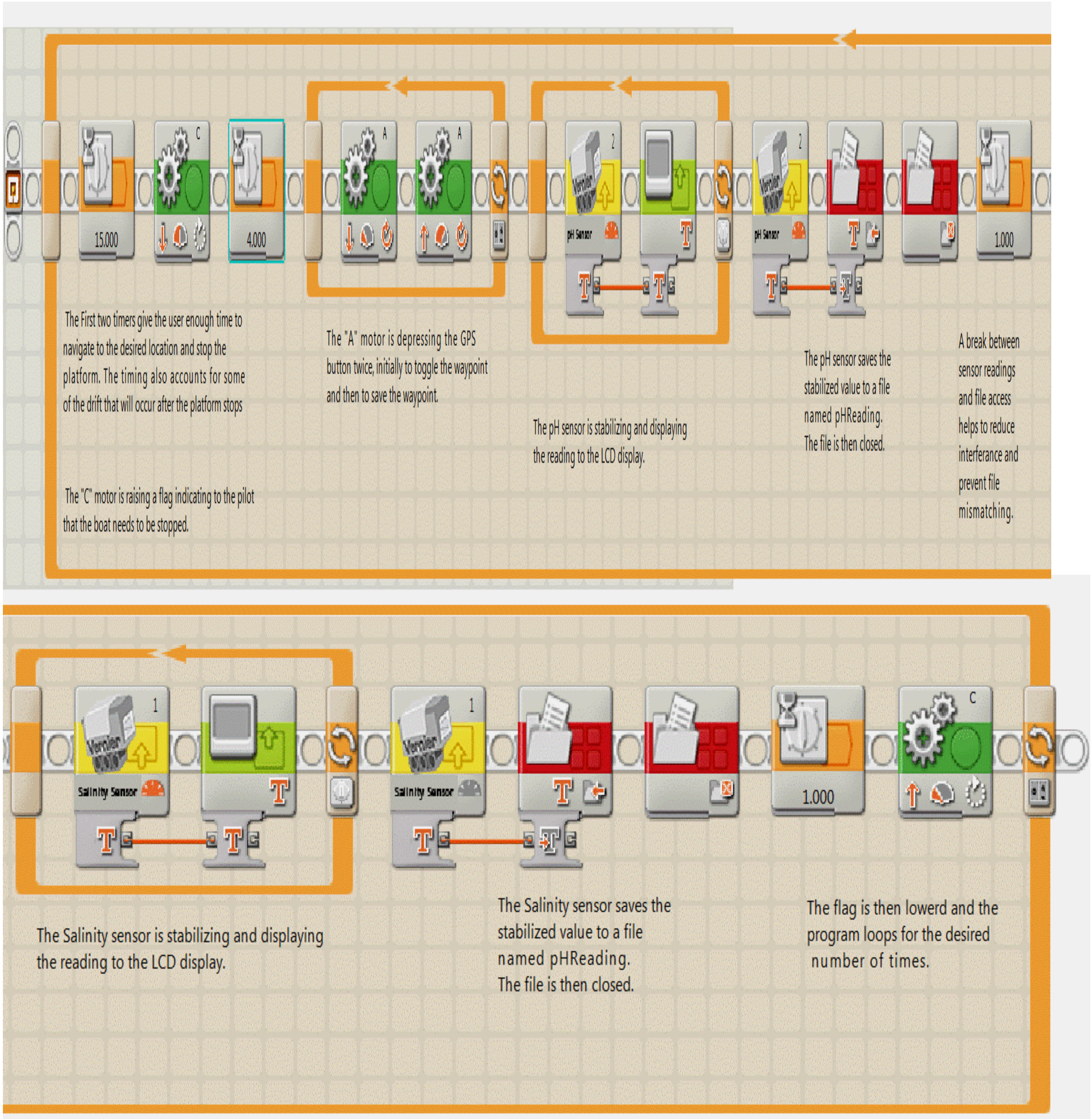
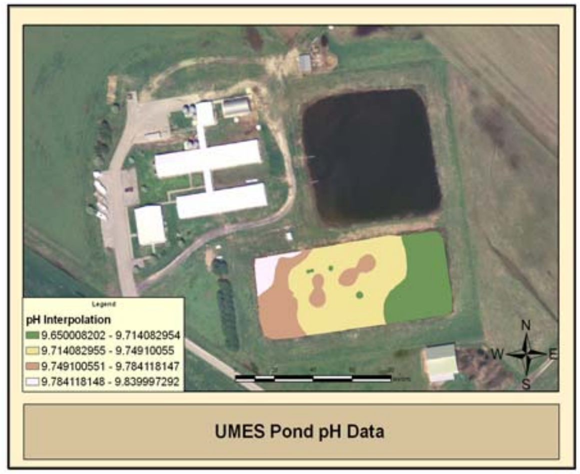


Figure 5: Lego Mindstorm NXT Code for collecting pH and salinity Data

Figure 5 displays the NXT code for collecting pH and salinity that was used during the summer, as well as by the Marine Botany(BIOL 202) student team. Note that the two sections of the code shown below one another for clarity, is actually two parts of one single continuous loop. The student team in the Instrumentation (ENGE 380) course who worked on the Aquabot added two more sections to the code for dissolved oxygen and surface temperature sensors that they calibrated and integrated to the system.

Figure 6 shows the data collected from one of the first data collection runs of the Aquabot in the summer on a UMES pond and the corresponding interpolated surface maps of the data over the entire pond.

pH	Salinity (ppt)	Position
9.65	0.63	N38.21414 W75.68128
9.68	0.36	N38.21390 W75.68137
9.74	0.36	N38.21387 W75.68195
9.76	0.63	N38.21395 W75.68216
9.72	0.72	N38.21403 W75.68199
9.78	0.18	N38.21402 W75.68171
9.82	0.90	N38.21401 W75.68221
9.78	0.90	N38.21387 W75.68208
9.72	0.90	N38.21396 W75.68171
9.74	1.08	N38.21415 W75.68165
9.78	0.63	N38.21403 W75.68188
9.84	1.08	N38.21417 W75.68201
9.78	0.99	N38.21415 W75.68201
9.84	0.54	N38.21410 W75.68224
9.76	1.36	N38.21394 W75.68188
9.71	1.27	N38.21395 W75.68163
9.71	0.72	N38.21406 W75.68191
9.74	0.54	N38.21412 W75.68188
9.74	0.72	N38.21412 W75.68141
9.76	0.63	N38.21409 W75.68158
9.71	1.08	N38.21407 W75.68180
9.71	0.63	N38.21406 W75.68193



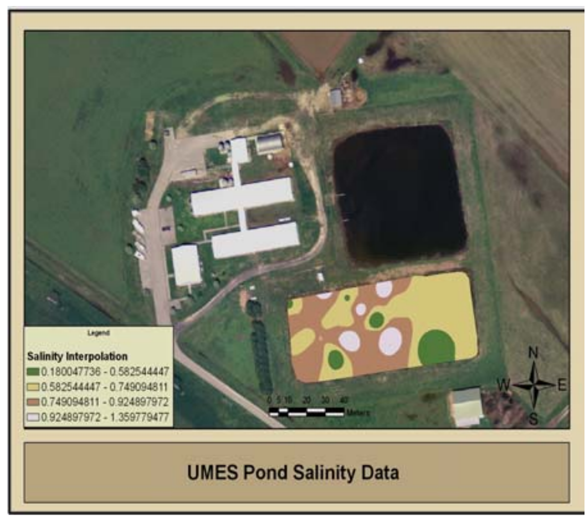


Figure 6: pH, Salinity, and GPS data from a UMES pond and corresponding surface maps.

Subsequently, the Aquabot was utilized to collect pH and salinity data at locations in the Assateague and Chincoteague coastal bays in the summer and mapped. In the fall, the Marine Botany student teams assigned to the Aquabot project also collected and mapped water quality data from the Assateague and Chincoteague bays. A sample surface interpolated map of data collected from the Assateague Bay is shown in Figure 7. After integration of all four sensors to the Aquabot, the ENGE 380 students had time for only one data collection run with the system in a UMES pond. The data and corresponding maps are shown in Figure 8.

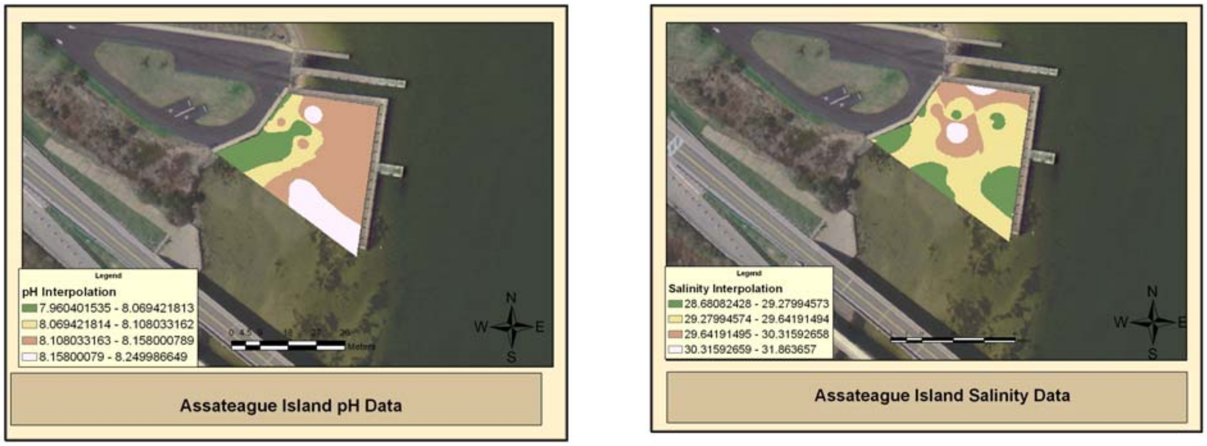


Figure 7: Surface interpolated pH and Salinity Data in a water body in Assateague Island

Latitude	Longitude	Waypoints		D.O. (mg/L)	Temp. (°C)	pH	Salinity
38.21379	-75.68216	1		4.9	8.3	4.11	5.22
38.21375	-75.68178333	3		4.85	8.5	4.09	5.67
38.2137833	-75.68148333	4		4.8	8.5	4.09	6.13
38.21384	-75.68108	6		4.77	8.4	4.09	6.15
38.2139667	-75.68106667	7		4.89	8.1	4.09	6.13
38.21405	-75.68148333	16		4.56	8.6	4.09	5.85
38.21408	-75.68166	17		4.47	8.3	4.11	5.4
38.214	-75.68193333	18		4.53	8	4.11	6.4
38.2139	-75.68221667	15		4.53	7.9	4.09	6.13
38.2141	-75.68224	14		4.61	8.1	4.11	5.76
38.21414	-75.68207	13		4.63	8	4.11	6.4
38.21417	-75.68176	11		4.6	8.3	4.09	5.22
38.21421	-75.68155	10		4.61	8.1	4.11	5.54
38.21422	-75.68134	9		4.66	8.1	4.24	5.64
38.2141833	-75.68114	8		4.33	7.9	4.11	5.71

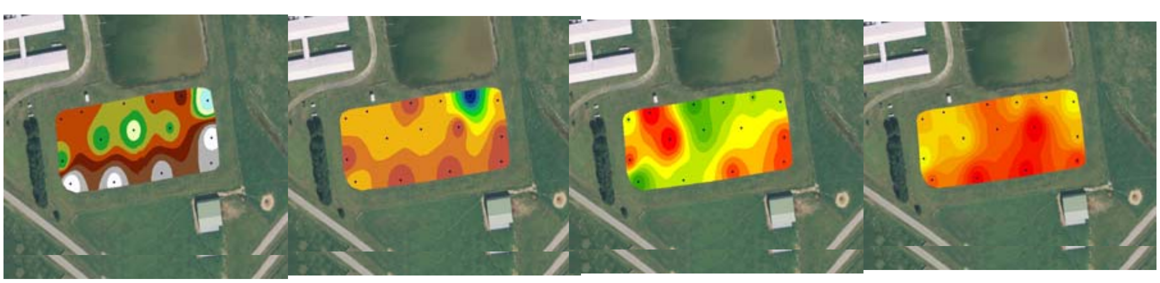


Figure 8: DO, Temp, pH, Salinity data maps developed by ENGE 380 students

6.0 Conclusions and Learning Outcomes

The Aquabot competently collects water quality data on a smaller and more affordable scale on stationary and slowly moving water bodies. The easily programmable NXT, and the easy to navigate radio controlled boat, allows for the user to effortlessly carry out the collection of data. Overall, the system has negligible error when compared to that of the YSI system. After proving the reliability of the sensors, the data were mapped and the Aquabot system logged water quality data that were consistent with the known areas of micro and macro-algal blooms. The system is open for more development. Since it is programmed in a LabVIEW environment with a few software and hardware upgrades, there is a possibility of its expansion into a fully autonomous platform. Efforts are underway to collaborate with National Aeronautics and Space Administration's (Wallops Island, Chincoteague) ROVER (Remotely Operated Vehicle for Exploration and Research) project for the development of an autonomous platform with gyrocompass, video system, ultrasonic sensors, GPS capability, and expanded data storage for navigating, assessing, and monitoring various aquatic environments with greater level of efficiency and precision.

The two courses, Marine Botany (BIOL 202) and Instrumentation (ENGE 380) incorporated Kolb's experiential learning theory[14] for contextualizing some activities for enhanced learning outcomes. This model has often been used to redesign courses in science and engineering with many pedagogical benefits. The Kolb model suggests that balance among the four stages leads to optimal learning, deeper understanding of concepts and applications, and longer retention of information. It is achieved through reflective observation (RO), and active experimentation (AE). However, a necessary condition for such construction of knowledge is that this knowledge should be grasped first. Knowledge depiction occurs through Concrete Experience (CE) or Abstract Conceptualization (AC).

A significant component of this project involved undergraduate students in experiential learning and research efforts. The undergraduate engineering summer exchange student involved in the project worked with a multidisciplinary team of faculty, graduate students, and NASA scientists, and learned new software tools and got introduced to the expanding field of geospatial information technologies. In the courses (Marine Botany and Instrumentation), the students were able to hone their communication skills through presentations and written reports, time management skills, ability to work in diverse teams and identify and solve problems pertaining to environmental and marine sciences and engineering, programming, and system design .

In the context of learning outcomes advocated by ABET for engineering students, the involvement in the project provided a platform to influence several of the *"a through k"* outcomes outlined by the Engineering Accreditation Commission[15], in particular, the ones delineated below:

- an ability to apply knowledge of mathematics, science, and engineering;
- an ability to design and conduct experiments, as well as to analyze and interpret data;

• an ability to function on multidisciplinary team;
• an ability to communicate effectively;
• a recognition of the need for, and an ability to engage in lifelong learning;
• a knowledge of contemporary issues; and
• an ability to use techniques, skills, and modern engineering practice.

7.0 Acknowledgments

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