SAMPLE: Small Autonomous Monitoring Platform for Lakes and Estuaries, a Student Engineering Project

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Abstract

SAMPLE is a **S**mall **A**utonomous **M**onitoring **P**latform for **L**akes and **E**stuaries. SAMPLE was designed and built using easily accessible materials and fitted with different sensors and electronics to allow autonomous navigation and data collection. It is an under-actuated Surface Autonomous Vehicle (SAV). Forward motion is provided by an air propeller. Heading control achieved by directing air with a rudder. The rudder is partially immersed in water for better sensitivity. Proportional and Proportional-Integral-Derivative (PID) control of the heading is achieved using GPS and compass sensor feedback, which are connected to an NXT Lego brick which serves as a microcontroller. Various water quality sensors that are incorporated in the SAMPLE platform include temperature, pH, salinity, and dissolved oxygen. SAMPLE is easy to use and transport. It offers a cost-effective way of monitoring selected geo-located water quality variables to provide insight into coastal ecosystems. It is also an excellent platform to involve engineering students in a comprehensive real-world design experience integrating electro-mechanical design, sensors & instrumentation, structured programming, and control systems. The SAMPLE platform was designed and developed by engineering students at University of Maryland Eastern Shore. The engineering students have also demonstrated and trained Marine Botany (Biol 202) students at the university to collect and map water quality data in lakes and ponds inside campus, as well as bays and estuaries nearby.

Introduction

There is a growing consensus in the scientific community and the population at large that unregulated anthropogenic activities have contributed significantly to the degradation of ecosystem health of water bodies in and around Delmarva Peninsula. Adverse environmental effects needs to be properly identified and possibly mitigated before it becomes unmanageable. This provides the need for monitoring of water bodies and periodic collection of water quality variable data. Data on the levels of nitrogen, phosphorus, dissolved oxygen, temperature, and pH will help marine biologists and river managers to identify trends, as well as short term fluctuations in health of water bodies, enabling scientists to assess environmental health of lakes, bays, and estuaries. This will provide a background for the eventual protection and conservation of endangered species and ecosystem health of water bodies.

Prevailing monitoring techniques are expensive, time consuming, and sometimes do not provide in-situ data analysis, increasing the possibility of sample contamination. Water ways inaccessible to humans and bigger boats are also largely ignored and seldom monitored.

An autonomous monitoring platform with in-situ data collection method will limit the chances of sample contamination, and provide an easy means of data collection. Inaccessible water ways can also be monitored with small devices such as SAMPLE as it can be launched from bigger boats to ground-truth satellite data. This paper gives the functional description of an autonomous monitoring platform SAMPLE (Small Autonomous Monitoring Platform for Lakes and

Estuaries) and some insight into the learning process that the student engineers went through during the course of the project.

SAMPLE is an autonomous boat that carries sensors to collect water quality variables in lakes and estuaries. It utilizes a single air-propeller and rudder system for navigation. It has been designed to be controlled remotely with a 2.4 GHz radio system with an onboard receiver. Alternatively, it can be controlled autonomously using a programmable NXT brick equipped with Geographical Positioning System (GPS) receiver and compass for navigation. When it is deployed, it is possible to switch between remote joystick control and fully autonomous mode using an r/c signal. The onboard memory of the microprocessor on the NXT brick logs the sensor data during operation along with GPS locations. SAMPLE has been and will continue to be used in the measuring and mapping of water quality variables. Display of the data acquired from the boat at different locations and times can be displayed on appropriate geo-referenced visualization tool. These maps provide an accurate description of the spatial and temporal variations of water quality parameters in selected water bodies.

SAMPLE provided an opportunity for an invaluable experiential learning experience, as well as meeting some of the outcomes of the Accreditation Board for Engineering and Technology (ABET). In particular outcomes related to ability to apply knowledge of mathematics, science and engineering to design a system to meet desired needs within realistic environmental and manufacturability constraints; ability to analyze and interpret data; ability to function on multidisciplinary teams; ability to communicate effectively, and an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice; were effectively integrated in the learning process by participating in the project.

Throughout the project, students tried to follow the steps outlined by David Kolb in his experiential learning cycle[1] shown in Figure 1. The Kolb's learning cycle outlines four main questions to be answered by every student working on any project to maximize learning. The questions are: "Why?", "What?", "How?", and "What if?".

Success of this project can be largely attributed to the multidisciplinary team consisting of engineering students and faculty, marine biology students and faculty, computer science students, and participating scientists and engineers from NASA Wallops Flight Facility who helped keep the project on track through effective communication, goal-setting, and appropriate monitoring and execution of tasks.

This project is a continuation of a project [2&3] started in summer 2009 at the university aimed at studying the effects of algal blooms in bays and open oceans. Back then, students used a similar remote controlled platform which did not have the autonomous capability available in SAMPLE.

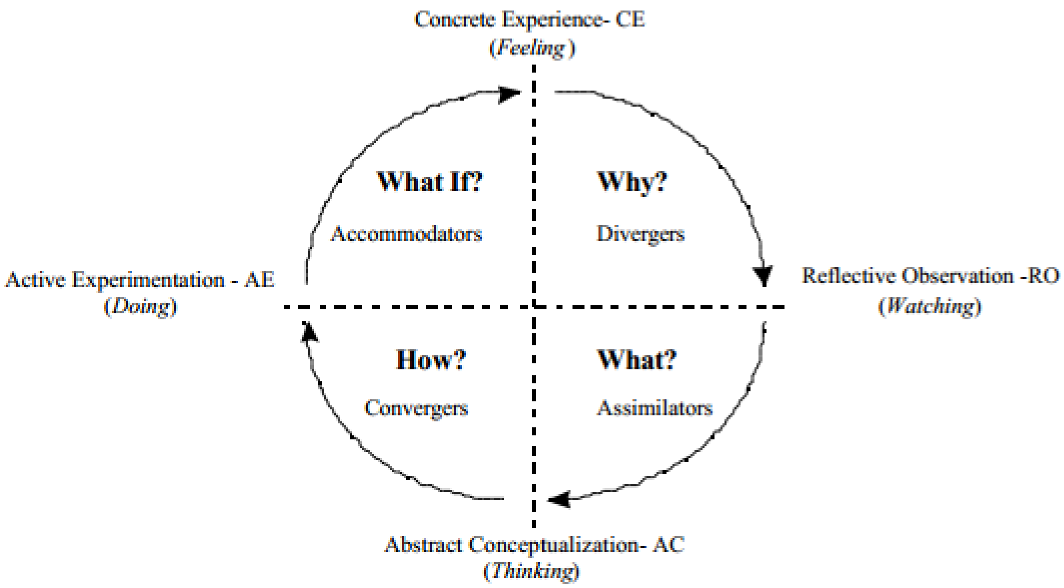

Figure 1 Kolb's Learning Cycle[1]

Functional Description

Design Specifications and Design Implementation

Both qualitative and quantitative design parameters were identified during team meetings based on projected needs of the device. Small-sized, lightweight, stable, ability to navigate shallow waters, ability to run autonomously, onboard power source designed for a continuous run of 45 minutes, space provision and/or attachments to hold all water quality sensors, and basic circuitry & electronics was outlined as working specifications, and various ways of implementing the design were investigated through simulations, numerical analysis, and test runs using physical prototypes.

Knowledge gained from various engineering courses were utilized in the analysis. For instance, Computer Aided Design course and proficiency with SolidWorks allowed visualization of various dimensions and design styles, before arriving at the finally shape and dimensions. Figure 2 shows SAMPLE's CAD model. Basic ideas introduced in Statics, Dynamics, and Fluid Mechanics courses helped realize the mechanical design. For example, significant efforts were devoted to properly layout all the components of the boat so that the center of gravity of the body and its center of buoyancy were as close to each other as possible for stability. Flow simulations enabled appropriate decisions to streamline the boat for better hydrodynamic characteristics such as a curved front and the addition of a fin in the rear to reduce wobbling. Furthermore, to achieve navigation in shallow waters, an air-propeller was used. SAMPLE was built from easily accessible materials like wood, styrophome, and epoxy. The final assembly processes were less complicated, since all the CAD drawings and dimensions were readily available to facilitate the manufacturing process.

Courses in programming, circuits, instrumentation, and control systems were also utilized to realize all the functionalities of this mechatronic device. SAMPLE is a multi-disciplinary project that required us to apply knowledge acquired from various engineering courses. This device will be used by marine biologists, and their input was sought periodically. Scientists and engineers from NASA Wallops Flight Facility also advised the project team from time to time when they visited the campus.

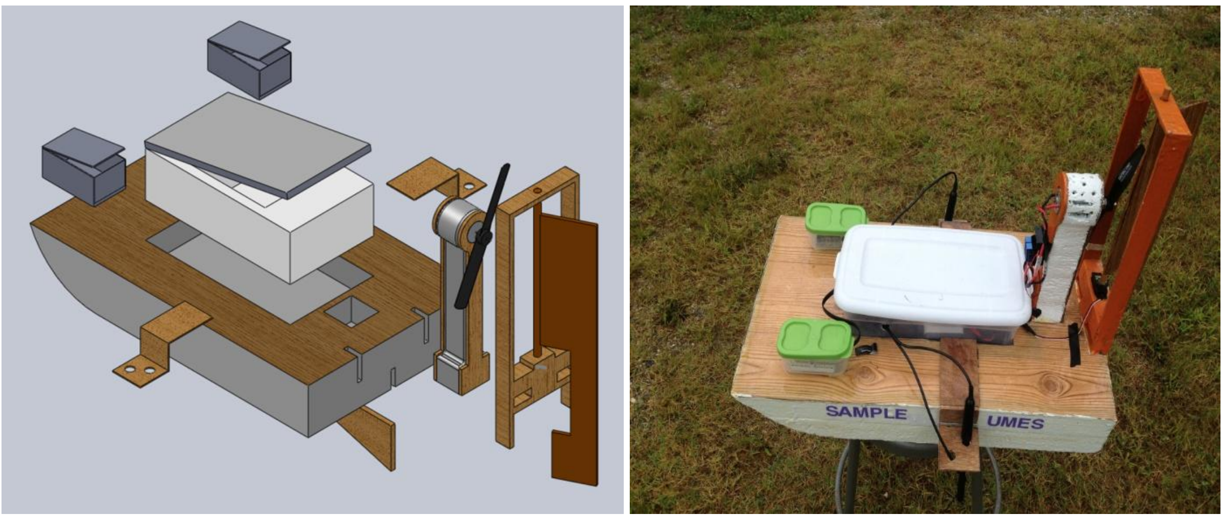

Figure 2 SAMPLE's CAD model and actual boat

Controlling SAMPLE

Initially navigation was achieved using a 2.4 GHz remote control radio system. . A user would steer the boat to the desired destination using joystick controller, while the LEGO NXT brick[4] was programmed to collect sensor data and store it in its own memory. Due to the lack of location accuracy, the need for repeatability, and to eliminate the operator from the control loop, autonomous control efforts were undertaken. SAMPLE is an under-actuated vehicle, forward motion is provided by an air propeller and heading control is achieved by a rudder partially immersed in water. Using GPS[5] and compass sensor feedback both proportional (P) and proportional-integral-derivative (PID) control for point-to-point navigation was achieved. Gains were tuned by trial and error. We tested two types of controls, P and PID. Figure 3 shows the flow diagram of the electrical components of the boat. Figure 4 shows the control model used for SAMPLE, and Figure 5 shows the results for two runs, one with proportional (P) control and one with PID control. The green lines connect the desired navigational points, and the red lines connect the actual path followed by the boat. It was observed that when using proportional control the boat was closer to the desired points.

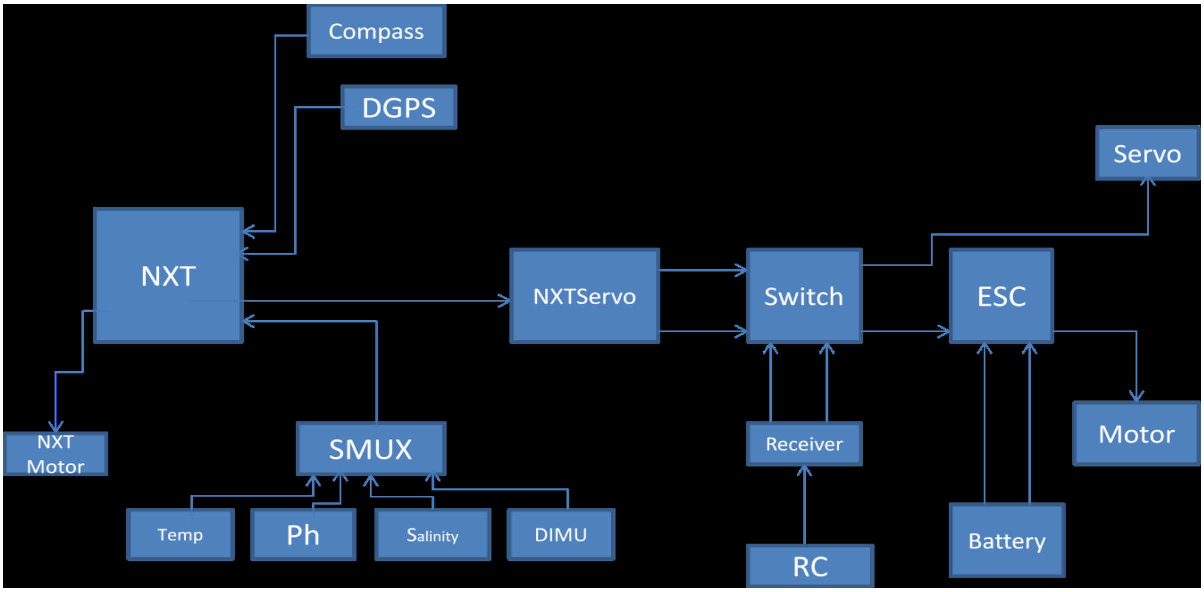

Figure 3 Flow diagram of the electrical components

Proportional control seemed to work better for this application, where only point-to-point navigation is desired and the boat is running at low speed at low wind conditions. The fluid drag provides damping to eliminate vibration, and due to slow speed, as well as, relatively little disturbance when the trials were performed steady state errors were not significant in moving from point to point. In future more advanced control strategies will be implemented when trajectory tracking efforts will be performed.

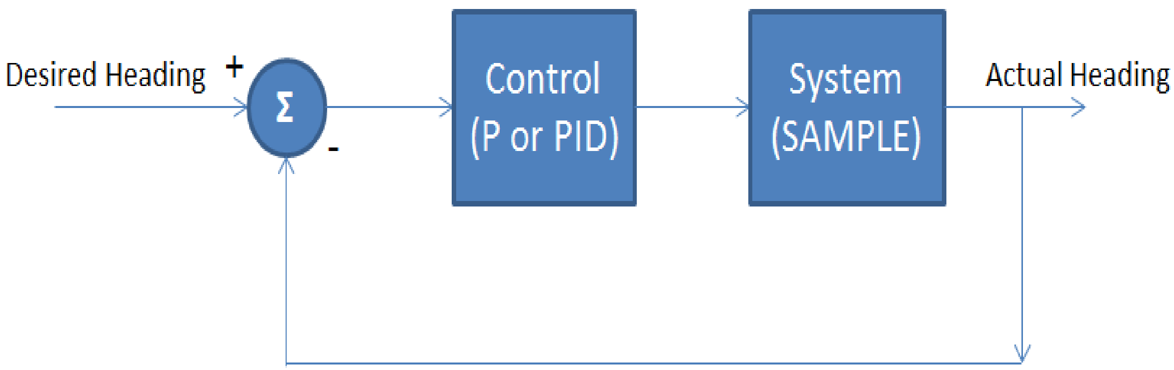

Figure 4 Feedback Control Model diagram

Figure 5 Proportional Control (left) and PID control (right) results

Results and Discussion

ID	Latitude	Longitude	Temperature	pH	DO
1	38.43171	-75.0579	32.5	6.8	4.7
2	38.43171	-75.0579	31.5	6.4	4.6
3	38.43168	-75.0579	33.8	7.2	1.5
4	38.43169	-75.058	34	7.5	1.8
5	38.43171	-75.058	33.9	7.5	2
6	38.43181	-75.058	33.8	7.3	2.2
7	38.43193	-75.058	33.9	7.3	2.1
8	38.43197	-75.058	33.9	7.5	2.4
9	38.43201	-75.0579	33.7	7.4	2.1
10	38.43208	-75.0578	34	7.2	1.9
11	38.43199	-75.0578	33.9	7.4	1.8
12	38.43185	-75.0578	33.8	7.4	1.9
13	38.43185	-75.0578	33.8	7.4	2.1
14	38.43178	-75.0578	33.7	7.4	2.1

Table 1 Results from an autonomous run in Ocean City, MD

The sensors mounted on the boat were acquired from Vernier instruments[6], and they collect in-situ data which are saved on the NXT brick. For the run shown in Table 1, data on pH level, dissolved oxygen content, and, temperature were collected on a selected water body in Ocean City, Maryland. The geo-located point data was displayed ARCMAP GIS[7] environment, and spatially interpolated using inverse distance weighting (IDW) to generate the graduated color-maps shown in Figure 5. From the Figure, a relationship between level of dissolved oxygen and temperature can be observed.

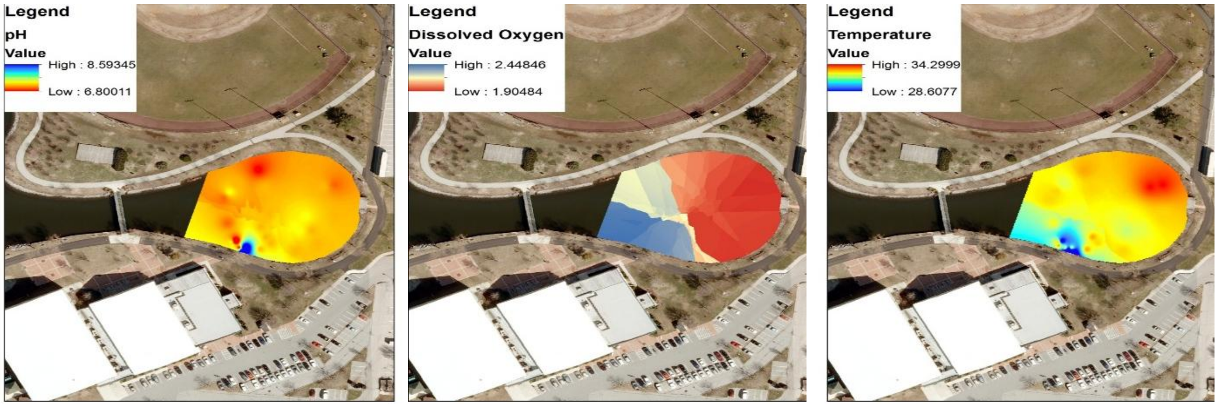

Figure 6 Geo-referenced data on GIS software for pH, Dissolved Oxygen, and Temperature respectively

Summary

The construction of the boat, testing of control algorithms, and collecting water quality data provided opportunities for learning both in field and laboratory settings, and allowed application of knowledge acquired from courses. Students were excited to be able to utilize the concepts, theories and principles learned in class into a physical system capable of achieving stipulated goals. A simple and efficient way of collecting water quality data has been achieved using readily available materials and control mechanism. The experience also enabled the students to hone their communication skills, improve leadership abilities, teamwork, and, provided a heightened sense of creativity.

SAMPLE is a continuing project, and new features are being added to improve its functionality. One of the features being worked on is a retractable sensor base to allow depth profiling. Future plans also include the addition of a docking station for recharging and easy launch, and, the capability to transmit collected data over 3G.

Two of the students involved in the project participated in the 2013 ASME Student Mechanism

Figure 7 Photo of the Students at IDETC 2013

and Robot Design Competition[8] (Undergraduate Robot Division) and were awarded third place in that division. The two students also attended the IDETC 2013 conference, which allowed them to interact with students and professors from various universities, adding to their learning experience. A photo of the students at the conference with the award certificate is shown in Figure 7. These students have also taken the lead role in writing this paper.

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