2006-1694: ROBOTIC AQUA SENSOR – AN UNDERGRADUATE MULTIDISCIPLINARY PROJECT

Hong Zhang, Rowan University

Ying Tang, Rowan University

Courtney Richmond, Rowan University

Patricia Mosto , Rowan University

Robotic Aqua Sensor – An Undergraduate Multidisciplinary Project

Abstract

The application of engineering skills to address the needs of non-engineers are always desired by industry, and working on these applications is critical to the success of our students. Starting in spring 2005, a group of Rowan undergraduate students from Mechanical Engineering, Electrical and Computer Engineering, and Biology have been working together to develop a mobile aqua sensor under the guidance of faculty from each of these departments. Within one year's time, the group has designed and built three generations of prototypes, conducted several experiments, and modified our design with inputs from all parties and from empirical results.

I. Introduction

Many professional biologists monitor the ecology or water quality of aquatic habitats, traditionally accomplishing these tasks by sampling in a discrete manner[1], in which sampling stations are typically selected in advance, and sampling is conducted by physically going to the field locations. This method is labor-intensive and time consuming. The number of stations that can be sampled is limited, and the sampling regime is generally not altered as data are collected. A more recent option is to anchor sensors and wireless transmitters such as distributed sensors[4] directly in the habitat, leaving them there to sample continuously or at predetermined discrete intervals. However, the cost of this option multiplies quickly when the number of deployments increases. Further, the processes necessary to anchor the deployed equipment, multiplied by several locations, may alter the original environment or create unexpected damages.

As an alternative, mobile sensor platforms such as Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV) are capable of remote data collection. However, these technologies are very expensive and often need a dedicated crew to maintain and operate them, often limiting their use to a handful of research institutes who can afford the associated costs. Although these organizations always encouraged external participation, the time and level of involvement required can be prohibitive for individuals or groups from smaller institutions. It is therefore desirable for smaller or less soluble educational institutions to have their own robotic probing and surveillance system if they intend to conduct these types of scientific studies in the field.

In this multidisciplinary project, we designed and built a low cost, low maintenance, easy to operate Interactive Mobile Aqua Probe & Surveillance (IMAPS) system for schools, researchers, and environmental and biological workers. The robotic sensor is designed to cruise a given water body, collect the necessary data or samples, observe and record the environment, and even search for the origin of point-source pollutants. Within a year, the designs have evolved through three generations, from a proof-of-concept prototype, to a field test video probe, to the final design of a pontoon-style model. Interdisciplinary tests and experiments have also been conducted to test the functions of the system.

The layout of this paper includes five sections. After this introduction, we will talk about the hardware design and software design in section II and section III, respectively. In section IV, we will introduce the experiments and applications conducted so far with the apparatus we designed and built. Section V provides a summary and final remarks about the project.

II. Hardware Design

The design is the result of a collaboration between faculty and students from multiple departments and disciplines. The faculty members proposed the primary structure at the beginning of the project, and then the students worked together to implement and modify the original design. During the process, the Mechanical Engineering students designed the vehicle's body structure, while the Electrical Engineering students focused on the communication among different components of the system. Faculty members from these two Engineering departments acted as advisors to ensure the project stayed on track, and provided technical help whenever necessary. Meanwhile, the Biological professors and students played the roles of project consultant and potential customers. They are the first end users and are already developing experiments to take advantage of the finished product in the classroom and laboratory applications. The biologists provided feedback throughout the design process, such that their concerns and needs could be addressed from the onset. At the time of writing this paper, the control structure evolved while the body structure saw several dramatic changes. In this section, we will give more details about both.

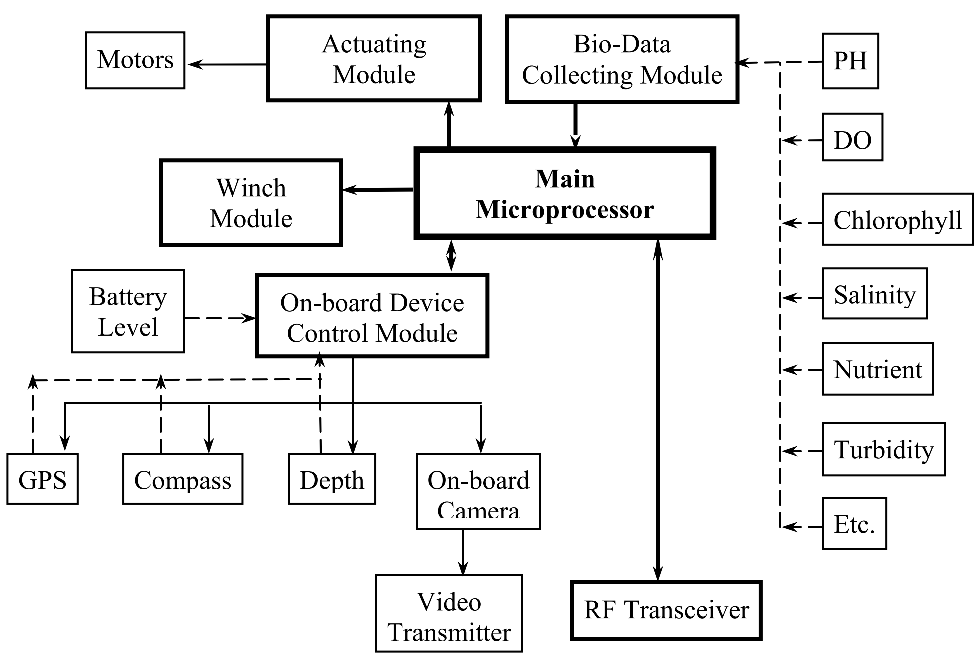


Figure 1: Block diagram of the agent.

We started with a simple agent-server approach. In the development of the IMAPS, there have been several iterative phases of improvement. The current configurations of the two parts are illustrated in Figure 1 and Figure 2. The field agent takes the form of a model boat. Depending on working conditions or design preference, it can take on various shapes, such as a torpedo, a racing boat, or a pontoon. In order to have the capability to maneuver and sample the water effectively, the agent was equipped with several interacting and cooperating units as shown in Figure 1. The units include an Actuating Module powered by solar charged batteries, an On-board Device Control Module to monitor the status of the vehicle and on-board systems, and a Winch Module to deploy the bio-sensors, such as temperature, pH, turbidity, dissolved oxygen, conductivity, chlorophyll, ion-specific inorganic nutrients, etc. All these modules are based on PIC 16 series microprocessor and are controlled by a Main Microprocessor. The Main Microprocessor also connects with the Bio-Data Collecting Module to retrieve data as they are collected and sends them in real time to the host station via a radio frequency (RF) transceiver. An on-board video camera is used to monitor the condition of the IMAPS and to visually inspect field conditions.

A high-end host computer is used to interactively communicate with and to control the agent. Real-time images and data are retrieved for analysis and display via the video receiver and the RF transceiver. Users can store the data into a data log and/or display them on the screen for visual inspection. The inputs or commands from users are relayed to the agent through the RF transceiver.

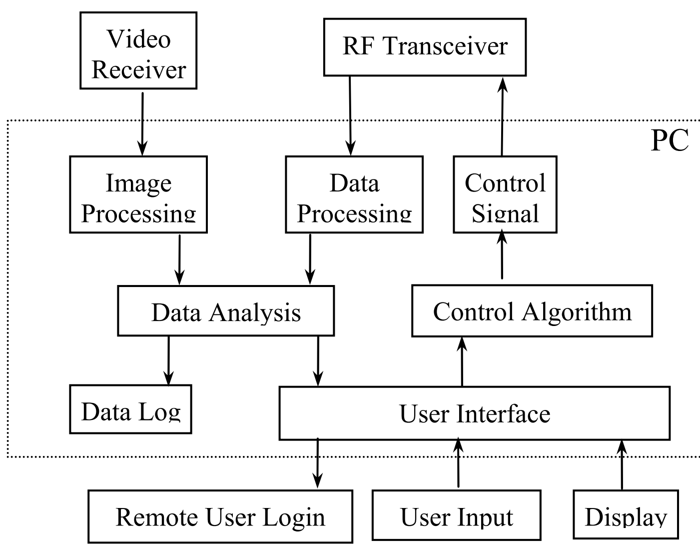
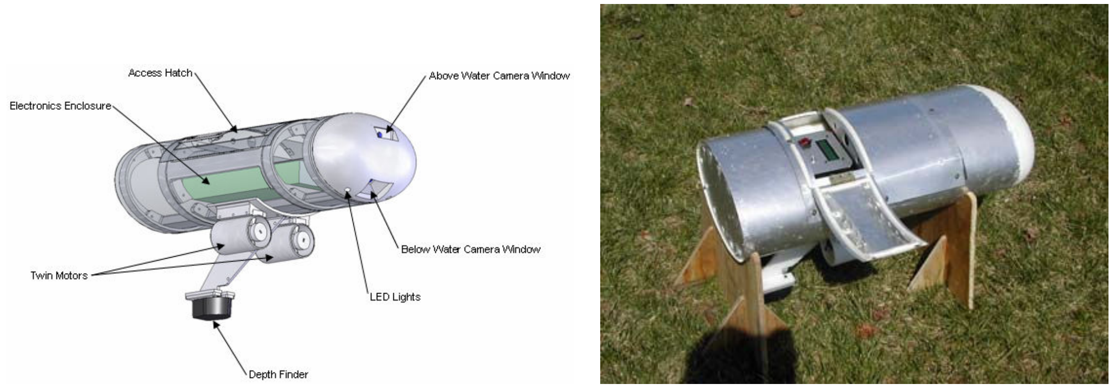


Figure 2: Block diagram of the host.

Unlike the control part, the body structure was primarily designed by undergraduate students, with three generations of hardware design. The first generation, a torpedo-shaped design, was conceived and fabricated to prove the concept and test the vital components. Figure 3A is a 3-D CAD rendering of the design, while Figure 3B is a working model with its electronic control panel exposed. Figure 4 shows the second generation design. The students named this the ‘mini-observation station’ or ‘video probe’. It is shown working on the coast of Florida conducting an experiment with the biologists studying seagrass populations in the summer 2005.

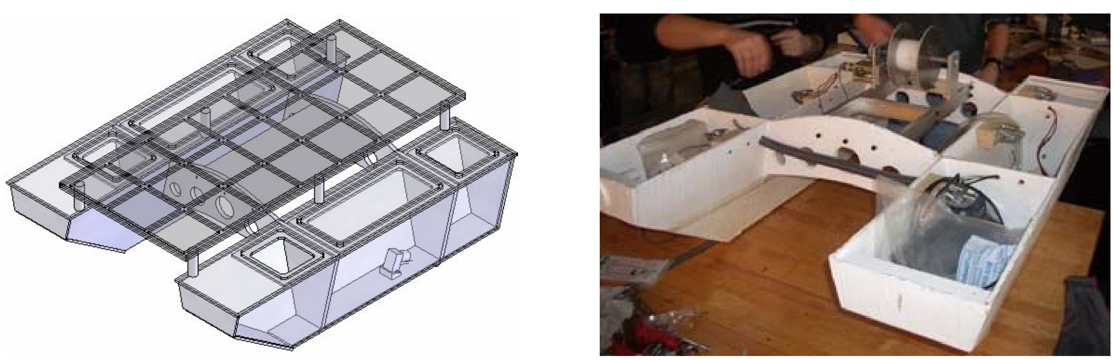


(A) (B)

Figure 3: The first generation IMAPS agent system – the Torpedo.

Figure 4: The second generation IMAPS agent – the Video Probe.

The mechanical design was finalized at the third generation, a pontoon-style double hull surface vehicle. Figure 5A is a 3-D CAD rendering of the design. With a moderate size (1m x 1m x 0.4m), the agent provides a fair amount of payload (about 20 kg) to carry common biological or chemical sensors. The double hull design makes it suitable for both calm water and light waves. Figure 5B shows a student working on the winch system of the prototype to finalize the fabrication and prepare it for a field test.



(A) (B)

Figure 5: The third generation IMAPS agent – the Pontoon.

III. Software Design

For convenient probe operation, an easy-to-use graphical user interface (GUI) has been developed. Figure 6 is a snapshot of the software. In this interface, a satellite photo or map of the targeted area is loaded into one sub-window to give an overview of the location. Two pointers indicate the current position of the IMAPS system and the desired sampling location selected by the user. Two sub-windows show the real-time video image sent back by two on-board cameras, one above the surface and one underwater. With a mouse click, the user can select to enlarge any of the sub-windows to obtain a closer view. When necessary, several groups of data can be shown in the other part of the interface window. These include the essential control data such as the thruster throttle, GPS location and heading of the agent, as well as the sensor data such as water temperature, pH, dissolved oxygen (DO) level, and turbidity of the water body.

With this interface, users will be able to remotely log onto the system, view the IMAPS location on a satellite photo or map of the targeted area while steering the IMAPS, and retrieve real-time sensor data and images of the site. This software will also provide users the options to apply different control algorithms, to select a variety of biological parameters to be tested, and to choose the output format as either tabular material in spreadsheet, graphic, or GIS files.

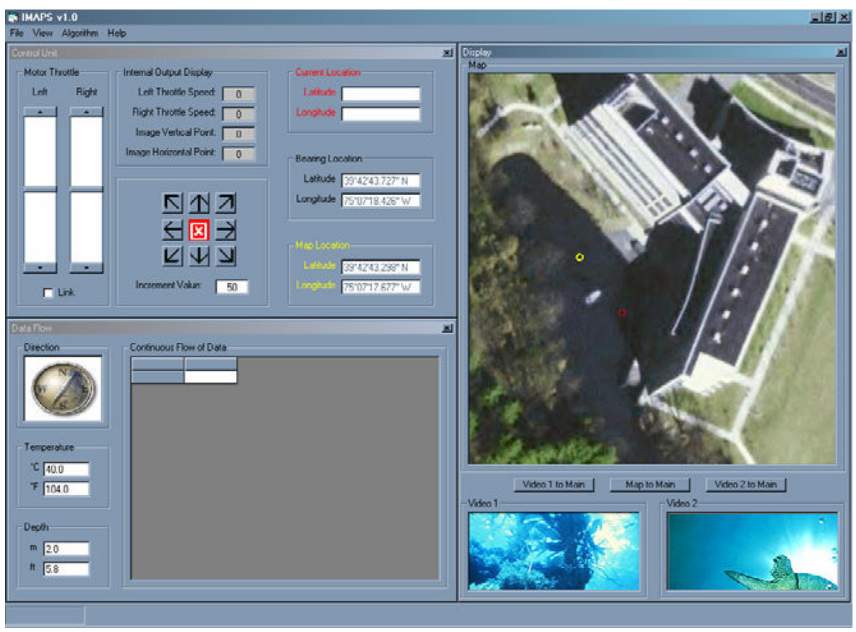


Figure 6: Graphic User Interface of the IMAPS System.

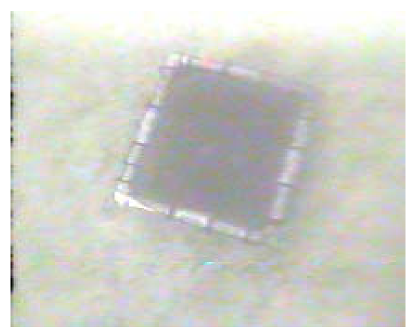
IV. Experiments and Applications

After the fabrication of each generation of the IMAPS, we conducted experiments to test its operation.

Figure 7A shows the first generation IMAPS prototype running on a local pond. It can be driven with a computer using a text-based Hyper Terminal program from a distance of about 30 meters. It can also send live video feed back to a TV or a computer equipped with a video capture card. Due to the lack of experience, the motors and propellers initially selected were not strong enough for these applications. The boat could only run at a slow speed about 0.1~0.2meter/second and could not resist event the current generated by a water fountain. However, the finished prototype proved the original concept of remotely controlling an agent boat using a host computer via real-time link. The knowledge and experience obtained in developing this generation prototype were vital and transferred well to the development of the following two generations.

Figure 7B is a photo taken by the second generation prototype, or the Video probe. In order to study a particular species of seagrass that grows only in the shallow lagoons of eastern Florida, a group of biologists went down to the Indian River Lagoon in June 2005. Their study is exploring the influence of human activities such as boating and coastal construction (e.g. docks) on the seagrass, which is only found in this lagoon and is federally . The traditional way of counting the population of the sea grass is to physically snorkel or scuba to the area where the seagrass grows, which is generally between 1 and 3 meters depth. In this particular study, which looked at the effects of light reduction on the seagrass, the researchers put down the apparatus shown in Figure 7B to create shade above the plants. They manually counted the number of leaves of individual plants at the beginning and end of the experiment, and they collected plants within a known 2-dimensonal area along the bottom to estimate plant density. This work is extremely tedious and time consuming. The video probe was used to take snapshots of the seagrass beds, and then image processing software was used to calculate the density of the seagrass from the video. The algorithm is still being refined; when finished, the efficiency of collecting these types of data will be significantly improved.

(A)



(B)

Figure 7: (A) The first generation IMAPS tested in a local pond. (B) Photo of a shading canopy in the seagrass experiment, taken by the second generation Video Probe.

When the third generation pontoon-style prototype was constructed, a comparative field test was performed by the students to have first-hand experience using the device to monitor water quality. Water properties including temperature, pH, and dissolved oxygen (DO) were collected at 10 stations in Rowan Pond. Data collection took place at the surface and at depths of increasing increments of 0.5m. Besides the water quality parameters, the depth at each station was recorded to provide a bathymetry plotof the pond.

To compare manual data collection to using the IMAPS probe to collect data, two students manually collected data from a pond. For this sampling, two persons were onboard a canoe; one to read, raise, and lower each sensor and the other to manually record the data (temperature, pH, DO and depth). The entire process of collecting and recording data was performed over a two day period and took over 7 hours. The time to move the canoe, raise and lower each sensor, anchor the canoe at each waypoint, and to manual record each data point was extremely time consuming and inefficient.

In comparison, only one operator is necessary when using the pontoon probe for the same experiment. The probe was sent out to the same stations to collect data on temperature and depth. Data collection was performed instantaneously on the laptop via wireless communication and movement from station to station was continuous. The entire process was performed in less than 20 minutes. Even though pH and DO were not recorded, the addition of those sensors would add approximately 30 seconds per sample. Additionally, the data collection from 0.5 m depth increments would increase the total sampling time, but overall, the total data collection process would be considerably less than that of conventional sampling methods, not to mention the reduction in effort associated with transporting the device instead of a canoe to the site.

From these data points, several 3-D contour plots were created using GIS software. Figure 8 shows contour plots of the surface temperature and depth distributions on Rowan Pond, both of which can currently be measured with the pontoon probe.

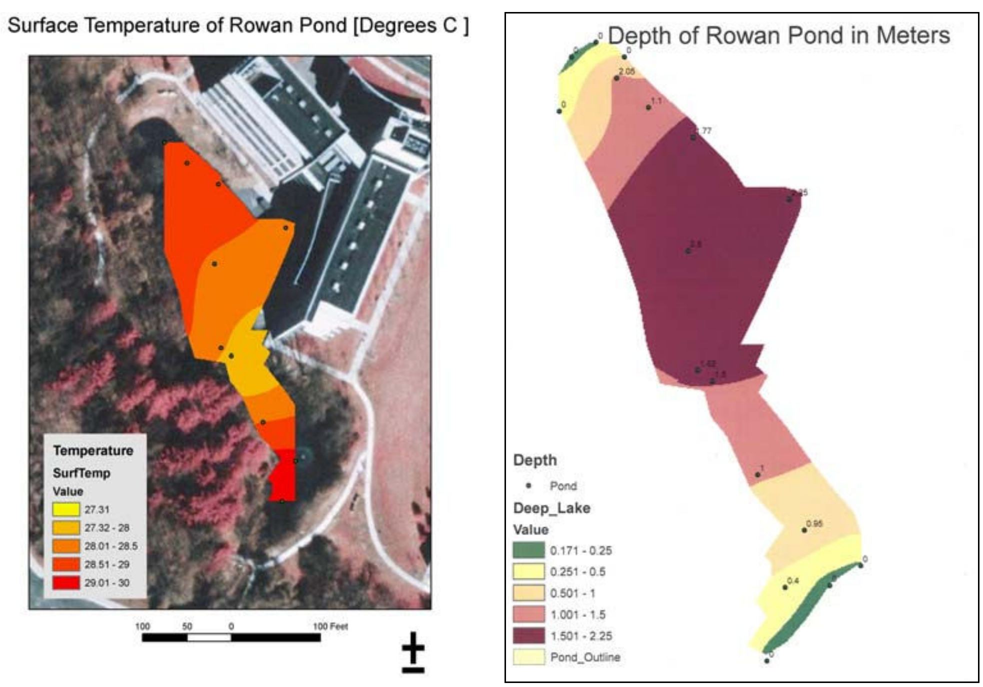


Figure 8: Surface temperature plot (left) and Bathymetry plot (right) of Rowan Pond.

V. Summary

Robots and robotic systems are making their ways into numerous fields. They are appearing from outer space exploration (Mars Rover[5]), to manufacturing[3], and to entertaining (Robot soccer[2]). However, with all the advances in robotics, the applications of robots in other scientific disciplines are still limited compared to their potential; this is especially true in the field of biology, where researchers, educators and students have to venture out to the wild to make observations, take air and water samples, and collect specimens. Although some on-site experiences are irreplaceable, many bring unnecessary costs, time and effort. This robotic aqua probe will help improve this situation because it can be left deployed in the field, while collecting and sending back useful data and broadcasting the visual and audio encounters to the remote users.

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