2006-1699: BUILDING AN INTERACTIVE MOBILE AQUA PROBE SYSTEM

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I. Introduction

Monitoring biological parameters of a body of water is important to assess the effect of pollution and overall health of an ecosystem. Traditional methods of manually collecting samples are tedious, time consuming and a poor use of resources. In contrast to this method, mounting sensors and dataloggers[1, 5] in the field allows continuous monitoring of specific, static locations. However, the cost of the method multiplies quickly with the number of stations. More recently, mobile sensor platforms, such as Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs), are developed to provide a flexible method of data acquisition. Nevertheless, these technologies can be very expensive, require a fulltime shipboard or land-based operator (ROVs), and often are not capable of real time data transmission (AUVs)[3]. Moreover, although some ROVs and AUVs have been deployed in various missions (e.g., REMUS[6]), difficulties arise for vehicles in shallow water and complex terrain[2, 4].

Therefore, there is a need to advance the aforementioned approaches and to provide a robust, cost-effective and flexible solution for extended and real-time, continuous and interactive data collection of a water body. In this paper, we will discuss a junior/senior design project of developing an Interactive Mobile Aqua Probing & Surveillance (IMAPS) system capable of continuously monitoring water properties and wirelessly communicating with a base station. The completed aqua probe system can be employed by scientists, educators and anyone interested in the study or monitoring of aquatic ecosystems.

Within a year, beginning in spring 2005, the design has evolved from a proof-of-concept prototype to a large pontoon-style robotic probe. Although the project is still on-going, exciting results have already been obtained in initial tests and applications. The most recent pontoon-type probe can retrieve immediate data of locations (longitude and latitude), depths and temperatures of many points of a pond within minutes, whereas in contrast, traditional manual sampling methods take hours to do so in the same field, not to mention the cumbersome preparation and clean-up processes.

In this paper, we will describe in detail the design, construction and testing of all three generations of the aquatic probe system. We will also summarize the skills and experiences obtained by the student team during the process of working from the idea to the realization of working prototypes.

II. Project Management

The entire design process has been conducted within the Rowan Univeristy Engineering Clinic. The Clinic is a format we developed in the Rowan School of Engineering to mimic real-life engineering. The motto of the Clinic is “Design, Build, and Test”. Clinic students are asked to follow a typical process of designing a new product in a manufacturing company. At the beginning of each semester, the faculty members prepare a list of possible projects and give short presentations to the students in the format of a job fair. The students are grouped according to their respective disciplines. The faculty members will rotate to each group if they think the specific skills from that group of students will be required for the project they proposed.

After reviewing each available job description, students make a list of their preferred projects and submit it to the program managers who act like a job placement manager. The program managers then make a match between faculty members and students, with consideration of their major, grade and GPA. Therefore, each project contains one or more sponsoring professors and a group of students with the appropriate skills and backgrounds.

The IMAPS project provoked a tremendous interest among both Mechanical Engineering (ME) and Electrical and Computer Engineering (ECE) students. It is a great opportunity for them to participate in faculty research while participating in a collaboration between engineering and non-engineering students and faculty. Throughout the 14 months of the project, we have hired 6 engineering students (3 ME and 3 ECE) to date, although not at the same time. The team showed a good balance of skills at different stages. Initially, more ME students were involved in the building of the basic structure and propulsion system. With the body finalized and the focus turned to control and interface, more ECE students joined and took charge of the project.

Regarding the transition between the students every semester, the faculty members have had to find ways to retain and re-distribute the knowledge and expertise accumulated in the prior group. One way is to keep at least one member from the prior team to stay in the new team, and to act as the seed. Another way is to promote clear documentation. At the end of each semester, a detailed formal report is required to summarize the work that has been done. It serves as an introduction material for the new member of the team.

III. The First Generation – A Torpedo Probe

The first aqua probe was built as a semester-long project to test basic principles of water craft design and propulsion. We will explain the detail of the probe with its mechanical design, electrical and software design, and performance analysis.

1. Mechanical Design.

The first probe was constructed with 20 gauge rust-resistant thin aluminum sheet metal over a high strength ABS skeleton (Figure 1). The sheet metal riveted together drastically reduced the overall weight and increase payload capacity comparing with a same size robot using solely PVC or ABS as the building material. Meanwhile, the ABS plastic frames (Figure 1-B) inside provided an easy–to-make (by using a 3-D fast prototyping machine with ABS as material) yet high strength structure to support the hull and onboard equipment.

(A) (B)

Figure 1: The first generation probe on dock (A) and the internal skeleton made from ABS plastic (B).

Internally, twenty 11-Amp Hour D-cell Nickel Metal Hydride (NiMh) batteries were used to power the probe. On top of the boat, an aluminum lid sealed with adhesive weather stripping was installed. The main enclosure was screwed into the ABS frame while a smaller, easily accessible door swings open using hinges. As the lid opens (see Figure 1A), a control panel is revealed. It houses the LCD display along with 2 toggle switches to turn on/off both the boat engine and the cameras.

For propulsion, two bilge pump motors were mounted side by side to incorporate differential steering (Figure 2). This type of design eliminated the need of a rudder, which in turn simplified the controls. The original bilge pump housings were stripped down in order to reveal the water proof motor compartments. The propellers, which allow forward and reverse motions, were then attached to the motor shafts. The motors were further encased in a motor housing, which was shrouded by an ABS shell for protection from floating debris. Also found on the underside of the boat is a dagger board that not only supports the Ray Marine depth finder, but also doubles as a directional stabilizer. By adding the depth finder below the hull, the effective center of mass was lowered with increased stability.

The probe used onboard wireless cameras for navigation and visual observation of the boat's surroundings. To obtain live video feeds from both above and below the water level, two onboard camera mounts were built into the nosecone. Wireless cameras were mounted into the nosecone and enclosed with transparent Lexan Plastic. These wireless cameras are powered by 9V batteries separate from the main battery set to conserve the power for maneuver capability.

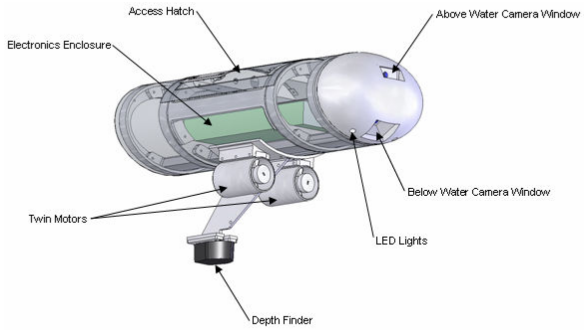
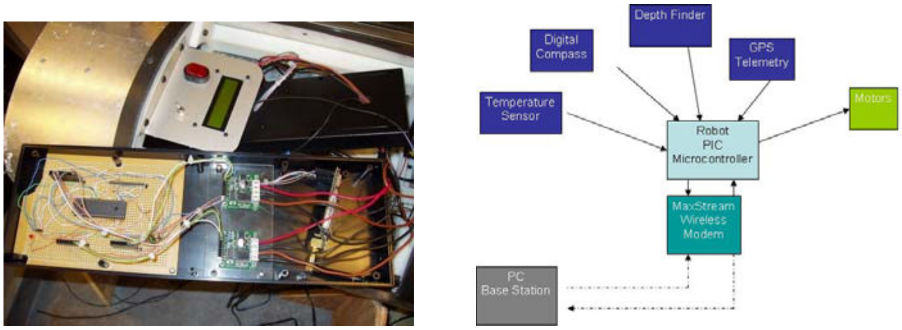


Figure 2: 3D internal/external view of final design.

2. Electrical and Software Design.

In order to control the aqua probe, a 40-pin 16F874A PIC (Programmable Integrated Circuit) microcontroller was used in a circuit to control the motors and data transmission (shown in Figure 3A).



(A) (B)

Figure 3: (A) Internal circuitry of probe. (B) Logic layout of electronic processes.

The control structure is shown in Figure 3B. The PIC is capable of receiving text-based commands from the wireless modem on board and converting those signals to commands for each motor controller. A code was designed so that commands entered from a Hyper Terminal at the wireless base station can control the speed and direction of the motors onboard. For example, typing in “1” on the keyboard wirelessly transmitted a signal to the PIC microcontroller to turn the motors on half speed forward. “2” “3” “4” “5” and “0” represent full speed forward, right turn, left turn, full reverse, and stop, respectively. The PIC also has been programmed to receive data from the on-board temperature sensor, compass, GPS, and depth finder.

3. Performance

The torpedo prototype aqua probe performed as expected. It enjoyed good maneuverability and transmitted video and temperature data back to the host station at a distance of about 30 meters. However, there were areas that could be improved upon, as it was the first generation design. The motors and propellers chosen could not provide the desired performance of speed and current resistance, despite thehuge battery reserve required to power them. In fact, the batteries account for 80% of the total weight, which left little buoyancy to support additional sensors. Finally, the video camera used was an all-in-one pin-hole camera/transmitter. The antenna wire had to be housed inside the unit with no way to extend it, severely limiting the video transmission range.

IV. The Second Generation – A Video Probe

The second probe was requested by the biologist collaborators on this project, for their summer research trip to Florida. These biologists are studying a species of sea grass that is unique to the shallow lagoons of eastern Florida. With the increasing anthropogenic activities and the associated reductions in water quality and light penetration, seagrasses (including the species under study) are facing declines and possible extinctions. The biologists working on this project and their student research team are quantifying the distributions and density of the seagrass population, in order to quantify the effect of human activities in the Indian River Lagoon in Florida. Their current tools include underwater cameras, 1'x1' PVC frames acting as shade canopies (as shown in Figure 4A) and scuba gears such that they can stay in 5~10 feet water to take pictures or, more frequently, to manually count seagrass densities. Our team was asked to devise a tool to make this process more efficient and productive.

1. The Probe Design.

The project goals for this probe were clear: design a smaller, lighter, faster, more agile boat capable of handling a harsher environment that can transmit a crisper, cleaner image farther than the prototype. It should also be easy to transport due to the long distance traveled for this stage of the work. The final design required 91 hours to build, but the results were exactly as envisioned, as shown in Figure 4B.

(A) (B)

Figure 4: (A) Biologist's experiment set up taken by the Video Probe; (B) Video probe photographing the bottom of Jupiter Inlet in eastern Florida.

In order to increase the speed, mobility, and range of the second model, Speed 400 motors, which are medium-grade power motors that consume a maximum 9 Amps, were chosen for a combination of speed and relatively low power consumption. Appropriate motor controllers were selected that can handle the amperage of the system. A compact version of high power-low weight NiMH batteries was used to save weight. Additionally, a superior video transmitter with a tested range of over 300 meters was chosen to provide a clearer, more stable image than the original prototype camera/transmitter combo.

The operating system used by the video probe was essentially the same as the operating system on the first prototype. The electronics allowed the craft to function as a remote-controlled boat with a video camera point at the bottom of the water body.

2. Performance

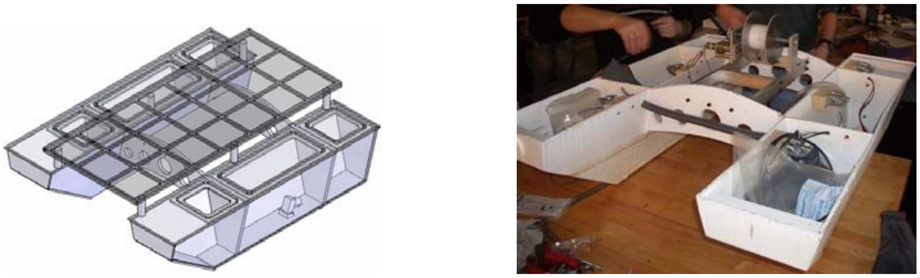
The second generation Video Probe performed exactly as anticipated from its design. It was essentially a custom-built speed boat with a video camera pointed into the water below the boat. There were several factors that were not taken to account when designing the probe. The most significant factor was the presence of waves. There are no waves on the local pond or in the water tank where most of the testing was performed. When the probe was tested in an estuarine field location, important functions were affected by even the weakest waves; the first function to be affected was the video. When the camera is rigidly attached to the bottom of the probe, it is always moving with the boat and the waves. This made the video footage rock back and forth. This constant motion made it difficult at times to distinguish between certain species of seagrass on the inlet floor. The other effect that waves had on the boat was loss of signal. When the probe was in a valley of a swell it occasionally affected the RF transmission. This sporadic lost of signal sometimes led to temporary adverse affects, such as loss of control and disrupted video feed. A larger and steadier design will be helpful to reduce these problems.

V. The Third Generation – A Pontoon Type Working Model

After returning from the experiments in Florida with this field experience, the design of a new, larger probe began. In order to reduce the effects of currents and waves, a larger -tyle double-hull design was selected. Buoyancy calculations were performed on several initial options. The final shape (as seen in Figure 5-A) and size (1m x 0.838m x 0.378m) were chosen for its handling of wave and payload.

1. Mechanical Design

This large aqua probe would need to be both durable and lightweight, while also having the ability to carry more payload than the previous two models. Several materials were considered, but the options were quickly narrowed down to ABS sheets or Luann plywood. Due to the lower cost ($25 compared to $400) and the ease of obtaining the material, plywood was chosen over the ABS sheets. Due to their satisfying past performance, the we elected to use the same NiMH batteries and Speed 400 motors with identical motor controllers to run this aqua probe.



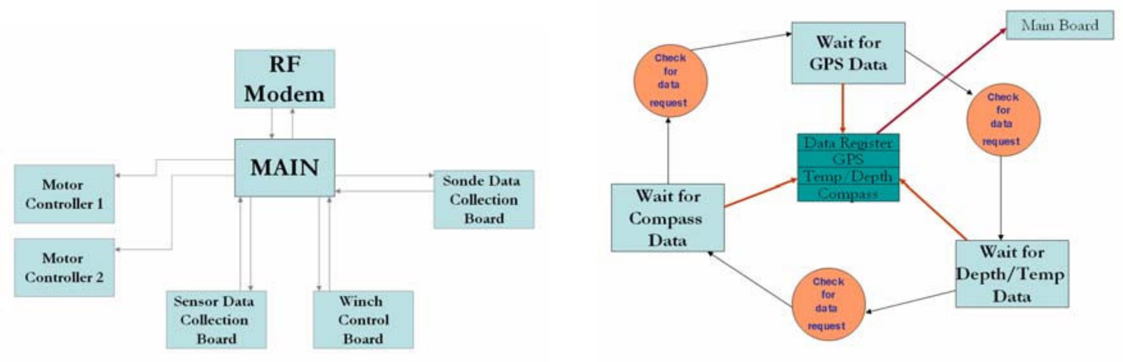
(A) (B)

Figure 5: SolidWorks rendering of the pontoon probe (A) and the working prototype model after a mission test with the winch installed ready to deploy biological sensor(B).

While the construction of the plywood aqua probe was taking place, different electronic components that it carries were tested. The depth finder and GPS were both integrated into a circuit board and a program was written to retrieve live data from those devices. After the wood was cut and glued together, the hull was fiber glassed, epoxied, and painted (Figure 5). Following the initial stability and leak testing, the boat was then outfitted with its electrical components.

2. Onboard Electronic Devices

The first generation aqua probe had only one onboard microcontroller for the single purpose of remote control. In contrast, the pontoon-style aqua probe contains a depth finder, a temperature sensor, a GPS receiver, and a digital compass – all of which transmit live, streaming data at 1Hz wirelessly back to the base station. Meanwhile, a winch mechanism designed to lower a biological sensor package (which measures various water parameters including, but not limited to pH, O_2, N_2, algae concentrations, and turbidity) is installed and ready to relay the data from the sensors to the host computer at time of writing this paper. It has become essential to implement an onboard network to alleviate bottleneck when transmitting data and control signals. For instance, it can take up to one second each for either GPS or Depth/Temperature to transmit their most recent readings. They might tie up the microcontroller waiting for the report from the units. At the meantime, other requests such as changing the speed and direction of the boat or retrieving biological data will be held in queue for seconds or simply lost. Therefore, a network of microcontrollers was used so that one single microcontroller would not be bogged down performing several different tasks.



(A) (B)

Figure 6: (A) Electronic layout of the pontoon probe. (B) Control diagram of the onboard network.

As seen in Figure 6A, a main control board is the central hub responsible for receiving data from the base station PC via the RF modem and doling out commands to the subsystem boards. Connected to the main control board (Figure 7A) as subsystems are motor controllers, the Onboard Sensor Data Collection Board (Figure 7B), the Winch Control Board (Figure 7C), and the Sonde Data collection board (not yet completed). Figure 6B illustrates the flowing of the data in this onboard network. Since each sensor can take up to a second to provide the microcontroller with fresh data, the whole system can provide completely new data once every 3 seconds, giving it a 1/3 Hz refresh rate.

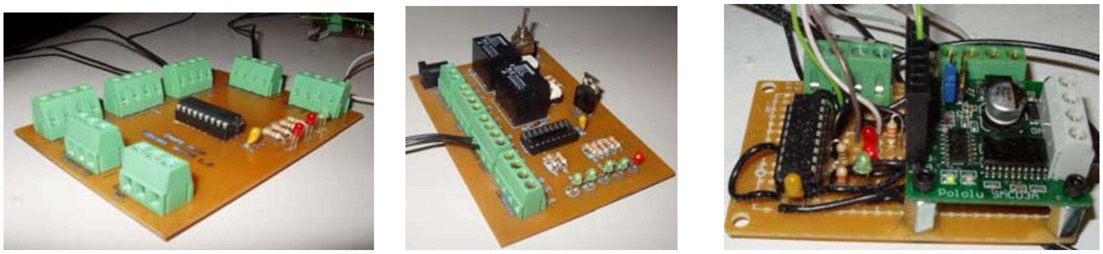
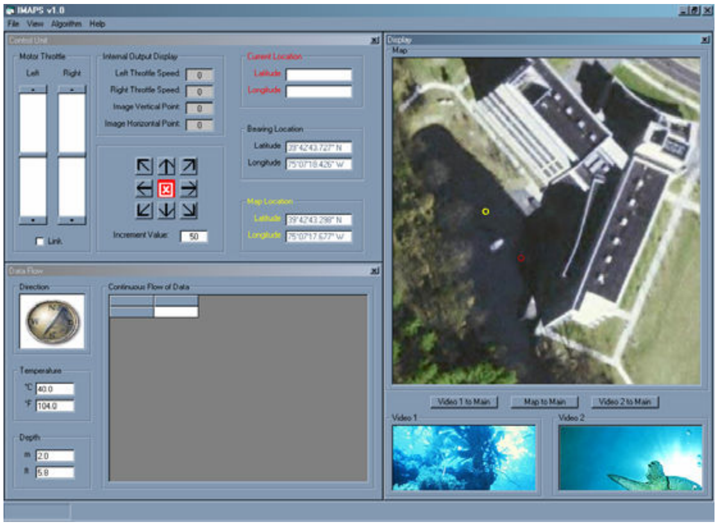

(A) (B) (C)

Figure 7: (A) The main control board. (B) The sensor data collection board. (C) The winch control board.

3. Software Design.

For the convenience of operating the probe for the non-engineering persons, an easy-to-use graphical user interface (GUI) is being developed.



Left Throttle Speed 0
Right Throttle Speed 0
Image Vertical Point 0
Image Horizontal Point 0

Current Location
Latitude
Longitude

Bearing Location
Latitude 39°42'43.727" N
Longitude 75°07'18.426" W

Map Location
Latitude 39°42'43.298" N
Longitude 75°07'17.677" W

Increment Value: 50

Temperature
°C 40.0
°F 104.0

Depth
m 2.0
ft 5.8

Figure 8: Graphic User Interface of the IMAPS System.

Figure 8 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 physical location. Two pointers indicate the current position of the IMAPS system and the desired position selected by the user. Meanwhile, two sub-windows show the real-time video image sent back by the on-board cameras. 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 throttle of the thruster, GPS location and heading of the agent, as well as the sensor data such as water temperature, pH level, dissolved oxygen (DO)level, and turbidity.

With this interface, users will be able to remotely log into the system, view the IMAPS location on a satellite photo or map of the targeted area while navigating the

IMAPS, and retrieve real-time sensor data and images of the site. This software will also provide users options of applying different control algorithms, selecting a variety of biological parameters to be tested, or choosing the output format as either tabular material in spreadsheet, graphic, or GIS files.

4. Performance

Although it is still not completely finished at the time of writing this paper, light field testing has begun on the third generation pontoon probe. This probe offers a good compromise between speed, cargo and power consumption.

A comparative experiment was set up to collect water quality data both manually and using the pontoon probe. In the manual collection, a two-person team consisted of a mechanical engineering student and a biology student were sent out to a local pond. They spent over 7 hours collecting data from 10 stations on this pond. The job included rowing a canoe to pre-selected positions located by a hand-held GPS receiver, anchoring the canoe, then lowering the sensor to collect data on temperature, pH, and dissolved oxygen (DO). In comparison, the pontoon probe was controlled by one operator and collected temperature and depth data of the same 10 points within just 20 minutes. Even though the pH and dissolved oxygen were not recorded at the probe since the data link to the Sonde is not yet complete, the time to accomplish all the same measurements is still expected to be significantly shorter than the manual method of data collection. If the time and effort of transporting, setting up and cleaning the canoe and probe are considered, the improvement of using our probe over manual work is even more dramatic.

VI. Skills Developed by the Participating Students

By participating in the project, the students obtained various skills and experiences that are seldom seen in a single session of regular classes. These include mechanical and electrical design, machining skill, programming skills, maritime experience, biological knowledge, and multidisciplinary communication and collaboration.

In order to design a working model of the IMAPS agent boat, the students needed to first determine what kind of sensors would be integrated into the boat, what kind of actuators were to be installed, and to then calculate the necessary working payload. From there, they needed to design the shape of the boat, which needed to accommodate the calculated payload, the deployment of the bio-sensors, the control of the boat, as well as the resistance of the wave and current. They consulted ship-making books, various hydrodynamics books and their Fluid Dynamics professor.

Further, the system is not a pure mechanical structure. Indeed, it is a computer-controlled electromechanical system with several embedded micro-computer systems in both agent and the host. In contrast, the majority of the students are mostly mechanical engineering, and they did not relish having to learn how to code the microprocessors and to make circuit boards. However, this did not stop them from mastering these techniques by self-learning and learning-from-practice. Within two semesters, the students can not only compile the microprocessor with both BASIC and C language, but also design a fairly complex schematic diagram, convert it to a printed circuit board, solder the electric components into it, and test the board for application.

Meanwhile, the project was conceived and conducted as a multidisciplinary project. The device is a mechatronic system, the interface and control requires a significant amount of programming, while the application is biological and environmental. Besides two professors from the Biological Sciences department, one Biology student was also involved to interact with the Mechanical Engineering students in developing the system. Therefore, the students needed to not only interact with professors from their own disciplines, but also interact with faculty and students from other majors. In fact, the engineering students worked seamlessly with people from the Biology Department. They went to the Indian River Lagoon in Florida in the summer of 2005 to test the second generation video probe and to study the influence of reductions in water quality on a species of seagrass only found at this location in eastern coastal Florida. They also conducted experiments at a local pond and compared the time and effort of using human power and the third generation pontoon-style probe to sample the water at various locations. The students from different disciplines learned to respect different working styles, communicate with different backgrounds, and design and fabricate a system with users' needs in mind.

VII. Summary

In this paper, we presented a year-long project of designing and fabricating an Interactive Mobile Aqua Probe Surveillance system. Within a year, the group consisted of students in Mechanical Engineering, Electrical and Computer Engineering and Biology; this group designed and built three generations of prototype and conducted several experiments

With each subsequent design, modifications and advancements were made that have brought this project closer to its ultimate goal of full autonomous water quality data collection. The first torpedo-style prototype was a crash course in learning the ins-and-outs of the electronic circuits, propulsion systems, and hull design. The second aqua probe, designed specifically for underwater video observation, possessed the positive attributes from the first prototype while eliminating the less favorable elements we identified in this probe. The propulsion system, control algorithms, and video transmission system were all upgraded. From the experience of designing and fabricating the first two aqua probes, the third pontoon probe design was born. This probe use the same propulsion system as the video probe while taking advantage of the large buoyant force offered by a pontoon design. The pontoon probe possessed the ruggedness and durability of the prototype design while maintaining the agility and swiftness of the video probe. This probe has the cargo capacity to carry a multitude of biological sensors as well as an onboard solar-power battery charger, making this design ideal for future modification and additions. With the addition of these sensors in the coming months and the shift of focus to autonomous control, this version of the aqua probe will be well suited for use by biologists interested in studying the water parameters of aquatic ecosystems both educationally and professionally.

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