AC 2007-1607: IMAPS — A MULTIDISCIPLINARY AQUATIC ROBOT PROJECT

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Abstract

Multidisciplinary skills and the willing and ability to apply engineering skills to non-engineering problems are always desired by industry and critical to the success of our students. Starting from 2005, a Rowan student team from Mechanical Engineering, Electrical and Computer Engineering, and Biology Science worked together to develop an aquatic robot under the guidance of faculties from these departments. In this multidisciplinary project, the students designed and built an easy-to-use yet versatile surface robot that can autonomously cruise on the surface of water and take underwater data in real time. In less than two years, the robot has evolved from a proof-of-concept prototype to a functioning robot that can autonomously pilot itself and test water quality as deep as 30m. Extensive field tests have been performed at various locations with different water qualities and weather conditions. Currently, the multidisciplinary group is gearing up to develop a third generation amphibious robot that can launch itself and return to the land. This robot, also called IMAPS^2, will also be applied to the biological or environmental research on difficult areas such as marshes.

I. Introduction

The ability to apply multidisciplinary or interdisciplinary concepts in real-world engineering problems is critical for the future growth of students. To promote this ability is therefore important for any engineering program. Starting from 2005, the departments of Mechanical Engineering, Electrical and Computer Engineering, and Biological Science of Rowan University started a multi-disciplinary project to build an aquatic robot for shallow water study and surveillance.

Ecological and biological studies of aquatic habitats, especially those in shallow-water, are often hindered by difficulties of accessing remote sites or the cost of collecting high resolution data in space and time. For example, manual sampling by workers in the field [14] offers limited sampling stations and numbers of observations. It is also sensitive to environmental and logistical conditions such as season, weather, terrain and access. In contrast, fixed sensors such as distributed sensors [12] or buoy stations [9] allow continuous monitoring of a specific location. However, their long term deployment can physically alter the environment and the cost of this option multiplies quickly with the number of stations. On the other hand, mobile sensor platforms such as Remotely Operated Vehicles (ROV) [1] and Autonomous Underwater Vehicles (AUV) [10] are capable of dynamic remote data collection. However, these vehicles are often designed for use in the deep environs of the open ocean. Their cost, size, and limited agility are not suitable for work in other aquatic habitats (e.g., shallow water).

Aware of these needs, the faculty of Engineering School and School of Art and Science proposed the development of a robust, cost-effective and flexible solution to continuously collect data from a water body interactively and in real time. Beginning in Spring 2005, we started design, build, test and apply a robotic aqua sensor, called the Interactive

Mobile Aqua Probe & Surveillance (IMAPS) system. The development is conducted with the format of a series of Junior/Senior Engineering Clinics.

At the College of Engineering at Rowan University, we have developed a curricular component, “Engineering Clinics” [3], to address this challenge in engineering education. Based upon the medical school model, students and faculty work side-by-side in Engineering Clinics on multidisciplinary or interdisciplinary laboratory experiments, design projects, applied researches, and product developments. While each clinic course has a specific theme, the underlying concept of engineering design permeates all clinics. The progression through clinics systematically develops our students as collaborative designers. This begins with the Freshmen Engineering Clinic, which introduces design through reverse engineering [9]. At the sophomore level, students experience their first open-ended project [5] and learn structured design. Finally, in the Junior and Senior Engineering Clinic, students work in multidisciplinary or interdisciplinary design teams on projects of greater complexity. The Engineering Clinic sequence offers students an opportunity to experience the art and science of design by applying the technical skills learned in the classroom, from interacting with faculty, in collaboration with students from different grades and different disciplines. This just-in-time approach to engineering design enables students to be involved in ambitious design projects as early as their sophomore year.

This paper presents collaborative efforts among the departments of Mechanical Engineering (ME), Electrical and Computer Engineering (ECE), and Biological Science (BIO) in engaging students to apply scientific and engineering principles to the design of this robotic aqua sensor. The IMAPS team consists of students from ME, ECE and BIO. To design and construct the IMAPS robot, they had to solve “real world” engineering problems as a team while making their individual contributions based upon their knowledge and skills. For instance, ME students were initially in charge of the basic structure and propulsion system of the IMAPS, where they were able to use their knowledge acquired in ME courses such as Fluid Mechanics, and System Dynamics and Control. With the body of the IMAPS finalized and most sensors in place, more ECE students were involved. They applied their hardware and software skills taught in ECE courses, such as Digital I, Electronic I/II and Microprocessor Design, to design and fabricate the electromechanical system.

As a proven successful Junior/Senior Engineering Clinic, this project of developing IMAPS offers a number of benefits as elaborated below.

- The IMAPS design is inherently multidisciplinary in nature, involving mechanical and electrical system integration, embedded system design, wireless communication and power management.
- The sophistication of subsystems like path planning, obstacle avoidance, and feedback control offer many opportunities for undergraduates to gain valuable research experience and be prepared for advanced degrees.
- The deadlines posed by this grant-sponsored project mimics the need in industry to carry out time-sensitive product design.

The layout of this paper is as follows. We will introduce the hardware and software design first, then talk about the experimental development to test the system. In the following sections, we will introduce the integration of the robot to the curriculum and its pedagogical impacts. The last section is a brief summary.

II. Hardware Design

For the purpose of wide adoption by the public, the development of the IMAPS adheres to the following design goals:

1) Inexpensive to obtain and maintain;
2) Straightforward to operate;
3) Low power consumption and long operate time;
4) Suitable for a wide range of water bodies;
5) Stable in variable water and weather conditions;
6) Flexible to conduct different tasks;
7) Enough payload to carry multiple instruments;
8) Open to accept user defined control algorithms.

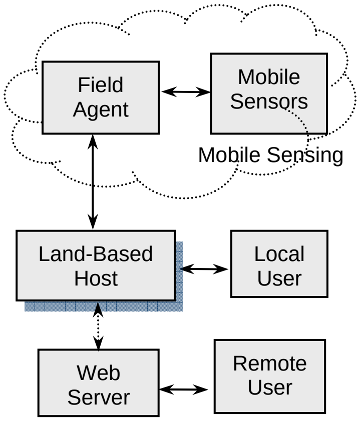


Figure 1: Block diagram of control.

Following the above goals, an agent-server approach (Figure 1) is chosen for the general structure of the IMAPS. The field agent takes the form of a model surface vehicle. Depending on working condition or design preference, it can carry different shapes, such as a torpedo, a racing boat, or a catamaran. In order to obtain the capability of maneuvering on the surface and sample the water, the agent is equipped with several interacting and cooperating units as shown in Figure 2A. 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 controlled by a mini computer, *Mini-ITX*, which 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. Two on-board infra-red enabled video cameras, one forward-oriented and the other downward-looking, are used to monitor the condition of the IMAPS and visually inspect field conditions in both day and night.

As shown in Figure 2B, a high end host computer is used to interactively communicate and 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.

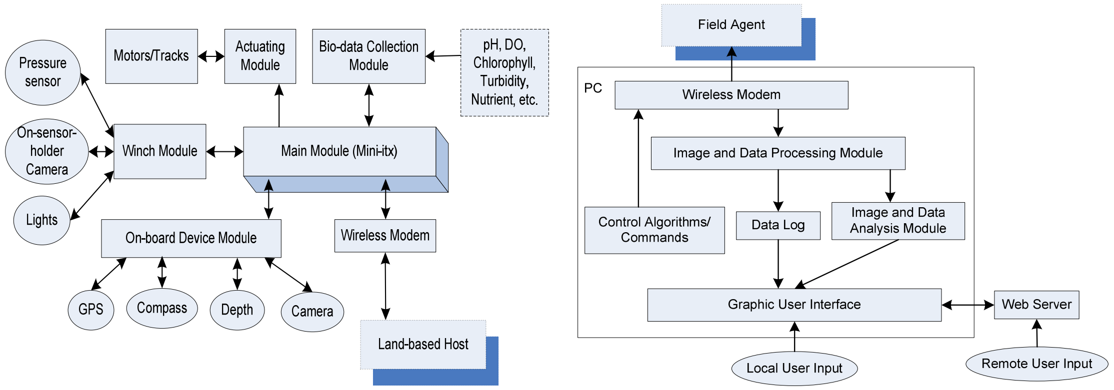
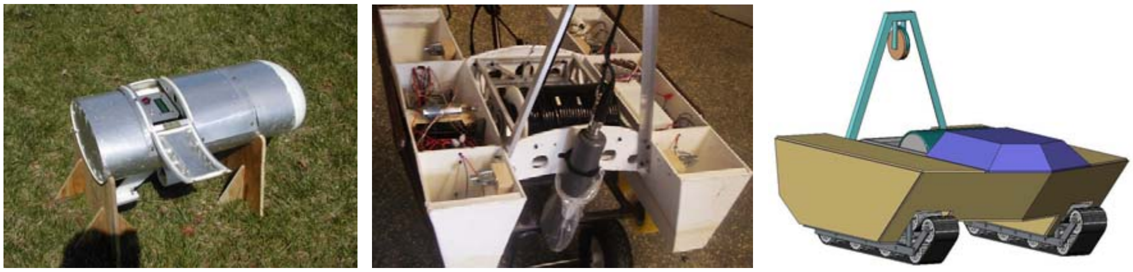


Figure 2: Block diagram of the agent and the host.

After two years development, the mechanical structure of the IMAPS agent has evolved with three major generations of improved understanding and increased design sophistication. As seen in Figure 3, the first one (A) is a torpedo style pure observer, the second generation (B) is a catamaran style Prober that can sample water 100ft deep, the current development is a tank style amphibious Explorer that can work on complex terrain such as marsh or creeks.



(A) (B) (C)

Figure 3: Three generations of IMAPS body structure.

III. Software Development

In order to maneuver the IMAPS, a web-based software package was designed with a user-friendly graphical user interface (GUI) and a variety of embedded underlying control algorithms. Figure 4 shows a snapshot of the user interface, which displays a satellite photo or map of the targeted area and real-time video images sent from the on-board cameras. Important data for robot control (such as thruster throttles and GPS locations of the IMAPS), and water quality monitoring (e.g. water temperature, pH level, dissolved oxygen (DO) level, and turbidity), can be displayed in the interface in real time.

With this interface, users are able to remotely log into the system, view the IMAPS location on a map, navigate the IMAPS, and retrieve real-time sensor data and images. This software will also provide users the options of applying different control algorithms, selecting a variety of biological parameters to be tested, or choosing the output format for further analysis.

For the convenience of operating the probe for the non-engineering persons an easy-to-use graphical user interface (GUI) is developed. As depicted in Figure 4A, a manual remote operation can be used with joystick or sliding bars. The users can easily adjust the thruster speed and navigate the robot. They can also easily switch to autonomous control as shown in Figure 4B. Users can choose several sampling stations on the map of the testing area as well as setting the depths desired for the sensors to collect data. They can select from various control algorithms or enter desired GPS stations as well.

Meanwhile, the GUI can toggle between showing the real-time image feedback from the on-board cameras or display the biological and environmental sensor data. Users will be able to select the method of data display, including seeing the raw data as text, in user-defined graphs, or both formats.

Time	Temp	SpCond	DOsat	Depth	pH	NH4+ N	Chl
14:55:58	23.72	0.001	103.5	10	9.17	1052	-0.3
14:55:59	23.72	0.001	103.5	9	9.17	1051	-0.1
14:56:00	23.72	0.001	103.6	8	9.17	1051	-0.2
14:56:01	23.72	0.001	103.6	7	9.17	1051	-0.3
14:56:02	23.72	0.001	103.6	6	9.17	1051	-0.3
14:56:03	23.72	0.001	103.6	5	9.17	1051	-0.1
14:56:04	23.72	0.001	103.6	4	9.17	1050	0
14:56:05	23.72	0.001	103.6	3	9.17	1048	0
14:56:06	23.72	0.001	103.6	2	9.17	1049	0.2
14:56:07	23.72	0.001	103.6	1	9.17	1049	0.2

(A) (B)

Figure 4: A snapshot of the GUI control interface. (A) Manual control. (B) Autonomous control.

IV. Experimental Development

With the progress of the project, biological and environmental experiments and tests were also developed by the BIO and engineering students.

One experiment is the water surface monitoring, where the IMAPS system is configured to collect data on the water surface. As depicted in Figure 5A, the agent, commanded by the host, can be used in many ways, including 1) to scan the surface of a water body with its probes to obtain a distribution map of a desired water parameter, 2) to “chase” a pollutant source by making decisions to move up a concentration gradient as real-time measurements are taken, or 3) to be manually controlled or dynamically anchored to survey plants or observe the activities of animals with the forward-oriented camera. Figure 5B shows the second generation IMAPS working on the surface of water.

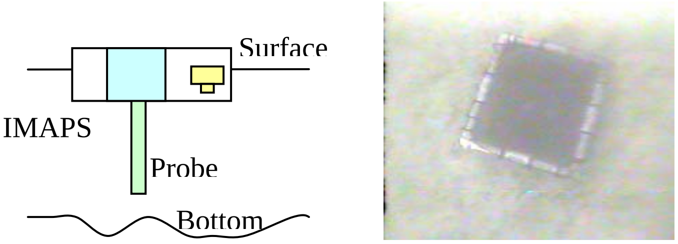
Within this context, a comparative analysis was conducted to assess the ability of the IMAPS in data sampling and collection in comparison to the traditional method. First, a two-person team was sent out to a local pond. They spent over 7 hours collecting data from 10 stations on this pond. The job included rowing a canoe to pre-selected positions located by a hand-held GPS receiver, anchoring the canoe, and then lowering an YSI Sonde bio-sensor into water to collect and record data. On the contrary, it only took half hour for one student to use the IMAPS for the same task. Figure 5C is the Bathymetry plot of Rowan Pond, a typical result of testing.

(A) (B) (C)

Figure 5: (A) Configuration of the IMAPS on water surface probing. (B) The IMAPS runs on water. (C) The Bathymetry plot of Rowan Pond.

Another experiment that we have developed is to index water parameters at different depths or study underwater ecology. As elaborated in Figure 6A, the winch on the IMAPS will lower the sensors to the desired depth for zooplankton measurement, hypoxia information and other data necessary to study the near-bottom ecology. Meanwhile, the onboard camera can be configured to face downward and obtain underwater images and video feed.

In the summer of 2005, two ME students and a group of BIO students went to the Indian River Lagoon in Florida. Using the underwater configuration of the IMAPS, they studied the influence of reduced water quality on a particular local species of sea grass in Florida. Figure 6B is a photo of a shading canopy taken by the onboard camera of the IMAPS. In contrast, existing practice requires a human to snorkel or scuba into the water and count the number of sea grass manually.



(A) (B)

Figure 6: (A) Configuration of the IMAPS on underwater probing. (B) Photo of a shading canopy in sea grass experiment.

V. Course Sequence Integration

The junior/senior engineering clinic sequence at Rowan is offered every semester. At the beginning of each semester, faculty members present a list of projects in a so called "Clinic Job Fair". After reviewing the project descriptions, students submit a list of their preferred projects to the clinic managers. They will then make a match between faculty members and students, considering students' major, grade and GPA.

The IMAPS project created a tremendous interest among students. Scores of ME and ECE students competed for the 3 positions offered by this project. Throughout the course of the project, we have recruited 6 engineering students, 3 ME and 3 ECE, although not at the same time. The team showed a well balance of skills at different stages.

The course schedules students and faculty sponsors to meet twice a week for 3 hours per session. As the project progresses, a series of mini-lectures with different topics were provided as needed. For instance, at the early phase of the IMPAS design, project management and design methodology were introduced. They helped students to understand the project goal, brainstorm potential approaches, and initiate preliminary timeline and plans. While the serious design took place, the contents of the mini-lectures became more technical oriented. These could be background and knowledge review, or be introduction of project specific materials, such as motor control, PIC microprocessor programming, and CAD. As the design evolved over the semesters, the topics extended to design optimization, reliability, and cost analysis. The semesters were very intensive, but many rose to the challenge because of the excitement that the IMAPS project offers.

Two conference format design reviews were conducted on the clinic projects in lieu of midterm and final exams. Not only did faculty members raise questions on the performance of each clinic team and their design methodology, the students of other project teams were free to affirm, contradict, or debate what was presented. The kaleidoscope of project topics provides a diversified exposure to the students. A final report regarding the accomplishment of the semester and future research directions was also mandatory. Students were also encouraged to submit their design to conferences and competitions. Indeed, the IMAPS team won the first place in oral presentation competition at the 2006 American Society of Mechanical Engineering Regional Student Conference. When the team brought the robot to 2006 National conference of American Association of Artificial Intelligence, they also won a Technical Innovation Award for multidisciplinary collaboration in the Robot Competition and Exhibition section.

Like many other clinic projects, IMAPS projects is grant-supported, more students were further recruited as summer interns to continue on this project. In summer 2006, two ECE, one ME and one BIO student were hired to refine the control algorithms, test the system, and develop sample experiments for future dissemination to schools, institutes, and environmental protection agencies.

VI. Pedagogical Impacts

The evolutionary process of the IMAPS project has highlighted a number of important pedagogical impacts that should be of interest to colleagues teaching this type of course.

1. *Transfer of Expertise*: With the complexity of the IMAPS, it is necessary to expand the development into multiple semesters. It then becomes extremely important to emphasize clear documentation for a smooth technology transition between successive generations of students. Besides the clarity needed for the project description, meticulous standards must be set forth for the accuracy of schematics, design process, and in-line document of code, etc.

2. *System perspective of the design*: "Systems" have become the organizing principle for how a project is viewed and how a design is accomplished. With the IMAPS project, for example, the complexity of the necessary subsystems and the need to integrate all of them elaborated a system-level design philosophy. A systematic set up of the project helped students understand that their courses were part of a design flow instead of separate bodies of knowledge. In the long run, student will be in a better position to appreciate the multidisciplinary nature of their respective majors.

3. *Impact on students*: By participating in the IMAPS project, the students obtained various experience and skills that were seldom seen in a single session of regular classes. For example, the project encouraged the students to exercise their skills and knowledge and apply them to a real-world problem. The open-ended nature of the project facilitated opportunities for the students to practice their problem-solving and critical thinking skills. Meanwhile, the project also helped to improve their communications skills as the students exchange their ideas with other team members and faculty mentors. In particular, while working within a multidisciplinary team, the students learned to respect and appreciate different disciplines, interact seamlessly with people from different backgrounds, and handle disagreement and pressure under deadline.

(A) (B)

Figure 7: (A) SolidWorks rendering of a working prototype. (B) The winch control board.

Furthermore, the project gave ample opportunities for students to practice technical skills learned in their major courses. For example, the theoretical calculation and computational modeling of the IMAPS strengthened students CAD skills learned in Machine Design courses as depicted in Figure 7A. The control circuitry interacting with several microprocessors, as shown in Figure 7B, allowed students to apply concepts learned in microprocessor design and digital courses. Meanwhile, the design of graphical user interface requires a full understanding of JAVA and Visual BASIC, the control algorithm prompts students to apply the knowledge learned in the Control class.

4. *Impact on curricula and engineering education*: Figure 8 indicates the impact of the IMAPS project on many core engineering and science courses. Most of the experiments conducted during the course of the project can easily be used in other engineering/science courses. For instance, the experiment of developing an electro-subsystem, such as RF wireless data acquisition, for the IMAPS can be a wonderful term project in microprocessor design course. Upon finishing the design of the IMAPS, the experiments on water surface monitoring and/or underwater ecology can be an important demonstration in a marine biology course or environment-related water resource course. Further, with some tailoring or modification, the structure and management of the project can be adopted for other remotely operated system design. For example, an unmanned blimp is equally challenging and fun, and its set-up and design process is very similar to that of our IMAPS.

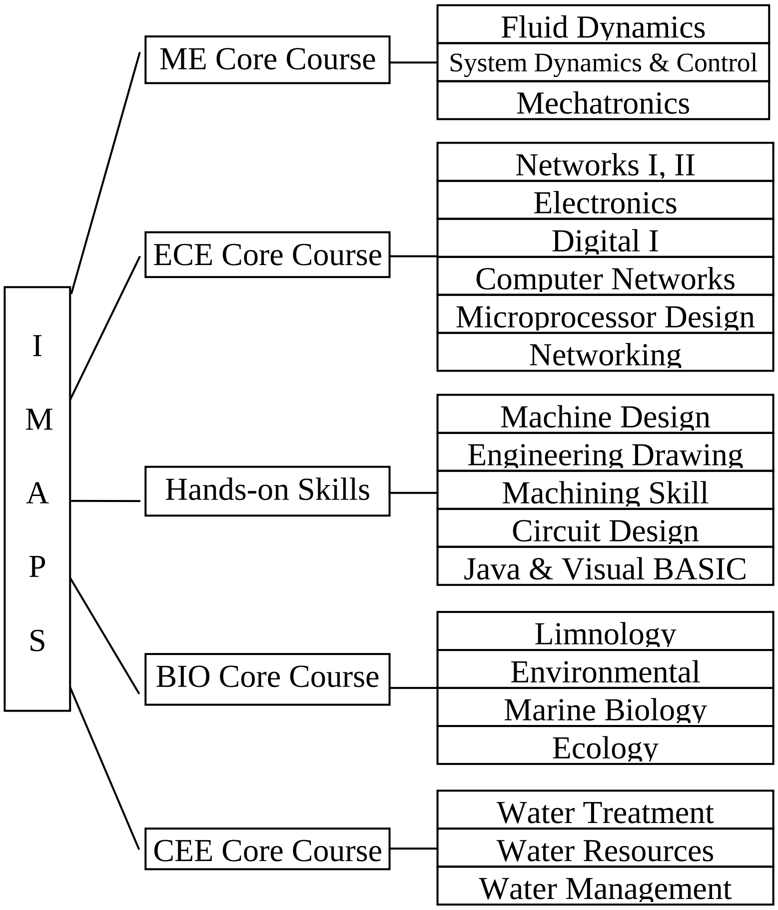


Figure 8: Impact at college courses.

VII. Summary

This paper presents a multi-year project of designing and fabricating a robotic aqua probe system. The course structure and content described in the paper can be easily adopted by other institutions for their capstone design or pertinent courses as laboratory experiments. The course assessment demonstrates that the project is an effective educational tool to excite and motivate students in applying their knowledge and skills from various subjects for a real life problem. With the future improvement of the existing prototype, the IMAPS will be well suited to be used by biologists in studying the water parameters of aquatic ecosystems both educationally and professionally.

Acknowledgement

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Reference

1. R. D. Ballard, The MEDEA/JASON Remotely Operated Vehicle System. Deep Sea Research 40:1673-1687, 1993.

2. J.G. Bellingham, J. Steitlien, J. Overland, S. Jajan, P. Stein, J. Stannard, W. Kirkwood, and D. Yoerger. An arctic basic observational capability using AUVs. *Oceanography*, 13: 64–70 (2000).

3. T.R. Chandrupatla, J.C. Chen, E. Constans, H.C. Gabler, J. Kadlowec, A.J. Marchese, P. von Lockette, and H. Zhang, Engineering Clinics: Integrating Design throughout the ME Curriculum. Proceedings of the IMECE (2002).

4. C.Y. Chong, S.P. Kumar, and A.H. Booz, Sensor Networks: Evolution, Opportunities and Challenges, Proceedings of the IEEE, Vol. 91, Issue 8, pp1247-1256 (2003).

5. E. Constans, J. Courtney, K. Dahm, J. Everett, R. Harvey, L. Head, D. Hutto, and H. Zhang, Design of Rowan Sophomore Clinic, In Proceeding of ASEE 2005 Annual Conference, Portland, Oregon, (2005).

6. E. Danson, The economics of scale: Using autonomous underwater vehicles (AUVs) for wide-area hydrographic survey and ocean data acquisition. Proceedings of FIG XXII, the 22nd Conference of the International Federation of Surveyors. Washington DC, USA (2002).

7. G.L. D'Spain, S.A. Jenkins, R. Zimmerman, J.C. Luby, and A.M. Thode, Underwater Acoustic Measurements with the Liberdade/X-Ray Flying Wing Glider, The Journal of the Acoustical Society of America, 117, **4**, p. 2624, (2005).

8. M. Dunbabin, J. Roberts, K. Usher, P. Corke. 2004. A new robot for environmental monitoring on the Great Barrier Reef. In N. Barnes and D. Austin (eds), Proceedings of the 2004 Australasian Conference on Robotics and Automation. Canberra, Australia (2004).

9. J. P. Dunne, A. H. Devol, and S. Emerson, The oceanic remote chemical/optical analyzer (ORCA) – an Autonomous Moored Profiler, Journal of Atmospheric and Oceanic Technology,19, **10**, pp. 1709–1721 (2002).

10. J. A. Farrell, S. Pang, and W. Li, Chemical Plume Tracing via an Autonomous Underwater Vehicle, IEEE Journal Of Oceanic Engineering, Vol. 30, No. 2, pp428-442, April 2005.

11. S. Mandayam, K. Jahan, and D. Cleary, Multidisciplinary Research using Nondestructive Evaluation, Proceedings of 2001 ASEE Annual Conference & Exposition: Peppers, Papers, Pueblos, and Professors; Albuquerque, NM, USA (2001).

12. J. Porter, P. Arzberger, H. Braun, P. Bryant, S. Gage, T. Hansen, P. Hanson, C. Lin, F. Lin, T. Kratz, W. Michener, S. Shapiro, And T. Williams, Wireless Sensor Networks For Ecology, BioScience, Vol. 55, No. 7, pp561-572, July 2005.

13. H. Zhang, and J. Kadlowec, ROBOTS! – Freshman Clinic in Mechanical Engineering. In proceedings of ASEE 2002 Annual Conference, Montreal, Canada, USA (2002).

14. Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters (EPA 600-4-90-030).