World Transactions on Engineering and Technology Education
Vol.5, No.3, 2006

Interactive Mobile Aqua Probe & Surveillance (IMAPS) – a multidisciplinary design project

Hong Zhang, Ying Tang, Courtney Richmond & Patricia Mosto

Rowan University
Glassboro, United States of America

ABSTRACT: Engineering educators are often challenged to develop effective teaching materials that promote student enthusiasm and motivation, and integrate state-of-the-art technology into the undergraduate curriculum. In this article, the authors present their efforts at Rowan University, Glassboro, USA, towards achieving these objectives. A project was developed specifically to engage students in discovering engineering and science principles through designing a robotic aqua sensor named the Interactive Mobile Aqua Probe & Surveillance (IMAPS) system. The multidisciplinary nature of this project involves students and faculty from the fields of mechanical, electrical and computer engineering, as well as marine biology and ecology. It also gives students a systematic perspective and facilitates their vision of the greater context and application of their work.

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 programme. The Accreditation Board for Engineering and Technology (ABET) criteria requires that *students must be prepared for engineering practice through the curriculum, culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints* [1].

The College of Engineering at Rowan University, Glassboro, USA, has developed a curricular component, *Engineering Clinics*, to address this challenge in engineering education [2]. 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 [3]. The progression through clinics systematically develops students as collaborative designers. This begins with the Freshmen Engineering Clinic, which introduces design through reverse engineering [4]. At the sophomore level, students experience their first open-ended project and learn structured design [5]. 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 (JIT) approach to engineering design enables students to be involved in ambitious design projects as early as their sophomore year.

While searching for a proper junior/senior clinic project, a need was identified in the field of environmental biology for an alternative to the traditional method of field sampling, which involves collecting samples at predetermined, discrete locations (eg points on a grid) and then bringing the samples back into the laboratory for analysis. This method is tedious and time-consuming. Current technologies, such as Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUV), provide a viable solution for observation and testing in deep waters [2][5-9]. However, these technologies are expensive, time-critical, difficult to operate, and often not suitable for shallow water and complex terrain. Therefore, it would be useful to develop a robust, cost-effective and flexible solution to continuously collect data from a water body interactively and in real time. Beginning in spring 2005, a sequence of Junior/Senior Engineering Clinics was initiated to develop a robotic aqua sensor, called the Interactive Mobile Aqua Probe & Surveillance (IMAPS) system.

In this article, the authors 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. As a proven successful Junior/Senior Engineering Clinic, this project offers a number of benefits as follows:

- 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 industry need to carry out time-sensitive product design.

IMPLEMENTATION EXPERIENCE

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 finalised 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. The overall design and implementation of the IMAPS is briefly described below.

As depicted in Figure 1, the control structure of the IMAPS takes a host and agent approach. The host is a high-end computer that stores and displays the data transmitted from the agent. It receives instructions from an operator and sends control signals to the agent. The agent is a tele-operated surface vehicle commanded by the host; it cruises on the water, collects data and transmits the information back to the host. For easy fabrication and maintenance, a modularised design was chosen; therefore, vehicle functions, such as actuation, status monitoring, sensor control and visual observation, are developed individually using independent microprocessor-based controllers. A main microprocessor coordinates interactions among the controllers and communicates with the host via wireless RF transmission. In this design, the overall control of the IMAPS was performed by a PIC 16F648A microcontroller. Pololu 3-amp motor controllers were utilised for the actual motor control scheme.

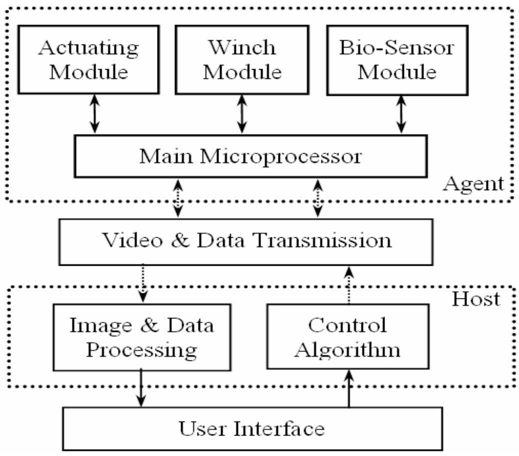


Figure 1: Block diagram of the control system.

As seen in Figure 2, the mechanical structure of the IMAPS agent has evolved with two major generations of improved understanding and increased design sophistication.

(A) (B)

Figure 2: Two generations of the IMAPS body structure.

In order to manoeuvre 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 3 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 onboard cameras. Important data for robot control (such as thruster throttles and GPS locations of the IMAPS), and water quality monitoring (eg water temperature, pH levels, dissolved oxygen (DO) level and turbidity) can be displayed in the interface in real time.

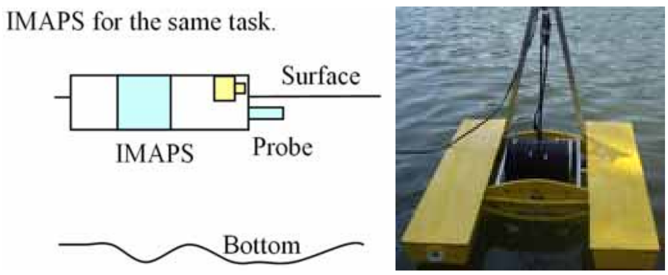
Figure 3: A snapshot of the GUI control interface.

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 with the options of applying different control algorithms, selecting a variety of biological parameters to be tested, or choosing the output format for further analysis.

EXPERIMENTAL DEVELOPMENT

With the progress of the project over three semesters, 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 4A, the agent, commanded by the host, can be used in many ways, including: scanning the surface of a water body with its probes to obtain a distribution map of a desired water parameter; *chasing* a pollutant source by making decisions to move up a concentration gradient as real-time measurements are taken; or be manually controlled or dynamically anchored to survey plants or observe the activities of animals with the forward-oriented camera.



(A) (B)

Figure 4: (A) Configuration of the IMAPS for water surface probing; (B) The IMAPS parked in a local lake.

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 seven 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.

Another experiment that has been developed is the indexing of water parameters at different depths or studying underwater ecology. As elaborated in Figure 5A, the winch on the IMAPS lowers 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 downwards 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 5B 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 then count the number of sea grass manually.

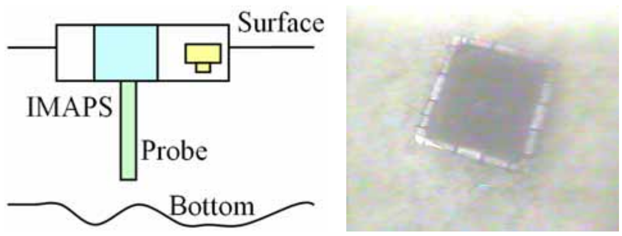


Figure 5: (A) Configuration of the IMAPS on underwater probing; (B) Photo of a shading canopy in sea grass experiment.

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 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 three positions offered by this project. Six engineering students, (three ME and three ECE) have been recruited throughout the course of the project, although not at the same time. The team showed a good balance of skills at different stages.

The course schedules students and faculty sponsors to meet twice a week for three 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 in orientation. These could cover background and knowledge review, or introduce project specific materials, such as motor control, PIC microprocessor programming and CAD. As the design evolved over the semesters, the topics extended to design optimisation, 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 mid-term and final examinations. Not only did faculty members raise questions on the performance of each clinic team and their design methodology, but students of other project teams were also free to affirm, contradict or debate what was presented. The kaleidoscope of project topics provides a diversified exposure to 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 the oral presentation competition at the *2006 American Society of Mechanical Engineering Regional Student Conference*. When the team brought the robot to the *2006 National Conference of the 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 are grant-supported. More students were further recruited as summer interns to continue on this project. In summer 2006, four students (two ECE, one ME and one BIO) were hired to refine the control algorithms, test the system and develop sample experiments for future dissemination to schools, institutes and environmental protection agencies.

PEDAGOGICAL ISSUES

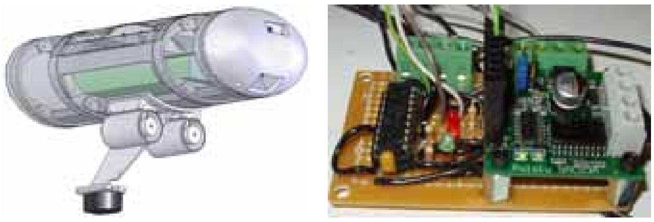
The evolutionary process of the IMAPS project has highlighted a number of important pedagogical issues that should be of interest to colleagues teaching this type of course.

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 emphasise 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 code documentation, etc.

System perspective of the design: *Systems* have become the organising 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, students will be in a better position to appreciate the multidisciplinary nature of their respective majors.

Impact on students: By participating in the IMAPS project, students obtained various experience and skills that were seldom seen in a single session of regular classes. For example, the project encouraged 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 students to practice their problem-solving and critical thinking skills. Meanwhile, the project also helped to improve their communications skills as students exchanged their ideas with other team members and faculty mentors. In particular, while working within a multidisciplinary team, students learned to respect and appreciate different disciplines, interact seamlessly with people from different backgrounds, and handle disagreement and pressure under deadlines.

Furthermore, the project gave ample opportunities for students to practice technical skills learned in their major courses. For example, the theoretical calculation and computational modelling of the IMAPS strengthened students' CAD skills learned in machine design courses, as depicted in Figure 6A. The control circuitry interacting with several microprocessors, as shown in Figure 6B, allowed students to apply concepts learned in microprocessor design and digital courses.



(A) (B)

Figure 6: (A) *SolidWorks* rendering of a working prototype, (B) the winch control board.

Impact on curricula and engineering education: Figure 7 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 be easily utilised 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 the IMAPS.

SUMMARY

A multi-year project of designing and fabricating a robotic aqua probe system is presented here. 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

The authors thank the support from Rowan Separate Budgeted Research fund and NSF CCLI grant DUE-0442861.

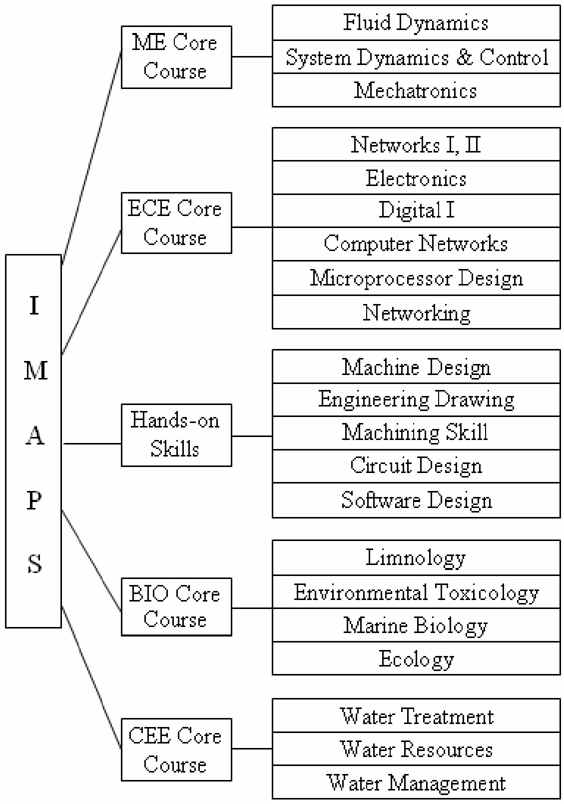


Figure 7: Impact at college courses.

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