AC 2009-237: A MULTIDISCIPLINARY UNDERGRADUATE PROJECT IMPLEMENTING A ROBOTIC ARM FOR THE ARTIFICIAL INSEMINATION OF ENDANGERED AMPHIBIAN SPECIES

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A Multidisciplinary Undergraduate Project Implementing a Robotic Arm for the Artificial Insemination of Endangered Amphibian Species

Abstract

This paper presents a pilot undergraduate project started in fall 2007 and completed in spring 2008 at Eastern Washington University. The goal of the project was to expose undergraduate electrical engineering students as early in the curriculum as possible to the challenges presented by real projects. The project had to be relatively long term, multidisciplinary, and it had to require both technical depth and breadth, problem solving skills, ethical responsibilities, communication skills, effective teamwork and planning skills. The basic idea was to engage students in an activity that would emulate as closely as possible the industrial environment they will be facing soon after graduation providing students with the opportunity to gain the skills and tools needed in the day-to-day practice of engineering. Toward this end, in collaboration with the biology department, a group of undergraduate electrical engineering students were challenged with the task of building a robotic arm for the artificial insemination of endangered amphibian species. The rationale was to maximize the fertilization success rate by using an artificial insemination process resembling the natural process as closely as possible. From the very beginning students were encouraged to work on the project independently and with as little supervision as possible. They were also asked to be in charge of all phases that characterize the design and development of a typical engineering system including system specification, project planning and management, feasibility analysis, system simulation and performance assessment, prototyping, verification and validation of the system functionality and its constraints requirements, system implementation and finally the documentation of the end product.

The paper is organized as follows. Section I provides a brief introduction, followed by the history of the project in Section II. Section III describes the various steps in the development of the project. Section IV outlines the technical and pedagogical contribution of the project. Finally, Section V concludes with a summary of the achievements and lessons learned during this process.

1. Introduction

The objective of the project presented in this paper was to engage undergraduate students into a learning activity spanning over several quarters and courses' knowledge. The underlying aim was to expose students to an experience that would resemble as closely as possible what they will likely face once they graduate. To this end we resolved the project should challenge students on the following areas: 1) teamwork and planning skills, 2) written and oral communication skills, 3) technical depth and breadth, 4) problem solving skills, and 5) multi-disciplinarity. However, when we tried to come out with a list a potential projects that would encompass all learning objectives we wanted to address, we realized the task was much harder than we anticipated. In fact, all initial projects we came out with, where somehow too "electrical engineering" oriented and were lacking the multidisciplinary nature desired for the project. Fortunately, when we almost ran out of options, a biology faculty and a group of his students approached us for help with a problem that finally seemed to have the multidisciplinary nature we were looking for.

The problem we were asked to solve was to develop some sort of electric device to improve the yield of artificial insemination for endangered amphibian species.

2. Background

Today's most common approach to perform artificial insemination consists of loading a pipette with a solution of sperm and then manually injecting the sperm into the egg's membrane. Figure 1 depicts and egg membrane being pierced by a pipette's needle during sperm injection.

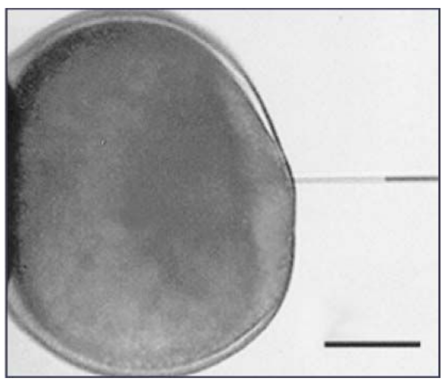

Figure 1. Egg's membrane pierced by a sperm loaded pipette

Unfortunately the approach described has major drawbacks which result in a very low fertilization rate. Having a low fertilization rate is costly and most of the time not a viable option when dealing with endangered species. In order to maximize the fertilization success rate, the artificial process should resemble the natural process as closely as possible. To this end, it is worth to notice that during natural fertilization, the spermatozoon does not penetrate the interior of the egg's membrane, but instead remains in contact with the egg's membrane until they eventually merge. The two major drawbacks of the manual artificial insemination process lie on the lack of systematic and reliable control of: 1) the force exerted by the pipette on the membrane egg, and 2) the time the pipette and the egg membrane are kept in contact.

After a valuable discussion phase among the electrical engineering students and the biology students, they agreed that the best way of addressing the problem was 1) to use an automatic robotic system, so that repeatability and accuracy of the insemination process could be guaranteed at every try, and 2) to use frogs for testing the viability of their ideas. There are many threatened species of frogs and in general frog eggs are large and, thus, require less precision when artificially inseminated.

Figure 2. Amphibian species

The robotic system the students designed consists of an embedded system driving a high speed linear actuator. The actuator is a self-contained motion device that enables the extension of a miniature mechanical arm. The arm is controlled by a DC motor. The magnitude and polarity of the voltage applied to the motor control speed and direction of the arm motion. The accuracy of the arm position is controlled by using the feedback voltage from the actuator's built-in precision mechanism. The actuator's arm is attached to a 7 µm diameter glass needle that is preloaded with a sperm cell for delivery into the egg's membrane. Since, the robotic process should resemble the natural process as closely as possible and during natural fertilization, the spermatozoon does not penetrate the interior of the egg's membrane, but instead remains in contact with the egg's membrane until they eventually merge, the embedded system is designed so that once the user starts the fertilization process the actuator's arm moves toward its target (i.e. the egg's membrane) at full velocity, pauses for the adequate amount of time, then retracts at full speed and stops.

Figure 3. Actuator's arm

3. Project Development

The various phases of the project development followed as closely as possible the pedagogical objectives we tried to address through this experience. The main steps adopted by the students as a guiding frame to complete the project were:

1. Project definition
2. Technical specifications
3. Project planning and management
4. Project execution
    a. Feasibility analysis (algorithms development, functional modeling, performance estimation and simulation)
    b. Proof of concept prototype implementation and verification
    c. Final product development and verification
    d. Project documentation: development manual and user guide
    e. Final presentation and future work

The various steps were not always followed sequentially; and indeed there have been “feedback loops” and “re-adjustment” in most of them.

The purpose of step 1 and 2 was to define the project’s objectives as thoroughly and clearly as possible. To this end students were asked to focus their attention on what problem or opportunity motivated the project, what were the major project’s constraints, what were the deliverables expected, and to ensure that all objectives were specific and measurable. The underlying goal was to push students to learn to deal with problems that are not necessarily in their field of study and of which at they do not have adequate background knowledge, so that they would grow to appreciate the importance of effective communication and ability to work on multi-disciplinary teams to integrate each other’s skills and knowledge. The outcome was a short technical specification addressing both the biological and the engineering characteristics that the design proposed for the artificial insemination of endangered amphibian species needed to possess.

In step 3 the main goals were to specify the time frame within which each project’s task will be achieved, to identify the resources needed to accomplish the tasks, and to develop a process to monitor progress during the execution of the project. In this case students broke down the project’s execution in a set of key tasks, and assigned time frames and resources to each one of them. However, they overlooked the importance of closely monitoring progress during the actual project execution.

Finally, step 4 consisted of the practical execution of the project. This has been probably the most successful of the four steps at least from an electrical engineering perspective. Students have successfully applied the knowledge they have gained through their curricula in courses such as: programming languages, circuit theory, electronics, microcontrollers, and control systems.

Feasibility analysis (i.e. algorithm development, functional modeling, performance assessment and simulation) was done with the aid of SystemC. SystemC is a computer design automation platform based on C++, and it consists of a C++ compiler, C++ class libraries and a simulation kernel [1]. This choice allows the use of the same language (i.e., C++), for describing both hardware and software. The behavior of the system has been described using a simple finite state machine as shown in Figure 4. A simulation example of the system behavior is provided in Figure 5.

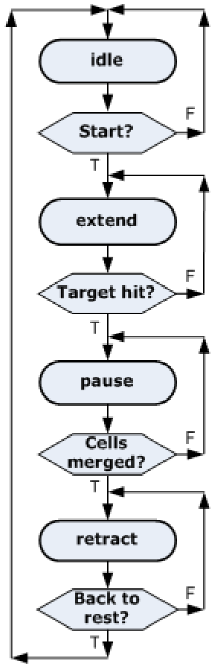

Figure 4. Finite state machine used for modeling the system behavior

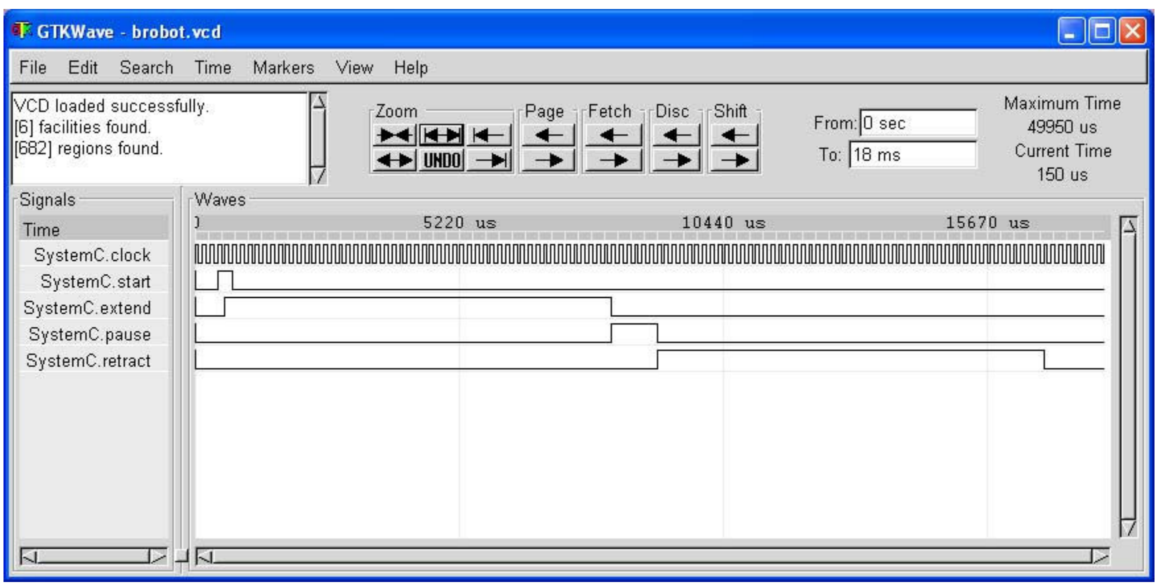

Figure 5. Simulation example illustrating the robotic system's behavior.

The major requirement to achieve the desired system's behavior is that the egg's membrane is not penetrated by the glass needle, which in effect implies a need to control as accurately as possible the speed, force, and position of the arm with respect to the target. Figure 6 shows a simplified block diagram of the robotic system design. The system consists of four main functional units: a 10-bit analog to digital converter (ADC), an 8-bit reduced instruction set

(RISC) architecture processor with an 8 MHz clock rate, an H-bridge to drive the DC motor, and the actuator moving the mechanical arm.

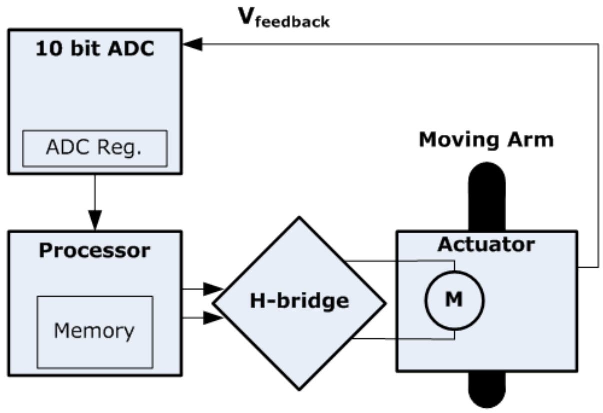

Figure 6. Robotic system: main functional units

The requirements adopted for the design of the system are: 1) the arm needs to extend 19 mm before it reaches the egg's membrane, 2) the velocity with which the arm reaches the eggs' membrane is 27mm/s and 3) the force with which the egg's membrane is hit is 10N. Figure 7 summarizes the basic algorithm used to control the robotic arm. The processor used to implement the algorithm is an Atmega8 RISC microcontroller manufactured by Atmel.

```
while (TRUE) do  // loop forever
    time        ← 0  // initialize time to 0
    extension ← 0 // initialize arm extension to 0
    if (start_button == TRUE) then
        while (extension < max_desired_extension) do
            extend arm //apply proper voltage to motor
            read feedback voltage
            extension ← convert(feedback_voltage)
        end
        while (time < merge_time) do
            increment time;
        end
        while (extension > 0) do
            retract arm //apply proper voltage to motor
            read feedback voltage
            extension ← convert(feedback_voltage)
        end
    end
end
```

Figure 7. Basic algorithm

Pictures of the system's prototype are show in Figure 8 and Figure 9. Direct measurements on the prototype validated the functionality of the system and showed that the estimations during the feasibility analysis phase were accurate within the 10%.

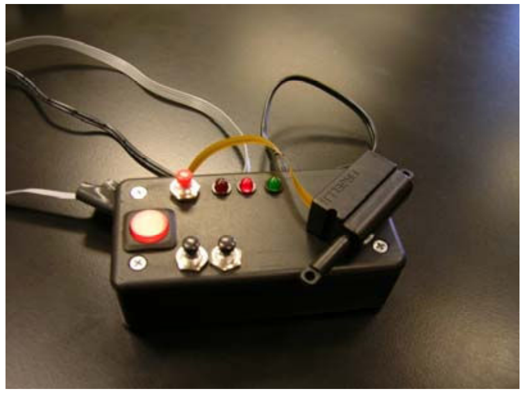

Figure 8. Prototype

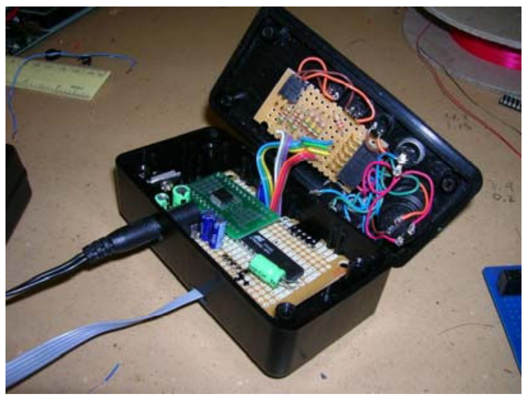

Figure 9. Internal view of the prototype

Improvements with respect to the prototype consisted in putting the final circuit on a printed circuit board and slightly modifying the range of operation of the linear actuator (i.e. the arm extension was slightly shorted to avoid sporadic stalls of the motor that happened when trying to extend the arm at its full extension).

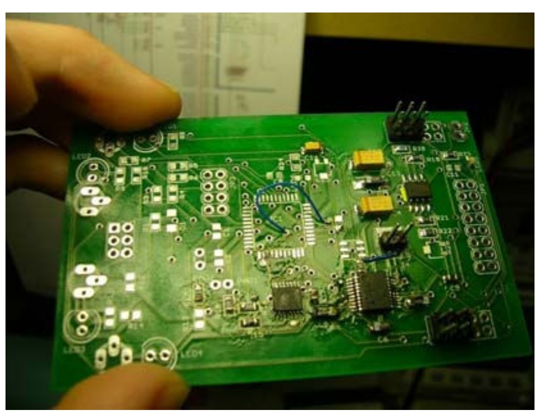

Figure 10. Printed Circuit Board

Table 1 summarizes for each project's step what are the activities/skills involved and what are the specific courses that foster the necessary student's learning objectives.

Table 1.

Project Phase	***Activities/skills involved***	***Courses***
Project definition	• multi-disciplinary learning • work effectively in multi-disciplinary teams • oral and written communication • identify, analyze and design methods to meet desired needs and solve problems • engage in independent learning	• ENGL 201/ English ENGL 205/ Tech. Writing • Most ENGR courses • Most ENGR courses
Project specification	• multi-disciplinary learning • work effectively in multi-disciplinary teams • oral and written communication • identify, analyze and design methods to meet desired needs and solve problems	• ENGL 201/English ENGL 205/Tech. Writing • Most ENGR courses
Project planning and management	• time and resource management • work effectively in teams • leadership principles • ethics • engineering economics	• ENGR 490/ Capstone • Most ENGR courses • ENGR 490/ Capstone • ENGR 490/ Capstone • ENGR 490/ Capstone
Project Execution	• apply knowledge of mathematics, science, and engineering • design and conduct experiments, as well as to analyze and interpret data • use techniques, skills, and engineering tools • engage in independent	• Most ENGR courses • Most ENGR courses • Most ENGR courses • Most ENGR courses

	learning • design systems, component, or processes to meet desired needs • algorithms and programming • finite state machines • electric prototyping • Microcontrollers operation • Motors operation • Feedback Theory	• Most ENGR courses • CS255/ C programming ENGR 260/ Microcontrollers ENGR 465/VHDL • ENGR 160/Digital Logic ENGR 465/VHDL • ENGR209, 210/ Circuit Theory ENGR 330, 331/ Electronics • ENGR 260/ Microcontrollers • ENGR 350/ Energy Systems ENGR 470/ Control Systems • ENGR 330, 331/ Electronics ENGR 470/ Control Systems

4. Lessons Learned

Overall the project was successful and students did an excellent job, however observing how the various steps unfolded brought to our attention many interesting unexpected findings.

First of all contrary to our expectations students had no problem at all with the multidisciplinary nature of the project, they worked and communicated effectively as team, they were most of the time able to work independently and did a fantastic job in solving all technical challenges they faced, regardless of whether they had already taken a course on the topic at hand or not. Having already taken a course on the challenge at hand affected the time it took students to come out with a viable solution, but it did not affect much the “quality” of the solution.

However, we must point out that our findings do not have significant statistical value and could be just a fortunate episode. In addition, we believe the “experiment” was biased by the fact that students’ involvement in the project was not part of mandatory course work. Students who chose to participate in the project were much more self-motivated than average, and the team was self formed with engineering students having already worked together on several other occasions. If on the other side, we decide to assume the findings as being valid we have to believe in Galileo words that: “You cannot teach a man anything; you can only help him find it within himself.”

Finally, the only project step that was not addressed in a satisfactory manner was project management. Students failed to closely monitor their progress and as a result they completed the project almost a quarter later than expected. This made impossible to follow up on how much the robotic arm effectively affected the fertilization rate of the amphibian species of interest.

5. Conclusion

Although the findings of the project do not have statistical value, we believe the effort put in the project was definitely well worth it. First, it made us doubt some of the common assumption and beliefs we had about student learning patterns, and second it has unveiled some drawbacks of our electrical engineering curriculum. One of the reasons we started the project was to test if the courses offered were preparing students adequately for their future career in industry. Interestingly enough, because of the fact that students often ended up addressing some of the project's challenges before taking the relevant course, when asked whether they felt their course work prepared them adequately for the project they participated in, students suggested that it was the other way around. They saw participating in the project instrumental for them to succeed in their course work, because it kept them more motivated and interested than they usually would have been. Finally, by closely monitoring the unfolding of the project we noticed that we had no systematic approach for addressing multidisciplinarity and that we did not expose our students to some of the learning objectives until very late in the curriculum

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