A Hybrid Approach for Modeling and Assessing Performance of Embedded Systems in a Biologically Critical Application

Claudio Talarico†, David Freiberger†, Tyler Jones†, Brandon Hopkins††, Charlie Herr††, Min-sung Koh†, Esteban Rodriguez-Marek†

Eastern Washington University • †Department of Engineering and Design • ††Department of Biology • Cheney, WA 99004, USA

Summary

This project was initially proposed by Dr. Claudio Talarico of Eastern Washington University's electrical engineering department. Previously he had worked with several students on a hardware design project and realized that the project could work as a platform for demonstrating high-level abstraction modeling of a hardware/software system using SystemC.

The original project was initiated by EWU's biology department. They needed a prototype controller for a linear actuator and came to the new electrical engineering department to ask for help (Figure 1). The project was turned over by Talarico to some of his students in a microprocessor class, as a practical assignment.

The biology segment of the project, initiated by Dr. Charles Herr and his graduate student Brandon Hopkins, plans to reproduce insemination of frog eggs in an artifical environment, and eventually automate the process to increase the success rate to a feasible level. The device described here is not accurate enough for it's application, but does serve as a demonstration of what is possible with future collaboration between departments.

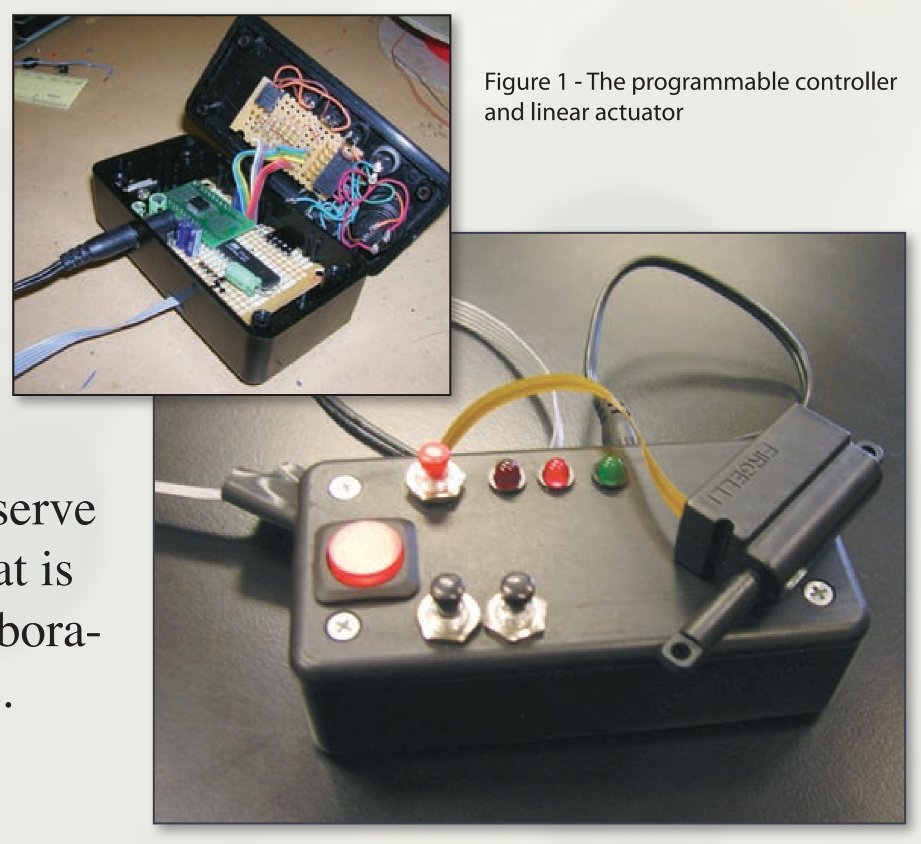


Figure 1 - The programmable controller and linear actuator

Simulation with SystemC

The controller system was modeled in SystemC, as a secondary project. A paper has been accepted for publsihing in IEEE about this subproject. The paper presents a hybrid approach for modeling and assessing the performance of embedded systems. Toward this objective, an implementation independent methodology is pursued where system behavior is represented by executable models that are based on both analytical and simulation methods. To illustrate and validate this approach it is applied to the design of the described robotic controller system (Figure 4). The solution adopted reduces assessment time by modeling system behavior only in terms of the performance metrics of interest. The two performance metrics used to assess the application considered are the velocity of the robotic arm tied to the sperm membrane and the force with which the arm hits the target (i.e., the egg's membrane). Formally, the desired behavior is captured through a C/C++ executable model, which uses finite state machines (FSM) as the underlying model of computation (MOC) (Figure 5). The results obtained demonstrate the robustness of the proposed method both in terms of design time and accuracy (Figure 3).

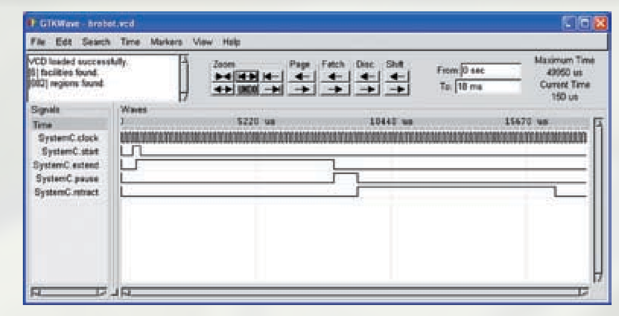
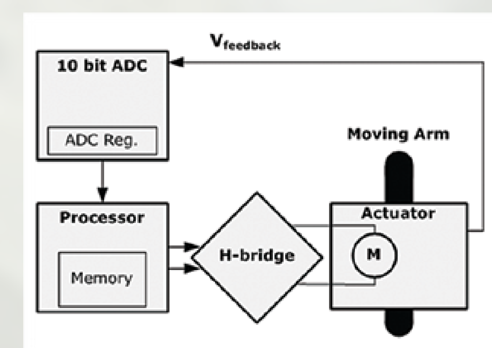


Figure 3 - System behavior waveforms



main functional units

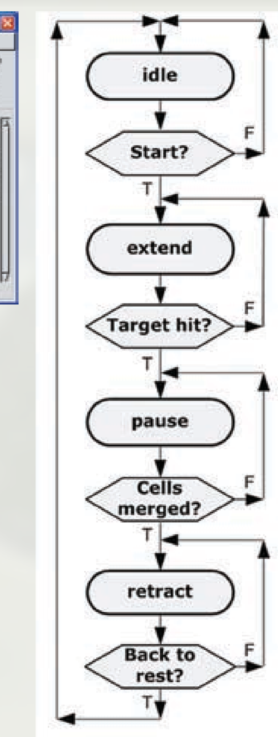


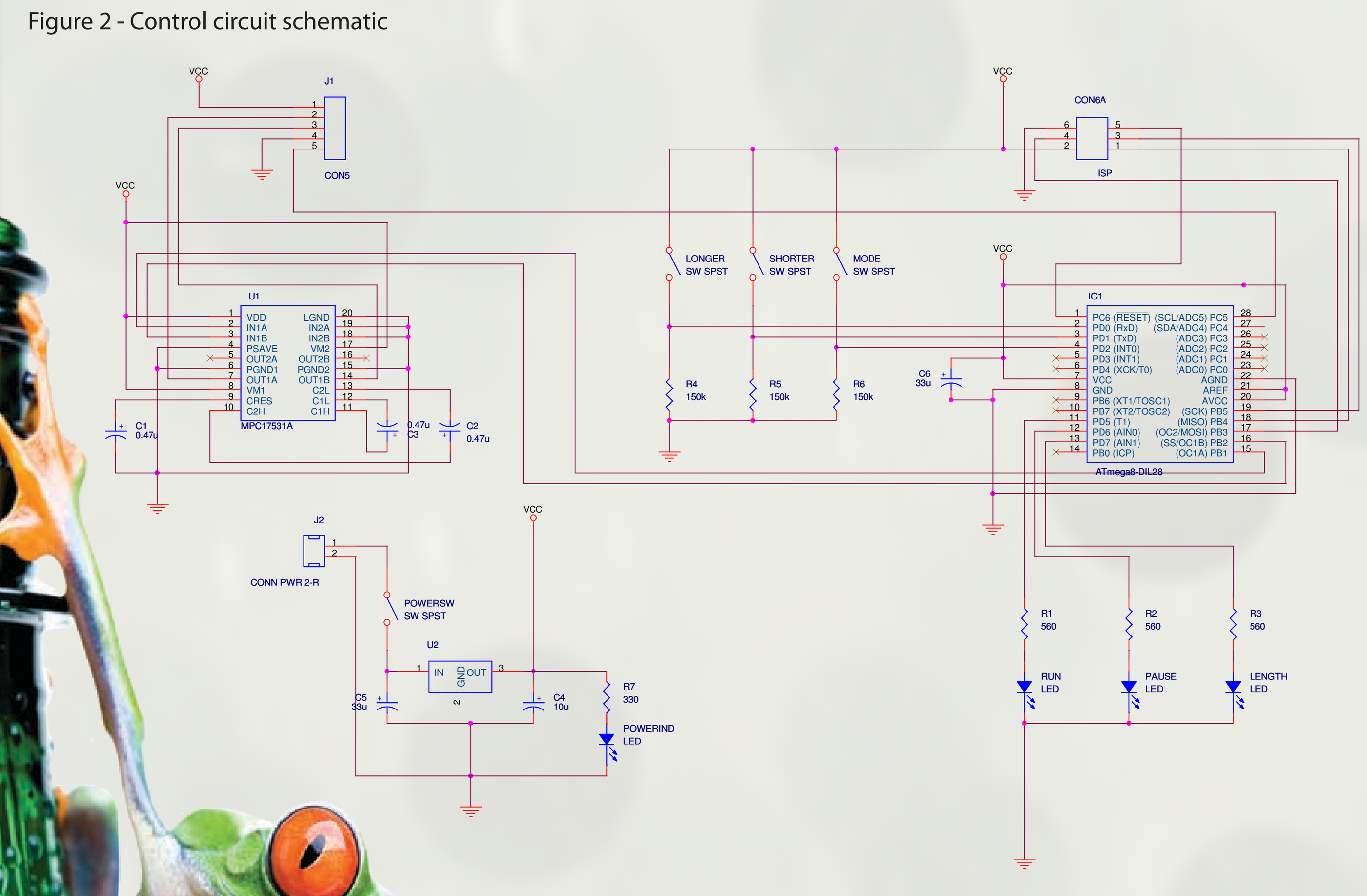
Figure 5 - Finite state machine used for modeling the system behavior

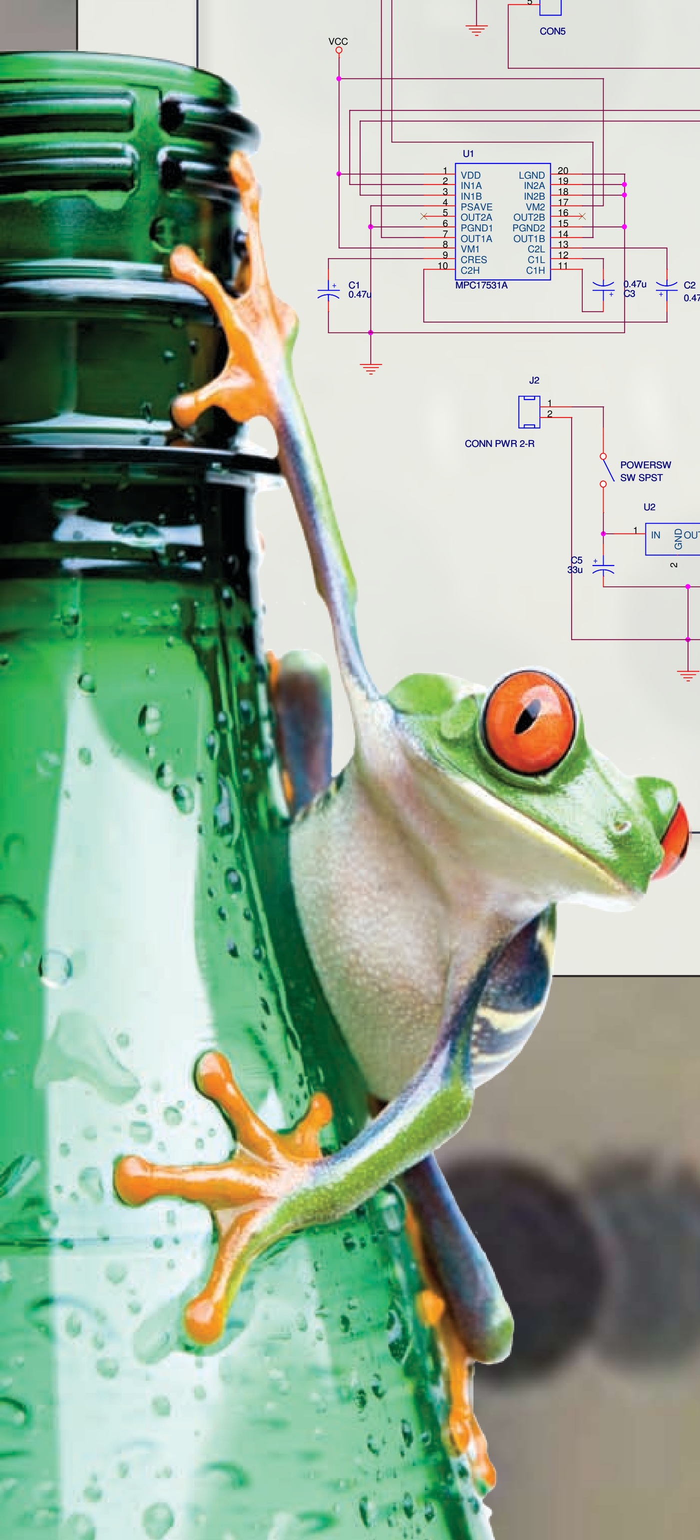
Design and Prototype Implementation

```
void Extend(void)
{
    MAXTEMP = MAX;
    MAX = Dlength;

    //go out
    sbi(PORTB, 1);
    DelayE(200000);
    cbi(PORTB, 1);

    Delay(250 * pause);

    //go in
    sbi(PORTB, 2);
```

The controller device uses an Atmel Atmega8 RISC microcontroller, programmed in C. The linear actuator is controlled by the microcontroller through an H-bridge. The H-bridge provides the required current to the actuator and allows direction control using just two I/O pins on the microcontroller. Power for the actuator and control circuit is supplied from a wall transformer regulated to 5 volts. (see Figure 2)

Figure 2 - Control circuit schematic





Application

World's First Automated Sperm Injection System

The World Conservation Union lists over 1,800 threatened species of amphibians as of the year 2008. Zoos and other wildlife preservatories have maintained frozen quantities of egg and sperms for many wild species, but until now have not been able to attain a successful motility rate with frozen / thawed eggs (Figure 6).

Figure 6 - Tree-frog eggs

Dr. Herr aims to solve this problem with several new innovations. First, a specially coated needle is loaded with sperm containing solution, and electrical properties are exploited to help determine how many sperm are in the tip of the needle (Figure 7). Second, after the egg is injected, the same method will be used to verify that a sperm has successfully entered the egg. Third, and most relevant to this project, is automation of the injection process, to speed up production and increase the motility rate to feasible levels.

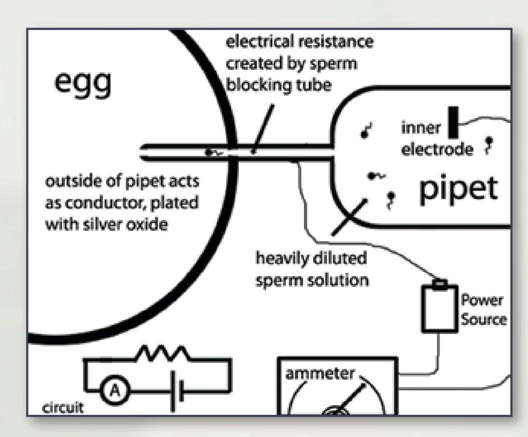


Figure 7 - Circuit model and diagram

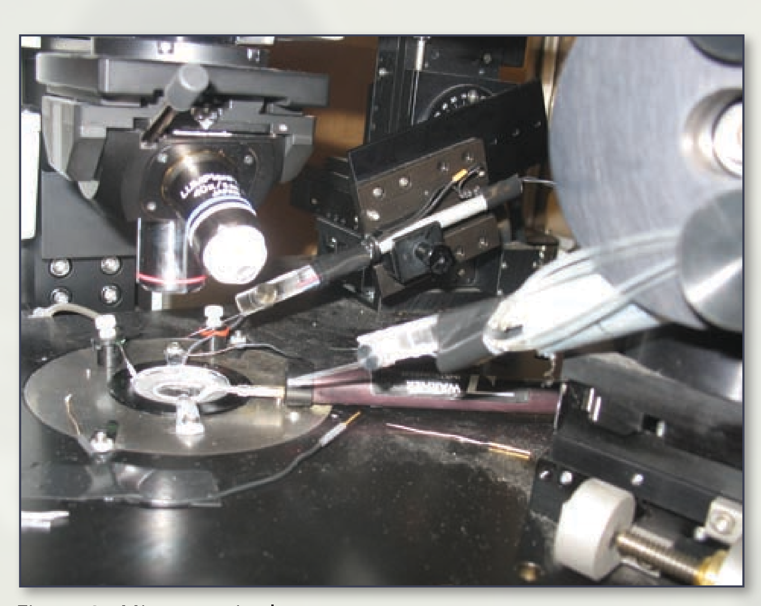


Figure 8 - Micro-manipulator

For automation of the injection system a linear actuator will be paired up with a pipette, which is capable of delivering a sperm inside a frog egg. This process is currently being accomplished through the manual manipulation of the pipette, which is laborious. The beauty of the linear actuator is its ability to turn the artificial insemination process into an assembly line increasing efficiency and throughput.

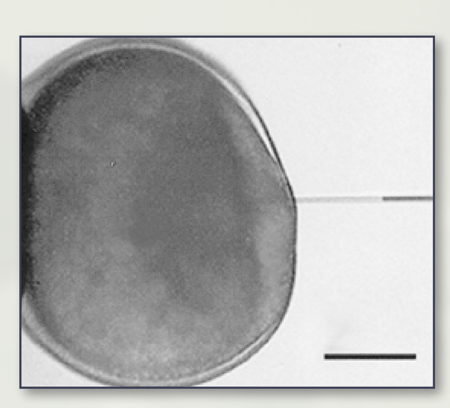


Figure 9 - Manual fertilization of fish egg (scale example)

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