Work In Progress - Multi-disciplinary Real-Time and Embedded Systems Laboratory and Course Sequence

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***Abstract* – Small electronic products for the mass market are increasingly incorporating programmable components. The software in these devices has constraints that are markedly different from software designed for a general-purpose computer. Most computing curricula deal almost exclusively with developing software for that general-purpose class. Real-time and embedded systems have increased in complexity; they no longer lie within a single discipline. Developers now must be cognizant of software engineering design methodologies and underlying hardware constraints. RIT is addressing this by developing a three-course sequence of cross-disciplinary real-time and embedded systems courses. We are teaching these courses in a studio-lab environment teaming computer engineering and software engineering students. The courses will introduce students to programming both microcontrollers and more sophisticated targets, use of a commercial real-time operating system and development environment, modeling and performance engineering of these systems, and their interactions with physical systems.**

Index Terms – Embedded systems, performance modeling, real-time systems, real-time systems curriculum.

INTRODUCTION

Embedded computers are ubiquitous, often in common products where they are invisible to the user. These embedded processors provide special purpose functionality as opposed to the general-purpose applications familiar to desktop computer users. A recent report[1] estimates that the typical household has 100 processors in its confines. By 2006 the number of such processors is expected to double. What is more, the growth rate for embedded processors far exceeds that of traditional computers. For this reason, educating our current engineering students in the best practices for real-time and embedded systems development is of great importance.

Many of these real-time and embedded systems directly interact with sensors and actuators or are safety critical components within larger systems. This imposes significant system constraints with respect to response time, platform architecture and safety considerations not found in general-purpose applications.

TARGET AUDIENCE AND COURSE FORMAT

At Rochester Inistitute of Technology we are developing a three academic quarter course sequence in real-time and embedded systems for senior level undergraduate computer engineering and software engineering students set in a studio-lab environment. The studio-lab is configured with twelve development stations at which one computer engineering student is partnered with a software engineering student for course projects. Each course is four academic quarter credit hours and meets for ten weeks of classes having a pair of two-hour studio sessions per week.

NON-TRADITIONAL CONCEPTS

By partnering computer engineering students with software engineering students we hope to cross-pollinate their educational backgrounds and improve their multidisciplinary design skills. The computer engineering students possess significant knowledge of electronics and control systems along with software development skills at the lower-levels. The software engineering students possess significant knowledge of how to engineer complex software systems including the design and modeling of those systems. They possess skills focused on the engineering of software that are more fully developed than for a student in the typical computer engineering program. Such a team is well suited for the development of real-time and embedded systems which straddle the boundary of hardware and software disciplines. In at least one course we plan to introduce hardware-software co-design topics to thoroughly anchor our overall objectives.

COURSE OUTLINES

The first course in this elective sequence is titled **Embedded and Real-Time Systems**. It presents a general road map of real-time and embedded systems. It introduces a representative family of microcontrollers that will exemplify unique positive features as well as limitations of microcontrollers in embedded and real-time systems. These microcontrollers will then be used as external, independent performance monitors of more complex real-time systems targeted on more robust platforms. The majority of this course presents material on a commercial real-time operating system and using it for programming projects on development systems and embedded target systems. Some fundamental material on real-time operating systems will also be presented. Example topics include

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scheduling algorithms, priority inversion, and configuration of a real-time operating system for a target platform and host development system. This first course has been offered at RIT in the fall and winter quarters of the 2003-2004 academic year.

The second course is titled **Modeling of Real-Time Systems**. This course introduces the modeling of real-time software systems. It takes an engineering approach to the design of these systems by analyzing a model of the system before beginning implementation. The course discusses primarily UML based methodologies. Implementation of real-time systems will be developed manually from the models and using automated tools to generate the code. This course is being offered for the first time in the spring quarter of 2004.

The third course is titled **Performance Engineering of Real-Time and Embedded Systems**. We will develop this course during the summer of 2004 for a scheduled first offering in the spring quarter of 2005. The course will be roughly divided in half with the first and second parts emphasizing performance of real-time systems and embedded systems, respectively. The real-time part of the course will present the control of physical systems on an intuitive level, although the computer engineering students should be able to contribute to the analytical and control algorithms from their required control systems courses. Students will perform experiments with an inverted pendulum system and a ball and balance beam. These experiments will highlight the effect of parameter tuning and system load on control of the physical apparatus. The experiments will culminate with student implementation of software controllers. The embedded systems part of the course will use a single-board computer running a commercial real-time operating system as the computing element. Input and output devices will be connected through an FPGA I/O controller. Students will measure initial system performance when the I/O controller is a pass-through interface between the processor and the devices. The students will then be able to make a hardware-software co-design tradeoff by placing more device control functionality in the FPGA. At each step the students will measure the change in system performance as the boundary between hardware and software is moved.

EVALUATION PLAN

This project has four components to its evaluation plan:

(1) Faculty at two collaborating institutions are being presented with course materials as they are being developed. These faculty will examine our materials and visit our campus at the end of the first year of development to evaluate our project at the midpoint of the NSF funded portion. They will continue to be presented with course materials and visit again near the end of the NSF funding period in June 2005 to provide their final formal evaluations.

(2) Students enrolled in the courses will be surveyed at the beginning of each course to assess their incoming backgrounds and at the end of each course to evaluate the course materials, the laboratory environment, the teaching effectiveness and their opinions of their learning outcomes.

(3) We will solicit comments and suggestions from FIE Conference attendees as we present this work in work-in-progress format in the fall of 2004. We plan to follow this up with a presentation of this project's final results through a complete paper submission to the FIE Conference in the fall of 2005.

(4) We have already begun some informal dialog on this project to target industries actively developing new processors and/or products for the real-time and embedded systems market.

INITIAL EVALUATIONS

As the project approached the halfway point we gathered some initial evaluations of our work. We had our academic collaborators review syllabi and course materials for the two courses that had been offered during the first year. We also obtained an evaluation from two industrial reviewers. The reviews were generally positive. A summary comment made by one set of reviewers was:

> "Overall, the collection of courses is excellent. The topics covered appear to address those things that companies engaged in the design of real-time, embedded systems are directly concerned with. Graduates possessing such knowledge should be very employable."

We also surveyed the students who took courses in this sequence during the first year. Our sample size of 18 represents about half of the students in the courses this year. These initial results were also encouraging. In response to the question "Which, if any, of these courses assisted you in obtaining a co-op or full-time position?", 4 students believe the first course helped them in this regard. The students stated that their experience with a commercial operating system and the range of projects they did impressed their potential employers. Nine students say they plan to seek employment in real-time or embedded systems work and 15 students agree that the multi-disciplinary nature of the project work was beneficial for their learning.

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