Interdisciplinary Research
Enhancing BAE Teaching and Research Programs

N. Zhang[1], M.L. Neilsen[2], D.H. Lenhert[3], M. Mizuno[2], G. Singh[2], and A.B. Gross[4]

[1] Department of Biological and Agricultural Engineering, Kansas State University (KSU), zhangn@ksu.edu*
[2] Department of Computing and Information Sciences, KSU, {neilsen,masaaki,singh}@cis.ksu.edu*
[3] Department of Electrical and Computer Engineering, KSU, lenhert@ksu.edu*
[4] The IDEA Center, 211 S. Seth Child Road, Manhattan, Kansas, agross@ksu.edu*

Abstract

An NSF-funded, interdisciplinary project of curriculum development and research on embedded system design has benefited teaching and research programs of the BAE Department at Kansas State University. The benefits included improvement in teaching of instrumentation and control courses, curriculum opportunity for BAE undergraduate and graduate students on embedded systems, enhancement of graduate research, and undergraduate research experiences.

Introduction

In a report of the Academic Program Administrators Committee of American Society of Agricultural Engineers (ASAE) issued in 1990, "Bioinstrumentation and Controls" was listed as a discipline core course of biological and agricultural engineering (BAE), together with "Properties of Biological Materials", "Transport Phenomena", and "Capstone Design Experience". This report "expresses the collective opinion of the Committee concerning the future direction of the undergraduate engineering programs" (ASAE, 1990). A decade has passed since the publication of this report. When we read it today, we are so much impressed by the vision of the people who participated in the writing of the report.

Computer and electronics-based instrumentation and control technologies have been applied in all areas within the discipline of BAE, including power and machinery, soil and water, food- and bio-processing, structure and environment, environmental engineering, and information technology. At the modern time, electronics-illiteracy for a biological and agricultural engineer is almost like language-illiteracy for a man. A

* This work was supported in part by the National Science Foundation under NSF-CRCD Grant #9980321.

biological and agricultural engineer must have a sufficient background in computer-based instrumentation and control to understand many biological and agricultural engineering problems, to communicate with other engineers, scientists, technicians, and producers, and to completely solve BAE problems or make successful designs.

Rapid development of computer technologies during recent years has allowed more computing capability to be embedded in agricultural, food, and forestry machinery systems and processes for real-time sensing and control. Graduates of the BAE Department working in industry have frequently reported the need for knowledge and skill-training in this area. The job market in embedded-system design has also developed during the recent years. BAE graduates often have opportunities of finding jobs in this area. Typical roles of BAE graduates in an embedded-system design team are to define applications, to establish specifications, and to test the systems in real-case applications. With a systematic training, they can serve as an important bridge between hardware/software design engineers and machinery system design engineers. To prepare BAE students for these jobs, fundamental knowledge and training on real-time embedded systems need to be included in the BAE curriculum.

Prompted by these needs, a faculty member in the BAE Department joined an effort of an interdisciplinary team in research and curriculum development on real-time embedded system design. Participants of the project included three faculty members in Computing and Information Sciences (CIS) and a faculty member in Electrical and Computer Engineering (EECE) within the College of Engineering. The interdisciplinary team has successfully received funding from the National Science Foundation's CRCD program.

Since 1999, the interdisciplinary team has developed a sequence of four undergraduate/graduate level courses on embedded system design that is open to engineering students in all disciplines. A graduate-certificate program and an undergraduate minor program were also developed based on this course sequence to allow interested students and industry professionals to receive concentrated graduate-level training on embedded-system design.

This interdisciplinary project has had a direct impact on the teaching and research programs in BAE. While the BAE Department makes direct contributions to the project, the Department benefited from this project in four aspects: improved teaching of the instrumentation and control courses, opportunities for BAE students to enroll in the embedded-system educational curriculum, enhanced graduate research, and research experience for undergraduate students.

The object of this paper is to describe the positive impact that the interdisciplinary project brought upon the teaching and research programs of BAE.

Improvement in BAE instrumentation and control courses

The BAE Department at Kansas State University (KSU) currently offers three courses in the area of instrumentation and control. An engineering course, “Instrumentation and Control” (BAE 640), is a required course for BAE students of all options. For the Agricultural Technology Management (ATM) discipline, which is an undergraduate program within the College of Agriculture, the BAE Department offers a course “Sensors and Controls” (ATM 450), which also is a required course. In addition, the Department offers a graduate-level course, “Measurement Systems” (BAE 840) to the M.S. and Ph.D. students. All of these courses are three credit-hour courses, with two hours for lectures and one hour for lab. These courses emphasize computer-based sensing and control technologies applied in modern agricultural machinery and processes (Zhang and Wang, 2001).

Rapid development of computer and electronics technologies during the recent years has greatly increased the use of embedded computer systems in farm machinery, environmental control systems, and food and feed processing plants. For example, a modern tractor may possess more than twenty embedded microcontrollers to perform various sensing and control functions. Many commercialized embedded computer systems also have been used in many data acquisition, machine vision, fluid power, machine control, and process control systems. Thus, it has become necessary to add content on embedded systems to the instrumentation and control courses offered in BAE.

Since 2000, introductions to microcontrollers and communication protocols among microcontrollers have been added to the teaching of BAE 640 and BAE 840. Furthermore, students taking these courses have been encouraged to use embedded microcontrollers in their course projects. A course project is a required part of the course. It accounts for one third of the course grade. Course projects were designed to provide training on problem solving in practical measurement and control applications. Examples of embedded systems developed for the course projects included Stampt-II microcontrollers used in a thermo-conductivity measurement system and a cattle respiration monitoring system, an Infineon C167CR microcontroller used in a color-detection system, and an Intel single-board computer used with a laser distance sensor for surface roughness measurement.

ATM 450, “Sensors and Controls” is a course offered to ATM students on electronics applied on modern agricultural machinery. This course uses a John Deere 8400 series tractor as an example to explain the electric and electronic system in details. Since most electronic systems on the tractor involved embedded microcontrollers, it has become necessary to introduce microcontrollers and microcontroller interfaces in the class. Starting in 2000, we also added a chapter designated to CCD (Chrysler Collision Detection) and Controller Area Network (CAN) communication in this course. Hardware and detailed information on CAN obtained through the interdisciplinary project have greatly helped this part of teaching.

Interdisciplinary curriculum

The interdisciplinary team designed a sequence of four courses as the core curriculum for embedded-system design. These courses are open to engineering students in all disciplines:

1. A remedial course consisting of three independent modules, intended to bring students with varying backgrounds up to speed,

2. An implementation course that allows students to work with state-of-the-art design tools, embedded development environments, and target platforms to interconnect a variety of sensors and actuators in complete real-time embedded systems,

3. A theory course covering both traditional scheduling theory and contemporary design methodologies, and

4. A project-based capstone course to complete a comprehensive design for a complex embedded system.

Five BAE graduate students have enrolled in these courses. Because of the difference in background, the students have experienced different degrees of difficulties. Two students had good background in electronics and computer programming before taking these courses. They performed very well in all courses of the sequence. On the contrary, three students had rather weak backgrounds in these areas and have encountered tremendous difficulties in these courses. Although the three modules of the first course were designed as "remedial courses", which would allow students in other engineering disciplines to study basic real-time electronics, data structures, and concurrent programming, these students still had to spend tremendous amount of time in order to catch up with the rest of the class. Obviously, teaching the remedial course remains to be a challenge to the interdisciplinary team in the future. If we want to keep the course sequence open to students in all engineering disciplines, we will have to develop more effective methods to teach these modules.

Enhancement of BAE graduate research

Students attending the embedded-system sequence courses benefited from the interdisciplinary expertise provided by the team. Two BAE Ph.D. students taking this course sequence further invited the team members into their supervisory committees. From committee meetings and frequent consulting, the students received important advice and assistance from the team members on their dissertation research. The students also took advantages of hardware and software available through the NSF grant to improve their microcontroller system design. This includes several Phytec single-board boards with Infineon C167CR microcontrollers and a Tasking embedded development environment software. Through cooperative team work, the students developed an integrated, real-time, embedded, weed-detection/spray-control system, which consisted of two weed sensors; three microcontrollers containing four types of peripheral modules - analog module (A/D), digital I/O module (DI/O), serial communication module (RS-232), and pulse-width-modulate module (PWM); a GPS unit; a spray unit with relays and PWM valves; and an optional PC computer. Communication among the microcontrollers and the GPS unit were through CAN (Figure 1).

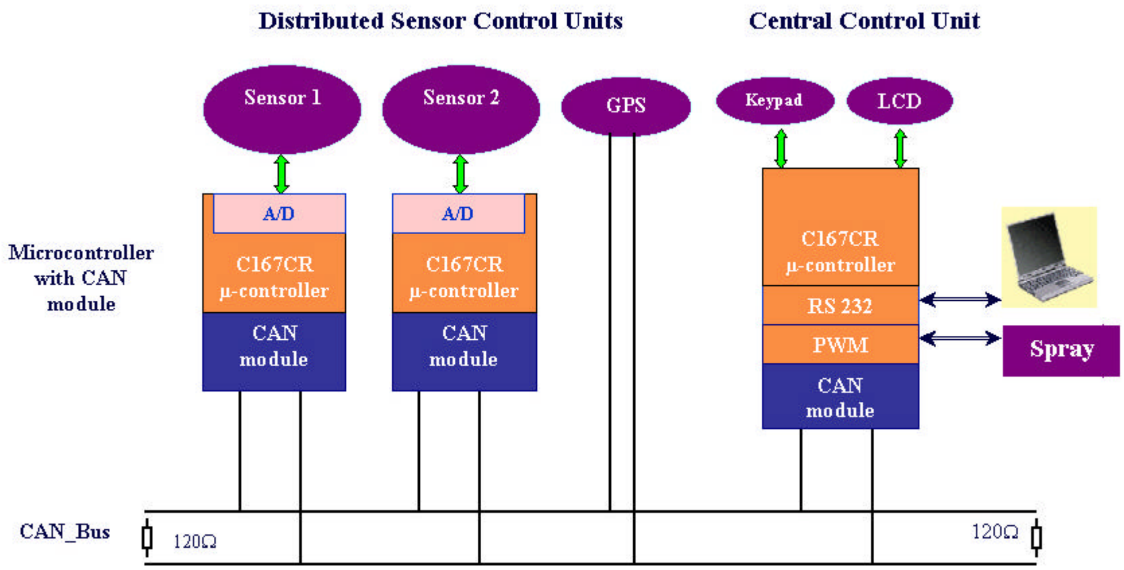

Figure 1 System Configuration

The system components can be grouped into five units based on distributed system hierarchy by functionality: two identical sensor control units (SCU), each composed of a weed sensor and a microcontroller with an A/D module; a central control unit (CCU), including a microcontroller with DI/O, PWM, and RS-232 modules, a keypad, and an LCD display; a GPS unit; and a spray unit (Figure 2) (Wang et al., 2001).

Development of such a complex system required a combination of knowledge in hardware and software, including object-oriented programming using C/C++; precise relationship between each C/C++ construct and corresponding assembly code generated by compilers; special techniques for implementing microcontrollers, such as initialization of programmable CPU modules and peripheral devices and linking techniques to produce ROM-able code; real-time operating systems, which provide an execution environment for concurrent threads; implementation of elements of a real-time operating system on bare hardware; implementation and internal workings of a microkernel; details of a real-time microkernel; real-time network protocol stack; CAN network architecture and various implementations; DA/AD converters, timers and counters, and PWM with variations of various microprocessors; device drivers, and applications for small, but complete, real-time embedded systems. All these aspects of knowledge were introduced through the implementation course of the embedded-system course sequence. Design and construction of the complete weed-sensing and spray-control system was a successful practice of the knowledge the student learned from these courses. On the other hand, success in the design of such a system also made a significant contribution to the embedded system research and curriculum-development project because it provided an excellent, practical example of real-time embedded systems and laid the foundation for the capstone design course – the last of the four-course sequence developed by the interdisciplinary team.

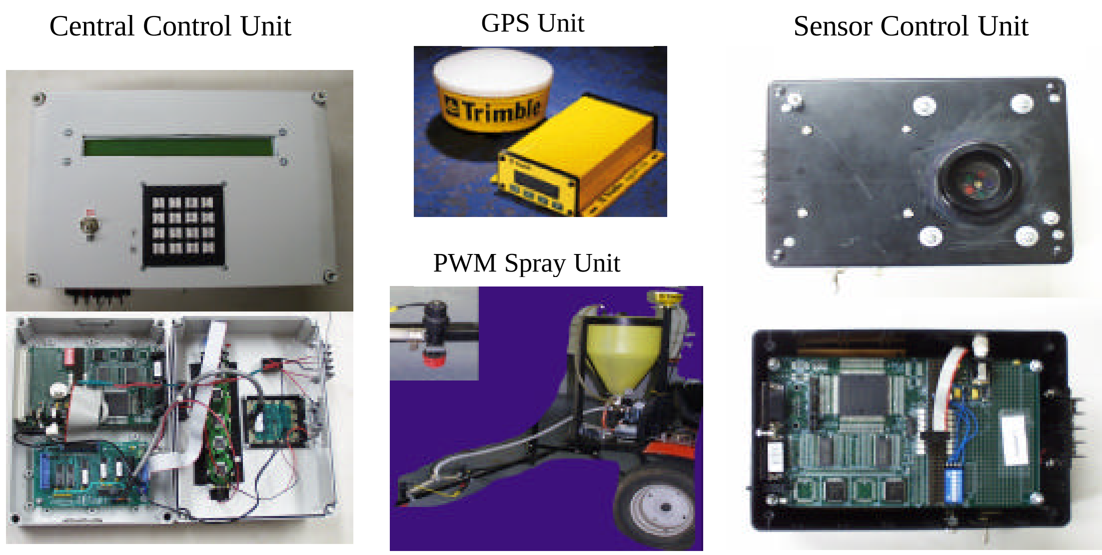

Figure 2. System components

The success of the two Ph.D. students' research on the weed-detection/spray-control system went far beyond the completion of the embedded-system design. The system they designed and rigorously tested has shown great potential in real applications in precision agriculture. During the summer of 2001, the system was tested in two wheat fields. The results showed that the system successfully detected and sprayed weeds with accuracies of above 80%. This included using models trained during day and night. The system was further tested on golf courses. With the ability of detecting weeds on small patches, potential for applications of the developed technology on commercial turfs is great.

During their research, the two Ph.D. students also made efforts to apply real-time embedded system theories in their design. This includes traditional scheduling theory, UML methodology, use case analysis and realization, specification of real-time properties, design patterns, and verification. After an extended study, one of the Ph.D. students has selected modular design of embedded systems as his dissertation topic. The work proposed includes various interface modules, modular design in compliance with ISO standards, use of a standard virtual terminal, and adoption of a higher-level CAN protocol – CANKingdom for precision agriculture applications (Wei et al., 2001). It is obvious that these topics would not have been possible without the support of the interdisciplinary team on embedded system design and curriculum development.

Undergraduate research experience

An important aspect of the interdisciplinary research and curriculum development project is to offer undergraduate students opportunities of acquiring research experiences in the embedded-system design area. As a part of the NSF project, we hired undergraduate students through the Undergraduate Research Experience (REU) program with NSF. One of the students we hired is an ATM student in the BAE Department. He worked in the weed-control system for two semesters. Prior to this experience, the only related background he had was the Sensors and Controls course (ATM 450) he took in the BAE Department.

This undergraduate student was involved in all aspects of the project, including building the mechanical structure on a test tractor; designing multiple brackets to mount the CCU, optical weed sensors, GPS unit, and speed radar; designing, building, and wiring of the CCU box, which included a microcontroller with DI/O, PWM, and Serial Communication modules, keypad, LCD display, and on/off switch; wiring of the entire system; and serving as the major force during the entire testing process. Figure 3 displays the physical layout of the system on the test tractor.

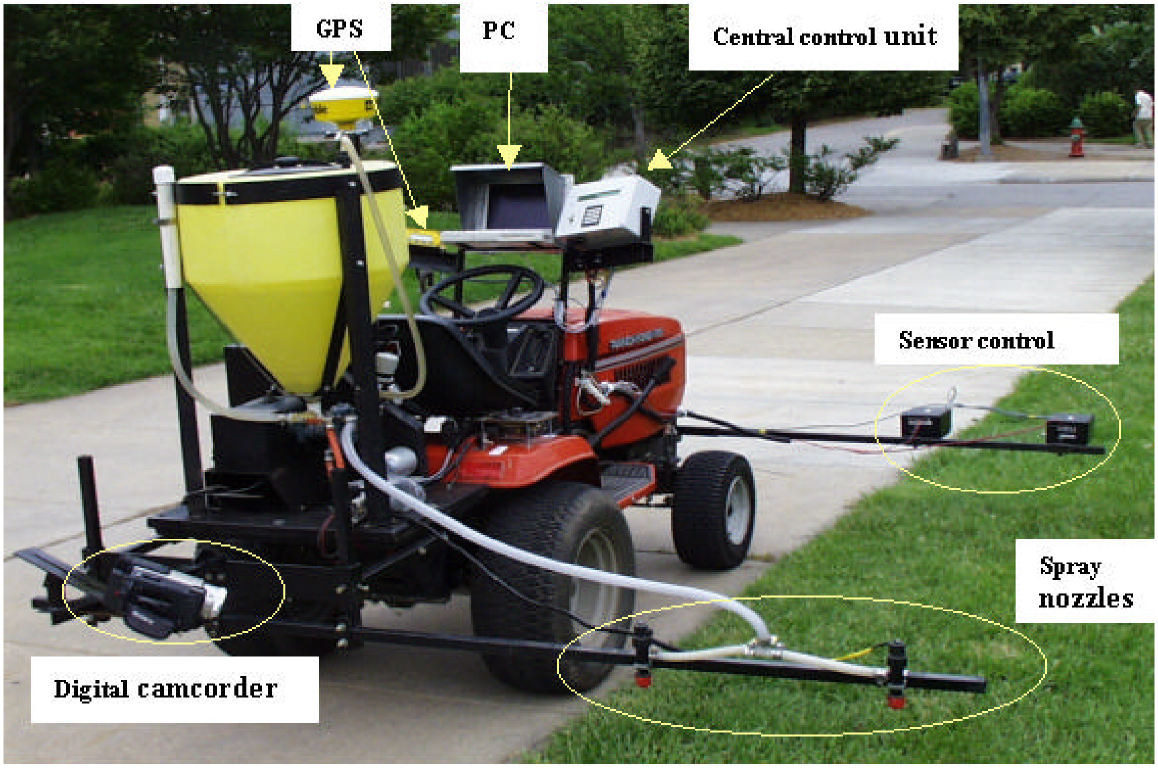

Figure 3. System configuration

In the final report to NSF, the student wrote: "The experience has been challenging and very beneficial as well. Gaining knowledge of the operations and uses of the Global Positioning System (GPS), how Controller Area Network (CAN) protocol can be used for communication among different computer devices, and how optical sensors work and are basically able to detect weeds within a crop in the field are just a few of the things I learned throughout my assistantship. I have also obtained some computer programming knowledge. *However, I feel that the opportunity to use and learn new problem-solving skills through the research I have done will be the most useful in the future.*"

The problems that the undergraduate student took major responsibilities to solve included shadows cast by the sensor boxes, which greatly affected the sensor performance, insufficient electric power available on the test tractor to run all the electrical devices at once, difficulty in positioning the sensor on target during training, malfunctioning of a sensor, inaccuracy of vehicle speed measurement, and difficulty in providing actual field weed-infestation information for comparison.

The student first diagnosed the shadow problem by training the sensors at different tractor traveling directions. Once the problem was diagnosed, the student was responsible for implementing a solution. His solution was to make a skirt using a soft cloth material to eliminate the shadows while not damaging the crops when traveling. He also placed light bulbs around each sensor in order to provide the light needed for training and testing. An unforeseen advantage to this solution was to allow training and testing at night or after dark. Figure 4 shows the system in operation at night.

Figure 4. The system in operation at night

For the power problem, the student added an additional alternator to the tractor. The complication he ran into when doing this was that the alternator had to be run in the opposite direction of its normal operation. Tractor charging system has been a topic of the ATM 450 course that the student had previously taken. However, the effect of reversed rotation of the rotor on power generation and cooling was a problem that the course did not address and the student had to deal with it himself. The student solved this problem by studying the principle of alternators and considering actual operating conditions.

For the sensor-positioning problem, the student created a device using a pulley system and plum to allow easy targeting for the sensor during training. Through patient diagnoses, the student finally detected that the malfunctioning of a sensor was caused by improper insulation of a connecting bolt. For inaccuracy of the ground speed measurement, the student conducted field calibration tests on both a GPS device and a radar ground speed sensor and finally selected the radar sensor.

To accurately record the actual weed infestation in the field, the student designed a movable grid (Figure 5) and a grading methodology. With the help of a field-level GIS, the student was able to generate accurate weed-infestation maps. An example of such maps is displayed in Figure 6.

As the student pointed out in his report, "I hope that you can see how this research experience has benefited me. The experience and knowledge gained through the research assistantship will be extremely helpful to me in the future. I feel that through great improvement on my problem-solving skills and increased knowledge of various electronics equipment, which this assistantship has allowed me to benefit from, I will be better suited for the vast job market. Thank you again for this opportunity to gain valuable experience and knowledge."

Figure 5. The wire grid used to record actual weed infestation.

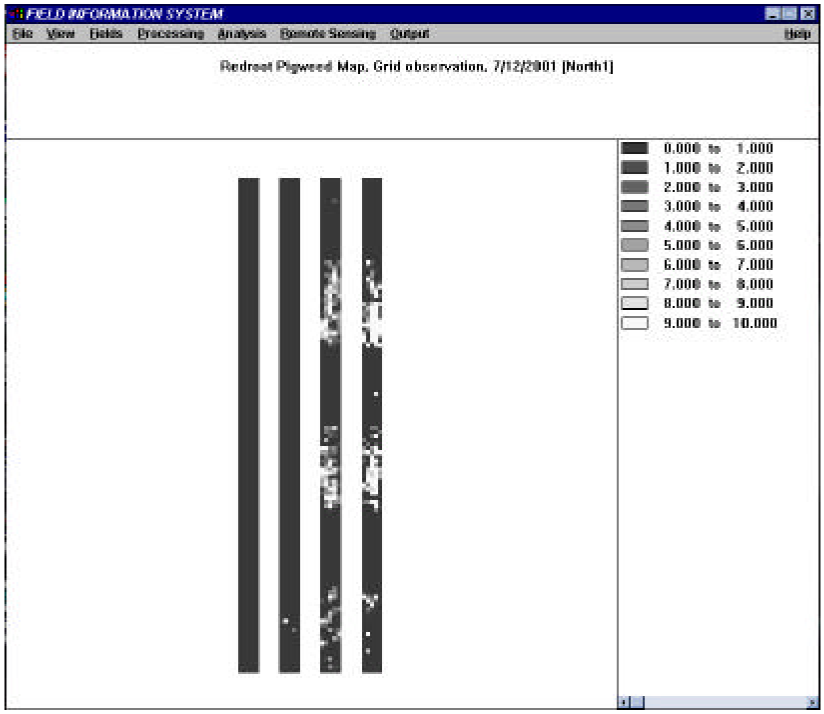

Figure 6. A weed-infestation map

Summary

The interdisciplinary project of curriculum development and research on embedded-system design has benefited the teaching and research programs of the Biological and Agricultural Engineering Department at Kansa State University. By participating in this project, we have improved teaching of the departmental undergraduate and graduate courses on instrumentation and control and enhanced student team projects in these courses. The curriculum developed by the interdisciplinary team has offered BAE students opportunities of a systematic education in the subject area of embedded system design. The embedded-system design curriculum has helped two BAE graduate students enhance the quality of their dissertation research. The research experience obtained by an undergraduate student through this project has greatly helped him in improving his problem-solving skills and preparing him for future career. These benefits would not have been possible without cooperation among faculty members with expertise in different disciplines.

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Biographical Information

NAIQIAN ZHANG is a Professor in the Department of Biological and Agricultural Engineering. His research interests include sensors and controls for biological and agricultural systems.

MITCHELL L. NEILSEN is an Assistant Professor in the Department of Computing and Information Sciences at Kansas State University. His research interests include real-time embedded systems, distributed systems, and distributed scientific computing.

DONALD H. LENHERT is the Paslay Professor in the Department of Electrical and Computer Engineering at Kansas State University. His research interests include embedded systems and digital testing.

MASAAKI MIZUNO is a Professor in the Department of Computing and Information Sciences at Kansas State University. His research interests include operating systems and distributed systems.

GURDIP SINGH is an Associate Professor in the Department of Computing and Information Sciences at Kansas State University. His research interests include network protocols, distributed systems, and verification.