Instrumentation Education in Agricultural and Biological Engineering

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Abstract

This paper presents the development of an instrumentation and data acquisition course in the Agricultural and Biological Engineering Department at Purdue University. The discussion includes the necessity for the course, the challenges in starting the laboratory course, a survey of similar courses at other institutions, the educational philosophy of the course, the course materials, the laboratory, and new opportunities associated with the development of the course.

Introduction

Today agricultural and biological engineers must be familiar with electronic instruments and computers. Electronic instruments are used in off-road vehicles, grain processors, automatic feeding systems, global positioning systems, irrigation control, and many other food and fiber production equipment. Computers have been produced in such quantities that the cost has now permitted many applications that were infeasible a few years ago. Practically everything in engineering can take advantage of computers.

The Agricultural and Biological Engineering Department at Purdue University has received significant feedback from industry indicating that the department's graduates need better training in instrumentation and measurement. Currently the department does not offer an undergraduate course specifically in instrumentation and measurement. The students get their training in instrumentation as they perform experiments in various other courses.

Many Agricultural and Biological Engineering departments in the US offer undergraduate courses in instrumentation and measurement. However, some Agricultural or Biological Engineering departments require that students take a three or four credit course in instrumentation and measurement from other departments such as Mechanical Engineering of Chemical Engineering. The latter strategy gives the students exposure and training in sensors and measurement without requiring the instructional resources from the department. The problem with this approach is that the class material is not designed specifically for agricultural and biological engineering applications. At Purdue, an example of an available course that might be a somewhat close match to the need for training in instrumentation and measurement for the agricultural and biological engineering students is ME 365 Measurement Systems, given by the School of Mechanical Engineering. However, the course outline shows that a large proportion of the course is on vibration testing of deformable solid bodies. Agricultural and biological engineers need much more knowledge in process control instrumentation.

Based on the above information, the Agricultural and Biological Engineering Department at Purdue University has decided to start offering an undergraduate course in instrumentation and measurement. The authors are drafting a plan for such a course to be given in the Fall 1998 semester on an experimental basis. The plan is outlined in this paper.

Challenges in offering an instrumentation course

Some agricultural or biological engineering departments do not offer any instrumentation course. The lack of instrumentation courses in those departments may be caused by several factors:

Facility

A good instrumentation course requires a laboratory that can be very expensive. Many agricultural and biological engineering departments have rather limited resources in terms of laboratory facilities and equipment. This resource limitation makes offering an instrumentation course very difficult.

Human resources

A laboratory course takes much more of faculty's, teaching assistants', and students' time than lecture courses for the same number of credits. Many agricultural and biological engineering departments cannot allocate instructors to teach instrumentation courses. Sometimes it also happens that none of the faculty members has extensive training or experience in instrumentation.

Size

If a department has few students, it may not be justifiable to offer a separate course in instrumentation. In that case, agricultural and biological engineering students may learn instrumentation from other courses or take an instrumentation course from other departments.

Curriculum

A bachelor's degree in engineering typically requires about 130 semester credits of courses. Among those credits, the majority are for science and engineering courses that are traditionally considered necessary, such as mathematics, physics, chemistry, biology, mechanics (including statics and dynamics), strength of materials or deformable bodies, fluid mechanics, soil science and engineering, humanities, and computer science. The rest of the credits are made up of courses specific to agricultural and biological engineering, such as tractors and their implements, agricultural machine design, soil and water engineering, food process engineering, etc. These courses leave little room for a course in instrumentation.

Interest

The faculty of some departments may not be interested in including an instrumentation course in their curriculum. The lack of interest in modern instrumentation in agriculture might be justified considering that agriculture was done for thousands of years with some success without much scientific instrumentation. Most other engineering disciplines evolved with more instrumentation throughout their history.

Undergraduate programs in the department

A fact that has to be considered in selecting the materials for this course is the fact that the Agricultural and Biological Engineering Department at Purdue offers more than one undergraduate program. The department offers the following undergraduate programs:

1. Agricultural Engineering, which is subdivided into
   1.a Machine Systems Engineering specialization
   1.b Environmental and Natural Resources Engineering specialization
2. Food Process Engineering.

Students typically enter the programs after one year of General Engineering education. Programs 1 and 2 have few upper division courses in common. Programs 1.a and 1.b are different mainly in the elective courses. An instrumentation course in the department has to cater to the needs of all the programs.

Instrumentation courses at other institutions

Courses offered at some institutions in the US and other countries feature interesting teaching methods or equipment that can be adopted to the instrumentation course in agricultural and biological engineering. A few examples of those courses are presented below.

Instructions in measurement methods in physical variables in agriculture and biology do not necessarily need complicated systems. Johnson (1995) at the University of Arkansas at Fayetteville demonstrated simple electrical circuits that can be used very effectively for measuring the intensity of lighting for plants, for measuring soil moisture, and for measuring temperature. All of the circuits require little more than inexpensive photocells, thermistors, and resistors. Felice et al. (1988) in Tucuman, Argentina, developed a low-cost but effective device to detect microorganism using electrical impedance. Global positioning systems, considered very expensive just a decade ago (Wolf, 1988), are now available at low cost for experiments with computer interfacing.

At the Instrumentation and Process Control laboratory at Bowling Green State University in Bowling Green, Ohio, students learn to analyze, design, build and test complete instrumentation and process control systems and compare their performance to modeled process control systems (Gedeon and Kolla, 1995). Students become familiar with instrumentation problems including loading, grounding, interaction between different blocks, non-linearity, effects of ambient conditions and interfacing real-world sensors and manipulators to computers.

At Indiana University-Purdue University at Indianapolis, Instrumentation is taught in the Mechanical Engineering Technology program with an emphasis on the concepts of measurement uncertainty, sensor theory, and the principles of feedback control (Bluestein, 1995). Using a process control trainer that utilizes a PLC to control the level or temperature of water in a tank, the students are exposed to controller principles and the concept of PID control.

At the University of Kansas, a personal computer (PC)-based Acquisition system is used in an undergraduate laboratory (Zhang et al., 1995). The experiments were designed to familiarize students with the data acquisition system, the applications of the system in an experiment, the concept of a dynamic loading, and to explore the effects of impact velocity and system stiffness on the dynamic factor. Experiments utilize a strain gauge and a recording instrument in an impact velocity test, a system stiffness test, and a ladder climbing test in which the strain on rungs of a ladder are measured as a person climbs it.

Sometimes instrumentation training is given in a series of courses. For example, at the University of Manchester there was a course taught in Instrument Design and Application that ran for three terms (Taylor and Payne, 1986). In the first term, students attended lectures and laboratory exercises that were broken into four different modules, Instrument design, Measurement in the presence of noise, Elements of instruments and Instrument interfacing. After students passed the first semester, they were allowed to take the second term of the course, which dealt with practical applications. Students prepared projects of which the majority were real industrial problems. Students designed the necessary instrument or apparatus to solve the problem and prepared a report on what the students intended to do. In the third term of the class the students completed, built and tested their design and instruments and prepared formal reports.

The use of the PC in instrumentation and data acquisition dated back to at least fifteen years ago. At Georgia Tech, students gained familiarity with the use of computers for data acquisition and motor speed control (Wepfer and Oehmke, 1985). Students compared the computers data with that of oscilloscopes, strain gauges, and temperature transducers. They also learned the fundamentals of programming the computer to allow them to control a physical process.

Today, computers are so common and inexpensive that their use should be considered seriously in setting up any new course. Data acquisition and digital signal processing boards are so widely available with various interesting features that even selecting the best ones to fit particular needs can be a challenging task (Jacob, 1993). High accuracy, high speed, high reliability and sophistication are sometimes important in analytical or industrial application (Haasz, 1996). However, in the undergraduate teaching laboratory proposed in this paper, PC plug-in boards may be adequate for the data acquisition system.

Course philosophy

The course is built around the concept that agricultural instrumentation has a biological aspect in addition to general instrumentation. (Johnson and Phillips, 1995, give an excellent description of biological engineering.) Understanding the measured biological variables is a very important part of agricultural and biological instrumentation. Principles of dynamics are the common foundation to all studies of instrumentation. Relationships among the variables to be measured, the transducers, signal conditioners, readout devices, and data acquisition systems must be understood for meaningful measurement. Engineers also need familiarity with electronics as well as knowledge of data acquisition and computer hardware. Confidence with electronic instrumentation and data acquisition with computers must be built through hands-on laboratory experiments

After taking this course, students will be able to:
1. Understand the principles of operation of common instrumentation systems
2. Select proper instruments
3. Use the instruments
4. Know the features and limitation of the instruments
5. Apply data acquisition principles such as A/D conversion and sampling rates
6. Integrate instruments into a computerized data acquisition system
7. Design simple electro-mechanical systems.

Course material and laboratory

General considerations

The general contents of the course are designed to span a broad knowledge of instrumentation and data acquisition rather than to teach a few principles in depth. The contents include:

1. Statistics, particularly concepts of precision, accuracy and resolution, analysis of errors and their propagation
2. Basic principles of dynamics, mainly the application of differential equations to physical and biological phenomena
3. Basic transducer and signal conditioning principles: how physical variables are translated into electronic signals and computer inputs
4. Basic electronics, such as RLC circuits, operational amplifiers, signal conditioning, noise, etc
5. Properties of biological materials and variables in environmental sciences that make measurements in agricultural and biological engineering different from measurements in other areas of engineering.
6. Measurement of common physical and biological phenomena including temperature, pressure, level, flow, mechanical motion, optical signals, moisture and humidity, colors, pH, etc.
7. Data acquisition, display, storage and processing with computers
8. Practical aspects of instrumentation, including specification of instruments, skills in using instruments, economic consideration.

Instruments

Like most laboratory courses in instrumentation, this course is equipped with instruments that are commonly used in industry, such as temperature, pressure, flow and level transducers. However, this course also includes biological and environmental applications of measurement principles.

Moisture measurements include conductance and capacitance methods. Humidity measurement includes sling hygrometers, electrolytic hygrometers, and solid-state hygrometers. PH measurement is done with a pH meter connected to a PC. The course also introduces electronic aspects of soil physical property measurements that are not covered in other courses in the department. The course teaches the coordination of yield monitoring with global positioning systems. Water quality measurements include an experiment to determine the relationship between conductivity and soluble salt concentration (Schwab et al., 1981). Also covered are precipitation measurements, remote transmission of data, and protection of instrumentation from lightning.

To gain familiarity with electronic circuits, students design and build simple signal conditioners such as the Wheatstone bridge, low pass filter, integrator, and various digital circuits. Students use breadboards with power supplies, operational amplifiers, digital logic IC's, and passive electronic components to build the circuits.

Training rigs are used for experiments in controlling liquid level, temperature, pressure and flow. The rigs are equipped with computers running control algorithms and data acquisition programs. Some of the rigs have programmable logic controllers (PLC's). However, since control is not the emphasis of the laboratory class, minimal knowledge of control theory is required. Much of the laboratory time is spent acquiring data on-line and analyzing data off-line.

Data acquisition system

The purpose of the PC-based data acquisition in this course is to operate several transducers simultaneously to record and process data. Instead of being read visually and recorded on a sheet of paper, most of the values are transmitted to a computer with a data acquisition card. Data in the computer files can be further processed off-line with common programs such as Matlab or Excel.

The authors' observation of laboratory courses in many agricultural and biological engineering departments indicates that most of those courses have not taken full advantage of today's cost effectiveness of the PC. Today's PC's are so cost effective that it makes good economic sense to replace more expensive conventional instruments such as the oscilloscope and data recorder with PC's. With appropriate software, one PC can replace many instruments. The concept of *virtual instrumentation* (National Instruments, 1997) is adopted not only because of the cost effectiveness, but also because it helps prepare students for the future practice of using computers more than dedicated instruments to acquire data. This concept also allows easy implementation of simulation for pre-laboratory activities (Mosterman et al., 1994) and for effective illustration of complex interactions among biological systems (Pitts and Davis, 1996).

Opportunities

Hands-on laboratory sessions are expected to make students retain more knowledge because they *experience* the science rather than read it from a book or listen to lectures. Many studies resulted in this conclusion. See for example Felder and Silverman (1988). Working with real transducers and data acquisition system will also train students for real-world engineering practices in industry. However, laboratory courses require much more time and effort from the faculty, teaching assistants, and students compared to lecture courses. For this reason, effective teaching methodology has to be employed to make sure that the time and effort are not wasted. Starting this course gives opportunities to implement some excellent teaching ideas.

Increasing student involvement

Based on the finding that students learn more by experiencing what is taught (Wankat and Oreovicz, 1993), this course encourages a great deal of students' involvement. For example, circuits that students build successfully will be used in some of the later experiments. In the long run, teaching ideas such as guided design (Strano, 1995) can even enhance the curriculum in a broader scope.

Modular hardware utilization

Since the training rigs used in this course are controlled by computer programs, the rigs can be used for different experiments for other courses. For example, a process control course can use the training rigs for experiments with control algorithms, state-space control, PID controller tuning, etc. Additionally, the data acquisition system can be expanded later to include such functions as image acquisition and processing.

Computer-Aided Instruction

Educational technologies such as Computer Aided Instruction offers tremendous possibilities for improving learning (Flori, 1997). However, educational technologies should be selected carefully so that computer-aided instruction improves the results of learning without increasing studying time tremendously (Montgomery and Fogler, 1996). Interactive multimedia teaching aids should also be considered sometime later. Regan and Sheppard (1996) give an excellent list of references on this teaching aid. Again, the implementation should be done with caution since the extra effort and resources may and may not improve student's learning.

Assessment

Since this course is started as a response to input from industry, the most important measure the success of the course is the feedback from the graduates from the department who work in industry. This feedback can only be obtained years after the students take the course. Formative assessment (Shaeiwitz, 1996), such as students' feedback while the course is administered, may or may not reflect how much students actually learn. However, this assessment helps determine how students feel about the course.

Course web site

At the time this paper was written, the course was still under development. The course will be offered in Fall 1998 semester on an experimental basis. Details of the course can be found at http://pasture.ecn.purdue.edu/~sumali/newclass.html.

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