An Improved Instrumentation and Controls Course for Agricultural and Biological Engineering

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Abstract

Modern biological, biomedical, and agricultural systems use electronic sensors, instrumentation, and computers for acquisition of scientific data and for process control. Instrumentation is used for commercial product development, testing, and for research. An engineering course will be discussed, which addresses measurement principles, sensors, software, and characteristics of instrumentation and control systems with a variety of hands-on student activities. This is a required course for two ABET accredited biological and agricultural engineering degree programs. Students of both programs participate and interact within this single course. The course assumes the student to be a junior, senior, or first year graduate student who has had an introductory electronics course and has completed a majority of core and elective courses. The focus of student hands-on activities is through hardware applications and computer programming. Weekly laboratory activities include human exercise physiology and energy exchanges, electrocardiograms, spirometry, sensor response times, water quality and flow measurements, and proportional- integral- derivative (PID) and fuzzy logic temperature control. Some activities are web-based bringing local research projects and instrumentation to the classroom. Student teams also develop their own semester projects starting at midterm. Those projects are presented as papers and posters during an annual department open house. A summary of selected student projects for the past five years and student assessments will be discussed. Examples are presented in a draft book written by the instructor, who has taught this class for twenty-one years.

Keywords: Courseware, biological systems, sensors, electronics, measurements, controls.

Course Concept

Modern agricultural, biological, and biomedical instrumentation all use electronic sensors, analog and digital circuits, computers and microcontrollers for scientific measurements and process control. Instrumentation is used for commercial product development, testing, and basic research. The course described in this paper introduces basic measurement theory, applications of instrumentation and controls along with features of basic biological, environmental, and mechanical sensors. Sensors and transducers include contact, non-contact, mechanical, thermal, optical, ultrasonic, and other devices. A number of instrumentation books are currently published either as monographs (Webster, 1999, Nachtigal, 1990, Mitchell, 1983, and others), textbooks (Daly, 1993, Carr, 1996, and others), or as small, but significant paperbacks (Turner and Hill, 1999 and Ramsey 1996). Monographs are best used as library reserve resource materials. Some books feature a programming language for instrumentation and controls. Examples are Khalid (2000), Olansen and Rosow (2002), Travis and Kring (2006), and Khoo (1999). Most text books depend on the student's previous course background to understand the material presented. A new text book being completed by the author provides the student of this discipline an opportunity to understand and gain practical experience with modern measurement equipment, data acquisition, and digital control systems. The course project initially discussed by Meyer (2008) assumes that the audience is a junior, senior pre-engineer, or a first–year graduate student.

Fourteen topic areas for the instrumentation and controls course are presented in Table 1. The student begins with a study during week 1, the analysis of static and dynamic signals using an oscilloscope. Background is further enhanced by learning about features and capabilities of signal processing circuitry and digital acquisition. From that background, the student can select modern data logging equipment for the problem at hand according to specifications for obtaining the best measurement performance. Automation of digital measurements not only includes hardware but software. LabVIEW® (www.ni.com or National Instruments, Austin, TX) programming is an excellent software tool and has been used for the past five years in this course.

During the first five weeks, there is a concurrent and intensive introduction to LabVIEW along with fundamental instruction of instrumentation electronics. LabVIEW Instructional modules and examples are available at various web-sites for demonstrating and simulating electronic circuits and responses. Most instrumentation textbooks cover analog and digital principles for instrumentation but in different orders and formats (e.g. Johnson, 2006, Northrop, 1997). Reinforcement of principles and introduction to practical instrumentation and control examples can only be offered through hands-on laboratory exercises, demonstrations, and preparation of a final team project. Laboratory exercises for this course include experiments with temperature sensing, fluid flow, stress-strain, displacement, load-cell, ultrasonic proximity sensors, and optical sensors, applied to problems of the discipline. Computer interfacing and communication with instrumentation includes serial and parallel circuits, universal serial bus (USB), analog-to-digital, digital-to-analog, networking, and wireless applications. A team project begins at mid semester after being selected and approved from either a furnished list or according to student special emphasis interests. Many times these projects come from other members of the faculty or from industry.

A new book emphasizes the use of an instrumentation programming language in addition to measurement and sensor fundamentals. Modern software includes both graphical or object oriented and script programming for specialized computations and controls. LabVIEW 8.6 as an example and has a powerful parallel-processing, data flow operating system. This latest version can utilize multi core processor hardware of the modern desktop computers. LabVIEW also provides Mathscript® programming which has distinctive customizing advantages for algorithmic development. Mathscript® is also a subset of MATLAB® script (The Mathworks, Natick, MA) and as a top-down computational language offers additional mathematical functions for processing large data sets and arrays. Agricultural Engineering (AGEN) and Biological Systems Engineering (BSEN) students learn MATLAB as freshman. Mathscript is especially useful for adaptive modeling and instrumentation, where real time data drives both simulation and validation of results. Examples include stress-strain measurements and plant water use measurements. A web example used is real time greenhouse monitoring with emphasis on thermodynamics. Other examples include a processing model linked with a proportional-integral -differential or a fuzzy logic controller. Psychrometrics for a sensible, latent heat, and radiation analyses of heat exchange from moist surfaces are best computed with Mathscript models.

Table 1. Instrumentation and Controls - Schedule of Topics.

Tentative Weekly Schedule of Topics – Fall 2008	
Week 1	Measurements for Physical and Biological Systems – Actual and LabVIEW virtual Oscilloscopes.
Week 2	Analog signal conditioning circuits.
Week 3	LabVIEW Exercises (charts, arrays, visual modeling, etc.).
Week 4	Digital signal processing (NI, MCC, Vernier, and LabJACK – LabVIEW addons).
Week 5	Advanced LabVIEW Exercises (communications, internet, etc.).
Week 6	Sound and Ultrasonic Proximity measurements.
Week 7	Thermal Sensors and Temperature Transducers –Response Times.
Week 8	Biomedical sensors (Force, heart rate, spirometry).
Week 9	Velocity and Flow Sensors.
Week 10	Water Quality Sensors.
Week 11	Introductory Machine Vision (NI IMAQ®).
Week 12	Introduction to Fuzzy Controls (NI Controls Add-on).
Week 13	Final Controls: Stepper motors, modutrols, and actuators
Week 14	Introduction to Classical Controls (NI Controls Add-on).

Over the years, it has become apparent that many instrumentation textbooks have been written for special audiences in various fields of engineering. There has also been a recent proliferation of instrumentation monographs, many of which are included in the reference list. Monographs and refereed instrumentation papers are certainly of interest to senior agricultural and biological engineers, but may not provide the practice exercises needed. If one searches the internet, they will find numerous commercial sensors and instrumentation sites, and possibly be overwhelmed by the plethora of technical information. Sufficient background and experience to evaluate and select such systems is required.

This course provides the student the opportunity to operate modern electronic measurement equipment, including an oscilloscope, data acquisition, microcontrollers, and digital control systems. The course assumes the student has had a basic physics course and has taken most of the core agricultural and biological systems engineering courses. This course addresses practical instrumentation and control systems through hands-on laboratory exercises, in-class demonstrations, and a semester student team project. Student teams present their projects as posters during the annual Department Open House (E-Day) in December.

Course Objectives

The objectives and expected outcomes of this course are to[1]:

1. learn the technical language, terms, and definitions for electronic sensors and instrumentation. Acquire technical skills for selecting and using electronic sensors and modern data-logging equipment. (**knowledge),**
2. develop an understanding of the physical mechanisms of basic sensors and how they interact with the measurand in biological, biomedical, and agricultural applications. (**comprehension),**
3. enhance the ability to select components, design, assemble, and operate measurement systems for specific applications (**application)**,
4. learn basic analytical and research skills to aid in selecting and applying instrumentation for specific applications, first by understanding the process, and then applying the measurement system (**Analysis)**,
5. provide the student the opportunity to design, develop and present a specific measurement system relative to his /her area of technical interest and choice (**synthesis),**
6. provide the opportunity to use and improve oral and written communication skills to describe the development, evaluation, and performance of an electronic instrumentation system. Provide the basis for understanding the need for life-long learning of new measurement systems (**evaluation)**.

Laboratory Exercises

The first ten weeks of the course are devoted to formal laboratory exercises and preparation of good lab reports. Laboratory reports are often limited to a two-page narrative, typical of the size expected by industry. The dynamics and characteristics of electronic sensors are very important in measurements. During the very first lab, students learn to operate a modern digital oscilloscope. Students analyze unknown signals provided by a signal generator that include sinusoidal, square, and impulse signals. The students use the fast Fourier transform to analyze signal and noise frequencies. A second lab is devoted to wiring and soldering skills (a lost art) through the construction of a very compact microphone circuit board. The response time of sensors and the aperture time of sample frequency of analog-digital conversion are important in matching instrumentation to desired measurement objectives. The students study the response time of various temperature sensors which include thermocouple, thermistors, integrated temperature sensors, and infrared sensors. The student design and build a LabVIEW virtual instrument (VI) logger program using a data acquisition (DAQ) device of choice (Figure 1). DAQ's are commercially available and many are supported by LabVIEW user libraries, LabVIEW DAQmx, or the Universal LabVIEW Library. After creating their own logger program, the student proceeds to temperature measurements, force measurements (using an arm strength torque device with strain gages (Figure 2), an instrumented exercise bike, and other force/torque/flow devices used for human physiological measurements of work and power.

[1] Corresponding to Bloom's Taxonomy (Bloom, 1956).

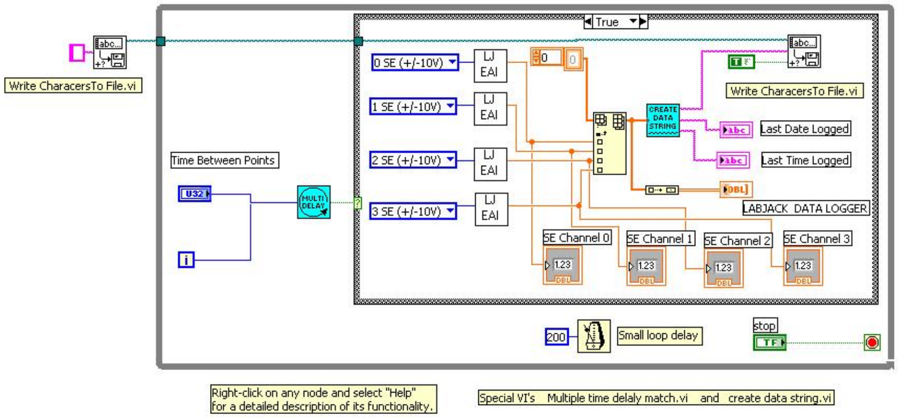

Figure 1. Block diagram for the LabJack data logger virtual instrument (VI).

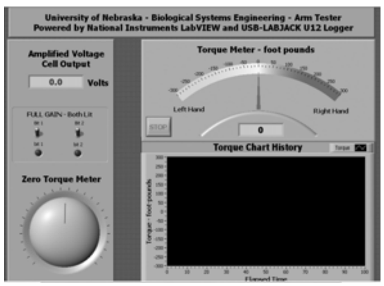

Figure 2a. Front Panel for the Arm Wrestler virtual instrument (VI).

Figure 2b. Instrumentation Amplifier (courtesy: www.labjack.com).

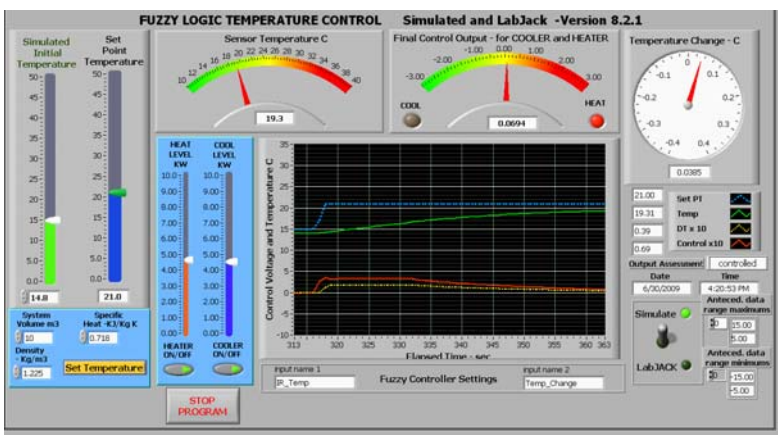

Figure 3. Front Panel of a LabVIEW fuzzy controller exercise.

The mathematics of basic process control is presented. A fuzzy logic temperature control exercise is conducted using fuzzy membership functions and inferences shown in Table 2 (Ross, 2004, Mamdani, 1974, and Zadeh, 1965) [2]. Figure 3 shows the Front Panel.

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[2] Mention of commercial products or trade names are for reference only and not to the exclusion of others that might be suitable.

Table 2. Linguistic Antecedents and Consequences for a Temperature Fuzzy Controller.

Temperature Change	**Current Temperature is: °C** [1]				
	Far Below	Near Below	Set Point	Near Above	Far Above
Fast decrease (F-D)	**I-100** or High heat, Fan[2] Off	**I-100** or Medium Heat Fan Off	**I-50** or Medium Heat Fan Off	**I-50** or Low Heat Fan On	**N_C** or Heat Off Fan On
Slow Decrease (S-D)	**I-100** or High Heat Fan Off	**I-50** or Low Heat Fan Off	**I-50** or Low Heat Fan On	**N_C** or Low Heat Fan Off	**R-50** or Heat Off Fan On
No Change (NC)	**I-50** or Medium Heat Fan Off	**I-50** or Low Heat Fan On	**N_C** or Heat Off Fan Off	**R-50** or Heat Off Fan On	**R-50** or Heat Off Fan On
Slow Increase (S-I)	**R-50** or Medium Heat Fan Off	**N_C** or Low Heat Fan Off	**R-50** or Heat Off Fan On	**R-50** or Heat Off Fan On	**R-100** or Heat Off Fan On
Fast Increase (F-I)	**N_C** or Low Heat Fan Off	**R-50** or Low Heat Fan On	**R-50** or Heat Off Fan On	**R-100** or Heat Off Fan On	**R-100** or Heat Off Fan On

[1] Relative to the set-point.

[2] Equipment used.

1. LabJack U12 Logger (www.labjack.com).
2. Type J thermocouple with monolithic thermocouple amplifier and cold junction.
3. Infrared temperature Sensor
4. A handheld independent digital voltage meter.
5. Thermos filled with ice and hot water and a precision alcohol thermometer to measure and check thermocouple readings.
6. An infrared black-body plate to check infrared sensor readings.
7. Digital-to-Analog (DAC) Control Unit for 110-volt lamp used as a heater.
8. On-Off Control Unit for the Fan.

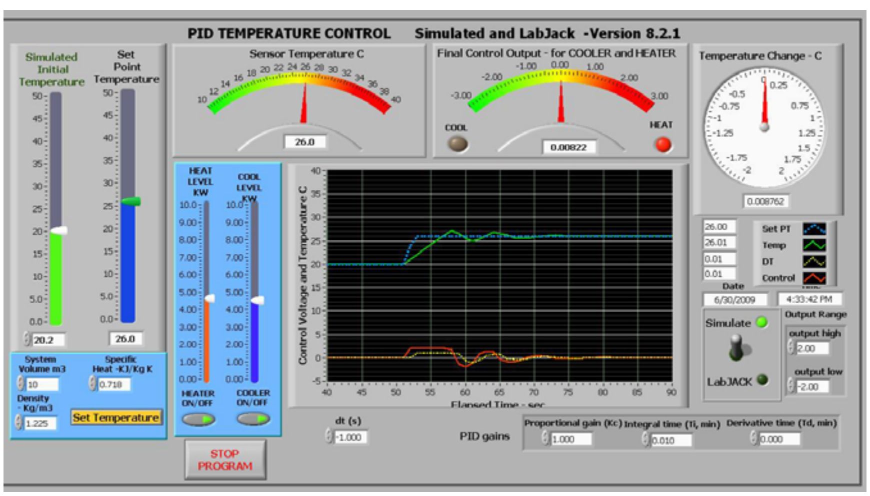


Figure 4. Front Panel of a LabVIEW PID controller exercise

Figure 4 shows an equivalent proportional-integral-derivative temperature controller. Both the fuzzy and the PID controllers are used with solid-state final controls to operate a fan and a heater for controlling surface temperature of a living green plant. An infrared leaf temperature sensor and an integrated circuit sensor for air temperature are used.

Student Team Projects

The final six weeks of the class are also devoted to student team projects. Team student instrumentation and controls projects are selected from a prescribed list provided by the instructor. All projects were instructional in nature and did not generate research data that would require institutional board review (IRB). The students developed the projects as a group and presented them as posters at an annual Department open house. The open house includes invited other students, alumni, faculty, administrators and potential employers. Team sizes are either two or three members. The principles of Michaelsen, et al. (2004 and 2007) are considered in team group planning and facilitation. The final written term paper was graded according to the instrument shown in Appendix B. A brief summary description of selected projects for the years 2004 -2008 are given below**.** For some projects, the major pieces of electronic equipment are also given.

1. Penman-Monteith Evapotranspiration Real-Time Adaptive Model (2008)

The goal of this project was to create a LABVIEW real time model for calculating water loss in a system through evaporation of plants. Sensors were used to measure solar radiation (Rs) and the maximum and minimum temperatures for the day are determined to calculate evapotranspiration. The group used the Penman-Monteith equation and data was obtained from greenhouse water hydrangea plants.

2. A Comparison of Water Quality Sensors (2008)

This team tested the accuracy of several water quality sensors from Vernier® (www.vernier.com). These sensors included pH, dissolved oxygen, and turbidity. A LabVIEW program using the GO!Link® interface was written to analyze and record signals from the sensors. Those results were compared to the readings of a more expensive and industry standard Yellowstone Scientific Instruments (YSI) 6600 EDS multi-parameter continuous water quality monitor systems.

3. Domestic Humidifier and Temperature Control

This team modified a standard domestic ultrasonic humidifier for use in a small Plexiglas chamber. Such a chamber might be similar size to a prenatal incubator. Also, humidifiers that are purchased and used by the general public or family operate in a strict on/off basis without regulation or regard to the surrounding environment. This limitation can result in excessive or sudden humidification of the environment, which can cause discomfort and even may be detrimental to the user. The team modified the humidifier and the control system such that it responded to not only the humidity of the environment but also to the temperature. Additional modifications were made to this humidifier to allow for a more linear or controlled disbursement of humid air into the surrounding environment. The team utilized LabVIEW to regulate the programmed system coupled with a Front Panel relative humidity and temperature display.

4. Monitoring dissolved oxygen (DO) for water quality for a local wetland area (2008)

Naturally, the oxygen is one of the most important elements to the living creature. Adequate dissolved oxygen (DO) is necessary for good water quality and for sustaining aquatic life. The level of DO may fluctuate over the time and environmental effect. Wetland areas require good water quality to provide a habitat for wildlife, fish and unusual plants, by reducing flooding and soil erosion, supplying water, produce food and fiber and for recreational and educational opportunities (NGPC, 2008). Environmentalists need timely DO measurements to monitor and maintain the water quality. The team developed a simple LabVIEW program using the Vernier DO sensor and applied it to some local wetland areas around Lincoln, NE.

5. Respiration and Heart Rate Monitoring for Selected Exercises (2008)

The Vernier Respiration and Heart Rate Monitors were used during selected exercises to measure respiration rate and heart rates, respectively. Respiration and heart rates are measured according to the body electrical activity resulted from potential changes on cell membrane when oxygen is inhaled or exhaled. Patterns of the respiration and heart beating were displayed as waveforms on the Front Panel of a LabVIEW program. As the intensity of the exercises increases, the frequency of the waveform goes up which indicates a faster respiration rate and heart beat of the subject.

6. Comparison of Spirometer and Respiratory Sensors for Breathing Measurements (2008)

The goal of this project was to create a LabVIEW® virtual instrument that would simultaneously graph and save data to Microsoft Excel from both a spirometer and respiratory effort belt sensors during various selected exercises. The data was used to compare and relate times of the peaks associated with inhalation and exhalation for the two transducers. Such information would be an important part of calibration for determining how to use a respiratory monitoring belt to estimate volumetric flow rate for breathing.

7. Ultrasonic Measurement of Water Levels with an Embedded System (2007)

The area of ground water and surface water interactions is an important political issue in Nebraska. The most well known example is that of the Republican River basin in Southwest Nebraska where irrigators have been asked to shut down wells due to a perceived impact on ground water base flow and hence surface water flows in the River as it flows into Kansas. It is very likely that there are periods during an irrigation season where ground water levels are adequate to provide base flow to rivers and streams. Basic equations are described in hydrogeologic literature that can be used to estimate ground water discharge into a river or stream. In general, these equations consider factors such as aquifer hydraulic conductivity, stream bed conductance, and the relative water levels between the river and the adjacent ground water. By applying real time monitoring of the relative water levels between a river or stream and it's adjacent ground water, it would be possible to immediately assess if a ground water to surface water discharging or recharging condition was occurring.

Equipment: Basic Stamp 2® with 32 MHz processor (www.parallax.com), ultrasound range finder transducer, serial Bluetooth to a laptop computer, LabVIEW 8.2.1 (VISA).

8. The Energy Balance of Turf Grass System in an Environmental Chamber (2007)

This team project was an investigation and measurement of the energy components for latent and sensible heat and the radiation balance for flats of irrigated and non-irrigated blue grass turf. Continuous measurements of temperature, humidity, canopy temperature, and short and long wave radiation were taken in Chase Hall environmental chamber simulating an early spring day. The energy balance was based on the first law of Thermodynamics, but included estimates of stomata and aerodynamic resistances. A web-based instrumentation demonstration and a webcam were presented at the open house using a laptop with wireless internet connection.
Equipment: Measurement Computing® USB-5203 (Norton, MA), LabJack U12, temperature and relative humidity probe, infrared temperature sensors, thermocouples, pyranometers, wet-bulb psychrometers, thin film load cell lysimeters for flats, web cam, and LabVIEW 8.2.1 and IMAQ®.

9. Control of an Ethanol Fermentation Process (2006).

A fermentation process in continuous production of ethanol requires monitoring and maintaining parameters such as temperature, pH, and flow rate. Fermentation by yeast requires optimum temperature in the range of 37^{o}C, and pH of 5. The temperature can be controlled by switching on or off a heater system. The pH can be controlled by adding acid or NaOH. These adjustments have to be done rapidly to improve the efficiency of the fermentation process. Both proportional-integral-derivative (PID) controller and fuzzy logic controller were compared for controlling the process variables. Control accuracies and response timings of both controllers were reported. LabVIEW and the Controls add-on were used for building the controls to monitor the process.

Equipment: LabJACK U12, two solid-state relays (SSR), thermocouple cold bridge modules, flow meter, and LabVIEW 8.

10. Design and Implementation of LabVIEW in a Functional Home Security System (2006)

This team decided to design a functional home security system using LabVIEW software. The difference between the proposed security system and the ones commercially available is that the proposed system can be operated using a home PC and adapted to any complex infrastructure of a modern home. In addition to ease of adaptation, customization of the signals will be possible through voice instruction and warnings; the voice could be from the users instead of a preset audio file playback. Status of the system could be monitored from an intranet or internet connection. The scope of this project is limited to a two room house with one window in each room.

Equipment: LabJACK U12, microphone, motion sensor, 2-solid state relays (SSR), notebook computer, and LabVIEW 8.

11. Optical insect/beetle detection trap (2006)

This team designed and tested a three-sensor optical insect/beetle detection and enumeration system. An express virtual instrument counter was programmed with an analog voltage logger and was used to threshold pulse counts using cockroaches passing through the device. Equipment: LabJACK U12, photo diodes, resistors, 1.5-inch diameter PVC tube, and LabVIEW 8.

12. An Analysis of the Quarter Scale tractor for Strength under Dynamic Loading (2005)

An important aspect of the national quarter-scale tractor design competition was correct sizing of structural components to meet strength requirements while minimizing material, cost, and weight. The 2005 quarter scale tractor was designed using the Solid Works® (Concord, MA) design program, so a theoretical analysis of frame stresses was also accomplished, but needed experimental verification. Using a, the team strategically placed strain gauges on different parts of the tractor frame to determine actual stress and strains, during a dynamic loading test. With this data, more accurate predictions of the strength and integrity of this year's tractor design were achieved.

Equipment: Campbell Scientific CR5000 (Logan, UT), strain gage amplifier, and strain gages.

13. Ergonomic Improvements to an On-the-go Weed Scouting System (2005)

A certified commercial crop consultant is currently scouting and mapping weeds and providing herbicide recommendations to growers. His system uses an all-terrain-vehicle (ATV) and a hand-held portable-data-acquisition device (PDA) along with a global positioning system (GPS) to record visually sighted weeds and estimated populations. This team project developed a simple hand control, switches, and LED species indicators for data entry to improve the efficiency and accuracy of the weed mapping process. The method for traversing tram lines for visual assessment of weeds continues to be a successful enterprise by the crop consultant and is featured at: (http://www.deere.com/en_US/ag/pdf/furrow/2007/summer_07_F0702816.pdf).

Equipment: Motorola 6811 embedded controller with switch and LED interface.

14. Determination of Pear Quality Using Machine Vision and an Electronic Nose (2004).

Marketable fruit quality is a subjective set of measurable quality factors, and represents a major problem for human graders, in determining how these factors should be combined for grading decisions. This project used an electronic nose and machine vision as a fusion method for determining fruit ripeness and/or quality. To do the classification, fuzzy inference systems were trained using the nose to recognize different aromas, based on ripeness and/or quality. Machine vision was used to analyze color and shape and develop criteria for fruit quality and/or ripeness. The end goal was to use multi-sensor data acquisition to determine fruit quality/ripeness using the various input parameters.

Equipment: Cyrano electronic nose (Cyrano Sciences, inc., Pasadena, CA), color digital camera, MATLAB with Fuzzy Logic, and Image Processing Toolboxes.

15. Mice Detection Using Sounds (2004).

The purpose of this project was to detect rodents or rodent activity using sound in food storage areas. The project will use the sound card of a personal computer as a sensor. Computer programs were written to first record and then analyze laboratory mice noises and vocalizations. The animal sounds were analyzed as a particular range of frequencies that are distinguishable when graphically analyzed. The main difficulty of the project was to determine this range of frequencies. A final goal of this project was to develop a method to detect not only the presence, but possibly the exact location of rodents.

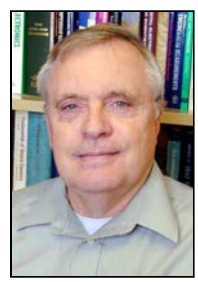
Equipment: Camcorder to record mice sounds and computer with an audio card and software.

Student Acceptance

Class size has ranged from 20 to 40 students. Student reaction to this class has been very good. The overall class score was (3.01 ± 0.15 /4.0). The overall instructor score was (3.46 ± 0.48 /4.0). Students were quite complimentary about the course and that the instructor did a good job. The material was considered very relevant. Examinations were fair, but long. Improvements could be made in the new textbook. Posters at the open house were well-done. Project reports were well-written.

Biographical Information

George Meyer, Professor, has taught graduate and undergraduate classes that involve plant and animal growth and environmental factors, modeling, and instrumentation and controls for both agricultural and biological systems engineering students for 31 years. He has received national paper awards and recognition for his work in distance education and has received university teaching awards. His current research include measurement and modeling of crop water stress, fuzzy logic controls for turf irrigation management, and machine vision detection, enumeration, and plant species identification for spot spraying control and precision agriculture.



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Appendix A

Catalog Description: Instrumentation and Controls (3 cr) Lec 2. Lab 2. Prereq: Analysis and design of instrumentation and controls for agricultural and biological production, management, and processing. Theory of sensors and transducers, analog and digital electrical control circuits, and the interfacing of computers with instruments and controls. Emphasis on signal analysis and interpretation for improving system performance.

Text Books: **LABVIEW 8 Student Edition** (includes Version 8.5) National Instruments, **Inc.** by Robert Bishop, *The University of Texas at Austin.* ISBN: 0-13-199918-4, Publisher: Prentice Hall, Copyright: 2008.

Instrumentation and Controls For Agricultural and Biological Engineering Applications using LabVIEW® as a Software Support System (Draft) by G.E. Meyer.

Format: This course is 3 credits (2 weekly lectures and a two-hour laboratory).

Appendix B. FINAL REPORT - SCORE SHEET – 125 Points

CATEGORIES	**POSSIBLE POINTS**	**POINTS GIVEN**	**COMMENTS**
SIGNED LETTER OF TRANSMITTAL	**Report must be signed by all team members, signifying all have contributed!**		
REPORT CONTENT AND FORMAT			
Summary - Single descriptive paragraph or abstract.	**5**		
Background and Literature Review - Cites useful literature, previous instrumentation approaches, and describes purpose and impact of the project.	**15**		
Objectives - Overall objective and 1-2 sub objectives.	**5**		
Procedure/ Methods - Sensors used. Data acquisition method. Appropriate equations, units, numbered, and cited. Refers to sample calculations or results in appendix. Support with pictures, figures and/or tables, as appropriate.	**20**		
Results and Discussion - Reports details and results of development efforts, methods, testing, with table and figure support.	**20**		
Conclusions - Appropriate conclusions that match objectives. Suggestions for future work.	**10**		
References (Complete citations - ASAE method).	**5**		
Figures and Tables - Appropriate amount of significant digits, information displayed, correctly justified, labeled, footnotes, and captions in the correct position. Landscapes attached correctly to the report. Stands by themselves.	**10**		
Appendices - Appropriate supporting material. Examples: computer code used, manufacturer's specific sheets, sample calculations, samples of raw data, and cost data (not required, unless requested).	**10**		
OVERALL REPORT APPEARANCE	**0**		
Neatness and Writing Quality - Proper spacing, justification, proper grammar, correct spelling, and page numbers. Drawings and sketches are neat and properly labeled.	**15**		
Overall Creativity - Shows interest and enthusiasm in project.	**10**		
FINAL TOTAL SCORE	**125**		

Courses Intended Primarily for Students in Agricultural and Biological Engineering and Biological and Food Process Engineering. Undergraduate Level/Lower-Division Courses. ABE 12000 Introduction to Agricultural and Biological Engineering Sem. 1 and 2. Lab. 2, cr. 1. Introduction to engineering technologies and career opportunities involved in agricultural and biological engineering.Â This course educates students in the use, selection, and design of instrumentation and data acquisition systems for agricultural, food, environmental and biological systems. Emphasis will be on measurement of position (GPS), force, pressure, power, torque, flow, and temperature along with environmental sensors. The Department of Biological and Agricultural Engineering (BAE) applies engineering principles and the fundamentals of biologically-based systems and tools, primarily in agriculture and the environment. The scope of BAE ranges in scale from the molecular to the ecosystem level, for the safe, efficient, and environmentally sound production, processing and management of agricultural, biological and natural resources. From biomechanics to food processing and water management, weâ€™re engineering solutions for a sustainable future. The BAE department provides excellent educational opportunities at t