AC 2009-386: A LOW-COST APPROACH TO INTEGRATING SENSOR TECHNOLOGY IN MULTIDISCIPLINARY COURSES

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A Low-Cost Approach to Integrate Sensor Technology in Multidisciplinary Courses

1. Introduction

Sensor technologies have received tremendous attention from both academic and industry fields. Unfortunately, high costs of laboratory equipments and spacing have prohibited many Engineering and Technology programs to offer courses in sensors, sensor networks, and related topics. Consequently, graduates from these programs often lack thorough understanding of sensor technologies and networks and their hardware/software design issues. As a result, these students will be in disadvantageous position in the current competitive job market.

In this project we introduce an introductory multi-disciplinary-based laboratory experiment, which provides basic theoretical knowledge about various types of sensing devices. The laboratory experiment and related lectures are primarily for students enrolled in different undergraduate science (biology, physics, bio molecular, etc.), engineering, and technology courses possibly with limited background in electronics. The proposed experiment can be utilized as an add-on component to courses with laboratory activities covering physical computing, instrumentations, computer-based measurement technology, or related topics. In addition, programs such as inter-disciplinary team-based learning[1] can greatly benefit from such experiment.

In this paper we also show how interested and more advanced students can develop more involved projects using advanced programming and wireless communications. We conclude the paper by showing student responses to the quantitative and free-form questions concerning the implementation of the sensor laboratory experiment.

2. Background

An immense number of new services and products have been introduced in the past two decades, many of which are monitoring and measuring physical parameters using various sensors. Consequently, sensor technology has been extended to many diverse fields, such as environment, medicine, and wildlife.

Today, a large number of industries are devoting significant investments in research and development of various sensor technologies and sensor networks. A growing number of industries are also looking into development of *intelligent* sensors and actuators to monitor physical parameters. As a result, more and more instruments and process control systems are utilizing sensors.

Unfortunately, as in many other universities and colleges, our curriculums in Engineering, Electronic Engineering Technologies, Computer Engineering Technologies, and science related majors do not offer any specific courses in sensor technologies. Laboratory experiments in physics and chemistry only demonstrate basic electrical and physical measurements in order to reinforce lectures in particular areas. Consequently, many of our undergraduate students have very little experience with sensor and actuator technologies and networks.

This paper reports an experimental approach to introduce sensor technology to second and third year college students taking core science courses, such as physics, chemistry, or first year electronics. The key advantage of the proposed sensor experiment is that it requires minimum space, low-cost hardware equipment, and minimum programming knowledge. In the proposed framework, students learn about basic concepts of data acquisition (DAQ) systems, graphical-based programming (such as LabVIEW), and various sensing devices to monitor temperature, tilt, direction, and vibration. This framework is designed such that students can readily modify the original setup and create their own innovative lab environments and virtual instrumentations. Hence, students can design their own filters, signal processing algorithms, and signal coupling mechanisms to accurately analyze the inputs. Similar setups can cost as high as $1000[1].

3. Classroom Experiment

Integration of laboratory experiments with class lectures can be an effective approach in teaching basic concepts in sensor technology. In designing the introductory materials to sensor technology, we focused on four objectives:

a) Demonstrating how basic knowledge of electronics can practically benefit students even in non-engineering fields;
b) Providing students with necessary software and hardware tools such that they can continue their design project beyond laboratory time limits;
c) Encouraging students from different disciplines to interact and collaborate towards an innovative design project;
d) Promoting student creativity by asking students to utilize their knowledge and talents in solving a real-world problem.

In order to successfully achieve the above objectives, we implemented the following methodology. First, we introduce students with the basic concepts in sensor technologies. Then, through demonstration and hands-on experiments, students become familiar with available hardware and software tools and their functionalities. Finally, students are asked to implement a design project using the provided tools.

Table 1 lists the details of each class lecture as scheduled. Note that we introduced the experiment in the middle of the semester, around the 6th week. As noted in the table, the first and second introductory lectures include a brief introduction to data acquisition systems and description of basic sensor technologies. In particular, we discuss the underlying technologies in designing accelerometers and temperature sensors. Practical topics, such as analog-to-digital converters, sampling rate, and acquisition time were also briefly covered in these lectures.

The third and forth lectures focused on introducing LabVIEW[5] and its applications. We covered basic features of LabVIEW programming and demonstrated a few basic programming examples. The lecture was followed by a separate laboratory time for hands-on practice with LabVIEW and interfacing it to the DAQ.

In the final lecture, we introduced our own in-house designed head-tracking system, a DAQ-based system connected to an accelerometer and a temperature sensor and monitored via LabVIEW. Then, students were asked to setup the experiment as shown in the lab handout and record their results and evaluate the accuracy of the system.

Table 1. Lecture and laboratory materials for introducing the add-on sensor experiment in a 12-week multidisciplinary course[1].

Week	Lecture	Duration (*)	Lecture coverage
6	1	1:30	- Basic electronic review (depending on students' backgrounds) - Introduction to sensor technologies
6	2	1:30	- Examples of sensors and actuators - Introduction to accelerometers and temperature sensors - Introduction to analog-digital converters
7	3	1:30	- Introduction to DAQ systems - Measurement constrains in DAQ systems - Introduction to LabVIEW
7	4	2:30	- Demonstrating LabVIEW examples - Head tracking experiment
8	-	-	- Creating groups - Posting design project proposal on the discussion group
12	-	-	- Presenting the final working prototype - Submitting the formal project report
(*) Duration of each lecture (in hours).			

In week eight students were grouped such that each group contained students from different disciplines. In order to ensure various prospective are discussed in each group, we required each group to have at least one male and one female student. Each group was given the complete set of hardware and software tools. LabVIEW software could be obtained from national instrument site free of charge for 2 to 4 weeks. Interested students could also obtain LabVIEW student version for about $75. Each group was given four weeks to complete the proposed design project and present a formal final report. A final report template was provided to each group.

Throughout the semester, we required all the students to post their progress, issues, and problems, on the class discussion group, powered by groups.yahoo.com. All groups were encouraged to create their own web page or Blog. In order to assist students, we setup a few informal half-an-hour extra sessions for students to discuss their problems and questions. In each session the instructor also addressed some of the issues posted on the discussion group.

3.1. Required Hardware and Software Tools

In this section we briefly describe the hardware and software tools provided to each group.

Data acquisition system: There are many types of DAQs available in the market. We provided each group of students an NI USB-6008 DAQ manufactured by National Instruments. This device costs about $110. NI USB-6008[7] has a USB interface and

[1] All course materials including lab manuals and setups can be obtained from reference [9].

provides connection to eight analog input (AI) channels, two analog output (AO) channels, 12 digital input/output (DIO) channels, and a 32-bit counter with a full-speed USB interface. The maximum input signal voltage is ±10 Volts. The maximum out voltage is limited to ±5 Volts. No external power supplies are required for NI USB-6008. Another alternative DAQ system is LabJack U3 DAQ, which costs slightly less. A more advanced model of LabJack, U12 DAQ, is Internet enabled and the data can be transferred and monitored remotely.

Accelerometer sensor: In our experiment we used an ADXL 330 accelerometer. Sparkfun provides a convenient breakout board for the triple axis ADXL330 from Analog Devices[3]. ADXL 330 is a capacitive accelerometer that senses a change in electrical capacitance, with respect to acceleration. Capacitive accelerometer sensing element consists of two parallel plate capacitors acting in a differential mode[6]. These capacitors operate in a bridge circuit, along with two fixed capacitors, and alter the peak voltage when subjected to acceleration. The change in voltage corresponds to change in acceleration. The cost of the breakout board is about $23.

Temperature sensor: In our experiment we used a single-wire high precision temperature sensor from Dallas Semiconductor (e.g., DS18S20). The cost of such devices is about $8.00.

LabVIEW soft: Each group was given a CD with the following LabVIEW-based programs:

a) Interfacing programs to access analog and digital channels on NI USB-6008 and LabJack U3 DAQs. National instrument offers Measurement & Automation software (MAX), which can be used to communicate with the DAQ. However, we provided students with our own customized LabVIEW-based modules to communicate with NI USB-6008 system.
b) A complete set of virtual instruments to convert the DAQ into a digital multimeter, signal generator, oscilloscope, and power supply source. Using these programs interested students could readily convert their DAQ into various electronic measurement devices.
c) The complete program set for controlling the head tracking system, which was performed in the lab. All related setup documents were also included.
d) A complete set of lecture materials and final report template.

3.2. Head Tracking Laboratory Experiment

In order to integrate software and hardware tools together and demonstrate capabilities of the provided sensors (e.g., accelerometer and temperature sensors), we developed a simple laboratory experiment which was aimed to be potentially appealing to both female and male students. Our intention was to make the experiment as gender-neutral as possible. In the following paragraphs we briefly describe the experiment.

The purpose of the head tracking experiment was to monitor the head movement of the user, while measuring the external body temperature. In our setup the acceterometer sensor was placed on the user's chin or forehead. The outputs of the sensors were acquired through the DAQ and processed using a simple signal processing program written in LabVIEW.

In this experiment students learn how the head rotation is converted into *tilt* measurement and displayed on the front panel of the virtual instrument on the PC. Students are encouraged to change various parameters in the front panel and observe the sensitivity of the system as the user moves his/her head. An alarm can be triggered if the user moves beyond the tolerable changes. The alarm can also be set off if the user makes sudden changes. Through this experiment we also demonstrated how such simple devices can be used to detect medical problems such as seizure.

The actual setup of the experimentation was very simple and only involved interfacing the DAQ to a PC and connecting four individual wires from the accelerometer and the temperature sensor to the DAQ. The setup is show in Figure 1.

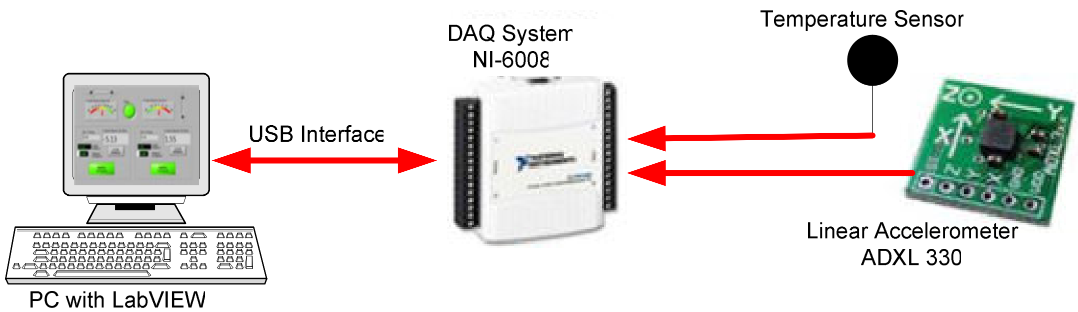

Figure 1: Setup for the head tracking experiment.

Figure 2 shows different monitoring parameters on the front panel. The directional indicators on the control panel identify the direction of the user's movement (e.g., right/left and up/down). Throughout the experiment, students were encouraged to change the reference head position and measure the relative movement with reference to the original head position. Tolerance values are used to activate the alarm if the movement is beyond the set thresholds in X and Y directions.

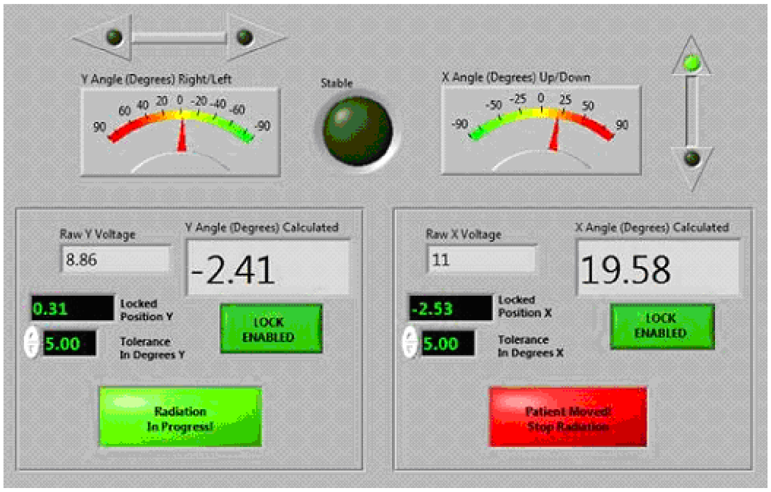

Figure 2: LabVIEW front panel used in the head tracking experiment.

3.3. Student Project Examples

Majority of our students did not have any problem finding a project idea and most students were highly motivated to find an interesting and useful topic. Examples of projects designed by our students are as follow:

- Comparing engine vibration in different automobiles;
- Evaluating the suspension systems in different automobiles;
- Monitoring a baby's movement while sleeping;
- Capturing the disposition of a punching bag upon impact;
- Measuring acceleration of a sliding box;
- Monitoring walking patterns;
- Measuring vibration in different cell phone models.

3.4. Extended Laboratory Experiments

Interested and more advanced students were encouraged to use wireless modules (e.g., Xbee) to transfer the data to the PC. These students were provided a series of LabVIEW interface programs, which can be readily interfaced with XBee[8]. Student handouts also provided a clear setup description for interfacing the sensing devices to the wireless transmitter.

Figure 3 indicates a basic setup used for interfacing the sensors to the PC using an Xbee wireless transmitter and receiver. In this case, the outputs of the sensors are directed to the 10-bit analog-to-digital converter (DAQ) unit on the XBee transmitter module. The corresponding digital data is sent to the OEM RF module providing wireless data communication over ZigBee/802.15.4 protocol[4]. The receiver Xbee is connected to the PC via a USB cable.

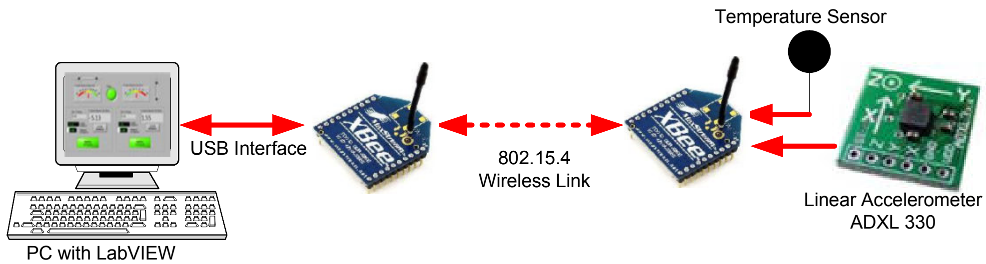

Figure 3: Interfacing with the sensing devices using wireless Xbee.

Figure 4 depicts the basic wiring used to interface the accelerometer to the Xbee transmitted. Due to portability of the wireless sensors, students using the wireless approach typically were able to design more interesting projects.

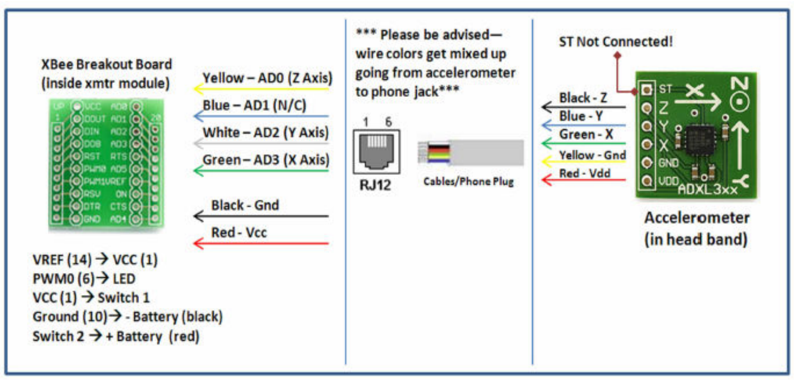

Figure 4: Basic wiring used to interface the accelerometer with Xbee; extracted from the lab manual.

Another interesting extension to the experiment can be integrating LabView Datalogging and Supervisory Control (DSC) Module. The DSC module incorporates networking, data basing (SQL 92 and ODBC 2.5 compliant), and data logging within the LabView program. Using the DSC module, students can map each hardware device into variable, and hence, obtaining more flexibility doing less programming. For example, the DSC module can perform all of the logic for activating the alarm module. Furthermore, students could use DSC module to record the data over time and examine trends in the head movements in each individual. The DSC module includes over 4,000 graphics[10] that can be used to create more professional virtual instrument front panels.

4. Experiment Outcomes

Our main motivation in developing this experiment was providing an introductory section on sensor technology that can be added to intermediate courses across different programs, including Computer Science (CS), Electronic Engineering (EE), Computer Engineering Technology (CET), Mechanical Engineering (ME), and various Sciences majors.

4.1. Assessment Results

The sensor experiment was integrated in both sections of second year physics and one section of first year electronics. All students enrolled in these sections had at least one semester of programming. These courses typically cover the basic electronics in the first six weeks. In second half of the semester, we included the related lectures for two consecutive weeks, as shown in Table 1. Most materials were covered during lab times in order to avoid interfering with the main class lectures. At the end of the semester, the students were asked to complete a mandatory short survey for the course and give their feedback on the sensor laboratory materials and project. The survey was primarily based on quantitative questions with the last question asking for student comments and suggestions. The combined demographics of the three sections were as follow: 20% CS, 50% Biology, 22% EE, and 8% Physics. The responses to some of the quantitative questions concerning the sensor laboratory experiment are shown in Table 2.

Table 2. Student responses to the laboratory experiment.

1- The sensor experiment was			
☐Easy	☐Ok	☐Complex	
20%	**70%**	**10%**	
2- The sensor project made me enhance my understanding of sensor technologies and electronics			
☐Strongly Agree	☐Agree	☐Disagree	☐Strongly disagree
35%	**55%**	**10%**	**0%**
3- The time dedicated to complete the sensor project was			
☐Too short	☐About right	☐Long	☐Too Long
0%	**55%**	**40%**	**5%**
4- The sensor project should be continued in the future			
☐Strongly Agree	☐Agree	☐Disagree	☐Strongly disagree
19%	**70%**	**9%**	**2%**
5- Students should be given more time to complete the wireless portion			
☐Strongly Agree	☐Agree	☐Disagree	☐Strongly disagree
40%	**40%**	**20%**	**0%**
6- I will probably take other classes covering sensor technologies			
☐Strongly Agree	☐Agree	☐Disagree	☐Strongly disagree
10%	**40%**	**30%**	**20%**
7- I feel this class helped me to better understand some laboratory aspects of my major classes			
☐Strongly Agree	☐Agree	☐Disagree	☐Strongly disagree
30%	**40%**	**20%**	**10%**
8- It was fun to collaborate with students majoring in different fields			
☐Strongly Agree	☐Agree	☐Disagree	☐Strongly disagree
30%	**50%**	**15%**	**5%**
9- Students were give sufficient instructions on using the hardware and software tools and lab equipments were sufficient			
☐Strongly Agree	☐Agree	☐Disagree	☐Strongly disagree
5%	**25%**	**50%**	**20%**

In their comments, many students indicated that, in spite the fact that they felt the project was very educational, more time must be given to complete the assignment. Some students believed that instructions listed in the lab handouts were not very clear. In fact, throughout the experiment, the students were very active in providing corrections and their feedbacks greatly assisted us in updating lab handouts.

In regards to lab equipments, most students expressed that they were given proper tools. However, they also expressed that more assistance should be provided during the semester, in particular with regards to LabVIEW programming. In general, most students expressed satisfactions with their lab partners from different disciplines and found her/him helpful in completing the project.

Almost 95 percent the students completed a working prototype by the end of the semester. About 10 percent of students with more knowledge about programming and electronics used Xbee in their design project.

5. Conclusion

In this paper we presented a practical sensor experiment which can be added to multidisciplinary courses. Student responses to the quantitative and free-form questions concerning the implementation of the sensor laboratory indicated that majority of students found the experiment interesting and helpful in enhancing their learning. The complexity of the experiment appeared to be satisfactory to most students and, overall, their feedback was positive. Based on students' feedbacks, we learned that a number of measurements, including improvement of instructions in the lab manual and lab equipment, can further improve their learning experience in sensor technologies. This experiment also proved to be a good starting point for future development of courses in sensor technologies.

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