Developing System-Thinking Oriented Learning Modules of Networked Measurement Systems for Undergraduate Engineering Curriculum

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Abstract

This paper describes the design of a set of system-thinking oriented learning modules of network measurement systems for data acquisition and instrumentation courses. The courseware was designed based entirely on open source components: including commercial-off-the-shelf (COTS) Wireless Sensor Nodes (WSN) and open source TinyOS-based software. The objective of the module is to introduce students to system-thinking oriented design of networked measurement systems, while taking into consideration the differences and details at component, system, and networking levels. The pedagogical model harnesses a wide range of wirelessly networked hardware/software co-design skills in engineering and technology (E&T) education to address a need for such skills in 21st century instrumentation and measurement workforces. The six project-based learning modules with twenty-two hands-on experiments were developed for the networked measurement systems cover topics including how to select a sensor, fundamentals in analog and digital systems, and fundamentals of networking and data logging. Students learn about the system-oriented design procedures, configuration and programming of wirelessly networked sensor nodes, visualization and analysis of monitoring data from any individual sensor on the node, as well as the state of the node. After completing these modules, students will be able to design, develop, and implement a networked measurement system to solve real world problems.

Introduction

Recent advances in sensing, computing, and communication have shifted the paradigm in the practices of instrumentation and measurement, resulting in a proliferation of networked data acquisition systems usage in industries such as manufacturing, aerospace, agriculture, healthcare, and homeland security. As a result, the need to prepare 21st century instrumentation and measurement professionals to design, implement, and operate such systems is imperative. Given the tremendous advances in wireless networking technology, wirelessly networked data acquisition (DAQ) systems are seeing increased adoption in the real world. Wireless sensor networks (WSN) have been shown to be an effective educational platform for students to learn about networked DAQ mainly because they get the hands-on experience of hardware/software co-design. In the traditional setting, instructors setup the whole data acquisition system before the class due to its complexity. Students, on the other hand, would not have the opportunity to experience the details of the DAQ (its components, how they are connected and collaborate with each other to achieve the data collection objective). Instead, their involvement focuses more on how to visualize and analyze the data after getting data output from the DAQ software driver.

In this paper, we describe in detail a set of system-thinking oriented learning modules for data acquisition (DAQ) and instrumentation courses. Instead of focusing on individual components of such systems, the modules are intended to guide students to focus on the functionality of each component and the effect of its interaction with others in the system. The critical thinking skills trained in these modules enable students to make decisions during the development and implementation of such DAQ systems to solve real world problems under the constraints of available resources (funds, time, personnel, etc.) The courseware was designed based entirely on open source components: including commercial-off-the-shelf (COTS) Wireless Sensor Nodes (WSN) and open source TinyOS-based software. The objective of the module is to introduce students to system-thinking oriented design of networked measurement systems, taking into consideration necessary details at component, system, and networking levels. The pedagogical model harnesses a wide range of wirelessly networked hardware/software co-design skills in engineering and technology education to address a need in 21st century instrumentation and measurement workforces. The developed modules have been offered in several courses since 2010 and the assessment results demonstrate that they not only effectively introduced recent technology advances in wireless sensor networks to students, but also nurtured their system-level critical thinking skills.

Six project-based WSN learning modules with twenty-two hands-on experiments were developed to teach students the fundamentals of WSN design and how to develop networked data acquisition systems to monitor and control a physical system. These six modules were distributed across four WSN technical content areas: component-level, system-level, network-level, and capstone/project-level. Learning outcomes in each area reflect the overall goals of the project and include: (1) at the component level, students will demonstrate their ability to (a) select appropriate sensors to monitor physical phenomena and (b) design analog and digital signal conditioning circuits to connect them to microcontroller/computers; (2) at the system level, students will be able to identify and use current technology practiced in monitoring and control systems; (3) at the network level, students will be able to (a) understand fundamental concepts of WSN, and (b) design and develop such a system; and (4) at the capstone/project level, students will be able to demonstrate their capability to design, develop, implement, and test a networked data acquisition system to monitor and control a physical system based on customer requirements collected.

At the **component** level, learning modules and related hands-on experiments were developed from a system design perspective to provide an opportunity for students to learn how to select the appropriate sensors to monitor the physical phenomenon and how to design necessary analog and digital signal conditioning circuits to connect them to micro-controller/computers. The **system** level learning modules were designed to help students familiarize themselves with current technology used in monitoring and control such as integrated sensor boards, commercial-off-the-shelf (COTS) general purpose DAQ hardware and software development environment.

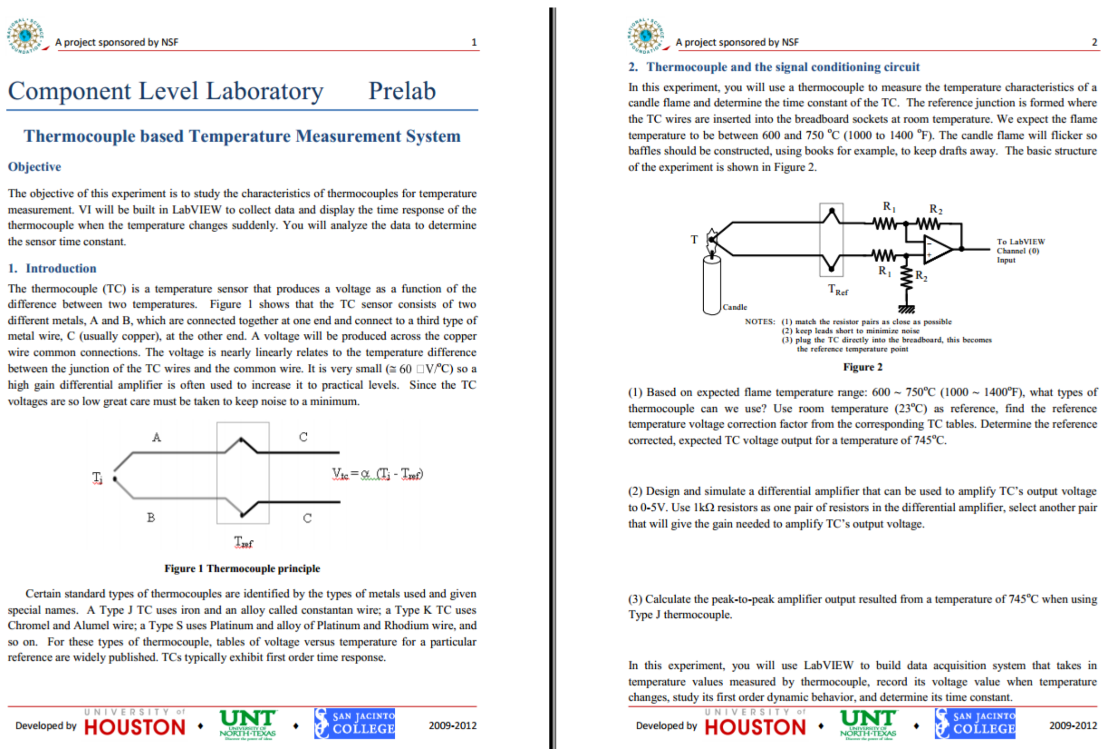
At the **network** level, six hands-on experiments were developed to teach fundamentals of WSN with emphasis on the research-oriented TinyOS-based open platform. After students successfully complete these learning modules, they are entrusted to develop a WSN for a real world application. Three such systems were developed to illustrate the design process of such a system and to assist students' efforts in their capstone projects. All of the manuals for the hands-on experiments can be accessed from project website [1].

In the next section, we will describe the component and system level learning modules; Section 3 will detail the network level learning modules, while Section 4 focuses on capstone projects. Section 5 discusses assessment results collected from the courses we offered. Finally, Section 6 concludes the paper and provides some insight towards future direction of improving STEM education.

Component and System Level Learning Modules

Component level learning modules include two parts: (1) analog and digital signal conditioning and (2) sensors. The analog and digital signal conditioning module serves as the bridge for students to reflect on what they have learned in courses such as analog circuits and digital logic and apply the relevant concepts to signal conditioning, with a focus on **op**erational **amp**lification (OpAmp) and digital signal conditioning circuits such as analog-to-digital-converters (ADC) and digital-to-analog-converters (DAC). The five hands-on experiments developed for this module include: RC circuits frequency response and Multisim workbench (a circuit design and simulation tool from National Instruments (NI) [2]); analog power source and regulation circuits; basic OpAmp circuits; OpAmp signal conditioning circuits and linearization; and implementing comparators in pSoCs (programmable system-on-a-chip).

A set of multi-media lecture notes and three hands-on experiments were developed to facilitate students' learning of various sensing technologies to measure temperature/thermal, mechanical (motion/force/pressure/flow), and optical phenomenon. The three hands-on experiments developed in this module include: (1) thermistor and first order time response; (2) DAQ design for thermocouples; (3) and strain gauges and load cell. Through these experiments, students are expected to verify the static and dynamic behavior of the sensors they learned in theory and connect sensors' performance with their respective specification sheet. Figure 1 shows a sample of the component level thermal sensor experiment pre-lab manual developed for thermocouples. The full manual can be accessed from the website of the project [3].



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Component Level Laboratory Prelab

Thermocouple based Temperature Measurement System

Objective

The objective of this experiment is to study the characteristics of thermocouples for temperature measurement. VI will be built in LabVIEW to collect data and display the time response of the thermocouple when the temperature changes suddenly. You will analyze the data to determine the sensor time constant.

1. Introduction

The thermocouple (TC) is a temperature sensor that produces a voltage as a function of the difference between two temperatures. Figure 1 shows that the TC sensor consists of two different metals, A and B, which are connected together at one end and connect to a third type of metal wire, C (usually copper), at the other end. A voltage will be produced across the copper wire common connections. The voltage is nearly linearly relates to the temperature difference between the junction of the TC wires and the common wire. It is very small (≅ 60 □V/°C) so a high gain differential amplifier is often used to increase it to practical levels. Since the TC voltages are so low great care must be taken to keep noise to a minimum.

Figure 1 Thermocouple principle

Certain standard types of thermocouples are identified by the types of metals used and given special names. A Type J TC uses iron and an alloy called constantan wire; a Type K TC uses Chromel and Alumel wire; a Type S uses Platinum and alloy of Platinum and Rhodium wire, and so on. For these types of thermocouple, tables of voltage versus temperature for a particular reference are widely published. TCs typically exhibit first order time response.

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2. Thermocouple and the signal conditioning circuit

In this experiment, you will use a thermocouple to measure the temperature characteristics of a candle flame and determine the time constant of the TC. The reference junction is formed where the TC wires are inserted into the breadboard sockets at room temperature. We expect the flame temperature to be between 600 and 750 °C (1000 to 1400 °F). The candle flame will flicker so baffles should be constructed, using books for example, to keep drafts away. The basic structure of the experiment is shown in Figure 2.

Figure 2

(1) Based on expected flame temperature range: 600 ~ 750°C (1000 ~ 1400°F), what types of thermocouple can we use? Use room temperature (23°C) as reference, find the reference temperature voltage correction factor from the corresponding TC tables. Determine the reference corrected, expected TC voltage output for a temperature of 745°C.

(2) Design and simulate a differential amplifier that can be used to amplify TC's output voltage to 0-5V. Use 1kΩ resistors as one pair of resistors in the differential amplifier, select another pair that will give the gain needed to amplify TC's output voltage.

(3) Calculate the peak-to-peak amplifier output resulted from a temperature of 745°C when using Type J thermocouple.

In this experiment, you will use LabVIEW to build data acquisition system that takes in temperature values measured by thermocouple, record its voltage value when temperature changes, study its first order dynamic behavior, and determine its time constant.

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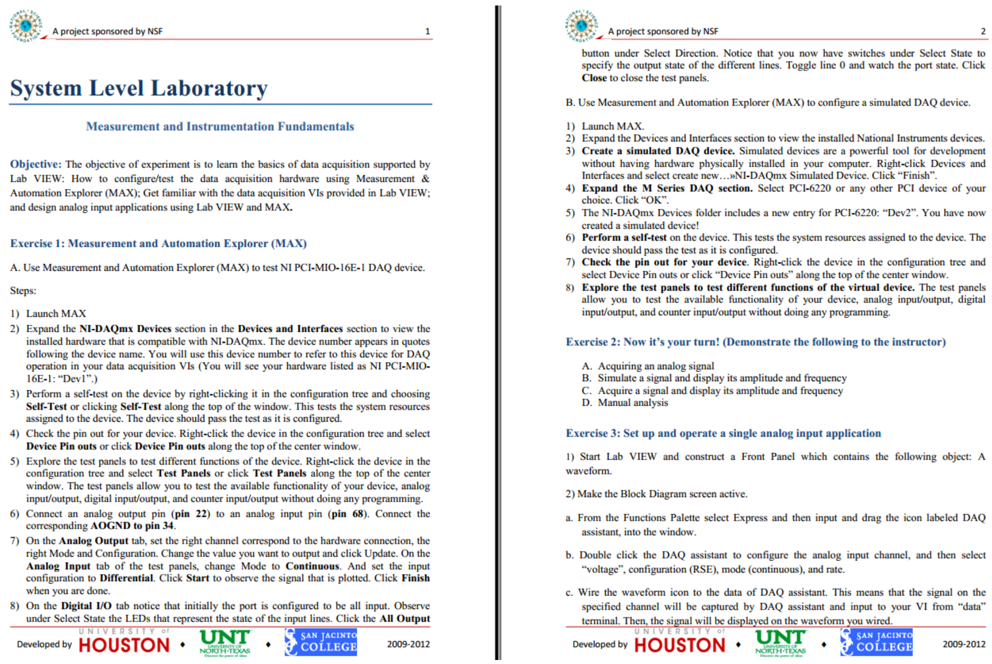
Figure 1 Component Level Experiment: Thermocouple Pre-lab



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System Level Laboratory

Measurement and Instrumentation Fundamentals

Objective: The objective of experiment is to learn the basics of data acquisition supported by Lab VIEW: How to configure/test the data acquisition hardware using Measurement & Automation Explorer (MAX); Get familiar with the data acquisition VIs provided in Lab VIEW; and design analog input applications using Lab VIEW and MAX.

Exercise 1: Measurement and Automation Explorer (MAX)

A. Use Measurement and Automation Explorer (MAX) to test NI PCI-MIO-16E-1 DAQ device.

Steps:

1) Launch MAX
2) Expand the **NI-DAQmx Devices** section in the **Devices and Interfaces** section to view the installed hardware that is compatible with NI-DAQmx. The device number appears in quotes following the device name. You will use this device number to refer to this device for DAQ operation in your data acquisition VIs (You will see your hardware listed as NI PCI-MIO-16E-1: "Dev1".)
3) Perform a self-test on the device by right-clicking it in the configuration tree and choosing **Self-Test** or clicking **Self-Test** along the top of the window. This tests the system resources assigned to the device. The device should pass the test as it is configured.
4) Check the pin out for your device. Right-click the device in the configuration tree and select **Device Pin outs** or click **Device Pin outs** along the top of the center window.
5) Explore the test panels to test different functions of the device. Right-click the device in the configuration tree and select **Test Panels** or click **Test Panels** along the top of the center window. The test panels allow you to test the available functionality of your device, analog input/output, digital input/output, and counter input/output without doing any programming.
6) Connect an analog output pin (**pin 22**) to an analog input pin (**pin 68**). Connect the corresponding **AOGND to pin 34**.
7) On the **Analog Output** tab, set the right channel correspond to the hardware connection, the right Mode and Configuration. Change the value you want to output and click Update. On the **Analog Input** tab of the test panels, change Mode to **Continuous**. And set the input configuration to **Differential**. Click **Start** to observe the signal that is plotted. Click **Finish** when you are done.
8) On the **Digital I/O** tab notice that initially the port is configured to be all input. Observe under Select State the LEDs that represent the state of the input lines. Click the **All Output**

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button under Select Direction. Notice that you now have switches under Select State to specify the output state of the different lines. Toggle line 0 and watch the port state. Click **Close** to close the test panels.

B. Use Measurement and Automation Explorer (MAX) to configure a simulated DAQ device.

1) Launch MAX.
2) Expand the Devices and Interfaces section to view the installed National Instruments devices.
3) **Create a simulated DAQ device.** Simulated devices are a powerful tool for development without having hardware physically installed in your computer. Right-click Devices and Interfaces and select create new…»NI-DAQmx Simulated Device. Click "Finish".
4) **Expand the M Series DAQ section.** Select PCI-6220 or any other PCI device of your choice. Click "OK".
5) The NI-DAQmx Devices folder includes a new entry for PCI-6220: "Dev2". You have now created a simulated device!
6) **Perform a self-test** on the device. This tests the system resources assigned to the device. The device should pass the test as it is configured.
7) **Check the pin out for your device**. Right-click the device in the configuration tree and select Device Pin outs or click "Device Pin outs" along the top of the center window.
8) **Explore the test panels to test different functions of the virtual device.** The test panels allow you to test the available functionality of your device, analog input/output, digital input/output, and counter input/output without doing any programming.

Exercise 2: Now it's your turn! (Demonstrate the following to the instructor)

A. Acquiring an analog signal
B. Simulate a signal and display its amplitude and frequency
C. Acquire a signal and display its amplitude and frequency
D. Manual analysis

Exercise 3: Set up and operate a single analog input application

1) Start Lab VIEW and construct a Front Panel which contains the following object: A waveform.

2) Make the Block Diagram screen active.

a. From the Functions Palette select Express and then input and drag the icon labeled DAQ assistant, into the window.

b. Double click the DAQ assistant to configure the analog input channel, and then select "voltage", configuration (RSE), mode (continuous), and rate.

c. Wire the waveform icon to the data of DAQ assistant. This means that the signal on the specified channel will be captured by DAQ assistant and input to your VI from "data" terminal. Then, the signal will be displayed on the waveform you wired.

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Figure 2 System Level Experiment: Measurement and Instrumentation Fundamentals

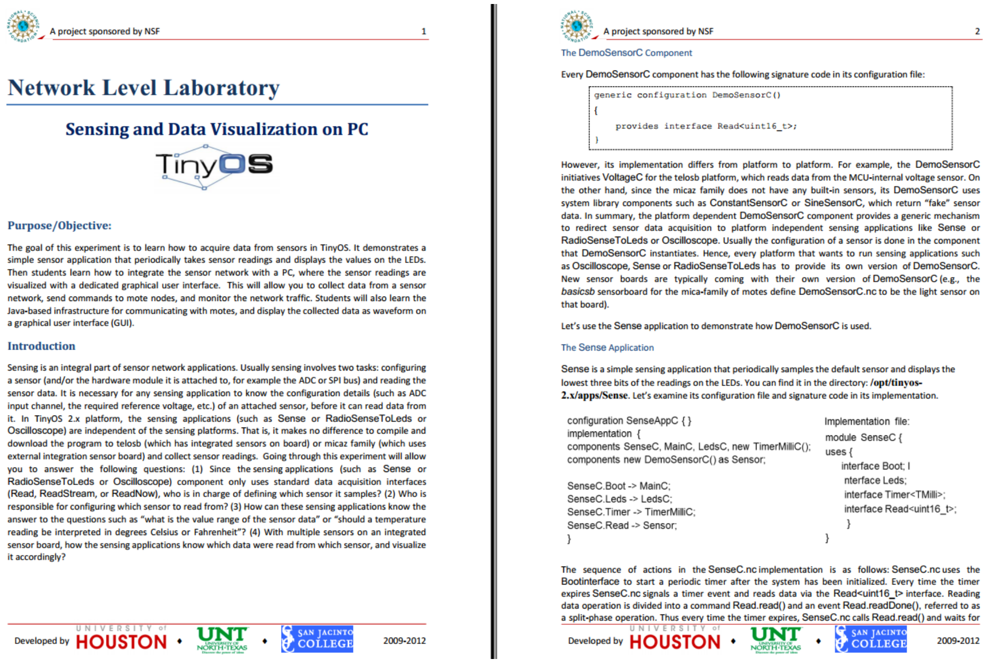
Five hands-on experiments were developed at the system level in addition to the multi-media lecture notes and learning material to provide students with experience in selecting proper DAQ systems and sensor integration boards or developing the necessary interfaces (when none is available) to incorporate new sensors into existing system architecture (using FGPA or pSoC). The five hands-on experiments enable students to gain experience on utilizing generic DAQ hardware from a system design perspective. The first two experiments introduce DAQ hardware and software development environment from NI: (1) developing virtual instrumentation (VI) in LabVIEW, and (2) its measurement configuration package: MAX (Measurement & Automation Explorer). Figure 2 shows a sample of the lab manual developed at the system level for measurement and instrumentation fundamentals. The full manual can be accessed from the website of the project [4]. The remaining three modules introduce basic concepts on (1) Programmable System-on-Chip (pSoC); (2) how to design ADC/DAC using pSoC creator [5]; and (3) how to implement LCD display control using pSoC.

After students complete the component and system level learning modules, they should to be able to design, implement, and demonstrate a data acquisition system for a real world application by selecting the proper sensing components and designing and implementing necessary analog and digital conditioning circuits.

Network Level Learning Modules

At the network level, two modules were developed. The "Introduction to Computer and Sensor Networks" module includes a set of lecture notes covering networking components, architecture, topology, and functions of different protocol layers (including video clips showing the switches and routers used in network infrastructure) and how they are configured. In addition to a set of multi-media lecture notes, the "Fundamentals of WSN" module includes six hands-on experiments that teach basic WSN hardware and software platforms [6,7]. They are: (1) WSN structure and architecture [8,9]; (2) WSN programming (TinyOS-based NesC programming [10,11]; (3) LabVIEW based graphical programming [12,13]); (4) network topology; (5)

protocol configuration [14-22]; and some (6) practical considerations [21-31]. Figure 3 shows a sample experiment developed at the networking level for WSN based sensing and data visualization on PC. The full manual can be accessed from the website of the project [32]. The set of NI WSN nodes bridges the gap between traditional DAQ and advances in WSN by allowing integration of DAQ design, data logging, visualization, and control in their graphical programming data-flow based application development environment, LabVIEW.



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Network Level Laboratory

Sensing and Data Visualization on PC

TinyOS

Purpose/Objective:

The goal of this experiment is to learn how to acquire data from sensors in TinyOS. It demonstrates a simple sensor application that periodically takes sensor readings and displays the values on the LEDs. Then students learn how to integrate the sensor network with a PC, where the sensor readings are visualized with a dedicated graphical user interface. This will allow you to collect data from a sensor network, send commands to mote nodes, and monitor the network traffic. Students will also learn the Java-based infrastructure for communicating with motes, and display the collected data as waveform on a graphical user interface (GUI).

Introduction

Sensing is an integral part of sensor network applications. Usually sensing involves two tasks: configuring a sensor (and/or the hardware module it is attached to, for example the ADC or SPI bus) and reading the sensor data. It is necessary for any sensing application to know the configuration details (such as ADC input channel, the required reference voltage, etc.) of an attached sensor, before it can read data from it. In TinyOS 2.x platform, the sensing applications (such as Sense or RadioSenseToLeds or Oscilloscope) are independent of the sensing platforms. That is, it makes no difference to compile and download the program to telosb (which has integrated sensors on board) or micaz family (which uses external integration sensor board) and collect sensor readings. Going through this experiment will allow you to answer the following questions: (1) Since the sensing applications (such as Sense or RadioSenseToLeds or Oscilloscope) component only uses standard data acquisition interfaces (Read, ReadStream, or ReadNow), who is in charge of defining which sensor it samples? (2) Who is responsible for configuring which sensor to read from? (3) How can these sensing applications know the answer to the questions such as "what is the value range of the sensor data" or "should a temperature reading be interpreted in degrees Celsius or Fahrenheit"? (4) With multiple sensors on an integrated sensor board, how the sensing applications know which data were read from which sensor, and visualize it accordingly?

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The DemoSensorC Component

Every DemoSensorC component has the following signature code in its configuration file:

```
generic configuration DemoSensorC()
{
    provides interface Read<uint16_t>;
}
```

However, its implementation differs from platform to platform. For example, the DemoSensorC initiatives VoltageC for the telosb platform, which reads data from the MCU-internal voltage sensor. On the other hand, since the micaz family does not have any built-in sensors, its DemoSensorC uses system library components such as ConstantSensorC or SineSensorC, which return "fake" sensor data. In summary, the platform dependent DemoSensorC component provides a generic mechanism to redirect sensor data acquisition to platform independent sensing applications like Sense or RadioSenseToLeds or Oscilloscope. Usually the configuration of a sensor is done in the component that DemoSensorC instantiates. Hence, every platform that wants to run sensing applications such as Oscilloscope, Sense or RadioSenseToLeds has to provide its own version of DemoSensorC. New sensor boards are typically coming with their own version of DemoSensorC (e.g., the *basicsb* sensorboard for the mica-family of motes define DemoSensorC.nc to be the light sensor on that board).

Let's use the Sense application to demonstrate how DemoSensorC is used.

The Sense Application

Sense is a simple sensing application that periodically samples the default sensor and displays the lowest three bits of the readings on the LEDs. You can find it in the directory: **/opt/tinyos-2.x/apps/Sense**. Let's examine its configuration file and signature code in its implementation.

```
configuration SenseAppC { }
implementation {
components SenseC, MainC, LedsC, new TimerMilliC();
components new DemoSensorC() as Sensor;

SenseC.Boot -> MainC;
SenseC.Leds -> LedsC;
SenseC.Timer -> TimerMilliC;
SenseC.Read -> Sensor;
}
```

Implementation file:

```
module SenseC {
uses {
    interface Boot; I
     nterface Leds;
     interface Timer<TMilli>;
     interface Read<uint16_t>;
      }
}
```

The sequence of actions in the SenseC.nc implementation is as follows: SenseC.nc uses the Bootinterface to start a periodic timer after the system has been initialized. Every time the timer expires SenseC.nc signals a timer event and reads data via the Read<uint16_t> interface. Reading data operation is divided into a command Read.read() and an event Read.readDone(), referred to as a split-phase operation. Thus every time the timer expires, SenseC.nc calls Read.read() and waits for

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Figure 3 Network Level Experiment: WSN Sensing and Data Visualization

Capstone Design Projects

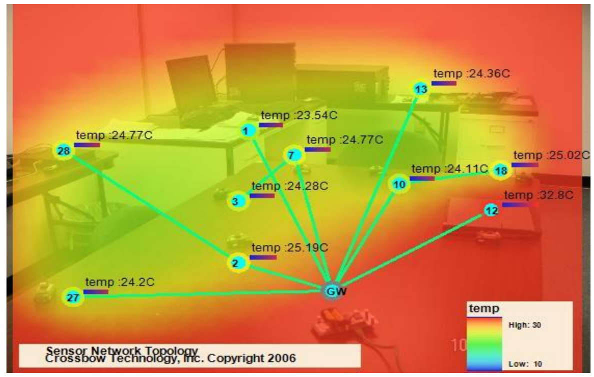
Three project-oriented WSN systems were developed for real world applications: (1) in-door environment monitoring, (2) smart vibration platform monitoring [33], and (3) smart home environment monitoring and control [34]. Note that the smart home project integrated control with monitoring, results in a wireless sensor and actuator network (WSAN). Any of these capstone projects can be used to demonstrate the design process of a WSN-based networked DAQ system, while the remaining ones can be assigned as possible course project topics for students. Figure 4 shows the finished system setups for these capstone projects.

In summary, six project-based hands-on learning modules were developed, covering the design, development, implementation, and operation aspects of a networked data acquisition (DAQ) system for a real-world system monitoring and control. Students completing these modules should be able to design, implement, and deploy a complete networked measurement system solution for any real-world application.

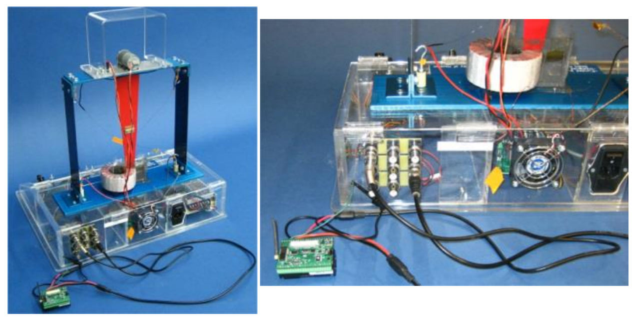
Project Evaluation and Assessment Results

Because of their modular nature, instructors can select any one or a combination of hands-on experiments from different levels (component, system, and network) and integrate them into their courses as experiments, course projects, or demonstrations. For example, any number of hands-on experiments in the analog and digital signal conditioning learning module can be adopted as a course project towards the end of the semester in freshman and sophomore courses such as Analog Circuit, Digital Logic, and Communication Circuits. Learning modules on sensing components and hands-on experiments at the system level for measurement and instrumentation can be incorporated into junior and senior level measurement and instrumentation courses across Engineering and Technology programs. The learning module on wireless sensor networks (WSN) and its associated hands-on experiments focus on the network level and require basic networking knowledge and programming skills. The module can be incorporated into senior level courses such as System Design, Senior Project (capstone course), or senior elective courses on computer network.

All the learning modules developed have been tested in undergraduate courses in computer E&T, mechanical engineering, and computer science programs (at the community college level) with many of them being adopted as regular course material. Table 1 summarizes the courses for which the learning modules were offered and the number of students registered in those courses. The total number of undergraduate students benefiting from the learning modules up to Spring 2012 is 479, among which 270 students in four courses (10 classes) participated in the anonymous and voluntary surveys. Figure 5 shows a sample of students participating in capstone project demonstrations, implementing and demonstrating their experiments and projects using the learning modules developed.



(a) Indoor environment monitoring system;



(b) Smart vibration structure monitoring;

(c) Smart home environment monitoring and control

Figure 4: WSN Capstone Projects – System Setup

Since Spring 2010, ten hands-on experiments selected from learning modules at the component and system levels have been offered and tested in a junior level computer E&T course, Sensors and Applications (ELET3403). The course was designed to introduce measurement and instrumentation concepts to students after they learned about electric circuits, digital logic, and micro-processor architecture. It is offered every semester with an average of 20 students enrolled. These modules successfully improved students' learning outcome and enhanced their critical thinking skills. Towards the end of the course, all students were able to apply the knowledge they learned in the Computer Engineering Technology (CET) program to design a functional data acquisition system for a real world application. Because of their success, these learning modules have been adopted as regular course material (i.e., institutionalized) in the CET program.

Table 1 Integrating WSN learning modules into Undergraduate Courses

Univ. of Houston		San Jacinto		Univ. of North Texas	
Courses	**Enr.**	**Courses**	**Enr.**	**Courses**	**Enr.**
Sensors and Application	6 x 20	Fundamentals of Networking Technology	20	Embedded system design	30
Intro to Mech. Engr.	84	Intro to Computer Systems	26		
Intelligent Structure Systems	43	Advanced hardware	11	Computer engineering design	30
		Programming fundamentals	22		
Into to Cyber Physical System	23	computer architecture and programming	20	Wireless networks and protocols	30
		Convergence technology	20		

Figure 5 Active Student Participation in Demonstrations and Experiments.

Learning modules at the network level have been offered in a new senior elective course in Spring 2012 in the CET program, with emphasis on WSN system design. Figure 6 shows the survey results from students in the senior elective course regarding the effectiveness of these modules and hands-on experiments in facilitating their learning of the WSN and nurturing their system-level critical thinking skills.

Students in the course were generally positive about the impact of the modules, particularly regarding the hands-on experiments. This aligns with our original goal, since hands-on experiences are designed to be more engaging for students. The same logic applies to the results of the question related to the degree of exposure to practical aspects of WSN since practical application is the focus of the modules. A majority of students felt that their critical thinking skills were improved by participating in the learning modules. Again, this sentiment is consistent with the goals of the modules which, in many cases, ask students to evaluate the usefulness of particular components in a specific situation.

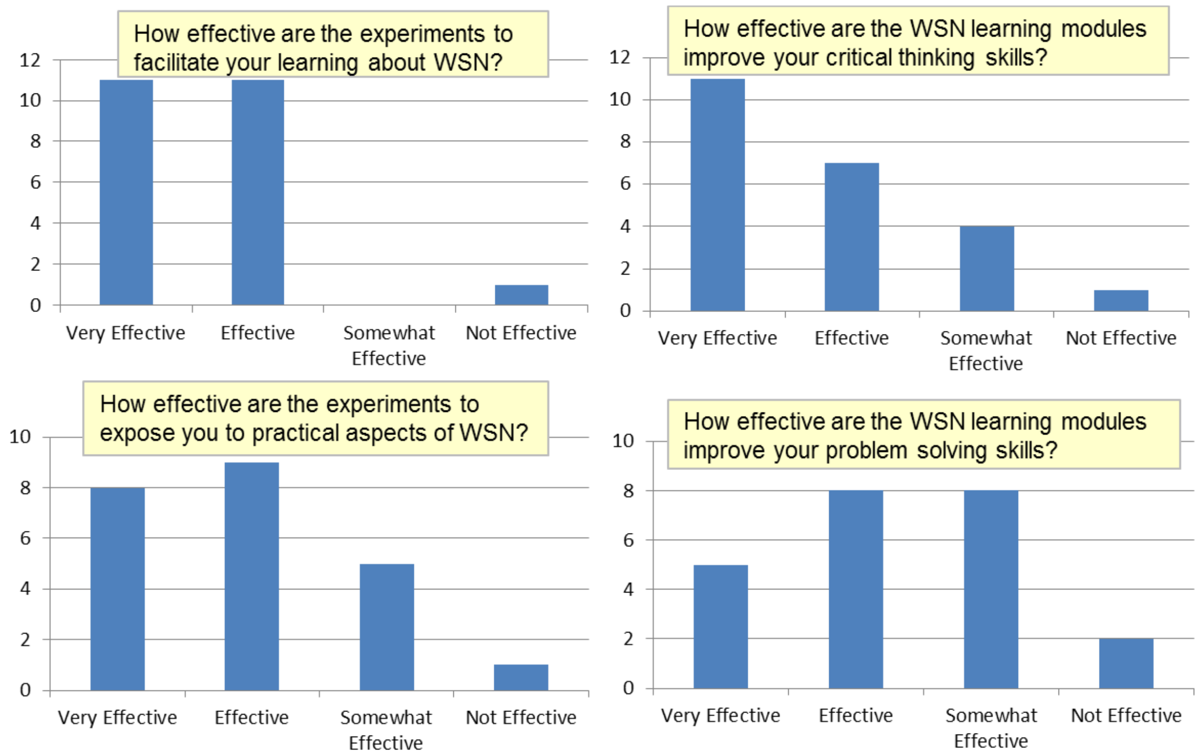


Figure 6 Senior Level Design Course Survey Results Regarding the Network Level Wireless Sensor Networks Learning Module

In addition, demonstrations on WSN-based monitoring and control systems have been offered in courses of Mechanical Engineering and Computer Science and Engineering programs at the university. Figure 7 shows a sample of survey results from a freshman course "Introduction to Mechanical Engineering" after the demonstration of wireless data aggregation on a smart vibration platform. Again, the effectiveness of these learning modules in facilitating students' learning of WSN concept and application is confirmed. As with the senior level course, the majority of students indicate that the experiment is an effective tool for learning about concepts. Indeed, students' responses suggested that they welcome more demonstrations of emerging technology.

Although student attitude surveys are only indirect measures of module effectiveness, these small indicators suggest that an approach focused on active demonstration and hands-on learning is worthwhile. At the senior level courses, students' mastery of the concepts is demonstrated by the final project they completed in a team. Instructors and teaching assistants provided guidance and assistance when students struggled with applying the theory and concepts they learned towards solving problems encountered when putting together their final project. Traditional forms of assessment such as quizzes, tests, mini-research papers, and discussions are used to identify and provide feedback and guidance on difficult theories and concepts students struggle to master. In addition, instructors all agreed that students are very much engaged in the technical content taught in the class as well as participating in discussion out-of-class. As the project takes root, further efforts will be made to systematically document student performance to evaluate the effectiveness of these modules on learning.

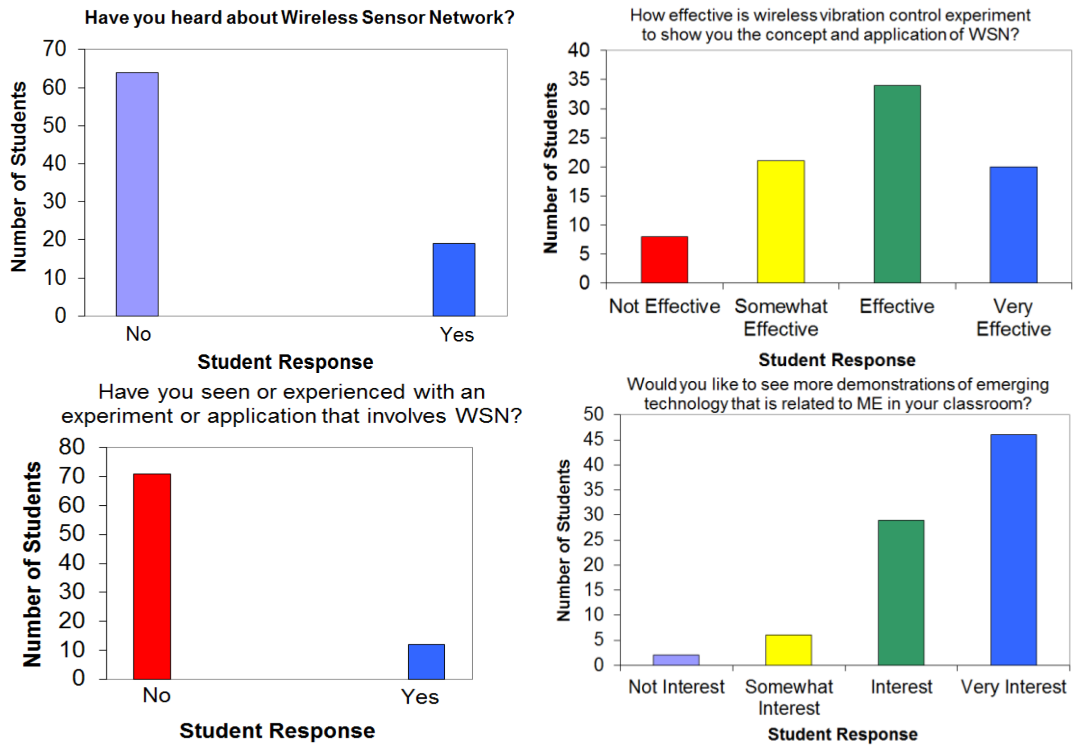


Figure 7 Similar Survey Results from the Freshman Level "Introduction to Mechanical Engineering" Course

Conclusion

This paper presented details of our design of a set of system-thinking oriented learning modules to facilitate undergraduate students learning about measurement and instrumentation, especially regarding recent advances in networked data acquisition systems. The six learning modules with twenty-two hands-on experiments developed for the networked measurement systems cover a wide range of topics. After completing these learning modules, students should be able to design, develop, implement and deploy a complete networked measurement system solution for a real-world system. Throughout the testing of these learning modules since 2010, instructors and teaching assistants were consistently gathering and providing feedback from and to students on how the modules can be improved to the developers. The evaluation results, including survey from students, confirm the flexibility and effectiveness of these learning modules to infuse recent advances in WSN in undergraduate measurement and instrumentation courses of engineering and technology (E&T) curricular.

Implementation of the modules is ongoing. Small successes have been documented in terms of student responses to the effectiveness of the modules. Further evaluation of student performance will allow for more concrete statements regarding whether students have made gains in learning about WSN concepts and skills. During the project, tremendous effort from the instructor and teaching assistances is required. However, as the project takes root, we are confident that instructors using the developed module will need to exert comparable effort when preparing for a new course. The modular nature of the learning modules makes it possible to incorporate one at a time to make the process manageable.

We hope to form and grow a community of educators and researchers who are interested in transforming undergraduate engineering education using the versatile WSN as platform. The modules can be used to assist in teaching difficult concepts from numerous courses that range from freshman to senior level across E&T programs. As pointed out by Pellegrino [35], we are not expecting that one particular course will use all the learning modules. Rather, each course should focus on its own difficult concepts and how to select the proper learning module that can facilitate students' learning to facilitate their deep understanding of the technical content. By engaging students in the learning process, we hope to inspire them to continue developing their expertise in the networked DAQ area both during their higher education years and after they start their professional career.

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