

AC 2007-1477: INTEGRATING RECENT ADVANCES IN SENSOR NETWORK INTO UNDERGRADUATE CURRICULUM VIA HYBRID DELIVERIES OF LECTURE AND LABORATORY

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Integrating Recent Advances in Sensor Network into Undergraduate Curriculum via Hybrid Deliveries of Lecture and Laboratory

Abstract

The current human resources development has been marked by learning new and improved methods to develop, implement and operate new and complex equipment of our times. To meet those changing technological needs, the Engineering Technology Department at the University of Houston is expanding the Intelligent Sensor GRid and INformatics (ISGRIN) Research Lab to integrate modern sensors, sensor networks and their applications in courses and laboratories for its undergraduate students. In this paper, we present the results of the curriculum development; including course setup, lecture and laboratory design, and research result in hybrid delivery methods of the lecture and laboratory, as well as student assessment design and preliminary feedback from voluntary student group.

I. Introduction

The current and future evolutionary growth of sensor networks and applications is due to their capability to integrate wireless communication, processing and sensing technologies. An important part of the sensor networks and applications is the ability of “intelligent” sensors to gather an extensive data, use algorithms to process and interpret data and to finally present information for decision. The other important part is that as sensors become cheaper and cheaper, it becomes possible to add them in various instrumentation and process control systems that are currently too expensive. This in turn requires a new curriculum for technical expertise at all levels to develop, install, operate as well as maintain the individual sensor nodes as well as the network system as a whole.

To support the development of the new curriculum, members of the faculty in the engineering technology department are currently working on new curriculum development plan for modern instrumentation systems and sensor networks. The overarching goal of the inter-disciplinary curriculum development of the instrumentation systems and sensor networks is to provide (i) broad overview to detailed design and development knowledge and (ii) hands-on experience for junior and senior students from five programs: Computer Engineering (Technology), Electrical Power Systems (Technology), Mechanical, Manufacturing (Technology), and Civil Engineering (Technology).

The development of this new course on modern instrumentation systems and sensor networks focuses on topics such as circuits, sensors and measurements. With the rapid development of distributed control and control system networks, the need for modern computer based controllers becomes inevitable. Hence, this new curriculum development will incorporate some of the major

changes in the way instrumentation and measurement systems are implemented. Modern instrumentation systems require the use of the wide spread internet based resources as shown in figure 1. From just the perspective of instrumentation lab delivery, a student from a remote location will be able to access measurement and control instrumentation located in the physical lab without any travel. Moreover this will give the student an opportunity to repeat the experiments as many times as they wish in order to be able to operate the measurement and instrumentation equipment. Research in [1, 2] shows that remote measurement systems have been realized using the internet as a communication tool with a minimum bandwidth and cost.

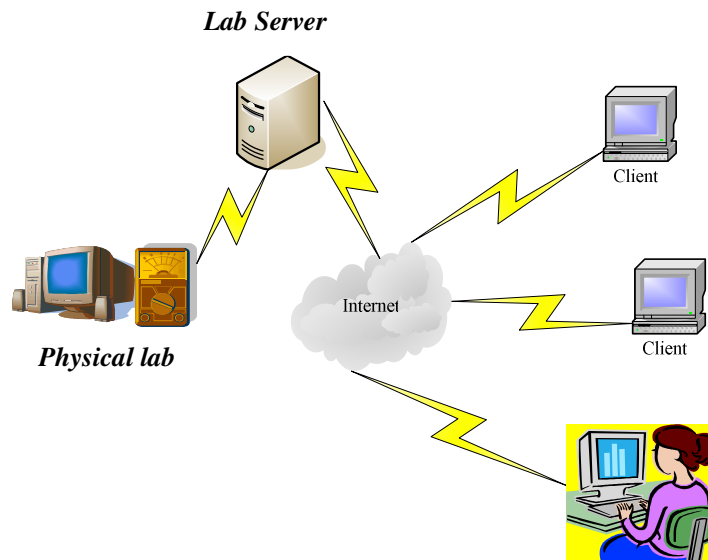


Figure 1 Lab resources sharing using the internet

In [3] it is shown that students can do simulations of the actual experiments either on the student's PC or from remotely located PCs. In terms of remote teaching, institutions use web support to post their courses including the lecture notes, assignments as well as any administrative announcements [4, 5].

The authors researched about current curriculum and course offering from various websites of universities with instrumentation and / or sensor network courses offered to find whether they are incorporating advances in sensor network into the sensor and instrumentation curriculum. The finding was not encouraging. Specifically, it is rather rare to see remotely accessible sensor/instrumentation labs, where students have the opportunity to access the actual lab from their locations. Since the new advances in sensor network mostly occurred in networking and communication community, most of the sensor network (including wireless sensor network) courses are offered as elective for students majoring in networking and communication, typically at graduate level. The lab experiments are designed based on the assumption that students had previous knowledge about fundamentals of communication and networking, and focusing on characterizing networking behavior of different protocols, communication mechanism, etc.

On the other hand, the traditional instrumentation and sensor courses are continuing focusing on physical fundamentals of various sensing elements and the signal conditioning circuits to digitize and conditioning analog input. They have a very limited coverage of integrated MEMS sensors typically used in general purpose sensor network research and application. As the result, students interested in instrumentation are not exposed to the most up-to-date technology since most of the courses are offered at other departments, if not different colleges.

The remainder of this paper is organized as follows. The next section will present the general course setup for the instrumentation systems and sensor networks. The third section will present details of the necessary lab equipment and software for hybrid delivery systems. The detailed laboratory design including a sample case study is presented in the fourth section. Preliminary assessment results are presented in the fifth section. Conclusion and future works is presented finally.

II. Curriculum Development for Integrated Instrumentation Program

The Engineering Technology department offered ELET 3304: control and instrumentation course as elective for senior students in both power and computer engineering technology programs for a year. At the junior level, students in the computer engineering technology program are required to take a prerequisite course on ELET 3303: OpAmp circuits and applications. Students in the power engineering technology are not required to take the OpAmp course.

There exists obvious overlap between the two courses in that the signal conditioning section in the control and instrumentation course focuses on various OpAmp circuits too. Similar overlap exists in the laboratory experiments. Noticing this, the faculty teaching the control and instrumentation did a survey among students enrolled in the course. The survey asked students whether or not the OpAmp topics should be covered in the course, and a set of questions about OpAmp signal conditioning circuits assessing students' knowledge about the topic.

We summarize our observations that trigger the course renovation below:

- (1) Students from power engineering technology program do not have background in OpAmp and need coverage of the topic in the course.
- (2) Students from computer engineering technology program that have taken the OpAmp course before feel it is necessary to have a brief refreshing section for basic OpAmp signal conditioning circuits.
- (3) Students from computer engineering technology program that were enrolled in both courses concurrently feel that even though there are overlapping contents in both courses, since they can apply the knowledge learned from the OpAmp course to sensor signal conditioning part in the control and instrumentation course, it not only helps them understands the circuits, but also pushes them to use the concepts; making the concepts their own knowledge.
- (4) When discussing the survey results with the students, students that have taken OpAmp course previously (sometimes one- or two- years ago, because of the non-traditional student population in the department) agreed that if they had the chance to apply the OpAmp concepts to real problem, they would be able to retain the knowledge.

Besides the above results from students' assessment, we also casually talked with industry advisory board members as well as representatives from companies attending college's career fair and hiring our graduates. Even though different companies have different requirements for their employee, they all expressed the necessity and urgency of introducing engineering concepts and knowledge not only at component level, but more importantly at system level. Companies that are end users of sensor and data acquisition systems, such as those from oil and energy industry, aerospace industry, and medical and service industry, want to see their new hiring know more on how to use and maintain the system instead of details such as sensing characteristics and physical mechanism. Companies that are developing such systems also want to see their new hiring be able to work in the most up-to-date development environment such as Labview and for sensor network, TinyOS; and able to design a DAQ system from system perspective.

These findings triggered discussion among faculties in the power and computer engineering technology programs to develop more courses in instrumentation and data acquisition systems. The first step is to combine the OpAmp and Control Instrumentation courses and make it a required course for junior students from both programs.

The members of the faculty also brainstormed about the course setup in such a program and agree that courses should cover fundamentals of both instrumentation and networking. The topics that should be covered in such a program include but not limited to the following: basics and fundamentals of sensors and measurement (currently offered as ELET3403 Sensors and Applications course), Computer Networks, Networking protocols and programming, manufacturing systems control, principles of mechatronics; and sensor network applications. Sensor network applications will be a capstone course that is project-oriented. Students with backgrounds in EE, CS, ME, etc., can choose the course as elective to build a sensor-network based real-world application. All courses in the curriculum will have integrated laboratory experiments developed using popular data acquisition and simulation platforms, such as Labview, Matlab/Simulink and sensor network platform such as TinyOS and Java. The laboratory materials and experiments specifically emphasize the integration between simulation, remote-accessible experiments and face to face interaction.

III. Hybrid Course Delivery

Nowadays, the internet and World Wide Web present exciting new possibilities for delivering instructional materials to remote students in a virtual class room while simultaneously leading traditional class room/lab training at on site facility. Research in [6] has shown that students participating in a hybrid instructional delivery system performed at a significantly higher level than students participating in just traditional face to face instruction delivery. With the merger of the two most popular e-learning platforms, Blackboard and WebCT in Feb. 2006, instructors and trainers can expect excellent features from both products to be integrated. We have researched about various e-learning platforms including Desire2Learn[7], Edumate[8], Moodle[9], and OLAT[10], in addition to Blackboard [11] and WebCT [12]. We choose to use WebCT in our hybrid course delivery because it provides the best features among these e-learning platforms, is being integrated with Blackboard, and has been supported by the University of Houston for a

long time. With merger with Blackboard, we are expecting WebCT to adopt more functions that will balance the flexibility and ease of use as well as accessibility to student with disability. The basic features of WebCT that we are using in the course delivery include:

- Email system and contact list for the course;
- Discussion board and live chat;
- Content posting service such as posting documents and webpages;
- Course management functions such as announcement and grade book; and
- Interactive quiz capability.

We are also exploring school-centric instant messaging and voice chat tool from Horizon Wimba [13] that integrates with webCT's live chat capability as well as various live video streaming and podcast technologies to bring the lecture contents to students "wherever, whenever".

The lecture modules and laboratory experiments are designed with hybrid delivery in mind. In essence, we not only post lecture notes and laboratory manuals onto WebCT. Instead, an array of complementary contents such as manufacturing lists and their websites for sensor and data acquisition systems (as shown in Table I), Wikipedia for the instrumentation and measurement, professional organizations' events announcements, and other relevant information are shared with students through webCT in a timely manner. Students also learn about build-in information technology skills by participating in the hybrid instruction delivery.

Currently, the department is offering a full year course ELET 3403: Sensors and Applications for junior undergraduate CET major students. The main focus of the course is to introduce students to fundamentals of sensor technology and its applications. The course covers Op-Amp and signal conditioning circuits, modern sensors, ADC/DAC, AC/DC, and interfaces between these components. In this case WebCT is highly used in supporting the delivery of the course as well as the corresponding lab. Some of the features the WebCT include the posting of student copy lecture notes, posting of individual grades, posting of announcements, use of *Turnitin* assignments, voice board and voice direct. It also includes student WebCT use tracking as well as chat and whiteboard. In addition we are also working with other faculty in ME technology department to develop a new similar course that is tailored specifically to the ME major students.

Using the new approach of hybrid delivery, students will be able to solve measurement and control application challenges. In this case graphical application development environment (e.g., Labview) together with the internet can be used to solve the challenges more quickly and with a greater flexibility. In summary, the hybrid instruction delivery combines face to face and online modules in teaching so that the class/lab has lesser seating time than the traditional schedule would require.

For all these visions to become reality, however, traditional engineering technology lecture and laboratory approaches need plenty of improvement. In the next sections, details in laboratory experiments design are presented to integrated advances in sensor network.

IV. Equipment and Software

To develop the course and laboratory experiments, the authors researched about current available sensor network and smart sensor development kits, their hardware platform and the supporting software development environments; as well as sensors and smart sensor manufactures.

Table I summarizes the results of our research by listing available (smart) sensor and sensor systems of 34 vendors, the general description of the system, and the type of communication it supports.

Table I Available sensor and sensor system vendors

Vendor Name	Description	Communication
AeroComm	Input RS232, ZigBee Compliant Transceivers	ZigBee Compliant
Adalet Wireless	Proprietary Network	Ethernet Access Point, no ZigBee
All Sensors	Specialty in Pressure Sensors	RS232, USB Interface, No TEDS
Apogee Technology Inc.	Wireless Transceivers	Bluetooth Compliant
ARC	Sells Sensors and Instrumentation	
ArchRock	NI User Interface Software, using Crossbows, Nod Platforms, ZigBee	ZigBee Compliant
Atlas	Plug & Play Service	Atlas
Biopac	Data acquisition kits for biomedical applications	Support both wired and wireless communication.
Coronis Systems	Uses proprietary standard, cooperation with Wavenis	
Cronis	Cooperation with Wavenis	Bluetooth Compliant
Crossbow Inc.	General purpose wireless sensor network kits: Mica2 (433 or 868/900MHz ISM band radio frequency communication), MICAz (2.4 GHz ISM band with support for IEEE 802.15.4/ZigBee)	global 433MHz, 868/900MHz, 2.4 GHz ISM band with support for IEEE802.15.4/ZigBee
Ember	Radio Communications Boards, Networking Modules	ZigBee Compliant
Eensors Inc.	IEEE 1451 Compliant	TEDS Compliant
Freescale	RF Transceiver Chips	ZigBee Compliant
Frontline	ZigBee Sniffer	ZigBee Compliant
Helicomm	IP Link Modules, IEEE 8051 based Embedded Networking	ZigBee Compliant
Honeywell	Rugged Sensors	TEDS Compliant
Innovative Wireless Technologies	12 Units (nodes) Gateway Included	Proprietary Network
Jennic	Sensors Included in Kit	ZigBee Compliant
LasCar Electronics	Datalogger USB Memory Stick for Sensors	Miscellaneous
Microstrain	Sensor Intregrable RF Transceiver Chips	ZigBee Compliant
Max Stream	Chip Manufacturer	ZigBee Compliant
Moteiv Inc.	General purpose wireless sensor network kits: Tmote Invent, Tmote Sky	2.4GHz IEEE 802.15.4 ISM with support for IEEE 802.15.4/ZigBee
National Instruments	TEDS Information	TEDS Compliant
Oceana Sensors	Remote Controlling Interface, Software available	Uses Bluetooth to communicate with Industrial Computer

S3C Incorporation	Wireless Network Pressure Sensor, Sensors and Networking at same time	ZigBee Compliant
Smart Sensor Systems	IEEE 1451 Compliant	
Solitica	Chorus Sensor Control Hub	
Talon Inc.	Cooperation with Renesas	ZigBee Compliant
Texas Instruments	Intelligent Instrumentation	Ethernet Compliant
USB ZigBee Dongle	ZigBee Sniffer	ZigBee Compliant
(WINA) Wireless Industrial Networking Alliance	Mission - harmonization of the standards	Wireless Networks
Z-Link	Transceivers	ZigBee Compliant
ZMD	Wireless Kits	ZigBee Compliant

All these systems can be classified into two major categories:

- (1) Data Acquisition and Control Instrumentation Systems: represented by National Instruments and dSpace. They have their own software and hardware platform and can interact with various types of analog and digital sensors. Both companies have strong support team and development team and their products have been adopted in both industry dealing with automation and process control systems and academic researching about mechatronics and robotics systems.
- (2) General purpose sensor network systems: represented by Crossbow © and Moteiv©. Their sensor network systems originate from researches in networking and communication, and use integrated MEMS sensors. They also adopted open development language such as Java and simplified C (NesC).

The control and instrumentation course used Labview and NI PCI6220 DAQ boards from National Instruments for some time. We expand the course to include lecture and laboratory experiments on wireless sensor networks and their applications. In the following section, detailed experiment design and study cases will be presented.

V. Laboratory Design

The design of laboratory experiments and the corresponding manuals involves more than the development of the individual experiments for performing the required activities. It entails designing the interaction among these laboratory modules.

The laboratory is designed to facilitate the logic sequence of students' learning. In specific, experiments are designed to introduce sensor and instrumentation concepts and practical skills at three levels: component level, system level and real world applications. As shown in Table II, sixteen experiments are designed covering these three levels. The application part can also be used as topics for students' final projects in the course.

Table II Summary of Experiments Offered in ELET 3405 in Fall 2006

Topic	Description	Comment
National Instrument Fundamental	Introduction to LabVIEW; Data Acquisition foundations	Component level
Op-Amp fundamental	Introduction to Electronics Workbench/RC Frequency Response; DC Analysis of Inverting/Non-Inverting Op Amp Circuits; Voltage Controlled Sources (VCS), Current Controlled Sources (CCS), Linear Combination (Summing) Circuit	
Op-Amp application	Analog Signal Conditioning	
Temperature sensor	The Thermister and First Order Time Response; Temperature measurement using Thermocouples	
Pressure sensor	Weight scale with Strain Gauges	
Sensor interface	Oximeter finger probe sensor interface; Research on integrated sensor interface in flow-meter; Integrated multifunction sensor board for sensor networks	System level
Sensor application	Pulmonary function examination; Reaction time measurement	Applications
Sensor network system	Activity monitoring system; Temperature monitoring system	

Laboratory design at component level

At component levels, experiments are designed to assist students' learning process of data acquisition fundamentals, basic Op-Amp circuitry and their functions, and verifying the characteristics of different types of sensors using both traditional signal conditioning circuits and LabVIEW.

Two experiments are designed for students to get hands-on experience of LabVIEW8.0 and NI PCI6220 Data Acquisition (DAQ) board. LabVIEW8.0 is one of the most popular data acquisition graphical application development platform used both in industry and research. NI PCI 6220 is a 16-Bit, 250 kS/s, low cost M series multifunction data acquisition card mostly used for educational purpose. It has 16 analog inputs, 24 digital I/O, 32 bit counter, and more than 70 signal conditioning options, which make it a wide choice for our laboratory. Coming with Labview 8.0, we have Measurement & Automation (MAX). MAX is a configuration console

which provides access to all National Instrument products we have. With it, students can manage, test and configure all physical or virtual devices, as well as software, virtual channels or tasks, and IVI instrument drivers.

Op-Amp circuitry such as those used for DC analysis, VCS, CCS, and circuit summation are studied in a set of experiments. Afterwards, students are asked to design Op-Amp based signal conditioning circuit to convert the analog sensor output to voltage and digitize it to appropriate range. Sensor's nonlinearity is also studied and students are asked to implement linearization function within LabVIEW.

The third part at the component level is the sensor characterization. Experiments are designed to study commonly used temperature and pressure sensors. Students have the opportunity to apply the knowledge they've learned to build simple applications in Labview to verify sensor characteristics, measure the temperature using thermocouple, and build a weight scale based on pressure sensor.

Laboratory design at system level

Several experiments are designed to give students hands-on experiences of integrated sensor circuits and interfaces that are used in industry. Some medical sensor and its interface board and integrated multifunction sensor board used for research projects are provided by ISGRIN to give undergraduates the opportunity to learn the advances in sensor technology. The equipments include the oximeter finger probe sensor, medical flow meter and its interface, and the integrated multifunctional sensor board using in sensor networks from Crossbow© and Moteiv©. With help from graduate assistants, our undergraduate students successfully synthesize and applied their knowledge about sensor and circuits gained from previous experiments to the understanding of sensors' functions and building interfacing circuitry (when interfacing board is not available, such as for the Oximeter finger probe sensor) and programs in Labview that interact with the interfacing circuits. They are also asked to extend programs they've built in previous lab sessions at component level to visualize and analyze the measurements they've taken.

Real-World applications

This part is designed to let students use those sensor interfaces examined in previous part to set up some real-world applications. For example, biomedical sensors from BioPac Inc. are used to do pulmonary function examination, reaction time measurement etc. In these experiments, students also gain experience with data acquisition unit BioPac MP35 and Biopac Student Lab PRO®. BioPac System MP35 is a modulated, easy-used hardware designed for educational laboratory purpose. It has an internal microprocessor to control data acquisition and communication with the computer. And it has four 9-pin analog input channels designed as simple sensor connectors. Although not so flexible and powerful as LabVIEW, Biopac Student Lab PRO® is more professional in data analysis in biomedical applications.

Case Study 1: Figure 2 shows the equipment setup and data graph gained by a group of students doing the pulmonary function examination. The students set up the sensing equipment, connected it to the data acquisition unit, and were able to acquire the data. After that, they

analyzed pulmonary functional parameters using Biopac Student Lab PRO® and drew some conclusions.

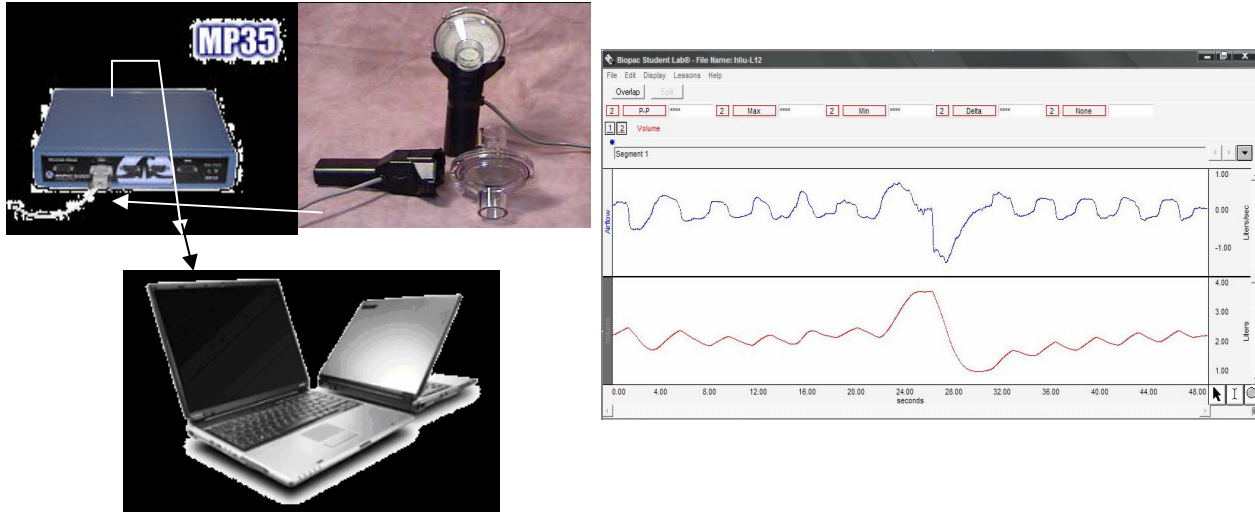


Figure 2 Sample system of pulmonary function examination

Case Study 2: Figure 3 shows the sample application of reaction time measurement system set up by other student group. They used BioPac System MP35 and hand switch that they had examined to get the reaction time of two subjects in ten tests. In this application, they were able to interface the equipment to LabVIEW in order to visualize the reaction time of two volunteer students as shown in the plot below.

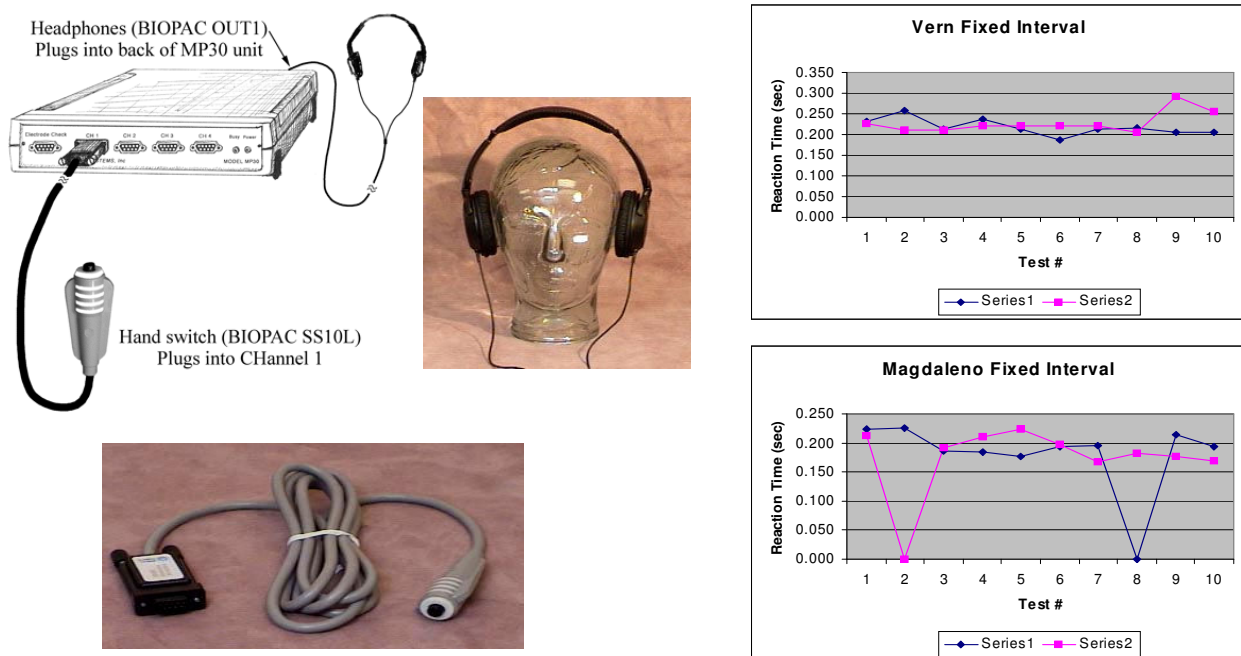


Figure 3 Sample system of reaction time measurement

Case Study 3: Figure 4 shows a sample room temperature monitoring system set up by students using the multifunctional sensor board and communication module from Crossbow©. Although

this is a simple and small sensor network application, students were able to experience a real world application of wire less sensor communication systems.

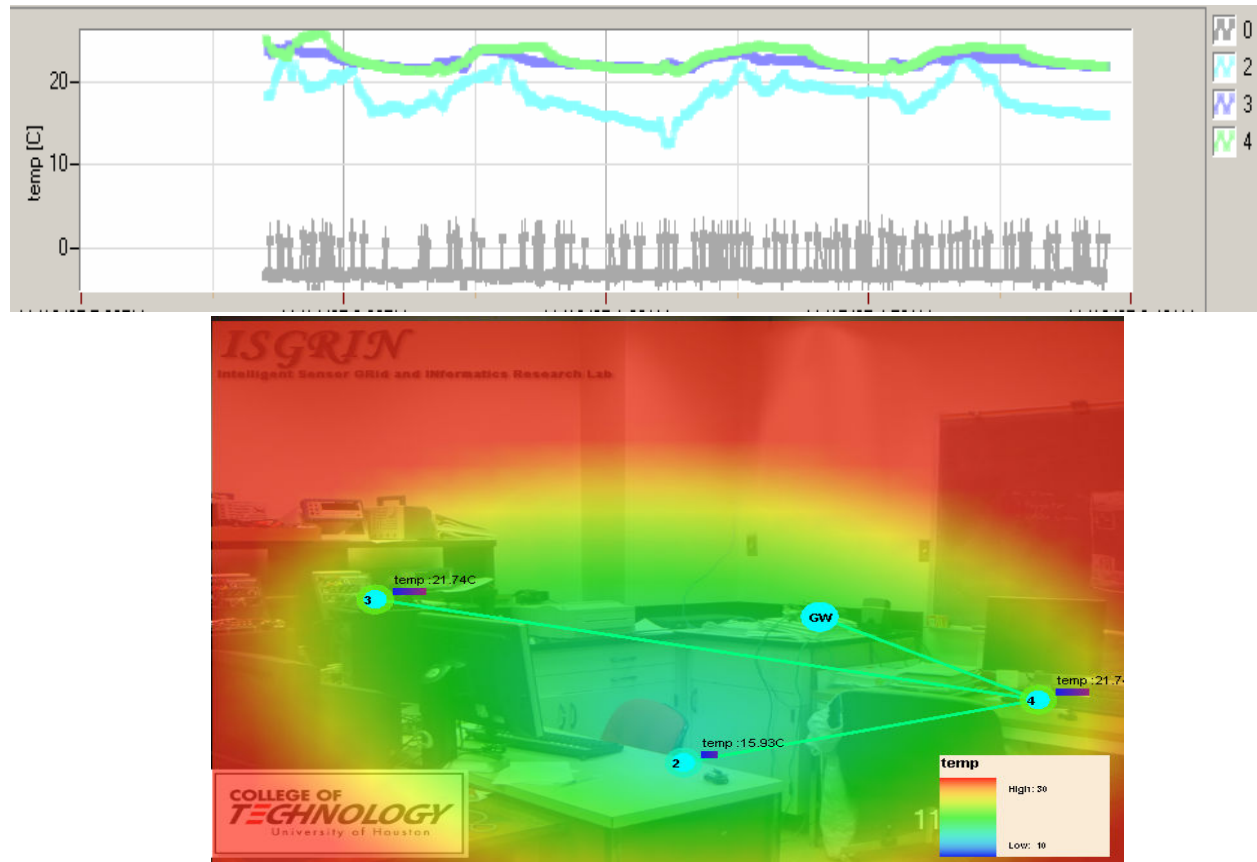


Figure 4 Sample room temperature monitoring system

VI. Preliminary Assessment

This section presents the assessment instruments we designed in this study as well as their corresponding preliminary results. The purpose of the survey is to ask students who took the class on “Sensors and Applications” to rate the lecture and laboratory based on how far the new course helped them to develop the application of this relatively new technology. The chart shown in figure 5 shows the results obtained from the survey taken during Fall 2006. Since the course is offered every semester, we are modifying the assessment instrument and conducting additional surveys from students taking the class during Spring 2007 and external evaluators, such as our industry advisory board members, faculty members from our department as well as from various schools of Engineering. This process is in line with the standards of the Accreditation Board for Engineering Technology (ABET) that require individual departments to assess such new course and their outcomes.

In Fall 2006, the assessment has been conducted for a set of forty questions covering from lecture delivery and laboratory details as well as evaluation of the instructor and graduate assistant. Some representative questions of the assessment categories are listed below. The corresponding student response summary is shown in Figure 5. Based on the survey results,

(question 3) majority of students (80%) agree that the new experiments designed helped them gain new skills and increased their practical knowledge. In addition, (question 5) 70% of students feel the experiments are logically sequenced. However, a lot of students (70%) also feel we can do better in explaining and relate concept and theory they learned from lecture with the experiments in our lab manuals (Question 1) and have more challenging questions in our pre-lab procedures (Question 2). We are modifying the lab manuals and pre-lab procedures based on more detailed feedback from students.

Question 1: (Lab Manual) The lab manual explained concepts clearly.

Question 2: (Pre-Lab Session) The pre-lab was good preparation for the lab.

Question 3: (Laboratory) I gained new skills and increased my practical knowledge.

Question 4: (Lab Equipments and Components) The labs have state of the art equipment.

Question 5: (Laboratory Organization) The experiments were logically sequenced.

Question 6: (Laboratory Worksheet and Report) The guidelines for the lab worksheets are clear.

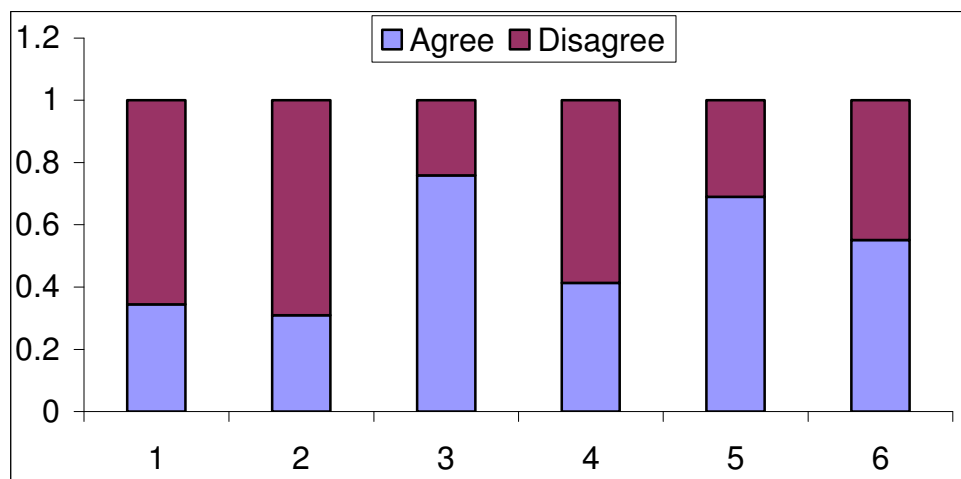


Figure 5. Summary of Student Assessment

VII. Conclusion and Future Works

The web based hybrid instruction delivery develops a uniform, repeatable and comprehensive instruction delivery system for effective teaching methodology and emphasizes the desirable teaching qualities we wish to model. As the new hybrid delivery technology continues to develop, we envision a very different instruction delivery than the one we use today. Rather than bringing the students to the lab we can bring the lab to the students. In this paper, we presented the preliminary results of curriculum development for an integrated instrumentation program and described in detail how we integrated recent advances in sensor network into undergraduate junior level sensor application course (ELET3405). This is made in an effort to make instruction delivery methodology of current technology that will translate into better teaching practices, which ultimately benefits our students. Preliminary results from the two student surveys show that this new approach of instruction delivery will bring a new era of teaching and learning process for both the faculty and students.

Currently we are working on the development of lab experiments that are specifically suited to hybrid delivery. In terms of increasing our efforts in interdisciplinary cooperation we are further working with other departments to develop more courses which could be integrated into the application of sensors.

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