AC 2008-2136: INTEGRATING SENSOR NETWORKS IN UNDERGRADUATE CURRICULUM: A MARRIAGE BETWEEN THEORY AND PRACTICE

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Introduction

Wireless Sensor Networks are composed of small nodes equipped with sensor(s), a wireless radio, and limited computational power. Sensor nodes are used as data collectors and also in data forwarding. The nodes collect the sensed data and use their neighbors to forward it to the destination. In general, a network is composed of several sensor nodes and one or more destinations or gateway (also called "sink") nodes that receive the collected data and may process it and take the appropriate actions. The network can have a large or small number of nodes depending on the needs of the application. Sensor networks were originally motivated by military applications such as surveillance, but were quickly found to be useful in diverse civilian applications, such as environmental monitoring, healthcare, home automation, space exploration, chemical processing, disaster relief, etc. This diverse set of applications, spanning multiple fields, sparks interests of students with varied backgrounds.

In this paper, we detail the ongoing efforts at Drexel University, aimed at adapting the successes of previous experiences in teaching sensor networks at the undergraduate level[1-6], to create a new laboratory-based undergraduate course in sensor networks, and to make extensive use of the new laboratory's modular experiments in other courses and disciplines. The project is funded by NSF CCLI program of the Division of Undergraduate Education.

Sensor networks as a pedagogical tool

We believe that sensor network experiments can be very pedagogical in illustrating many abstract concepts in other courses/disciplines. For example, medium access and routing protocols can be used in undergraduate networking sequence courses; basics of radio communication can illustrate concepts in an introductory telecommunication course; a Digital Signal Processing (DSP) sequence dealing with image/biomedical modeling and interpretation, using curve modeling with parametric models such as Bezier and B-splines could be illustrated with an experiment dealing with traffic engineering where students are asked to route important data from a node to a destination node while adhering to a predetermined trajectory described by such parametric models; as part of the stochastic system course, students are introduced to detection and hypothesis testing theory and Receiver Operating Characteristic (ROC) analysis. An experiment can be developed to ask the students to track a moving toy vehicle in a room by integrating and routing the proximity data from the sensors to a sink node for data and decision fusion. Similarly, simple probability concepts taught at the junior level can be illustrated with simple experiments.

Aiming at a tight integration of theoretical concepts with a hands-on laboratory experience, we designed modular experiments to be used as a platform to naturally improve understanding of networking and concepts in other courses such as DSP, stochastic and non-deterministic systems, biomedical imaging, as well as freshman and senior design projects. This will provide the students with an exciting learning environment and will make the mastery of important STEM discipline fun, practical and tangible. We next describe the curriculum modifications brought on by the project.

Impact on Curriculum

The curriculum modifications proposed in this project are centered on the creation of an Embedded Networked Sensors Laboratory with its modular experiments and outreach activities. Table 1 shows Drexel engineering curriculum with the shaded area presenting courses that are impacted by the project.

Year	Term	Drexel Curriculum for Telecom, Networking and DSP Engineering Majors				
1	1 2 3	Mathematical & Physical Foundations of Engineering		Chemical & Biological Foundations of Engineering	Engineering Design and Laboratory	Liberal Studies and Seminars
2	4 5	Systems	Energy	Materials	Introductory Prof. Courses	Eval. & Presentation of Experim. Data
3	6 7	MATH	Third & Forth Year Professional Courses		Lab	Liberal Studies
4	8 9	Forth Year Professional Course Inter-disciplinary			Lab	Liberal Studies Electives
5	10 11 12	ECE Senior Design	ECE Technical Electives	Telecom, Networking, DSP Sequences	Free Elective	Liberal Studies Electives

Table 1: Drexel Curriculum for Telecom, Networking, and DSP Engineering Major Students - Gray cells represent where changes will incorporate embedded networked sensing systems and networking laboratory. Drexel offers a full five-year program with 12 quarters of academic work and six quarters of Co-op experience.

Year	Course Title	Project Activities
1st	Freshman Design	Simple real-world application based projects
3rd	ENGR 361, Statistical Analysis of Engineering Systems	Experiments illustrating probability concepts
4th	Undergraduate Research Opportunity	Development of new experiments (mini-project)
5th	Senior Design	Sensor Network Based Wide Area Power Monitoring and Control System
		ParkSmart: A distributed parking search system using wireless sensor networks
		Tracking a Phenomena over Time and Space in a Sensor Network Environment
	ECEC-511: Wireless Communications ECET-512: Wireless Networks	Developing MAC protocols, clustering and energy-aware routing, location awareness, etc.

Table 2: Course and laboratory integration to Drexel's Telecommunications and Networking Curriculum

More details on the integration of the laboratory with relevant courses are listed in Table 2. Freshman design projects are offered to first year students with the objective of attracting them to the subject and to electrical engineering. Juniors are exposed to experiments illustrating concepts taught in the ENGR 361 introductory probability course. On their 4th/5th year, students take an introductory class in embedded networked sensors and will execute experiments illustrating the basic OS functionalities, embedded programming, MAC layer, routing protocols, localization techniques, etc. Students also have an option to engage in mini-projects proposing new experiments that can illustrate simple concepts taught in other courses. The project equipment will also serve to be used in senior design projects in the 5^{th} year.

Wireless Embedded Networks Laboratory

A new course specifically target to undergraduate students is being offered this winter term (ECEC 490 Wireless Embedded Networks Laboratory). The course is laboratory based and is heavily focused on programming sensor nodes. The course started with an introduction to sensor networks and its diverse applications and design requirements. Students were also introduced to TinyOS and their first program on nesC (the language used to program the motes), which was a simple counter.

The course is organized in weekly laboratory assignments, preceded by a pre-lab assignment. Pre-labs are intended to prepare students for the content needed in their laboratory assignments. Students must complete and turn in their prelabs before their lab session. After completing their weekly lab assignment, a report is due. Pre-labs are individual work, while labs and reports can be group work (groups of two students). Weekly quizzes, based on pre-labs and lab reports, are held in the beginning of the following lecture. There are no midterms or final exams in the course. Student's performance is evaluated through their pre-labs, quizzes, and lab reports. An optional extra credit mini-project was also proposed. Students choosing to work on a mini-project will select a topic from another course that can be better illustrated with an experiment using sensor networks. At the end of the course, students will present a demo of the experiment related to their mini-projects. We envision having one or two experiments that demonstrate concepts from other disciplines at the end of the course.

Preliminary set of importable experiments

An initial set of importable experiments is being developed. One of the experiments will be used in a guest lecture in the DSP senior sequence (Spring 2008) and another will be used in the Statistical Pattern Recognition course being offered this quarter (Winter 2008).

A. Local, Selected and Consensus Decision on Target Detection

A simple experiment will be developed where a target shows in the vicinity of a cluster of nodes at various distances from it. The goal here is to convey to the sink, either based on the hottest node in the cluster, on a select few (concept of maximum redundancy), or on all the nodes in the cluster, whether the cluster decides there is a target (alternative hypothesis) or there is none (null hypothesis) at various false alarm rates. The students will be asked to first determine the empirical distribution (histograms) of the node sensor output as a function of the distance of the target from the node, where a target is assumed present if it is within a radius R of the node and assumed non-present if the distance exceeds the threshold distance R. From these histograms, an ROC curve (probability of detection versus false alarm curve) is obtained and for each point, the appropriate threshold is calculated. The measured sensed data or some statistics of it will be compared to the threshold for accepting or rejecting that there is a target. Then they will place the target at a fixed position and turn all the nodes in the cluster and test three different protocols in detecting the target. The students will move the target closer to the cluster as well as away from it and check their results against the ground truth (no target is in the cluster vicinity if the target is at a distance R from the closest node in the cluster). They will also check how turning off nodes (simulating sensor node damage) can impact the decision on each of the three protocols.

What do the students need to know?

On the theoretical level, the students are expected to be familiar with basic probability and statistics concepts related to testing simple binary hypothesis testing (courses like random signals). On the experimental level the students should know how to use radio communication between nodes, messaging and displaying data, and doing simple signal processing at the node level.

Where would this experiment be imported?

It is natural to import this experiment or a variation of it to illustrate these concepts through hand on experiment using sensor networks in courses like fundamentals of communication theory, or fundamentals of non-deterministic signal processing at the undergraduate level, or statistical pattern recognition and detection and estimation at the graduate level.

B. Motion Tracking

This experiment builds on the previous one by having the target move amongst a few clusters of sensors (3 or 4 clusters that are well separated with distances greater than the minimum distance R for target identification). As the target enters the vicinity of the cluster, at a given time t, they will determine the hottest node in the cluster and record that point for that time as the closest point for the trace of the target motion. At time $t+\Delta t$, a new hottest node is found, and a new point recorded as the next point (new node address). This will continue as long as the target is within the limit R of the cluster, and will become invisible until such time when it enters the vicinity of another cluster after time interval $M\Delta t$, where at such point in time, new points will be recorded. Based on a constant velocity assumption, the students will be asked to compute the velocity of the target by fitting a straight line through these points and will be asked to predict the time when the target should reach a given cluster in the path of the moving target and determine whether or not it will be sensed based on the detection threshold. The student will also be asked to determine the rough location of a new cluster, based on the new cluster sensing the target and the precomputed velocity up to that point.

What do the students need to know?

In addition to the requirements given for the previous experiment, knowledge of simple motion equations and line fitting will be needed.

Where would this experiment be imported?

It is natural to import this experiment or a variation of it to illustrate these concepts through hands-on experiment using sensor networks in courses like fundamentals of intelligent decision, or fundamentals of imaging at the undergraduate level, or statistical pattern recognition and detection and estimation, and computer vision at the graduate level.

Senior Design Projects

Three senior design projects have been proposed thus far: "Sensor Network Based Wide Area Power Monitoring and Control System," "ParkSmart: A distributed parking search system using wireless sensor networks," and "Tracking a Phenomena over Time and Space in a Sensor Network Environment." A summary of each project is given below.

A. Sensor Network Based Wide Area Power Monitoring and Control System

The purpose of this project is to build an easy-to-use system, which will allow consumers to simultaneously monitor and control the power consumption of their appliances or electronics connected to the system. Successful execution of this system will ultimately save the user or company money by observing the power paid for. By using current wireless networking technology, this system will be portable and easily expandable to fit a variety of consumers needs. Homeowners may be concerned about certain household appliances while campuses and larger scaled complexes could save even more money by monitoring numerous industrial devices. Power consumption data from various locations will be wirelessly collected and stored onto a single computer. This system will include a user interface to display and compare relative power measurements of all appliances being monitored at a given time.

Our solution to conveniently minimize an electric bill is to measure the power consumption of a device using a hardware configuration consisting of a power monitoring integrated circuit, microcontroller, and a wireless communication interface. This configuration will allow the device to capture AC power characteristics of a load and output the result in a digital format. This data will be sent to the PC via wireless transmission. The wireless transmission will be handled by a wireless module that will be able to send, receive, and route data; consequently allowing the system to be used over a broad area. Once the data is sent to the PC, it will be displayed on screen through a user interface created specifically for this system. The proposed method of accomplishing this is to use a web interface to display the data. This will allow for convenient remote administration of the system from any PC with an Internet connection. A relay will be implemented into the hardware, as well. It will be used to give the user (or code) the option to remotely disable the power source to a specific device and consequently eliminate all power consumption of the load. The students successfully completed and demonstrated their working system to the senior design committee on May 2007.

B. ParkSmart: A distributed parking search system using wireless sensor networks

Finding a parking spot in Center City, Philadelphia, or any other major city, or urban college campus can be a extremely difficult, tedious, and stressful experience, not to mention the additional fuel and pollution caused by unnecessary driving of vehicles. This senior design project deals with the design and implementation of an intelligent parking system, which will locate the set of empty parking spots that are closest to the user and return the locations in an easy-to-use fashion. A sensor network will be used for detection, information gathering and system communication. Sensor networks differ from traditional wireless ad-hoc networks in several aspects, the most important being the number of nodes, which can be of several orders of magnitude higher than in ad hoc networks, the node density, the fact that sensor nodes are prone to failure, the dynamic topology of a sensor network, which changes very frequently, and the fact that sensor nodes (motes) are limited in power, computational capacity, and memory. As a system prototype, we will use individual sensor motes communicating directly with a base station (motes can be attached to parking meters or embedded into the parking spot). A metal detector will be interfaced with a mote in order to detect the presence or absence of a car and communicate this information to the base station. The base station will be responsible for getting the user's location, the status of each parking spot and guiding the user to the closest empty spot(s). The user's location will be tracked via a GPS module used in conjunction with a sensor node located in the user's vehicle. A customized GoogleMaps interface will be used to display the information to the user. Time and resources permitting, extra features such as parking spot reservation may also be included.

C. Tracking a Phenomena over Time and Space in a Sensor Network Environment

The need and deployment of large scale sensor networks (SN) is imminent. The SN environment presents its own challenges ranging from the sheer number of nodes; the node density; the fact that sensor nodes are prone to failure; the dynamic topology of the SN, which changes very frequently; and the fact that sensor nodes are limited in power, computational capacity, and memory. These factors present a major hindrance towards a rapid and reliable decision and early monitoring and tracking of a phenomenon in the vicinity of such SN. This senior design project deals with the problem of rapid and reliable tracking and ultimately prediction of the phenomena as it propagates amongst the sensor nodes. This is demonstrated by considering a testbed, which consists of a moving remote control toy vehicle in a lab setting where a large number of sensor networks are installed and where the many of the shortcomings of the network are emulated in our experimental setting and solutions to these limitations are proposed and designed. As the vehicle travels, the closest sensor will detect the motion and then triggers the neighboring sensors to track it (waking them up). The neighboring sensor will readily do the same in tracking and awakening the appropriate sensor around it. While tracking is taking place, the node with higher value (hot) sends the information to the base. The proceeding sensors will do the same as they gain a value higher that the initial state. Because the sensors have unique addresses, the base will draw a path of the moving object on the desktop monitor using appropriate software provided by TinyOS. When certain number of data points is collected, the system will be able to predict the path of the vehicle. In an ideal scenario where there are no faulty sensors nodes, or where nodes have infinite power, or when the sensors on the node work perfectly, the above aforementioned solution to the tracking problem will be adequate. However, deviations from this ideal scenario, would dictate changes to the ideal tracking algorithm that would require a consensus within the neighborhood of a vicinity node. We will explore such design and come up with appropriate fast solutions that seek majority rule neighborhood decision for determining the state of a node and indirectly that of the vehicle being in its immediate vicinity. We will also consider robustness issues of our designed algorithm with regards to changes in the topology of the SSN, ranging from changes in density distribution of the nodes and their placements.

Outreach, future work and conclusion

Initial outreach activities have concentrated on mentoring High School teachers and students. This past summer a high school student participating in the Drexel Summer Mentorship program, run by the College of Engineering, worked on a project with a practical application. The project was to setup sensor nodes at the entrance of a room to count the number of people entering and exiting the room. The successful completion of the project culminated in a poster, which was presented in a poster session for all the summer mentorship attendees from around the country.

We are currently working on developing new importable experiments and are in the process of creating a complete lab manual with pre-labs, experiments, and lab report questions. Evaluations (multi-method matched group evaluation[7]) will be carried out to assess retention, improved attitude towards networking and other disciplines for which experiments are developed. Thus far we have found that undergraduate students are very interested in the subject of sensor networks (given the demand for the new course and offered senior design projects).

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Bibliography

1. The "moteLab" at Harvard University, http://motelab.eecs.harvard.edu/
2. The Wireless Sensor Network Laboratory (WSNL) at Stanford University, http://wsnl.stanford.edu/
3. The Embedded Networks and Applications Laboratory "ENALAB" at Yale University, http://www.eng.yale.edu/enalab/
4. Networked & Embedded Systems Laboratory (NESL) at University of California, Los Angeles, http://nesl.ee.ucla.edu/
5. UCLA's Center for Embedded Networked Sensing, http://cens.ucla.edu/
6. The MANTIS (MultimodAl NeTworks of In-situ Sensors) project lab, a part of the Computer Science Department at the University of Colorado, Boulder, http://mantis.cs.colorado.edu/tikiwiki/tikiindex.php.
7. J. W. Creswell, “Research Design: Qualitative, Quantitative, and Mixed Methods Approaches,” Sage Publications, Thousand Oaks, CA., 2002.