

Towards Enhancing Undergraduate Pervasive Computing Skills: An Innovative Multi-Disciplinary Approach ¹

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Abstract – Pervasive Computing is becoming more and more prevalent in our society. Rapid developments in wireless technologies and Sensor-network-based smart spaces are creating an urgent need for well trained Pervasive Computing Engineers. This NSF-funded project seeks to enhance our undergraduate computing skills by establishing a Wireless & Mobile Computing lab environment. Our project has the following innovations: (1) The establishment of a Pervasive Computing Lab, which provides an integrated wireless-plus-wired networking platform. (2) Multi-disciplinary nature: We believe that Computer Engineering students also need to have certain knowledge in other disciplines (such as Computer Science) in order to adapt to the future career requirements. (3) Innovative Course/lab development: Three new courses (Pervasive Computing Architecture & Design, Principles of Wireless & Mobile Networks, and Data Management for Pervasive Computing) have been developed during this project to enhance the undergraduate curriculum of both majors. A series of lab assignments are developed to provide a hands-on experience to the students.

Index Terms – Computer Engineering Education, Multi-discipline education, Pervasive Computing, Sensor Networks

1. INTRODUCTION

“On the future of information computing, the clearest part of my vision is that of nomadic computing and smart spaces... Nomadic computing refers to the technology that enables end users who travel from place to place to gain access to Internet services in a transparent fashion, no matter where they travel. However, nomadic computing is only one step. The next step will enable us to move out from the netherworld of cyberspace to the physical world of smart spaces. Our environment will come alive with technology, through actuators, sensors and communication. ... Looking a bit further out, I see a networking future that includes the following additional key components. I see intelligent software agents deployed across the network whose function is to mine data, act on that data, and carry out tasks dynamically and adaptively.... The Internet will essentially be a *pervasive* global nervous system!” [1]

The above citation is from Dr. Leonard Kleinrock, a famous computing scientist, the Inventor of Internet Technology, currently a professor of Computer Science at University of California Los Angeles.

Pervasive Computing is becoming more and more prevalent in our society [6]. Rapid developments in wireless networks and sensor technologies are creating an urgent need for well trained pervasive computing engineers. As pointed out by Dr. Leonard Kleinrock (see above), Pervasive Computing includes mainly the following three components [2-5]:

(1) *Nomadic Computing*. Advances in wireless technologies have enabled portable devices to support many important nomadic (i.e. mobile) applications, including multimedia communication [7], telemedicine [8-11], and home networking [12, 13]. Unfortunately, most universities do not have appropriate nomadic computing curriculum materials for undergraduates. Several universities have a few relevant graduate courses that exceed the ability of most undergraduate students. In this project we create suitable curricula with appropriate depth and coverage in terms of the undergraduate learners.

(2) *Sensor-based Smart Spaces*. Smart Spaces refer to the environment monitoring/control systems through tiny sensors and actuators. Many applications use them to detect fire, earthquake, water pollution, and homeland security intrusions [15]. This project uses sensor networks as the educational platform of Smart Spaces.

(3) *Data Management in mobile computing platforms*. For many years Computer Science (CS) undergraduate education has focused on data management in traditional central-based databases [14]. However, with the coming of pervasive computing, an ever-increasing degree of information is collected by use of distributed nomadic networks [4, 5]. We should therefore not only teach our undergraduate students the traditional topics in database management, but also provide them with substantial exposure to the data management issues in pervasive computing environments.

The vast majority of today’s Computer Engineering / Computer Science undergraduate programs pay marginal attention, at best, to pervasive computing development, despite the fact that it has evolved into a critical field, influencing a

¹ This project is supported by US NSF CCLI Grant: DUE # 0511098 on Pervasive Computing lab development.

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broad range of industry from healthcare to manufacturing, to defense. From a career viewpoint, this is a rapidly advancing field that lacks a trained workforce to satisfy the requirements of the wireless industry. We must confess that currently, our undergraduate students have very little understanding of *pervasive computing* hardware/software other than elementary networking knowledge.

Known as a leader in the undergraduate education, Rochester Institute of Technology (RIT) is undertaking an effort to enhance the *pervasive computing* skills of our undergraduate students. Since 2005, we have made a pioneering attempt for undergraduate education based on the innovative adaptation of other successful wireless labs in the US such as WINLAB at Rutgers University.

2. PROPOSED PERSVASIVE COMPUTING LAB ARCHITECTURE

We are in the process of implementing an undergraduate-education-oriented *Pervasive Computing Lab (PCL)* and to develop relevant courses. As shown in Figure 1, the PCL has important educational elements for both undergraduate programs: (1) A human-friendly middleware framework that includes typical Computer Science (CS) education topics such as Data Mining and Java GUI; (2) Computer Engineering (CE) students can learn the integration of typical pervasive networks including high-speed Wireless Local Area Network (WLAN), Ad hoc Networks, and Wireless Sensor Networks (WSN) that are typical examples of Smart Spaces. (3) Security issues in pervasive environments will also be emphasized for both majors.

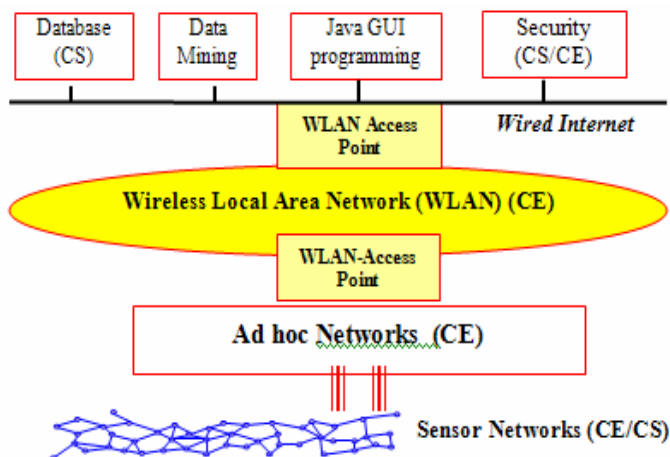


Figure 1. Pervasive Computing Lab architecture

Our lab equipment selection considers the characteristics of the three components in *pervasive computing* systems (see Section 1) and our PCL architecture (Figure 1):

(1) *Equipment for learning Nomadic Computing* (the first component of pervasive computing) Nomadic computing systems mainly include Ad hoc Networks, Wireless LAN, Cellular Networks and other mobile platforms [3,4]. We

choose the following equipment to train our students on the design of *nomadic computing* systems:

- Set up Ad-hoc Networks through Personal Data Assistants (PDAs) (we use Compaq iPAQ series, see Figure 2 left). The reason of choosing iPAQ instead of other PDA models is that it runs Linux and allows students to modify the system codes to design wireless routing/MAC protocols.
 - Set up Wireless LAN (WLAN) through Cisco WLAN Access Points (AP), laptop PCs (for setting up WLAN mobile terminals) and Cisco WLAN cards (to be installed in each laptop for WLAN terminal-AP communications).
 - On Cellular Networks training: because it is too costly to build a cellular network hardware platform, we will install OPNET software (<http://www.opnet.com>) on some Desktop PCs to teach our students on the Radio Frequency (RF) design in the third-generation (3G) cellular networks,
- (2) Equipment for learning Smart Spaces (the second component of pervasive computing): the Crossbow classroom-oriented MICAz nodes (a type of microsensors, see <http://www.xbow.com>) are a good choice for *Smart Spaces* training due to their programmable routing/MAC stack in the sensor and the reusable Java-based interfaces. To learn the design principle of *sensor networks*, students are asked to use *Crossbow* nodes (see Figure 2 right) to design a small sensor network with required communication performance (such as delay).
- (3) *Equipment for learning Data Management in Mobile Platforms* (the third component of pervasive computing): For this component, we also use *Crossbow* nodes (the same as above) that can be programmed to run distributed database software. We have developed three lab assignments on the application of Cougar tool [16] to the distributed database design in wireless platforms.



Figure 2. (left) iPAQ (right) Mica2Dot sensors

3. PERVASIVE COMPUTING CURRICULUM ENHANCEMENT

Based on the above Pervasive Computing concept, we are in the process of developing three courses that (a) appear to make a cohesive sequence, (b) cover the core topics in the benchmark courses, and (c) upper-level undergraduate students in both majors can take them. These courses are listed as follows:

- (1) CECS 400 *Data Management in Pervasive Computing*. This course concentrates on data mining issues and distributed database management in *pervasive computing* environments.
- (2) CECS 500 *Principle of Wireless & Mobile Networks*. This course examines the principles of current *nomadic computing* systems including cellular networks & CDMA, ad hoc networks, GPS and wireless LAN. The lab exercises include Physical and MAC design using OPNET.
- (3) CECS 550 *Pervasive Computing Architecture & Design*. This course discusses the system architecture, hardware components, smart spaces (such as sensor networks), network security and software applications in *pervasive computing* platforms.

The target audience is 3rd/4th/5th-year undergraduate students in our CE and CS programs. The above three courses are offered in separate quarters of each academic year. For each section of class, two lab sections (section size: about 20) are managed with the help of 2~4 lab TAs.

To exemplify the PCL courses, we have provided our teaching topics on the course “*Principle of Wireless & Mobile Networks*” as shown in Figure 3. It has covered the most important wireless computing platforms such as ad hoc networks, sensor networks, Bluetooth, wireless Local Area Networks and cellular networks. Our teaching focus is the networking protocols, hardware architecture and Physical layer principles. Thus our students will be able to adapt to current wireless industry environments.

Time	Teaching topics	Lab Assignments
Week 1	Introduction to the course; Basic theories on radio transmission characteristics;	Lab 1: OPNET simulation basic wireless link model
Week 2	Slow fading and fast fading, path loss models; the influence of mobility on receiving radio frequency.	
Week 3	Wireless modulation (BPSK, MSK, etc.), CDMA	Lab 2: OPNET simulation: path loss analysis
Week 4	Wireless LAN (I) – Architecture & protocol	Lab 3: Cisco WLAN design – PHY/MAC layer analysis
Week 5	Wireless LAN (II) – IEEE 802.11 MAC	

Week 6	Ad hoc Networks (1) – architecture; existing routing protocol; Mid-term exam	Lab 4: MANET design – routing protocols (using CAMPAQ iPAQ)
Week 7	Ad hoc Networks (2) – MAC design; Bluetooth	
Week 8	Cellular Networks (1) – cell model, frequency reuse, interference, handoff.	
Week 9	Cellular Networks (2) – 2G /3G architecture	Lab 5: Cellular Networks design through OPNET
Week 10	Satellite networks, GPS; Final Exam Review.	

Figure 3. Teaching Topics of *Principle of Wireless & Mobile Networks*

4. EDUCATION PERFORMANCE EVALUATION

To evaluate the teaching performance on Pervasive Computing, we have invited two wireless experts from other universities to come to RIT. They freely commented on the following aspects:

- Is the course/lab material appropriate and relevant to the profession?
- Is the material being presented in a logical and cohesive way?
- Is the time and emphasis that is being placed on each topic appropriate?
- Are the experiments/projects/lab equipment appropriate to accomplish the aforementioned two project objectives (see *Introduction* section)?

They have provided some important ideas on how to integrated sensor hardware and software education for both CE and CS students.

The author is currently the Associate Director of Rochester SigmaXi Chapter and also a local IEEE Communication Society officer. Each year there are a few meetings providing opportunities for exchanging education experiences on how to improve undergraduate computing learning. We have also asked two to three *pervasive computing* experts from the local IEEE / Sigmaxi Chapters to evaluate our PCL outcomes.

We have also used surveys and tests (administered at the beginning and end of each course) to evaluate the student learning outcomes. The attitudinal survey can measure the students’ interest in Pervasive Computing and their self-assessment of achievement of the course outcomes.

In our offered course, “*Principle of Wireless & Mobile Networks*”, we have adopted the multi-disciplinary education methodology, i.e. teaching both Computer Engineering and Computer Science topics for two majors. Based on our investigation on the project interests of 60 students, about one-third of students (most of them coming from Computer

Science Department) enjoy building different software applications for Xbow sensors such as Mica2 and Mica2Dot [17]. And 31% students (most of them coming from Computer Engineering Department) like making sensor hardware from some out-of-shelf components (such as microcontroller, memory, radio & antenna, sensor chips and power units). 21% students like OPNET software [18] labs for simulating wireless networks. OPNET is a difficult tool to use since it requires complicated Finite State Machine programming. Only 12% students like ns-2 simulation tool. The reason is that they need to use a stand-alone Unix machine to write the codes. And also ns-2 has some bugs that are not easy to fix.

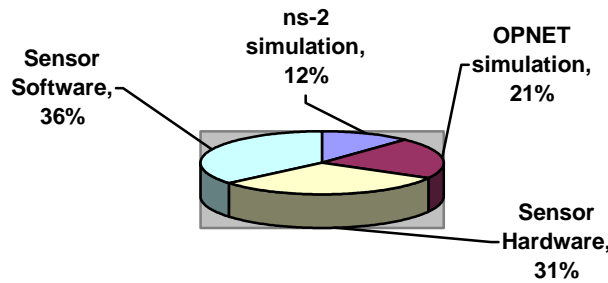


Figure 4. Student projects choice

We have also investigated the students' learning outcomes in two continuous quarters: Spring 2005 and Summer 2005 in the Networking course. As shown in Figure 5, the students have higher grades in later quarter. This could come from the PIs' teaching performance improvement since we have learned from previous experiences. Among the four groups of students, the Master Degree students have highest average score, which may be due to their solid networking foundations during their undergraduate studies. The undergraduate students with co-op⁴ experiences can do the wireless networking labs better than individuals without co-op experiences. We have also used team works to carry out those labs (each team has 2 to 3 students). We have found that students can share experiences and submit better results.

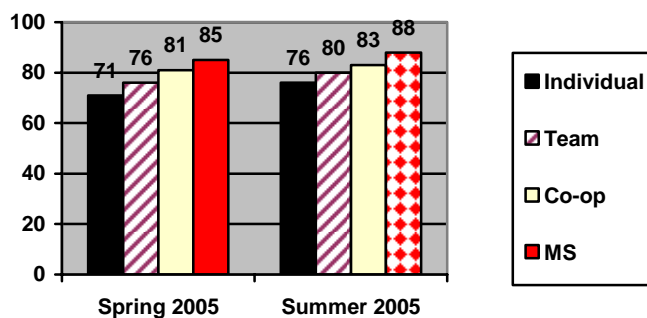


Figure 5. Students' average lab grades

⁴ RIT requires students to obtain 4-5 co-ops during their 5-year undergraduate study. Those co-ops help students get hands-on experiences in their disciplines.

• **Pervasive Computing Lab examples:**

In the following discussions, we will exemplify our developed multi-disciplinary pervasive computing labs that have attracted the students' strong interest during our teaching.

Example 1: Sensor Network Time Synchronization Labs

Latest advancements in micro-sensor technology have led to the development of low cost and low power sensing devices with computational capabilities and wireless sensing communication capabilities. Time Synchronization is one critical aspect of such sensor networks at many layers of its design. The applications envisioned on such a network mandated collaborative execution of a distributed task amongst a large set of sensor nodes which is realized by exchanging messages that are time stamped using the local clock at the nodes. Thus Time synchronization is an indispensable piece of infrastructure in such systems.

Time Synchronization can either be (1) Sender-Receiver based (Figure 6) or (2) Receiver – Receiver based (Figure 7).

Sender-Receiver synchronization (similar to NTP)

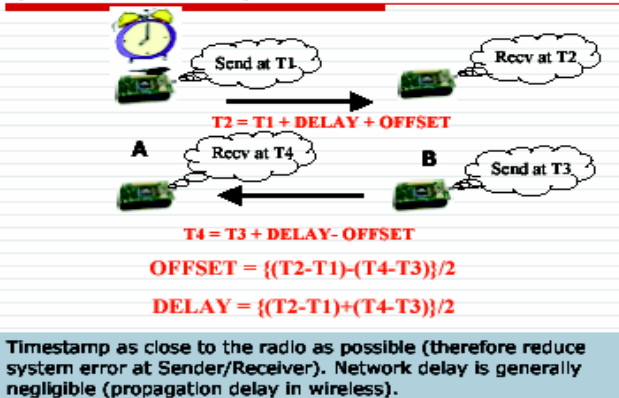


Figure 6. Time Synchronization (sender-receiver-based)

Receiver-Receiver synchronization removes sender uncertainty.

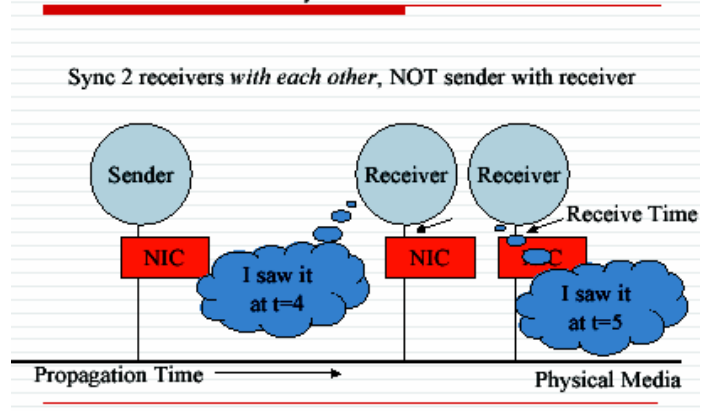


Figure 7. Time Synchronization (receiver-receiver-based)

Some sources of clock errors include Sender uncertainty, Receiver uncertainty or Propagation delay. This project assignment is based on Sender-receiver protocol and each team will be provided with one Xbow programming board and two Mica2 wireless motes. As shown in Figure 8, this project includes 5 labs to be finished in one quarter (10 weeks). The last part of the assignment requires the use of a third mica2. This project requires extensive using of TinyOS and NesC programming language.

Lab session	Grade	No of Weeks
1. TinyOS Setup & reading	10%	3
2. Basic Synch	30%	1
3. Estimate Offset & Drift	60%	3
4. MAC Layer Time stamping	70%	1
5. Logging errors and demo	100%	2

Figure 8. Time Synchronization Labs (Grading policy)

This project worked very well during our Networking teaching. Many students felt that they had learned a lot of practical knowledge on wireless sensor networks besides theoretical wireless protocol details.

Example 2: Sensor Network Database (TinyDB)

The above example emphasizes more on Computer Engineering experiences through the using of Xbow sensors. To include some Computer Science knowledge into Engineering education (to achieve multi-disciplinary education), we have provided Database education for Engineering students. Figure 9 is our lab hardware setup. It includes a gateway (Xbow PIA board) and three Mica2 nodes (with sensor boards). The sensor can detect light, temperature, smoke and humidity.

TinyDB [19] is an important research topic in sensor network database applications. We have built a lab based on TinyDB research results for undergraduate teaching. The students were asked to install Database software in some sensors to collect sensed data from environments. Figure 10 shows the window interface on the sensor data query results. It is similar to SQL query, i.e. use SELECT language to obtain sensor data from multiple sensors.

The students enjoyed this lab very much. Please see [20] on their lab reports. The second author of this paper has developed Wireless Data Mining course that covers many important topics on sensor data management such as novelty

detection from sensor data stream, classification of sensor data based on feature extraction, sensor database organization, etc.

The Engineering students have improved their software skills through C/Java programming in this lab. They have also obtained some important Computer Science knowledge such as database management, TinyOS (Operating System for sensor networks), and data mining.

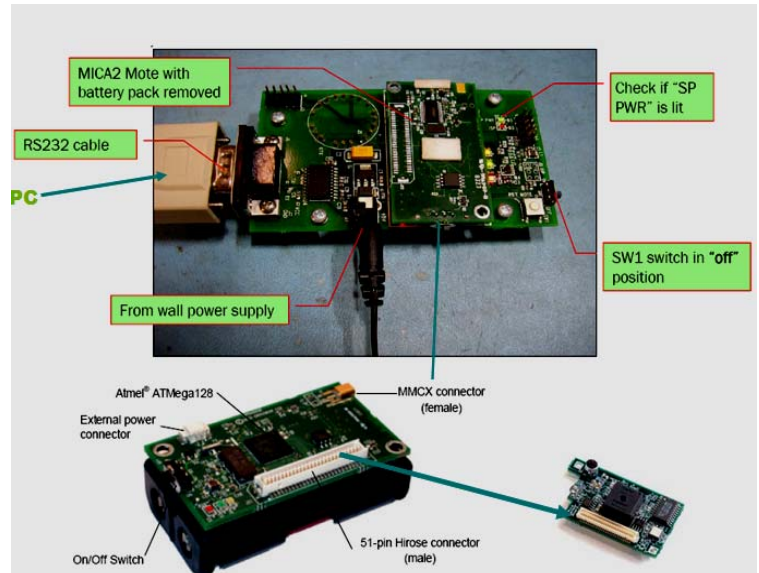


Figure 9. TinyDB Lab setup

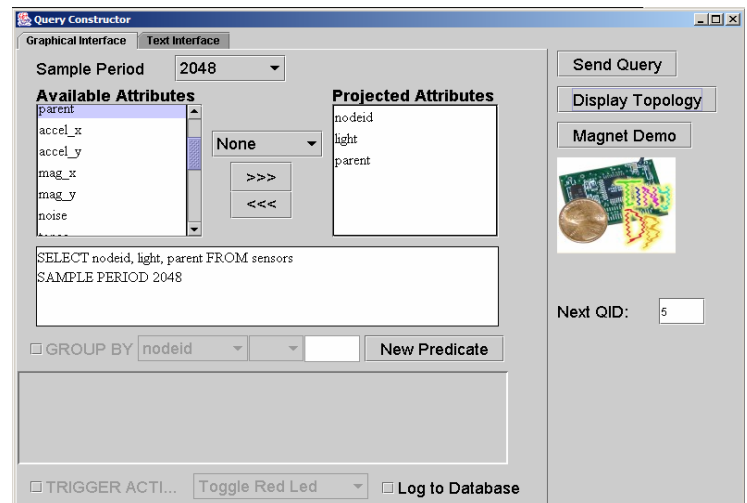


Figure 10. TinyDB Interface

5. CONCLUSIONS

Considering the long term, our CE program is lacking the *nomadic computing* and *smart spaces* education resources. The proposed PCL concept provides multiple types of *nomadic computing / Smart Spaces* platforms with integrated software exploring environment. On the other hand, currently the CS program at RIT has only a basic *data communication*

course and its data management teaching is based on traditional central database systems. The PCL enables our CS students to learn programming methodology in an integrated hardware/software *pervasive networking* environment.

To the best of our knowledge, our PCL is the first attempt to establish a contemporary *pervasive computing* lab for undergraduate CE/CS teaching. During this project we have put much effort to reproduce our PCL experience at other schools. So far, a handful of universities have shown strong interests in our PCL concepts. For example, the CE department at Clarkson University would like to establish a similar lab for undergraduate teaching.

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