AC 2009-1869: WORK IN PROGRESS: WIRELESS BIOMEDICAL DATA COLLECTION--A LABORATORY TO PREPARE STUDENTS FOR EMERGING ENGINEERING AREAS

Virgilio Gonzalez, University of Texas, El Paso

Eric Freudenthal, University of Texas, El Paso

Homer Nazeran, University of Texas, El Paso

Work in progress: Wireless Biomedical Data Collection, a Laboratory to Prepare Students into Emerging Engineering Areas

Abstract

The authors present different modules created between the Computer Science and Electrical Engineering programs for a new laboratory with a focus on wireless sensors applied toward biomedical data collection. Students in those programs typically have little exposure to the growing area of biomedical telemetry and control because most of their courses are restricted to classical discipline subjects.

To address these motivational and technical needs, we are implementing a course with hands-on emphasis. The course exposes the students to the needs and the nature of interconnected bio-medical systems, and engages them in the development of networked applications for embedded wireless devices.

This elective course is being jointly offered by the Electrical Engineering and Computer Science departments beginning in the spring of 2009 and targets upper division undergraduate and graduate students from both departments. Prerequisites include a course in computer organization and proficiency with a high level imperative programming language.

The planned laboratory modules expose the student to the process of designing a biomedical wireless data collection system where they are required to apply concepts from several areas. A team of instructors from CS, ECE and BME backgrounds will provide the foundation of basic concepts required and then the student teams will collaborate to the final design. The approach attempts to exemplify the type of work that could take place in a real application.

Introduction

The University of Texas at El Paso offers bachelor programs in Electrical Engineering and in Computer Science. In recent years the College of Engineering began the process of creating a multidisciplinary graduate program in Biomedical Engineering by attracting specialized faculty across different departments, such as electrical engineering, mechanical engineering and computer science.

The CS and EE programs are structured to have, at the senior level, several elective courses that help the students specialize within their disciplines. Our hypothesis is that we might attract more students into the biomedical field by applying existing skills from the original programs. The proposed course is considered a special topics class but might be adopted permanently if we could offer it successfully for several semesters. This is also available as an option for the graduate programs.

Sensor systems and instrumentation play a common role across several engineering disciplines while engineering applications to healthcare are expected to grow in the future[10,12]. The authors consider that a course combining electrical engineering, computer science and biomedical engineering applications gives students the exposure to real problems in an emerging area. The goal is to engage more students into the field and provide skills that are transferable to many other areas.

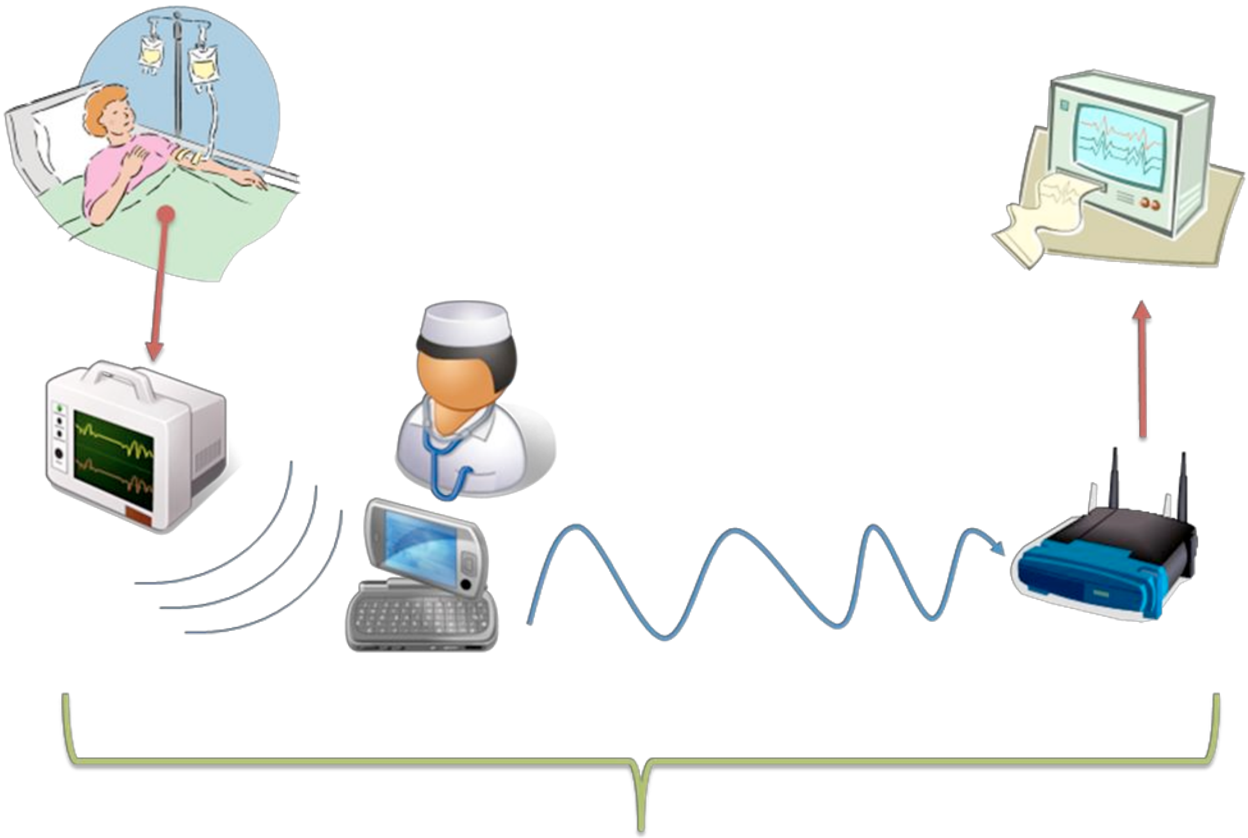

Figure 1, Wireless biomedical data collection

An increasing fraction of medical devices are becoming network connected[10,12], primarily with the objective of improving monitoring or control while reducing the need for direct human intervention (Figure 1). Small portable wireless devices will play an increasing role in the process. The collection of medical readings from the human body requires a wide array of measurements that must be adjusted to different diagnostics; however a generic model can be applied. In all cases a sequence shall begin with the acquisition of patient signs. Then a wireless collecting device will obtain the needed data and transmit it to a central location. Finally a common repository will be able to process the information to generate a diagnostic.

Based on our previous example a mixture of computer science, systems, biomedical, mechanical and electrical engineering disciplines will be required to assemble future instruments. There are several examples in the literature examining the utility of self organizing wireless sensor networks (WSN) applied to healthcare [4, 7, 8] and the technical expertise needed in related technologies [2].

We selected an open platform, for the laboratory exercises, that could be easily configured by the students while keeping a relative low cost. Students used several laptop computers and smart phones to represent processing and collection devices. We deployed Linux environments installed on virtual machines in the laptops, and the systems were complemented by Linux-based smart phones. The platform enabled a simple portable solution for the class.

Course Objectives and Structure

The course was designed for existing students in the CS and ECE programs. The prerequisites are basic programming skills and microprocessor knowledge. There are other optional courses in networking, biomedical instrumentation and systems integration; however they are not prerequisites. The content offered in this class covers the basic skills in those areas.

The official course outcomes listed in the syllabus are:

- Student shall be able to operate, configure, program and test relevant communication & processing systems for wireless networking.
- Student shall be able to identify characteristics of signal acquisition, monitoring, control; and apply them in the design of biomedical systems.
- Student shall be able to identify the characteristics of wireless communications and apply major protocols (wired, networked, ad-hoc, point-to-point, and epidemic)
- Student shall be able to identify security, reliability, and legal issues in wireless communications for biomed.

The assessment of the course outcomes will be provided by the successful completion of the assigned projects, the inclusion of theory concepts in the exams and the performance demonstrated through the class active learning exercises.

The semester is structured in 12 weekly modules focusing in one area of content. There are three major tracks for the content (Biomedical signals, Communications, and System configuration) and each is scheduled in 4 modules. In addition the first week is dedicated for the course introduction and the last week is used for student presentations. The class meets once every week for a three hour session.

The pedagogical approach involves much practice in configuring and programming embedded Linux on several devices to perform the required tasks. The equipment employed is very portable and can be taken easily into a regular classroom. Each module is a session of three hours because approximately two hours are dedicated to cover the content theory and the rest is to work on the projects.

We applied some collaborative learning techniques that were introduced in a workshop from the project Catalyst[9] at Bucknell University. The class was divided into eight heterogeneous teams mixing three-to-four CS and EE students. This mixture allows each team to benefit from the specialized skills associated with each major and better replicates the multidisciplinary environment encountered in industry. Each team is assigned a laptop on which they are initially responsible for installing the "Gentoo" [1] Linux distribution. Later in the course, each of these groups will also be assigned an OpenMoko[3] cell phone, and their projects will involve the creation of radio-connected applications that will incorporate radio communication between the cell-phones and the laptops which simulate medical control and monitoring applications.

Several approaches to student assessment are employed. There are three scheduled exams covering a combination of the theory from each module. The course has a strong practical component thus the grading has a large weight on weekly assignments and the final project, including reports. Finally, as we employ some active learning techniques, we give points for participation and team work by using an online collaboration tool called Ubiquitous Presenter from UCSD[11].

Module List

1. Introduction. Basic outline of course. Relationship between human body functions, signals and communications.
    a. Course policies and outline
    b. Modern Biomedical environment.
    c. Chain Human --> Signals --> Sensors --> Acquisition --> Preprocessing --> Communications --> Storage and Processing.
    d. Principles of networking
2. Systems 1: Principles of operating systems, installation and VMware.
    a. Allocation of equipment, teams
    b. Intro to virtualization, Unix/Linux, file systems, network configuration, X-windows, ssh, sshd, scp, emacs
3. Systems 2: Customization of target systems.
    a. Intro to python
    b. Cross development and tunneled communication tools
4. Communications 1: Introduction to communication protocols
    a. Types of networks and layers
    b. Layer 2 communications, (Serial ports, IEEE802 and others).
    c. Basic configuration and applications
5. Biomed 1: Origin of biological signals.
    a. Hierarchical organization: Cells, Tissues, Organs and Systems.
    b. Basic cellular structure
    c. Bioelectric process
6. Communications 2: Internet Protocol.
    a. IP packets and addressing,
    b. Subnets, network and local communications
    c. Transport layer(TCP, UDP, RTP)
7. Biomed 2: General anatomy and body functions
    a. Human systems (respiratory, cardiovascular, muscular, skeletal, integumentary, digestive, urinary, endocrine, lymphatic and nervous).

    b. Vital signs
8. Systems 3: Design of interactive applications.
    a. Intro to Python
    b. Intro Programming for TCP/IP & http demo
9. Communications 3: Routing, circuits and other performance considerations.
    a. Point to Point methods
    b. Broadcast
    c. Spanning Tree
    d. Circuit switched routing
    e. Packet routing
10. Biomed 3: Biomedical signal processing.
11. Systems 4: Security topics and SSL libraries
12. Communications 4: Physical links and transmission considerations.
13. Biomed 4: Biomedical selected topics.
14. Project presentations and Conclusions

Biomedical Modules

The focus of these modules is a basic understanding of the types of signals acquired from measurements in the human body because the Electrical Engineering department offers a specialized course on biomedical instrumentation. Our course in biomedical communication is complementary in that instrumentation is only lightly surveyed to the extent that it motivates the need for various communication modalities.

The areas of biomedical content assume that the students do not have a previous background on the subject. Therefore they are provided with an overview of the most relevant topics needed to work in the instrumentation. First there is an introduction to the cell and the construction of tissues, organs and systems. Later the students were presented with a description of the origin of biomedical signals. A second module presents an overview of human anatomy and basic vital signs. Finally they are exposed to more details in biomedical instrumentation.

The principles in the biomedical instrumentation assume the following chain of elements: Human --> Signals --> Sensors --> Acquisition --> Preprocessing --> Communications --> Storage and Processing.

- The human body is the element to be observed. There are multiple signs that can be observed in a patient to aid in the diagnostic process.
- The different measurement types generate diverse signals that have a varied set of requirements. For example the temperature of the patient could be sampled once every 10 minutes but an electrocardiogram might need 1 KHz sampling rate.
- The sensors are the physical devices that detect the biomedical signals.
- The acquisition process does the necessary signal conditioning and captures the data.
- The preprocessing phase prepares the information to be sent to the communication subsystem
- The communication subsystem employs multiple techniques to transmit the data according to the signal characteristics, resources available and healthcare needs.

- The final storage and processing of the collected information enables the diagnostic process.

Communications modules

The principles covered include a gentle introduction the layering of hardware and protocols. The course will survey the key concepts underlying the TCP/IP networking model while the radio subsystems will generally be treated as “black boxes” with convenient interfaces. For example some topics include stream (TCP) and datagram (UDP), LAN/ WAN and routing, serial connection topologies and the nature of wireless transmission including the gross characteristics of Wi-Fi, Bluetooth, and RFID communication.

Most of the commercial instruments support serial ports or, more recently, USB interfaces. Wireless network become more popular each day and almost all laptops today support Wi-Fi. At the same time most cell phones and PDAs operate with Bluetooth connections thus providing convenient access to the mobile environment. This combination enables the wireless environment for the data acquisition. The students are presented with the task of taking data in one device and transmit it wirelessly to the destination using the most adequate communication protocols.

While the short term goal of this track is to enable the construction of small demonstration class projects, the ultimate goals of this track is to provide sufficient “networked systems literacy” by preparing the students to understand and configure simple wired and wireless networks and to enable future involvement in projects that include communications.

Systems Modules

Much of the course is focused upon preparing students to develop applications for online embedded systems. This section begins with a motivated overview of the hardware and software environments chosen for this class. This is followed by descriptions of the major components of embedded systems; including modules on configuration, communication, security, and network programming.

A large variety of compilers and run-time environments are available for Linux and therefore the choice of programming language is not of deep importance. Our objective is to focus on programming concepts rather than language details. Due to its simple syntax, rich libraries and wide adoption for scientific and online systems, short learning curve, and availability for Linux, all programming examples presented in class will be in Python.

Student programming assignments will begin with implementations of a simple TCP protocol such HTTP (approximately 15 lines of code for both clients and servers) and be extended to include the implementation of a simulated biomedical monitoring application.

There is increasing awareness of the importance of all aspects of computer security in biomedical communications. To this end, students will be introduced to the key aspects of computer security including privacy, integrity, irrefutability, cryptography, availability, transitive delegation, trusted computing and access control. The security modules will be interleaved among the programming modules and the final student projects will utilize standard libraries that implement key-exchange protocols to provide end-to-end privacy, integrity, and identification properties.

Selection of a Target Development Environment

Cell phones have become ubiquitous and students are highly motivated by the potential of understanding how they work. Modern smart phones have enough processing and communications capabilities making them ideal as portable data acquisition devices. The focus of the proposed development environment is to provide an architectural overview of the software required to implement flexible online embedded systems, and to provide hands-on experience with such environment. Several embedded development platforms were considered for this course including Symbian, Windows Mobile [5] and Linux. We chose a Linux-ARM platform for the following reasons:

- Unlike windows mobile whose runtime environment differs significantly from Windows desktop, embedded Linux systems can be constructed with the same system software and runtime tools. This permits students to easily transfer knowledge between these domains.
- There is copious online documentation on how Linux systems are configured. Furthermore, deliberately trimmed down “bare-bone” installation environments such as Gentoo and Linux-from-scratch have been published. These bare-bone systems are pedagogically useful because they expose the full process of system configuration and force students to directly manage low level interfaces.
- Linux and a plethora of development tools are freely available without license costs.
- Linux is well supported by a wide range of low cost ARM platforms and education boards such as OpenMoko’s open cell phone and Texas Instruments’ Beagle Board.

To this end, we chose the “OpenMoko” Linux-based cell phone as our principal target embedded system [3]. The OpenMoko project has developed a flexible low-cost cell phone with a completely “open” electrical design and software “stack.” We view this platform as an excellent teaching environment for our course, because it integrates an ARM CPU, four commodity radio subsystems of relevance to biomedical applications (Bluetooth, Wi-Fi, GSM, and GPS), a high resolution touch-screen, SD storage and USB interfaces into a compact, attractive and low cost ($300) cell-phone format. Texas Instruments generously donated ten “Beagle Board” embedded systems built upon their low-power OMAP-2 processor which includes both ARM and DISP cores. The Beagle Board exposes a large number of the OMAP’s I/O interfaces and Linux has been ported to it. The beagle boards will be exploited to enable students to construct larger networked systems and to permit students to explore the process and challenges of developing software for multiple related platforms.

The communications capabilities enable the interfacing with several off the shelf instruments available in the ECE labs. The devices support serial, USB and other interfaces that can be connected to the development environments and convert the data to a wireless format. Some of the experiments include instruments used by the other biomedical courses allowing the students to focus on the interfacing problem.

The PC based Linux installations are implemented within virtualized environments running as guests under the Windows operating system already installed on each laptop. VMWare Inc. has generously provided limited time duration licenses to students attending this course. This use of virtualization provides several pedagogical features: (1) VMWare is available for Linux, Windows, and MacOS, and therefore permits students to exactly duplicate the course development environment on their home computers without disruption of their normal operating environments and avoids early frustration with system configuration; (2) virtualization enables students to easily manage multiple "virtual" installations on a single host which enables experimentation and permits the networking of multiple virtualized hosts within a single computer; (3) virtual machines can be configured with limited resources that mimic those available on the cell-phone target, and finally; (4) virtualization is becoming increasingly important secure embedded devices (an increasingly central concern of bio-medical applications) due to the security properties it provides.

Results

There are three major elements used initially to determine if the proposed course will be able to satisfy our objectives. The first is the number of students enrolled into the class. The second is the creation of materials that can be used elsewhere. The third is the result of a student survey at the end of the course.

The course is being offered as a special topic elective for the Computer Science and Electrical Engineering departments. The enrollment distribution is shown in Table 1. Furthermore, approximately four additional students are attending as informal auditors. The average enrollment is approximately 10 students in a senior elective in the EE program. Therefore this showed a larger interest for the students compared to other courses in the department.

Table 1, Student enrollment

	COMPUTER SCIENCE	ELECTRICAL ENGINEERING	TOTAL
Undergraduate	10	15	25
Graduate	4	4	8
Total	14	19	33

The students are involved in the process of creating the materials and support documentation by adding content to a "Wiki" module. In order to facilitate replication of this course both here and elsewhere, all instructional materials are being posted to a web site hosted at the University (http://wiki.utep.edu/display/biocomm/Home).

The course is still in progress, at the time of writing this article, and the result of the student surveys are not available yet. We plan to present them during the ASEE conference.

Conclusions

This work-in-progress project report describes an elective course designed to introduce students to biomedical communications including an intense hands-on introduction to embedded systems and communications. We anticipate that students who attend this course will be made aware of many design issues related to the design and construction of communication systems for embedded medical devices and will be prepared to contribute to their design. This complements the University's research in biomedical sensors and can enable synergistic development of devices and their communication infrastructure.

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