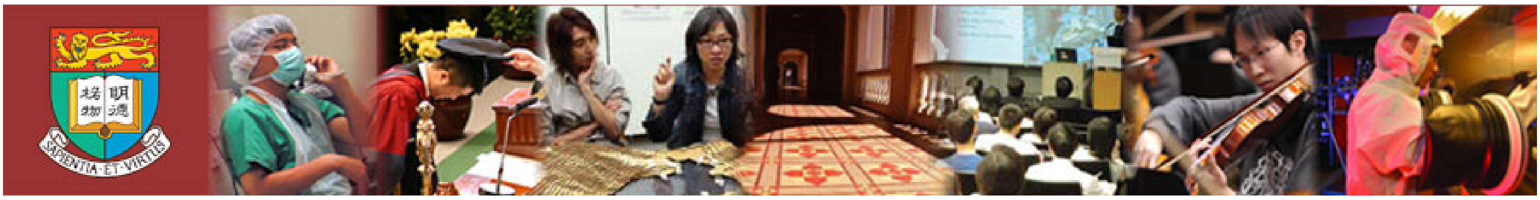

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Integration of a Wireless Sensor Network Project for Introductory Circuits and Systems Teaching

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***Abstract*—This paper presents an integration of a wireless sensor network design project in an introductory course about circuits and systems. In the project, students will design a wireless sensor network that constitutes of sensors, for a creative surveillance application. Through a versatile project vehicle, project-oriented learning modules, a comprehensive assessment strategy and public learning communities, students can learn contemporary concepts of circuits and systems from the system perspective, as well as develop ability to design a basic electronic system.**

I. Introduction

Due to the advancement of electronic technologies, engineers require a new set of engineering skills as well as integrated and system-level mindset that cannot be learned from traditional instructional methods. Therefore, different instructional methods have been proposed [1]. For example, integrated and creative-oriented project-based learning has been proposed for teaching both introductory [2], [3] and advanced electronics topics [4], [5]. Meanwhile, UC Berkeley has proposed an introductory electronics course that focuses on "design", "circuits", "technology trends" and "physical realization" [6]. In that course, students can learn basic circuit analysis through intuitive project boards. However, aforementioned courses have not clearly described the comprehensive scope of circuits and systems (CAS). In particular, they have not covered contemporary and frontier topics about CAS, such as sensory systems, CAS for wireless communications as well as power-aware CAS.

On the other hand, wireless sensor networks (WSNs), systems that constitute of sensors, micro-controllers and wireless transceivers, have been widely used in different surveillance applications [7]. Technically, WSNs are intuitive and loosely defined engineering systems that can be restructured and extended easily. Pedagogically, WSNs is suitable to illustrate basic CAS concepts, contemporary daily applications as well as frontier topics in CAS. Therefore, WSNs are suitable for introductory CAS teaching. However, most existing courses about WSN are for post-graduates or are mainly focused on embedded systems, networking and distributed systems [8]–[10]. As a result, they cannot be directly adopted for teaching introductory CAS.

In this paper, we describe how a WSN design project can be used for teaching introductory CAS. The purpose of the integration is to introduce a wide and contemporary scope of CAS, broaden students' general engineering skills, and to attract students to study CAS. The role of WSNs in CAS is outlined in Section II. The course organization, project-oriented learning modules, the project vehicle and assessment are then discussed in Sections III, IV, V and VI, respectively.

II. The Role of Wireless Sensor Networks in Circuits and Systems

In general, a circuit system is a set of individual circuit components that work interactively with a defined set of inputs and outputs. On top of that, it always converts, processes and stores signals to manipulate the environment. Among various systems, WSNs are one of the examples that can exhibit characteristics of conventional systems and contemporary systems (e.g. distributed processing, power-aware processing). They are circuit systems that contain numerous distributed systems (i.e. sensor nodes). Each sensor node in WSNs is an autonomous circuit system that usually has its own micro-controller and power source. In addition, each node usually contains sensors that examine surrounding environments. Furthermore, each node has a wireless transceiver to broadcast recorded quantities.

In summary, the complexity of sensor nodes usually depends on the storage, power, communication medium, application and deployed environment. Because of the nature of WSNs, the study of WSN spans several different disciplines, such as sensors, wireless communications, energy, embedded systems, control systems and software/hardware engineering.

III. Course Organization

The main objective of the course is to introduce first-year students to CAS. The course will involve connected learning activities and assessments that take place over 13 teaching weeks (i.e., 20 lecture hours and 16 laboratory hours). The schedule of learning activities and assessments is shown in Table I. After attending lectures and laboratory exercises, students will build a WSN prototype in a group of four students. At the end of the course, students will demonstrate the prototype.

After the course, engineering students should be able to apply technical knowledge and design a system to meet desired needs within realistic constraints. To achieve these

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requirements, students should be able to achieve the following outcomes by the end of this introductory course:

- Identify electrical devices (sensors), micro-controllers and measuring instruments
- Acquire basic knowledge about electric circuits, sensing, circuit architectures and wireless sensor networks
- Identify, formulate, design, implement and analyze a basic and scalable electronic system

Instead of teaching topics using a conventional bottom-up approach, a top-down system approach will be taken. In other words, high-level concepts will be first explained, in order to supply students with the confidence, motivation and understanding needed to explore details of implementations.

IV. Learning Modules

Before the design of WSN, students will learn from four learning modules. Contents of modules will be related to the design of the WSN, as well as other relevant technical topics. Each module contains lectures and laboratory exercises. In laboratory exercises, students will work with groups and gain hands-on experience in working with components that used in the project. Furthermore, the completeness and functionality of implemented circuits will be checked. Through these activities and the project vehicle, students will learn from different perspectives and learning environments. In addition, implemented circuits constructed in laboratory exercises can be used as core modules in the project.

A. Module 1: Circuit and Systems

This module will introduce signals, systems and circuit systems. In the module, students will also learn about architecture and limitations of basic circuit systems and embedded systems. In particular, students will learn the major components of a basic computer system and the process of data storage and instruction execution as well as pipelining and power management in computer systems. Moreover, students will learn about "design for scalability and power-awareness".

In the laboratory, students will use basic hardware description languages and an integrated development environment to implement a digital control system that reads analogue/digital signal and makes the external light emitting diode blink. In addition, students will also learn how modeling, simulation and prototyping are involved in the process of product design.

B. Module 2: Circuits and Sensors

This module will explore topics about circuit analysis, power and input-output interface. Through the module, students will explore how sensory systems can measure physical quantities and interact with the physical world. Furthermore, analog systems and digital systems as well as the process of data acquisition will be also discussed.

In the laboratory, students will explore sensors that can be used in the project, and build sensing circuits. Furthermore, students will know about errors, inaccuracies, discretization and other factors that influence the sensing process. Moreover, students will learn to measure electrical quantities and verify the functionality of analog and digital circuits.

C. Module 3: Wireless Communications in Circuit Systems

This module will explore basic topics in wireless data communications, such as packet switching, media access control (MAC) and circuits for communications. Through the module, students can learn how systems communicate with each other through wireless propagation. Furthermore, the class will also discuss how nodes communicate via a base station network, and how collisions of transmission can be avoided through simple mechanisms.

In the laboratory, students will implement a wireless data communication process, and verify whether multiple sensor nodes can share the same wireless communication channel.

D. Module 4: Wireless Sensor Networks and Circuits Systems

This module will teach about sensor networks, wireless systems and communication between nodes. Furthermore, students will learn about a variety of WSN applications, as well as requirements and constraints in the WSN system design. On top of that, a case study of a laboratory surveillance WSN (c.f. Section V-C) will be used to link materials in topics to design practice. Furthermore, through the case study, students will learn to identify major tasks associated with the WSN design. In addition, students will learn about scalability and limitations of WSNs.

In the laboratory, students will build on top of prototypes from previous modules to construct a basic WSN that can continuously measure physical quantities and send messages to the base station. Besides gaining experience of constructing basic electronic systems, students will learn how physical limitations (e.g. transmission range and power) affect the design of WSNs (e.g. placement of sensor nodes, selection of communication mechanisms and activating mechanisms).

E. Project Facilitation Tutorial

In order to help students design the WSN, a project facilitation tutorial has been prepared. In the tutorial, interesting projects in [11] have been outlined for inspirations. Furthermore, in order to help students familiarize with the design process, the following instructions will be given to students:

- *To improve collaboration: Decide an application; Hold a weekly group working session*
- *To improve creativity: Explore ways of using sensors for unconventional applications*
- *To improve problem solving: Identify allowed resources; Design and evaluate process of sensing and transmission; Evaluate the prototype*

F. Learning via Online Learning Communities

Learning with mega-scale public (online) learning communities can facilitate self-learning, as well as encourage active engagement in learning via alternative learning environments. In the project, students will be encouraged to learn constructively with the online Arduino learning community. For example, in the Arduino wiki ("Playground"), students can learn from user-generated contents (e.g. code, circuit diagrams, tutorials, success/failure stories of design, tips and tricks)

TABLE I

THE SCHEDULE OF ACTIVITIES IN THE COURSE.

Week	Learning activities	Activities in the laboratory	Assessment tools
1	Course introduction		
2	Circuits and systems		
3	Computer systems	Laboratory (circuit systems)	Laboratory work sheet
4	Circuits analysis		
5	Circuits and sensors	Laboratory (sensors)	Laboratory work sheet
6	Computer networking		Technical questions
7	Wireless communication	Laboratory (networking)	Laboratory work sheet
8	Systems in WSN		
9	Applications of WSN	Laboratory (WSN)	Laboratory work sheet
10	Project facilitation	Sensor node implementation	Interim presentation
11		Sensor node implementation	Technical questions
12		Sensor node implementation	
13		Sensor node implementation	Prototype demonstration

contributed from the public, as well as contribute materials to the public. Furthermore, students can ask for a prompt help in the forum. Furthermore, the teaching process can be facilitated by social networking technologies [12].

V. PROJECT VEHICLE

In the project, each group will design a WSN for an innovative surveillance application, as well as implement two hardware prototype (a sensor node and a base station) with its sensing mechanisms. The course will be focused on CAS knowledge and students' creativity, therefore, the content of hardware programming and wireless communications will be minimized.

A. Micro-controllers

In the project, an open-source and standard microcontroller platform Arduino will be used. In particular, in order to simplify the wireless communication process, an Arduino-compatible, antenna-embedded microcontroller project board Zigduino [13] will be used. The project board contains an Atmega 128RFA1 processor and a 2.4 GHz antenna. Besides the wireless communication port, there are 14 digital input/output ports and six analogue input ports on the board that can be connected to sensors. Furthermore, a basic wireless MAC mechanism will be used for communications.

The Arduino microcontroller can be programmed by a simple Wiring-based language. Furthermore, samples codes for system control, digital/analog input/output, display, measurement and wireless communication will be given to students. Therefore, students do not require intermediate technical skills, programming skills and electronic knowledge to implement circuits with sensors. As a result, students can easily make prototype, and eventually build functional and creative WSN systems.

B. Sensors

In the project, a wide range of sensors can be used for the measurement of physical quantities. For example, the following sensors can be used to measure various quantities:

- Kinematics quantities: rotary angle, collision, motion, acceleration, orientation, shocking, vibration

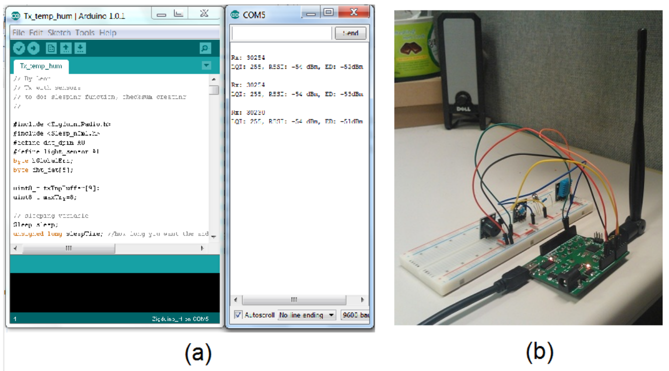

Fig. 1. A sample WSN sensor node in the course. (a) Program code for the hardware; and (b) Hardware.

- Environment quantities: toxic gas, moisture, humidity, temperature, light, sound, infra red, magnetic field
- Other quantities: voltage, current, human contact, metal contact

Provided sensor components will have standardized requirements for signal and power, such that sensors are compatible to micro-controller boards and project boards.

C. A Sample WSN Project: Laboratory Surveillance

Students' first technical design can be facilitated if a sample prototype can be given to them. Therefore, a sample laboratory surveillance WSN system has been developed [14]. The sample WSN prototype is shown in Fig. 1.

Incentives of constructing a laboratory surveillance WSN is that contemporary experimentations become highly complicated, and require volatile materials as well as sophisticated equipment. Through real-time monitoring, a safe, reliable and efficient environment can be provided for the facilitation of hands-on experimentations as well as the alleviation of equipment deteriorations.

In the sensor node of the project, sensors have been installed to measure environment conditions (e.g. temperature and relative humility) in the laboratory. Measured physical quantities are then processed by the microcontroller, and finally messages are sent to the base station via a simple single-hop acknowledged communication mechanism. In order to improve reliability of sensor nodes in the WSN, a disconnection alarm and an adaptive sensing mechanism have been installed in the system. In the future, the system can be expanded to form a large-scale WSN for surveillance of high-end industries.

VI. Assessment in the Project

A comprehensive on-going evaluation strategy will be adopted to assess students' technical understanding and skills.

A. Laboratory Work - 10% of the Grade

Four laboratory exercises will be given to students. In these exercises, students will demonstrate their ability of using equipment, designing circuits and using micro-controller boards. Furthermore, students will answer individually about the procedure of the experiment, such that every student can be able to implement a prototype in the following stages.

B. Real-World Technical Questioning - 35% of the Grade

In order to consolidate students' technical understanding, two individual homework assignments will be given to students. Assignments are closely related to the project. In particular, students will resolve situations that may happen in their project. Through solving questions, students can analyze and synthesize circuits from perspectives of systems, circuits and devices, such that students can build up their debugging skills and improve their design efficiency.

C. Interim Presentation - 5% of the Grade

After laboratory exercises, each group will give a four-minute presentation on their design. In particular, they will describe functions and working principles of the proposed WSN through a function block diagram. The assessment will be based on the feasibility of the project. Furthermore, comments will be given to students to facilitate the implementation.

D. Prototype Demonstration - 50% of the Grade

In the prototype demonstration, each project group will give a ten-minute demonstration. In the demonstration, students will describe features and functions of the prototype, as well as demonstrate the working mechanism of the implemented prototype. The assessment of the demonstration can be based on the following criteria:

1) Functionality (40%): We can count on the completeness of the prototype and the robustness of the sensing process: the system must be able to examine the environmental condition and transmit measured quantities to the base station.
2) Creativity (30%): We can count on the novelty and creativity of the surveillance application. Bonus can be given if the project can make a positive impact to the society or is for humanitarian development.
3) Practicability (20%): We can count on the extensibility and maintainability of the designed WSN.
4) Course relevance (10%): We can count on how students can apply the course knowledge to the design. For example, students can describe how the proposed system demonstrates the concept of "system architecture".

VII. Conclusion

In this paper, we have shown the integration of a wireless sensor network design project in teaching introductory circuits and systems (CAS). Sensor nodes that constitute of micro-controllers and various sensors have been used as the project vehicle. Through the project vehicle, learning modules and assessment, students can learn distinctive CAS topics (e.g. sensory systems and power-aware circuits). Besides developing student's creativity, students can acquire both technical knowledge and technical skills in the course. These experiences can be used as the grounding for other CAS courses, such as courses about electric/electronic devices/circuits, microprocessors and wireless communications.

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