Integrating NEMS/MEMS with IoT Applications into an Innovative ECE Senior Elective Course

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Abstract— **State of the art technologies in micro- and nano- electromechanical systems (MEMS and NEMS) devices have been proposed to address important issues in renewable energies, health sciences, consumer electronics, and information technology. Incorporation of MEMS / NEMS interfaces when creating a system on chip (SOC) utilizes knowledge of nanotechnology materials and devices, which is delivered as part of the new course. The new course offers software and hardware designs in nano and micro technology devices, along with widely-utilized interfaces to IoT devices and wireless systems. The course features hands-on practice on developing SOC's with MEMS / NEMS devices and is designed to prepare students for industrial and research careers. Advanced devices such as micro-motors/micro-robots, nano-motors/nano-robots, and means of navigating and imaging them within micro and nanoscale dimensions are covered with applications.**

Keywords—MEMS; NEMS; IoT; Applications; ECE

I. INTRODUCTION

In recent years, advanced electronics have incorporated micro- electromechanical systems (MEMS) and nano-electromechanical systems (NEMS) components in the architecture of integrated microsystems as applied to sensors and advanced signal processing systems. The multi-physics nature of these devices has motivated multidisciplinary engineering groups to participate in the development of embedded systems for high quality sensing devices.

Based on industry needs for these elements, our Industrial Advisory Board (IAB) made a strong recommendation to offer some IoT and MEMS components within the engineering curriculum. A faculty team from the Department of Electrical and Computer Engineering (ECE) has carried out the development of a 3 credit hour senior elective course that builds on the existing microprocessors and electronic device courses within the ECE curriculum. The intent is to include hands-on experience for applying IoT wearable devices and MEMS / NEMS into an ECE curriculum senior course that is highly integrated into various engineering applications areas such as communications, VLSI design, and wireless systems. The course addresses the need of industry for the IoT wearable devices and for the MEMS / NEMS integrated systems used in high quality sensing systems. The course also covers simulation and practical models for these devices. Some of the materials covered in the course are structured from advanced textbooks [1] and [2], and lab manuals from different manufacturers [3], [4] and [5].

In addition to these electrical and computer engineering course objectives, a section from the new course is delivered to a sophomore mechanical engineering electronics course, addressing device models within MEMS sensors and actuators.

This paper details the software and hardware development course topics for MEMS / NEMS and IoT applications. Assessment data for students' satisfactions for both the electrical and computer engineering senior course, and mechanical engineering sophomore course, as well as a sample assessment data for meeting the course outcomes, will be presented.

II. MEMS / NEMS, WEARABLES AND IOT DEVICES COURSE STRUCTURE

The new course was developed to provide our students with the latest technology and applications in using practical sensor systems and wearable and IoT devices. The course is a three-credit hour senior level elective course which is divided into three one-credit hour modules, each five weeks in duration.

The first module covers MEMS / NEMS sensors and devices with applications. The second module covers wearable and IoT devices with Bluetooth and wireless features. The third module is a project course allowing students to select a comprehensive project from module I (MEMS / NEMS simulation and fabrication devices) or from module II (wearable and IoT devices). The students may also choose a project that integrates both Module I and Module II topics. This module III pre-requisites are module I and module II

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courses. The last two lectures of module III course are dedicated to students' presentations and demonstrations of the projects. The three-credit hour course outcomes and lecture topics are shown in Table I and Table II respectively.

TABLE I. MEMS / NEMS, WEARABLES AND IOT DEVICES COURSE OUTCOMES

	Upon successful completion of the course, students should be able to:
Module I	1. Learn the features of the smart materials from nanoscale microscales [a] 2. Apply both types of materials into MEMS / NEMS [c, e] 3. Design for integrated sensor systems [c]
Module II	4. Learn the various functions of the wearable and IoT devices and boards [k] 5. Learn how to program the wearable and IoT embedded systems [e, k] 6. Conduct the laboratory associated with the wearable and IoT systems [b, e]
Module III	7. Fabricate nanosensor devices using thin film technology, and utilizing simulation via TCAD software [c, e]; 8. Design wearable and IoT devices [c, e]

TABLE II. MEMS / NEMS, WEARABLES AND IOT DEVICES COURSE LECTURE TOPICS

	Lecture Topics	**No. of Lectures**
Module I	1. An overview on semiconductors and nanomaterials	1 lecture
	2. Thin film technology; evaporation and sputtering, CVD, and epitaxial growth	3 lectures
	3. Nano/micro sensors: The pressure sensor, the temperature sensor, the gas sensor, the flow sensor, the magnetic sensor, the accelerometer, and gyroscope	4 lectures
	4. The integrated sensor	1 lecture
	5. Module I test	The 10th lecture
Module II	6. Introduction to Wearable and Internet of Things systems	1 lecture
	7. Sensors and Sensor Fusion.	1 lecture
	8. Designing with Embedded Processors.	2 lectures
	9. Tools for wearable and IoT applications.	1 lecture
	10. Embedded TCP/IP Stacks for wearable and IoT devices.	2 lectures
	11. Designing using Bluetooth and wireless transceivers.	1 lecture
	12. Designing Wearable and IoT Systems	1 lecture
	13. Module II Test	The 20th lecture
Module III	14. Course Project	8 lectures
	15. Project Presentations	2 lectures

The MEMS / NEMS module of the course integrates software Technology Computer Aided Design (TCAD) tools and hardware implementations and is a project-based course where students learn design software for the device process, then fabricate the devices in the school laboratories. Students gain new experiences with the use of apparatus systems, including thin film fabrication, Characterization System, Scanning Electron Microscope (SEM), Raman Spectroscopy, and X-Ray Diffraction instrument.

The wearable and IoT devices module of the course introduces the students to wearable and Internet of Things systems. The course also covers sensors and sensor fusion, and tools for wearable and IoT applications. Students design wearable and IoT systems using embedded processors and Bluetooth and wireless transceivers. The lab for this module has the supporting software and hardware. The software available in the lab include mbed online, KDS, SDK, MDK, Processor Expert and CodeWarrior. Students will further gain experience on using advanced embedded systems such as FRDM-K64F, FRDM-KW40Z, Hexiwear and S32V234 for embedded processing, Shields and Sensors such On-board Internal sensors, Grove sensors and Click sensors for sensing, and WiFi, Bluetooth, Ethernet, Thread and NFC for connectivity.

The complete structure of this three-credit hour senior level elective ECE course is depicted in Figure 1.

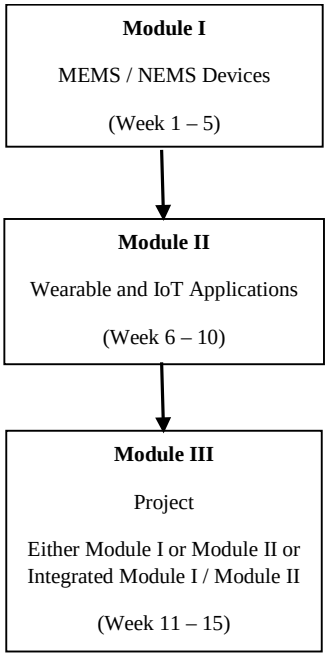

Fig. 1. Three Module Course Structure

Nine undergraduate students under supervision of two faculty members have enrolled in various research projects to develop the material for the new course. For example, two students were assigned a summer research project to develop

the IoT and wearable devices topics for the laboratory materials of the module.

III. Sample Projects

One of the module III projects used integrated module I and module II topics to develop a wireless gas sensing system. To implement the system, a gas sensing device is integrated with a micro-controller board; then an IoT platform is used to receive information from the micro-controller board and to send the information over the internet.

Input signal from the gas sensing device is received by the Freedom K64f micro-controller board at an analog input pin. Input is processed by the ARM mbed online compiler. If the gas sensor receives voltage higher than the threshold, the output data is sent to the IoT platform in real time. A notification and the data are then sent to a client server through emails, messages or twitter. An overview of the wireless gas sensing system is shown in Figure 2.

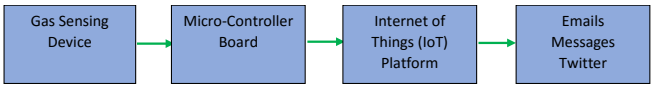

Fig. 2. Wireless Gas Sensing System Overview

Potential medical applications of this sample project would be to use a nano-scale highly sensitive gas sensing device to develop a compact breath analyzer enabling non-invasive early detection of various diseases, such as asthma, lung cancer, and diabetes.

The IoT topic projects included a music synthesizer, a gesture-controlled FM radio, a music player, and a simple reminder program. For example, for the synthesizer project, the group created an experimental musical instrument that played by changing the magnetic field around the Hexiware wearable device. The magnetic field near the Hexiware device activates the notes and modulating the magnetic field creates the different notes.

IV. Results and Discussion

This section includes:

A. Students' satisfaction data based on delivering an introductory MEMS / NEMS material in Fall 2016 in an ECE sophomore level course offered to mechanical engineering students,

B. Students' satisfaction data from the new senior level elective course offered within the ECE curriculum, and

C. Sample assessment data for meeting the course outcomes.

A. Students' satisfaction data based on delivering an introductory MEMS / NEMS material in Fall 2016 in an ECE sophomore level course offered to mechanical engineering students

Some MEMS / NEMS components of the new course were incorporated into the electrical and electronics circuits class offered to mechanical engineering students, in order to inspire them for some MEMS or mechatronics projects associated with the course materials. The feedback from the mechanical engineering students for the course materials presented to them in the Fall 2016 semester has been favorable. The students were very interested in the discussions on MEMS / NEMS devices. The students' satisfaction data, shown in Table III and Figure 3, indicates 85.3% (29 out of 34) students benefited from the MEMS / NEMS introduction presentation.

TABLE III. MEMS / NEMS Introduction Survey Questions and Responses

	MEMS / NEMS Introduction Survey Questions to Mechanical Engineering Students	**5 Strongly Agree**	**4 Agree**	**3 Somewhat Agree**	**2 Disagree**	**1 Strongly Disagree**	**AVG**
1	I benefited from MEMS and NEMS introduction presented on Tuesday.	**6**	**13**	**10**	**4**	**1**	**3.6**
2	I am currently involved in one or more MEMS / NEMS related project(s).	**0**	**0**	**8**	**12**	**14**	**1.8**
3	I am interested in pursuing a MEMES / NEMS related project in the future.	**2**	**10**	**13**	**5**	**4**	**3.0**

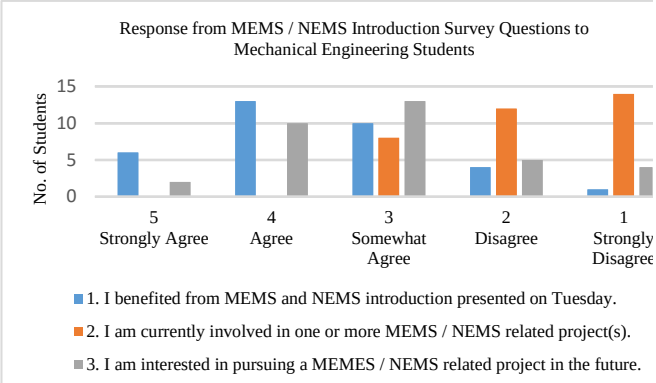

Fig. 3. MEMS / NEMS Introduction Survey Questions and Responses

In addition, 73.5% (25 out of 34) of students are interested in pursuing a MEMS / NEMS related project in the future. Only 23.5% (8 out of 34) students were involved in any related project at the time of the survey. Therefore, the data indicates the new topic appeals to more students than to simply those students already involved in it.

B. *Students' satisfaction data from the new senior level elective course offered within the ECE curriculum*

The survey questions and the responses from the senior students enrolled in the new ECE course are shown in Figure 4 and Table IV. Table IV provides a tabulated data described in Figure 4.

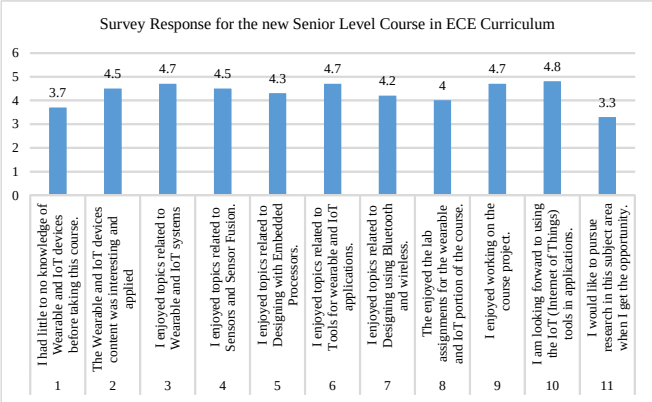

Fig. 4. IoT Survey Questions and Responses for Senior ECE Students

TABLE IV. IOT SURVEY QUESTIONS AND RESPONSES FOR SENIOR ECE STUDENTS

#	**Survey Questions to Senior Students in the new Course in ECE Curriculum**	**AVG**
1	I had little to no knowledge of Wearable and IoT devices before taking this course.	3.7
2	The Wearable and IoT devices content was interesting and applied	4.5
3	I enjoyed topics related to *Wearable and IoT systems*	4.7
4	I enjoyed topics related to *Sensors and Sensor Fusion*.	4.5
5	I enjoyed topics related to *Designing with Embedded Processors.*	4.3
6	I enjoyed topics related to *Tools for wearable and IoT applications.*	4.7
7	I enjoyed topics related to *Designing using Bluetooth and wireless.*	4.2
8	The enjoyed the lab assignments for the wearable and IoT portion of the course.	4
9	I enjoyed working on the course project.	4.7
10	I am looking forward to using the IoT (Internet of Things) tools in applications.	4.8
11	I would like to pursue research in this subject area when I get the opportunity.	3.3

The scale used for the questions is as follows:
5 – Strongly Agree, 4 – Agree, 3 – Somewhat Agree, 2 – Disagree, 1 – Strongly Disagree

As the data and positive scoring indicate, the students were very satisfied with the course materials and the experience of the practical teaching model. Students were excited and attached to using IoT tools in applications. The new course also attracted their research interests in the subject. Interestingly enough, the questions related to IoT applications (#10) and IoT research (#11) had the highest (4.8) and the lowest (3.3) average scores respectively. This indicates the students showed more interest in applying the IoT tools in applications rather than pursuing research in the IoT subject area. Overall, the contents have met the objectives of the course, and the course was an enjoyable experience for all students.

C. *Sample assessment data for meeting the course outcomes*

To illustrate how students were tested to meet the course outcomes, Table V shows sample questions and topics that were available for use in the module I exam.

TABLE V. QUESTIONS AND THE TOPICS THAT MAY BE INCLUDED IN MODULE I EXAM

Questions and the topics covered in module I exam may include:
1. Elaboration on giant magnetoresistance (GMR) based sensors
2. Nanotechnology features in medical imaging
3. Applications for ferrofluids
4. Diagram for the Scanning Tunneling Microscope (STM) system
5. Function of the piezoelectric material used in electron microscopy
6. Magnetic proximity and eddy current sensors
7. Diagrams of the LVDT (linear variable differential transformers) in displacement sensors
8. Define the GSSA (gas sensing signature array), and different parameters of the array.
9. Circuits for outputting the sensed gas presence in voltage form.
10. Theory of the NEMS/MEMS based gyroscopes.
11. Elaboration on the issues of obtaining practical measurements when using NEMS devices.

The students satisfy the course outcomes and the typical average exam score for the MEMS / NEMS module of the course is 88%.

V. CONCLUSION

The new senior elective electrical and computer engineering course has successfully met the objectives of introducing our students to state of the art technology hardware and software in MEMS / NEMS and IoT devices. Based on the survey results and high average grades on exams, the students are very satisfied with the course outcomes and have effectively learned the material. The new course has also addressed the feedback from out Industrial Advisory Board (IAB). The students were exposed to highly sophisticated equipment and are ready to use the tools in related MEMS / NEMS and IoT industry applications. The sophomore mechanical engineering students are also very interested in the MEMS / NEMS and IoT introduction and the subject has attracted the students toward multidisciplinary research and future mechatronics courses.

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