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Curriculum Innovations through Advancement of MEMS/NEMS and Wearable Devices Technologies

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Abstract

State of the art technologies using both micro- and nano- electromechanical systems (MEMS and NEMS) and wearable and Internet of Things (IoT) devices have impacted our daily lives in applications including wearable devices and sensor technology as applied to renewable energies and health sciences, among others. Several examples are device implants, optical devices, micro and nanomachining, embedded systems and integrated nano sensor systems. The recent Electrical and Computer Engineering (ECE) and Mechanical Engineering (ME) curricula lacked inclusion of these elements within their programs. Close scrutiny to the need of local industry from engineering graduates has emphasized the motivation to develop these materials into the engineering curricula.

Within the ECE curriculum, a new senior course was developed to cover MEMS/NEMS devices as well as wearable and IoT devices with Bluetooth and wireless features. The MEMS/NEMS module of the new course integrates software CAD tools and hardware implementations. It is a project-based course where students learn software for the device process, then fabricate the device in the school laboratories. The wearable and IoT devices module introduces the students to Wearable and Internet of Things systems. It covers sensors and sensor fusion, embedded processors, tools for wearable and IoT applications, and design using Bluetooth and wireless IoT systems. The new course development objectives are hands-on practice, and preparation of senior students for industrial and research careers.

In addition, an introductory MEMS topic section is added in the sophomore level electrical engineering course offered to mechanical engineering students. It introduces MEMS devices employed as energy conversion devices. Based on our recent feedback, the students have favorably accepted this MEMS addition to the course.

This paper details the software and hardware development elements of the new course. It also presents the assessment data for students' satisfaction for both the electrical and computer engineering (ECE), and mechanical engineering (ME) students.

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.

Upon close scrutiny of the industry need 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 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] and [4].

II. The Course Development

2.1 Undergraduate research courses during the 2016 academic year

The development of this course was achieved by providing senior students with research and design experiences in related topic areas. The research experience from undergraduate students has been very productive. In Spring, Summer, and Fall 2016, the course materials were developed. The materials included the TCAD simulation laboratory, IoT wearable device laboratory, and an introduction to nano-scale based advanced devices. The laboratory component of NEMS/MEMS module was developed in the Integrated Nanosystem Development Institute (INDI) which belongs to our campus. Table 1 summarizes the research topics assigned and performed by ECE students.

Table 1: Research courses used in the development of the new senior course

Semester	Student Status	Research Components
Spring 2016	Two students for summer research	Developed the IoT and wearable devices topics for the laboratory materials of the courses.
Summer 2016	One senior ECE student	TCAD software development (for Device fabrication process for semiconductor and nanomaterials). A lab manual was developed.
Summer 2016	Two students assigned for Undergraduate Summer Research	MEMS Sensors
Summer 2016	One RET (Research Experience for Teachers) funded by NSF research work (joined with graduate student work)	MEMS sensor hardware development
Fall 2016	Two students assigned under undergraduate research courses	Integrated sensor system

Nine undergraduate students have participated in the development of the new course under the supervision of two faculty members. Students who participated in the software and hardware development have done an excellent job in the course projects. Their confidence in the course materials has led the department to assign them as teaching assistants for the newly developed course.

2.2 MEMS / NEMS software and hardware development

In the MEMS / NEMS module of the course, students use Technology Computer-Aided Design (TCAD) to learn design software for the device fabrication process. The devices are then made in the school laboratories. The 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 instruments. The hardware apparatus suite was chosen based on evaluation of specific capabilities such as precision, accuracy, and high speed; it is used for testing and characterization as well as fabrication.

2.3 IoT software and hardware development

In the IoT module of the course, 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 tools 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.

III. The Developed Course

The purpose of this course is to provide students with the state-of-the-art technology and applications in various engineering fields with hands on experience on using practical sensor systems, wearable and IoT devices. Three credit hour course, covering three main components “Modules”: (1) five weeks for MEMS/NEMS, (2) five weeks for IoT and wearable devices, and (3) five weeks for a team project that could be from one area or from integrated IoT and MEMS/NEMS areas.

3.1 Module I – MEMS / NEMS

Module I is a one-credit-hour course and five weeks in duration. This first module covers MEMS / NEMS devices / sensors with applications. Module I course outcomes, lecture topics and sample course project titles are outlined in Tables 2, 3 and 4 respectively.

Table 2: Module I Course Outcomes

Module I - Upon successful completion of the course, students should be able to:
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]

Table 3: Module I Lecture Topics

Module I - Lecture Topics	No. of Lectures
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

Table 4: Module I Course Project Titles

Module I - Sample Course Project Titles
• High sensitivity graphemes gas sensors • High efficiency photo voltaic graphene cells • Low power SoC (System on Chip) for integrated nano sensor system

3.2 Module II – IoT

Module II is a one-credit-hour course and five weeks in duration. This second module covers wearable and IoT devices with Bluetooth and wireless features. Module I1 course outcomes, lecture topics, and sample course project titles are outlined in Tables 5, 6 and 7 respectively.

Table 5: Module II Course Outcomes

Module II - Upon successful completion of the course, students should be able to:
1. Learn the various functions of the wearable and IoT devices and boards [k] 2. Learn how to program the wearable and IoT embedded systems [e, k] 3. Conduct the laboratory associated with the wearable and IoT systems [b, e]

Table 6: Module II Lecture Topics

Module II - Lecture Topics	No. of Lectures
1. Introduction to Wearable and Internet of Things systems	1 lecture
2. Sensors and Sensor Fusion.	1 lecture
3. Designing with Embedded Processors.	2 lecture
4. Tools for wearable and IoT applications.	1 lecture
5. Embedded TCP/IP Stacks for wearable and IoT devices.	2 lecture
6. Designing using Bluetooth and wireless transceivers.	1 lecture
7. Designing Wearable and IoT Systems	1 lecture
8. Module II Test	The 20th lecture

Table 7: Module II Course Project Titles

Module II - Sample Course Project Titles
• Mini BoT for obstacle detection • Spectrum analyzer music visualizer using FRDM-K64F • Voice recognizer • Alert System

3.3 Module III – Projects Course

Module III is also a one-credit-hour course and five weeks in duration. This third module's pre-requisites are the first two modules, and it is a project course allowing students to select a 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 course structure is summarized in Figure 1.

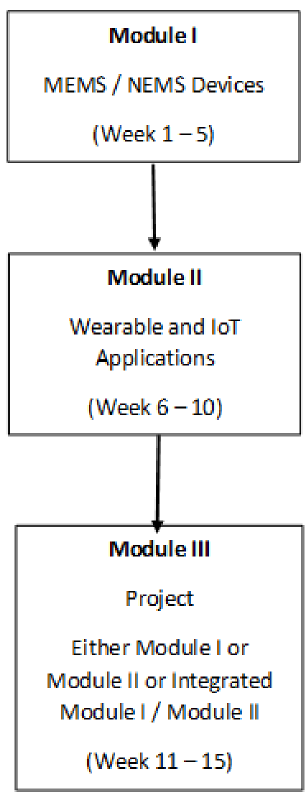

Figure 1: Three Module Course Structure

Students who complete the three modules may use the 3 credit hours as an elective course for electrical engineering or computer engineering programs.

Module III course outcomes and lecture topics are outlined in Tables 8 and 9 respectively.

Table 8: Module III Course Outcomes

Module III - Upon successful completion of the course, students should be able to:
1. Fabricate nanosensor devices using thin film technology, and utilizing simulation via TCAD software [c, e]; 2. Design wearable and IoT devices [c, e]

Table 9: Module III Lecture Topics

Module III - Lecture Topics	No. of Lectures
1. Course project	8 lectures
2. Project presentations	2 lectures

In the last five weeks of the semester, students select a comprehensive project based on either nano / microsensors (from Module I) or wearable and IoT devices (from Module II) or integrated Module I / Module II sources. Final presentations are held in the last two lectures of the semester.

Projects applications include renewable energy, automotive industry, consumer electronics, and medical devices.

Computer tool usages include, Synopsis TCAD, NXP's Embedded Processors and C Language.

IV. Results and Discussions

The results included in this section cover the assessment data for two different components:

1. Data received from the Sophomore level mechanical engineering students from the delivered introductory MENS/NEMS materials in Fall 2016

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 10 and Figure 2, indicates 85.3% (29 out of 34) students benefited from the MEMS / NEMS introduction presentation. 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.

Table 10: MEMS / NEMS Introduction Survey Questions and Responses

MEMS / NEMS Introduction Survey Questions to Mechanical Engineering Studnets	5 Strongly Agree	4 Agree	3 Somewhat Agree	2 Disagree	1 Strongly Disagree	Average
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

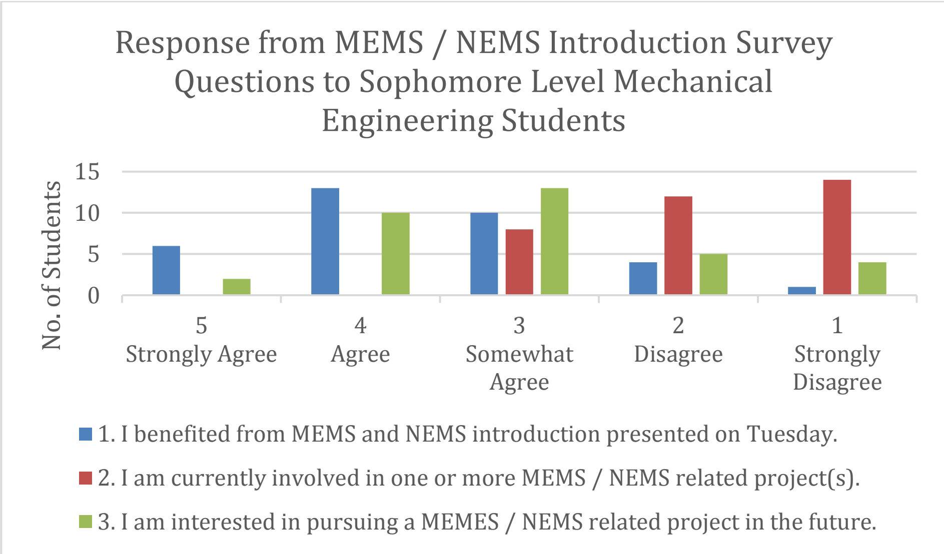

Figure 2: MEMS / NEMS Introduction Survey Questions and Responses

2. Assessment data from the students in the new Senior 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 3 and Table11.

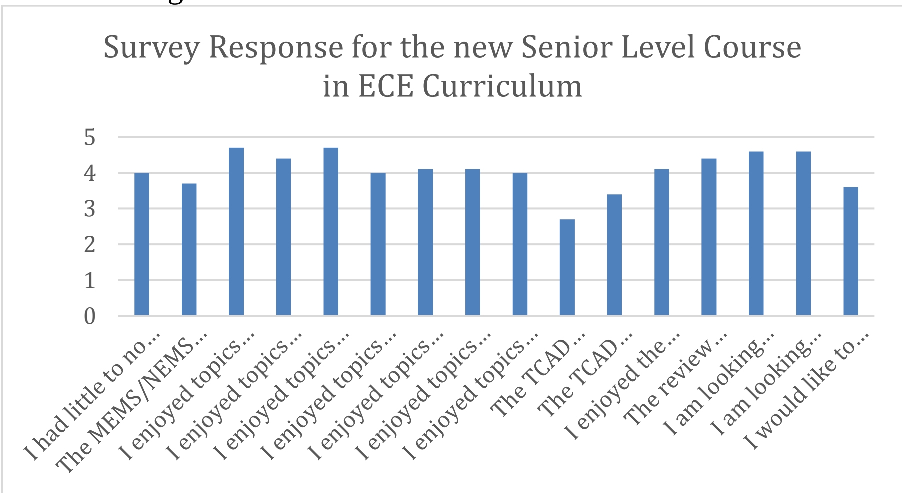

Figure 3: Survey Questions and Responses for Senior ECE Students

Table 11 provides the tabulated data described in Figure 3.

Table 11: 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 MEMS/NEMS before taking this course.	4
2	The MEMS/NEMS devices and systems content was what I expected.	3.7
3	I enjoyed topics related to Nanomaterials and Applications.	4.7
4	I enjoyed topics related to Electron Microscopy.	4.4
5	I enjoyed topics related to MEMS Sensors.	4.7
6	I enjoyed topics related to NEMS Graphene Based Devices.	4
7	I enjoyed topics related to Micro and Nano Motors.	4.1
8	I enjoyed topics related to Micro and Nano Robots.	4.1
9	I enjoyed topics related to Applications for Accelerometers and Gyroscopes in Pre-fall Detection.	4
10	The TCAD software simulation helped me learn the fabrication process.	2.7
11	The TCAD software tutorial was easy to follow.	3.4
12	I enjoyed the topics of the term papers associated with the class materials on MEMS/NEMS.	4.1
13	The review questions provided were appropriate for test preparation.	4.4
14	I am looking forward to using fabrication equipment for thin film technology and SEM (scanning electron microscope) for testing the NANO device in the course project.	4.6
15	I am looking forward to using the IoT (Internet of Things) tools to produce a wearable “wireless” system that transmits MEMS/NEMS device information.	4.6
16	I would like to pursue research in this subject area when I get the opportunity.	3.6

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. The new course also attracted their research interests in the future. Students were excited and attached to the use of MEMS / NEMS fabrication and testing machines including exposures to Scanning Electron Microscope (SEM), Raman Spectroscopy and X-Ray Diffraction instruments. The dissatisfaction issue with TCAD software simulation (question #10) was related to issuing the students’ accounts and switching software from one operating system to another. In the future offerings, this problem will be resolved before starting the course. Overall, the contents have met the objectives of the course, and the course was an enjoyable experience for all students.

V. CONCLUSION

The new course has met the objectives in effectively introducing the state of the art technology in software and hardware for senior electrical and computer engineering students. A portion of the course was delivered to mechanical engineering students in order to attract them toward multidisciplinary research and further involvement in mechatronics courses. The new course has prepared students to engage in research projects within both ECE and ME departments, and has addressed the feedback from our Industrial Advisory Board (IAB). The integration of knowledge using NEMS and MEMS with the IoT devices has enhanced the students' understanding of applications and related wireless systems. The high sensitivity Graphene gas sensor with IoT devices was an appropriate project for the students offering exposure to fabrication processes and highly sophisticated equipment, and interfacing them to IoT wireless devices.

Acknowledgement

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