AC 2011-105: INTRODUCTION OF MECHATRONIC TECHNOLOGY INTO CROSS-DEPARTMENT PRODUCT DESIGN CURRICULA

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Introduction of Mechatronic Technology into Cross-Department Product Design Curricula

Abstract

This paper presents the work that is currently conducted by faculty in the departments of mechanical engineering technology and computer engineering technology to introduce mechatronic technology into product design curricula of both departments. This work is funded by the NSF ATE (National Science Foundation Advanced Technology Education), Award No. DUE-1003712 recently awarded to New York City College of Technology.

Advances in computer technology and semiconductor electronics have created a new product design field called **mechatronics**. Mechatronics treats product design as system design that requires the tight integration of mechanical components, electrical/electronic systems, industrial design ideas, computer-control systems, embedded systems, and intelligent software into the product design and development processes. It requires engineers, technicians, and designers from various disciplines to possess broader knowledge beyond their specialized fields and to work together concurrently. This concurrent engineering and mechatronic design approach, which emphasizes team collaboration, has become the new industry standard in product design and development. Mechatronic technology has been identified as one of the top 10 highly influential emerging technologies of the 21st century by MIT's Technology Review and by the International Center for Leadership in Education.

Students from both departments were given mechatronic/robotic design projects that required them to use actual mechanical, electrical/electronic hardware and software that are currently being used by the industry. This enabled the instructor to simulate real life product design activities inside the classroom and laboratory. Not only were students exposed to the latest in mechatronics, they also learned the concurrent engineering design approach. Students were given a framework of fundamental design knowledge with hands-on cross-disciplinary activities that allow them to develop an interdisciplinary understanding and integrated approach to product design. Through these hands-on activities, students will also learn the concept of product lifecycle management and sharpen their teamwork skills.

Curriculums of the all three programs (mechanical engineering technology, electro-mechanical engineering technology, and industrial design technology) will be modified to create cross-departmental design projects. Students will learn how to design, construct, evaluate, operate, and test mechatronic products. Activities include: 3D design and modeling, materials and manufacturing process selection, mechanical and structural design, electrical/electronic design, computer control with embedded systems, interfacing, programming, and project management. These simulated product design activities will give students a better understanding of product design processes and provide them with much needed hands-on experience.

Students who enroll in this training program will serve as student mentors to help local high school students to engage in various pre-engineering activities such as FIRST Robotic Competition (FRC) and FIRST Tech Challenge (FTC). These activities have been proven very

effective in attracting high school students to study STEM related fields in colleges and universities.

1. Mechatronics

Mechatronics is defined as a multidisciplinary engineering system design. It is the synergistic combination of mechanical engineering, electrical and electronic engineering, computer engineering, and systems design engineering in order to design and manufacture useful products. To put into perspective, mechatronics treats product design as a system design that requires the tight integration of mechanical components, electrical/electronic systems, industrial design ideas, computer-control systems, embedded systems, and intelligent software into the product design and development processes. It also requires engineers, technicians, and designers from various disciplines to possess broader knowledge beyond their specialized fields and to work together concurrently[1-2]. This concurrent engineering and mechatronic design approach, which emphasizes team collaboration, has become the new industry standard in product design and development. Mechatronic technology has been identified as one of the top10 highly influential emerging technologies of the 21st century by MIT's Technology Review and by the International Center for Leadership in Education[3-4].

2. Linking Engineering Education to Secondary Education

In this country, currently, only 5% of college degrees are in engineering, compared with 20% in Japan and Germany, and 40% in China[5]. This is partly due to the lack of hands-on opportunities in high schools in which students can participate actively, and the lack of pre-engineering programs in high schools that can produce long lasting interest[6]. The FIRST Robotics Competition (FRC) has been proven to be very effective in building high school students' interest in science, engineering, and technology across the nation. FRC started in 1992 with only 28 teams participating. In 2009, 1680 high schools participated in the FRC across the United States. Over 42,000 students were involved. It had a tremendous impact in high schools. Many students who participated in the FRC have ended up going to colleges and majoring in engineering, science, and technology[7]. In a recent study conducted by Brandeis University involving high schools students in New York City and the Detroit area, it was found that when compared to other high school graduates with similar preparation in mathematics and science, FIRST participants were (1) nearly twice as likely to major in science or engineering than comparison students (55% vs. 28%); (2) more than three times as likely to major in engineering (41% vs. 13%) than the comparison students, and seven times the average among US college students overall[8-9].

The Mechatronics Technology Center (MTC) to be established at New York City of Technology by the NSF ATE grant adopts the robotic technology used by FIRST's FRC and FTC divisions. As a result, it also serves as a platform to provide training to New York City high school students and teachers who are involved in FRC, FTC and other pre-engineering activities.

Nationally, technician education practice must align with industry practice or face the risk of losing national competitiveness in the new mechatronic product design and development area. New York City College of Technology (NYCCT), as a top producer of associate-degree recipients from underrepresented minority groups, has the opportunity to lead in training technicians to use project-based concurrent design, moving away from the current paradigm of sequential design within disciplinary boundaries to bring educational practice into sync with industry needs. This approach has been proven to drive much higher levels of performance by empowering each participant; speeding development by eliminating resource bottlenecks; and to improve quality and creativity in product development by bringing together multiple perspectives to solve problems and share specialized insights across a range of products[10].

3. Goal and Objectives

Our goal is to change the paradigm for technician education in mechanical engineering technology, electro-mechanical technology, and industrial design technology programs by making concurrent design and mechatronics the hallmark of these programs at City Tech. Our objectives are:

1) To create a product design/mechatronics technology center (MTC) that provides hands-on training platform to teach emerging mechatronic product design technology to emulate the robotics training program developed by the Robotics Academy at Carnegie Mellon University.

2) To establish linkages through collaborations in a form of partnership that provides a pathway from secondary to post-secondary educational institutions to industry, using mechatronics and concurrent design as the tool. This would enable high schools, two-year and four-year college programs, and the industry to operate synergistically as a system.

3) To develop internships to bring workforce training directly into college. This would lead to create a certificate program in providing opportunities for incumbent workforce and high school technology teaches to be trained on emerging mechatronic/robotic technology

4) To articulates with 4-year programs in computer engineering technology, industrial design technology, and career and technical teacher education at City Tech as well as other 4-year engineering and technology institutions. This would help to establish a pipeline to supply graduates at different levels with well-balanced practical engineering knowledge and adaptable technical skills.

Each program that this proposal is aimed at improving plays a vital role in the US economy. Industrial design, for example, has been identified as a crucial element at improving productivity[11]. Industries such as medical devices, consumer electronics, automobiles, and home appliances depend on industrial design for innovation and competitive advantage[12-13]. The technology fields that this program covers in mechatronic technology includes design, materials selection, manufacturing, and testing fields that have been identified by ATE as well as by “Engineer of 2020” report, and elsewhere[5,14-16] as vital for the nation’s economic prosperity.

4. Mechatronics Technology Center (MTC)

4.1. Creation of MTC

The MTC will consist of a new robotic laboratory and several existing laboratories. The existing laboratories are: CAD, Materials Testing, Manufacturing, Control Systems, Instrumentation, and Computer Controlled Systems Laboratories. Many laboratories are equipped with the state-of-art software and hardware as shown in the following Table 1:

Table 1: Software and Hardware

Software	Hardware
Pro Engineers, Autodesk Inventor, MasterCAM, Matlab, Maya, LabVIEW, NXT Compiler, FIRST Robotic Compiler, RobotC, Arduino Compiler, Java NetBeans IDE, Micro C and MS Visual Studio Compiler	CompactRIO, LabVIEW FPGA, NI C Series Module, NI Single-Board RIO, NI myDAQ, Lego's Mindstorm NXT Brick, FRC, FTC, Arduino Micro-controller, Netduino Micro-controller, Arduino Shields/Modules, IC Atmega328, Pic18 Micro-controller

The software is installed in all labs; whereas, the hardware is kept in a few labs. New machines such as a CNC milling center, injection molding, water jet, and 3D printers have been purchased in recent years. Funding will be used to establish the robotic laboratory that forms the core of the MTC.

4.2. Timelines and Activities

We estimate that it will take three years to fully implement the product design/Mechatronics Technology Center. The timelines and activities are shown in the following Table 2:

Table 2: Timelines and Activities

Summer 2010	Fall 2010	Spring 2011
Professional development; Train college students on research; Modify existing curricula	Professional & curricula developments; Train mentors; After school robotic program; Consult with industry partners	Teach new courses; Train mentors; After school robotic program; Develop internship program; Hold dissemination activities
Summer 2011	**Fall 2011**	**Spring 2012**
Training high school students and teachers; Develop training modules; Contact partners and develop internship programs	Teach new courses; Train mentors; After school robotic program; Work on certificate program	Teach new course; Train mentors; After school robotic program; Establish new industry links; Hold dissemination activities
Summer 2012	**Fall 2012**	**Spring 2013**
Train high school students and teachers; Contact industry partners and develop internship programs; Develop training modules	Teach & refine new design courses; Train mentors; After school robotic program; Establish articulation partners; Hold dissemination activities	Finalize training modules; Train mentors; After school robotic program; Finalize articulation; Disseminate results; Finalize certificate program

4.3. Robotic Laboratory

The robotic laboratory will feature robotic systems used by both the FIRST Robotic Competition (FRC) division (upper level) and FIRST TECH Challenge (FTC) division (mid level) to be purchased for the project. FIRST Robot Kits were chosen because of following reasons:

1) The FIRST Kits' open architecture. Unlike many other educational robot kits, which provide a fixed configuration and are used mainly for programming, FIRST robot kits provide mainly the enabling components used in the industry (robot controller, electrical/electronic devices, motors, sensors, diagnostic software etc). This allows us to create projects to simulate actual industry activities in designing, constructing, testing, evaluating, and programming mechatronic products. It emphasizes creative thinking, innovation, problem solving, and hands-on teamwork.

2) FIRST Robot Kits represent the latest robotic technology used in the industry. In the FRC division, the National Instrument's state of the art CompactRIO (cRIO) programmable automation controller is used as the robot controller[17]. The cRIO features an embedded real-time processor for reliable stand-alone or distributed operation and is embedded with a Field Programmable Gate Array (FPGA) chip to provide the flexibility, performance, and reliability for custom hardware integration. This will enable us to create projects that touch all aspects of mechatronic design and applications. The FTC Kit which is much affordable uses Lego's Mindstorm NXT Brick as the robot controller[18]. It will be used mainly to teach robot programming and control. Both kits are used to address different needs of the program.

3) City Tech students (from cross-department with different majors), once taught with the FIRST technology, can serve as student mentors to help local high school robotic teams in various FRC and FTC events. Because of similar ages, it is easier for the college student mentors to get into hot discussion with the high school students. There are many colleges and universities that have robotic programs. But most of them do not teach the hardware and software that FIRST uses. As a result, many of these college students cannot provide much technical help to the high schools' FRC and FTC teams.

4.4. Professional Development of Faculty and Staff

Faculty and lab technicians will attend workshops on robotics curriculum creation. The goal is to create a mechatronic curriculum similar to the robotic curriculum developed by the Robotics Academy at the Carnegie Mellon University[19] (CMU). The director of the Robotics Academy at CMU has agreed to provide the training. This will lead us to our long-term goal to create a City-wide Robotic Training Initiative that emulates the successful Robotics Corridor Program developed by the Robotics Academy and other institutions in Pennsylvania. The Robotics Corridor is a consortium established in Southwest Pennsylvania to develop necessary educational infrastructure to support a $100 billion emerging robotics and intelligent systems industry[20].

Faculty and lab technicians have attended workshops on how to use National Instrument's CompactRIO embedded control platform as a robot controller. Faculty members learned the following software packages during the training: LabVIEW, LabVIEW Real-Time, Single-Board RIO, and LabVIEW FPGA. In addition, the MTC had invited experts from National Instrument (NI) to conduct the training on NI modules and instruments.

Also, the MTC had invited our own experienced City Tech faculty members to conduct workshops in Arduino micro-controller, Arduino modules and shields, Arduino Sketch, and electromechanical interfaces using Arduino. With the knowledge of Arduino, faculty members will collaborate with CMU Robotics Academy using RobotC for Arduino.

4.6. Curriculum Development and Implementation

The curricula of the three programs will be modified to create cross-departmental design projects. Students will learn how to design, construct, evaluate, operate, and test mechatronic products. Activities include: 3D design and modeling, materials and manufacturing processes selection, mechanical and structural design, electrical/electronic design, computer control with embedded systems, interfacing, programming, and project management. These simulated product design activities will give our students a better understanding of product design processes and provide them with much needed hands-on experience.

A hands-on cognitive apprenticeship-type training approach will be used to effectively deliver the training material. In conventional schooling, the "practice" of problem solving, reading comprehension and writing is not at all obvious and the thinking processes are often invisible to both students and teachers. It is very difficult to understand the logic of programming; however people in general understand better when they see a program that makes a motor turn and a sensor to react. This cognitive apprenticeship training makes the process of thinking visible[21-22].

Six courses in the three programs will be modified: MECH 2335 – Advanced Dynamics and Kinematics, MECH 2410 - Machine Design, IND 2313 - Industrial Design I, IND 2410 - Industrial Design II, EMT 2461 - Electromechanical Systems Software Interface and EMT 2480 – Electromechanical Systems Laboratory. Details of these courses can be found at www.citytech.cuny.edu/academics/deptsites/metech/index.html and www.citytech.cuny.edu/academics/deptsites/cetech/index.html.

5. Collaboration with Our Partners

We will collaborate with our educational, industrial, regional high schools, and FIRST partners to fully utilize the Mechatronics Technology Center (MTC) to meet the needs of our constituents.

5.1 Robotic Training for Our High School and FIRST Partners

The MTC will be available on weekends for high school and FIRST partners to conduct robotic training. In the past, NYC FIRST conducted a series of workshops each year taught by volunteers. However, because of the lack of the state of art facilities with proper hardware setup, the training was not effective. The MTC and the student mentors produced through this project will tremendously improve our ability to help high schools and FIRST partners to deliver the training materials. This will dramatically increase the number of high schools interested to participate in FRC and FTC activities.

We have provided after school training programs to local high school robotic teams located within one-hour-commuting distance from City Tech. Top City Tech students have been selected to serve as student mentors. Mentors have organized the training under the supervision of faculty members. Starting from the second year, each summer, we will offer two robotic training classes to high school students. Each class section will run for 8 weeks and will have 20 students in each class.

5.2 Establishing Industrial Links

Since the Mechanical Engineering Technology, Industrial Design Technology, Electromechanical Engineering Technology, and Computer Engineering Technology programs are accredited by TAC/ABET, we are required to have industry advisory board. Our industry partners currently include Con Edison, Power Authority of New York, MTA, LIRR, Metro North, Verizon, IBM, Linda Tools, Hercules Heat Treat Co., Honeybee Robotics, Scott Jordan Furniture Co, Canon, elevator industry, CUNY, Department of Education, and others. These companies either produce mechatronic products or maintain and use mechatronic products. They all hired our graduates in the past.

5.3. Articulating with Four Year Programs

This project will articulate with the 4-year programs in computer engineering technology, industrial design technology, and in career and technology teacher education as well as with other four-year degree institutions. NYU Poly has agreed to work with us on articulation agreement so qualified graduates from City Tech can pursuit a higher engineering degree at NYU Poly. We will continue to seek more articulation agreements with other higher learning institutions.

5.4 Dissemination of Information through Web Site

Web-based training materials will be developed to facilitate the teaching and learning of mechatronic design projects. Details of the web-based training information will be posted at www.mtccitytech.org. This web site has been up and running since Fall of 2010. It has information about the MTC, calendar of past and future events and training sessions, and a growing technical reference section. Videos of some of the projects conducted at the MTC are also been posted on the web site.

6. Assessment Plans

Multiple assessment tools will be used to evaluate and to determine if the project objectives and outcomes are met. The tools are:

- A database of college students and high school students trained by the project will be set up. This will allow us to document the training activities and to keep track of each participant's progress. In addition a separate database will be setup to document the inputs from the industry and institutional partners.

- Employer survey, feedback from our partners, and graduate's placement records will be used as direct assessment tools to evaluate the project objectives. Alumni survey will also be used. We will use the following direct assessment tools to evaluate the project outcomes: Faculty survey, Student's portfolio, oral exam and interview conducted by a Product Design Advisory Board, and mechatronic design rubrics.

- Survey questionnaires and mechatronic design rubrics will be developed during the professional development phase after consulting with experts from the Robotics Academy and other organizations. An external evaluator with an expertise in mechatronic design and teaching will be sought.

- We will assess the longitudinal impact on high school students grades compared to their peers who did not participate in this program. The rate of college enrollment into engineering and technology curriculums for participating high school students will also be assessed. Finally, we evaluate the effectiveness of this project to attract under-represented minority groups and women into STEM (Science, Technology, Engineering, and Mathematics) fields.

7. Project Outcomes

The success of the program and the effectiveness of the training as a result of the curricula modification will be first measured by students' ability to do the following:

- A mastery of the hands-on knowledge, techniques, and skills in mechatronic design and applications
- An ability to apply concurrent engineering concepts in product design applications
- Technical expertise in selecting mechatronic components, materials, and manufacturing processes
- An ability to analyze, design, and implement hardware and software as embedded system
- An ability to utilize mathematics and science in support of mechatronic design
- An ability to function as a team member and to communicate effectively, both in written and oral forms
- An ability to follow the timelines of the design project.

The certificate program in mechatronic product design and application and the articulation with the career and technology teacher education program will attract more people to become high school technology teachers and provide an opportunity for existing high school teachers to upgrade their skills.

8. Conclusion

We believe the project if fully implemented will significantly improve our ability to provide the kind of training that industry is looking for in the mechatronic product design and application.

City Tech students will benefit tremendously through these integrated concurrent engineering and mechatronic product design activities. In addition, by introducing the Learning Products Designs through Hands-on Robotics Projects, the impact of NYC public high school and NYC industry partners will be significant.

9. Acknowledgement

The work is funded by a grant from the National Science Foundation Advanced Technology Education Division. The award number is NSF ATE No DUE-1003712. The authors appreciate greatly the support from the NSF.

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