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First-Time Experience of Teaching a Project-Based Mechatronics Course

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First-Time Experience of Teaching a Project-Based Mechatronics Course

Abstract: The Department of Engineering and Computer Science at York College of Pennsylvania developed a new Mechatronics course for sophomore mechanical engineering students. The objective of this course is to introduce essential aspects of electronics so that mechanical engineering (ME) students can design and build basic electro-mechanical systems. This course adopted lecture-lab format to provide necessary circuit analysis background. Hands-on laboratory exercises designed to incorporate electrical circuit components, circuit analysis (AC and DC), sensors and actuators, and microcontrollers. Students also learned how to create simple electro-mechanical devices using basic components. During the latter half of the semester, students were tasked with group projects to design, build, and test electro-mechanical systems. These projects aimed to bring mechanical engineering, electronics, and computer control together. This paper describes the first-time experience of developing the course and managing student projects. This paper also presents students' feedback regarding the course and highlights student projects with testing and fabrication results.

Introduction

Mechatronics is a cross-disciplinary course that combines mechanical, electrical, and computing under one platform. Most mechanical engineering programs include a mechatronics course to introduce electronics, sensors, actuators, and computing to mechanical engineering students. This is an emerging field, and the scope of mechatronics varies from robotics to guided missiles applications. Some institutions designed mechatronic programs to satisfy growing industry needs in this area[1,2], while others make it a concentration area for mechanical engineering students[3]. Most institutions offer only one course in this area. Mechatronics prepares students to work in an interdisciplinary engineering team and develop strong skills to solve complex problems that cross disciplinary boundaries. Figure 1 illustrates how three major engineering disciplines—mechanical, electrical, and computer engineering are directly involved in mechatronics. Other disciplines such as material, industrial, and chemical engineering have an indirect connection with mechatronics[4]. Current literatures argue that there is a clear need for engineering graduates with knowledge and skill in mechatronics[4,5]. It is our responsibility to equip our engineering graduates with such skills and knowledge.

Background of Mechatronics at York College of Pennsylvania (YCP)

The engineering program at YCP has a mandatory cooperative (co-op) education that requires students to work in the industry for three semesters. The Engineering and Computer Science Department offers electrical, computer, and mechanical engineering degrees as well as computer science degree. Mechanical engineering students used to take a regular circuit analysis class to gain necessary knowledge in electrical systems. This course was designed for electrical and computer engineering students with an in-depth analysis of circuit theories. Mechanical engineering (ME) students need more application oriented learning than theory. The mechanical engineering program took an initiative to survey industry partners and students to redesign the electrical circuit analysis course to equip ME students appropriately. Co-op employers evaluate engineering students and engineering programs after each co-op employment. One of the questions the department asked "What areas could YCP Engineering improve on to better prepare the students?" The department also asked the similar question to the students. Mechanical engineering students and co-op employers recommended an application based electronic course closely related to mechanical systems. Following this recommendation, the program coordinator asked this instructor to design a course on mechatronics.

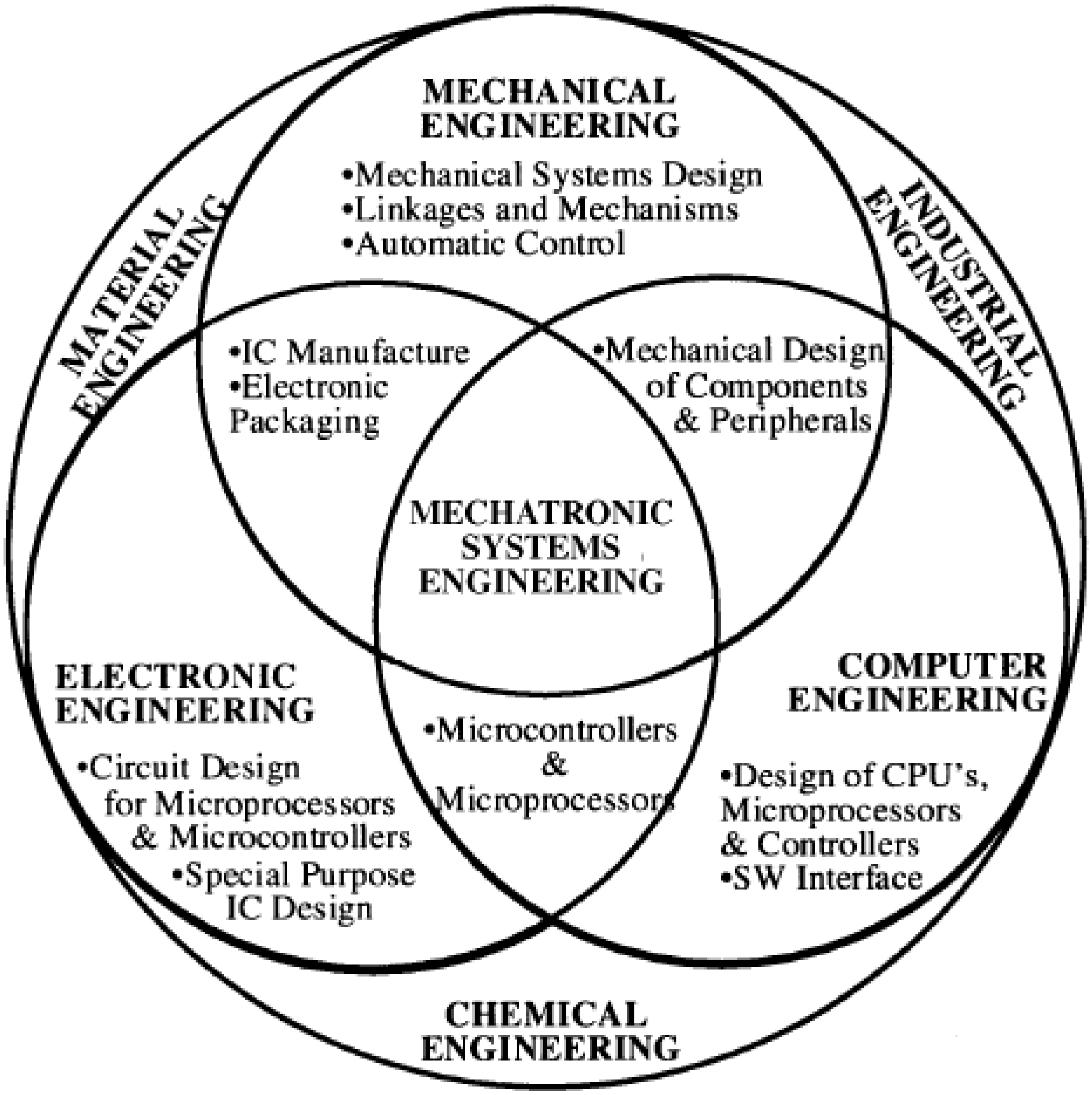

Fig. 1: The multi-disciplinary nature of mechatronics[4]

Course Overview

This new mechatronics course is to replace the circuit analysis course for mechanical engineering students. The prerequisites for this course are Computation Method in Engineering (MATLAB programing for mechanical engineers), Engineering Physics II (electricity and magnetism), and EPADS I (a freshman design class). The challenge was to design a mechatronics course for students without any circuit analysis background. This course laid the foundation based on Engineering Physics II knowledge. Objectives of this course are the following:

- Hands-on experience in circuit analysis,
- Signal conditioning,
- Integration of sensors into electro-mechanical application,
- Integration of digital circuit and microcontroller into electro-mechanical application, and
- System-level design experience using electronics, sensor, actuators, and microcontroller.

Mechatronics is a 4-credit course and is taught in an integrated lecture-lab format. In this format, there is no separate laboratory time. Class meets three days a week for two hours each day. The instructor uses class time for both the lecture and laboratory activities. There is no disconnect between lecture and laboratory. Students use the information they just received to conduct laboratory experiments. Dale's cone of learning indicates that we only retain 20% of what we hear, 30% of what we see, 50% of what we hear and see, 70% of what we say, and astonishingly 90% of what we both say and do[6]. This course tries to facilitate student centered learning by focusing on applications rather than the detail explanation of circuit theory. The instructor provides appropriate information on a topic so that students can conduct experiments and learn by doing hands-on activities. Topic and time allocation is shown in Table I. There are a total of 25 lecture-lab sessions and three exams. In every lecture-lab session, lecture time is about 40-45 minutes and students spend about 60 minutes exploring the concept(s) in a laboratory setup. A microcontroller with programming activity is integrated in almost every laboratory experiment. The main objective of this course is to learn by doing the hands-on activities. Here is the list of electrical and electronic components this course used to facilitate laboratory experiments:

- Arduino Uno R3
- MOSFET, diode, and LED
- H-bridge, op-amp, and buzzer
- Temperature sensor, flex sensor, touch sensor, light sensor, and weight sensor
- Stepper motor and dc motor
- Discrete electrical components

Student Learning Outcomes

The mechatronics course at York College of Pennsylvania includes the following student learning outcomes. These outcomes are directly related to the ABET student outcomes[7]. The mechanical engineering program does not require any formal assessment data from this course as the program collects required assessment data from other courses. Student learning outcomes:

- An ability to apply knowledge of mathematics, science, and engineering (a)
- An ability to conduct experiments as well as to interpret data (b).
- An ability to use modern engineering software tools needed in professional engineering practice (k).

- An ability to use modern engineering equipment and tools needed in professional engineering practice (k).

The instructor collected assessment data from laboratory activities, projects, and exams to evaluate student-learning outcomes.

Challenges

Mechanical engineering students are not naturally inclined to electronics and cannot relate themselves to circuit analysis without appropriate activities. Most of them do not want to be in this class. Lack of motivation was the major obstacle that the instructor faced while teaching this course. Often students spoke out about their dissatisfaction for this specific course requirement. The instructor used real world applications and interdisciplinary design examples to motivate students. Students are encouraged to share their experiences with mechatronics applications. Examples range from smart table saw and computer numerical control (CNC) machine in the machine shop to hybrid and electric cars. The objective is to demonstrate the interdisciplinary aspects of engineering design. This course also conveys the message that no engineering discipline lives in an isolated island. Mechanical engineers often need to interact with machineries, and knowledge in electrical interface would make mechanical engineers more versatile and effective.

Table I: Topic and Time Allocation

Topic	Time	Remark
Circuit analysis	Week 1 - 3	Ohms law, KVL, KCL, capacitance, inductance, filters, electrical sources and source conversion.
Signal conditioning	Week 4 - 5	Op-amp, ADC, and DAC
Sensor and actuator	Week 6-7	Sensors, motors, diodes, and MOSFET
Alternating current (ac) systems	Week 8 -9	ac circuits, transformer, ac/dc conversion
System-level design experience (project)	Week 10-14	Making progress in group projects, demonstration, presentation, and final report submission.

Project Guidelines

Mechatronic systems involve a combination of sensing, computing, and actuating devices. Mechatronic applications vary from simple heating and cooling systems to complex robotic surgical devices. Students are to design a mechatronic device to accomplish a particular task relevant to societal needs. In addition, students' design should show evidence of effort to optimize each of the following aspects of a typical engineering design: cost, reliability, efficiency, operability, and safety. Teams may not purchase or use an off-the-shelf complete solution. The intent of the project is for each team to design and build a customized solution using component-devices approved by the course instructor. Teams must address how they attempted to meet each specification in their project report. Table II shows a tentative project timeline.

Student Projects

The mechatronics class had three sections and there were 17 projects in total. Students worked in a group to plan, design, fabricate, and test the prototype. Group size varied from two to four students. Each project includes sensing, processing, and actuating to control an electromechanical device, typically a motor. The objective of the project is to demonstrate a system level application of mechatronics. Upon the approval from the instructor, students were given full responsibility to select components, create a test bench, prove concept(s), develop interface circuitry, and integrate all sub-systems. This paper highlights three projects out of seventeen.

Carbon mono-oxide (CO) detector: Motivation of this project were to improve on conventional CO sensors, add ventilation system to sensor, increase safety in homes and businesses, expand knowledge by using circuit components not used in class, and create a product not on the market. An example of the decision-making process of this project is shown in Figure 2. Figure 3 shows sub-systems of the same project and the integration of sub-systems. Figure 4 shows a fabricated CO detector system prototype. The team used CO spray for demonstration, and the prototype worked as expected.

Table II: Tentative Project Timeline

Mon, 3/16	Team Organization and Brainstorming Team Deliverable: list of brainstorming ideas emailed to instructor (customer)
Mon, 3/23	Team Design Concept Team Deliverable: 1-2 paragraph design concept e-mailed to instructor
Mon, 3/30	Preliminary Experimentation—groups develop and perform experiment(s) to help refine their design concept
Mon, 4/13	Design Refinement and Continued Experimentation Team Deliverable: 1-2 paragraph discussion of what you did and your experiment results either confirmed or resulted in change to their original design concept. Memo e-mailed to instructor
Wed, 4/15	Schematic/Bill Of Materials Circuit analysis, Solidworks model, and programming Team Deliverable: BOM and schematic, with circuit analysis
Friday, 4/17	Continue experimenting, programming, discussion with instructor, and Solidworks model for the future production.
Wed, 4/22	Parts in hand: breadboard/test circuit Team Deliverable: circuit Layout drawings, breadboard testing, and final Solidworks model
Fri, 4/24; Mon, 4/27; Wed, 4/29	Testing and experiments
Fri, 5/1; Mon 5/4	Final testing
Wed, 5/6	Project demonstration
Wed, 5/13	Team Deliverable: Final Project Presentations and Report

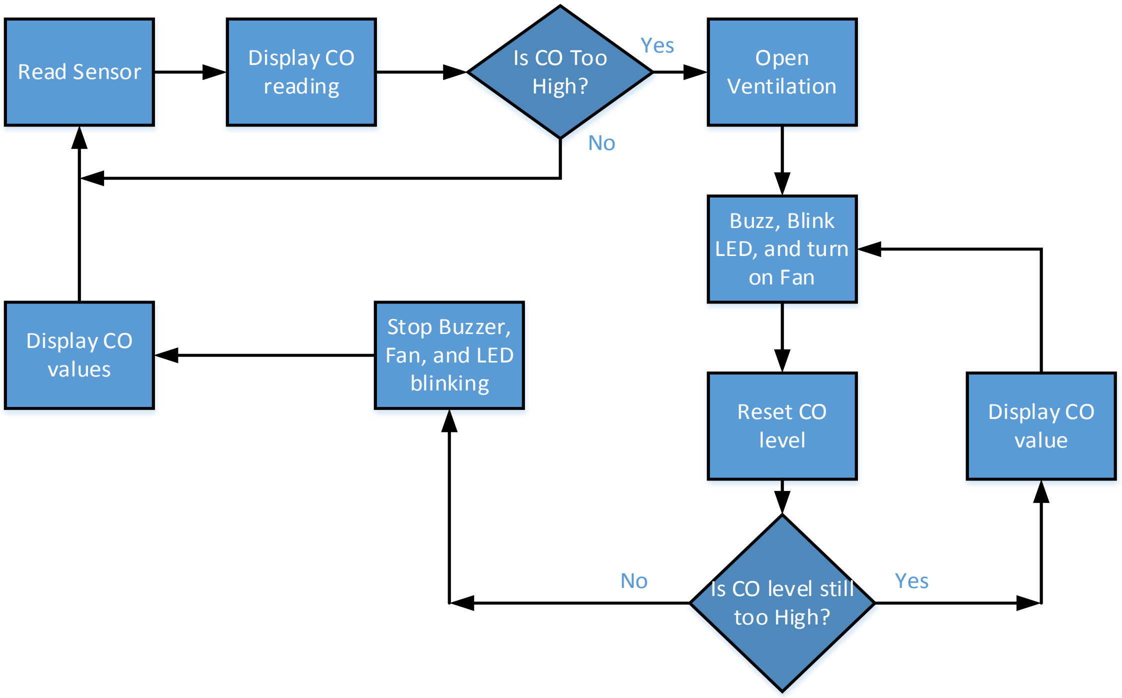

Fig. 2: Decision making process of the CO detector

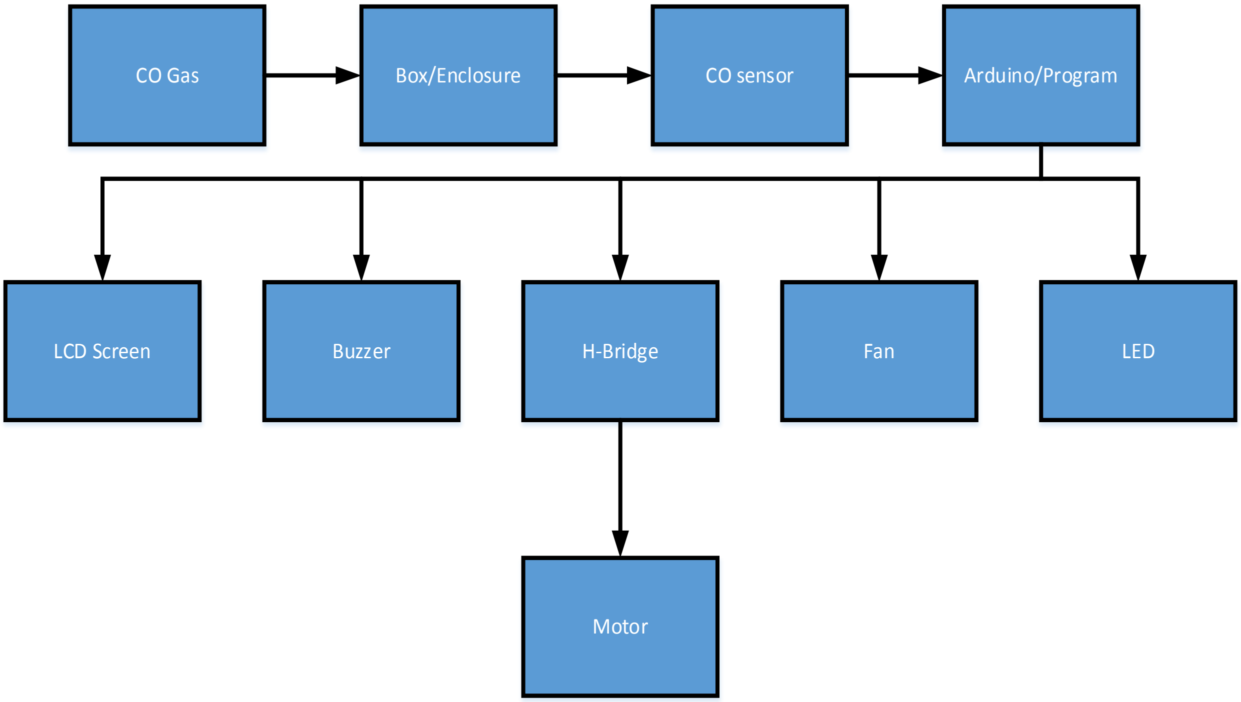

Fig. 3: Sub-systems of the CO detector

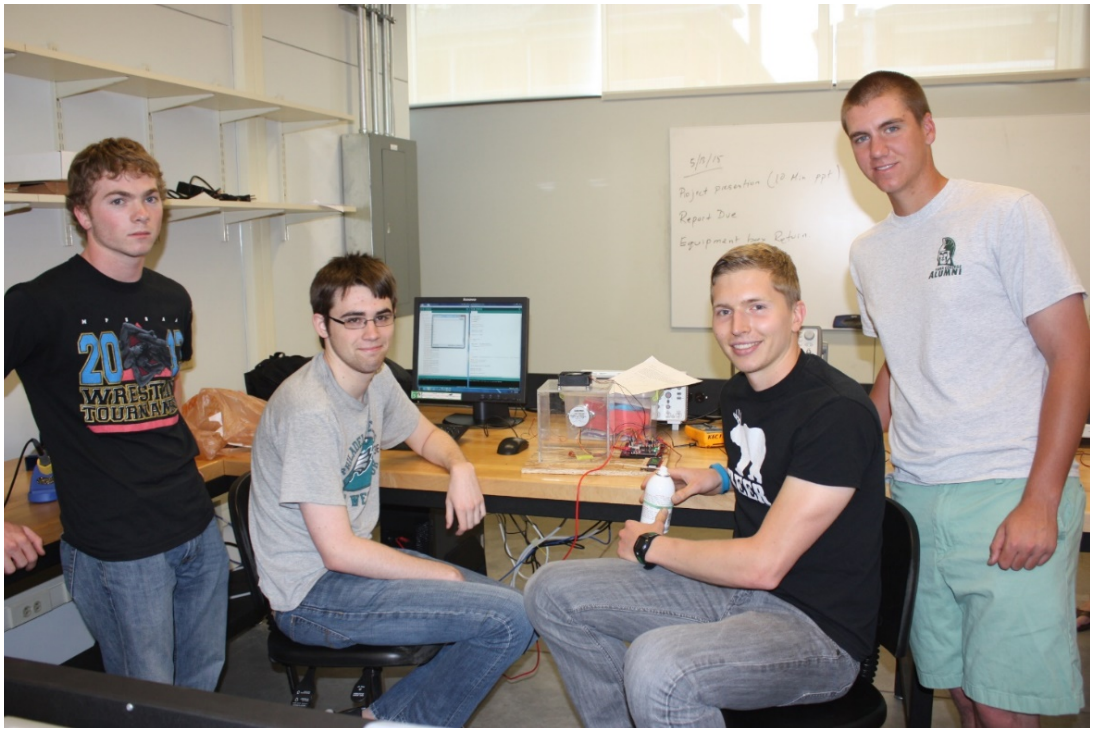

Fig. 4: CO detector system prototype

Robotic arm: This team created a robotic arm by combining a joystick, H-bridge, motors, potentiometer, and Arduino Mega board. This team also incorporated a 7-segment display to show the speed of the motor. Figure 5 shows the electrical diagram of the projects. Figure 6 shows the fabricated robotic arm in action. This robotic arm was able to transfer objects from one bowl to another with little difficulties. Overall, the prototype demonstration was a success.

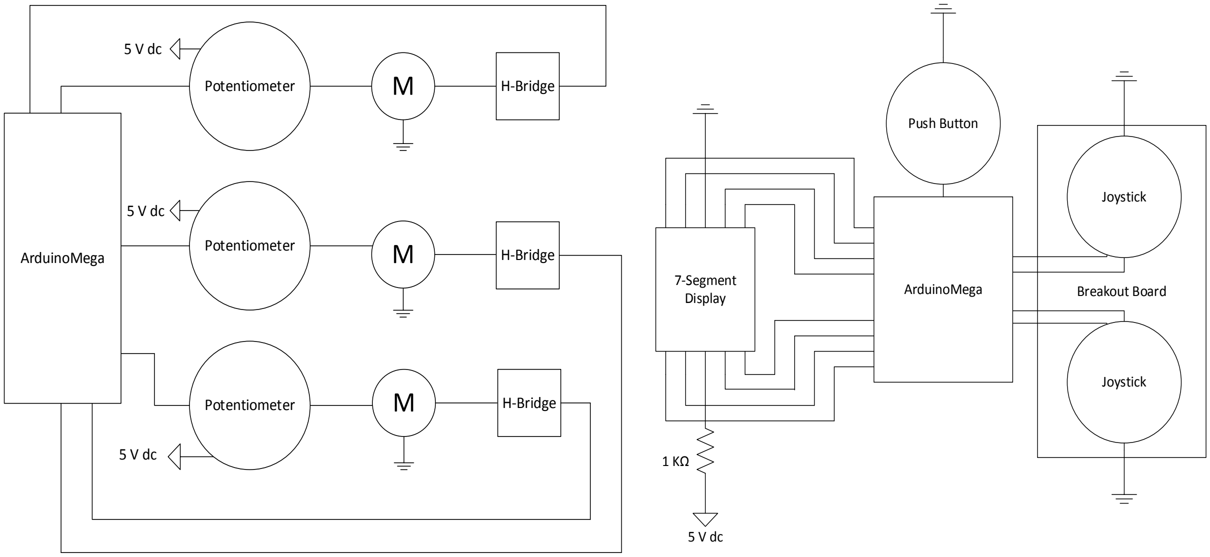

Fig. 5: Electrical diagram of robotic arm

Fig. 6: Robotic arm demonstration

Active Tracking Solar Array (ATSA): This design was for an autonomous platform that could independently track the movements of the sun and provide power in doing so. The design is entirely self-contained, running on a single 12-volt battery that powers the platform, and is in turn charged by the solar panels mounted on the platform. ATSA has two degrees of freedom, tight motion tolerances, and fully programmable reactions based on conditions. Figure 7 shows the actual prototype system along with sensor array that tracks the sun. The system demonstration worked well after some adjustments for the sun intensity. Figure 8 shows demonstration activity outside the engineering building.

Other notable projects are a coffee mug heater, water dispenser, automated blinds, skittle sorter, automated golf ball tee, conductivity-sorting mechanism, automated material sorting based on weight, gumball machine, and coffee cooling machine.

Student Learning Outcome Assessment

Assessment rubrics were developed for each learning outcome, and appropriate course activities were targeted to assess the particular outcomes. Assessment data is available for two sections out of three sections. An assessment rubric for “An ability to apply knowledge of mathematics, science, and engineering” is shown below:

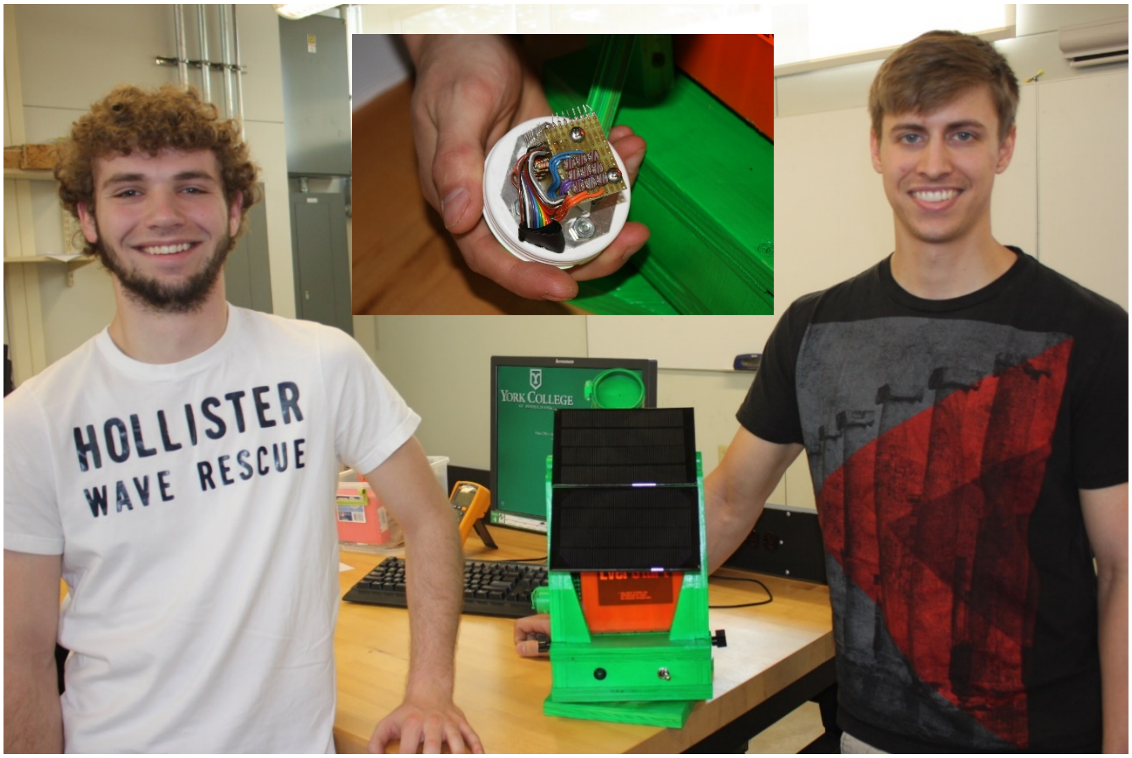

Fig. 7: Active tracking solar array prototype

Fig. 8: Active tracking solar array prototype demonstration

Type of student work used for assessment: Temperature sensor implementation with op-amp and Arduino Uno

Assessment Rubric			
Attribute	**Exceeds Expectations**	**Meets Expectations**	**Below Expectations**
• Op-amp amplifier design and implementation • Temperature sensor data interpretation	• Students did not require any help to design and build an op-amp amplifier to collect data from a temperature sensor. • Correctly converted temperature sensor data to Celsius and Fahrenheit.	• Students needed some help from instructor to design and build an op-amp amplifier to collect data from a temperature sensor. • Temperature sensor data interpretation required some help from the instructor.	• Students required extensive help from the instructor to build an op-amp amplifier and to interpret temperature data.
Student Achievement			
Number of students: 21	4/21 (19%)	11/21 (52%)	6/21 (29%)

Majority of the students were able to apply mathematics, science, and engineering knowledge to build and test a circuit to collect data from a temperature sensor. Similar rubric were used to assess other student learning outcomes. Few weaknesses were noticed in programming with Arduino Uno. Students often required help to make the circuit work with Arduino board. Students became proficient in using power supply and multimeter. Some students still required help to use oscilloscope and signal generator appropriately. Overall, more than 50% of students either exceeded or met the expectation for each outcome.

Student Feedback on Overall Course

Twenty-one students participated in the survey and the results are shown in Figure 9. Student feedback shows that the first offering of this course went well. More than 85% of students said that they learned a great deal about mechatronics application, and 57% of students found this course enjoyable while learning mechatronics. There is no alert shown in the survey, but improvement can be made in the following areas to make the course more effective and student centered. The pace of the lecture needs to be adjusted and give students enough time to understand the materials and catch up with the lecture. The laboratory experiment needs more time, and students suggested to discuss the experimental results in the class. This will improve their understanding of theory and applications.

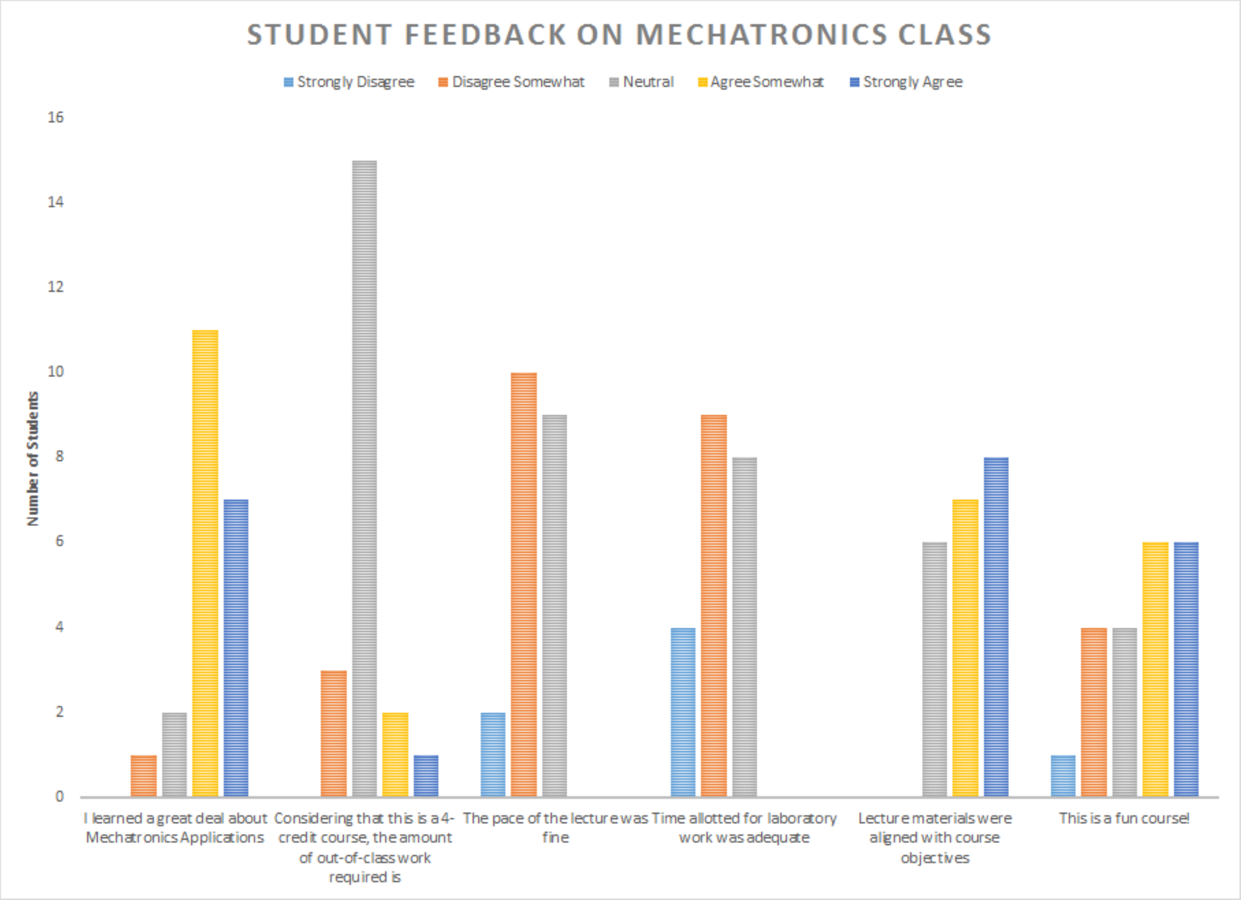

Fig. 9: Student feedback on mechatronics class

Conclusions

The first time experience of designing and teaching a mechatronics course for mechanical engineering students who do not have circuit background was challenging. Special consideration was given to hands-on experiences through laboratory exercises and system level design approach through the project. Lecture –lab format was effective in keeping the students engaged in learning. Course objectives were satisfied by daily activities in an integrated lecture-lab teaching environment as well as with a term project that brings all necessary components of mechatronics together. Assessment data showed that the majority of the students met or exceeded each student-learning outcome targeted for this course. Student feedback indicated that most students enjoyed the course and learned a great deal about mechatronics.

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