120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013
ATLANTA

Paper ID #7188

Development of A Mechatronics Studio Course in Mechanical Engineering

Dr. Biswanath Samanta, Georgia Southern University

Dr. Biswanath Samanta is in the Department of Mechanical Engineering at Georgia Southern University at Statesboro, Ga. His expertise and research interests include broad areas of system dynamics and control, robotics, mechatronics, intelligent systems, advanced signal processing, prognostics and health management, and applications of computational intelligence in engineering and biomedicine. Dr. Samanta has developed and taught numerous courses in these areas and supervised students at both undergraduate and graduate levels. He has more than 100 refereed research articles published by professional bodies like ASME, IMechE, AIAA, and IEEE. The papers are regularly cited by independent researchers in their publications (more than 1,500 citations). He is a member of ASEE, ASME and a senior member of IEEE.

Dr. Yong Zhu, Department of Mechanical Engineering, Georgia Southern University, Statesboro, GA 30458

Dr. Yong Zhu is currently an assistant professor in the Department of Mechanical Engineering at Georgia Southern University, Statesboro, Ga. His current research interests include mechatronics, design and control of portable energetic systems.

Development of A Mechatronics Studio Course in Mechanical Engineering

Abstract: This paper reports the development of a mechatronics studio course in Mechanical Engineering (ME) undergraduate program at Georgia Southern University. The course covers three broad areas: mechatronic instrumentation, computer based data acquisition and analysis, and microcontroller programming and interfacing. This is a required 2-credit course in the ME program. The course is delivered in studio format for four contact hours per week with one hour of lecture and three hours of interactive session of problem solving and laboratory experiment. For each topic covered, students get the theoretical background and the hands-on experience in the laboratory setting. Both formative and summative assessment of the students' performance in the course are done as a part of the overall assessment and evaluation plan of the department for ABET accreditation of the ME program. Both direct and indirect forms of assessment are considered. The paper reports the details of the course materials and the results of assessment. The positive response of the students and their performance in the course are encouraging. Future steps of continuous improvement process for the course are also discussed.

I. Introduction

The need for adapting engineering education to the 21st century has been widely recognized and best practices currently in place in several US universities have been identified[1-9]. The adaptation calls for a shift in emphasis from traditional discipline-specific to multidisciplinary domains to retain competitive edge of US in innovation through STEM education and research for the new century. Multidisciplinary education and research is viewed as a means to revitalize STEM education providing real-world, hands-on research experiences to students for better recruitment, retention, progression and graduation[4-9]. Education research also supports and advocates the learning centered environment for engineering education in the 21st century[10-16]. Mechatronics and Robotics are adopted as effective means of engaging engineering students in multidisciplinary education and research[17-21].

Mechatronics integrates concepts from multiple engineering disciplines like Mechanical (ME), Electrical and Electronics (EE), Computer, and Control leading to application-based systems that can be made adaptive and intelligent[22-40]. The importance and interest in Mechatronics education is increasing with ever growing presence of mechatronic products and systems spanning almost every walk of life from household consumer items to health care, manufacturing, transportation and defense systems, among others. The need for introducing Mechatronics in engineering disciplines has been long recognized, at both international and national levels. However, the adoption of Mechatronics as a course and/or a program has started at a slower pace in the US universities compared to the international counterparts [32, 33]. In the US, it has been considered in various forms and at different levels in engineering curricula. As examples, Mechatronics has been proposed as a module at freshman level in an Introduction to Engineering course[35], a senior elective to ME/EE, a required course in EE/ME [26, 28, 30], a track/concentration option[31], a separate program[34] and also a graduate course or graduate degree option[33]. The course has been delivered in different formats from traditional lecture and lab combination[26, 37] to entirely project-based approach[30, 39]. The coverage of topics also varies depending on the program [32, 33].

Though studio pedagogy was introduced in engineering design where "students learn how to learn and how to apply their knowledge simultaneously" [40], there is an excellent scope for implementing this pedagogy in mechatronics [41]. The present paper reports the development of a required mechatronics studio course for undergraduate ME juniors at Georgia Southern University. The course is delivered in studio format through a combination of lectures covering theoretical background and interactive sessions of problem solving and laboratory experiments and projects.

The remainder of this paper is devoted to detailed descriptions of the activities designed into the mechatronics studio course. Section II briefly describes the course design outlining the its objectives, the coverage of ABET program outcomes, the course content and the course requirement. In Section III, laboratory experiments and project are briefly discussed. Section IV deals with assessment process covering end of course students' survey and analysis of students' performance in the course. Section V summarizes the salient aspects of the paper with some comments about ongoing/future plans of continuous improvement process for this course.

II. Course Design

Mechatronics Studio is a required 2- credit course in ME program with Circuits and Electronics as the pre-requisite course. In addition, it is expected that students successfully complete a two-course sequence of Physics and Differential Equations prior to taking this course. Mechatronics Studio, though not formally declared as a pre-requisite, is used in senior level courses like Energy Systems Lab, Mechanical System Design and electives like Control Systems. Three broad areas are covered in this course: mechatronic instrumentation, computer based data acquisition and analysis, and microcontroller programing and interfacing. Emphasis is placed on hands-on projects with computers and microcontrollers covering data acquisition, analysis and control for development of mechatronic systems.

Learning Outcomes

The course covers three broad areas: mechatronic instrumentation, computer based data acquisition and analysis, and microcontroller programming and interfacing. Upon successful completion of the course, the students will be able to:

- (i) identify the process and modern tools of data acquisition,
- (ii) acquire and display signals from sensors related to mechanical engineering measurements,
- (iii) analyze, interpret and report experimental data,
- (iv) apply analog signal processing and digital circuits in mechatronic systems, and
- (v) select sensors and actuators for designing and implementing mechatronic systems.

These course objectives are related to the ABET *program outcomes*:

- (i) an ability to apply knowledge of mathematics, science, and engineering (ABET criterion 3.a),

(ii) an ability to design and conduct experiments, as well as to analyze and interpret data (3.b),
(iii) an ability to identify, formulate, and solve engineering problems (3.e),
(iv) an ability to communicate effectively (3.g), and
(v) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (3.k).

Course Content

The course covers the following topics: measurement fundamentals- accuracy, precision, repeatability, statistical data analysis; basic circuits and instrumentation- transients, frequency response, filtering; analog signal processing using operational amplifiers- inverting and non-inverting amplifiers, comparator, buffer, integrator, differentiator, instrumentation amplifiers; sensors-strain gages, thermocouples, RTD, thermistors, accelerometers; computer based data acquisition and introduction to LabVIEW; microcontroller programming and interfacing; digital circuits; actuators; programmable logic controllers; mechatronic systems and control. The course has a prescribed textbook[38] and a lab manual[42]. In addition to the textbook, students are directed to other sources of information through use of internet and other references for their project work. The lecture materials were posted on the university course website. The 2-credit course is delivered in studio format for four contact hours per week with one hour of lecture and three hours of interactive session of problem solving and laboratory experiment. For each topic covered, students get the theoretical background and the hands-on experience in the laboratory setting.

Course Requirements

The course has five components: quizzes, mid-term exam, final exam, lab experiments and project. The students are required to take four quizzes, spread over the semester, each contributing 5% to the total course grade, one mid-term exam with 10%, and the comprehensive final exam with 20%. The written exams contribute 50% of the total course grade. The other 50% of the course grade is distributed in 12 lab experiments (a total of 35%) and a robotics project (15%). The theoretical concept-level understanding of the course materials and their applications are tested in quizzes and exams while the experiments are designed to reinforce those concepts in laboratory setting. The project helps in integrating the information and experience gained in this course with their previous knowledge, both at component and system levels consolidating their understanding. The students have access to the lab and the robots to work on their projects beyond the normal class hours, under the supervision of graduate assistants working the lab. The weekly schedule for the course is presented in Table 1 showing the coverage of the topics, the associated lab experiments, and project. The schedule of the quizzes and exams are also included in the table. The quizzes and exams are designed to evaluate theoretical ability of students in the topics covered. The questions are also linked with experimental parts to motivate the students find connections between the lectures and the labs. The students are required to prepare lab reports with specific deliverables relating the experiments and the theory.

Table 1: Weekly schedule of course

Week #	Topics, Quiz/Exam	Reading [38, 42]
Week 1	Introduction to Mechatronics and Measurement Systems Intro to Lab equipment, Project	Chap 1
Week 2	Measurement Fundamentals Lab 1: Basic measurement and data presentation	Appendix A, Notes
Week 3	Basic electrical circuits and instrumentation, Quiz 1 Lab 2: Basic circuits and instrumentation	Chap 2, 4
Week 4	Analog Signal Processing using Operational Amplifiers Lab 3: Basic operational amplifier circuits –Part A	Chap 5
Week 5	Sensors, Quiz 2 Lab 4: Operational amplifier applications- Integrator, Differentiator- Part B	Chap 9
Week 6	Sensors Lab 5: Measurement using strain gages	Chap 9
Week 7	Data Acquisition and Introduction to LabVIEW, Lab 6: Introduction to LabVIEW	Chap 8, Notes
Week 8	Data acquisition and analysis using LabVIEW Mid-Term Exam Lab7: Data acquisition with a thermocouple using LabVIEW	Chap 8, Notes
Week 9	Microcontroller Programming and Interfacing Lab 8: Data acquisition and analysis using LabVIEW, Project Status Review	Chap 7, Notes
Week 10	Spring Break- No Classes	
Week 11	Digital Circuits Lab 9: Introduction to BASIC STAMP II	Chap 6
Week 12	Digital Circuits, Quiz 3 Lab 10 : Design of an alarm system	Chap 6
Week 13	Actuators Lab 11: DC motor drive and control	Chap 10
Week 14	Programmable Logic Controllers, Quiz 4 Lab 12: PLC programming	Notes
Week 15	Mechatronic Systems and Control Project	Chap 11
Week 16	Mechatronic Systems and Control Project Presentation	Chap 11
Week 17	Final Exam (Comprehensive)	

III. Lab Experiments and Project

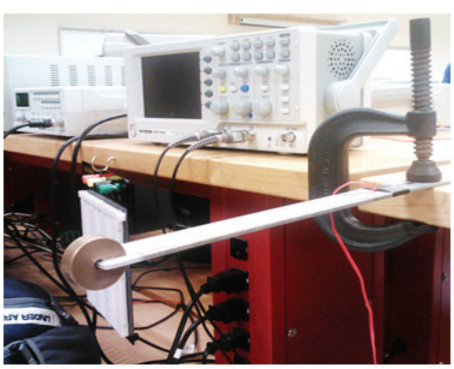
The laboratory experiments are described in detail in a lab manual[42] prepared for this course. The experiments are categorized into three groups as discussed briefly in the following subsections.

Mechatronic Instrumentation

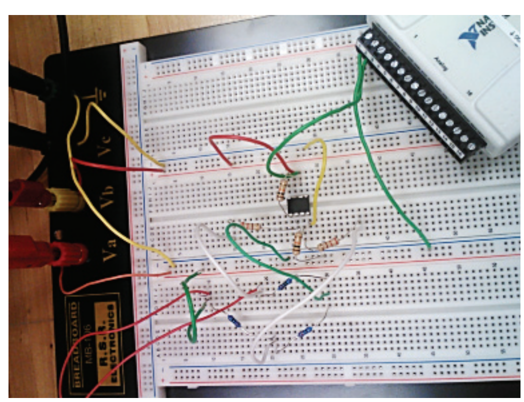
The first group of experiments focuses on analog devices, sensors and circuits covering the basic instrumentation, data analysis, analog sensors and op-amp circuits. These experiments help the students get familiarized with the basic statistical data processing, the instruments that are used in the lab. The labs also help the students learn to build and analyze some basic circuits for analog signal processing. Lab 1 deals with the basic techniques of statistics and data processing in measurement process using Excel and Matlab. Lab 2 helps students become familiar with the instruments, such as digital storage oscilloscope, function generator, digital multimeter and DC Power Supply, through the time and frequency response measurements of an RC low-pass filter. Labs 3 and 4 cover the applications of operational amplifiers. The students build and analyze basic op-amp circuits, such as a non-inverting amplifier, a comparator, an integrator and a differentiator. Lab 5 introduces students to the measurement of strain using a strain gage mounted near the fixed end of a cantilever beam and the signal conditioning circuit. The students build a Wheatstone bridge and an op-amp circuit to amplify the bridge output signal. The relationships of cantilever tip displacement, the strain and the output voltage are studied from the experiment.

Computer Based Data Acquisition and Analysis

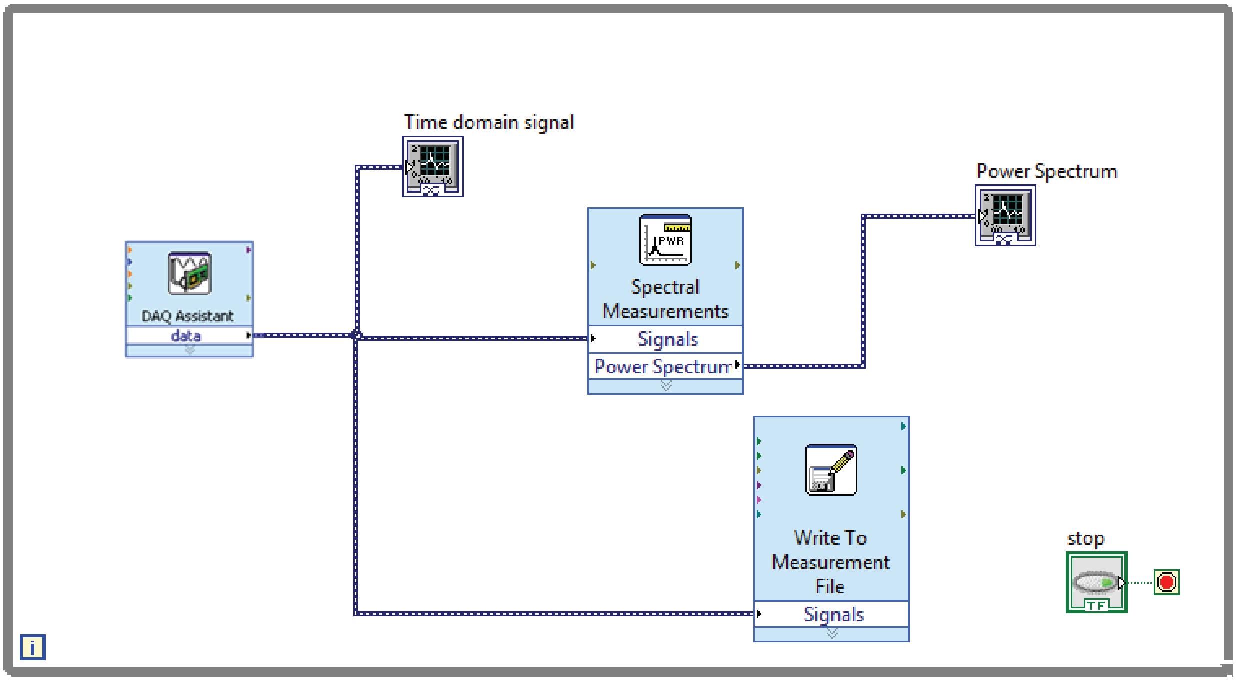
The second group of experiments focuses on the LabVIEW based data acquisition and analysis. This prepares the students for more advanced commercial software based data acquisition skills, upon which they could further develop real time control system skills for senior design or graduate studies. Lab 6 introduces the basic programming skill of LabVIEW by building VIs and displaying signals. Lab 7 introduces temperature measurement with thermocouples and data acquisition using the LabVIEW DAQ Assistant and a small, portable DAQ board, NI USB-TC01[43], that can be connected to a computer through a USB port. Lab 8 introduces data acquisition and analysis using LabVIEW, through USB-6009[43], for acquiring data from a vibrating cantilever with a strain gage mounted on it near its fixed end. Figure 1 shows the experimental setup, the analog circuit for signal conditioning and amplification, the LabVIEW VI, and snapshots of vibration signals and their power spectra for Lab 8 as a representative example. The theoretical background for this section consists of data sampling and acquisition, A/D, D/A conversion, sensors/actuators and second order linear system natural frequency and damping ratio.



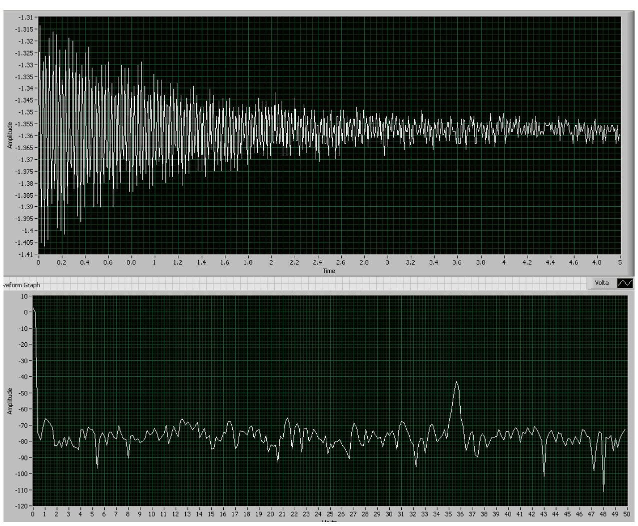
(a)

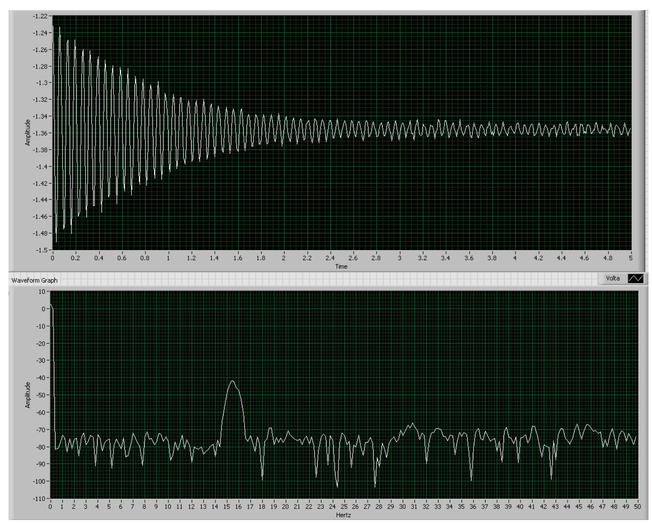


(b)



(c)





(d) (e)

Figure 1. Experiment 8: Cantilever vibration (a) experimental setup, (b) circuit diagram for Wheatstone bridge and difference amplifier, (c) LabVIEW block diagram virtual instrument (VI), (d) vibration signal and its power spectrum without tip mass, and (e) vibration signal and its power spectrum with tip mass.

Microcontroller Programming and Interfacing

The third group of experiments focuses on microcontroller based system. First, the programming of BASIC Stamp 2 from Parallax and the syntax of PBASIC[44] are introduced; then the design of logic networks and their implementation using digital IC are covered. The students are able to use a microcontroller to control a DC motor through an H-bridge. Finally, the fundamentals of PLC based control are introduced to help the students gain some knowledge of PLC analog/digital inputs/output and programming for logic functions, numerical computation, conditional branching etc. Lab 9 introduces the basic programming of BASIC Stamp 2 and the syntax of PBASIC. The students use BASIC Stamp microcontroller to control various on/off logic of LEDs. Lab10 introduces design of logic networks and their implementation using digital IC circuits (logic gates- AND, OR, NAND, NOR) through design and implementation of a home security system. Lab 11 uses a microcontroller for controlling a DC motor through an L298 H-bridge IC. Lab12 helps the students understand the fundamentals of PLC analog/digital inputs/outputs and learn BASIC stamp PLC programming to perform tasks such as logic functions, numerical computation, and conditional branching. The theoretical background for this section consists of microcontroller based system infrastructure, Boolean expression, IC gates and digital logic design and manipulation.

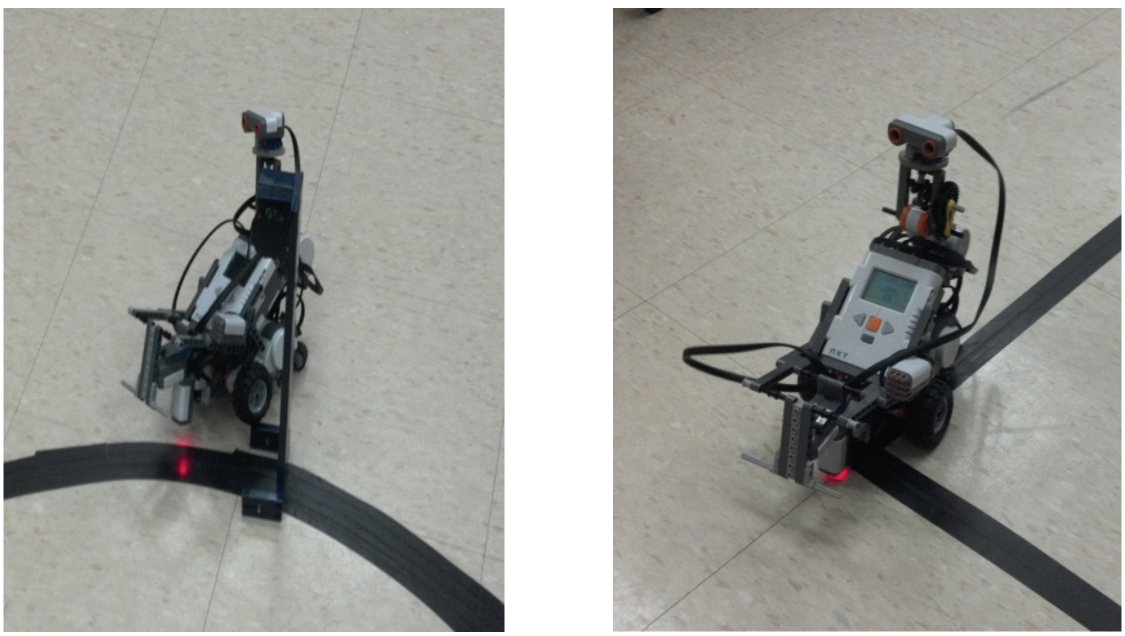


Figure 2. A LEGO NXT robot on the move for one student's project (a) navigating around an obstacle, (b) following a line, preparing to turn

Robotics Project

The final course project features hands-on activities with the LEGO NXT and Parallax Boe-Bot robots. The students are given LEGO NXT and Boe-Bot kits which they assemble and interface. The project involves interfacing the sensors, the motors, calibration of sensors and characterization of the motors. The LEGO NXT robots are programmed using LabVIEW and the Boe-Bots are programmed using PBASIC. The robots are programmed for basic functions like obstacle avoidance, following a path and following a moving target. The project was also carried out in the form of robot race to encourage the students to understand the code, polish the programming skills, pursue smarter and more efficient control algorithms and better tuned gains for faster response and obstacle avoidance. Figure 2 shows a LEGO NXT robot navigating around an obstacle while following a path and preparing to make a turn, from one of the students' project. The course project provides an opportunity for the students to solve an open-ended practical engineering challenge and understand the key elements of mechatronics. It can be seen that this course is the synergistic integration of mechanical engineering with electronics and computer control, which is the core of mechatronics. The emphasis has been placed on the application and the synergistic use of the students' knowledge on software, instruments, circuits and dynamics.

IV. Assessment

Both formative and summative assessment of the students' performance in the course are done as a part of the overall assessment and evaluation plan of the department for ABET accreditation of the ME program. Both direct and indirect forms of assessment are considered. The positive response of the students and their performance in the course are encouraging. The details of the results of assessment are presented here.

End of Course Survey

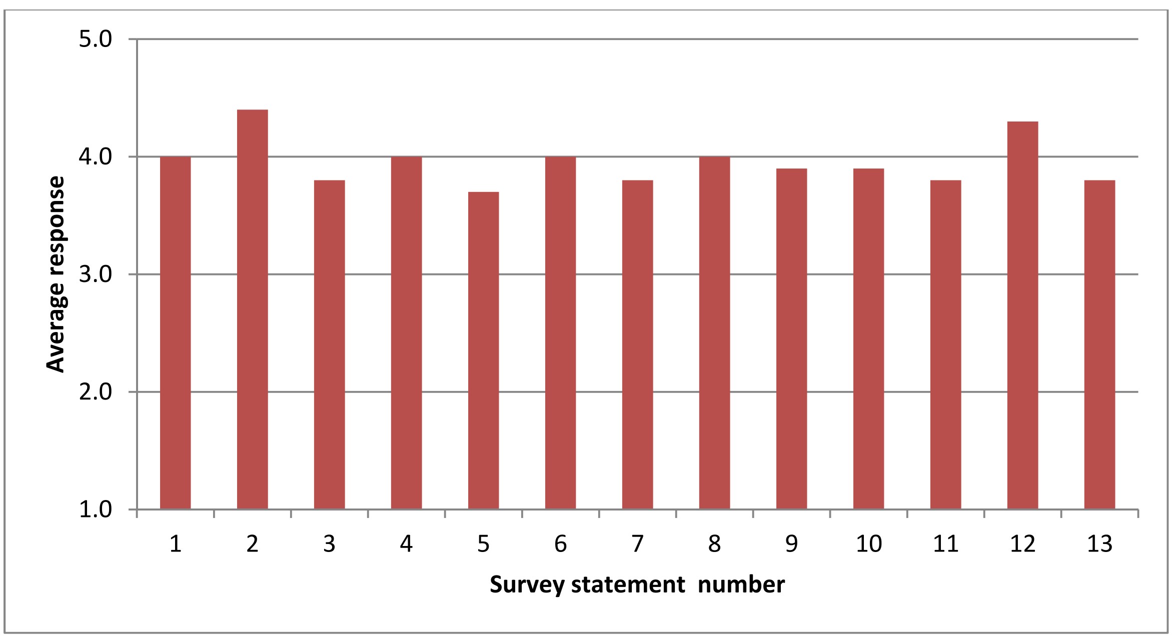
In the final class of the course, students are asked to complete a survey about the course. The survey consists of 13 statements as shown in Table 2. The students are asked to respond to each statement by writing a number from 1 to 5 corresponding to the degree of agreement with the statement using the following scale: 1: Strongly Disagree, 2: Disagree, 3: Neutral, 4: Agree, 5: Strongly Agree. In addition to the numerical response, the students were also asked to write their comments.

Table 2: End of course students' survey statements

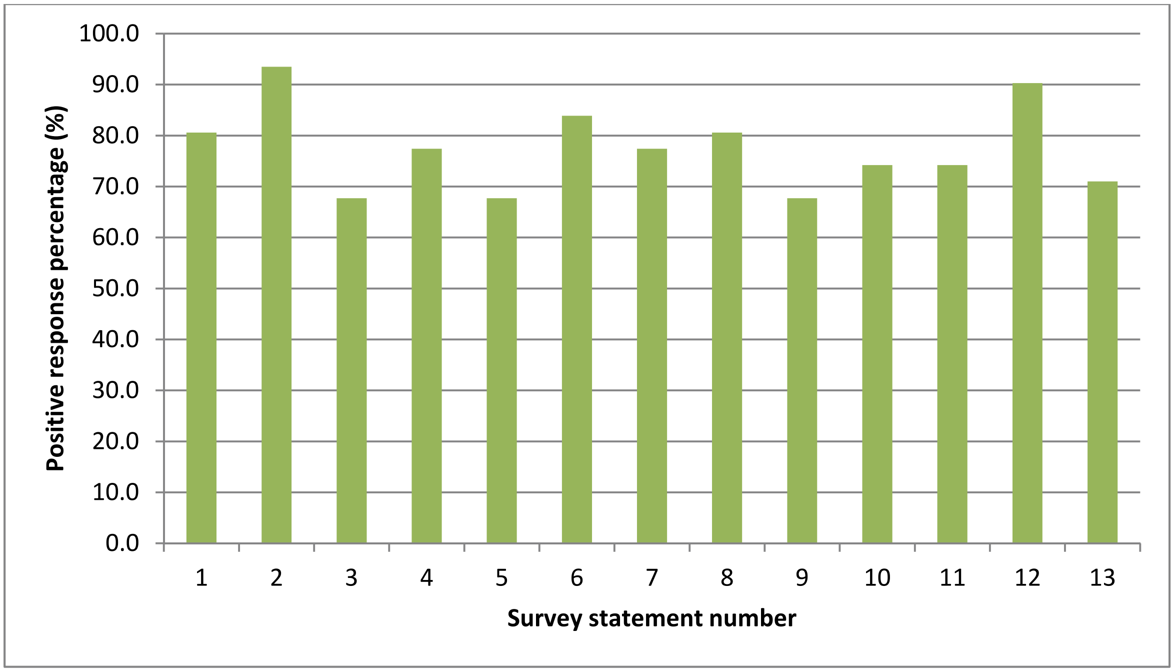
Based on my learning and understanding after taking this course: 1. I have knowledge of measurement process. 2. I can work with basic electrical devices like multimeters, signal generators, DC power supply and oscilloscopes. 3. I have knowledge of sensors like strain gages, thermocouples and other robotic sensors (touch, ultrasound, IR, light). 4. I can make basic circuits for interfacing sensors. 5. I have knowledge of analog circuits like Wheatstone bridge. 6. I have knowledge of operational amplifiers. 7. I can acquire and analyze data using LabVIEW. 8. I can program a microcontroller and use digital logic circuits. 9. I can develop programs to navigate a mobile robot. 10. I have basic knowledge of selecting DC motors. 11. I have basic knowledge of PLC. 12. I can conduct laboratory experiments and interpret results. 13. The lab 8 (Cantilever vibration using LabVIEW) and robotics project helped us understand and integrate the topics of this course.

31 students out of 32 enrolled responded to the survey and the survey results are presented in

Figs. 3(a) and (b). Figure 3(a) shows the distribution of average response to the statements. The average response ranges from 3.7 (statement 5) to 4.4 (statement 2). Fig. 3(b) shows the distribution of positive (score of 4 or more) response percentage for the statements. 80.6% of students agree or strongly agree that they have knowledge of measurement process. 93.5% of students agree or strongly agree that they can work with basic electrical devices like multimeters, signal generators, DC power supply and oscilloscopes. 67.7% of students agree or strongly agree that they have knowledge of sensors like strain gages, thermocouples and other robotic sensors (touch, ultrasound, IR, light). 77.4% of students agree or strongly agree that they can make basic circuits for interfacing sensors. 67.7% of students agree or strongly agree that they have knowledge of analog circuits like Wheatstone bridge. 83.9% of students agree or strongly agree that they have knowledge of operational amplifiers. 77.4% of students agree or strongly agree that they can acquire and analyze data using LabVIEW. 80.6% of students agree or strongly agree that they can program a microcontroller and use digital logic circuits. 67.7% of students agree or strongly agree that they can develop programs to navigate a mobile robot. 74.2% of students agree or strongly agree that they have basic knowledge of selecting DC motors. 74.2% of students agree or strongly agree that they have basic knowledge of PLC. 90.3% of students agree or strongly agree that they can conduct laboratory experiments and interpret results. 71% of students agree or strongly agree that the lab 8 (Cantilever vibration using LabVIEW) and robotics project helped them understand and integrate the topics of this course.



(a)



(b)

Figure 3. Summary of end of course students' survey response (a) average response, (b) positive response percentage.

Some of the students' comments include "*It would have been better if we had more time set aside for the robot projec*t", "*Mobile robot project helped us understand the most*", "*Possibly start robot project earlier and work on it every other lab to learn more about them*", "*I liked the robot project, wish we had used it earlier*", "*More class time for robots*" and "*More time for robot, less theory*". It is very evident that the students liked working on the robot project and would like to have more class time allotted to the project.

Analysis of Students' Performance

The students' performance in each of the five course components was also analyzed. Four quizzes were given at regular intervals during the semester. Each graded quiz was returned to the students with written comments within a week. The model answers were discussed in the class and also posted. Figure 4 shows the variation of average quiz grades during the course period (49.6%, 72.1%, 81.3% and 84%) . The average grade varied from 49.6% (for quiz 1) to 84% (for quiz 4) with a sharp improvements between quiz 1 and quiz 2 (22.5%) and between quiz 2 and quiz 3 (9.2%). The average grade reached 84% in the last quiz. This shows the positive effect the feedback had on the students during the formative assessment process.

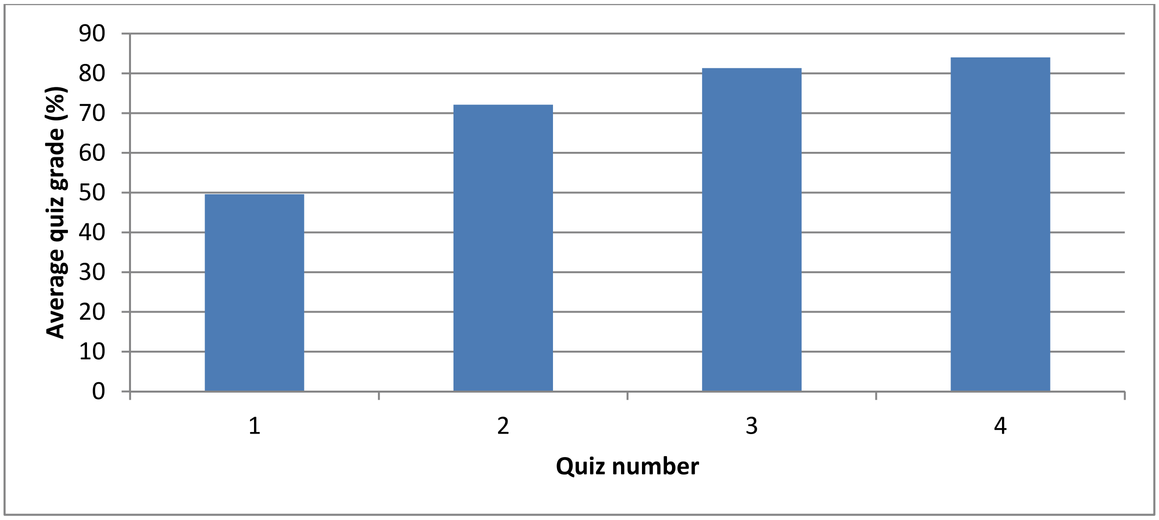


Figure 4. Distribution of average quiz grades

Students were required to submit a lab report within a week of each experiment conducted. Lab reports were graded and returned with comments in the following week. Lab grades were also plotted and the variations of average lab grades over the semester were not very significant.

Figure 5 shows the distribution of average grades for each of the five course components and the overall average course grade. It is interesting to see that first three components involving written exams have relatively lower averages compared to the hands-on parts dealing with lab experiments and project. The average grades are 71.9%, 77.7%, 67.2%, 88.3%, 88.6% for quizzes, mid-term exam, the final exam, labs and the project respectively. The overall average grade for the course is 81.5%.

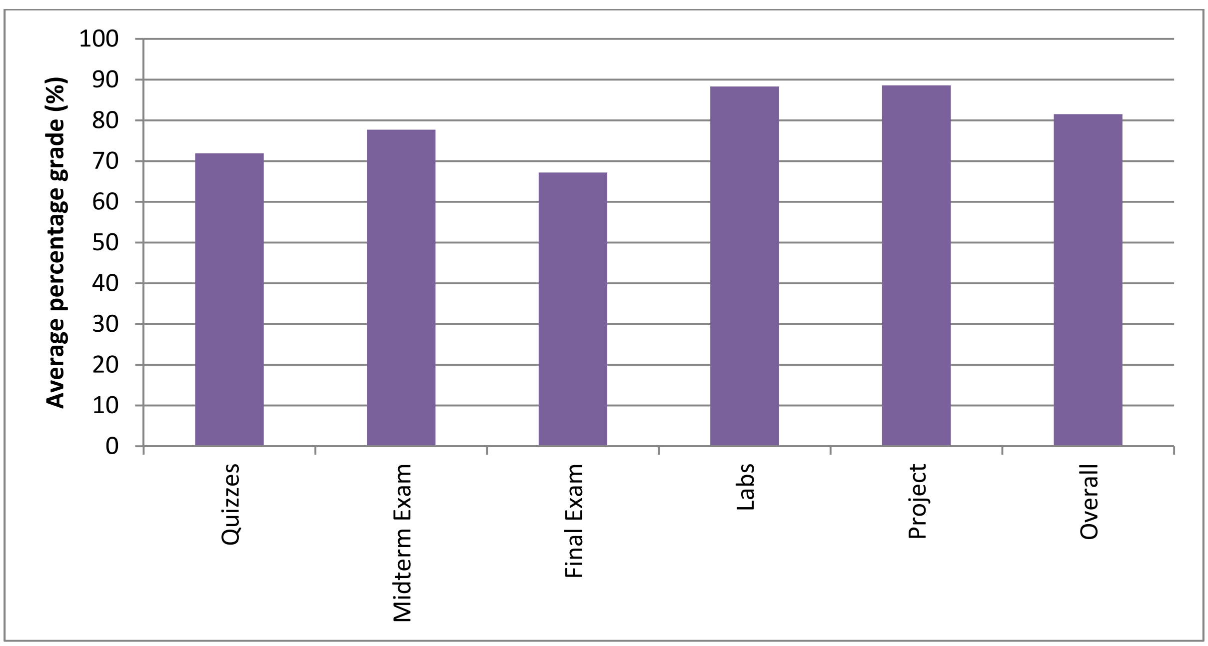


Figure 5. Distribution of average percentage grades for all components

V. Conclusions

A pilot course on mechatronics in studio lab setting has been developed and offered in the undergraduate ME program at Georgia Southern University. The course covers fundamentals of mechatronics instruments, analog circuits, data acquisition, digital circuits and microcontroller based system design, programming and interfacing. Through this course, students gain the theoretical knowledge, problem solving skills and the experimental abilities that are pre-requisite for senior level courses. The students are required to carry out laboratory experiments with the support and understanding of related theoretical background. The course provides students an opportunity to integrate and apply previous knowledge of mechanical and electrical engineering and help them gain experience to solve real world engineering problems. Students are able to develop practical problem solving skills, record and analyze experimental measurements and write technical reports.

The course was offered for the first time in Fall 2012 and is also offered in the current semester (Spring 2013). Based on the feedback from students' survey, the robotics projects have been assigned from the beginning of the semester. Students are working on their projects and their progress is regularly monitored. Based on the evaluation of students' performance in quizzes and exams in the previous semester, the students in Spring 2013 were given a test on the pre-requisite course (Circuits and Electronics) at the beginning of the semester. The students were informed about the test about two weeks in advance to give them enough time to review the pre-requisite course. The test scores of the pre-requisite test showed some weakness in students' understanding and application of the concepts. On further analysis, it was revealed that most of the students took the pre-requisite course quite some time back and delayed taking Mechatronics till their final semesters since Mechatronics was not listed formally as a pre-requisite to senior level courses. It was brought to the notice of the department and the curriculum has been revised to make Mechatronics as a pre-requisite to senior level required courses like Thermal Science Lab, and Mechanical System Design, effective from Fall 2013. This step would ensure that students complete Mechatronics immediately after Circuits and Electronics. For the current semester (Spring 2013), some of the topics from the pre-requisite course were reviewed and blended with the new topics from Mechatronics. From the current semester, pre-lab assignment has been introduced for each experiment. Students are required to hand in the completed assignment that is evaluated and returned with grades before starting the lab. The pre-lab assignments contribute 20% to the lab grade. In addition, more practice problems are covered in problem solving sessions. Based on the mid-term survey and assessment, these measures are appreciated by the students and indicate positive results. A full analysis of the students' performance and survey results will be undertaken at the end of the semester.

The students' performance in the written exams, especially the final, will be monitored and analyzed further in the next offerings of the course. The measures like pre-requisite test and pre-lab assignments, introduced in the current semester will also be monitored for assessing their effectiveness and appropriate steps will be taken for improvements.

Bibliography

1. National Academy of Engineering (2011). *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, National Academies Press, Washington, D. C., http://www.nap.edu/catalog/11338.html.
2. Lavelle, J. P. and Bottomley, L. J. (2011). NAE grand challenges and academic culture in engineering education at NC State, *ASEE Southeast Section Conference*.
3. Peercy, P. S. and Cramer, S. M. (2011). Redefining quality in engineering education through hybrid instruction, *Journal of Engineering Education,* 100(4), pp. 625–629.
4. National Academy of Engineering (2012). Infusing real world experiences into engineering education, The National Academies Press, Washington, DC, www.nap.edu.
5. ASEE (2012). Innovation with impact: creating a culture for scholarly and systematic innovation in engineering education, http://www.asee.org/about-us/the-organization/advisory-committees/Innovation-with-Impact.
6. ASEE (2012), Going the distance: best practices and strategies for retaining engineering, engineering technology and computing students, http://www.asee.org/retention-project.
7. Matthews, M. (2012). Keeping students in engineering: a research-to-practice brief, http://www.asee.org/retention-project/keeping-students-in-engineering-a-research-guide-to-improving-retention.
8. Brown, M. K., Hershock, C., Finelli, C. J., and O'Neal, C. (2009). Teaching for retention in science, engineering, and math disciplines: a guide for faculty. Occasional Paper No. 25. Ann Arbor, MI: Center for Research on Learning and Teaching, University of Michigan.
9. Knight, D. W, Carlson, L. E, and Sullivan, J. F. (2007). Improving engineering student retention through hands-on, team based, first-year design projects, *ASEE 31st International Conference on Research in Engineering Education*, Honolulu, HI, June 22 – 24, 2007.
10. Hsu, A. and Malkin, F. (2011). Shifting the focus from teaching to learning: rethinking the role of the teacher educator, *Contemporary Issues In Education Research,* 4(12), pp. 43-49.
11. Felder, R. M. and Brent, R. (2009). Active learning: an introduction, *ASQ Higher Education Brief*, *2*(4), August 2009.
12. Froyd, J. E. (2008). Evidence for the efficacy of student-active learning pedagogies, *NSF CCLI Conference presentation*, http://ccliconference.org/reports-resources/.
13. Full, R. J. (2008). The value of interdisciplinary research-based instruction, *NSF CCLI Conference presentation*, http://ccliconference.org/reports-resources/.
14. Prince, M. J. and Felder, R. M. (2007). Does faculty research improve undergraduate teaching? an analysis of existing and potential synergies, *Journal of Engineering Education,* 96(4), pp. 283-294.
15. Prince, M. J. and Felder, R. M. (2007). The many faces of inductive teaching and learning, *Journal of College Science Teaching,* 36(5), pp. 14-20.
16. Prince, M. J., and Felder, R. M. (2006). Inductive teaching and learning methods: definitions, comparisons, and research bases. *Journal of Engineering Education,* 95(2), pp. 123–138.
17. Matarić, M., Fasola, J., and Feil-Seifer, D. J. (2008), Robotics as a tool for immersive, hands-on freshmen engineering instruction, *Proceedings ASEE Annual Conference*.
18. Craig, K. C., and Park, H. (2010). Multidisciplinary freshman engineering, *IEEE Conf. on Transforming Engineering Education: Creating Interdisciplinary Skills for Complex Global Environments*, 10.1109/TEE.2010.5508876 , pp. 1-18.
19. Craig, K. C., and Nagurka, M. L. (2010). Multidisciplinary engineering systems 2nd and 3rd year college-wide courses, *IEEE Conf. on Transforming Engineering Education: Creating Interdisciplinary Skills for Complex Global Environments*, 10.1109/TEE.2010.5508868, pp. 1-15.
20. Craig, K. C., and Voglewede, P. A. (2010). Multidisciplinary engineering systems graduate education: master of engineering in mechatronics, *IEEE Conf. on Transforming Engineering Education: Creating Interdisciplinary Skills for Complex Global Environments*, 10.1109/TEE.2010. 5508819, pp. 1-14.

21. Samanta, B., and Turner, G. (2013). Development of a mechatronics and intelligent systems laboratory for teaching and research, *Computers in Education Journal*, vol. 4, no. 1, pp. 60-72.
22. Craig, K. C. (1999). Mechatronics at Rensselaer: a two-course senior-elective sequence in mechanical engineering, *IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, pp. 452-458.
23. Craig, K. C. (2001). Is anything really new in mechatronics education? *IEEE Robotics & Automation Magazine*, vol.8, no. 2, pp.12-19.
24. Tomizuka, M. (2002). Mechatronics: From 20th to 21st century, *Control Engineering Practice*, vol.10, pp. 877-886.
25. Ghone, M., Schubert, M., and Wagner, J. R. (2003). Development of a mechatronics laboratory- eliminating barriers to manufacturing instrumentation and control, *IEEE Transactions on Industrial Electronics,* vol. 50, no. 2, pp. 394-397.
26. Giurgiutiu, V., Lyons, J., Rocheleau, D. and Liu, W. (2005). Mechatronics/microcontroller education for mechanical engineering students at the University of South Carolina, *Mechatronics*, vol. 15, pp. 1025–1036.
27. Habib, M. K. (2007). Mechatronics—A unifying interdisciplinary and intelligent engineering science paradigm, *IEEE Industrial Electronics Magazine*, vol. 1, no. 2, pp. 12–24.
28. Voiculescu, I., and Liaw, B. (2007). A novel labwork approach for teaching a mechatronics course, *ASEE Annual Conference Proceedings*.
29. Brown, A. S. (2008). Who owns mechatronics? *ASME Mechanical Engineering Magazine*, pp. 24-29.
30. Rogers, J., Rabb, R., Korpela, C., and Ebel, R. (2009). Learning mechatronics through graduated experimentation, *ASEE Annual Conference Proceedings*.
31. Ruhala, R., and Kuban, P. (2009). A new mechatronics curriculum within an accredited B.S.E. program, *ASEE Annual Conference Proceedings*.
32. Das, S, Yost, S.A., and Krishnan, M. (2010). A 10-year mechatronics curriculum development initiative: Relevance, content, and results—Part I, *IEEE Transactions on Education*, vol. 53, no. 2, pp. 194 - 201.
33. Krishnan, M., Das, S., and Yost, S.A. (2010). A 10-year mechatronics curriculum development initiative: Relevance, content, and results—Part II, *IEEE Transactions on Education*, vol. 53, no. 2, pp. 202-208.
34. Currier, P., Goff, R. and Terpenny, J. (2010). A proposed learner-centered mechatronics engineering instructional program, *ASEE Southeast Section Conference Proceedings*.
35. Castles,R. T., Zephirin, T., Lohani, V. K., and Kachroo, P. (2010). Design and implementation of a mechatronics learning module in a large first-semester engineering course, *IEEE Transactions on Education*, vol. 53, no. 3, pp. 445-454.
36. Gómez-de-Gabriel, J. M., Mandow, A., Fernández-Lozano, J., and García-Cerezo, A. J. (2011). Using LEGO NXT mobile robots with LabVIEW for undergraduate courses on mechatronics, *IEEE Transactions on Education*, vol. 54, no. 1, pp. 41-47.
37. Moallem, M., and Roshan, Y. M. (2011). Development of a course and laboratory for embedded control of mechatronic systems, *ASEE Annual Conference Proceedings*.
38. Alciatore, D. G. and Histand, M. B. (2011). *Introduction to Mechatronics and Measurement systems*, 4th edition, McGraw Hill.
39. Shiller, Z. (2013). A bottom-up approach to teaching robotics and mechatronics to mechanical engineers, *IEEE Transactions on Education*, vol. 56, no.1, pp. 103-109.
40. Thompson, B. E. (2002). Studio pedagogy for engineering design, *International Journal of Engineering Education*, vol. 18, no. 1, pp. 39-49.
41. Habash, R. W. Y., Suurtamm, C., Necsulescu, D. S. (2011). Mechatronics learning studio: from "Play and Learn" to industry-inspired green energy applications, *IEEE Transactions on Education*, vol. 54, no. 4, pp. 667-674.
42. Samanta, B., and Zhu, Y. (2013). *MENG3521Lab Manual - Mechatronics Studio Lab*, Georgia Southern University.
43. http://www.ni.com
44. http://www.parallax.com