Development and Implementation of a Mechatronics Senior-Level Course in a Traditional Electrical Engineering Program

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Abstract

This paper discusses the development and implementation of a mechatronics course in a traditional electrical engineering program in an undergraduate college. This course is at the senior and first-year graduate levels, and designed for both electrical and mechanical engineering majors. It was proposed as an elective, in preparation for future programs in mechatronics. Mechatronics is the synergistic combination of electrical, mechanical, and control engineering, and computer science. Modern cost-effective and quality products are often intelligent mechatronic systems or involve mechatronic subsystems. Typical examples are robots. The design of such systems requires a multidisciplinary systems approach that is not taught in traditional specialized engineering disciplines such as electrical and mechanical engineering. The traditional design approach follows the waterfall model, whereby the input from each engineering discipline is considered serially, in stages. This approach is recognized today as ineffective and costly, as it results in designs that are not optimized. A mechatronic systems approach involves the simultaneous optimization of all aspects of the design over its life cycle. The Mechatronics course was designed as a first course in mechatronics that makes use of the more advanced mathematical knowledge of electrical and mechanical engineering seniors. The course emphasized mathematical modeling and a term project involving the design of a mechatronic system was required. Twelve of the enrolled students were electrical and one was mechanical engineering majors. All aspects of mechatronics were covered, including: mechatronics system design, modeling and simulation of physical systems, sensors and transducers, actuators, system control, signals and systems, signal conditioning and real-time interfacing. The traditional control theory was reviewed and state-space control theory was introduced. Laboratory experimentation included Matlab and Simulink simulations. Lessons learned and the relevance for introducing mechatronics programs are discussed.

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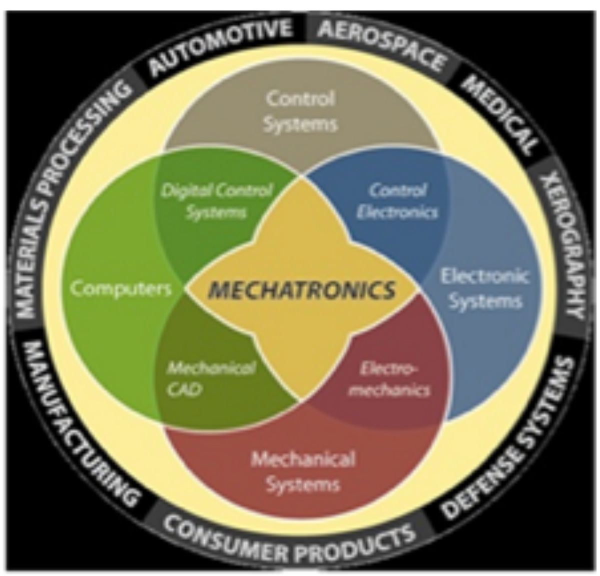
1. Introduction

This paper discusses the development and implementation of a mechatronics course in a traditional electrical engineering program in an undergraduate college. This four-credit course is at the senior and first-year graduate levels, and designed for both electrical and mechanical engineering majors. It was proposed as an elective, in preparation for future programs in mechatronics.

Mechatronics is the synergistic combination of electrical, mechanical, and control engineering, and computer science [1,5-7]. To this should be added systems engineering as the combination of these disciplines in mechatronics design requires a systems approach. Mechatronics Engineering educators agree that mechatronics is as much a design philosophy inherently multidisciplinary, in contrast to traditional engineering disciplines [1,5-7]. Modern design systems are often complex and intelligence through microprocessors in the form of microcontrollers. DSPs or FPGAs. It is well known that these designs are more cost-effective and more optimized and therefore more desirable to industry [1,5-7]. Therefore, by their nature modern intelligent products require a multidisciplinary system approach to their design. Engineering, however, is traditionally taught as "compartmentalized" disciplines such as electrical, mechanical, civil, chemical, biomedical, etc. [1,5-7]. Typically engineering curricula include a common core of freshman level calculus-based physics, often limited to two courses, and starting to specialize in their respective disciplines in their sophomore year, and more so in their junior and senior years.



Source: Ahm2307 at English Wikipedia

Fig.1: Mechatronics as multidisciplinary systems engineering

For example electrical engineering majors, often do not take foundation courses in mechanical engineering such statics, mechanics of materials and dynamics. The only exposure to mechanics they have is through basic general physics I. In mechanical engineering, however, students are required to take these courses. Physics majors are also required to take more advanced mechanics and electrical courses. Therefore while mechanical engineering and physics majors get the necessary training in mechanics at a more advanced level, the electrical engineering majors do not.

As a result, graduates of these traditional disciplines are overspecialized, possess depth in their discipline but little breadth [5-7]. This makes it difficult for them to take the required systems approach in their design and research projects. Since the optimization of the design requires a mechatronics approach [1,5-7], the modern multidisciplinary engineer must have adequate knowledge of both electrical and mechanical engineering, beyond the basic freshman and sophomore level coursework.

Mechatronics is more widely taught outside the United States, especially in Europe, Asia and Australia. There are few programs in mechatronics in the USA. One of them is the electromechanical engineering programs at Wentworth Institute of Technology, Boston, MA, where the author has taught for fourteen years. This is a five-year program that is ABET-accredited in both electrical and mechanical engineering. Some mechanical and electrical engineering programs offer concentration in mechatronics. There are several approaches to implementing these programs and concentrations and because Mechatronics is relatively young discipline, introduced in the 1980's, there are no established model or best approaches. Thus, mechatronics programs depend on the context and the department where they are hosted. The author's approach was to evaluate the context and resources available and design a mechatronics program by starting with an appropriate pilot course.

The author, has recently joined the electrical engineering program at Merrimack College, a primarily undergraduate college in Massachusetts. One of his objectives was to design an appropriate mechatronics program or concentration, and also consider a Master's level program.

The electrical engineering program at Merrimack College is an undergraduate program, established about a decade ago, that is ABET-accredited. Based on his research and assessment of the needs and resources available at the college, the author decided to develop a pilot course in mechatronics in the form of the senior elective entitled: Special Topics: Mechatronics.

The author's objective was to design a course at the senior level that will also be a required graduate course for a future Master's program in Mechatronics. This course was to be open to both electrical and mechanical engineering undergraduate majors. The larger mechanical engineering program at Merrimack College also offers Master's degrees, and this course was also available to graduate students in the program.

2. Course Structure, Contents and Teaching Approach

2.1 Course structure and contents:

There were initially fourteen students, all of them were seniors in electrical engineering and one was a senior in mechanical engineering. The senior status in electrical or mechanical engineering was required and there were no other prerequisites. A syllabus was developed. The course was a four-credits course meeting for one hour and fifteen minutes on Tuesdays and Thursdays and one hour and forty minutes on Fridays. The following were the course objectives as stated in the syllabus:

Course Description: This course is an introduction to mechatronics and its applications.

Course Objectives:
After completing this course, students will be able to:
- design a mechatronic system
- perform all stages required in the design of a mechatronic systems
- mathematically model and simulate a mechatronic system
- understand, model and use the various modules of a mechatronic system

The syllabus listed the following course contents:

Table 1: Course contents

Topic	Chapter
Mechatronics system design	1
Modeling and simulation of physical systems	2
Sensors and transducers	3
Actuating devices	4
System control - logic methods	5
Signals, systems, and control	6
Signal conditioning and real-time interfacing	7
Case studies	8

More specifically, because students were not expected to have had any background in mechatronics, the following topics, all of which are involved in mechatronic system design, were to be covered:

Mechatronic system design:
- What is mechatronics
- Integrated design issues in mechatronics
- The mechatronics design process
- Mechatronics key elements
- Applications in mechatronics

Modeling and simulation of physical systems

- The Laplace transform
- Transfer function modeling
- State-space modeling
- Block diagrams, manipulations, and simulation
- Modeling—direct method
- Modeling—analogy approach
- Electrical systems
- Mechanical translational systems
- Mechanical rotational systems
- Electrical–mechanical coupling
- Fluid systems
- Thermal systems

Sensors and transducers:

- Introduction to sensors and transducers
- Sensitivity analysis—influence of component variation
- Sensors for motion and position measurement
- Digital sensors for motion measurement
- Force, torque, and tactile sensors
- Vibration—acceleration sensors
- Sensors for flow measurement
- Temperature sensing devices
- Sensor applications

Introduction to signals, systems, and controls

- Laplace transform solution of ordinary differential equations
- System representation
- Linearization of nonlinear systems
- Time delays
- Measures of system performance
- Root locus
- Bode plots
- Controller design using pole placement method

Signal conditioning and real-time interfacing:

- Introduction
- Elements of a data acquisition and control system
- Transducers and signal conditioning
- Devices for data conversion

- Data conversion process
- Application software

<u>System control - logic methods</u>

- Number systems in mechatronics
- Binary logic
- Karnaugh map minimization
- Programmable logic controllers

2.2 Choosing the textbook:

There are few Mechatronics textbooks compared to other engineering disciplines. The textbook "Mechatronics System Design" by Devdas Shetty, Richard A. Kolk [1] was selected. The author found that this textbook had the most comprehensive and integrated contents that was well organized and included the topics listed in the course contents above, and was popular internationally. The above topics clearly cover all aspects of mechatronics, as discussed above.

In the author's judgement, however, some key topics regarding the mathematical modeling of dynamic systems were not adequately covered by the above textbook. He therefore used an additional textbook as a reference to cover these topics. This is a textbook he used while teaching the fifth year Electromechanical Systems at Wentworth Institute of Technology. This textbook is "Dynamic Systems" by Ogata [2]. From his experience, the author was well satisfied with this textbook.

2.3 Teaching approach:

The teaching approach was as follows:

Since both electrical and mechanical engineering seniors had taken the same advanced mathematics coursework, especially differential equations, and the same introductory physics coursework, the instructor (author) decided that it was best to cover topics in both electrical and mechanical engineering using the more advanced mathematics that both majors would understand. When he introduced mechanical engineering concepts, he built on the concepts learned in introductory physics, but at a more advanced mathematical level and similarly with the electrical engineering concepts.

For example, he covered thoroughly the Laplace Transform method as done by Ogata [2] and used it to cover electrical circuit analysis, signals and systems, and feedback control systems, as well as mechanical and electromechanical systems [2]. His approach was to emphasize the similarity in the mathematical modeling of all the systems. The use of the Laplace transform is required in the mathematical modeling of dynamic systems, electrical, mechanical, and mechatronic. Note that usually, when students are introduced to their respective programs concepts such as circuit theory, usually a sophomore level electrical engineering course, these concepts are not covered at the more advanced mathematical level, using the Laplace Transform. This is because students often acquire this mathematical knowledge later, in their junior or senior years. Therefore, the students in the present course were taught important mathematical modeling skills applicable both in electrical and mechanical engineering.

In addition, most of the students in this class (all the EE majors) were concurrently taking a required electrical engineering course: Feedback Control, but not the mechanical engineering senior. Therefore, the classical transfer-function method was first discussed in depth and this was followed by an in-depth treatment of modern state-space modeling, which is well covered in the textbook of Ogata [2]. In this way both the mechanical and electrical engineering senior acquire all needed concepts of both classical and modern control theory. Note that state-space control theory is not covered in the EE Feedback Control course as is typical in similar courses at other colleges an universities. Another reason for covering state-space control theory is that this approach is covered in Master's programs, and this course was meant to also serve as a graduate-level course for potential future master's level programs in mechatronics.

In summary, in this course, the mathematical modeling of electrical, mechanical, and electromechanical systems was emphasized. This is because mathematical modeling is not adequately covered in typical undergraduate engineering curricula [5-7]. However, mathematical modeling is known to be very important for effective engineering design and research and development [5-7].

2.4 Laboratory projects:

Based on the author's philosophy and experience, he considered laboratory work to be a necessary concurrent activity. Therefore he planned to assigned a number of laboratory projects in the form of Matlab and Simulink simulations projects. No physical experiments were deemed necessary because of time constrains and since students had to implement a term mechatronics project where they are required to develop a physical system.

The following lab projects were to be assigned:

<u>Lab Project 1</u>: Tutorial in Matlab and Simulink.
Some students in the class had little or no experience with Matlab and Simulink. Therefore Tutorials were selected from Mathsoft and other sources and posted on Blackboard.

<u>Lab Project 2</u>: Transfer Function Modeling with Matlab
<u>Objectives:</u>
Learn to use Matlab to

- model dynamic systems using the transfer function
  - predict the response to various inputs
  - predict the response to various initial conditions
- model mechanical and electrical systems
- use Matlab to perform partial fraction expansions and find the inverse-Laplace transform.

<u>Equipment:</u> Laptop with Matlab.

Lab Project 3: State-Space Modeling with Matlab
Objectives:
Learn to use Matlab to
- model dynamic systems using state-space modeling
  - predict the response to various inputs
  - predict the response to various initial conditions
- model mechanical and electrical systems

Equipment: Laptop with Matlab.

Lab Project 4: Design of PID controllers with Matlab/Simulink
Objectives:
- Learn to use Matlab/Simulink to design PID controllers

Equipment: Laptop with Matlab/Simulink.

2.5 Term project:

Another important component of the course was the assignment of a term project. The author, based on his past experience [3-4], considered a project-based approach was necessary for an adequate understanding of course material and the mechatronics approach. Therefore, based on his prior success [3-4], he had students form teams in the first week of the semester and he met each team at a consultation during the Friday two-hours lecture session that he used as a laboratory session when needed. After meeting at consultation, the author helped each team choose the most appropriate project topic. These consultations were necessary to provide guidance and making sure the project satisfies basic requirements. These included:

1. Must be a mechatronics project, i.e. involve electrical, mechanical, computer and control engineering aspects.
2. The scope must be such that it is neither too small nor too large so that it can be implemented in one semester

The teams were then asked to meet the instructor (the author) as needed outside class. In addition, based on his past experience [3-4], he used some Friday lab seasons to meet each team to consult with them and check on their progress. Each team was required to submit a formal final report at the end of the semester and make a 10 minute formal presentation.

All projects were to include sensors, actuators and a microcontroller and the design of circuit interfaces with the microcontroller including the electronics and power electronics when applicable in the project. The design approach was to follow the multidisciplinary systems approach illustrated in Fig. 2 below.

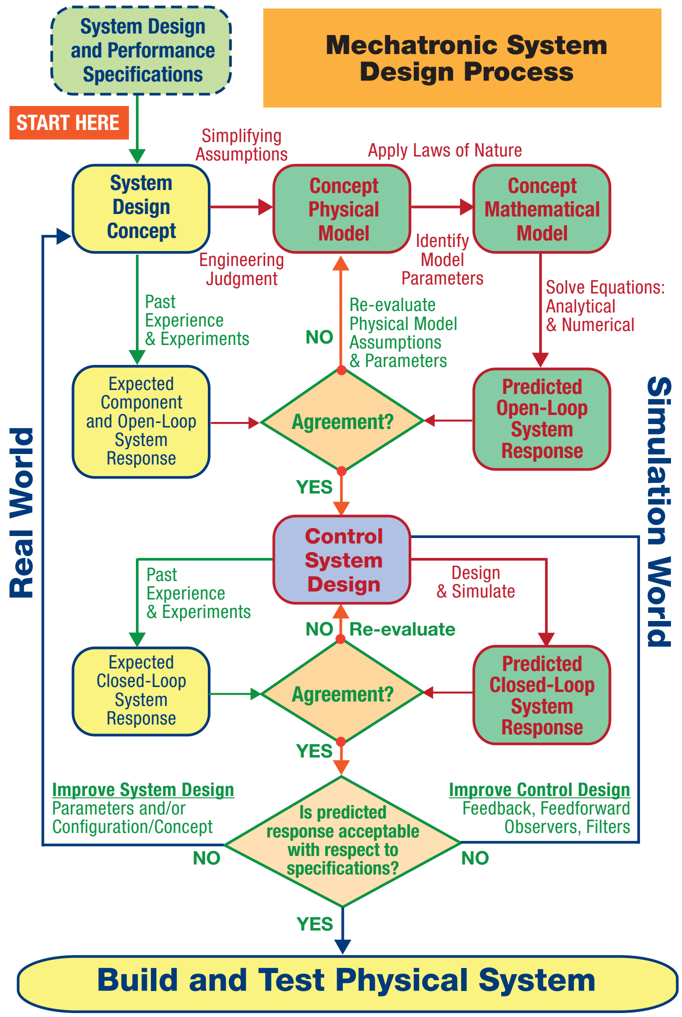


Fig. 2: The Mechatronics system design process according to Kevin Craig [6]

Early in the semester, the instructor reviewed the case studies in the last chapter of the textbook [1], so as to illustrate to the students what was expected of their term mechatronics project. The textbook includes a comprehensive discussion of several mechatronics projects case studies. Students were asked to study all the case studies. In class, the instructor discussed at length the following case study that he selected as the best representative of what is expected of the term project.:

3. Case study: Auto-Control System for Greenhouse Temperature [1]

Overview The purpose of the project is to develop an automatic control system that will ensure that the temperature within the greenhouse (Figs. 3-4) is always maintained at a specified value. An electric light source is used as a heat source, a variable speed fan regulates the temperature within the greenhouse, and a thermocoupler monitors the temperature. A PID controller developed using LabVIEW is used as the automatic control for the system. The heat source is switched on and an internal temperature for the green house is selected. As the temperature rises and passes the desired temperature, the variable speed fan is switched on; this reduces the internal temperature. As the internal temperature approaches the desired temperature, the fan speed is reduced by use of a PID controller. A manual override for the system is included, and as an added precaution a Boolean logic circuit will switch off the heat source if the fan is unable to reduce the internal temperature of the greenhouse effectively [1].

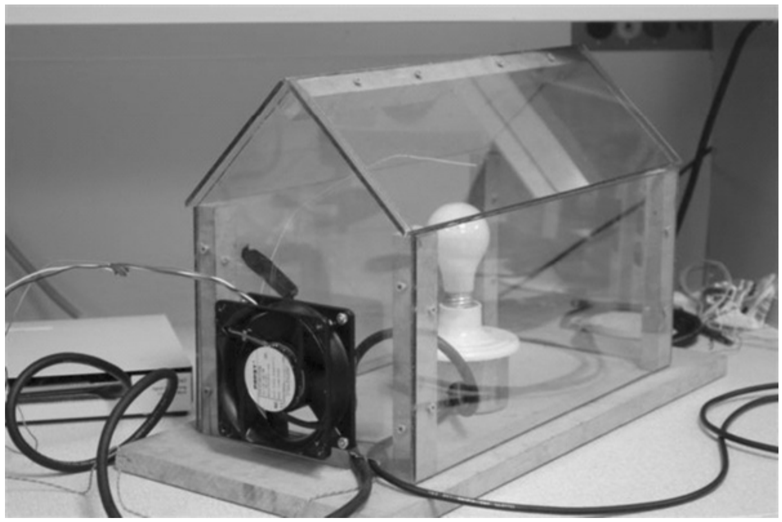
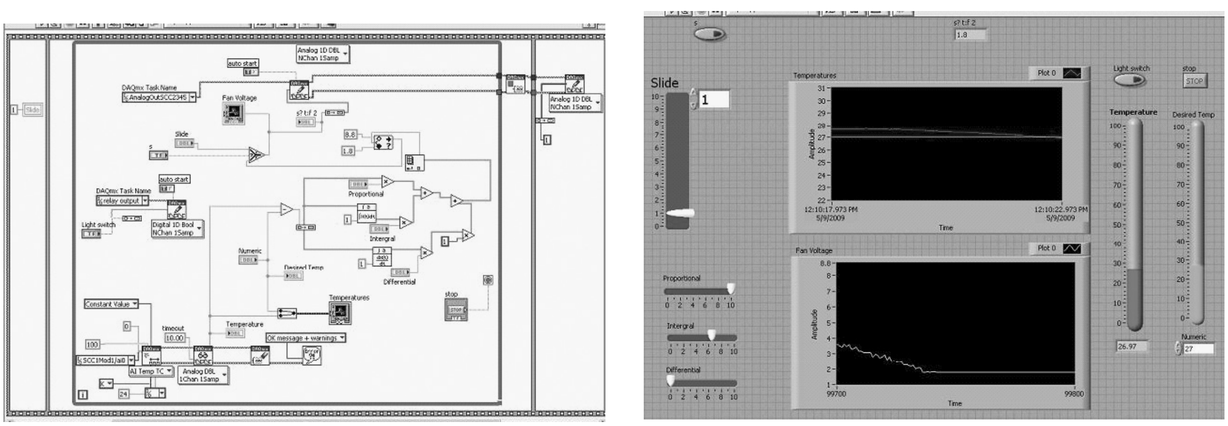


Fig. 3: Physical model of the greenhouse [1]



(a) (b)

Fig. 4: (a) Block diagram for the greenhouse (b) Front panel for greenhouse [1]

4. Assessment of Student Work

The following is the grading weight the author used to assess student performance :

- HW (10%)
- Attendance and Participation (5%)
- 2 Tests 10% each (20%)
- Term project (25%)
- Lab projects (15%)
- Final exam (25%)

5. Course Assessment

Since the course started in spring 2019, on January 16, and will end in May 2, 2019, no formal assessment has been made yet. So far, one student indicated that she was highly satisfied with the course design and content and its delivery. Following his past successful experience while teaching electromechanical engineering [3-4], the author plans to conduct a thorough survey at the end of the semester in the form of a questionnaire to be completed by students anonymously.

6. Summary and Conclusions

Mechatronics is modern multidisciplinary systems engineering [1,5-7]. The National Academy of engineering has predicted in its 2005 report the the engineer of 20/20 will have to be multidisciplinary [8]. A mechatronics approach is required in the design of optimized and cost-effective modern products, having built-in intelligence, which must be optimized over the product life-cycle [1,5-7]. Therefore, there is great demand for mechatronics in industry [1,5-7]. There are however few mechatronics undergraduate and graduate programs in the USA. Some electrical and mechanical engineering programs offer concentrations in mechatronics. Mechatronics is more popular outside the USA, especially in Europe, Asia, and Australia. Therefore, the challenge for American universities and colleges is to find the most effective and cost-effective way of introducing mechatronics in their curricula.

The author has presented a case study based on a new course that he has developed and taught in the spring semester of 2019. Drawing on his fourteen years of experience teaching electromechanical engineering at Wentworth Institute of Technology [3-4], the author has presented a possible effective model for introducing mechatronics programs in American higher education. This model introduces mechatronics to seniors and first-year Master’s level majors in both electrical and mechanical engineering. It does so uniquely by emphasizing mathematical modeling and a term design project and presenting the material using advanced engineering mathematics. This course could be a key course around which to develop BS,and Master’s programs, or concentrations in mechatronics. This course can also be be taken as a senior and or graduate elective. The author has found that in addition to his f experience teaching mechatronics (electromechanical engineering), his background in physics (PhD in condensed matter physics) was also very helpful.

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Biography:

Salah Badjou, is associate professor of electrical engineering at Merrimack College, Andover , Massachusetts. He holds in Ph.D. in Condensed Matter Physics from Northeastern University. He has academic and industrial research experience in applied physics, chemical, electrical and biomedical engineering. He taught electromechanical engineering at Wentworth Institute of Technology from 2000 to 2014. Dr. Badjou is also co-principal of American Polytechnic Institute (www.ampolytech.com). Contact:. Email: sbadjous@ampolytech.com. Tel.: (781) 491-4219.