PLANTING THE SEEDS FOR A MECHATRONIC CURRICULUM AT UALR

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Abstract: In February, 1999, UALR instituted a program in Systems Engineering. The program recognises the need for highly multidisciplinary, design-oriented education. This created a natural context into which a mechatronics discipline can be introduced. A course sequence in mechatronics is being developed to supplement the systems engineering curriculum and consists of the sequence Introduction to Engineering, C Programming, Elements of Mechanical Design, Circuits and Systems, Digital Systems, Control Theory, Instrumentation and Measurements, and Mechatronics. Facilities have been developed to allow students to design and analyse their parts in CAD, export them to a CAM program, which generates NC code for the CNC milling machine or lathe. This allows students to rapidly generate parts, and therefore create synergistic, integrated mechanical/electrical designs within a semester.

1. INTRODUCTION

In February, 1999, the University of Arkansas at Little Rock (UALR) instituted a program in Systems Engineering and redesigned its graduate programs in Applied Science. This was accomplished in conjunction with the formation of the Donaghey College of Information Science and Systems Engineering (CISSE). Both programs recognise the need for highly multidisciplinary, design-oriented education. This created a natural context into which a mechatronics discipline could be introduced. The courses for the Systems Engineering program are being developed as the class entering in Fall 1999 advances. Hence, the Freshman classes were developed in Fall 1999/Spring 2000. The Sophomore classes will be developed in Fall 2000/ Spring 2001. The Junior classes will be develop in Fall 2001/Spring 2002. And the Senior classes will be developed in Fall 2002/Spring 2003, at which time the first class will matriculate.

UALR's Systems Engineering program trains students to design, analyse, simulate, and optimise complex systems. Its current foci are on telecommunications and computer systems. The program has a core of systems analysis and simulation courses. The focus areas are primarily composed of electrical engineering speciality courses.

The systems engineering design philosophy is different from a component design or analysis philosophy, which is the training a traditional mechanical or electrical engineer receives. A system designer uses models and simulations of components to optimise the cost and performance of a system. His main focus is the interface between components, and he either matches specifications among different components or he drives the component design process to achieve necessary specifications. His models are usually less detailed than a component designer's models.

Mechatronics is the "synergistic combination of mechanical engineering, electronics, control systems and computers." (Craig, 1999) Since it is a combination of several disciplines, mechatronic design requires an inherently multidisciplinary approach. The mechatronics design revolution is fueled by the recent advent of inexpensive microprocessors and microcontrollers, the explosion of compact, inexpensive semiconductor-based sensors, and the improved power and efficiency of electric motors.

At the 1999 IEEE/ASME Advanced Integrated Mechatronics Conference, an international representation of mechatronics programs was presented. Most of these programs originated in a mechanical engineering department and are either a single course (Bergh, 1999; Carryer, 1999; Luecke, 1999; Trumper, 1999) or a two course sequence (Craig, 1999; Gardner, 1999). Some of the programs offered a structured sequence, such as a “thread” (Murray, 1999), a “stem” (Hsu, 1999), or a minor (Erkmen and Erkmen, 1999).

In those programs developing from a mechanical engineering curriculum, the introductory mechatronics course is usually an intensive embedded control or real-time programming course. Except for the situations where mechatronics is a capstone senior design course, very little mechanical design is actually accomplished through the course. Either structured laboratory exercises are performed or a real-time programming exercise is done with an existing mechanical system.

The only programs that truly accommodate a mechatronics education are the programs that either have the proper prerequisites (Bergh, 1999; Carryer, 1999), have an open ended capstone design (Craig, 1999; Gardner, 1999; Luecke, 1999; Hsu, 1999; Murray, 1999), or have a graduate component (Craig, 1999; Carryer, 1999). A single course in mechatronics, although it provides a very useful skill set to a mechanical engineer, cannot accomplish a complete mechatronic education.

Most programs recognise that teaching assembly language skills or low-level embedded programming are counterproductive. Several programs use a Basic Stamp or PIC microcontroller (Gardner, 1999; Luecke, 1999) while others proceed along the code-generation route (Craig, 1999; Trumper, 1999). The former approach has inexpensive hardware at the expense of computing power. The latter approach is significantly more expensive; however, more elaborate control algorithms can be implemented, and the course can focus on design rather than programming.

Mechatronics design can be seen as a systems engineering approach where the elements of the system are a mixture of mechanical, electrical, control, and software components. UALR’s systems engineering program contains training in three out of four elements that a mechatronic design engineer requires. The fourth element, mechanical design and analysis skills, can be added (at least in a minimal sense) through two or three intensive mechanical engineering courses. These courses cannot cover the breadth of a mechanical engineering curriculum. Just as most mechatronics curricula must teach intensive electrical and embedded control skills to mechanical engineering students, UALR’s program has the inverse problem of teaching intensive mechanical design skills to systems engineering students. The capstone mechatronic design course must integrate the electrical design skills, the real-time programming and control skills, with the intensive mechanical engineering skills, through a multidisciplinary mechatronic design project.

2. CURRICULUM

The proposed mechatronics sequence is shown in Table 1. Implementation of this sequence has begun with the development of SYEN1305 in the Spring 2000 semester, including a special section which works concurrently with the national U. S. FIRST program. The remaining courses will be developed as the junior and senior classes advance in 2002 and 2003.

Throughout the design courses, several common factors are stressed.

All courses contain a laboratory component. The laboratory provides exercises illustrating attributes of typical design elements. These exercises form a database of what elements are available to the designer and encourage him to look for examples in his everyday life. The laboratory experience also trains students in the use of common engineering measurement tools, and teaches them how to use measurements in problem-solving process.

The design element toolbox is further enhanced with case studies of successful and unsuccessful designs. These studies are drawn from research projects (Wright, 1999), case studies formed by other researchers (e.g., Craig, 1999; Gardner, 1999; Luecke, 1999), and previous class designs.

The toolbox is further expanded through exercises in reverse engineering. Many successful engineers, who matriculated ten years ago, can recall their pre-college days, in which they took things apart either to fix them or to figure out how they worked. Sadly, most college engineering students do not share this experience and require formal training. Reverse engineering and analogy is a formal method to teach students how to disassemble devices and to determine their function and specifications.

Many engineering students have chosen this profession because they are good in mathematics and loathe writing. Unfortunately for them, the modern engineer must be able to communicate ideas through writing as about 30% of his function. Therefore, written communications, through weekly memos and a final report, are required in all courses in the mechatronics discipline as a significant graded component.

By its multidisciplinary nature, mechatronics engineers will work in teams. Few engineers can maintain current mastery of all the disciplines necessary to design a mechatronic product. A mechatronic design engineer must understand enough about the sub-disciplines to communicate with component designers. He must be able to work in a team environment.

"The proof is in the pudding." Regardless of his mastery of classroom exercises, laboratories, homework exercises, and examinations, an independent, free-form design project must be accomplished to reinforce and to assess design skills. The project must start with a determination of specifications, development of a design configuration, analysis and simulation to refine the design configuration, manufacture of a prototype, and validation of the prototype against specifications.

Cost and budgets is stressed in all courses. This often-neglected component of the engineering education is the most important design restriction in industry. Students are encouraged to account for all the hidden costs as well, including machining costs, non-recurring engineering costs, and transportation costs.

2.1. Overview of Mechatronics Sequence

Students start in Freshman year in Introduction to Engineering. In the next two years, students develop the prerequisites, such as Circuits and Systems, Digital Systems, Linear Control Theory, Elements of Mechanical Design, and Dynamics, to prepare for a capstone Mechatronics I course at the senior level. Students may continue with either Masters or Doctoral studies in the Engineering Science program offered through the Department of Applied Science. An Advanced Mechatronics course is offered in this program and supplementary courses may be offered through Special Topics.

2.2. Course Descriptions

SYEN 1305. Introduction to Engineering. Two hours per week of lecture and practicum and two hours per week of laboratory.

Laboratory:

Eight 'canned' electronics laboratory exercises introduce students to the use of laboratory test equipment (multimeter, oscilloscope, function generator, bread-board, power supply). Students learn to bread-board circuits according to a schematic and measure electrical quantities, such as current and voltage at key points in the circuit. Concepts, such as Ohm's law and Kirchoff's laws are introduced through the measurements. Subtle concepts, such as power supply noise and ground loops are also introduced. Time domain and primitive frequency domain measurement, using the oscilloscope are introduced.

Two laboratories are devoted to building a computer from components and installing an operating system (linux). Two laboratories are devoted to reverse engineering a mechanical product. The final two exercises are devoted to friction and springs, and gears, sprockets, and timing belts.

Lecture/Practicum:

The initial lectures introduce the engineering profession, ethics, and philosophy. Because the systems engineering curriculum has no formal statics course, a set of lectures discussing vectors, forces, and engineering statics is covered to prepare students for the engineering fundamentals examination. A lecture on parametric, feature-based solid modelling and CAD and a lecture on CAM and CNC machining follow. Time and Project Management (critical paths, goals, deadlines, timelines) are covered.

The final lectures cover the qualitative attributes (precision, durability, cost) of basic mechanical elements, such as fasteners (bolts, rivets, welding), drive elements (gears, sprockets, timing gears; pitch, ratios), and bearing surfaces (bearings, bushings). Materials (aluminum, steel, brass, plastic) are discussed qualitatively (strength, weight, cost, conductivity). Drills and taps are covered. Friction and lubrication are covered.

A simple design project, such as design a gear train or a mouse-trap powered car (c.f. SECME) is introduced at the mid-point of the semester. The class is split into teams to facilitate resource usage over a large class and to take advantage of 'group learning' where more experienced members can help the less experienced students. A group report, including some calculations, detail of how to fabricate the design, CAD drawings of final parts and fixtures, CAM program showing tooling and tool paths, and cost of the design (including fixtures and labour) is required.

Those designs which are sufficiently detailed and well-documented are built by a trained machinist and tested against specifications. In most design courses, student designs are built by the student; however, in most industries, an engineer must communicate with a machinist to have a design built. Since most Freshman engineering students do not have machining skills, this is an opportunity to teach the students to communicate with a machine shop.

Designs which, based on the report, are clearly not feasible, will receive lower grades and feedback as to why they cannot work. This provides some incentive to avoid waiting until the last minute to begin the design process.

After the introduction of the design project, practica are interspersed with the lectures. These involve brain-storming sessions, design advice and consultation, and hands-on exercises to assist in the design process.

U. S. FIRST section. A Special section of Introduction to Engineering, similar to U. S. Coast Guard's program (Hiles, 1997) was implemented to function in conjunction with the national U. S. FIRST design competition.

The FIRST competition requires an engineering team to design and build a tele-operated mobile robot in a 42-day time frame from a kit of parts and a restricted list of allowable materials. Ideally, engineers work in conjunction with pre-college students to perform the design. Although most corporate teams assign a large engineering staff to perform the design and allow their pre-college students to “shadow” the engineers, UALR attempts to partner its faculty, engineering students, and pre-college students in a functional training relationship. Several other universities have sponsored FIRST teams (Clough and Yadav-Olney, 1997; Durgin, 1997; Staab, et al. 1997), usually as an extracurricular activity.

Each year the problem is different, and mechanisms from previous years are not allowed. This encourages teams to begin with a blank sheet of paper. The 2000 competition required a robot to pick up 13 inch diameter rubber balls and place them in a six foot high trough. To get to the balls, a robot either had to manoeuvre under a 30 inch high limbo bar or climb a 15 degree slope. Machines were confined to a 30 inch by 36 inch footprint and could not weigh more than 130 pounds. Machines initially had to be less than 5 feet high. The final competition version of UALR’s robot is shown in Figure 1.

The big task must be broken into smaller tasks. UALR's Introduction to Systems Engineering students function as project leaders to supervise and train their pre-college proto-engineers. Pre-college students and Freshman engineering students must learn practical design skills through a heuristic (rather than analytical) process, since they do not possess the mathematical skills at this level in their development.

Because the FIRST competition starts in January, shortly after the beginning of the Spring semester, the course must be front-loaded. The first six weeks consist of an intensive brain-storm, design, and build phase. The contact hours are doubled (i.e. six one hour lectures per week), and the lectures proceed in a slightly different order and at a faster pace, similar to a summer course. In addition to the lectures, a mandatory two-hour design session follows each lecture. Homework assignments are drawn from analysis necessary to design the robot. After a six week hiatus, the final two weeks of the semester consist of a normal paced, retroactive analysis phase. The laboratory proceeds in sync with the regular section.

ASCI 3301. Elements of Mechanical Design. Three hours per week of lecture. This course is currently under development.

The first half of the course is an intensive study of geometry, forces, stress, and strain. Material properties (strength, ductility, fatigue) are covered. Homework exercises are designed to include Finite Element calculations as well as analytical solutions to standard stress analysis problems.

A practicum covering machine shop operation and rudimentary machining and fixturing runs simultaneously with the early lectures.

The second half of the course covers design with typical mechanical elements such as joints, power transmission, bearings, and linkages.

Two minor designs are required during the semester, each of which stresses choices of basic design elements. Calculations on the chosen design elements are required. The calculations may be supplemented with Finite Element simulation. As with Introduction to Engineering, a report, including CAD, CAM, fixtures, fabrication methods, and costs, is required. The best designs will be fabricated.

The final project consists of a design competition, loosely based on MIT’s 2.007 (formerly 2.70) design course (http://pergatory.mit.edu/2.007/). The design will have some element of human interface and some use of selected sensors and motors. Initially, this competition will be a scaled down version of the 2.007 competition. The complexity will grow as course materials and experience are obtained.

ASCI 4325. Instrumentation and Measurements. Two hours per week of lecture and two hours per week of laboratory.

Lecture:
The components of a digital data acquisition system are introduced. This provides a context in which the remainder of the semester progresses. The goal of this course is that students thoroughly understand the components of a measurement process and how to interpret measurement data.

Probability and uncertainty are covered. Knowledge of the measurement process is used to estimate the tolerance on a measurement. The transducer as a multivariable process is discussed. Dual sensitivities and non-linear behaviour of the transducer are discussed. Regression, linearization, and calibration are introduced.

A survey of the operating principles of standard sensors to measure mechanical quantities (position, speed, angular speed, temperature, strain, pressure, and force) is done. Frequency response of transducers is emphasised.

Digital data acquisition is introduced. Sampling and filtering is covered, focussing on how to select sampling rates and filter type and cut-off frequencies. Analog to digital conversion and quantization of measurements is discussed. Conversion time, multiplexing, and uncertainty associated with quantization are discussed.

Laboratory:
Canned laboratory exercises and calculations are designed to illustrate the concepts expounded in the lectures. A strain gage based force transducer is used to illustrate signal conditioning, amplification, uncertainty, calibration, and regression. A thermocouple is used to illustrate noise, ground loops, non-linear compensation, calibration, and

quantization. A microphone is used to illustrate filtering and anti-aliasing.

<u>*ASCI 4335. Mechatronics I.*</u> Two hours per week of lecture, two hours per week of laboratory. This course is currently under development. Restricted enrolment.

Students who satisfy the prerequisites for mechatronics (SYEN1300, SYEN1305, PHYS 2321, SYEN2315, SYEN3330, SYEN3364, ASCI3301, ASCI4325) have already accomplished component designs in Introduction to Engineering, Design of Mechanical Elements, Circuits and Systems, Digital Systems, and Linear Control Theory. Mechatronics I can focus on a semester long design of a complex mechatronic system, such as an autonomous mobile robot.

This course uses a concept similar to Penn State's advanced mechatronics course (Gardner, 1999). The big design project is divided over several teams, each of which designs a part. Communication and interfaces between groups are stressed. Project management is important, because one group falling behind can damage the entire project. At the end of the project, a report from each of the groups is required. The report must document the design process and how the design meets specifications.

Before the semester begins, the task is chosen and specifications generated. An organisational chart for the project team is generated and job descriptions written (E.g., overall project manager, software design lead, CAD lead). Prospective students must apply for a position, submit a resume, and interview.

The project must be completed within budget. Otherwise, dire penalties will be applied. In order to give the students some design flexibility and to avoid long purchasing delays, the choices of components are restricted.

Motors and sensors are restricted to those which are 'in stock' at the university. These components are acquired by a variety of means, including donations, cannibalisation of obsolete machinery and defunct projects, and specific purchases for the course. A catalog containing parts, specifications, cost and stock is prepared for each offering.

Machining time is also billed at the rate applied to research contracts. Since this is internal accounting, no money changes hands. However, students are encouraged to consider machining costs and delays in both budgets and schedules. Some machining can be performed by the students, thereby saving money and time at the expense of precision.

The students must choose their processor from a list of options. Students will have to trade off ease of use versus cost and processing power. Available processor configurations are:

- Blue Earth Microcontroller
- Innovation FIRST controller or Basic Stamp
- TI DSP Development Kit
- Pentium Motherboard

The lectures cover those attributes of a mechatronic system which have not been covered in the component courses. These subjects include actuators (DC motors, stepper motors, pneumatics, and hydraulics) and real-time programming. Power sources, such as line power, batteries, solar power, engines, and fuel cells, are discussed.

How to make mechatronic design trade-offs will be covered through case studies and discussion during the design project. Case studies are drawn from research, past class projects, and the literature.

3. LABORATORY FACILITIES

Most of the courses in the mechatronic discipline will be hosted in CISSE's Studio Classroom. The Studio Classroom contains thirty networked computer stations running Windows NT. Software, such as Matlab, Simulink, Pro/Engineer, Patran, NASTRAN, and FeatureCAM, are available to be run during the class sessions. Some of these computers will soon include a data acquisition board to run a virtual digital storage oscilloscope.

The Applied Science Electronics Lab contains five stations including computer, digital storage oscilloscope, function generator, power supply, powered bread-board, multimeter, and soldering station. After the laboratory equipment described by Trumper (1999) and Arkin, et al. (1997), it is planned to include a Dspace controller board in these computers. This will allow control algorithms to be designed in block diagram format and implemented quickly in hardware.

The Graduate Institute of Technology (GIT) machine shop, which supports CISSE, contains two production quality CNC machines (Bridgeport Mill, Daewoo Lathe). A student machine shop area, containing milling machines, lathes, band-saws, etc. is also available for class support.

4. CONCLUSION

Mechanical and System designers need to be familiar with a mechatronic design philosophy. The real world has a large mechanical component. Even systems engineers with a predominantly electrical/software focus will have to interface with the mechanical world.

Mechanical designs will increasingly rely on integrating mechatronic concepts. A newly graduated mechanical engineer is at a disadvantage if he does not understand embedded control.

Standard mechanical engineering design methodology is the umbrella under which mechatronics fits. The mechatronic engineer's toolbox is simply augmented with additional tools, such as control algorithms, sensors and actuators, and electronic components.

REFERENCES

Arkin, R. C., Lee, K. M., McGinnis, L. F., Zhou, C., (1997) The Development of a Shared Interdisciplinary Intelligent Mechatronics Laboratory, *Journal of Engineering Education*, 113-118.

Bergh, C. F., Kita, A., Ume, I. C. (1999), Development of Mechatronics Course in the School of Mechanical Engineering at Georgia Tech, *Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 459-465.

Carryer, J. E. (1999), Undergraduate Mechatronics at Stanford University, *Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 585-591.

Clough, J. M., Yadav-Olney, S. N. (1997), FIRST - Engineering Partnerships Between University of Wisconsin-Platteville and Platteville High School, *Proceedings of the 1997 ASEE Annual Conference*, session 2325.

Craig, K. (1999), MECHATRONICS AT RENSSELAER: A TWO-COURSE SENIOR-ELECTIVE SEQUENCE IN MECHANICAL ENGINEERING, *Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 452-458.

Durgin, W. W. (1997), University Participation in FIRST WPI's Experience, *Proceedings of the 1997 ASEE Annual Conference*, session 2325.

Erkmen, I., Erkmen, A., M. (1999), A Mechatronics Minor Program Imbedding Design via a Multidisciplinary International Virtual Design Studio, *Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 592-597.

Gardner, J. F., Lamancus, J. S., Sommer, H. J. (1999), Mechatronics II: Advanced Mechatronics for Mechanical Engineering Students, *Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 472-476.

Hiles, K. E. (1997), A Project-Based Freshman Engineering Design Experience – FIRST, *Proceedings of the 1997 ASEE Annual Conference*, session 2325.

Hsu, T. R. and Wang, J. (1999), A Mechatronics Curriculum Stem for Undergraduate Mechanical Engineering Education, *Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 577-584.

Lueke, G. R. (1999), "MUSCLETRONICS" TEACHING MECHATRONICS WITH FLUID POWER SYSTEMS, *Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 466-471.

Murray, W. R. and Garbini, J. L. (1999), Mechatronics Capstone Design Projects at the University of Washington, *Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 598-604.

Staab, G., Evans, S., Godez, S., Engdahl, E. (1997), TOGA PARTY - Developing a Tradition, *Proceedings of the 1997 ASEE Annual Conference*, session 2325.

Trumper, D. M., Ludwick, S. J. (1999), Development of 2.737 Mechatronics at MIT, *Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 446-451.

Wilczynski, V., Dixon, G. W., Kiemcik, C. G. (1998), A Robotics Competition to Interest Minorities in Engineering, *Proceedings of the 1998 ASEE Annual Conference*, session 2670.

Wright, A. B. (2000), *Mechatronic Design of a Treaded Mobile Robot for Mine Sweeping*, submitted to J. Arkansas Academy of Sciences, http://theduchy.ualr.edu/papers/aas2.pdf.

Table 1. Mechatronics Course Sequence

Semester	Course Code	
Spring	**SYEN 1300**	**Introduction to C/C++ Programming**
Spring	**SYEN 1305**	**Introduction to Engineering**
Spring	**PHYS 2321**	**Physics for Scientists and Engineers I**
Fall	**SYEN 2315**	**Circuits and Systems**
Spring	**SYEN 3330**	**Digital Systems**
Fall	**SYEN 3364**	**Linear Control Theory**
Fall	**ASCI 3301**	**Elements of Mechanical Design**
Spring	**ASCI 4325**	**Instrumentation and Measurements**
Fall	**ASCI 4335**	**Mechatronics I**

Figure 1. UALR's first FIRST robot