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Introduction of Mechatronics Specialization through Concentration Areas in the Mechanical and Electrical Engineering Technology Programs

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Abstract

The last few decades have experienced an explosion of technology, both in industry and in customer products. A large variety of embedded systems from various areas of applications, digital electronics, internet of things, automatically controlled products, and ultimately mechatronics systems are part of the everyday life. The changes in the industries, consumer markets and implicitly in the job markets, impose changes in the academic programs and curricula. Recently, mechatronics undergraduate programs started being developed in 2 or 4 years colleges across the nation, mainly driven by international companies operating in countries that already offer mechatronics degrees ranging from high school to doctoral programs. Most of the time there are independent mechatronics programs, mainly at the community college level, but mechatronics areas of specialization were also developed under either electrical or mechanical engineering programs, through senior elective courses. In the College of Engineering and Technology at Old Dominion University there are currently well established, accredited electrical and mechanical engineering technology programs, and steps are being taken to introduce the option for mechatronics specialization. A mechatronics concentration area was already introduced under the mechanical engineering technology (MET) program with new courses developed to provide skills in mechatronics, hydraulics, and simulation of mechatronics systems, complementing the existing courses focusing on automation, industrial robotics, computer integrated manufacturing, and computer numerical control. The electrical engineering technology (EET) program, with a current curriculum that includes a large number of courses to provide the foundation for mechatronics, is taking its turn in the development of a mechatronics concentration area. This paper discusses the introduction of mechatronics specialization through concertation areas in the mechanical and electrical engineering technology programs at Old Dominion University, with emphasis on the implementation challenges. This specialization model offers students the choice to incline the balance between the electrical and mechanical components of their mechatronics education through their major and minor selection, and in consonance with their individual strengths and preferences.

1. Introduction

The term *Mechatronics* was the first time introduced in 1969 by a Japanese electrical engineer in a Yaskawa company[1]. After Yaskawa released all trademark rights in 1982, the term became widely used all over the world. Mechatronics technology is used to define the development of products and manufacturing processes, and very often is considered similar to robotics or electromechanical systems technology. There are multiple definitions of mechatronics introduced by various engineering communities. One of them is proposed by the International Federation of the Theory of Machines and Mechanism (IFTMM): "*Mechatronics is the synergistic combination of precision mechanical engineering, electronic control, and systems thinking in design of products and manufacturing processes* [1]". Another group, led by the Packaging Machinery Manufacturers Institute (PMMI) and Mid-Atlantic Mechatronics Advisory Committee

(MAMAC), provided the following definition: *"Mechatronics is the synergistic application of mechanical engineering, electrical engineering, controls engineering, and computer science to create useful products. It is a skill and knowledge set used by mechatronics engineering technicians to assure the automation that drives modern manufacturing delivers its potential for higher productivity and output [2]."* The IEEE/ASME definition is as follows: *"Synergetic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes" [3]*.

A Mechatronics Certification program was first developed by the Packaging Machinery Manufacturers Institute (PMMI) [4] and added to the Competency Model Clearinghouse by the U.S. Department of Labor [5]. This competency model defines mechatronics as "*systems, processes, and standards supporting the application of integrated manufacturing systems*" [5]. Another example of mechatronics certification is the Siemens Mechatronics Certificate, which is driven by the industry needs, and for which Siemens usually provides training on the pneumatic didactic training workstations such as Festo Didactic learning systems MPS-500 [6].

Mechatronics Pathways

Mechatronics has been identified as one of the manufacturing areas that currently has a shortage of highly skilled workers in the U.S. workforce [2]. Technical schools and community colleges across the nation have started mechatronics certificate programs and A. A. S. or A. S. degree programs in mechatronics as a result of industry driven initiatives. These efforts are so widespread that National Science Foundation Advanced Technology Education (NSF ATE) program has an entire panel dedicated to mechatronics at the community college level each year. Articulation agreements across the country are enabling pathways among two and four year degree programs (2 + 2) [2]. Two year programs are focusing on developing curriculum for future employees that would use mechatronics knowledge in industrial maintained applications where along with mechanical and electrical systems, they will have the necessary background about machining, electronics, logic control, and other skills that are related to the maintenance of industrial robots and automated equipment in integrated manufacturing systems.

Some examples of mechatronics pathways at different education levels are mentioned here:

- *Mechatronics in High School*

Mechatronics has been added to the Virginia Career Technical Education Manufacturing pathway. The two lead faculty for the mechatronics area of specialization at Old Dominion University and Tidewater Community College served on a panel that introduced this curriculum in 2017, as part of the project *Higher Education Pathways for Maritime Mechatronics Technicians* (MechTech), funded through a grant from the Office of Naval Research [7]. A part of this project was the development of three mechatronics courses: Mechatronics I [8], Mechatronics II [9], and Mechatronics III [10].

- *Mechatronics at Community Colleges*

The Commonwealth of Virginia has four programs in mechatronics at the associate of applied sciences level: Paul D. Camp, Franklin, Virginia – has a mechatronics program; Thomas Nelson, Hampton, Virginia – has mechatronics under Advanced Integrated Manufacturing Technology[11]; Virginia Western, Roanoke, Virginia - has the program Mechatronics Systems Engineering Technology with two areas of specialization, Design Engineering Technology Specialization and Electrical Engineering Technology Specialization[11]; and Tidewater Community College, Chesapeake, VA. – has a mechatronics associate of applied science degree under the Manufacturing and Transportation program.

- *Mechatronics Programs in 4-years University Programs and graduate programs*

The Mechatronics Engineering Technology program at Purdue University's Calumet Campus has been developed as part of NSF ATE grant[12-14]. This program focuses on a packaging automation and it is supported by the Packaging Machinery Manufacturers Institute (PMMI) [14]. Before that program, three universities offered degrees in mechatronics engineering but they did not fit the needs of the packaging industry. Currently there are six ABET accredited mechatronics programs in the United States: California State University, Chico, CA; Central Connecticut State University, New Britain, CT; Kennesaw State University, Kennesaw, GA; North Carolina State University at Raleigh, Raleigh, NC; Purdue University Northwest (Formerly Purdue University North Central), Calumet, IN, and University of North Carolina at Asheville, Asheville, NC [15].

2. Mechatronics options under Engineering Technology (ET) Program

The Engineering Technology Department at Old Dominion University (ODU) has well established traditional civil, electrical and mechanical engineering technology programs, which prepare students for the local industries. As the job market becomes more and more dynamic and the need for modern technological skills becomes essential for graduates looking to secure jobs, academic programs have to adapt to the needs of the industry and introduce new courses, specialization areas or even full programs to respond to these growing needs. Mechatronics is one specialization area that the engineering technology department at ODU decided to address in response to the changes in the job markets. The mechanical and electrical engineering technology programs in the department already have good collaboration in terms of interdisciplinary undergraduate projects and senior design projects, as well as through courses opened to students in both programs, mostly through courses related to computer skills and applied mathematical analytic skills.

2.1. First step, MET Mechatronics Systems Area of Concentration

The first step directly taken towards the mechatronics option in the ET department was under the mechanical engineering technology (MET) program in 2014. While the program already offered fundamental courses for mechanical curriculum in statics, dynamics, and fluid mechanics for example, along with courses in automation control, industrial robotics, computer integrated manufacturing, and computer numerical control, there were not yet courses specific to mechatronics specialization. Bridge courses towards the electrical side of mechatronics were available under the dual enrolment courses, and electronics/hardware courses were available through minor specialization in electrical engineering technology (EET), but a clearly defined mechatronics pathway in the program curriculum was not yet established a few years ago. Thus, not knowing ahead what to look for, potential students might not have realized that the option for a mechatronics specialization was in fact available.

In response to the feedback received from the Industrial Advisory Board (IAB), indicating the need in the local industry job market for the mechatronics specialization, the MET program introduced a new faculty line in 2012. The newly recruited faculty started developing 400-level senior elective courses specific to mechatronics, such as *Introduction to Mechatronics*, and *Mechatronic System Design* [16]. Additionally, the course *Modeling and Simulations of Mechatronics Systems* has been added to MET curriculum in 2014 through funding from the Office of Naval Research Mechatronic Pathways[17]. The newly developed courses provide students with skills in mechatronics, automotive mechatronics, electro-hydraulics, simulation of mechatronics systems, and are complementing already existing courses in the MET curriculum that are focused on automation, industrial robotics, computer integrated manufacturing, computer numerical control. Along with developing new courses, some existing courses have been modified to reflect electrified mechanisms, such as a Solid Modeling course [18]. Through these courses, students were exposed to areas specific to electrical engineers, such as electronics hardware, microprocessors, and microcontrollers programming and coding. While MET students get exposed to some topics in electrical engineering technology through three EET courses in their curriculum, as these are service courses opened to all students in engineering technology, these courses are not programming intense courses. This motivated the choice in the MET mechatronics courses for friendly platforms with the Arduino processors, for which there is a lot of open source material that students can access outside of class if interested to go deeper in the topics. The method of delivery for these courses was either class, synchronous on-line or asynchronous, and the courses were well received by the students. However, a common commentary that students make is that they feel the need for more advanced courses to prepare them in programing microcontrollers that are used in industry, and this can be achieved through courses in the EET program. As a result of completing mechatronics courses, many students have included mechatronics as part of their senior projects designs [19].

With the development of the new mechatronics courses, the MET program added to the 2014-2015 catalog the Mechatronics Systems area of concentration, which follows the common MET curriculum and recommends MET senior elective courses in mechatronics. If students select a minor in EET, then they can take four electronics or hardware related EET courses to complement their mechanical background with a strong electrical side, and the major and minor together would provide a strong mechatronics foundation.

2.2 Introducing EET Mechatronics Concentration Area

The Rationale for an EET Mechatronics Specialization

Starting with the 2018-2019 catalog, the EET program is introducing the option for mechatronics, as a newly developed concentration area. While the program offers a strong package of electronics, communications, and power electronics courses that provide a good foundation for mechatronics specialization, to clearly signal the mechatronics option to the incoming students, the actual "mechatronics" name should be specified within the offered curriculum. From the MET experience over the last few years, EET faculty have come to the conclusion that there is enough interest among students for a stronger curriculum and a more interdisciplinary approach for mechatronics. The EET program did not have the availability of a new faculty line to develop a new direction, therefore existing resources were to be used in putting together the new concentration area. The solution was to initiate the concentration area by compiling the existing along with only a few new EET courses, and the available MET mechatronics related courses. While formulating a mechatronics pathway out of mostly existing courses sounds fairly easy, implementing it in practice would face various constraints, including total credit hours for graduation or overlap between concentration areas within the program.

Currently, the EET program offers two concentration areas: Computer Engineering Technology Concentration (ComET) and Electrical Systems Technology Concentration (SysET). While these two concentration areas are consistent with the traditional partition of an electrical and computer engineering program into computer engineering and electrical engineering, EET faculty found that most of the time students coming into the program have no difficulty in understanding the ComET specialization, but they are not always sure of the SysET specifics and what exactly are they finally going to specialize in. Although under the SysET concentration area students have the flexibility to direct their studies towards electronics, communications or power systems, it would be more beneficial for them to have these pathways clearly defined from the very entrance into the program. The students should be able to better align their course selection with their final goals, and not leave aside the final semesters to settle on a specialization area. Additionally, clearly defined specializations pathways will avoid having the senior courses distributed among various specialization areas without a clear focus on something specific, and it should ultimately help students with their job applications.

In response to the current trends in industry and academic programs around the nation, an updated EET program curriculum was developed and introduced in the 2018-2019 catalog, having the goal of modernizing the program, and raising it to the current standards and terminology. Terms such as "embedded systems" or "mechatronics", which are in high demands in the present-day industry, need to be developed through course offerings and emphasized with clear specialization statements on students' transcripts too. The backbone of the curriculum update was the replacement of the Electrical Systems Technology concentration area with four new concentration areas, which are specific to the specialization fields: Communications Systems Technology concentration area, Embedded Systems Technology concentration area, Mechatronics Engineering Technology concentration area, and Power Systems Technology concentration area. To support the five concentration areas in the new curriculum, a couple of the existing courses are revised, and a few new courses are introduced. For each concentration area, 4 years study plans were developed to clearly outline the course pathways. While the large majority of courses are common for all the concentration areas and are specific to the EET program, each concentration area outlines certain courses, which might be shared with another concentration area but not with the entire program. Such courses will be required courses for the concentration area for which they are specific, and would be elective courses for the other concentration areas. For example, a 300 level Electric Power and Machinery course is required for the power and mechatronics tracks and is an elective course for the other concentration areas, and a 400 level Electrical Power Systems course is required for the power track and is an elective course for any other concentration area.

Implementation Challenges

The introduction of the MET mechatronics concentration area was very smooth, since it was implemented through the addition of senior elective courses only to the existing curriculum, without affecting the core of required courses, therefore expanding the specialization choices through elective courses. In the EET case, a more thorough revision of the curriculum is sought, since course revisions will also affect lower division courses, and the set of required courses will vary slightly among concentration areas. Several constraints had to be considered altogether for this update project:

- Maintaining the overall number of credits required for graduation.
- Keeping alignment with the community colleges' curricula, since a large number of students are coming with associate degrees from community colleges and continue the EET program toward a bachelor degree.
- Having a common core of courses over all the concentration areas, and having these courses scheduled in the same semesters for each concentration area's 4-years study plan.
- Aligning the course sequences specific to each specialization path with the long range schedule of all EET courses per fall, spring and summer semesters.
- Last but not least, having faculty available to develop or modify and teach all the courses needed for each semester.

A major constraint in compiling a new concentration area is the introduction of new required courses while staying within the allowed total number of credits for graduation. For the proposed curriculum update, this issue came into considerations twice: once in order to introduce new, specialized EET courses to support the overall proposed changes in the curriculum, and again when MET mechatronics specific courses were to be introduced into the study plan of the newly developed EET mechatronics concentration area. In the first case the solution came from replacing older courses with newly developed ones, and by having some courses required only for their specific concentration areas and no longer required for the other concentration areas. For example, a course in communication principles previously required by the entire EET program, continues to be a required course in its specialization area but it is no longer required in the power systems concentration area, making room this way for courses more specific to that field. Vice versa, a power course previously required for all EET students is no longer required for those pursuing the communication specialization area and it can be substituted with an area specific course. To develop the EET mechatronics concentration area, the introduction of new courses seemed to be an even harder problem. Trading EET courses for MET courses in order to create a mechatronics specialization was not a viable solution without weakening the EET core curriculum. The solution in this case came from the fact that both EET and MET programs require a minor for graduation. Several minor options are available for students, and frequently MET students pick EET as minor and vice-versa. However, in such cases it often happens that the set of courses the students select to fulfil the minor requirements is not structured, the selection being mostly driven by the course availability or scheduling, or student own preference. Under the newly developed EET mechatronics concentration areas, the students would have the minor course selection aligned with the mechatronics specialization.

Specifics of the EET Mechatronics Concentration Area Implementation

The EET program curriculum follows a traditional structure with courses in the areas of AC/DC circuit analysis, logic circuitry, analog and digital electronics, linear electronics, microprocessors and microcontrollers, communication systems, electrical power systems and machinery, and programmable machine controls. While microprocessor fundamentals are introduced in a 100-level course along with logic circuitry and digital interface devices, no actual microprocessor course was previously within the lower division set of courses. The implementation of the curriculum update started with the introduction of such course. The necessary credit hours for the new course came from eliminating one of the two 200-level analog electronics courses, and compacting the content for analog electronics into a single course. The new course is a 200-level course named *Introduction to Microprocessors and Microcontrollers,* and aligns with a current 200 level course offered by the community colleges, such that the students coming with associate degrees into the EET program can have their credit transferred properly. The microprocessors/ microcontrollers course sequence continues with a required 300-level course, *Advanced Microprocessors and Microcontrollers*, and a 400-level course, *Microcontrollers/Embedded Based Designs,* which is a required course for the Embedded Systems concentration area, and an elective course for the other concentrations. Under the new catalog, the 200 and the 300 level courses mentioned above are required courses for all concentration areas. While the 300 and 400 level courses are not new courses, under the new catalog they will undergo content update.

The course descriptions for the microprocessors/ microcontrollers course sequence are as follows:

EET2XX – *Introduction to Microprocessors and Microcontrollers:*
Introduction to software and hardware related to PIC16FXXX 8 bit microprocessor and microcontroller architectures, interface circuitry, and system designs. Programming of internal and external hardware/peripherals, communication protocols between the logic circuits,

peripherals, and MCUs. The course focus is on ASM programming and design along with an introduction to C coding.

EET3XX – *Advanced Microprocessors and Microcontrollers*

A second course in the digital electronics course sequence. The course uses C programming for software/hardware design with ARM M4 and PIC microcontrollers, interface circuitry, simulation, and system designs in CAD circuit layout. The focus is on applications of microprocessor-based system design.

EET4XX – *Microcontrollers/Embedded Based Designs*

Advanced embedded system designs. Topics include ADC, DAC, EEPROM External Memories, temperature sensor, digital RF wireless communications, communications in synchronous and asynchronous serial forms of SCI, SPI, & I^2C, and parallel communication in system integration and design. The 32 bit ARM M4 with C programming designs are used in the course.

Another course sequence that undergoes major modifications under the new catalog covers Programmable Logic Controllers (PLC). Previously, a single course was offered in this area, a 400 level elective course. The newly developed course sequence includes two 300-level required courses, *Introduction to PLCs* followed by *Instrumentation*, and a 400 level elective course, *Automatic Control Systems*. The course descriptions for the PLC course sequence are as follows:

EET3XX – *Introduction to PLCs*

Application oriented experiments and design problems in programmable controller setup and programming techniques with emphasis on practical applications. Networking PLCs and HMIs. Computer assignments include ladder programs simulation.

EET3XX – *Instrumentation*

Fundamental concepts of electromechanical devices used in mechatronics and automation control systems. The working principles, calibration, interfacing methods and control loops of analog and digital instrumentation devices in a process control system. The instrumentation devices, including sensors, actuators, signal conditioning circuits and data acquisition boards, will be used in class projects as basic feedback control blocks in practical simulation and PLC based mechatronics systems. The simulation projects use PLC hardware, MATLAB and/or LabView software.

EET4XX – *Automatic Control Systems*

A study of modern control devices and applications including electrical, mechanical and pneumatic types.

With the revision of the microprocessors/microcontrollers and the PLC course sequences as described above, the EET program was able to introduce the 4-years study plan for the EET mechatronics concentration area with the technical content presented in Table 1. The description of the EET mechatronics concentration area also stipulates that “EET Mechatronics concentration will automatically satisfy a minor in MET”. The MET minor courses can be selected from the following set of courses: 3XX - *Automation and Controls*, 4XX – *Introduction to Robotics*, 4XX – *Introduction to Mechatronics*, 4XX – *Mechatronics Systems Design*, 4XX – *Modeling and Simulation of Mechatronics Systems*, 4XX – *Computer Integrated Manufacturing*.

For most of these courses the pre-requisites are minimal and do not add to the total credit hours required for graduation.

Table 1: EET Mechatronics concentration - technical courses 4-years study plan

Freshman Year	
Logic Controllers and Microprocessors	DC Electrical Circuits
Sophomore Year	
AC Electrical Circuits Electronic Devices and Circuits	Introduction to Microprocessors/Microcontrollers
Junior Year	
Advanced Circuit Analysis Advanced Technical Analysis Digital Electronics Electrical Power Systems & Machinery	Wireless Communications I Advanced Microprocessors & Microcontrollers Linear Electronics Introduction to PLCs 1x MET Minor Course
Senior Year	
Instrumentation 1x EET Senior Elective Course 1x MET Minor Course Introduction to Senior Design	Energy and the Environment Senior Project 1x EET Senior Elective Course 2x MET Minor Courses

3. Future Steps

The deployment of the EET curriculum update through a package of four new concentration areas ended up being a challenging project. After detailed analysis of the various options, the EET faculty decided that the best choice is to introduce all these concentrations areas simultaneously. From the student perspective this option will provide them with a full perspective of their choices. Logistically, introducing them one by one would have created more implementation problems. However, for a small faculty group it is not feasible to update and develop too many courses at once. With the new concentration areas deployed, the efforts for the next few years will focus on the development of new courses and the updating of the current ones, in order to bring the curriculum to the desired format. For the EET mechatronics concentration area this will materialize in introducing EET courses such as: Introduction to Programming, Introduction to Networking, Advanced PLCs and Industrial Networking, Advanced Motion Control Systems. These courses will be also good choices for the MET mechatronics concentration area, to fulfill the EET minor requirements associated with MET mechatronics specialization. Furthermore, a CAD design course should also be included into the EET mechatronics curriculum, either from the existing MET courses or as a new course specifically designed for EET students. To further expose students majoring in electrical engineering technology to the mechanical side of the electro-mechanical/mechatronics systems, the EET mechatronics curriculum may also include courses to cover topics such as kinematics, dynamics and mechanisms, or machine elements.

The introduction of two mechatronics concentration areas within the same department but under two different programs might be a unique case. Since the mechatronics field is a merge of mechanical, electrical and computer engineering fields, without introducing a completely new program in mechatronics technology, it makes more sense for an engineering technology department with electrical and mechanical programs to offer both choices for students willing to specialize in mechatronics. Consequently, individuals may choose to emphasize either the mechanical or the electrical side of their mechatronics specialization. This asymmetric structure of the specialization might become an advantage for the graduates looking for jobs.

Throughout the next several years, both mechanical and electrical programs will closely monitor the student enrolment in mechatronics concentrations, while EET program will also monitor the percentage distribution of incoming EET students among the newly introduced concentration areas. Student surveys will be conducted upon graduation to get a better understanding of their perception of the new program structure. Alumni and employer surveys will also be conducted. The results of these assessments will help to decide if mechatronics should continue as concentration areas under mechanical and electrical technology programs, or the two concentrations may better merge into a new mechatronics program within the department.

4. Conclusions

This paper discusses the introduction of the mechatronics specialization in the engineering technology department at Old Dominion University. The implementation presented might be a unique case, since mechatronics is not introduced as a separated program, but through concentration areas within both electrical and mechanical engineering technology programs. Even though this implementation choice might have been in a large part the result of logistic considerations, the flexibility introduced in the program turns into its strength, addressing the students' inclination towards either the electrical or the mechanical side of mechatronics. Within a formal mechatronics program the weight distribution may be equilibrated between electrical and mechanical courses, but through the choice of two concentration areas the balance can lean towards either sides. Ultimately it is the student's choice to decide the major - minor balance for the mechatronics specialization. The paper discusses in details the implementation approach within each program, as well as the constraints that had to be addressed.

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