Stackable Graduate Certificates Leading to Master of Science in Mechatronics

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Abstract

Mechatronics Degrees are very common in Japan and Europe but just started gaining momentum in the United States. In 2019, Department of Applied Computing (AC) in the College of Computing at Michigan Tech pioneered Master of Science (MS) degree in mechatronics that allows pathways for traditional and technology-oriented engineering students in the advance graduate studies. In addition, students from community colleges participating in articulation agreements with Michigan Tech Electrical Engineering Technology (EET) program can enter MS degree in Mechatronics upon completion of two years study earning Bachelor of Science (BS) degree in EET. In 2020, AC department introduced BS degree in Mechatronics. Both BS and MS degrees in Mechatronics are gaining significant momentum with the increase in enrollment in double digest. Along with standalone degrees in Mechatronics, Michigan Tech introduced 15-credit graduate certificate in Mechatronics. The most recent development was the proposition of three stackable graduate certificates leading to MS degree in Mechatronics.

In this paper, authors focus on graduate certificates and reveal lessons learned.

Introduction

Modern industrial processes are not just mechanical or electrical. Instead, any equipment used in industry nowadays is an electromechanical device with advanced controls. Mechatronics is an vital basis for the anticipated evolution in automation and manufacturing. There is a substantial need for undergraduate and graduate education in Mechatronics as the approach of engineering programs has altered providing stronger connection of the curriculum with skills needed in industry. Mechatronics degrees are very common in Japan and Europe but just started gaining momentum in the United States. In 2019, Department of Applied Computing (AC) in the College of Computing at Michigan Tech pioneered Master of Science (MS) degree in mechatronics that allows pathways for traditional and technology-oriented engineering students in the advance graduate studies [1-3]. Figure 1 depicts the current structure of the MS degree in Mechatronics at Michigan Tech. As figure reveals, students from the community colleges participating in articulation agreements with Michigan Tech's Electrical Engineering Technology (EET) program can enter MS degree in Mechatronics upon completion of two years study and earning Bachelor of Science (BS) degree in EET. Also, the degree has been designed to fit the international students and students from the other universities.

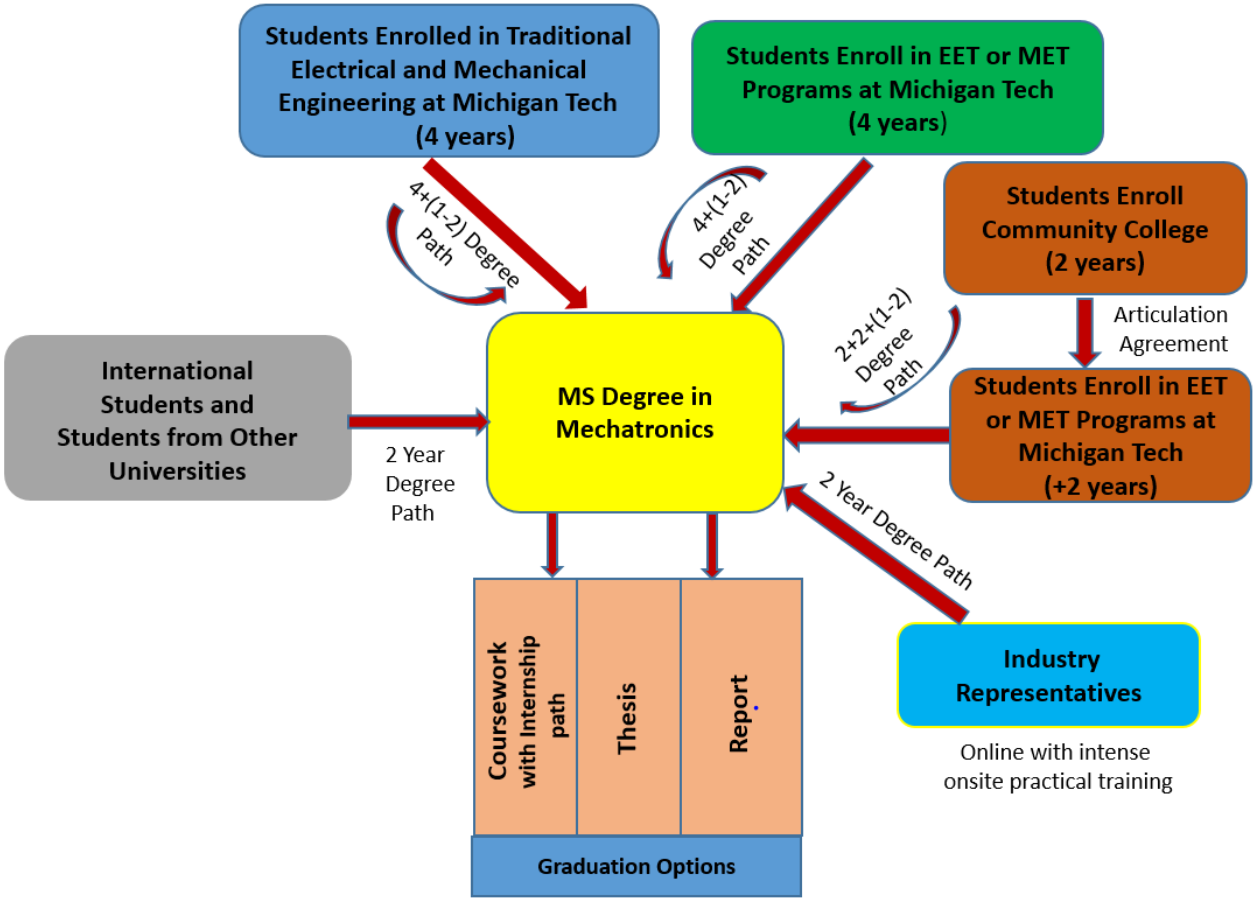

Fig. 1. Overview of the proposed model of Master of Science degree in Mechatronics at Michigan Tech.

Furthermore, in 2020, AC department introduced BS degree in Mechatronics but the details are omitted in this paper. Both BS and MS degrees in Mechatronics are both very young programs ay Michigan Tech but are gaining significant momentum with the increase in enrollment in double digest. Figure 2 (a, b) represents the enrollment trends in MS and BS programs respectively. As it can be seen from the figures below the MS in Mechatronics gained 180% growth by going from 10 students in 2020 to 28 in 2021. One-year old BS in Mechatronics program gained 29 students in one year.

Along with standalone degrees in Mechatronics, Michigan Tech introduced 15-credit graduate certificate in Mechatronics. The most recent development was the proposition of three stackable graduate certificates leading to MS degree in Mechatronics. This paper targets the development of the graduate certificates, their current standing and lessons learned.

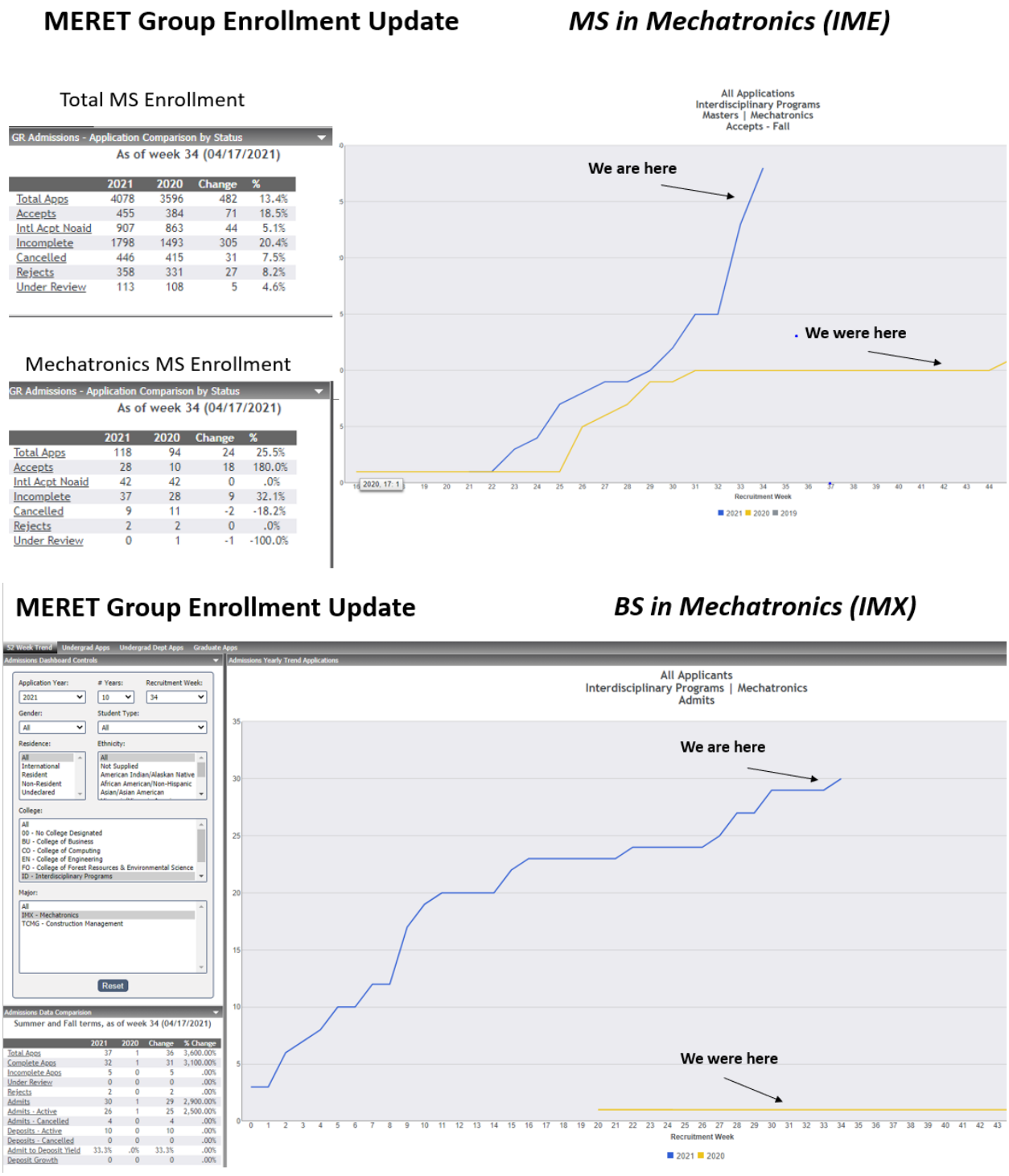

Fig. 2. Enrollment trends in (a) MS program in Mechatronics; (b) BS program in Mechatronics.

Fifteen-Credit Graduate Certificate in Mechatronics

"According to the latest U.S. Bureau of Labor Statistics, the number of jobs for Mechatronics Engineers is expected to experience moderate growth, specifically in Michigan and Wisconsin, which needs to be supported by new specialists as shown in the table below." [1] Michigan Tech situated in the State of Michigan is tactically located near big-3 automotive companies GM, Ford and Chrysler that require Mechatronics specialists.

The fifteen-credit graduate certificate in Mechatronics was introduced along with MS on Mechatronics in 2019. It has been specifically designed for qualified graduate students at Michigan Tech. Table 1 depicts the certificate's curriculum map for students with different majors. The Graduate Certificate will be available for graduate students from ECE, EET, MEEM, and MET disciplines as long as they complete required courses in Mechanical, Electrical, and Cybersecurity.

Table 1. Courses for graduate certificate in Mechatronics.

Disciplines			
Path 1 (suggested for EET major)	Path 2 (suggested for MET major)	Path 3 (suggested for MEEM major)	Path 4 (suggested for EE major)
EET5144 Real-Time Robotics Systems and EET5373 Advanced PLC	EET5144 Real-Time Robotics Systems and EET5373 Advanced PLC	EET5144 Real-Time Robotics Systems and EET5373 Advanced PLC	EET5144 Real-Time Robotics Systems and EET5373 Advanced PLC
MET3130 Statistics and Dynamics	EET3373 Introduction to PLC	EET3373 Introduction to PLC	EET3373 Introduction to PLC
MET 5800 Dynamics and Kinematics of Robotics Platforms	MET 5800 Dynamics and Kinematics of Robotics Platforms	MEEM 5705 Introduction to Robotics and Mechatronics	MET 5800 Dynamics and Kinematics of Robotics Platforms
SAT 3812 Cyber Security I	SAT 3812 Cyber Security I	EE 5455/MEEM5300 Cybersecurity of Industrial Control Systems or SAT 3812 Cyber Security I	EE 5455/MEEM5300 Cybersecurity of Industrial Control Systems or SAT 3812 Cyber Security I

The key courses, shown in the Table 1 below, have been selected to fulfill the certificate requirements. Considering that knowledge of robotic systems and advanced programmable logic controllers are necessary skills for Mechatronics specialists, the core courses selected are EET 5144 Real-time Robotics Systems and EET 5373 Advanced PLC. "Job descriptions from Tesla, Ford, Fanuc, GM, and many other companies dealing with automation, all call for a specific knowledge of Fanuc robots and Programmable Logic Controllers". [1, 3] Additional courses were added to stress the needed in Mechatronics areas. After two years of the certificate existence at Michigan Tech, the low enrollment has been observed. We attribute this to the relatively large number of credits (15) needed to acquire the certificate. Also, during the last two years, Michigan Tech's policy for introducing the certificates has changed limiting the number of credits to 10-11. More certificates of the new format rolled out at Michigan Tech and the initially proposed 15-credit certificate in Mechatronics became obsolete.

The overcome the issue, the Department of Applied Computing in the College of Computing and the Department of Manufacturing and Mechanical Engineering Technology in the College of Engineering join the efforts to introduce three graduate, stackable certificates leading to Master of Science in Mechatronics. These certificates are: "Industrial Robotics," "Automation and Controls in Mechatronics Systems," and "Fluid Power in Mechatronics Systems." All three certificates are comprised of the core courses for MS in Mechatronics.

Graduate Certificate 1: "Industrial Robotics"

Many existing jobs will be automated in the next ten years, and robotics will be a major driver for global job creation over the next five years. These trends are made clear in a study conducted by the market research firm Metra Martech, "Positive Impact of Industrial Robots on Employment." [2]. The EET program in the department of Applied Computing in the College of Computing at Michigan Tech is a Certified Training and Education Site for FANUC Robotics Material Handling and iR-Vision 2D directed by FANUC certified instructor Dr. Sergeyev. Since 2013, Michigan Tech has been FANUC Authorized Certified Training Facility. Under this agreement, Michigan Tech is a regional training center specializing in industrial robotics and automation, eligible to train and certify students from Michigan Tech and other institutions, industry representatives, and displaced workers. Michigan Tech is one of only three existing FANUC Authorized Satellite Training Programs in the United States and the only one in the state of Michigan.

The eight-credit "Industrial Robotics" certificate consists of two, four-credit hour courses EET5144 Real-Time Robotics Systems and EET5147 Industrial Robotic Vision Systems. Both courses come with FANUC industrial certification. Upon successful completion of the courses, eligible students receive "Material HandlingPro" and "iRVision-2D" FANUC industrial certificates. The Certificate "Industrial Robotics" is designed to develop skills and competencies in operating, programming, troubleshooting FANUC industrial robots, configuring and setting up robotic vision systems commonly used to enhance industrial processes. The curriculum contains significant laboratory component operating industrial-scale FANUC robots and learning industry standards of Roboguide simulation software. The proposed "Industrial Robotics" Graduate certificate will attract students from various departments at Michigan Tech and will make them more marketable in very demanding job market nowadays.

Below are the descriptions of the courses included in the "Industrial Robotics" graduate certificate:

EET 5144 Real-Time Robotics Systems (4 credits): Covers the components of a robot system, safety, concepts of a work-cell system, geometry, path control, automation sensors, programming techniques, hardware, and software.

EET 5147 Industrial Robotic Vision System (4 credits): Procedures for setting up, teaching, testing, and modifying robot vision systems widely used in industrial automation. Introduces advanced Teach Pendant Programming to develop complex scenarios for integrating robots into industrial cells. The final project must demonstrate proficiency in setting up and

programming an advanced robotic vision scenario.

Upon successful completion of this certificate, students will be able to do the following:

1. Understand and apply safe techniques for operating industrial robots.
2. Demonstrate the proficiencies of manipulating and programming industrial robots.
3. Apply knowledge for configuring robotic vision systems.
4. Demonstrate effective written and oral communication skills.

Graduate Certificate 2: "Automation and Controls in Mechatronics Systems"

The data collected for the Master of Science degree in Mechatronics and its analysis can be directly related to the Graduate Certificate Automation and Controls in Mechatronics Systems. Students pursuing undergraduate or graduate studies in different fields will be attracted by the opportunity to receive an additional breadth of knowledge and credentials in the field of Automation and Controls without necessarily committing to a standalone degree.

The Certificate in "Automation and Controls in Mechatronics Systems" concentrates on industrial automation and control systems. Students will learn about advanced concepts in programmable logic control including sensors and actuators. Sensor calibration and pneumatic power regulation are taught alongside the programming of pneumatic and electrical actuators. Sensor types discussed include ultrasonic, optical, magnetic and electrostatic field devices. In addition to programming controllers, students will study feedback control systems prevalent in industrial settings. Control circuits, stability criteria, digitization of control signals and non-linear control concepts are covered.

The Certificate in Automation and Controls in Mechatronics Systems is designed to develop skills and competencies in advanced programmable logic controllers, industrial sensors/actuators, human machine interfacing, feedback control electrical circuits, non-linear digital control concepts, and feedback control systems. The curriculum integrates application of these skills in real-world problems and implementation of application specific solutions.

Below are the descriptions of the courses included in the 11-credit "Automation and Controls in Mechatronics Systems" graduate certificate:

EET5373 Advanced PLC (4cr): Using Allen Bradley ControlLogix and SLC500 programmable controllers, the course covers structured programming, Sequential Function Charts, networking, proportional integral differential control, data acquisition and interfacing. The course requires proposing, executing and defending the graduate level, and related to the course material, project.

EET 5311 Advanced Circuits and Controls (4cr): This course starts with the modeling and analysis of circuits in the time domain. The solution of a circuit is simplified by using Laplace transform. The circuits are further studied in the frequency domain by using Bode plots. The

sinusoidal components of a signal are studied by using Fourier technique. Discrete-time systems will also be discussed, and linear control techniques will be addressed.

MET 5801 Controls of Dynamic Systems (3cr): This course covers the modeling, analysis, and control of dynamic systems. It uses the controlling equations for the control of mechanical and electrical systems. Theory is verified with simulation and lab testing.

Upon successful completion of this certificate, students will acquire the following skills:

1. Analyze electrical control circuits using techniques such as Laplace Transform, transfer functions and Fourier Transform.
2. Model, analyze, and control dynamic systems
3. Demonstrate proficiencies programming Allen-Bradley programmable logic controllers for application in industrial automation.
4. Demonstrate effective written and oral communication skills.

Graduate Certificate 3: "Fluid Power in Mechatronics Systems"

Fluid power, both hydraulic and pneumatic, systems are integral to the automation that enables robotic applications. For instance, the end effectors of robots are often pneumatically controlled. Large components in automated systems are generally hydraulically controlled to accommodate the high forces and loads. Precision motion control is required in most applications to regulate speed and position, or force and pressure. The dynamics and kinematics of robotic platforms involves analyzing the relation between the joint actuator torques and resulting motion, so that programs can be optimized without exceeding the robot capabilities. Finally, incorporating a safety mindset into the design of automated systems is critical, so that robotics can operate in an environment alongside production workers.

This certificate will prepare students for professional certification in three different fluid power specialist categories. More details are available from the International Fluid Power Society [4]. In addition, if a graduate student is a Professional Engineer (PE), or has a degree from an ABET accredited university they can also become a Fluid Power Engineer. The MMET Department is prepared to deliver this curriculum with faculty having multiple years of industry experience in Fluid Power industries. Gift awards in FY21 and FY22 from the National Fluid Power Association and the Parker Foundation have been used to develop the Fluid Power curriculum and lab facilities. Private donations have also added to the capabilities for world-class research and teaching of fluid power and motion control.

The ten-credit "Fluid Power in Mechatronics Systems" certificate consists of three, three-credit hour courses, and a one-credit course. These courses are all part of the interdisciplinary MS in Mechatronics.

Below are the descriptions of the courses included in the 10-credit "Fluid Power in Mechatronics Systems" graduate certificate:

MET 4377 - Applied Fluid Power (3cr): An introduction to fluid power components and systems. The course includes component selection, circuit design, electrical interfaces, and

system troubleshooting and maintenance. A laboratory exposes students to system hardware and circuit simulation techniques for mobile and industrial applications.

MET 5378 - Advanced Hydraulics: Electro-hydraulic Components & Systems (3cr): This course covers electro-hydraulic components including solenoid operated valves, proportional valves, and servo valves. Also covered are hydraulic systems including open-loop and closed-loop.

MET 5400 - Key Factors of Holistic Safety Programs (1cr): Students learn best industry safety practices with respect to; risk management, lockout/energy isolation, fluid power and electrical symbols, basic circuit design and machine design, and sequence of operation involved with automation controls and mechanical motion.

MET 5800 - Dynamics and Kinematics of Robotics Platforms (3cr): This course covers the dynamics and kinematics of rigid bodies as the foundation for analyzing the motion of robots. Robotic kinematics is reviewed by analyzing the motion of the robot. The dynamics is reviewed by analyzing the relation between the joint actuator torques and resulting motion.

Upon successful completion of this certificate, students will be able to do the following:

1. Develop specifications to reduce risks and select safety components.
2. Demonstrate concepts in kinematics and dynamics of robot manipulators.
3. Assess operating principles and design considerations for fluid power electro-hydraulic components and systems.
4. Demonstrate effective written and oral communication skills.

Stackable Model

The three graduate certificates are designed to be stackable to lead to the MS in Mechatronics. The model is shown in Figure 3. Three certificates account for a total of 29 credits. With the addition of one 3- credit cybersecurity course, the student can secure the MS degree in Mechatronics.

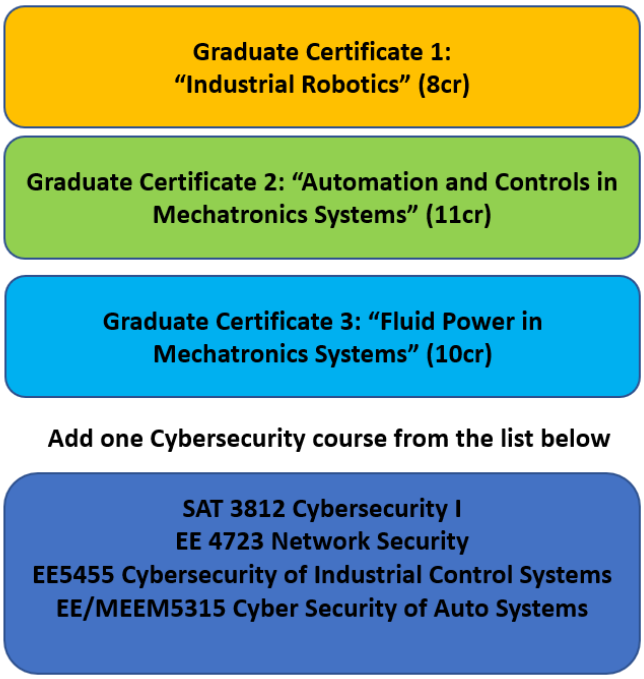

Fig. 3. Stackable model leading to MS in Mechatronics.

Conclusion

The paper describes pioneering efforts of Michigan Tech to promote Mechatronics field of study. During the last two years, the department of Applied Computing in the College of Computing introduced two degrees in Mechatronics: one at undergraduate and one at the graduate levels. Both degrees models are very flexible and designed to accommodate the needs of traditional and technology students. In addition, the degrees are open to the community college students, international students, and representatives from industry. Two graduate certificate models have been described in details. The 15-credit certificate introduced in the earlier stages did not gain the popularity among the students and was supplanted by three smaller graduate certificates leading to MS degree in Mechatronics at Michigan Tech.

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Biographies

ALEKSANDR SERGEYEV is a professor of Mechatronics, Electrical, and Robotics Engineering Technology program in the Department of Applied Computing at Michigan Tech. He is a Director of FANUC Authorized Certified Robotic Training Center, and a Director for Master of Science in Mechatronics degree program at Michigan Tech. Dr. Sergeyev is a member of SPIE, ATMAE, IEEE, and ASEE professional organizations, and has mentored numerous undergraduate senior design projects and student publications.

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JOHN L. IRWIN is a tenured professor, Mechanical Engineering Technology, and chair of the MMET Department in the College of Engineering, at Michigan Technological University. He is director of the Research and Innovation in STEAM Education Institute at Michigan Tech. His research focus is on teaching and learning in computer aided design, analysis, & manufacturing subjects. His service with ASEE includes secretary for the Engineering Technology Division, vice-chair for Engineering Technology Council, and liaison to the Corporate Member Council. Dr. Irwin also serves as chair of the Society of Manufacturing Engineers Education and Accreditation Committee, and SME representative to ABET Engineering Technology Accreditation Commission.