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Mechatronics Bachelor Curriculum Development in Light of Industry 4.0 Technology Needs: Contrasting US and German University Curricula

Paniz Hazaveh
Michigan Technological University, pkhanmoh@mtu.edu

Aleksandr Sergeyev
Michigan Technological University, avsergue@mtu.edu

Nathir Rawashdeh
Michigan Technological University, narawash@mtu.edu

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Paniz Hazaveh, Aleksandr Sergeyev, Nathir Rawashdeh

Michigan Technological University

Abstract

This study compares Mechatronics bachelor curricula at universities in the United States of America and German universities. Mechatronics education is relatively new in the United States, but has been common in Germany for over a decade. With the multidisciplinary nature of technologies required by the 4'th industrial revolution, a.k.a. Industry 4.0, composing an appropriate Mechatronics curriculum becomes a challenge and an opportunity. This paper studies how Mechatronics education can address the future needs of industry, while building on a specific university's strengths and industry links. We have also analyzed the new undergraduate Mechatronics program at Michigan Technological University (MTU) and compared its content to other US and German universities.

Introduction

We live in an exciting time where digital technology and the impact of computers and technology in human life has been surprising. Computers are listening, talking and even vacuuming for us. Computers are changing the way we live and work. Every company in the United states and across the globe is reconsidering their ways of operation. The business models are changing the methods of manufacturing, transportation and delivery. This continuous change from traditional ways to using smart technologies such as artificial intelligence, (AI) is what is referred to as the 4th industrial revolution or Industry 4.0 [1]. Engineering fields used to be isolated from each other and each engineer would only be familiar with a particular engineering discipline, but this has changed over the past two decades [2]; As the current manufacturing environment is adapting with industry 4.0, there is a growing need for multidisciplinary knowledge in different fields of engineering and computing. Manufacturing, which is one of the basic blocks of the economy in the United States, now depends on individuals who have the capacity of applying this interdisciplinary knowledge [1, 3].

It is evident that there is a need to create educational environments where Industry 4.0 concepts can be introduced and practiced. Therefore, there has been a transition in universities across the nation towards creating more interdisciplinary curricula such as Mechatronics [3]. Mechatronics is the integration between mechanical Engineering, electrical engineering and computing and can

be simply defined as a bridge between functionality of a hardware and a software to control the hardware [4]. In this study we explore the gaps in Mechatronics curricula and analyze the Mechatronics curriculum in three relevant universities in the United States in comparison with German universities which have been offering Mechatronics degrees much longer than the United States [5]. We also explore the relevance of Mechatronics degree at Michigan technological university to industry and we discuss the role of computing in Mechatronics specifically at Michigan tech.

Industry 4.0 and Mechatronics

The fourth industrial revolution would not be possible without the progress in computing and data science. The interdisciplinary knowledge of mechanical engineering, electrical engineering and Computer Science is necessary to address the new needs of the industry [1,6]. Japanese engineer Tetsuro Mori of the Yasakawa Electric Corporation coined the term Mechatronics in 1971 [7]. Mechatronics has started from a multidisciplinary identity where students take courses from different disciplines and is evolving to where new interdisciplinary courses have been designed specifically for this curriculum. The Bochum University of Applied Sciences was the first to establish a full-time program in Mechatronics in 1993/1994. Since then, various Mechatronic programs have been created around the world [5, 8]. The diagram in figure 1, categorizes the Industry 4.0 technologies and learning disciplines in Mechatronics [9].

It is notable that most of them can be considered computing heavy. For example, the purely computing category includes cloud computing, cyber security and artificial intelligence (AI). In electrical engineering, the Internet of Things (IoT) requires electrical engineering and programming, i. e. computing skills. In the overlap of mechanical engineering and computing, the following areas can be listed: manufacturing execution systems; computer maintenance management; 3D printing; product lifecycle management.

The Industry 4.0 technologies that require all three disciplines, meaning computing, electrical engineering and mechanical engineering, can be found in the center of the diagram in figure 1. This center can be labeled as “Mechatronics”. This highlights the ever-increasing connectivity, and interdisciplinary nature of current and future technologies, and thus also, the importance of Mechatronics education. These technologies include: human machine interface (HMI) design; collaborative robotics (Co-Bots); automated guided vehicles (AGV); real-time locating systems (RTLS); digital twins of mechanical systems and factories; smart sensors with embedded controllers; connected cyber physical systems; supervisory control and data acquisition systems (SCADA); virtual reality (VR).

As we can see in this chart, computing has a major role in electrical and mechanical engineering and where they overlap. One of the very first integration of computing and engineering in industry was programmable logic controllers (PLCs). Since then, the role of computing in industry has gone through different eras and the increasing need for sharing and analyzing big and real time data makes computing a significant part of Industry 4.0 [6]. The interdisciplinary program of Mechatronics relies heavily on computing related disciplines and there is a growing need for Mechatronics programs across the nation to prepare individuals for the automation industry.

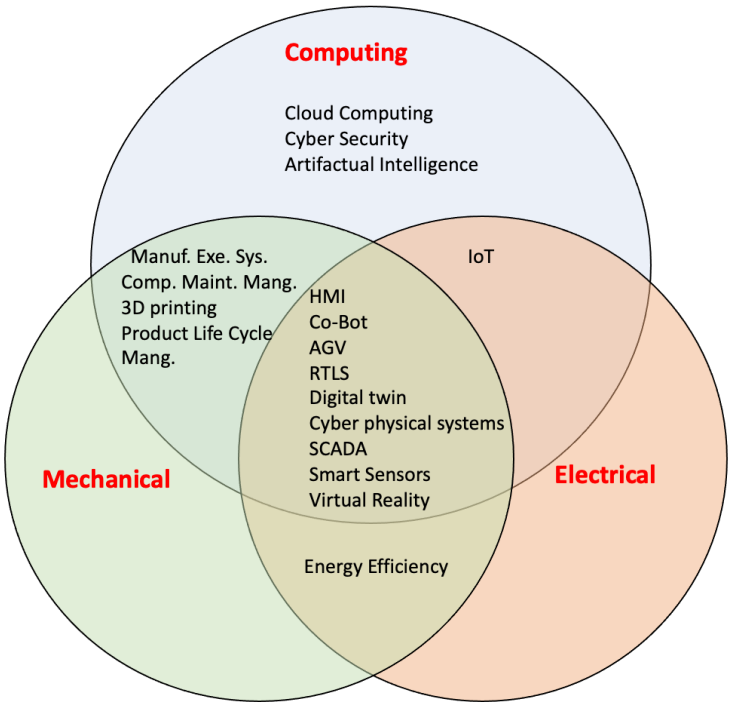

Figure 1. Industry 4.0 technologies in the light of Mechatronics disciplines

The following plot summarizes the job market outlook for Mechatronics degree graduates compared to other closely related disciplines. The data was collected from the repository of the Bureau of Labor Statistics [10]. It can be seen that Mechatronics is among the highest paying jobs and the growth is as high as electrical, robotics and mechanical engineering. In 2018, Mechatronics jobs outnumber electrical engineering technologists 'nationwide.

Mechatronics Curriculum

The number of Mechatronics programs in the United States are still limited. In this section we analyze the Mechatronics program in 3 American universities to help us better detect the gaps between the curricula and the industry needs. At first, we compare the United States Mechatronics curricula with German universities which have been the forefront of Mechatronics then we focus on analyzing the curricula at Michigan Technological University.

The average German curriculum in applied engineering university is a 7-semester long degree versus the American curriculum which is 8 semesters long [5]. Previous research done on German Mechatronics degree content has classified student learning into 6 different categories: sciences; electrical engineering; mechanical engineering; computing; industry internship; [5]. Inspired by this study we have analyzed the requirements for Mechatronics programs at Michigan Tech, Purdue university and Wichita state university. We have included the number of credit hours (CH) they each spend on these categories in Table 1.

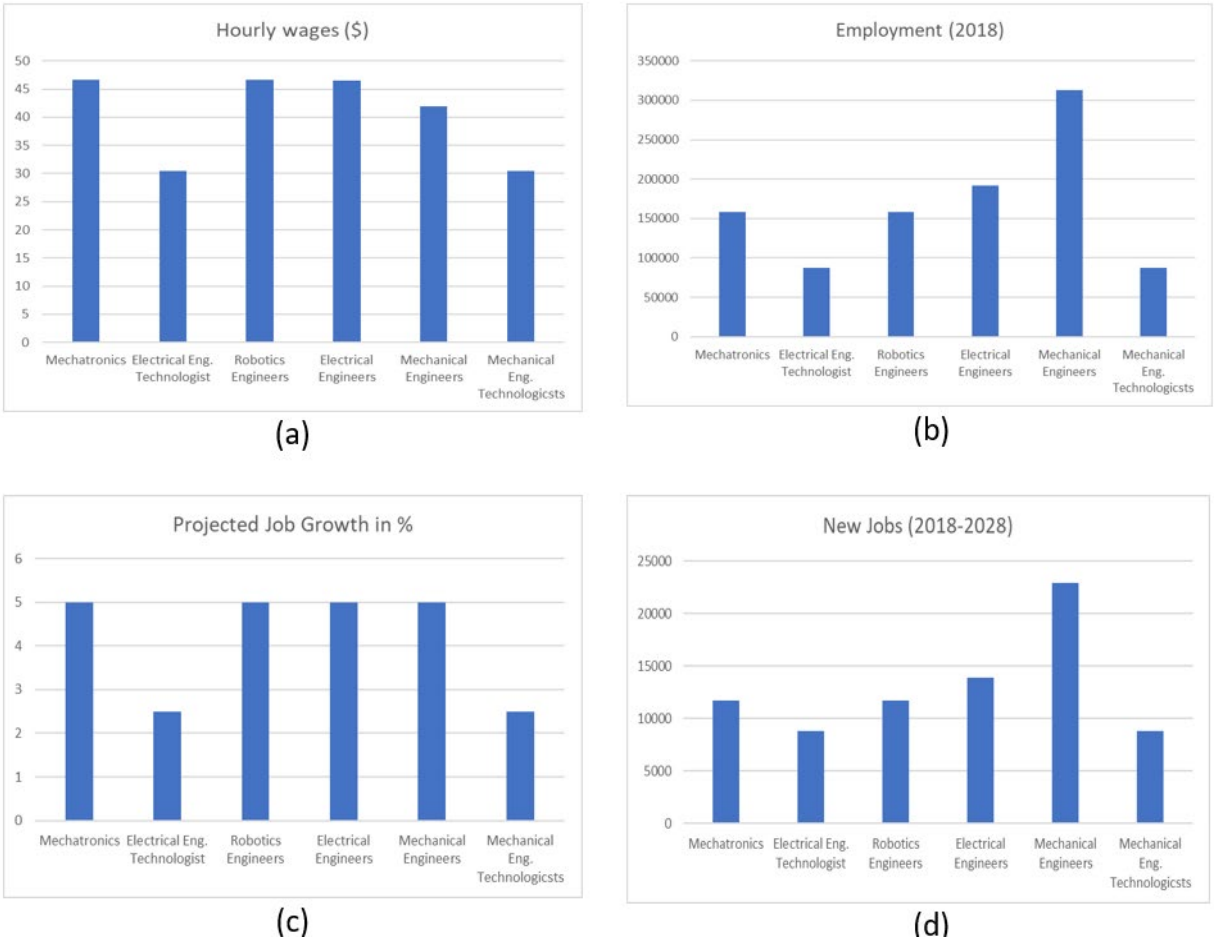

Figure 2. Job market outlook for Mechatronics graduates.

Bachelor Mechatronics Curricula in the United States and Germany

We have calculated an average of credit hours in three American universities for each category for comparison we have also included the average number of credit hours German universities dedicate to each of these categories.

The first observation made was that the significant difference between the Mechatronics curriculum in the United states and Germany is the total number of required credit hours to obtain a B.S. degree. The number of required credit hours in Germany is more than the average of 3 American universities by 24 credit hours. This Was surprising as the American curriculum tends to be longer by one semester therefore, we dug deeper to understand this difference. To have a visual tool for better understanding we have plotted all the credit hours in these 6 categories in the following bar chart for the average of 3 American universities (CH_USA) and average in German universities (CH_Germany).

Table 1. Column 1,2 and 3: Number of credit hours (CH) spent in different categories of Mechatronics B.S. program at Michigan Technological University, Purdue University and Wichita State University. Column 4 and 5: Average number of credit hours spent in different categories for the 3 American universities and Germany.

	Michigan Tech	Purdue university	Wichita State Univ.	Average in USA	Average in Germany
1- Fundamentals in mathematics and natural **sciences** (mathematics, physics, computer science, chemistry, material sciences)	23 CH	27 CH	27 CH	26 CH	28 CH
2- Fundamentals of mechanical and electrical engineering **& Computing (** Micro-computer and controller techniques, engineering mechanics, electrical circuits and electronics, programming/software engineering, design and manufacturing, measurements, thermo and fluid mechanics, automation, pneumatics and hydraulics, electrical drives and machines)	55 CH	35 CH	42 CH	44 CH	35 CH
3-Mechatronics (mechatronic systems, modeling and simulation, control, PLC, mechatronic design, sensors, actuators, system theory, mechatronic materials)	24 CH	24 CH	13 CH	21 CH	14 CH
4- General topics (business administration, project management, team and personal leading, presentation techniques, languages, soft skills)	25 CH	28 CH	33 CH	29 CH	38 CH
5- Internship	0	0	0	0	10 CH
6- Bachelor thesis/ enterprise/Senior Design	6 CH	6 CH	6 CH	6 CH	9 CH
Total number of CH	122 CH	120 CH	120 CH	120.6 CH	144 CH

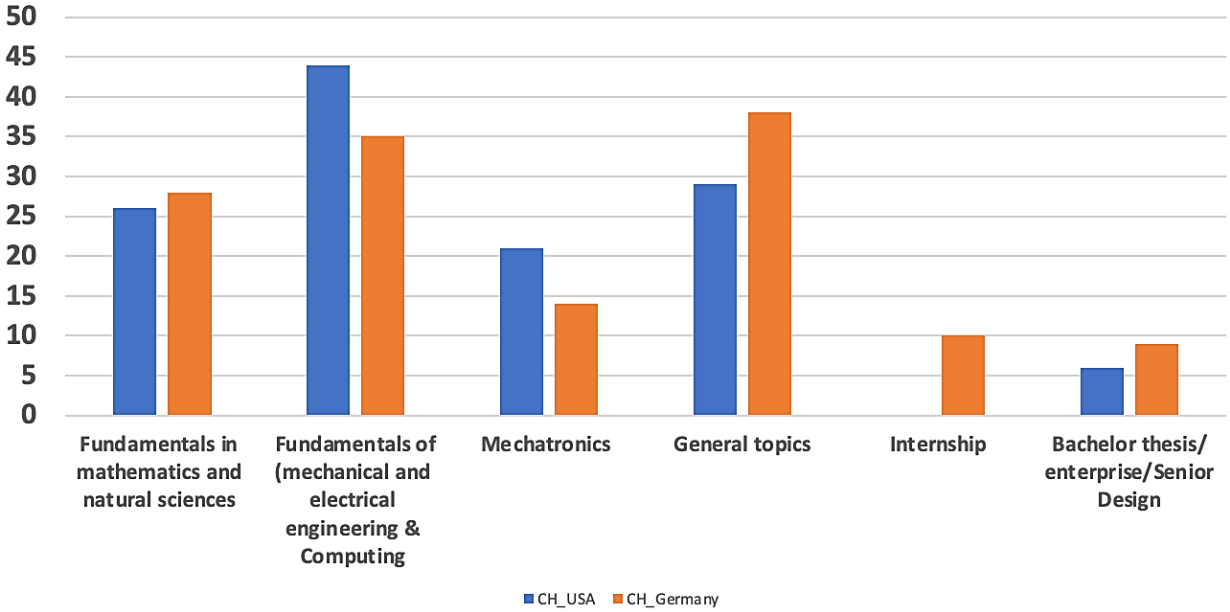

Figure 3. Average number of credit hours in each category of the mechatronics program in the US and Germany.

The required internship in the German curriculum is potentially the most notable distinction between the two curricula with a weight of 10 Credit hours. In the United States career services facilitates events such as career fair which gives students the option of finding internships and co-op opportunities which are outside of the program degree. The number of credits hours spent on the Senior Design project (Thesis) is also higher by 3 credit hours in Germany and the projects are usually technically sponsored by industry which again strengthens the role of industry in this degree. The total of 13 CH of required internship and the higher weight for the senior design projects in Germany compared to the U.S. makes up most of the difference between the total credit hours.

There is no significant difference between the average number of credits that students take in fundamental courses but the chart suggests that in American universities the time that students spend on fundamental engineering and Mechatronics topics is higher despite the shorter curriculum.

Mechatronics curricula at Michigan Tech

In the curriculum design of B.S. of Mechatronics at Michigan Technological University, the relevance to Industry 4.0 technologies, as summarized in figure 1, was taken into account. There are 26 required courses in Mechatronics curricula which involve computing. These computing related courses are listed in table 2 and are almost 20% of the whole curriculum. This curriculum also includes fundamental courses in the categories of science, mechanical engineering and electrical engineering, such as mathematics, computer science, physics, statics, dynamics, and circuits. Since this Mechatronics curriculum is based on the programs of engineering technology, there is a strong laboratory experience offered to the students. Labs such as PLC; industrial robots; digital logic; programming; electric machines; electric circuits; automatic control and data acquisition are part of the curriculum which helps students to gain the necessary hands-on

experience. The labs are often equipped by the support of industry sponsorships. Industry collaborations are an important enabler of applied learning, which are utilized in Michigan tech's Mechatronics curriculum in two ways:1- Voluntary but popular Internships 2- Senior design projects. The senior design projects are two semester long and are often industry funded projects where students finish a task for a company [11-14]. At the end of each semester students present their work to faculty and an industry advisory board which is made of the program sponsors from the industry. This plays a huge role in strengthening industry links.

Table 2. Computing oriented mandatory courses in the mechatronics bachelor degree curriculum at Michigan Technological University

Mandatory Computing Oriented Courses in Mechatronics curricula at Michigan Tech with a total of 26 credit hours	o EET3131 Instrumentation or EET425 3 LabVIEW (3) o SAT3812 Cyber Security 1 (3) o CS1090 or equivalent (3) o EET2411 Digital Electronics (3) o EET4311 Adv. Circuits & Controls (3) o EET4141 Microcontroller Interfacing (4) o EET3373 Intro to Programmable Controllers (3) o EET4144 Real Time Robotic Systems (4)

In addition to the new B.S. program in Mechatronics, graduates have the option to build on their basic knowledge by enrolling in Mechatronics master's program, which focuses on industrial automation and robotics. Overall, the goal of the Mechatronics program at Michigan Tech is to keep students up to speed with industry 4.0 and the role of computing in the real world.

Results and summary

In this study we compared the Mechatronics bachelor curricula in three American universities (Wichita state university, Purdue university and Michigan Tech university) with the average German curriculum. The result highlights the similarities and differences between the two systems. The multidisciplinary nature of Mechatronics allows each university to tailor its program to suit local industry and build on its technical strengths. Mechatronics degree offerings in American universities are relatively recent compared to German universities. The Mechatronics program in Germany is only 7 semesters long which is shorter compared to the 8 semesters program in the United States but interestingly there are more required credit hours in the German curriculum. The significant difference between the number of credit hours comes from: 1- The senior design which is weighted 9 credit hours instead of 6, and 2-The internship which is a part of the curriculum for a total of 10 credit hours in German curriculum. Both of these differences potentially strengthen the relationship between the industry and the Mechatronics program which is the goal in applied engineering institutions in Germany.

The 7 semesters long model in Germany is dominant in applied engineering universities. This model can lead to a Master's degree which is 3 semesters long making it a 10 semesters (5 years) program for earning both a bachelor's and master's degree, compared to the United states where students need to spend 14 semesters (7 years) to earn both.

One of the strengths of the new Mechatronics undergraduate program at Michigan Tech is the number of credit hours spent on specialized Mechatronics courses, which is more than the German curriculum. This program specifically focuses on introducing Industry 4.0 engineering and computing technologies and there are many specialized Mechatronic courses which involve computing.

Conclusions

As the prevalence of Industry 4.0 technologies increases the need for graduates with exposure to multidisciplinary knowledge of engineering and computing therefore universities across the nation are developing Mechatronics programs which can address this need. The observations made on the differences between Mechatronics in the United States and Germany are motivational to find ways to narrow the gap between industry and academia in the United States. Emphasizing on industry sponsored projects for senior design and more internship and co-op opportunities for students can potentially strengthen Mechatronics programs across the United states.

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Biographies

PANIZ HAZAVEH received her PhD in Electrical and Computer Engineering from the Michigan Technological University in 2018 with a focus on Single Electron Transistors. She has been a Lecturer in Electrical Engineering and Electrical Engineering Technology at MTU since 2017 where she is currently a Lecturer in the College of Computing.

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.

NATHIR RAWASHDEH is an assistant professor at the department of applied computing at Michigan Tech. since August 2019. Prior to this appointment, he was an associate professor in the Mechatronics Engineering Department at the German Jordanian University, where he spent 10 years. His industrial experience includes 5 years with Lexmark International, Inc. Lexington-Kentucky and MathWorks, Inc. in Natick-Massachusetts. Dr. Rawashdeh is a Senior Member of the IEEE and has experience with European-funded research capacity building projects. His research interests include mobile robots, autonomous driving, image processing and sensor fusion.