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Implementing Mechatronics Design Methodology in Mechanical Engineering Technology Senior Design Projects at the Old Dominion University

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Dr. Vukica Jovanovic, Old Dominion University

Dr. Jovanovic is currently serving as Assistant Professor of Mechanical Engineering Technology Department, Frank Batten College of Engineering and Technology, Old Dominion University, Norfolk, VA. Prior to joining ODU's Engineering Technology Department Dr. Jovanovic was teaching at Trine University, Angola, Indiana at Design Engineering Technology Department. Before Trine, she was working as an instructor and a graduate research assistant at Product Lifecycle Management Center of Excellence at Purdue University. She also served as instructor in STEM Academic Boot Camp, Diversity Program. Prior to joining Purdue, Dr. Jovanovic worked as a faculty at University of Novi Sad at departments of Industrial Engineering and Management. Dr. Jovanovic received M.Eng. (dipl.ing.) degree from University of Novi Sad, Serbia in Robotics, Mechatronics and Automation and M.Sc. (Magistar) degree in Production Systems Design, both at Department of Industrial Engineering. She received a PhD in Mechanical Engineering Technology from Purdue University. In addition, Dr. Jovanovic's scholarly publications include 50 journal articles and papers in conference proceedings, two technical reports, and seven poster presentations focusing on mechatronics, product identification, product lifecycle management, assembly systems, collaborative engineering, automation, and energy efficiency. She was active member of European Robotic Association EUROBOT, and currently serves as a co-advisor of ODU IEEE Car Team. She had internships in engineering services, aerospace, and power generation industries.

Dr. Jennifer Grimsley Michaeli PE, Old Dominion University

Dr. Michaeli is an Assistant Professor in the Department of Engineering Technology of Old Dominion University. She received her PhD in Mechanical Engineering from Old Dominion University, her MSc in Ocean Systems Management from Massachusetts Institute of Technology, and her BSc in Naval Architecture and Marine Engineering from Webb Institute. Prior to her arrival to ODU, Dr. Michaeli over 15 years with the Department of Defense and industry as a Naval Architect and Program Manager where she carried out design and engineering, construction and testing for marine vehicles. At ODU, Dr. Michaeli's research and educational interests include topics concerning naval architecture, marine engineering, design, manufacturing and testing of composites and lightweight structures, and engineering multi-criteria decision methodologies. Dr. Michaeli is actively involved in industry-government-academia partnerships to further the advancement of naval and marine engineering.

Dr. Otilia Popescu, Old Dominion University

Dr. Otilia Popescu received the Engineering Diploma and M.S. degree from the Polytechnic Institute of Bucharest, Romania, and the PhD degree from Rutgers University, all in Electrical and Computer Engineering. Her research interests are in the general areas of communication systems, control theory, and signal processing. She is currently an Assistant Professor in the Department of Engineering Technology, Old Dominion University in Norfolk, Virginia, teaching courses for the Electrical Engineering Technology track. Prior to joining ODU she had academic positions at the University of Texas at Dallas, University of Texas at San Antonio, Rutgers University, and Politehnica University of Bucharest.

To date, Dr. Popescu has co-authored over 30 papers published in peer-reviewed journals and conferences. She is senior member of the IEEE. Dr. Popescu has participated in the technical program committee for various IEEE conferences, including ICC, VTC, GLOBECOM, and CAMAD.

Prof. Moustafa R. Moustafa, Old Dominion University

Professor Moustafa joined the Mechanical Engineering Technology department in August of 1979. Since then, he continuously taught, advised, guided and supervised students helping them to acquire the necessary knowledge, education, technical, ethical and communication skills. Professor Moustafa's expertise is in the areas of machine design, computer aided design and solid modeling. Moustafa taught courses in 2-D and 3-D Cad, statics and dynamics, strength of materials, design of machine elements, mechanical systems design and senior design project. He is in charge of the senior design project for the mechanical engineering technology department. He encourages seniors to work on practical projects. Some of these projects are provided by local industrial and manufacturing corporations He has been instrumental in the development and offering of online senior classes to off campus students in support of the growing trend of distance education. He was the manager of one of the 1st AutoCAD Authorized training centers in the Nation. He taught hundreds of continuing education classes and trained thousands of professionals in AutoCAD software products over many years. Professor Moustafa is the faculty advisor of the student chapter of the Society of Manufacturing Engineers.

Professor Moustafa was the PI for several applied projects conducted through Virginia's Applied Technology and Professional Development Center (VATPDC).

Dr. Mileta Tomovic, Old Dominion University

Dr. Tomovic received BS in Mechanical Engineering from University of Belgrade, MS in Mechanical Engineering from MIT, and PhD in Mechanical Engineering from University of Michigan. Dr. Tomovic is currently serving as Chair of Engineering Technology Department, F. Batten College of Engineering and Technology, Old Dominion University, Norfolk, VA. Prior to joining ODU Dr. Tomovic had seventeen years of teaching and research experience at Purdue University, with emphasis on development and delivery of manufacturing curriculum, conducting applied research, and engagement with Indiana industry. While at Purdue University, Dr. Tomovic served as W. C. Furnas Professor of Enterprise Excellence, University Faculty Scholar, Director of Digital Enterprise Center, and Special Assistant to Dean for Advanced Manufacturing. He has co-authored one textbook on materials and manufacturing processes that has been adopted by over 50 national and international institutions of higher education. In addition, he has authored or co-authored over 60 papers in journals and conference proceedings, focused on applied research related to design and manufacturability issues, as well as issues related to mechanical engineering technology education. Dr. Tomovic made over 20 invited presentations nationally and internationally on the issues of design optimization and manufacturability. He has co-authored four patents, and over 100 technical reports on practical industrial problems related to product design and manufacturing process improvements. Dr. Tomovic is also serving as Honorary Visiting Professor at Beihang University, Beijing, China.

Prof. Alok K. Verma P.E., Old Dominion University

Dr. Alok K. Verma is Ray Ferrari Professor and, Director of the Lean Institute at Old Dominion University. He also serves as the President of the International Society of Agile Manufacturing (ISAM) and the chief editor of the International Journal of Agile Manufacturing (IJAM). Alok received his B.S. in Aeronautical Engineering from IIT Kanpur, MS in Engineering Mechanics and PhD in Mechanical Engineering from ODU. Prof. Verma is a licensed professional engineer in the state of Virginia, a certified manufacturing engineer and has certifications in Lean Manufacturing and Six Sigma. He has organized several international conferences as General Chair, including ICAM-2006 and ICAM-1999 and also serves as associate editor for three International Journals. His scholarly publications include 35 journal papers and 55 papers in conference proceedings. Dr. Verma has developed and delivered training program in Lean Enterprise & Design for Manufacturing for Northrop Grumman Newport News, STIHL and several other companies in U.S. He has developed simulation based training programs for shipbuilding and repair industry under two grants from the National Shipbuilding Research Program (NSRP) and continues to work to improve STEM education with support from two National Science Foundation, (NSF) grants. He is well known internationally and has been invited to deliver keynote addresses at several national and international conferences on Lean/Agile manufacturing. Dr. Verma has received the Regional Alumni Award for Excellence for contribution to Lean Manufacturing research, the International Education Award at ODU and Ben Sparks Medal by ASME. He is active in ASME, ASEE, SME and SNAME. Dr. Verma continues to serve the Hampton Roads community in various leadership positions.

Dr. Cheng Y. Lin P.E., Old Dominion University

Dr. Lin is a Professor and Program Director of Mechanical Engineering Technology at Old Dominion University. He received his PhD of Mechanical Engineering from Texas A&M University in 1989, and is a registered Professional Engineer in Virginia. Dr. Lin has expertise in automation control, machine design, CAD/CAM, CNC, geometric dimensioning and

Implementing Mechatronics Design Methodology in Mechanical Engineering Technology Senior Design Projects at Old Dominion University

In recent years, the nature of engineering design has changed due to advances in embedded system design and computer technologies. It is rare to engineer a purely mechanical design that does not incorporate electrical and electronic components. Mechanical engineers and mechanical engineering technologists must possess a multi-disciplinary knowledge with the understanding of both mechanical and electrical systems. For this purpose, undergraduate programs in engineering technology have added mechatronics courses to their curriculum. Mechatronics is a design process that is multi-disciplinary in nature and integrates principles of many engineering disciplines including, but not limited to, mechanical engineering, electrical engineering, and controls engineering. These courses typically incorporate problem-based learning and project-based pedagogy to effectively build the student's knowledge and understanding. Old Dominion University's Mechanical Engineering Technology (ODU MET) program offers undergraduate courses related to Advanced Manufacturing including Robotics; Automation; Lean Manufacturing; Computer Integrated Manufacturing; and Advanced Manufacturing Processes. Recently, two new courses related to mechatronics were added to the same focus area. In addition, ODU MET program has placed an increased emphasis on mechatronics for students' senior design projects. This paper highlights the benefits of including mechatronics in the ODU MET curriculum and presents several recent senior design projects that showcase how the student has incorporated multi-disciplinary principles into the design and build of a functional mechatronic device. By embedding these experience into their senior design project, students are exposed to other engineering technology areas, learn the terminology of other professions, and feel more confident to join the workforce with the cross-disciplinary skills needed to be successful.

Introduction

The term mechatronics became a widely used term for multi-disciplinary engineering that crosses over the conventional boundaries of engineering including, but not limited to mechanical engineering, electrical engineering, computer engineering and controls engineering[1]. Modern industrial applications are complex and require engineers and technologists to have a multi-disciplinary understanding of the synergy between mechanical systems, control systems, electronic systems, and computers[2-4]. Beyond industrial applications, mechatronic systems are found in everyday products such as printers, washing machines, coffee makers, vehicles, airplanes, medical equipment, machine tools, etc[5-7]. The mechatronic design approach to engineering focuses on providing industry with a new set of engineers who are able to design in a multi-disciplinary environment[8] by replacing conventional design methodologies with a multi-domain collaboration[9], as shown in Figure 1.

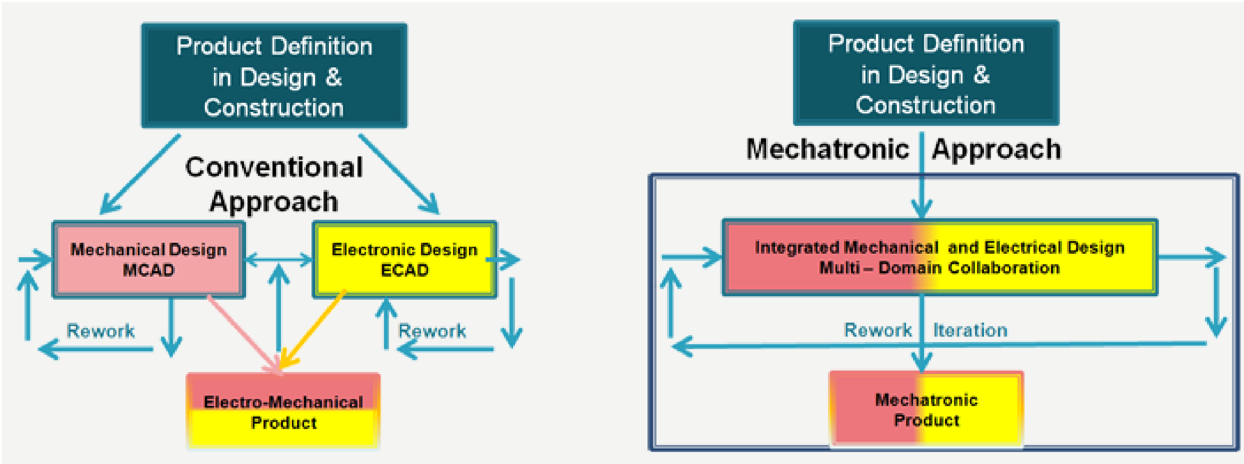


Figure 1: Mechatronic Design Approach[9]

In 1983, Japan's Toyohashi University offered one of the first courses in Mechatronics Engineering[10]. By the mid 1980's, many universities in Europe began offering Mechatronics courses as well[11]. The United Kingdon first offered a Mechatronic course at postgraduate level, and by 1988 offered a coure at undergraduate level as well[12]. Over the past 30 years, universities across the globe are incorporating Mechatronics courses into their undergraduate and graduate engineering curriculums[2] including Associate of Science degree, Bachelor of Science degree (U.S., Australia and U.K.), Bachelor of Engineering degree (Europe and Asia), Master of Science degree and doctoral degrees. Additionally, vocational high school programs as well as certificate programs dedicated to mechatronics are being offered[13-18]. Many universities that offer mechatronics courses also have mechatronics research laboratories[19-21].

Mechatronics course curriculums cover a range of multi-disciplinary engineering topics including programming, graphical user interfaces (GUI), embedded systems, microcontrollers, controls, sensors, electrical motors, encoders, as well as pneumatic and hydraulic systems[1, 2, 22]. Mechatronics courses are typically project-based and include the design of a mechatronic device based on given objectives and design specifications[1]. This project-based learning approach allows students to become more engaged in the learning process through experiments and hands-on activities and has proven effective in increasing the student's ability to learn and retain the material[23]. Mechatronics system design has many opportunities for students to get involved in creative engineering tasks and to engage in experiential learning. Mechatronics courses are typically offered to engineering and computer science students, and recently are offered to science students who apply knowledge related to mechatronics system design in their scientific experiments such as in the areas of chemistry[1], to enable more reliable measurements in experiments in the area of physics with the use of sensors, microcontrollers and step motors[24], and to train future surgeons with the assistance of mechatronic devices[25]. Modern scientific experiments incorporate mechatronic devices for more reliable and precise measurements.

Mechanical Engineering Technology Curriculum & Electromechanical Systems

Electrical Engineering Technology Core Courses in MET Program: Old Dominion University's Mechanical Engineering Technology (ODU MET) program offers undergraduate courses related to Advanced Manufacturing including Robotics; Automation; Lean Manufacturing; Computer Integrated Manufacturing; and Advanced Manufacturing Processes. Additionally, the ODU MET program requires students take three courses from the area of Electrical Engineering Technology: EET 305 Advanced Technical Analysis, EET 350 Fundamentals of Electrical Technology and EET 355 Electrical Laboratory. The course descriptions are outlined below.

EET 305 Advanced Technical Analysis (Lecture 3 hours; 3 credits): Analytical and computational methods to support upper-division engineering technology courses. Topics include linear algebra, ordinary differential equations of engineering systems, elements of vector analysis, introductory statistical concepts, and software usage/development. A significant portion of the course is devoted to the use of MATLAB to support engineering analysis and design.

EET 350 Fundamentals of Electrical Technology (Lecture 3 hours; 3 credits): A comprehensive course in electrical engineering technology for nonmajors. Major topics are basic electricity, AC and DC circuits, circuit analysis, linear electronics and digital electronics. Students learn the basic laws of DC circuits including Ohm and Kirchoff laws, voltage and current divider rules, Thevenin's and Norton's theorems, mesh and node analysis. Students also learn about inductance and capacitance, about boundary conditions for energy storage elements in transient circuits, and first order circuits with DC excitation. In AC circuits, students study phasor analysis, AC impedance and AC voltage-current relationships, conversion between series and parallel circuits and resonance phenomenon. The course introduces students to the basics of electronic devices, diodes, transistors and operational amplifiers, and to digital circuits with topics including basic and advanced combinational forms (basic boolean algebra, logic diagrams, decoders/encoders and multiplexers), and sequential forms (parallel and serial registers, counters and memories). The latter half of the course introduces concepts of power systems fundamentals, three-phase circuits, transformers, and DC and AC machines.

EET 355 Electrical Laboratory (Laboratory 2 hours; 1 credit). This is the lab-based course associated with EET350 and covers select electrical laboratory topics for nonmajors. The first objective of this course is to introduce students to the use of electrical circuit instruments including a multimeter, function generator, and oscilloscope and to learn basic wiring and beadboarding. After learning basic measurements and instrumentation, students learn to predict and verify Ohm's law and Kirchoff's law for voltage and current, to verify the theorems of superposition and maximum power transfer, and to verify Thevenin's and Norton's theorems. Other topics covered include AC circuits, phasor analysis, principles of reactive elements in AC circuits, and the basics of filtering using passive elements. The latter part of the course covers AC and DC motor configurations.

Recently, two new courses related to mechatronics have been added to the ODU MET program:

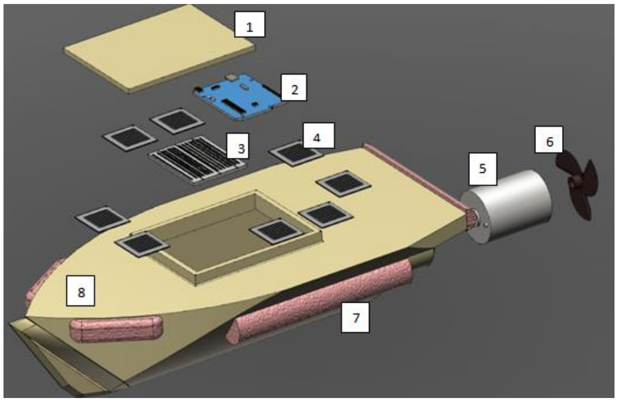
MET 426 – Introduction to Mechatronic (Lecture 3 hours; 3 credits): - A study of the mechatronics concepts and their application on actual problems encountered in engineering practice. This course includes the basics of electromechanical systems, electrical circuits, solid-state devices, and digital circuits and motors, all of which are fundamental to understanding mechatronic systems. This course provides students with knowledge in the following areas: basics about electric circuits and components used in mechatronic systems; applications of semiconductor electronics in mechatronics; importance of system response in mechatronic systems; analog signal processing using operational amplifiers; application of digital circuits in mechatronics; microcontroller programming and interfacing; data acquisition in mechatronics; and the application of sensors and actuators in mechatronics[26]. The course includes a final project where students assemble and program a Sumo Bot that must compete against other Sumo Bots on various challenges[27].

MET 427 - Mechatronic System Design (Lecture 3 hours; 3 credits): - A study of the integrated modelling and optimal design of a physical system which includes sensors, actuators, electronic components, and embedded digital control systems. The course includes simultaneous optimal design practice with respect to the realization of the design specifications related to different engineering domains. The course builds on MET 426 and adds more understanding regarding robust design, house of quality, design specifications, components used in mechatronic systems, practical application of hydraulics in mechatronics systems, electrical actuation systems in mechatronics, elements of mechanical system in mechatronics, and microcontroller programming and interfacing[26]. The course is primarily lecture-based but also includes project-based learning. These activities focus on applications of sensors and actuators in mechatronics, application of digital circuits in mechatronics, and microcontroller programming. The course includes a final project where students design and build a fire alarm robot to meet certain design requirements and constraints[27].

Senior Design Projects – Integration of Mechatronics Methodology

In addition to offering two new courses in mechatronics, the ODU MET program has placed an increased emphasis on mechatronics for students' senior design projects. Several recent senior design projects are presented below and showcase how the student has incorporated multi-disciplinary principles into the design and build of a functional mechatronic device. By embedding these experience into their senior design project, students are exposed to other engineering technology areas, learn the terminology of other professions, and feel more confident to join the workforce with the cross-disciplinary skills needed to be successful.

Solar Boat – Conceptual Design Senior Design Project: This senior design project in spring 2013 researched the technologies related to solar-powered marine vessels and included a conceptual design for a solar-powered boat[28]. The proposed boat design was a small hull (initial dimensions of the design envelope were 40 cm x 20 cm x 10 cm), powered by a minimum of four solar panels located on the top of the boat that deliver 4.8V each and 35mA. The four solar panels provide enough voltage to power the Arduino controller and the 12V DC motor. The solar-powered boat concept is shown in Figure 2. The boat concept was designed to have sufficient space for wiring, controller, solar panels, breadboard, and motor, with reserve for add-on components. All of the components would attach to the hull with Epoxy. Screws or other fasteners would add too much weight to the boat and not allow it to float. Waterproof epoxy would be used to seal and waterproof the DC motor from the interior. Foam floats were added to provide extra stability in the water. The interior of the hull houses the Arduino controller and breadboard, as shown in Figure 2. A hatch provides access to the interior. Additional space on the top of the hull is reserved for additional solar panels and hardware components.



1. Cover for the interior of the boat
2. Arduino Controller
3. Breadboard
4. Solar Panels
5. 12V DC motor
6. Propeller
7. Polyethylene foam floats
8. Hull of the boat

Figure 2: Explode state and basic parts of a solar boat concept[28]

Multi-Surface Electric Cart Senior Design Project: The objective of this project was to design and build an electrically powered beach cart, as shown in Figure 3, with the capacity to transport equipment through sand, hence removing the need to manually carry coolers and other cumbersome objects by hand[29]. The use of a mechanized machine alleviates beach-goers from both the physical exertion required from transporting a heavy load over distances as well as removes the hazards associated with carrying awkward loads. Student team recycled a used electric wheel chair for their major mechanical, electrical, and electronic components. The final design was made to carry a 100 pounds payload capacity, 2' x 3' payload area, 30 degree max incline, and maximum speed of 4.25 miles per hour. It was controlled by a tethered remote with battery charge indicator, variable speed with two 350 watt high torque motors, and two 12V Lead acid batteries, connected in series, with 12 hours running battery life.

Figure 3: Multi-Surface Electric Cart tested on various surfaces[29]

Self-Powered E-Bike Senior Design Project

The main goal of the Self-Power E-Bike senior design project was to replace the battery source with a more permanent source of hub motor power supply[30].

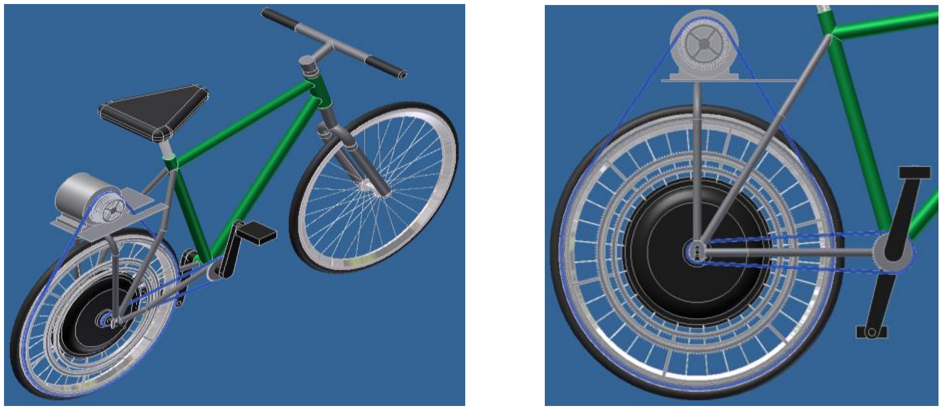


Figure 4: Conceptual design of Self-Powered E-Bike[30]

Calculations for this design included: motor requirements for overcoming typical bicycle obstacles such as climbing hills, wind resistance (drag) and rolling resistance, output power requirements in this chapter were used in coordination with the dynamic performance data provided by the motor manufacturers, maximum velocity on level ground as well as its maximum velocity while climbing its maximum rated hill grade[31].

Evaluation / Assessment

All senior design projects presented in this paper were completed by students who took at least one of the mechatronics courses. Qualitative comments that were retrieved from students confirmed that students felt a great sense of achievement in the design, build and verification of their workable designs and gained confidence through implementing mechatronics principles in multidisciplinary projects. Students responded that they felt better prepared for their future careers in industry. Student responses indicated that the mechatronics courses and the multi-disciplinary projects also facilitated a peer-to-peer learning environment across disciplines – specifically that MET students would seek technical advice from their peers in different engineering disciplines. Finally, students responded that these types of multi-disciplinary projects in which students are required to design and build an electromechanical (mechatronic) system are thought provoking and compel students to achieve a level of understanding beyond the skills obtained in the standard curriculum – the addition of the mechatronics courses aided students in achieving a higher level of understanding for these multi-disciplinary systems.

Student responses as well as instructor assessments indicate the need to continue to incorporate more advanced hands-on skills related to sensors, actuators, microcontrollers, electrical and electronic components in order to keep pace with the development of these technologies in industry. To further broaden the EET skills acquired by MET students through mechatronics courses and senior design projects, ODU will pursue integration of a wireless communications component to applicable projects. For example, for the multi-surface electric cart project, the wired remote that controls the cart and monitors the battery charge may be replaced by a wireless interface that is based on Arduino microcontrollers working along with XBee wireless modules. For the e-bike project, a wireless rotation sensor may be mounted on the bicycle wheel and interfaced with an Arduino microcontroller with XBee wireless module to enable speed/distance calculations and the display of relevant information on an LCD display mounted on the bicycle handle. The Arduino microcontroller may also collect battery state/charge data to and integrate this information with the speed/distance calculations to display an approximate range over which the e-bike is operational. Future senior design teams may also bring together students with different majors, such as Mechanical and Electrical Engineering Technology, along with advisors from both areas.

Conclusion

Mechanical engineers and mechanical engineering technologists must possess a multi-disciplinary knowledge with the understanding of both mechanical and electrical systems. For this purpose, ODU MET program recently added two new courses related to Mechatronics and has placed an increased emphasis on mechatronics for students' senior design projects. This paper highlights the benefits of including mechatronics in the ODU MET curriculum and presents several recent senior design projects that showcase how the student has incorporated multi-disciplinary principles into the design and build of a functional mechatronic device. ODU MET program considers the integration of mechatronics courses into the curriculum a success as evidenced in part through the realization of the students' multi-disciplinary senior design projects. By embedding these experience into their senior design project, students are exposed to other engineering technology areas, learn the terminology of other professions, and feel more confident to join the workforce with the cross-disciplinary skills needed to be successful.

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Jerome Mallone and Amanda Abalon designed the solar boat shown in Figure 2. Robert Lathrop, Manuel Soares, and Cabel Rich designed and built multi-surface electric cart shown in Figure 3. Students Zachary Seegers and Robert Quinn designed self-powered E-bike show in Figure 4. We would like to acknowledge their hard work on this project and thank them for allowing the use of the images.

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