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Memo

February 3, 2020

To: Randy Smith, Vice Provost for Academic Programs
Office of Academic Affairs

From: Rosie Quinzon-Bonello, Assistant Dean for Curriculum and Assessment

RE: Robotics and Autonomous Systems UG Minor Proposal

Attached is a proposal submitted by the Department of Mechanical and Aerospace Engineering to establish an Undergraduate Minor in Robotics and Autonomous Systems.

On January 13, 2020 the College of Engineering Committee for Academic Affairs (CCAA) discussed and unanimously approved that the proposal to be forwarded to CAA for review.

If you require additional information, please contact me.

Yours sincerely,

Rosie Quinzon-Bonello
Assistant Dean for Curriculum and Assessment

The Ohio State University
College of Engineering
Proposal for a

Robotics and Autonomous Systems Undergraduate Minor

1/29/2020

Background and Content: In response to national and local needs for trained Robotics and Autonomous Systems (RAS) engineers and researchers, we are proposing a RAS minor program. While not exclusive, the advanced and interdisciplinary nature of the RAS minor core courses means that the anticipated set of students who will enroll in the courses are undergraduate students in engineering and physics majors, particularly in their later years. To understand this subject, students must have a basic understanding of various subjects ranging from hardware design of mechatronic systems, dynamics and kinematics analysis of multi-body systems, software and controller development for these systems, and domain specific applications of RAS. Many courses covering these subjects are offered in the junior and senior level in engineering and physics majors. To prepare for this minor, students are expected to have sufficient preparation of mathematics, software programming skill etc. These constraints are warranted by the fact that the subject matter of the minor is at an advanced level, but we believe the target population of students in the College of Engineering and Dept. of Physics is large enough to warrant such constraints.

Robotics and Autonomous Systems (RAS) is believed to be one of the transformative technologies for several key fields including healthcare, manufacturing and public safety in the United States. As we know, restructuring of US manufacturing is essential to the future of economic growth and the creation of new jobs and ensuring competitiveness of US industry. However due to a shortfall of investment of robotics research in the past decades, the US is losing leadership in this area. As a result, industry has found difficulty in hiring high quality employees in the robotics and automation field. Resurgence of RAS has been fueled by recent advances in fast, mobile, computing, artificial intelligence, and machine learning. At the local level, students in STEM disciplines at OSU have a strong interest in pursuing career in the RAS area. However, they have difficulty in identifying courses in RAS not because we are short of faculty members or courses in this area, but because the visibility of RAS is not well promoted.

The main objectives of the RAS minor program are:

1) *Expose students to robotics and autonomous systems engineering subjects ranging from design, analysis, control, interaction and operation.*
2) *Equip students with an understanding of the robotics engineering fundamentals and basic research skills needed to succeed in R&D for the automation, healthcare and manufacturing industries*
3) *Promote student interest in a career path in automation, manufacturing and healthcare in which robotic and autonomous technologies play a central role.*
4) *Produce a high quality work force that is essential to revitalize manufacturing in the United States.*

Key topics include:

- Kinematic and dynamic analysis of multi-body systems
- Mechanical design of robotic and autonomous systems
- Analysis and design of mechatronics systems for robotic sensors and actuators

- System optimization, motion planning and control of robotic systems
- Analysis and design of aircraft, helicopter and missile flight control systems and the associated guidance and navigation systems.
- Spacecraft (satellite) control systems analysis and design.
- Autonomy in the context of modern vehicles; cruise control, anti-lock brake systems (ABS), steering control/lane keeping; introduction to automated highway systems (AHS).
- Design and analysis of linear and nonlinear dynamical systems and feedback control systems
- Digital signal processing, design of discrete-time filters, selected topics in adaptive and/or multidimensional signal processing.
- Design, application, and computer logic and control of various mechanical, pneumatic, electrical, and electronic sensors and actuator devices for industrial systems.
- Operating principles, selection, use of proximity and optical sensors; switches, relays, actuators; electric motors and controls; electro-pneumatic devices; integration of these for automated industrial systems.
- Artificial intelligence and big data technologies for design, analysis and decision making in automated industrial systems and manufacturing robots
- Human interactions with robots and autonomous systems
- Study practical applications of robotics and automation to macroscale/microscale manufacturing, energy and smart grids, cybersecurity and social networks.
- Robotic surgery and assistive device technology and their application to healthcare and rehabilitation
- Computer visions and image analysis for robotics

Student Interest: Student interest in RAS already exists on campus, demonstrated by the existence and popularity of several student organizations and events. For instance, the Underwater Robotics Team attracts 40-50 students from several engineering disciplines such as ECE, MAE and ISE. The Underwater Robotics Team is an interdisciplinary student project team that specializes in the design, construction, and operation of Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs). Students from a variety of majors are responsible for every aspect of building the vehicles, including machining the housings, soldering the circuit boards, and developing the software. There are also ongoing student-led efforts to establish a campus-wide battlebot competition. Another example is FIRST Robotics at Ohio State (FROS). The purpose of FIRST Robotics at Ohio State (FROS) is to mentor and encourage high school students in areas of science and technology. In addition, other student-led activities are:

- Buckeye space launch initiative
- ECOcar
- Unmanned Aerospace Vehicles/Drone/ aero Mars rover/JPL
- Design-Build-Fly

In addition, the newly launched seminar series in robotics and automation by the MAE department has become one of the most popular series within MAE. This RAS minor program will benefit students in many majors:

- Mechanical Engineering
- Aerospace Engineering
- Electrical and Computer Engineering
- Integrated System Engineering
- Computer Science Engineering

- Biomedical Engineering
- Civil, Environmental and Geodetic Engineering
- Agricultural Engineering

Four departments (MAE, ECE, ISE and CSE) have contributed to this proposal for the RAS minor program. However, it is anticipated that other units beyond those initiating this minor may join the effort by contributing to course development, teaching, and cross-listing of courses.

Requirements for the Minor: The successful completion of the Minor requires completing 12 credit hours. The RAS Minor is composed of two parts:

1. The successful completion of one of the required courses: Introduction to Real Time Robotics Systems (ECE5463) or Introduction to Real Time Robotics Systems (ME5463),
2. The successful completion of at least nine (9) additional credits from selected courses from several engineering major programs including: Mechanical Engineering, Aerospace Engineering, Electrical and Computer Engineering, Integrated System Engineering and Computer Science and Engineering.

Completion of Introduction to Robotics (ECE 5463/ME 5463) is established to assure students have the fundamental robotics and automation knowledge and skills for success in the minor.

Requirements for completion of the minor are summarized in the following table.

Robotics and Automation Minor: Curricular Requirements	
Robotics and Automation Core Courses (Choose one course)	**Credits**
1. Introduction to Real Time Robotics Systems (ECE/ME 5463, Cross-listing)	3
Elective Courses (Choose minimum 3 credits)	**Credits**
1. ME 5372 - Design and control of mechatronics systems	3
2. ME 5751 – Design and manufacturing of compliant mechanisms and robots	3
3. ME 5194.20(*) - Machine learning for engineers	3
4. ME 5194.y (*) - Smart product design	3
5. AE 5621 - Guidance, Navigation and Control of Aerospace Vehicles	3
6. AE 5620 - Stability and Control of Flight Vehicles	3
7. ECE 3551 - Introduction to Feedback Control Systems	3
8. ECE 5200 - Introduction to Digital Signal Processing	3
9. ECE 5553 - Autonomy in Vehicles	3
10. ECE 4194.02 - Group study in machine learning	3
11. ISE 5520 - Industrial Automation	1.5
12. ISE 5525 - Industrial Robotics	1.5

13. ISE 5740 - Cognitive Engineering Systems: Human-Centered Automation	3
14. ISE 5760 - Visual Analytics for Sensemaking	3
15. CSE 5052: Survey of Artificial Intelligence for Non-Majors	3
16. CSE 3521: Survey of Artificial Intelligence 1	3
17. CSE 5524: Computer Vision for Human-Computer Interaction	3
Research Credits**	**Credits**
1. ME 4998 - Undergraduate Research in ME 2. ME 4998H – Honor Undergraduate Research in ME 3. ME 4999 - Undergraduate Research for Thesis 4. ME 4999H - Undergraduate Research for Honors Thesis 5. AE 4998 - Undergraduate Research for Thesis in AE 6. AE 4998H - Honor Undergraduate Research for Honor Thesis in AE 7. AE 4999 - Undergraduate Research for Thesis in AE 8. AE 4999H - Undergraduate Research for Honor Thesis in AE 9. ECE 4998.01 - Undergraduate Research in ECE 10. ECE 4998.01H - Undergraduate Honors Research in ECE 11. ECE 4999.01 - Undergraduate Thesis Research in ECE 12. ECE 4999.01H - Undergraduate Honors Thesis Research in ECE 13. ECE 4999.01 - Undergraduate Thesis Research in ECE 14. ECE 4999.01H - Undergraduate Honors Thesis Research in ECE 15. ISE 4998 - Undergraduate Research in ISE 16. ISE 4998H - Undergraduate Honors Research in ISE 17. ISE 4999 - Undergraduate Thesis Research in ISE 18. ISE 4999H - Undergraduate Honors Thesis Research in ISE 19. CSE 4998 - Undergraduate Research in CSE 20. CSE 4998H - Undergraduate Honors Research in CSE 21. CSE 4999 - Undergraduate Thesis Research in CSE 22. CSE 4999H - Undergraduate Honors Thesis Research in CSE	
***** temporary**,** will be converted to a permanent course ******To research credits for the minor, the project must be R&A relevant. Research credits for the minor is subject to approval of minor coordinator with consulting with the point-of-contact for the student's major program.	

Sample course plan for earning the RAS minor

Students can earn the RAS minor by following either the course track or the research track. Example schedules are the following

Course only track for ME students

Autumn	Credits	Spring	Credits
ME 5463, Introduction to real time robotic systems	3	ME 5194.20 Machine learning for engineering	3
ME 5751: Design and manufacturing of compliant mechanisms and robots	3	ME 5194.y Smart product design	3

Course + Research credit track for ME students

Autumn	Credits	Spring	Credits
ME 5463, Introduction to real time robotic systems	3	ME 5751: Design and manufacturing of compliant mechanisms and robots	3
ME 4999H: Undergraduate Research for Honor Thesis	3	ME 4999H: Undergraduate Research for Honor Thesis	3

Course + Research credit track for Physics students

Autumn	Credits	Spring	Credits
ME 5463, Introduction to real time robotic systems	3	ME 5194.20 Machine learning for engineering	3
ME 4998 - Undergraduate Research in ME	3	ME 4998 - Undergraduate Research in ME	3

Administration and Oversight of Minor: The minor will be administered by the Department of Mechanical and Aerospace Engineering. The academic advising staff in that department will serve as coordinators for the minor.

General Guidelines

- Required for graduation: No
- Credit hours required: A minimum of 12 credit hours including 3 credit hours from the required course and at least 3 credit hours from the elective courses. The other credit hours can be from other elective courses or research credits (graded as letter grades).
- Filing Minor Form: The student must fill out the Minor Student Information Form (see below) with all required information, and get this approved by the Minor Advisor.
- Changing the minor: Once the minor has been filed, any changes must be approved by the Minor Advisor. This form is available on the College of Engineering website
- Grades required: No grade below a C- will be permitted in courses comprising the minor
- A minimum 2.00 cumulative point-hour ratio is required for the minor
- Course work graded Pass/Non-pass cannot count on the minor
- Transfer credit hours allowed: No more than 6 hours of transfer credit may be applied to the minor
- Overlap with GE courses: No more than 6 hours can overlap

Overlap with the major and additional minor(s): The minor must be in a different subject from the major (as identified by the registrar's official listing of approved majors). Each minor completed must contain a minimum of 12 hours distinct from the major and/or additional minors.

Existing Programs at Other Institutions: In addition to several major robotics programs in leading institute such as CMU and Michigan, there are quite a few undergraduate robotics minor programs nationwide. Here are several examples.

1. Georgia Institute of Technology (Robotics Minor Program)
   http://catalog.gatech.edu/programs/minor-robotics/
2. Cornell University (Robotics Minor)
   https://www.engineering.cornell.edu/students/undergraduate-students/curriculum/majors-and-minors/robotics-minor
3. Carnegie Mellon University (Undergraduate Robotics Minor Program)
   https://www.ri.cmu.edu/education/academic-programs/undergraduate-options/how-to-apply/undergraduate-robotics-minor-application/
4. Johns Hopkins University (Robotics Minor Program)
   https://lcsr.jhu.edu/robotics-minor/
5. University at Buffalo (Robotics Minor Program)
   https://catalog.buffalo.edu/academicprograms/robotics_minor.html
6. University of Massachusetts at Lowell (Robotics Minor Program)
   https://www.uml.edu/Catalog/Undergraduate/Sciences/Departments/Computer-Science/Robotics-Minor.aspx
7. Northeastern University (Robotics Minor Program)
   http://www.coe.neu.edu/degrees/robotics-minor
8. Worcester Polytechnic Institute (Robotics Engineering Minor)
   https://www.wpi.edu/academics/study/robotics-engineering-minor

Assessment Plan

The Mechanical and Aerospace Engineering (MAE) Undergraduate Studies Committee and minor coordinator will be charged with assuring the assessment of the minor. Each participating department will appoint a faculty member as the point-of-contact for the minor program. An assessment survey will be administered by the Minor Coordinator to students once they complete all requirements of the Robotics and Automation minor. This assessment will address 1) the attainment of the learning objective for the minor, 2) structure, availability, and appropriateness of courses in the minor and 3) the students' experiences completing the minor. Completion of this assessment will be the students' last step in successfully finishing the minor requirements. This data, along with enrollment data, will be reviewed annually by the MAE Undergraduate Studies Committee.

Proposal Authors:

For additional information contact: Prof. Haijun Su (su.298@osu, 614-292-2239)

Required Courses					
Offering Unit	**Course #**	**Title**	**Cr**	**Pre-requisites**	**Description**
ME/ECE	5463	Introduction to Real Time Robotics Systems	3	MATH 2177 or MATH 2174, or MATH 2415 and MATH 2568; and PHYSICS 1250 or PHYSICS 1250H or PHYSICS 1260 or PHYSICS 2300; and CE 1221 or CSE 1222 or ENGR 1181 or ENGR 1281.01 or ENGR 1281.0X or ENGR 1221 or ENGR 1222; or grad standing in engineering or permission of instructor (**). ECE and ME cross-listing	Components of a robot system; robot forward and inverse kinematics; robot dynamics; robot force generation, robot trajectory generation

Elective Courses					
Offering Unit	**Course #**	**Title**	**Cr**	**Pre-requisites**	**Description**
ME	5372	Design and control of mechatronics systems	3	ME3360 or ME3361, or Grad standing in MechEng, or permission of instructor.	Introduction to multi-domain (mechanical, thermal, fluid, electrical, electronic, electro-mechanical) system design, dynamic modeling, and control system design and analysis techniques.
ME	5751	Design and manufacturing of compliant mechanisms and robots	3	ME 3751 or equiv, or Grad standing in Engineering or permission of instructor (**)	Introduces methods and theories for kinematic and force analysis, synthesis of rigid body and compliant (flexible) mechanisms and robots. Pseudo-rigid-body model and CAD/CAE software will be used for modeling and analysis study. Students will be required to work on a team project to solve a real world design problem related to mechanisms and robots.
ME	5194.20*	Applied Machine Learning in MAE and Robotics	3	Senior or graduating standing in MAE or permission of instructor (**). Not open to students with credit for CSE 5523, ECE 4194.02 (Intro to ML for ECE) or ECE 7868 or CSE 5523, or other Machine Learning-related courses at Ohio State.	The course will cover the foundations of various machine learning methods briefly and provide an applied hands-on introduction to machine learning as relevant to MAE and robotics. Applications in MAE and robotics will be explored in homework and project assignments, with subject-specific datasets and problems. The goal of this course is to provide undergraduate and early graduate students with the knowledge and skills useful in both industry and research.
ME	5194.y*	Group study in Smart product design	3	Senior or graduate standing in MAE	Introduction to the concepts and process of embedded product design, a.k.a. Smart Product Design, through an application based, structured design process and practice their application in the design of smart and interconnected products.
AE	5620	Stability and Control of Flight Vehicles	3	AE3521	Analysis and design of aircraft, helicopter and missile flight control systems and the associated guidance and navigation systems.

AE	5621	Guidance, Navigation and Control of Aerospace Vehicles	3	AE3521	Spacecraft (satellite) control systems analysis and design.
ECE	3551	Introduction to Feedback Control Systems	3	ECE3050 (352)	Provides fundamental concepts in feedback control systems design and analysis.
ECE	5200	Introduction to Digital Signal Processing	3	ECE 3050 (352), and Stat 3470 (427) or Math 530; or Grad standing.	Sampling and reconstruction; discrete-time rate conversion; processing of discrete-time signals; design of discrete-time filters, selected topics in adaptive and/or multidimensional signal processing.
ECE	5553	Autonomy in Vehicles	3	ECE3551, ECE 5551 (551), or Grad standing in Engineering.	Autonomy in the context of modern vehicles; cruise control, anti-lock brake systems (ABS), steering control/lane keeping; introduction to automated highway systems (AHS).
ECE	4194.02*	Group study in machine learning	3		
ISE	5520	Industrial Automation	1.5	ISE2500, or Grad standing in Engineering.	Industrial Automation teaches the design, application, and computer logic and control of various mechanical, pneumatic, electrical, and electronic sensors and actuator devices for industrial systems.
ISE	5525	Industrial Robotics	1.5	ISE 2500, or Grad standing in Engineering.	Operating principles, selection, use of proximity and optical sensors; switches, relays, actuators; electric motors and controls; electro-pneumatic devices; integration of these for automated industrial systems.

ISE	5740	Cognitive Engineering Systems: Human-Centered Automation	3	Sr. or Grad standing in ISE, or permission of instructor.	Provides key concepts to make autonomous systems, robots, and artificially intelligent systems team players with responsible people.
ISE	5760	Visual Analytics for Sensemaking	3	Jr., Sr., or Grad standing.	Students learn about information visualization techniques that help people analyze massive amounts of digital data to combat overload and aid sensemaking with applications in retail and financial decision making, logistics, information systems, manufacturing, healthcare, energy and smart grids, cybersecurity and social networks.
CSE	5052	Survey of Artificial Intelligence for Non-Majors	3	Prereq: 1211, 1221, 1222, 1223, or 2221, or Grad standing. Not open to students with credit for 3521 (630), 4521, or 5521, or students enrolled in a CSE or CIS major.	Survey of the basic concepts and techniques in artificial intelligence, including problem solving, knowledge representation, and machine learning.
CSE	3521	Survey of Artificial Intelligence 1	3	Prereq: 2331 or 5331. Not open to students with credit for 5521.	Survey of basic concepts and techniques in artificial intelligence, including problem solving, knowledge representation, and machine learning.
CSE	5524	Computer Vision for Human-Computer Interaction	3	Prereq: 2331, or Sr or Grad standing. Not open to students with credit for 634.	Computer vision algorithms for use in human-computer interactive systems; image formation, image features, segmentation, shape analysis, object tracking, motion calculation, and applications.
* temporary, will be converted to a permanent course ** pre-requisite change to be submitted, pending CAA approval					

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November 18, 2019

Rosario Quinzon-Bonello
College Committee on Academic Affairs

Dear Rosie,

The Department of Computer Science and Engineering supports the proposal for a new minor in Robotics and Autonomous Systems (RAS). Our Undergraduate and Graduate Studies Committees have reviewed the latest version of the proposal.

We do note, however, that we cannot guarantee that students in the minor will be able to enroll in the CSE courses that are included in the list of possible technical electives for the minor. Because of current enrollment pressures in CSE, students completing a minor have lower priority for course enrollment than students who need the same courses for their major and for graduation requirements. Given the number of alternative courses from which students can choose technical electives, however, this limitation should not pose a significant challenge for students to complete the minor.

Sincerely,

Rephael Wenger
Associate Chair, Computer Science and Engineering

THE OHIO STATE UNIVERSITY

Department of Electrical and Computer Engineering

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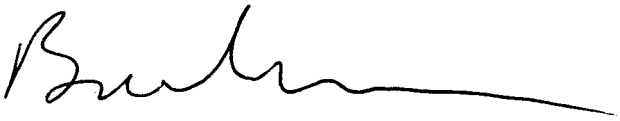
November 1, 2019

Rosario Quinzon-Bonello
College Committee on Academic Affairs

Dear Rosie,

The Department of Electrical and Computer Engineering fully supports the proposal for a new minor in Robotics and Autonomous Systems. The proposal has been reviewed by our Controls Committee and Curriculum Committee.

Sincerely yours,



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THE OHIO STATE UNIVERSITY

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5 Nov. 2019

Rosario Quinzon-Bonello, M.Ed.
Assistant Dean for Curriculum and Assessment
College of Engineering
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Dear Rosie,

The Department of Integrated Systems Engineering fully supports the proposal for a new minor in Robotics and Autonomous Systems. The proposal has been reviewed by the Chair and Associate Chair of our Department and the chairs of our Undergraduate and Graduate Studies Committees. We had received input from faculty, which was incorporated at an earlier stage in the development of the minor. We recently hired some new faculty whose areas of expertise are relevant to this new minor. We have shared the current draft of the minor with them, as well. A comment was added to the draft, based on their interest in this new minor. Please also see a couple of corrections that were made to the draft (V17).

Sincerely,

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