Graduate Programs in Advanced Systems Engineering

UTC Institute for Advanced Systems Engineering, University of Connecticut

Mission

To train the engineer of the next decade: the one who is not constrained by disciplines, bridges the gap between theory and application in the field of systems engineering and can transform and disrupt industrial engineering practices. The UTC-IASE program of UConn aims to produce these “2020 engineers” at a substantial capacity by adoption of a bold, scalable, interdisciplinary, and modular approach to graduate STEM education that focuses on the application of theory, modern computational methods, state-of-the-art software tools on complex industrial systems.

About the UTC Institute for Advanced Systems Engineering (UTC-IASE)
The UTC Institute for Advanced Systems Engineering (UTC-IASE) is a coordinated effort by the United Technologies Corporation and the University of Connecticut, focused on enhancing the capability and capacity of engineers with “systems thinking” in the nation and worldwide. The UTC-IASE serves as a hub for world-class research, project-based learning by globally-distributed teams of students and industrial outreach activities focused on model-based systems engineering of complex systems that are built from, and depend upon, the synergy of computational and physical components. Through transformative research, education, and workforce development, the UTC-IASE has the mission to produce, disseminate and commercialize new science and technology in the field of cyber-physical systems engineering.

Why Systems Engineering?
The convergence of computation, communications and control enable cyber-physical systems (CPS) to have learning and predictive capabilities capable of adapting to changing situations. Motivated by the increasing complexity of advanced products and the digital revolution, the UTC-IASE trains engineers in urgently needed CPS-related disciplines that are pivotal to innovation and product enhancement in the globally competitive economy. With its industrial base and focus and excellent faculty, the Institute is positioned to advance the science base of CPS and to accelerate its technological translation into sustained industrial growth.

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Graduate Certificate Program Objectives

- Engineers and Technical Managers learn how systems engineering practices, processes, and methods can be applied to design cyber-physical systems.
- Graduates see the “big picture” of systems engineering from an organizational and process viewpoint and can apply basic design methodologies of systems engineering to cyber-physical systems.
- Students engage in a multidisciplinary environment promoting experientially-based expertise in model-based systems engineering.
- Offer customized programs (graduate certificates and Master’s of Engineering) in advanced systems engineering for professionals, addressing challenges in modern cyber-physical systems that cannot be addressed by traditional domain specific methods and tools.

Program Outcomes. By the end of the Graduate Certificate, graduates can:

- Describe processes, methods, and practices of systems engineering.
- Apply systems engineering practices and methods to relevant examples.
- Develop system requirements, architectures, specifications, verifications, and tests.
- Analyze systems using systems engineering approaches to increase system performance.
- Recognize important systems engineering and systems thinking strategies and practices in examples and cases.
- Develop analytical skills in evaluating the performance of cyber-physical systems and/or the technical systems that support the systems engineering effort.

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What’s exciting about this program? Why do you care?

A recent report by the National Academies of Sciences, Engineering and Medicine\(^1\) emphasizes that the future cyber-physical systems (CPS) workforce is likely to include a combination of engineers trained in foundational fields (such as electrical and computing engineering, mechanical engineering, systems engineering, and computer science); engineers trained in specific applied engineering fields (such as aerospace and civil engineering); and CPS engineers, who focus on the knowledge and skills spanning cyber technology and physical systems that operate in the physical world. The future CPS workforce needs to understand the principles that define the integration of physical and cyber aspects in areas such as communication and networking, real-time operation, distributed and embedded systems, physical properties of hardware and the environment, and human interaction. The Academic Program of the UTC-IASE addresses this need with training programs that cut across the areas of systems engineering, modeling, control, communications and networking.

Programs Offered

The UTC-IASE Academic Program offers professional training through non-research-based University Graduate Certificates open to professional engineers, interested in obtaining specific skills in the field of Advanced Systems Engineering. A Master of Engineering (MENG) degree is also offered, targeting practicing engineers interested in expanding their skills and academic standing. Courses are delivered via distance learning mechanisms, and course content is available to participants using web-based communication and educational platforms. Courses are offered to geographically-dispersed and time-constrained professionals with a modular approach, in which courses are split into 5-15 min online pre-recorded modules, with supporting information provided in the form of book chapters and papers of relevance to each subject. Interactive, “live” discussion sessions follow the course modules, using a two-way audio, video, and document sharing system for problem solution, discussion and interaction with the instructor and other students. Private social media sessions are opened for the students and instructors to interact at any time during the course. Access to software and programming tools is available through UConn’s virtual PC system. Students have remote access to a virtual desktop with installs of the software utilized by a course (Matlab, Modelica, CAD tools, etc.). The courses available to students are summarized in the following sketches and discussed in detail in the Appendix of this document.

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Graduate Certificate in Advanced Systems Engineering

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4 Courses, 12 Credit Hours

Master's of Engineering (MEng) in Advanced Systems Engineering

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3 Courses Required

Capstone Course

MS Engineering in Systems Engineering Total: 10 Courses, 30 Credit Hours
Graduate Certificate Holders: 6 Additional Courses Needed
Select 2-3 Courses from Foundation to Fulfill 3 Course Requirement
Select Remaining 2-3 Courses from Introduction, Modeling, & Concentration Courses to Fulfill Requirements + 1 Capstone Course

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Graduate Courses in Systems Engineering

SE 5000 Intro to Systems Engineering

What’s Exciting About this Course? Learning the foundations of systems engineering and gaining an in-depth knowledge of system engineering principles, processes, and methods. Reading about how others apply and excel at Systems Engineering through examples and case studies. Discussing and sharing best practices and challenges with classmates and instructor for building effective systems engineering functions and processes. Applying systems thinking concepts to structured challenges.

Course Description. An introduction to the hard and soft skills that are required of good systems engineers. Lectures follow the competency models for systems engineers and include topics such as systems thinking, needs identification, requirements formulation, architecture definition, technical management, design integration, as well as verification and validation of designs. Some of the key systems engineering (SE) standards will be covered and the roles of organizations in enabling engineers to develop systems will be explored. Applications of SE concepts and tools in various settings will be discussed through examples and case studies. Students will learn to apply the SE methodologies in modern complex system development environments such as aerospace and defense, transportation, energy, communications, and modern software-intensive systems.

Course Outcomes

• Describe processes, methods, and practices of systems engineering.
• Apply systems engineering practices and methods to relevant examples.
• Develop requirements, architectures, specifications, verifications, and tests.
• Analyze systems using systems engineering approaches to increase performance.
• Recognize important systems engineering and systems thinking strategies and practices in examples and cases.


Course Objectives and Links to Overall Program Goals

Engineers obtain a strong foundational knowledge of systems engineering principles and practices, which can be leveraged and applied in later courses when analyzing and designing cyberphysical systems. Engineers see the “big picture” of systems engineering from an organizational and process viewpoint.
Graduate Courses in Systems Engineering
SE 5001/5095 Model-Based Systems Engineering

What’s Exciting About this Course? Applying the knowledge of systems engineering principles, processes, and methods to design cyberphysical systems. Creating architectures, models, and simulations that relate and test all system elements, interfaces, interactions, and performance.

Course Description. This course is designed to provide students with the foundations of model-based systems engineering. Students will develop skills in the areas of fundamental logical, behavioral, physical representations of engineered cyberphysical systems. Topics include software and systems requirements engineering, interface design and modeling, system architecting, system verification and testing, and system simulation. Emphasis is placed on modeling cyberphysical systems using modern MBSE tools. Examples include a water distiller, a residential security system, an automobile, an elevator, and a geospatial library for the demonstration of the theoretical and practical aspects of systems modeling. The course is designed for all graduate students pursuing engineering degrees.

Course Outcomes

• Describe the processes, methods, and practices of model-based systems engineering.
• Apply model-based systems engineering practices and methods to relevant examples.
• Develop and relate requirements, architectures, behavior, specifications, verifications, and tests that represent cyberphysical systems using model-based systems engineering methods.
• Analyze systems using model-based systems engineering approaches to increase performance.
• Simulate the behavior and performance of cyberphysical systems.
• Communicate effectively in teams, via interim and final project progress reports.

Topics: Creating Requirements, Requirements Modeling, Define the System Context and Boundary, Define Interfaces and External Interface Elements, Define the System Behavior, Advanced System Behavior Modeling, Introduction to Simulating Cyberphysical Systems, Allocate the Behavior to Physical Components, Defining Physical Components, Failure Modes and Effect Analysis (FMEA), Verification Requirements and Test Plans, Integrating and Deploying SysML and MBSE into a Systems Development Environment.

Course Objectives and Links to Overall Program Goals
Engineers obtain a strong foundational knowledge of model-based systems engineering principles and practices, which can be leveraged and applied in later courses when analyzing and designing cyberphysical systems. Engineers can model and present the complex relationships between needs, requirements, architecture, and behavior for cyber-physical systems.
Graduate Courses in Systems Engineering
SE 5101/5201 Foundations of Acausal Physical Systems Modeling

What’s Exciting About this Course? Developing skills in the areas of fundamental physical and mathematical representations of heat transfer, fluid transport, separations, and their incorporation in large-scale systems. Introducing concepts on how systems can be architected and designed with the aid of models and the basic principles of model-based systems engineering. Understanding the key aspects and advantages of acausal, equation-oriented modeling languages.

Course Description. This course introduces concepts on how systems can be architected and designed with the aid of models and the basic principles of model-based systems engineering. Topics include system and component requirements specification, creation of system models for design and control analysis of physical systems. Emphasis is placed on the modeling of such systems in the equation oriented programming environment of the Modelica language, and the utilization of these system models within the Functional Mockup Interface for co-simulation and Model Exchange. Examples of Aircraft Environmental Control, Chiller Plants, Engines, Power Generation, and Manufacturing Systems are used for the demonstration of the theoretical and modeling aspects of physical system modeling.

Course Outcomes
• Exhibit proficiency in simulating systems with heat and mass transfer, separation, and mixing, at different levels of complexity
• Become comfortable with concepts of acausal, equation oriented modeling
• Become knowledgeable of the role of modeling abstraction, reduction, and meta-modeling in the field of model-based systems engineering
• Understand how cyber-physical systems can be architected and designed with the aid of models
• Integrate acquired knowledge in the analysis of a physical system of their field.


Course Objectives and Links to Overall Program Goals
Engineers obtain a strong foundational knowledge of systems modeling principles and practices, which can be leveraged and applied in system analysis, design, control and specification, with focus on the analysis and design of cyberphysical systems.
Graduate Courses in Systems Engineering

SE 5102 Uncertainty Analysis, Robust Design, and Optimization

What’s Exciting About this Course? Learning to understand and quantify uncertainties in cyber-physical systems and how to handle and treat those uncertainties to design more robust complex systems.

Course Description. This course is designed to provide students with a thorough understanding of platform-based and model-driven methods for uncertainty analysis and robust design of cyber-physical systems. The course is organized into six learning modules: 1) Product development processes and robust design, 2) Concept sizing and margin analysis, 3) Uncertainty quantification and sensitivity analysis in design, 4) Capability analysis, 5) Robust design, 6) Root cause analysis with models.

Course Outcomes

- Exhibit proficiency in assessing margin and capability.
- Develop skills in model based uncertainty quantification for margin and capability assessment.
- Develop skills and understanding of sensitivity analysis and causes of margin loss.
- Exhibit proficiency in robust design.
- Develop skills in model based robust design for margin and capability improvement.
- Demonstrate ability to work in teams and to communicate effectively.
- Analyze, solve, and present a MBD approach to the design of industry relevant systems.
- Integrate acquired knowledge in the analysis of physical system.


Course Objectives and Links to Overall Program Goals

This course is designed to provide students with the foundations of model-driven methods for uncertainty analysis and robust design of cyber-physical systems. This course builds upon the understanding of systems engineering processes and systems engineering modeling to design more robust systems.
Graduate Courses in Systems Engineering
SE 5202 Foundations of Control

What’s Exciting About this Course? Applying the knowledge of systems engineering principles, processes, and methods to design practical feedback controllers for cyber-physical systems and analyze them for robustness, performance and stability. Use of MATLAB/Simulink (Dymola) for analysis and simulation.

Course Description. The objectives of this course are to familiarize the students with system design flows used for designing, implementing and verifying control systems and to provide skills necessary to design and analyze practical feedback controllers for cyber-physical systems. Successful students will be cognizant of the role of controls in the system design process and will be proficient in specifying control system requirements, especially as they relate to attenuation of load disturbances, robustness to dynamic system model uncertainty, actuator nonlinearities, and measurement noise; knowledgeable of the distinctions between modeling systems for control and understanding the fundamental limits of regulatory control systems; aware not only of practical control design architectures like PID controllers; but also cognizant of modern state-space formalism of multivariable systems; optimization based synthesis of estimators and controllers; followed by validation, testing, diagnostics and tuning. Use of computer-aided engineering tools based on MATLAB/Simulink (Dymola) in the design flows for control of cyber-physical systems is emphasized.

Course Outcomes
- Specify qualitative/quantitative control system requirements.
- Develop non-linear multi-variable model with uncertainties.
- Design classical and state-space controllers and estimators.
- Use MATLAB/Simulink (Dymola) to implement/analyze the cyber-physical control systems.


Course Objectives and Links to Overall Program Goals

Engineers can design, develop, and integrate control systems into complex cyberphysical systems. When combined with the foundational knowledge of systems engineering and model-based systems engineering methods and approaches, this course prepares engineers to design systems that satisfy stakeholder needs, while taking into account complex forms of interactions, and the demand for higher levels of quality and reliability through control.
Graduate Courses in Systems Engineering
SE 5301 Embedded/Networked Systems Modeling Abstractions

What’s Exciting About this Course? Familiarize with design flows used in industry for designing, implementing and verifying embedded systems, and learn skills necessary to specify requirements and perform platform-based design, analysis and modeling of embedded and networked systems.

Course Description. Students will become cognizant of the role of embedded controllers and devices in the system design process, as they relate to event-driven and data-driven systems, and supervisory control of hybrid (continuous and discrete-time) systems. This will include exposure to platform-based design principles with an emphasis on requirements capture and refinement to platform architecture mapping, analysis and verification. Students will learn the technical aspects of modeling principles relevant to embedded systems – specifically modeling system architecture, system functions, computation, software, real-time systems, and distributed systems. Use of software engineering tools (Rhapsody, Simulink, Stateflow and Simulink/MATLAB coder) in the embedded system design flows is emphasized.

Course Outcomes
- Learn what embedded systems are, what is desired and what can typically go wrong in embedded system design and implementation.
- Understand how to formulate and model embedded system requirements.
- Learn how to analyze and map requirements into embedded system architectures.
- Learn how to model system architectures, including heterogeneous systems, using a system modeling language, such as SysML for architecture analysis and design.
- Understand fundamental principles of finite state machines and their use in modeling embedded systems for time-critical, event-driven and data-centric systems.
- Learn the principles of modeling computation and functional units.
- Learn the principles of object and software modeling (using UML) and automatic code generation.
- Learn the basic concepts of real-time operating systems and real-time task models.
- Learn basic concepts of distributed systems modeling.


Course Objectives and Links to Overall Program Goals
Students can model and integrate system elements into more reliable networked cyber-physical systems. With the demand for increasing levels of complexity in systems, this course prepares engineers to design embedded systems that fulfill stakeholder needs by conforming more closely to system specifications.
Graduate Courses in Systems Engineering

SE 5302 Formal Methods

What’s Exciting About this Course? Learning to apply a set of Formal Methods techniques that leads to more reliable design of cyber-physical systems. Engineers can design complex systems that result in fewer deviations from the intended and expected behavior of the system.

Course Description. This course is designed to provide students with an introduction to formal methods as a framework for the specification, design, and verification of software-intensive embedded systems. Topics include automata theory, model checking, theorem proving, and system specification. Examples are driven by cyber-physical systems. The course is addressed to students in engineering who have had at least a year of software or embedded systems design experience.

Course Outcomes

- Gain familiarity with current system design flows in industry used for embedded system design, implementation and verification.
- Learn what formal methods are and how they are used in embedded systems design.
- Learn how to translate informal requirements to formal specifications.
- Learn languages for formal specifications and the applicability and appropriateness of various language choices for expressivity and efficiency.
- Learn how formal specifications and formal methods can be used in verification.
- Learn what model checking is and how it can be used in embedded systems verification.
- Learn the theory behind SAT solvers, SMT solvers, and bounded model checking.
- Learn how model checking can be used for real timed, continuous, and hybrid systems.
- Learn about program analysis – both static and dynamic.
- Learn about theorem proving and its use in embedded systems verification.
- The course is intended to serve as a key component to achieve standard work proficiency levels L2-L3 in embedded system design.


Course Objectives and Links to Overall Program Goals

Students can design, develop, and integrate system elements into more reliable cyberphysical systems. With the demand for increasing levels of complexity in systems, this course prepares engineers to design systems that fulfill stakeholder needs by conforming more closely to system specifications.
Graduate Courses in Systems Engineering

SE 5303 Design Flows for Embedded/Networked Systems

What’s Exciting About this Course? Applying the knowledge of systems engineering principles, processes, and methods to design embedded and networked systems. Understanding the constraints, requirements, architectures of hardware and software in cyber-physical systems.

Course Description. This course is designed to provide students with a thorough understanding of the cost, power, and performance constraints associated with the design of software and hardware in embedded/network systems. The student will develop skills in understanding requirements for embedded software systems, hardware architecture, and communication protocols in the design of embedded systems. Special emphasis will be placed on distributed embedded systems and real-time systems. The course will cover all the three main aspects of embedded systems namely, hardware, software, and network communication. Examples are driven by cyber-physical systems.

Course Outcomes

- Develop several hardware, software, and network architectures for a given embedded system.
- Evaluate the cost, power, and performance tradeoffs associated with each architecture.

Topics: Foundations of microarchitectures, x86 assembly language, cost and power constraints, FPGAs and ASICs, programmable logic controllers, foundations of real-time operating systems, worst case execution time (WCET), ISO stack for networking, network protocols like TCP/IP, UDP, ATM, protocols for embedded systems like ZigBee, ZWave, CAN, TTP, distributed computing protocols like Chord and Pastry.

Course Objectives and Links to Overall Program Goals

Students can design, develop, and integrate embedded and networked systems into complex cyberphysical systems. With the emergence of the Internet of Things, this course prepares engineers to design systems that satisfy stakeholder needs, while taking into account the complexity of new interfaces and interactions.