Course Syllabus

ECSE 4961/6961: *Modeling &Simulation for Cyber-Physical Systems*

Credit hours: 3

Semester/ year: Fall 2018
Meeting days: Tuesdays, and Fridays, 12:30 -1:50 PM.
Room location: JONSSN 4304
Webpage: LMS/Blackboard through this link.

Prerequisites or other requirements:

- ENGR 2090, MATH 4800, or equivalent; or permission of instructor.
- Corequisite (for 4961 students): MATH 4800, CSCI 4800, or equivalent; or permission of instructor.

Instructor: Dr. Luigi Vanfretti, Professor, Electrical, Computer, and Systems Engineering
Office location: JEC 6022
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Email address: luigi.vanfretti@gmail.com (please don't use my @rpi.edu address).

Course description

This course develops a solid basis for students to model and simulate cyber-physical systems using computer-based object-oriented equation-based modeling languages and tools with the goal of building models with high reusability. The course covers both theoretical and practical issues related to numerical simulation methods for CPS, including continuous time, discontinuous/discrete and timed clocked systems. Aspects of code-generation and real-time simulation for embedded systems are introduced. These foundations allow for the modeling and simulation of embedded systems which will be carried out "virtually" (by simulation) and physically using the Arduino and Raspberry Pi.

Course goals/objectives

Cyber-physical systems (CPS) are engineered systems that are built from, and depend upon, the seamless integration of computation and physical components. Advances in CPS will enable capability, adaptability, scalability, resiliency, safety, security, and usability that will expand the horizons of these critical systems. CPS technologies are transforming the way people interact with engineered systems, just as the Internet has transformed the way people interact with information. New, smart CPS drive innovation and competition in a range of application domains including aeronautics, building design, energy, electrical power grids, healthcare, manufacturing, and transportation, to name a few.
In this course students will develop and master a toolset of theory, methods, computer languages and software tools for modeling and simulating cyber-physical systems. Utilizing these skills, the students will be able to architect, model, design, simulate and analyze dynamic characteristics of cyber-physical systems that are critical for society and have the possibility to transform the way humans interact with engineered systems.

Student Learning Outcomes

1. ***Comprehend*** the fundamental principles of modeling and simulation of continuous, discrete, hybrid and timed-clocked systems that lead to the formulation of cyber-physical system models.
2. ***Comprehend*** and ***apply*** computer-and-equation based object-oriented languages for modeling of cyber-physical systems using the Modelica language.
3. ***Comprehend*** and ***explain*** methods used for symbolic transformation of computer models, efficiency issues in numerical solutions and effect of nonlinearities, higher-and-varying index problems, initialization methods, event handling, and other numerical issues related to mathematical solvers used for simulation and co-simulation.
4. ***Construct*** simulation models for cyber-physical systems using the Modelica language in Modelica Environments such as Dymola and OpenModelica.
5. ***Comprehend*** and ***explain*** the concept of real-time simulation, and hardware-in-the-loop simulation.
6. ***Comprehend*** concepts of embedded systems and ***apply*** solutions for real-time simulation.

Additional Learning Outcome for 65114 students

- ***A.*** ***Apply*** learning outcomes 1-4 to a problem specific to your own research or one of the following preferential projects in power engineering M&S:
  - M&S of power system components for positive sequence simulation in the OpenIPSL library (see list of potential models herein: https://github.com/OpenIPSL/OpenIPSL/projects)
  - Mixed positive sequence and three-phase models for power electronic-based components (e.g. VSC-HVDC, FACTS, Battery Energy Storage, etc.)
  - Power electronic systems for traction, e.g. automotive applications, aerospace, etc.
- ***B.*** ***Or, Apply*** learning outcomes 1-4 to a problem specific to your own research or one of the following preferential projects in multi-domain simulation:
  - Multi-domain M&S of power systems and fuel cell energy sources using the **Fuel Cell library.**
  - Multi-domain M&S of power systems and hydro-power systems using the **HydroPower Library.**
  - Multi-domain M&S of power systems and Rankine Cycle steam turbines using the **ThermalPower Library.**
- ***C.*** ***Or, Apply*** learning outcomes 5-6 to a problem specific to your own research or one of the following preferential projects in cyber-physical systems simulation:
  - **Interface simulation outputs from the OpenIPSL** pseudo-PMU model to TCP using the Modelica Device library.
  - **Control design, coding and simulation for the 6-DOF arm robot** using the Modelica Arduino library.
  - **Model PMUs using timed clocked** sensors with different loop rates using the the Modelica Synchronous library.
  - **Develop a hardware-in-the-loop simulator** using the Rasphberry Pi and an Arduino.

Course Contents / Topics

1. Introduction to M&S for CPS
2. Fundamentals Numerical Algorithms: Numerical Integration for Differential-Algebraic Equations
3. Developing Equation-Based Object-Oriented System Models using Modelica and the MSL
4. Understanding Numerical Problems and Debugging Models
5. Building Models and Simulations for Re-use
6. Hybrid Modelling: Discontinuous, Sample-Data Systems, Discrete Event Simulation and Timed Clocks
7. CPS Modeling and Simulation: Embedded Systems, Model Exchange and Real-Time Simulation
8. System of Systems Engineering: Requirements and Specifications with integrated behaviour modelling

Course textbooks (required/mandatory)

- Francois E. Cellier and Ernesto Kofman, "Continuous System Simulation," Springer-Verlag New York, Inc. Secaucus, NJ, USA, 2006. ISBN:0387261028
- P. Fritzson, *Principles of Object-Oriented Modeling and Simulation with Modelica 3.3: A Cyber-Physical Approach.* Wiley-IEEE Press, 2014. ISBN: 978-1-118-85912-4.
- (Free-of-cost) Michael M. Tiller, *Modelica by Example*. E-book. On-line: http://book.xogeny.com
- Dymola User Manuals (Digital version is available with the software under ./Help/Documentation/)

Required Embedded Platform

- Arduino Uno

It is possible to find many options online, the following two are just suggestions:

- Official Arduino Starter Kit: https://store.arduino.cc/usa/arduino-starter-kit

Other Suggested Books and References:

- P. Fritzson, *Introduction to Modeling and Simulation of Technical and Physical Systems with Modelica.* Wiley-IEEE Press, 2011. ISBN: 978-1-118-01068-6.
- Francois E. Cellier, Continuous System Modeling. Springer, 1991.

Computing Tools

- Dymola – licenses to be provided by RPI.
- OpenModelica – open source software.
- Python, MATLAB/Simulink (campus license).

Grading Criteria

- *Quantitative assessment:*
    - 16 Homework/Workshops: 4 points each (except 1 workshop @5 points), 65%
    - 1 Lab: 10 points, 10%
    - 1 Final Project: 25%.
    - Total: 100 points
- *Letter grading criteria:* following individual achievements of learning outcomes, the criteria is:
    - A/A- high competency achieving the learning outcomes;
    - B+/B/B- good competency;
    - C+/C/C- marginal competency.
- Final Grade: The result from your quantitative assessment will be used as a **guideline**, in determining your final grade, using the table below. The letter grading criteria will be applied considering your performance, in particular, in the Final project. Observe that the "Additional Learning Outcomes" for students 65114 needs to be met through the project.

Quantitative Assessment Guideline Table

Letter Grade	Percent Grade	Letter Grade	Percent Grade
A	93 – 100	C+	77 – 79
A-	90 – 92	C	73 – 76
B+	87 – 89	C-	70 – 72
B	83 – 86	D+	67 – 69
B-	80 – 82	D	65 – 66
		E/F	Below 65

Homework/Workshop and Lab Assignments Policy

- All homework/lab assignments and projects will be graded by the instructor or TA.
- Credits are given for partially completed assignments.
- Homework submission via LMS/Blackboard, write-up, computer-based models and code used to solve the problems must be provided in a .zip file.
  - Be organized! Submissions lacking clear organization will be deducted 10% of the grade.
  - For the project and all assignments, a zip file should be organized and contain the following:
    - Naming convention: 2018_CPS_YourFirstandLastName_HomeworkNumberXY.zip
    - Folder organization:
      - ./report.pdf — Contains your report in either .pdf AND .docx files
      - ./presentation.pdf — Contains your presentation when applicable (e.g. lab and project) in .pdf AND .pptx format
      - ./experiments/ — contains the simulation result files (.mat) used for each of your plots in the report.
      - ./sourcecode/ — Your solution files in .mo and Modelica packages
      - ./other/ — Other documents, information you wish to include
- Late homework submission requires the instructor's permission and valid justification, NO late homework are accepted without prior permission.

Attendance policy
All students are expected to attend classes unless previously excused.

Other Policies

- **Extra credit policy:** Challenging yourself in this course and showing your own initiative in the solution of the homework/lab problems will be highly valued, and rewarded following the policy in the sequel:
  - Extra credits for exceptional and creative work in the approach to solve problems using computer-based modeling languages, and computer tools; at the instructors' discretion.
  - The instructor is willing to write you a good recommendation letter based on your individual work. (I do not provide recommendation letters to students that do not show high level of individual achievement).

- **Mobile/Electronic Devices:**
  - All mobile devices (cell/smart phones, etc.) **must be stored securely away during lecture and are not be used unless specifically directed otherwise by the instructor.**
  - Use of (or ANY interaction with) a mobile device during the without explicit permission of the instructor will be interpreted as the illicit transfer of exam data, will be considered an act of cheating and will be treated as such.
  - When working with computer problems in class, **messaging/email or similar applications should not be active in your computer**, only those used in class are allowed.

Academic integrity
Student-teacher relationships are built on trust. For example, students must trust that teachers have made appropriate decisions about the structure and content of the courses they teach, and teachers must trust that the assignments that students turn in are their own. Acts that violate this trust undermine the educational process. The Rensselaer Handbook of Student Rights and Responsibilities and The Graduate Student Supplement define various forms of Academic Dishonesty and you should make yourself familiar with these. In this class, all assignments that are turned in for a grade must

represent the student's own work. In cases where help was received, or teamwork was allowed, a notation on the assignment should indicate your collaboration.
Submission of any assignment that is in violation of this policy may result in a penalty of: A grade of zero will be given when the first violation is detected. If there is a subsequent infraction the student will receive a grade of F for the course.

Violations of academic integrity may also be reported to the appropriate Dean (Dean of Students for undergraduate students or the Dean of Graduate Education for graduate students, respectively).

If you have any question concerning this policy before submitting an assignment, please ask for clarification.