SE-5103: Design Flows for Robust Design

Course Coordinator: **A. Dutta**

Lecturers: **A. Dutta**

Course Objectives:

This course is designed to provide students with the platform-based design flows for robust design of systems. The student will develop skills in requirement analysis of systems, architectural selection, model-based system design, robustness assessment and improvement, verification and validation. Special emphasis will be placed on system development spanning sizing & performance, dynamics & controls and optimization under uncertainty. The course is addressed to students in engineering who are pursuing the System Modeling and Robust Design track.

Anticipated Student Outcomes

By the end of SE-5103, students will have achieved the following objectives:

1) Gain familiarity with current system design flows in industry.
2) Understand robust design in the context of V-design.
3) Formulate measures of performance.
4) Identify control and noise factors.
5) Model and identify dynamical systems.
6) Estimate the capability and improve it by Taguchi methods.
7) Formulate and perform multi objective robust optimization.
8) Implement robust optimal control system.
9) Get a sense of tolerances, reliability and failure rates.
10) Understand the context of robust design in the end-to-end process of product realization.

Pre-requisites

SE 5101, SE 5102

Course Outline

Lecture 1: Introduction and UTC Product Development Processes

Topics:

- Current UTC product development process.

- The V-design development process, Platform-based design principles.
- Introduction to modeling and control.
- Introduction to robust design: variables, experiments, quality, Taguchi methods.

Assignment:

Short report summarizing 5102 project.

Lecture 2: System Requirements, Architecture and Modeling

Topics:

- Requirements capture and sizing analysis.
- Physics based modeling and abstractions.
- State space and transfer function representations.
- System Identification and Matlab toolbox.

Assignment:

Model and identify a given electromechanical system.

Lecture 3: Context of Robust Design

Topics:

- Robust conceptual design.
- Case studies: robotics and prosthetics.
- Probability measures.
- Quality loss function.

Assignment:

Review a paper on robust conceptual design.

Lecture 4: Robust Design in Discrete variables

Topics:

- Introduce the concept of matrix experiments.
- Define the balancing property and orthogonality.
- Explain how to analyze data from matrix experiments.
- Practice conducting a matrix experiment using Minitab.

Assignment:

Replicate the robust design example using Minitab.

Lecture 5: Analysis of Variance

Topics:

- Introduce hypothesis testing.
- Introduce analysis of variance as practiced in robust design.
- Compare to analysis of means.
- Response surface methods.

Assignment:

Identify requirements, variables for robust design of vibration absorber.

Lecture 6: Robust Design in Continuous Variables

Topics:

- Robust optimization formulation.
- Constraint tightening and axiomatic design.
- Case study: continuously stirred tank reactor
- Conceptual design of tuned mass spring damper.

Assignment:

Perform a sizing analysis on the range of parameters of the vibration absorber.

Lecture 7: Robust Design for Dynamical Systems

Topics:

- Design of dynamical systems.
- Time domain: sensitivity and direct integration method.
- Harmonics: minimization of maximum method.
- Worked out examples of robust optimization techniques.

Assignment:

Perform Taguchi DoE, ANOM, ANOVA for the vibration absorber.

Mid-term Exam: Vibration Absorber Design (I)

Topics:

- Problem statement, platform based design.
- Robust conceptual design, architecture and sizing.
- Taguchi DoE, ANOM, ANOVA.
- Robust design formulation.

Assignment:

15 slides and 15 minutes of commentary on above.

Lecture 8: Robust and Stochastic Optimal Control

Topics:

- Constrained optimization with Matlab.
- Optimization based controller design.
- Model Predictive Control: linear, explicit, decentralized.
- Stochastic MPC: scenario tree approach.

Assignment:

Design a vibration control system.

Lecture 9: Multi-objective Robust Design

Topics:

- Robust MPC of HVAC system.
- Multidisciplinary system design optimization.
- Multi objective optimization.
- Compare and contrast over examples.

Assignment:

Formulate robust optimization problem for the vibration absorber analytically.

Lecture 10: Reliability & Failure

Topics:

- Reliability: mean time to failure.
- Empirical estimate of failure rate.
- The characteristic failure curve.
- Mixed Weibull distribution.

Assignment:

Prepare for the mid-term presentations (see below).

Lecture 11: Machine Learning & Tolerance in Design

Topics:

- Machine learning classifiers: feature vectors, norms.
- Mahalanobis Taguchi system.
- Tolerance design: worst case method.
- Root sum of square and Taguchi method.

Assignment:

Solve the multi objective robust optimization of vibration absorber.

Lecture 12: Capability Analysis & Summary

Topics:

- Capability formalism and evaluation.
- Testing the design: worst case approach.
- Embedded implementation: code generation and verification.
- Course summary: system flows for robust design.

Assignment:

Prepare for the end term (see below).

Final Exam: Vibration Absorber Design (II)

Topics:

- On robust design of vibration absorber.
- Minimize the displacements of system over a large range of frequencies.
- Despite uncertainties in mass and stiffness of main system.
- Verify the capability of the design with respect to requirements.

Assignment:

Research paper: abstract, introduction, robust design methodology, results, conclusions, references.

USEFUL READING

Primary Course Textbook

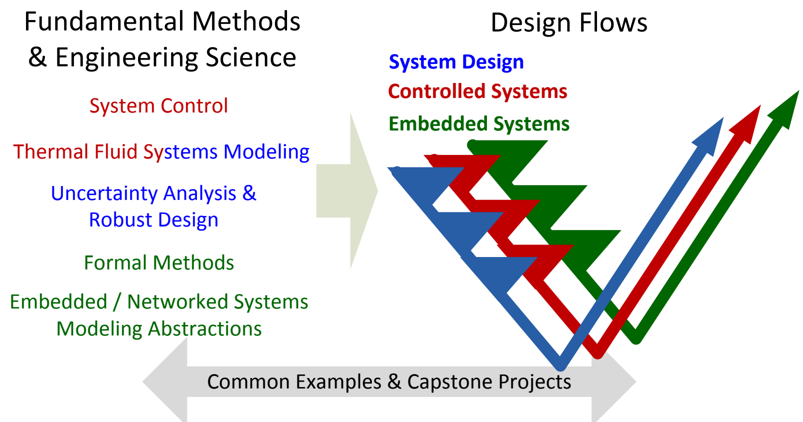
- *Park, Gyung-Jin. Analytic Methods for Design Practice, Springer 2007.*

Other References

- Dutta, A. et al. Model-based and model-free learning strategies for wet clutch control. Mechatronics, 24(8) pp. 1008-1020, 2014.

Helpful links:

- Virtual Computer Lab at UConn: http://skybox.uconn.edu/
- Course Material: https://lms.uconn.edu
- Institute for Advanced Systems Engineering: http://www.utc-iase.uconn.edu/



Coursework Targeting Student Outcomes

During the semester, students will be challenged in areas that are designed to help them to successfully realize proficiency in the student outcomes: Participation, Homework, Oral Presentations, and Project Report. The final course grade will be based on the following:

Grading

- Homework assignments, 40%
    - We expect approximately one assignment per week over the duration of the course.
- Mid-term exam, 30%
    - Implementation of robust design techniques on a simulated system.
- Final exam, 30%
    - A scientific report on the above project with background, analysis and conclusions.

Homework

Homework assignments will be posted in class, by email or on HuskyCT. Homework assignment due dates will be given with the assignment. No late homework will be accepted, as the homework will often be discussed in class. Each problem will be graded on a scale of 0-100.

Project, Presentations and Project Report

A project is to be developed by each student, which is expected to evolve during the entirety of the track. The portion of the project that is to be executed in this course refers mainly to platform-based robust design. The final deliverable (paper presentation) should identify the elements introduced in the course in a quantifiable manner and suggest a strategy for solution.

Software

This course will make extensive use of the following software tools:

- Matlab.
- Simulink.

Other Policies

Student Conduct:

http://www.dosa.uconn.edu/student_code.html. Students are responsible for adherence to the University of Connecticut student code of conduct. Perhaps the most important policy to pay attention to is the section on Student Academic Misconduct. "Academic misconduct is dishonest or unethical academic behavior that includes, but is not limited, to misrepresenting mastery in an academic area (e.g., cheating), intentionally or knowingly failing to properly credit information, research or ideas to their rightful originators or representing such information, research or ideas as your own (e.g., plagiarism)." Examples of academic misconduct in this class include, but are not limited to: copying solutions from the solutions manual, using solutions from students who have taken this course in previous years, copying your friends' homework, looking at another student's paper during an exam, lying to the professor or TA and incorrectly filling out the student workbook.

Attendance:

Attendance will not be taken; however, it is practically impossible to follow the class if classes are missed.

Absences:

Make-up of missed exams requires permission from the Dean of Students, see "Academic Regulations." Midterm-exams are treated the same as Final Examinations. Students involved in official University activities that conflict with class time must inform the instructor in writing prior to the anticipated absence and take the initiative to make up missed work in a timely fashion. In addition, students who will miss class for a religious observance must "inform their instructor in writing within the first three weeks of the semester, and prior to the anticipated absence, and should take the initiative to work out with the instructor a schedule for making up missed work."

Course Schedule*

Date	Lecture	References	Lecturers
09/08/2016	Lecture 1: Introduction and UTC Product Development Process	Delivered lecture	A. Dutta
09/15/2016	Lecture 2: Systems Requirements, Architecture and Modeling	Delivered lecture	A. Dutta
09/22/2016	*Lecture 3: Context of Robust Design*	Delivered lecture	A. Dutta
09/29/2016	Lecture 4: Robust Design in Discrete Variables	Delivered lecture	A. Dutta
10/06/2016	Lecture 5: Analysis of Variance	Delivered lecture	A. Dutta
10/13/2016	Lecture 6: Robust Design in Continuous Variables	Delivered lecture	A. Dutta
10/20/2016	Lecture 7: Robust Design for Dynamical Systems	Delivered lecture	A. Dutta
10/27/2016	Mid-term Exam: Vibration Absorber Design (I)	Presentation	Students!
11/03/2016	Lecture 8: Robust & Stochastic Optimal Control	Delivered lecture	A. Dutta
11/10/2016	Lecture 9: Multi-objective Robust Design	Delivered lecture	A. Dutta
11/17/2016	Lecture 10: Reliability & Failure	Delivered lecture	A. Dutta
11/24/2016	Lecture 11: Machine Learning & Tolerance in Design	Delivered lecture	A. Dutta
12/01/2016	Lecture 12: Capability Analysis & Summary	Delivered lecture	A. Dutta
12/08/2016	Final Exam: Vibration Absorber Design (II)	Paper submission	Students!