IE 513 Optimal System Design
(Multidisciplinary Design Optimization Approach)
Syllabus and General Course Information

Course Description

This course is designed to address the fundamental theories for engineering system (product) design and development in multidisciplinary environment. Product design and development process is viewed as a combination of decomposed activities that can be modeled as an enterprise product planning model and an engineering product development model, respectively. Product planning involves demand modeling, customers' preference analysis, and profit modeling under uncertainty. Product development involves analytical problem formulation to achieve the performance targets assigned at the enterprise level and multidisciplinary design optimization (MDO) can be utilized to model this problem. This course is composed of two major parts: analytical product planning and analytical product development based on the MDO theory. The treatment of topics is mathematically rigorous but with an emphasis on practical use. Students are required to work on a (individual or group) semester project utilizing available design optimization software, e.g. Matlab.

Course Objective

After completing the course, the student will be able to:

- Classify and explain modern optimization theory and design methodologies,
- Construct a realistic analytical model (from his/her research) based on modeling theory,
- Solve the analytical or mathematical model by applying analytical or computational optimization techniques,
- Interpret and describe the meaning of the optimal solution,
- Complete a comprehensive technical report on the semester project.

Lectures

Time: MW 11:00 AM – 12:40 PM
Location: 225A Talbot Lab

Instructor

Name: Prof. Harrison M. Kim
Office: Transportation Bldg Rm. 315
Phone: 217-265-9437
Office Hours: By email appointment
Email: hmkim@illinois.edu
Online: compass.illinois.edu (Course materials will be posted.)

Textbook

1. Papalambros, P.Y. and Wilde, D., *Principles of Optimal Design* (2^{nd} Ed.), Cambridge University Press, New York, 2000.
2. Course material (will be distributed throughout the semester.)

Prerequisites

- Undergraduate level Linear Algebra (or equivalent) is required.
- Graduate standing with fair familiarity with Matlab or other programming languages such as C/C++ or Fortran.
- Undergraduate students are not allowed to take the course.
- Prior knowledge on algorithm and optimization will be helpful, but not required.

Topics

1. Optimization model fundamentals:
    a. Optimal design concept
    b. Feasibility and boundedness
    c. Visualization of design space
    d. Analytical model construction
2. Analytical product development:
    a. Interior optimality conditions and line search methods
    b. Boundary optimality conditions and constrained optima
    c. Decomposition and coordination
    d. Multidisciplinary design optimization
    e. Analytical target cascading
    f. Design under uncertainty
    g. Product family design
3. Analytical product planning:
    a. Demand and price analysis
    b. Profit modeling under uncertainty
    c. Choice model theory
    d. Setting optimal targets for product development
    e. Exploration of disjunctive target space

Semester Project

A sample project:

1) Literature survey of analytical quantitative product development methodologies
2) Selection of one of the topics from the literature survey and build a simple example case
3) Demonstration of how this method and example can be applied to product design in combination with other interdisciplinary design framework possibly from classmates'
4) Devising a web-based model form that handles user's requirements to describe analysis models and upload made-up models in the model database
5) Demonstration of case study working in the web-based environment

Schedule

<table>
<tr><th>Phase</th><th>Topics</th><th>Contact hours</th></tr>
<tr><td rowspan="2">Phase I
(2 weeks)</td><td>Design Optimization Process Overview:
• Optimization formulations and engineering design.
• Basic concepts of models.
• Preference structures and Pareto optimality.
• Boundedness of models.</td><td>4 hrs</td></tr>
<tr><td>• Parametric solutions.
• Optimality conditions.
• Numerical methods.
• Computer software introduction.
• Simple case studies.</td><td>4 hrs</td></tr>
<tr><td>Phase II
(2 weeks)</td><td>Modeling and Monotonicity Analysis:
• Constraint activity.
• Monotonicity Principles I and II.
• Well-bounded models.
• Monotonicity table.
• Model transformations.
• Regional Monotonicity.</td><td>8 hrs</td></tr>
<tr><td rowspan="2">Phase III
(3 weeks)</td><td>Differential Theory: Interior & Boundary Optima
• Local Approximations of functions.
• Necessary and sufficient conditions.
• Gradient and Newton's methods.</td><td>6 hrs</td></tr>
<tr><td>• Line search.
• Generalized reduced gradient method.
• Karush-Kuhn-Tucker conditions.</td><td>6 hrs</td></tr>
<tr><td rowspan="4">Phase IV
(7 weeks)</td><td>Multidisciplinary System Design Optimization:
• Analytical Target Cascading
• Analytical Target Setting
• Collaborative Optimization</td><td>7 hrs</td></tr>
<tr><td>• Quasi-Separable problems
• Multilevel Optimization
• MDO by Lagrangian relaxation</td><td>7 hrs</td></tr>
<tr><td>• Handling Linking variables
• Alternating Directions Method
• Weight update scheme
• ATC for single product design optimization</td><td>7 hrs</td></tr>
<tr><td>• ATC for multiple product family
• ATC for reconfigurable system
• Design Optimization Practice and Advanced Topics.</td><td>7 hrs</td></tr>
</table>

The textbook will be used as follows.

Chapters 1, 2, 4, 5, 7 and 8 will be covered quite thoroughly, although some sections will be left as optional study.
Chapters 3 and 6 can be used for background studying but the material will be covered in a more condensed way through lectures, supplementary notes, and published articles.

Exams

There will be two exams.

Grading

Projects: 40% (Proposal due Sept/19/2016,
Interim Report due Oct/31/2016,
Interim Presentation (Nov/7/2016, 5-min elevator pitch)
Final Report due Dec/5/2016,
Final Presentation file due Dec/12/2016, 10 AM, via compass)
Report 35%, Presentation 5%)
Exam 1: 20% (Date TBA)
Exam 2: 20% (Date TBA)
Homework: 20%
Total 100%

Notes

- Students with disabilities are encouraged to contact Prof. Kim. Additional academic resources will be available through Disability Resources and Educational Services.