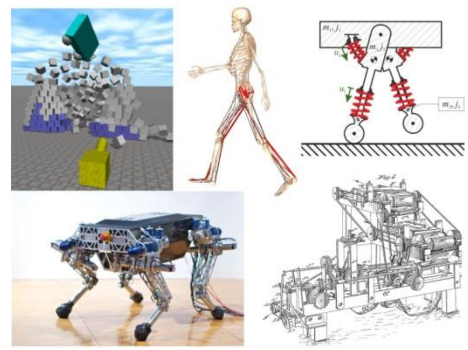
ME 543 Analytical and Computational Dynamics I Winter 2015

Course Description:



ME 543 deals with the dynamics of multibody systems. That is, of systems of rigid bodies that are connected through joints and other constraints. A large number of mechanical systems can be modeled this way and multibody dynamics are thus found virtually everywhere: In trucks and cars they govern the behavior of steering, suspension, or powertrains; in robotics, they are used to accurately plan and control highly dynamic motions; and in movies and computer games, they create the realistic behavior of virtual worlds. In a biomechanical analysis, even our own human body can be regarded as a multibody system.
ME 543 provides a solid theoretical background to describe such systems in a precise mathematical way. It develops tools and methods to create the governing differential equations analytically and it looks at algorithms that do so in a numerically efficient way. The course also covers advanced computational techniques and more sophisticated problems, including unilateral contacts and collisions. Over the course of the semester you will write your own dynamics engine in object-oriented MATLAB. You will be able to use all this knowledge to build better controllers for robots, to debug your solutions more intuitively, and to understand what is going on when you use off-the-shelf software for design or analysis.

Content:

From course catalogue: Modern analytical rigid body dynamics equation formulation and computational solution techniques applied to mechanical multibody systems. Kinematics of motion generalized coordinates and speeds, *analytical and computational determination of inertia properties*, generalized forces, *Gibb's function, Routhian,* Kanes's equations, *Hamilton's principle,* Lagrange's equations holonomic and nonholonomic constraints, constraint processing, computational simulation.
Deviations from this: Topics in grey are likely not covered, but instead the following: Recursive algorithms, Collisions, Screw theory, Applications in control, Matrix based methods.
Relation to other courses: There is some overlap with ME 540 (kinematics, motion of a single body, holonomic constraints) and ME 567 (kinematic chains, joint models, Jacobians).

Prerequisites*:*

An intermediate course in dynamics and vibrations that covered Newton/Euler and Lagrangian formulations for three-dimensional motion of particles and rigid bodies (for example, ME440), a good grasp of linear algebra, and some prior experience with MATLAB.

Instructor:

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Lectures:
MWF 2:30 – 3:30, 104 EWRE

Office Hours:
MW 3:30 – 5:00; in my office; and by appointment

Course Website:
Materials and announcements will be posted on ctools. https://ctools.umich.edu/

Reading Material:
There is no official course book, but I will upload parts of the following books and other material onto the course website:

- Amirouche, F.: Computational Methods in Multibody Dynamics
- Pfeiffer, F. & Glocker, C.: Multibody Dynamics with Unilateral Contacts
- Shabana, A.: Dynamics of Multibody Systems
- Wittenburg, J.: Dynamics of Systems of Rigid Bodies

Additional Reading:

- Huston, R.: Multibody Dynamics
- Featherstone, R.: Rigid Body Dynamics Algorithms
- Murray, R., Li, Z., and Sastry S.: A Mathematical Introduction to Robotic Manipulation
- Moon, F.: Applied Dynamics with Applications to Multibody and Mechatronic Systems

Homework:
Homework will be assigned regularly (about 9 sets) and posted on ctools. It is always due at the start of class. Due dates will be posted with each set of homework. You get a total of **three** late days which each grant you a 24h extension. You are encouraged to **discuss and work on homework in teams** but the final documents and programs must represent your own understanding of the material.

Please hand in your homework electronically as a **single PDF file called 'HWXY_uniquename.pdf'** (e.g., 'HW01_cdremy.pdf). This file can contain scans of handwritten notes and must include all required figures and supporting material. Always cite your sources clearly. On the first page, **state explicitly with whom you collaborated**. Matlab code should be submitted in separate files. Only submit code files that you created or changed. **Do not ZIP or otherwise archive your files**.

Project:
A small project will test your implementation skills at the end of the semester. It is similar in format to the homework sets but must be completed by yourself. Please see http://ram-lab.engin.umich.edu/me543_-_analytical_and_computational_dynamics.html for a video of the final project.

Exams

Midterm:	Wednesday, February 25 (TBC)	Time/Room: TBD
Final:	Thursday, April 30	10:30 am - 12:30 pm, Room: TBD

Grading Policy
Homework: 30%
Project: 20%
Midterm Exam: 20%
Final Exam: 30%

The Engineering Honor Code:
No member of the community shall take unfair advantage of any other member of the community. http://www.engin.umich.edu/students/honorcode/

Course Outline
(The bullet points below do not correspond to individual lectures and are not in the final order. Please refer to the course schedule on ctools for up-to-date information and reading assignments)

- *Introduction:* Applications of multi-body dynamics in robotics, biomechanics, and control; problems of inverse kinematics; inverse dynamics; forward dynamics
- *Tools:* MATLAB/Simulink and the SimMechanics Toolbox
- *Repetition:* Scalars, vectors, tensors, and coordinate systems
- Moving coordinate systems; differentiation in moving coordinate systems; kinematics of a rigid body
- *Tools:* The MATLAB Symbolic Math Toolbox
- *Tools:* Object Oriented Programming in Matlab
- *Repetition:* Fundamental laws of dynamics, applications to particles
- *Repetition:* Dynamics of a single body
- Constraints and minimal/generalized coordinates, speeds, and forces
- Nonholonomic and rehonomic constraints
- Jacobians; duality of forces and velocities; motion subspaces; constraint spaces
- Recursive Methods
- *Tools:* Advanced object oriented concepts: Inheritance, polymorphism
- Modeling multi-body systems; connectivity; trees and loops
- Principles of d'Alambert, Jourdain, Gauss
- Projected Newton – Euler –Equations
- Ithe canonical form of the equations of motion for a multi-body system
  $\mathbf{M}(\mathbf{q},t)\ddot{\mathbf{q}} = \mathbf{g}(\mathbf{q},t) + \mathbf{f}(\mathbf{q},\dot{\mathbf{q}},t) + \mathbf{J}(\mathbf{q},t)\boldsymbol{\lambda} + \mathbf{S}\boldsymbol{\tau}$
- Unilateral constraints; soft and hard contact models
- Collisions
- *Application:* Control examples using virtual constraints and virtual models
- Kinematics: Algorithms and implementations
- Inverse dynamics: Algorithms and implementations
- Forward dynamics: Algorithms and implementations