Systems Design 652

Dynamics of Multibody Systems

Instructor:

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Lectures:

Tuesdays@1:30-2:50 p.m.
Thursdays@1:30-2:50 p.m.
(E5-6127)

Web Pages:

http://real.uwaterloo.ca/~mcphee/sd652/sd652.html
and https://learn.uwaterloo.ca/d2l/home/448295

Evaluation:

Assignments = 60 %
Project = 40 %

Course Description:

Essentially, this course shows how an engineer can efficiently model and simulate the motion of complex multibody systems such as robots, humans, vehicles, and mechanisms. Systematic methods, including conventional approaches and linear graph theory, are used to generate kinematic and dynamic models for 2-d and 3-d systems of bodies connected by joints, springs, dampers, and actuators. The extension of these methods to biomechanics, vehicles, mechatronic systems and flexible robot manipulators is also presented. Numerical solutions for the dynamic equations provide a simulation of the system response, which will be obtained using commercial software packages (ADAMS, Matlab, MapleSim). The course concepts are demonstrated through applications to the kinematic and dynamic analysis of mechanisms, biomechatronic systems, serial and parallel robot manipulators, autonomous and hybrid vehicles, and other industrial multibody systems. Whenever possible, physical prototypes are brought to the lectures.

Course Contents:

I. Review of Kinematics and Dynamics: A two-week review of the material in SD 182/ME 212 and SD 553/ME 524, including degrees of freedom, particle and rigid body kinematics, moving reference frames, Newton-Euler equations, principle of virtual work, and Lagrange's equations.

II. Conventional Multibody Dynamics: The student is shown how commercial packages like ADAMS and Working Model can automatically generate and solve for the response of complex multibody systems. Shortcomings of these methods are discussed, as well as issues related to kinematics, forward and inverse dynamics, and singularities. We start with planar systems, to understand the basic theories, before moving on to three-dimensional multibody systems. Examples in Matlab will also be provided.

III. Advanced Modelling of Multibody Systems: Vectorial methods are used to create the constitutive equations for rigid bodies, revolute and prismatic joints, translational and rotational spring/damper/actuator components, applied forces and torques, and kinematic drivers. These component models are then combined to form multibody systems, the equations for which are automatically generated using linear graph theory and principles of mechanics. Numerical solution methods will be briefly reviewed, and Matlab routines will be used to solve the equations generated by the students for a variety of kinematic and dynamic applications. We will then use MapleSim, a commercial package that uses graph-theoretic algorithms, to generate symbolic equations and simulations for multibody applications.

IV. Advanced Applications: Finally, the student is introduced to some advanced topics in multibody dynamics, including:

- modelling of contact dynamics
- modelling of tires in vehicle dynamics
- modelling of biomechanical systems
- modelling of flexible bodies (e.g. elastic beams)
- incorporation of elements from other physical domains (e.g. hydraulic, electronic, pneumatic) into the system model. Robotic and biomechatronic examples will be presented.

Reference Materials

There is no published monograph that could be used as a single course textbook. Part II of the course is supported by the textbook by Haug [1]; this book, as well as a recently-updated version, is available on Learn. The text by Nikravesh [2] has much of the same material. The material on advanced modelling in Part III is covered in the set of course notes [3], which are available from the course web page.

Many advanced topics in multibody dynamics can be found in the excellent book by Garcia de Jalón and Bayo [4]. In the UW library, one can find other books on multibody dynamics [5-6], mechanism and machine theory [7-8], and advanced dynamics [9]. The latter is particularly useful for the review of kinematics and dynamics in Part I of the course. Reference [10] is a good overview of the basics of systems modelling, Yamaguchi [11] is an excellent book on multibody dynamic modelling of humans, and [12] provides a thorough coverage of applications to vehicle dynamics. Finally, there are several journals [13-15] that publish the latest research in multibody system dynamics.

1. *Computer-Aided Kinematics and Dynamics of Mechanical Systems*, Haug, Allyn and Bacon, 1989.
2. *Computer-Aided Analysis of Mechanical Systems*, Nikravesh, Prentice-Hall, 1988.
3. *Dynamics of Multibody Systems: Conventional and Graph-Theoretic Methods*, McPhee, SD 652 Course Notes, 2004.
4. *Kinematic and Dynamic Simulation of Multibody Systems*, Garcia de Jalón and Bayo, Springer-Verlag, 1994.
5. *Computational Methods in Multibody Dynamics*, Amirouche, Prentice-Hall, 1992.
6. *Dynamics of Multibody Systems*, 2nd ed., Shabana, Cambridge University Press, 1998.
7. *Mechanism Design: Analysis and Synthesis*, 4th ed., Erdman, Sandor, and Kota, Prentice-Hall, 2001.
8. *Design of Machinery*, 2nd ed., Norton, McGraw-Hill, 2001.
9. *Advanced Engineering Dynamics*, 2nd ed., Ginsberg, Cambridge University Press, 1995.
10. *Engineering Systems: Modelling, Analysis, and Design*, Chandrashekar and Savage, SD 351 Course Notes, 1997.
11. *Dynamic Modeling of Musculoskeletal Motion*, Yamaguchi, Kluwer, 2001.
12. *The Multibody Systems Approach to Vehicle Dynamics*, Blundell and Harty, SAE, 2004.
13. *Multibody System Dynamics*, Kluwer.
14. *Mechanics Based Design of Structures and Machines*, Marcel Dekker.
15. *Journal of Computational and Nonlinear Dynamics*, ASME.

Academic integrity, grievance, discipline, appeals and note for students with disabilities:

[The following statements MUST be included in all course outlines and/or websites.]

Academic integrity: In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. [Check the Office of Academic Integrity for more information.]

Grievance: A student who believes that a decision affecting some aspect of his/her university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4. When in doubt, please be certain to contact the department's administrative assistant who will provide further assistance.

Discipline: A student is expected to know what constitutes academic integrity to avoid committing an academic offence, and to take responsibility for his/her actions. [Check the Office of Academic Integrity for more information.] A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about "rules" for group work/collaboration should seek guidance from the course instructor, academic advisor, or the undergraduate associate dean. For information on categories of offences and types of penalties, students should refer to Policy 71, Student Discipline. For typical penalties, check Guidelines for the Assessment of Penalties.

Appeals: A decision made or penalty imposed under Policy 70, Student Petitions and Grievances (other than a petition) or Policy 71, Student Discipline may be appealed if there is a ground. A student who believes he/she has a ground for an appeal should refer to Policy 72, Student Appeals.

Note for students with disabilities: AccessAbility Services, located in Needles Hall, Room 1132, collaborates with all academic departments to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations to lessen the impact of your disability, please register with AccessAbility Services at the beginning of each academic term.

Turnitin.com and alternatives: Text matching software (Turnitin) will be used to screen assignments in this course. This is being done to verify that use of all material and sources in assignments is documented. In the first week of the term, details will be provided about the arrangements for the use of Turnitin and alternatives in this course.

Note: students must be given a reasonable option if they do not want to have their assignment screened by Turnitin. See Academic Integrity - Guidelines for Instructors for more information.