COURSE INFORMATION

Time: Tuesday 12:15 am - 01:45 pm
Location: H9
Credit: 4 ECTS credit points

INSTRUCTOR

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TEACHING ASSISTANTS

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RESOURCES

Web site: Available through course website. Please check regularly for announcements and updates.
Recommended: Robot modeling and control (Spong *et al.*) - An invitation to 3D machine vision (Ma *el al.*)
Reading: www.autolev.com, 2000.

PREREQUISITES

Students are expected to have a working knowledge of differential equations, linear systems, statics, kinematic and dynamics. Familiarity with programming, especially with Matlab is recommended.

PURPOSE

This course is designed to equip students with fundamental theories and computational methodologies that are used in (computer aided) analysis of multibody systems. Students will learn how to analytically formulate dynamics equations for multibody systems as well as how to utilize numerical algorithms to simulate such systems. Computational mechanics is of high value for the purposes of performance evaluation, sensitivity studies, control system design, model based monitoring and so on.

Students will be introduced to generalized coordinates and speeds, analytical and computational determination of inertia properties, generalized forces, Kanes method, Lagranges equations, holonomic and nonholonomic constraints. Computerized symbolic manipulation and time integration methods for dynamic analysis will be exercised.

Of the available techniques for formulating equations of motion for multibody systems, symbolic formulation and Kane's method will be emphasized. Being a vector based approach and making optimal use of generalized coordinates and speeds, Kanes method is preferred for its relative ease of computerization and its computational efficiency. Efficiency may be interpreted here both as producing equations efficiently (with the fewest symbolic operations) and producing efficient equations (which require the fewest numerical operations for their solution). Also, Kanes method produces equations in ordinary differential form (ODEs) even for nonholonomically constrained systems, which can be accommodated using (stabilized) standard solvers.

The emphasis in this course is not on the excessive mathematical abstraction but rather on an integrated understanding of modeling, equation derivation and numerical solution. A solid understanding of the principles of dynamics in the context of modern analytical and computational methods is aimed.

COURSE OBJECTIVES

The goal of this course is to equip each student with an integrated understanding of modeling, equation derivation and numerical solution of multibody systems. By the end of the course, each student should be able to do the following:

- Identify relevant points, bodies, and bases; choose generalized coordinates to represent a multibody system.
- Form the required position vectors and differentiate relevant vectors to form required velocities and accelerations.
- Formulate equations of motion for unconstrained systems.
- Form constraint equations and solve for independent variables, and formulate equations of motion for systems with constrains.
- Form work functions, calculate kinetic and potential energy of the system, and formulate the Lagrangian and express the equations of motion in a DAE form.
- Numerically solve for the DAEs using stabilized integration methods.
- Analyze the stability of a robotic system based on energy concepts.
- Design motion control system and analyze the closed-loop behavior.

HOMEWORKS

Homework will be assigned regularly and posted on the course website. Hardcopies will generally not be made available in class, so you will have to produce your own printout.

EXAMS

There will be one mid-term and one final exam. Since the course continually builds upon previous material, all exams will be comprehensive. In class exams are closed book, with one page of personally prepared notes.

LECTURE

Lectures will involve discussions and group activities. Extra lectures and problem solving sessions may be scheduled if necessary. Class participation and cooperation among students are highly encouraged. Student feedback will be collected throughout the semester and adaptation will be undertaken accordingly.

OTHER NOTES

Any student with a disability requiring accommodation in this course is encouraged to contact the instructor during the first two weeks of the semester.

TENTATIVE SCHEDULE AND TOPICS

WEEK	TOPICS
1 (Definitions)	Vectors, bases, frames, vector operations, simple rotations, vector functions, differentiation of vector functions
2 (Kinematics)	Angular velocities, differentiation in two reference frames, auxiliary reference frames state variables, kinematical differential equations, constraint equations and independent variables, forward and inverse kinematics
3	Robotic systems with opened- and closed-kinematical configurations
4 (Mass distribution)	Center of mass, inertia vectors, inertia scalars, inertia matrices, principle axes, principle planes, principle moment of inertia
5 (Forces)	Generalized active forces, principle of virtual work
6 (Dynamics)	Dynamical equations, auxiliary dynamical equations, numerical solution of differential equations of motion
7	Numerical simulation of systems with changing kinematic constraints
8 (Energy)	Work functions, kinetic and potential energy Lagrangian and DAEs
9 (Dynamics)	Hamiltonian mechanics and Hamiltonian dynamics, the principle of least action
10 (Control)	Trajectory planning, Qualitative behavior near equilibrium points,
11	numerical construction of phase portraits, Passivity and feedback systems
12	Lyapunov stability
13 (Visual servoing)	Image formation, matching point features, tracking lines features
14	Observability, realization, vision system design

GRADING POLICY

Your course grade is determined from the total points you receive from homeworks, midterm and final exams, and the project. Borderline grades are determined by class participation.

Homeworks and project must be submitted to my office by the end of the date due (midnight). No late problem sets are accepted (Extensions may be granted for special circumstances and only when requested in advance).

You are responsible for all information given in class verbally and/or in writing. Any information about the course on the web may be replaced by the information given in class.

Cooperative efforts at understanding the material and the assignments of the course are encouraged. However, you may only submit work that you have completed individually. For example, you may communicate verbally about methods for solving assigned problems, but sharing of written work is not permitted. Submitting any work that is not the result of a students own effort is considered cheating.

ACTIVITY	**WEIGHT [%]**
Homeworks	15
Quizzes	20
Midterm exam	25
Final exam	40

Additional Reading

- Moon, Applied Dynamics with Applications to Multibody and Mechatronic Systems, Wiley, 1998.
- Shabana, Computational Dynamics, Wiley-Interscience, 1994.
- Nikravesh, Computer-Aided Analysis of Mechanical Systems, Prentice Hall, 1987.
- Kane, Spacecraft Dynamics, Mcgraw-Hill College, 1981
- Seabra Pereira (ed.) and Ambrssio (ed.), Computational Dynamics in Multibody Systems, Springer, 2006.