ME 751
Computational Multibody Dynamics
Spring 2010

Time: 9:30 – 10:45 Tu & Th
Location: 2106ME
Instructor: Dan Negrut
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Course Page: http://sbel.wisc.edu/Courses/ME751/2010/index.htm and http://learnuw.wisc.edu
Grader: Naresh Khude (khude@wisc.edu)
Office Hours: Mo, Wd, Fr – 3-4 PM. Moreover, you can stop by anytime in the afternoon, I'd be happy to talk with you if I'm in my office.

Text: The first book will be the one that comes closest to the material covered in the class. Author provided a pdf of the entire book with permission to distribute it freely[1].

1. Computer-Aided Kinematics and Dynamics of Mechanical Systems, Volume I: Basic Methods, by Edward J. Haug, Allyn and Bacon, 1989
2. Dynamics of Multibody Systems, by Ahmed A. Shabana, 3rd ed., 2007[2]
3. Computer Methods for Ordinary Differential Equations and Differential-Algebraic Equations, by U. Ascher and L. Petzold, SIAM, 1998[2]
4. Vector Mechanics for Engineers – Dynamics, Ferdinand P. Beer, Jr., E. Russell Johnston, William E. Clausen, 8th Edition, 2007[2].
5. Solving Ordinary Differential Equations I: Nonstiff Problems, by E. Hairer, S. Norsett, G. Wanner, 1993
6. Solving Ordinary Differential Equations II: Stiff and differential-algebraic Problems (Second Revised Edition) by E. Hairer and G. Wanner, 2002
7. Numerical Methods in Multibody Dynamics, E. E. Soellner and C. Fuhrer, 2002 (out of print)
8. CUDA Programming Guide, Version 2.3, NVIDIA Corporation, July 2009[3]

Prerequisites: ME451 or equivalent, C programming, Elementary Linear Algebra and Calculus
Course Objectives: This course reviews and reinforces the student's understanding of Kinematics and Dynamics of multibody systems with immediate application to the dynamics of systems of rigid bodies. This course assumes knowledge of elementary vector algebra and the concepts of time and partial derivatives. The course ME451 or an elementary Physics course covering Newton's laws or course(s) on Statics and Dynamics will prove helpful in understanding the material covered. The course will place equal emphasis on gaining both an analytical understanding and insight/intuition on the subject. The material presented in the class will emphasize the analytical component of the subject, while the homeworks, particularly through the coding and ADAMS modeling assignments, will encourage you to see beyond equations and abstract constructs. It is also anticipated that this course will improve your MATLAB programming skills and help you learn how to model/simulate/analyze mechanical systems in ADAMS, the most widely used mechanical system simulation software package.

[1] Available at http://sbel.wisc.edu/Courses/ME751/2010/bookHaugPointers.htm
[2] Placed on reserve at Wendt Library
[3] Google this, available online and with the CUDA distribution

ME 751
Kinematics and Dynamics of Machine Systems
Course Grading

Grades will be based on your homework, a midterm examination, and a final project. All homework and exam scores will be maintained on the Learn@UW course website. This will allow you to monitor your performance and see aggregate scores for the rest of the class, which should give you a continuous idea of your performance. Should you have questions about your score, please contact the instructor. Specific score-related questions about homeworks and exam must be raised prior to the next class period after receiving the score. If homework that is turned in does not appear to be graded (missing) on the Learn@UW course website please bring that to the attention of the instructor within one week after the return of the corresponding set of graded homeworks.

Percentage participation to the final grade shall be distributed in the following manner:

Homework	=	**40%**
Midterm Exam	=	**20%**
Final Project	=	**40%**

The PowerPoint notes used in class, handwritten notes, and examples covered in class will be made available on the course web-site at http://sbel.wisc.edu/Courses/ME751/2010/index.htm.

Homework: Problems will be assigned regularly during the semester. All assigned homework will be collected at the beginning of class on the date due. No late homework will be accepted. Homework solutions should be *neat and well organized*. All necessary diagrams and calculations must be clearly shown. Homework solutions will be made available. The homework with the lowest score will be dropped when computing the final homework average.

Exams: The midterm exam will include problems as well as short-answer questions, and may include both take-home and in-class portions. In-class portions will be given during the lecture session shown on the schedule. Take-home problems, if any, will be more involved and may require the use of computational tools and/or software packages (MATLAB, ADAMS, Chrono::Engine). The best way to prepare for exams is to participate in class, learn the fundamental concepts, and redo homework and example problems.

Final Project: There will be no final exam. Instead, each student will choose a Final Project that he/she will be working on. A one hour final presentation will be made in front of the instructor and any other class student who chooses to attend the presentation. The presentation will be taped and made available to the rest of the students on Learn@UW. The one hour long presentation will be organized as follows: a 30-40 minute PPT document will be used to describe the final project and explain your contributions/innovations/achievements. The rest of the time will be dedicated to a Q&A session. Each student will choose after consultation with the instructor a one hour time slot for this presentation during the last week of class or finals' week.

The proposal for the Final Project is due on 03/04. The instructor will present an overview of all Final Project proposals submitted on 03/18. Examples of potential Final Projects are as follows:

- Investigation of animating rotation with Quaternion curves
- Practical implications of the parameterization of rotations using the exponential map
- Parallel collision detection on the GPU
- Comparison of penalty and DVI approaches for addressing frictional contact in rigid body dynamics
- Extension of the functionality of any open source dynamics engine (Chrono::Engine, IMP, etc.)
- On the use of iterative methods in multibody dynamics
- Rigid-Deformable body co-simulation for applications in biomechanics
- Methods of uncertainty quantification in multibody dynamics
- Advanced modeling in open source dynamics engine with validation in ADAMS
- Investigation of a ADAMS-MATLAB co-simulation approach for mechatronics applications
- Development of a computer game using an open source physics engine

You are encouraged to think of your interests and propose topics for the project that best fit them. You should try hard to leverage your ongoing research even though it might be slightly away from the core topics covered in the class. As long as the proposed project topic has to do with rigid body dynamics, numerical integration methods that solve the time evolution of a dynamic system, or draws on high performance computing, chances are that the final project proposal will be acceptable.

Disability requests: I must hear from anyone who has a disability that may require some modification of seating, testing or other class requirements so that appropriate arrangements may be made. Please see me after class or during my office hours.

Complaints: If you have a complaint regarding the course and if you are unsatisfied with the response of the instructor, then you should contact the Chair of the Department of Mechanical Engineering. The Chair's office is in 3065 Mechanical Engineering Building, and an appointment to see the Chair can be made by contacting the Department Office at 263-5372.

Letter Grades: Final letter grades will be based on the total score accumulated on homework and exams throughout the semester using the following scale:

Score	Grade
≥94	A
87-93	AB
80-86	B
73-79	BC
66-72	C
55-65	D
Below 55	F

ME 751[4]: Advanced Computational Multibody Dynamics

Spring 2010

Date	Topic	Details regarding learning objectives	HW
01/19	Review	Basic Matrix Algebra, Lagrange Multiplier Theorem	
01/21	Review	Calculus, Implicit Function Theorem, Newton's Method	HW 1
01/26	Kinematics Analysis (1)	Generalized coordinates. Kinematics of a rigid body in 3D space. Rotation of a rigid body in space	
01/28	Kinematics Analysis (2)	Rotation of a rigid body in space: Euler Angles, Euler Parameters, Rodriguez Angles	HW 2
02/02	Kinematics Analysis (3)	Kinematic Constraints: spherical, revolute, translational, cylindrical, etc. Overview of *ADAMS* [J. Madsen]	
02/04	Overview of ADAMS	Overview of *ADAMS* [J. Madsen, continue] *ADAMS & MATLAB* Cosimulation [M. Datar]	HW 3
02/09	Kinematics Analysis (4)	Position, Velocity, and Acceleration Analysis	
02/11	Dynamics Analysis (1)	Equations of Motion for one rigid body in Cartesian coordinates	HW 4
02/16	Dynamics Analysis (2)	Applied forces; Generalized forces	
02/18	Dynamics Analysis (3)	Equations of motion for constrained systems in Cartesian coordinates	HW 5
02/23	Dynamics Analysis (4)	Computation of Reaction Forces Overview of *Chrono::Engine* [H. Mazhar]	
02/25	Dynamics Analysis (5)	Deriving the equations of motion using Lagrangian or other non-Cartesian generalized coordinates	HW 6
03/02	Equilibrium Analysis and Inverse Dynamics	Problem setup, applications	
03/04	Numerical Integration Methods (1)	Explicit vs. Implicit Methods Stability, Convergence, Order of an Integration formula	HW 7
03/09	Numerical Integration Methods (2)	Multi-step Methods; Runge-Kutta Methods Step-size control in RK integration	
03/11	Numerical Integration Methods (3)	Methods for the numerical solution of index 3 DAEs Coordinate Partitioning Method	HW 8
03/16	Numerical Integration Methods (4)	Direct methods: BDF, Newmark, Generalized Alpha	
03/18	Numerical Integration Methods (5)	Examples, Numerical Integration Intermediate Course Evaluation Overview of Final Project Proposals	HW 9
03/23	Frictional Contact Problems in Rigid Body Dynamics	Introduction Penalty Methods	
03/25	Frictional Contact Problems in Rigid Body Dynamics	Penalty Methods	HW 10
03/30	SPRING	BREAK	NO CLASS
04/01	SPRING	BREAK	NO CLASS
04/06	Frictional Contact Problems in Rigid Body Dynamics	DVI-Based approaches LCP problems Anitescu-Tasora Approach	
04/08	Frictional Contact Problems in Rigid Body	Anitescu-Tasora Approach	HW 11

[4] Tentative schedule; changes might occur during the semester. Document will be updated to reflect these changes.

	Dynamics		
04/13	High Performance Computing (HPC) in Computational Dynamics	Quick C-programming intro Parallel Computing, Overview	
04/14	High Performance Computing (HPC) in Computational Dynamics	GPU Programming	HW 12
04/20	High Performance Computing (HPC) in Computational Dynamics	GPU Programming	
04/22	**Midterm Exam**		
04/27	Guest Lecture, Dr. Andrei Schaffer	MSC.Software	
04/29	Guest Lecture, Dr. Jonathan Cohen	NVIDIA Research	
05/04	Field Trip Leaving on 05/03, return on 05/04	John Deere (Moline, IL) National Advanced Driving Simulator (Iowa City)	
05/06	Guest Lecture, Richard Tonge	NVIDIA, PhysX	

Final Exam[5]: 05/14/2010, 12:25 – 2:25PM

HW 7 – Provide your Final Project proposal
HW 10– Prove Equation 14 of Anitescu-Tasora paper

[5] No written final exam for this class.