MECH 563 Robotics

(3 Credits)

Course Structure
3 hours of lecture per week, T/Th 8:00-9:30, DMP 101.

Course Grading (approximate scheme only)

Lab	10 %
Project	20 %
Midterm	30 %
Final Exam	40 %
	100 %

Instructor

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Course Text
Mark W. Spong, Seth Hutchinson and M. Vidyasagar, *Robot Modeling and Control*, John Wiley and Sons, 2006.

Course Website
Course information will be posted on VISTA – www.vista.ubc.ca. If you are registered in the course you should be able to access the course materials.

Course notes are available on the website. Bring the notes to class - they are indispensable.

References

1. Books

a) Sciavicco, L. and Siciliano, B., Modeling and Control of Robot Manipulators, McGraw Hill, New York, 2nd Ed, Springer-Verlag, 2000.
b) S. B. Niku, Introduction to Robotics, Analysis, Systems, Applications, Prentice Hall, 2001.
c) R.L. Andersson, *A Robotic Ping-Pong Player - Experiment in Real-Time Intelligent Control,* MIT Press, 1988.
d) J. Angeles, *Spatial Kinematic Chains: Analysis, Synthesis and Optimization*, Springer Verlag, 1982
e) H. Asada and J.J. Slotine, *Robot Analysis and Control*, Wiley-Interscience, 1986.
f) J.J. Craig, *Introduction to Robotics: Mechanics and Controls, Second Ed.*, Addison Wesley, 1989.
g) C.W. de Silva, *Control, Sensors and Actuators*, Prentice Hall, 1989.

h) K.S. Fu, R.C. Gonzalez, C.S. Lee, *Robotics: Control, Sensing, Vision, Intelligence, McGraw-Hill, 1987.*
i) J.M. McCarthy, *An Introduction to Theoretical Kinematics*, MIT Press, 1991
j) R.P. Paul, *Robot Manipulators: Mathematics, Programming and Control*, MIT Press, 1981.
k) G. Strang, *Linear Algebra and Its Applications*, Second Ed. Academic Press, 1980. (or your favorite linear algebra text)
l) S.G. Tzafestas, Ed., *Intelligent Robotic Systems*, Marcel Decker Inc., 1991.
m) T. Yoshikawa, *Foundations of Robotics - Analysis and Control*, MIT Press, 1990.
n) V. Daniel Hunt, *Robotics Sourcebook*, Elsevier, 1988.

2. Journals

a) ASME Journal of Dynamic Systems, Measurement and Control
b) Robotics and Autonomous Systems, Elsevier.
c) Robotica, Cambridge University Press.
d) Journal of Field Robotics, John Wiley and Sons
e) International Journal of Robotics Research, MIT Press
f) IEEE Transactions on Robotics
g) IEEE Transactions on Systems Man and Cybernetics
h) International Journal of Human-Robot Interaction

3. Software

a) Matlab – Student edition is fine.
b) Robotics Toolbox for Matlab by Peter I. Corke. See course website for the link to download this free toolbox.
c) ROS – Software is installed in the PACE lab. More information will be provided.

Tentative Course Outline	**Approx. # of hours**
1. Introduction to Robotics	1 Hour
1.1 What does a robot look like?	
1.2 What do robots do?	
1.3 Robot Manipulators	
1.4 Some of the Research Issues involving Robotic Manipulators	
1.5 Robots and Industry	
2. Rigid Motions	2 Hours
2.1 Review of Linear Algebra. Notations and Definitions.	
2.2 Frames and Rotations	
2.3 Basic Rotations	
2.4 Composition of Rotations	
2.5 More 'Fun' Properties of Rotation Matrices - The Axis-Angle Representation	
2.6 Homogeneous Transformations	
2.7 Basic Homogeneous Transformations	

- 2.8 Exercises

3. Forward Kinematics — 2 Hours
   - 3.1 Kinematic Chains
   - 3.2 The Devanit Hartenberg Convention
   - 3.3 Exercises
4. Inverse Kinematics — 2 Hours
   - 4.1 Overview
   - 4.2 Algebraic Solution
   - 4.3 Geometric Solution
   - 4.4 Numerical Solution
   - 4.5 Summary
   - 4.6 Exercises
5. Differential Kinematics — 4 Hours
   - 5.1 Differentiation of Rotation Matrices
   - 5.2 Velocity and Acceleration Kinematics
   - 5.3 The Manipulator Jacobian
   - 5.4 Geometric Formulation of the Jacobian
   - 5.5 Formulation of the Jacobian by Differentiation
   - 5.6 The General Jacobian Formulation
   - 5.7 Kinematic Singularities
   - 5.8 Redundancy
   - 5.9 Exercises
6. Manipulator Statics — 2 Hours
   - 6.1 Forces and Torques
   - 6.2 The Principle of Virtual Work
   - 6.3 The Generalized Statics Relationship
   - 6.4 The Stiffness/Compliance Matrix
   - 6.4 Exercises
7. Manipulator Dynamics — 5 Hours
   - 7.1 Hamilton's Principle
   - 7.2 Derivation of Lagrange's Equations from Hamilton's Principle
   - 7.3 Lagrange's Equations of Motion: Examples
   - 7.4 Formulation for Kinetic Energy for a N-Link Manipulator
   - 7.5 Generalized Equations of Motion for a N-Link Manipulator
   - 7.6 Example: Two-Link Planar Robot
   - 7.7 Christoffel Symbols
   - 7.8 The Recursive Newton Euler Formulation
   - 7.9 Direct and Inverse Dynamics
   - 7.10 Acceleration Directions
   - 7.11 Exercises

*8. Path and Trajectory Planning — 3 Hours
   - 8.1 Definitions
   - 8.2 Joint-Space Trajectories
   - 8.3 Work-Space Trajectories
   - 8.4 Optimal Motion Planning

8.5 Obstacle Avoidance
8.6 Exercises

9. Computer Vision — 4 Hours
   9.1 Image Processing Fundamentals
   9.2 Image Acquisition
   9.3 Frame Grabbing
   9.4 Image Formation
   9.5 Camera Calibration
   9.6 Introduction to Visual Servoing
10. Robot Motion Control — 3 Hours
   10.1 The Control Problem
   10.2 Actuator Dynamics
   10.3 PD Compensation
   10.4 PID Compensation
   10.5 Inverse Dynamics Compensation
   10.6 Exercises
11. Interaction Control — 2 Hours
   11.1 Single Degree of Freedom Stiffness Control
   11.2 Inverse Dynamics in Task Space
   11.3 Impedance control
   11.4 Exercises
12. Project presentation — 3-4 Hours

LAB

The lab outline will be posted on Connect in late January. The lab involves implementing a motion planning task on a Willow Garage PR2.

There are no marked assignments for the course. However, there are assignments given with each chapter of the notes and solutions will be posted.

MIDTERM

February 13. Closed book. Formula sheet provided.

FINAL EXAM: The final exam is scheduled by the university. It will be a closed book exam covering the complete course. The invigilators will not answer any questions regarding material on the exam, during the exam period.

All exams are CLOSED BOOK.

PROJECT: (20% of course mark).

Final Report Due Thursday, April 10th, 4:00pm. ***Late papers will not be accepted. Please plan ahead!***

This project consists of five parts:

1. Proposal. 1-2 pages plus reference material. **Due February 6th in Class**.
2. Technical Report. 4 pages maximum plus reference material. **Due March 6th in Class**
3. Simulation and/or Experiment that demonstrates your work.
4. Presentation, including item 3, scheduled for the last week of classes
5. Final report, in article format, 6-8 pages, 2 columns, single spaced, 12 point font, including figures and references. Major papers referenced should be attached as an appendix. **Due Thursday, April 10th, 4:00pm**.

Objective: To implement a robotics application based on recently published research work(s). Examples are:

- an efficient inverse kinematics routine for a certain class of robots
- a trajectory planner (design to meet some criteria or problem)
- a controller for a flexible robot
- a contact force controller
- a path planner for an articulated robot operating in a constrained environment
- minimum energy planner or controller for a redundant robot

Please note that rudimentary trajectory planners, inverse kinematic routines and controllers are implemented in the matlab toolbox. Work that simply reproduces these controllers is not acceptable. The toolbox can, however, be used within the project, and as a benchmark for comparison.

Instructions:

1. *Literature Review and Proposal*

Find at least one, and preferably several **recent** (*post 2003 vintage*) ***journal*** research papers regarding a ***specific, well-defined*** topic in robotics. ***Conference papers are ***NOT*** acceptable as they generally do not contain sufficient information to determine how the method described is implemented***. You can also use robotics text to assist your work, of course, however the project should be focused on a recently developed (post 2003) technique. Read and understand the concepts and methods used in this/these papers. Your proposal should describe the type of application you plan to undertake, the basis (research work) on which your application is based, the tools you will used to implement the application, and your expected results.

2. *Technical Report.*

By this time you should have a clear plan of how you will implement the application. You should have worked out all the equations that are required, and understand all the variables and values you will need to calculate and use in your simulation. You may have even started implementation. The technical report should lay out clearly how the simulation or experiment will be implemented. It should also give some consideration as to how you will clearly present your results to the class and the instructor.

3. *Simulation and/or Experiment*

You need to present your results in a visual manner such that other students can observer and evaluate them. This can be done using simulations in matab (using the avi capture facility) and/or graphs, charts, or (in the case of physical experiments) video.

4. *Presentation*

Be prepared to give a brief (maximum 10 minute) demonstration/description of your simulation to the class. Explain briefly the technique your simulation will demonstrate, and give one or two examples. A notebook computer and projector will be available for making your presentation. Students wishing to use this equipment should email their presentation to the instructor ***A MINIMUM OF 24 HOURS BEFORE*** the presentation.

5. Report

Present your work in article format with the typical sections (abstract, introduction, methodology, implementation, results, discussion/conclusions, references, etc.). For guidelines on how to format your article please see:
http://www.ieee.org/portal/cms_docs_iportals/iportals/publications/authors/transjnl/stylemanual.pdf

********Caution********:*** where students have difficulty with this project is with the selection of GOOD research papers from the literature. It is VERY important to select papers that provide **ALL** the data you need to ***reproduce*** the reported simulation. There are a LOT of papers in the literature which DO NOT provide sufficient information, so ***BE CAREFUL!!!*** You have been warned.

Important Note: It is completely unacceptable to copy text or figures from any published work without indicating that this is copied material (referencing the work), and submit it as your own work. This is plagiarism and will be dealt with under the UBC policy #69: Student Discipline.
http://www.universitycounsel.ubc.ca/policies/policy69.html

The work in your report should, therefore, NOT be a repetition of the contents of any published paper. Instead it should include a commentary, discussing the effectiveness of the method presented (in your view) and any problems you discovered in trying to implement it. **You SHOULD attach the main papers you have used to your report as an appendix**. (Not included in the page count.)

This project is to be done by individuals only. No marks will be given for group work.