**446.345 Introduction to Robotics**
**Spring 2013**
**Syllabus**

**Introduction**: This course provides a rigorous foundation for the mechanics, planning, and control of robots. The emphasis will be on learning the fundamental concepts and principles that underly robotics—the intent is to help students acquire a unified set of analytical tools for the modeling, planning, and control of robots, together with a reliable physical intuition that recognizes the unique and interdisciplinary nature of robotics. While there will be some discussion of the latest research trends and technological innovations in robotics, the emphasis is strongly on content that will serve as a foundation for whatever trends may appear later. In addition to advanced courses that address specialized topics in robotics, courses in computer graphics and animation, computer vision, computer-aided design, and multibody dynamics—essentially, any course in which spatial motions and rigid body physics plays a central part—should benefit from the contents of this course.

**Lectures**: Lectures will be held Mondays and Wednesdays from 11:00am to 12:30pm, in lecture hall 301-204. All lectures will be given in English. The course will also be videotaped; a camera crew will be present at all lectures.

**Discussion Section**: In addition to the lectures, students are expected to attend a one-hour discussion section each week. Discussion groups, consisting of approximately 10-15 students each, will be organized and run by the teaching assistants on a weekly basis, with the goal of reviewing the lecture material, solving practice problems, and giving the students an opportunity to ask questions. Discussion sections will meet on Thursdays and Fridays in the late afternoon; the meeting times and locations will be announced at a later date. Attendance in the discussion sections is mandatory.

**Course Instructor**: The instructor for the course is Frank Chongwoo Park. His office is located in Building 301, Room 1515. He can be reached at 880-7133, or by email at *fcp@snu.ac.kr*. Regular office hours will be maintained on Mondays and Wednesdays from 1:30-3:00; other times can be arranged by appointment.

**Teaching Assistants**: The teaching assistants for the course will be announced later on the first day of class. TA offices are located in the Robotics Laboratory, Building 302, Room 413. The main lab telephone number is 880-7149. Office hours maintained by each TA will be announced at a later date.

**Course Webpage**: A course webpage will be maintained at *http://etl.snu.ac.kr*. All lecture notes, homework assignments, solutions, and announcements will be made available on the course webpage. A monitored course discussion board will also be available. Personal communications with the teaching assistants should be conducted by email rather than through this course discussion board.

**Course Text**: The course text will be a set of lecture notes entitled *Introduction to Robotics: Mechanics, Planning, and Control*, by F.C. Park and K.M. Lynch. Chapters will be distributed at least a week prior to their coverage in lectures. For those who desire additional sources, the following references are recommended:

- J. Craig, *Introduction to Robotics: Mechanics and Control*, Prentice Hall, 2004. This is one of the most widely used and classical textbooks in robotics. its scope is roughly equivalent to that covered in the course, although it does not introduce the product of exponentials formalism, and differs significantly in style and presentation.
- R. Murray, Z. Li, and S. Sastry, *A Mathematical Introduction to Robotic Manipulation*, CRC Press, 1994. This text is a graduate level introduction to the contents of this course. It is highly mathematical and contains advanced material beyond what is covered in this course, but adopts the same geometric approach to robot mechanics that we do, and is a useful reference to those who wish to probe more deeply.
- M. Spong, S. Hutchinson, M. Vidyasagar, *Robot Modeling and Control*, Wiley, 2005. The exposition is similar to Craig, but with broader coverage of topics, i.e., vision and visual servo control, basics of motion planning, and a very accessible treatment of geometric nonlinear control, in addition to the standard material on robot mechanics and control.
- B. Siciliano, L. Sciavicco, L. Villani, G. Oriolo, *Robotics: Modelling, Planning and Control*, Springer, 2011. An even broader coverage of topics than Spong et al's book, this text also offers extensive coverage of mobile robots in addition to the standard material on robot mechanics, planning, and control.

**Grading**: The grading for the course will be based on weekly problem sets (5%), four in-class 30-minute quizzes (5% each), a midterm exam (25%), a final exam (40%), and participation in discussion sections (10%). The weights are approximate, and may be adjusted accordingly at the discretion of the instructor.

**Prerequisites**: The only prerequisites for the course are an understanding of rigid-body physics and mathematics at the sophomore level. The kinematics of particles and rigid bodies as covered in a sophomore dynamics course is useful but not necessary. There will be extensive use of concepts and techniques from linear algebra and differential equations; previous exposure to these subjects (corresponding to the material covered in a sophomore engineering mathematics course) is helpful but not essential, as these concepts will be covered in class.

**Lecture Schedule**: We will attempt to adhere as closely as possible to the following schedule of topics (topics for the final 2-3 lectures may be rearranged or modified depending on circumstances):

- **March 4** (M): Course introduction
- **March 6** (W): Joints, links, and actuators; mobility of a mechanism; Gruebler's formula and other methods for analyzing a mechanism's mobility
- **March 11** (M): Robot configuration space
- **March 13** (W): Planar force closure: contact models, convexity test
- **March 18** (M): Planar force closure: Nguyen's theorem for determining planar force closure, extensions to the spatial case
- **March 20** (W): Spatial force closure (QUIZ 1)

- **March 25** (M): Angular velocities, velocity and acceleration analysis using moving frames
- **March 27** (W): Rotations: the rotation group $SO(3)$, Euler angle and roll-pitch-yaw parametrizations of rotations
- **April 1** (M): Rigid-body motions: the $4 \times 4$ homogeneous transformations and the Special Euclidean group $SE(3)$
- **April 3** (W): Forward kinematics of open chains: the Denavit-Hartenberg representation
- **April 8** (M): Screw theory: exponential representation of rotations
- **April 10** (W): Screw theory: exponential representation of rigid-body motions (QUIZ 2)
- **April 15** (M): Forward kinematics of open chains: the product-of-exponentials formula
- **April 17** (W): Differential kinematics: angular and spatial velocities
- **April 22** (M): MIDTERM EXAM
- **April 24** (W): Differential kinematics: the manipulator Jacobian
- **April 29** (M): Differential kinematics: statics, kinematic singularity analysis, and other applications involving the manipulator Jacobian
- **May 1** (W): Inverse kinematics of six degree-of-freedom open chains: architectures that admit closed-form solutions
- **May 6** (M): QUIZ 3
- **May 8** (W): NO LECTURE (IEEE Int. Conf. Robotics)
- **May 13** (M): NO LECTURE (IEEE Int. Conf. Robotics)
- **May 15** (W): Inverse kinematics of six degree-of-freedom open chains: numerical methods; inverse kinematics of redundant open chains
- **May 20** (M): Closed chain kinematics: general formulation, an examination of the Jacobian and singularities via a five-bar linkage case study, the 6-6 platform and its special cases
- **May 22** (W): Motion planning: bug algorithms
- **May 27** (M): Motion planning: the potential field method (QUIZ 4)
- **May 29** (W): Basics of robot control: independent joint PID control control
- **June 3** (M): Basics of robot control: task space control, force control, hybrid force-position control
- **June 5** (W): Final exam review session
- **June 10** (M): FINAL EXAM (3 hours, 6-9PM, covering the entire course)