446.345 Introduction to Robotics
Spring 2014
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: For the 2014 spring semester, this course will be taught in a "flipped" format—students will be expected to take online lectures offered by the course instructor in conjunction with EdX-SNUx, and also attend weekly class meetings for discussion of the material. The online lectures will consist of two 75-minute sessions per week, and will be made available on SNU's Center for Teaching and Learning (CTL) website. Students are expected to study the lecture materials prior to the weekly class meetings.

The class discussion sessions will convene twice weekly. First, the entire class will meet with the course instructor on a designated day (primarily Wednesdays) to discuss the online lecture materials; this session will be conducted in English. Students will also meet in smaller weekly discussion groups of 15-20 students with a teaching assistant, on Thursday or Friday. The goal of these smaller sessions will be to further review the lecture material, solve practice problems, and offer the students an opportunity to ask questions and interact with the teaching assistant and fellow students in a more informal environment. These discussion groups will offer sessions in both English and Korean.

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 11:00-12:00; 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 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 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.

Tentative Sequence of Topics:

- **March 3** (M): Course introduction
- **March 5** (W): Joints, links, and actuators; mobility of a mechanism; Gruebler's formula and other methods for analyzing a mechanism's mobility
- **March 10** (M): Force closure: contact models, convexity test
- **March 12** (W): Force closure: Nguyen's theorem for determining planar force closure, extensions to the spatial case

- **March 17** (M): Planar force closure: Nguyen's theorem for determining planar force closure, extensions to the spatial case
- **March 19** (W): Spatial force closure (QUIZ 1)
- **March 24** (M): Angular velocities, velocity and acceleration analysis using moving frames
- **March 26** (W): Rotations: the rotation group $SO(3)$, Euler angle and roll-pitch-yaw parametrizations of rotations
- **March 30** (M): Rigid-body motions: the 4×4 homogeneous transformations and the Special Euclidean group $SE(3)$
- **April 2** (W): Forward kinematics of open chains: the Denavit-Hartenberg representation
- **April 7** (M): Screw theory: exponential representation of rotations
- **April 9** (W): Screw theory: exponential representation of rigid-body motions (QUIZ 2)
- **April 14** (M): Forward kinematics of open chains: the product-of-exponentials formula
- **April 16** (W): Differential kinematics: angular and spatial velocities
- **April 21** (M): MIDTERM EXAM
- **April 23** (W): Differential kinematics: the manipulator Jacobian
- **April 28** (M): Differential kinematics: statics, kinematic singularity analysis, and other applications involving the manipulator Jacobian
- **April 30** (W): Inverse kinematics of six degree-of-freedom open chains: architectures that admit closed-form solutions
- **May 5** (M): Inverse kinematics of six degree-of-freedom open chains: numerical methods (QUIZ 3)
- **May 7** (W): Inverse kinematics of of redundant open chains
- **May 12** (M): Closed chain kinematics: general formulation, an examination of the Jacobian and singularities via a five-bar linkage case study,
- **May 14** (W): Closed chain kinematics: the 6-6 platform and its special cases
- **May 19** (M): Motion planning: bug algorithms
- **May 22** (W): Motion planning: the potential field method (QUIZ 4)
- **May 26** (M): Motion planning: the rapidly exploring random tree algorithm
- **May 28** (W): Basics of robot control: independent joint PID control control
- **June 2** (M): Basics of robot control: task space control, force control, hybrid force-position control
- **June 4** (W): Final exam review session
- **June 9** (M): FINAL EXAM (3 hours, 6-9PM, covering the entire course)