BRIDGING THEORY AND PRACTICE IN A DUAL LEVEL ROBOTICS COURSE FOR MECHANICAL AND ELECTRICAL ENGINEERS

Ping Ren[1], Dennis Hong[1], Janis Terpenny[1, 2], Richard Goff[2]
[1]Department of Mechanical Engineering, Virginia Tech

[2]Department of Engineering Education, Virginia Tech

Abstract

As a diverse discipline, robotics is a synthesis of a variety of subjects such as kinematics, dynamics, controls, mechatronics, mechanical design, artificial intelligence etc. The crossover of multiple areas makes the instruction of robotics courses a challenging task. Traditional robotics courses in mechanical and electrical engineering mainly focus on the analysis and modeling of classical robotic systems such as a two-to-six degrees of freedom serial robotic manipulator or a simple wheeled mobile robot. However, as more and more new branches of robotics are emerging in recent years (biology-inspired robots, nanorobotics and so on), it has become clear that materials covered in traditional robotics courses are not sufficient for students to solve new problems or create new robotic systems. It is therefore imperative that robotics courses be updated, and in many cases, redesigned to account for new branches of robotics that call on students to be competent in the theoretical underpinnings and also have the skills and confidence to apply these to real applications demanded by current practice. This paper first introduces the importance of robotics courses in the curriculum of engineering programs, followed by results of a survey that reports on the features of robotics courses in several universities in the United States and a few other countries. The difficulties of designing a robotics course are then addressed. Finally, the structure of a new graduate/senior dual level robotics course is presented, including preliminary results and opportunities for future work.

Introduction

In the year of 2005, the Robotics Education Workshop took place in Robotics Systems and Science symposium at Massachusetts Institute of Technology (MIT) [1]. The main goal of this workshop was to discuss how to turn robotics into a core course that could be taught in every accredited Mechanical Engineering (ME), Electrical Engineering (EE), and Computer Science (CS) undergraduate and graduate program in the United States, indeed, all over the world. Over 30 robotics professors from universities and institutes in the US, Europe, and Asia participated in this discussion. All believed that the timing is right to start considering ways robotics could be taught broadly and then, determine and implement corresponding actions. This is mostly due to the computing revolution and recent advances in actuators and sensors, which make it possible that today's personal computers (PCs) could become tomorrow's personal robots (PRs). The importance of robot-related projects in engineering curriculum had already been well recognized by educationists [2], especially as a tool in the early stage of engineering programs to foster students' motivation and provide engineering design-oriented experience.

Currently in the US, complete robotics curricula are only available at a few universities that have very concentrated expertise in robotics research, such as Carnegie Mellon University (CMU), the University of Pennsylvania (UPenn) Georgia Tech and so on. In these universities, there are sufficient robotics and robotics-related courses for graduate students to fulfill the requirements towards doctoral degrees [3-5]. In addition to Ph.D. programs, some of these universities have also implemented Master of Science programs in robotics [6]. In contrast, many other schools with fewer resources for robotics research are challenged to offer even an introductory level robotics course because of the imbalance between ME, EE and CS topics, the lack of low cost teaching platforms and laboratories, etc.

Before analyzing the collected examples of robotics courses from different universities and institutes, two important characteristics of robotics and robots should be addressed:

1. Robotics is a synthesis of a variety of ME, EE and CS subjects. There is not a unified classification on these subjects, but in this paper, the subjects are generally divided into two groups for convenience. First, *Robotics Science*. This group mainly includes the theories upon which robots are analyzed, such as kinematics, dynamics, control theory, optimization theory, artificial intelligence, and so on. The second group is *Robotics System*, which mainly includes the key technologies used to implement the results of theoretical analysis, such as hardware design of robots, actuators, sensors, controllers, smart materials, electronics, software architecture, and so on. Since so many subjects are involved in robotics, it is not surprising that, by selecting different elements in the two groups, more than two introductory robotics courses without any overlap in topics could be created.

2. Robots can greatly foster students' innovation and creativity. The value of robot projects in the early stage of engineering programs mainly lies in the inspiration to provide innovative solutions to compelling problems and needs in a context that motivates learning design process and methods . With this approach, the theoretical analysis could possibly be limited or none and the hands-on activities of building robots with ready-made kits could be the focus. Students are transforming creative solutions into reality … an activity that is core to the field of robotics and the growing list of, emerging new branches such as humanoid robots, nanorobotics and biology-inspired robots. Certainly, higher-level robotics courses would be similarly well served by innovative problem solutions that were supported by knowledge and skills of design process and methods.

In the sections that follow, the main objective of this paper is first presented, followed by an analysis of the results from a survey conducted over twelve syllabi from different universities. The potential challenges for students when taking robotics courses are also investigated. Suggestions for instructors in course design and delivery are addressed. Finally, a suggested structure for graduate/senior dual level introductory robotics courses in ME or EE departments is presented along with preliminary results and opportunities for future work.

Objectives

The main objective of this paper is to combine knowledge of engineering education (effective approaches for student engagement and learning) with the authors' experiences in robotics research to design a graduate/senior level robotics course. In recent years, as a new course in ME and EE programs, robotics is playing an increasing role in drawing students into these programs and motivating interests in cutting-edge research areas. The design of such a course is a challenging task, which usually calls on continuous updates due to students' interests and newly emerging branches of robotics. The design process and considerations of such a robotics course, as an addition to the existing ME and EE curricula at Virginia Tech, are presented in this paper, including a suggested syllabus.

Robotics Syllabi Survey

This survey is conducted on a variety of twelve syllabi collected from different universities and institutes in the United States, Switzerland and Singapore. The documents of these courses were obtained from MIT OpenCourseWare [7], IEEE Robotics Course Ware [8] and the authors' personal correspondence with some professors. The selected universities and institutes for this survey range from prestigious Ivy League universities, well known research universities with expertise in robotics, advanced research institutions, to well-recognized teaching universities. These syllabi were all developed between 2003 and 2008, thus allowing the survey to be focused on the most current robotics courses. The basic information of the twelve samples is listed in the table in Appendix B.

Discussion Points

In the analysis below of the courses listed in Appendix B, the terms "Course 1" to "Course 12" are used to conveniently refer to the twelve survey samples.

Department and Course Number

Among the twelve samples, the departments or institutions that offer robotics courses are mainly ME, EE and CS. Usually, most students that choose and take robotics come from these three departments. In some instances, a particular robotics course that is offered in more than one department can have different course numbers in ME and EE respectively. This is the case for Course 11.

Courses Levels

In the samples of courses listed in the table, "SU" stands for senior undergraduate level, with "G" for graduate level and "AG" for advanced graduate level. There are two undergraduate courses, seven graduate courses, and one advanced graduate course in the table. Note that Course 5 and 9 have both an undergraduate and a graduate course number, so the level of the two courses is denoted with "G/SU". These two can serve as the paradigms of dual level robotics courses. In such courses, both undergraduate and graduate students will receive the same lectures, but the instructors' requirements on their assignments, labs, projects and exams can be different.

Prerequisites

For the departments that are able to provide both graduate and senior undergraduate robotics courses, the senior course is typically a prerequisite for the graduate course. Almost all robotics courses set mathematics and computer programming as prerequisites. Since most ME, EE and CS departments can offer engineering-oriented courses on applied mathematics, instructors would like to use these as the prerequisites to robotics courses, such as Courses 3, 5, 9, 10, and 12. The pre-required knowledge of mathematics mainly includes calculus, vector analysis and ordinary differential equations. Depending on the focuses of instruction, some courses may require fundamental knowledge on probability, dynamics, optimization, control etc. In order to verify the theories in robotics science or conduct tests on actual hardware, most courses require students to be competent in programming. Students must understand at least one technical programming language, such as C and C++, or a numerical computing language such as MATLAB, Mathematica and so on.

Textbooks

There is no unified robotics course syllabus; correspondingly, the unified textbook does not exist either. Depending on the coverage of material, instructors usually choose one book as the textbook to teach the fundamentals and use suggested reference books or the instructors' own notes to deliver advanced topics. The instructors of Courses 1, 6 and 12 use the books they authored as the textbooks, but they also provide other references. Among all the textbooks listed in the table, one book and its latest version received the most popularity and are chosen as the textbook by at least three instructors. This textbook is:

Spong, M.W. and M. Vidyasagar, *Robot Dynamics and Control*. 1989, John Wiley & Sons, Inc.
and its latest version:
Spong, M.W., Hutchinson, S., and M. Vidyasagar, *Robot Modeling and Control*. 2006, John Wiley & Sons, Inc.

This textbook sufficiently discusses the fundamentals of rigid body coordinates transformations, formulation of kinematics, dynamics and nonlinear controllers of serial robotic manipulators with two-to-six degrees of freedom. Due to the significant advances in vision sensors in past decades, the introduction to robotics vision and vision-based control are also included in the 2006 version. Also in the latest version, the authors outlined two possible course structures in the preface section, which is an important reference source for beginning instructors when designing robotics courses.

Besides the book discussed above, other suggested reference textbooks include:

H.Asada and J-J.Slotine, *Robot Analysis and Control*, 1986
J.Craig, *Introduction to Robotics: Mechanics and Control*, 1986
M.T.Mason, *Mechanics of Robotic Manipulation*, 2001
R.M. Murray, Z.Li, and S.S. Sastry, *A Mathematical Introduction to Robotics*, 1994
Lorenzo Sciavicco and Bruno Siciliano, *Modeling and Control of Robot Manipulators*, Second Edition, 2000

All of these textbooks can be treated as “general robotics” books because the fundamental mathematics background of robotics is intensively addressed. As for specialized topics in robotics, the course instructors in the table used the following books:

Mobile robots

R.Siegwart and I.R.Nourbakhsh, *Introduction to Autonomous Mobile Robots*, 2004
A. K. Peters *Mobile Robots, Inspiration to Implementation*
Dudek and Jekin, *Computational Principles of Mobile Robotics*
S.Thrun, W.Burgard, D.Fox, *Probabilistic Robotics*, 2006

Parallel robots

L-W. Tsai, *Robot Analysis: The Mechanics of Serial and Parallel Manipulators*, 1999
J.P. Merlet, *Parallel Robot*, 2000

Robot motion planning

LaValle, S., *Planning Algorithms*. 2006
J.C. Latombe. *Robot Motion Planning.* 1991
H. Choset, K. M. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L. E. Kavraki, and S. Thrun. *Principles of Robot Motion: Theory, Algorithms, and Implementations.* 2005

Artificial Intelligent

Russel & Norvig, *Artificial Intelligence, a Modern Approach*
Robin Murphy, *Introduction to AI Robotics*, 2000

Materials such as academic journals and magazines can be complementary to textbooks and reference books, especially when covering advanced topics. These suggested materials mainly include:

IEEE Robotics & Automation Magazine
IEEE Transactions on Robotics (previously *IEEE Transactions on Robotics and Automation)*
International Journal of Robotics Research
Journal of Robotic Systems
Robotica
ASME Journal of Mechanical Design
ASME Journal of Mechanisms and Robotics

Coverage of Topics and Robot Subject

Regarding instructors’ coverage on robotics topics, the twelve sample courses can be generally divided into three groups.

The first group of courses is mainly offered in ME/EE departments, such as Course 1, 4, 5, 10 and 11. The instructors in this group prefer to use serial robotic manipulators as the subject to study the fundamentals of robotics. Topics of these courses include the fundamental coordinate transformation of rigid bodies, kinematics and dynamics modeling. The specialized or advanced topics could cover nonlinear control, motion planning, implementation and design of hardware, software architecture and so on, depending on the expertise of the instructors and the departments. In some of these courses, robots other than serial robotic manipulators such as legged robots, parallel robots, surgical robots are briefly introduced.

In contrast with the aforementioned group of courses, the second group of robotics courses is mainly offered in CS departments, such as Course 6, 7, 9. These courses focus more on the intelligent programming of wheeled mobile robots. Instead of carrying out the kinematic and dynamic modeling of robots, these courses intensively study the navigation of such mobile robots, including the path planning, machine learning, reasoning, localization, mapping, human-robot interaction and so on.

Institutions with very strong background in robotics research can accommodate both robotic manipulators and mobile robots in one course, such as Course 2, 3, 8 and 12. It is notable that, in the third group of such robotics courses, the hardware-based labs and projects are also provided. Students can develop their own projects ranging from industrial robots, walking machines to multiple-cooperated wheeled robots.

Labs and Projects

Currently, robotics resources are concentrated at a few universities and institutions. Because of the high cost of robot electronics, not every university can offer robotics courses with labs and hardware-based projects. Low cost experimental robots and robot prototyping are also an active area in robotics research. The lab in Course 5 provides such a paradigm. The detailed information can be found in Ref. [9]. An industrial robot, Catalyst-5 from the Thermo Electron Corporation, is used as the platform for students' labs and course projects. Forward and inverse kinematics, velocity kinematics and singularity, path planning and obstacle avoidance, vision control and manipulation are carried out on this robotic manipulator. In the process of the project, students must correctly implement the first module before implementing the next one. This is also an interesting characteristic of robotics fundamentals. Notable labs and projects from other courses include the programming of mobile robots for cooperative operation, the manipulation of objects based on vision control and the design of the walking gaits of legged robots. Some of these projects have great value in both education and research.

Course Hours

All robotics courses in the table are typical 3-credit courses, which take 2.5 hours to 3 hours per week. The courses with labs usually require longer than 3 hours per week.

Grading Policies

The grading policy of these course samples is comprehensive. It is usually based on exams, homework, labs, quizzes and projects. A few instructors have requirements on students' participation. Both open and closed book exams are used and the course project often involves a written deliverable and an oral presentation.

Considerations for Students and Suggestions for Instructors

The complication of robotics courses renders difficulties to both students and instructors. Some considerations for students are investigated in this section, followed by suggestions to the instructors.

Considerations for students

Prerequisites

The prerequisites of robotics courses emphasize a lot of mathematics background. As the lectures proceed, the instructors could briefly review the knowledge of some math tools, but the students would be better to understand them before taking the course.

Students' interests and the actual course materials

Not every student is familiar with the content of robotics courses. Some students might expect to design a highly intelligent humanoid robot that can walk and talk. However, they probably will end up spending a lot of time with vector operations and differential equations. The possible frustration and disappointment received are bad for fostering students' interests in robots. The instructors would be better to introduce the current trends of robotics to students and use the early stage of computers as an analog.

Interactions with other disciplines

As the introductory section of this paper points out, robotics is an integration of various ME, EE, CS subjects. It should be expected that students taking robotics courses are from different backgrounds. Although they might already have backgrounds in kinematics, dynamics and control theory and so on, due to the novelty of robots, the ways those theories are treated and applied in robotics are slightly different from the classical ways they are used. Instructors should emphasize both the overlaps and differences between robotics and other disciplines and carefully guide students through the whole learning process. Thus, both students' understanding on robots and their previous backgrounds could be strengthened.

Suggestions for instructors

Grasp the insight of robotics

Inherently, most instructors of traditional robotics courses believe that a sound foundation on mathematic and physical principles is the way that leads to the mastering of robotics. However, Piepmeier, J., et al., from United States Naval Academy proposed that besides knowledge and experience on robotics, the insight on robotics in a global context should also be addressed [10]. They use three approaches, robot news, multimedia facts and mass media function, to foster students' insight on robots. Some robotics courses have already adopted these interesting methods, such as Course 11 in Appendix B.

Foster creativity in robotics courses

Since most robotics courses have high requirements on students' mathematic ability, the instructors are trying to deliver the analytical approaches to solve robotics problems to students in an intensive way. The importance of analytical and numerical tools in robotics analysis cannot be denied. However, the design innovations in robotics should also be emphasized. Most robotics concepts originated from initial creative ideas. For example, serial robotic manipulators come from industrial assembly lines; parallel robotic manipulator come from the motion simulation of aircraft; humanoid robots come from people's dream that robots can behave like human beings and serve for them. Further, mobile robots with novel locomotion are often inspired by biology. Such examples are countless. The complex nature of these novel robotic systems raises them to the level of academics, but creativity is still the keystone. Therefore, it is suggested the instructors not only assign problem-solving-oriented projects, but also give students the freedom to consider the design of their own robots, which could possibly become new branches of robotics in the future.

Balance robotics lab, prototyping and simulation

In robotics courses, computer simulation is usually used as a tool to verify the results of theoretical analysis. It is of low cost, and easy to implement after sufficient training. With graphics functions, the results can be displayed in an intuitive way through friendly interfaces. Almost all robotics courses require students to be competent in writing simulation codes. Nevertheless, simulations cannot completely substitute the functions of physical models, especially when the lectures, labs, or projects call on students' ability in hardware operation, i.e., the design and fabrication of robot prototypes. In an institution where robot resources are not adequate for scores of students to take labs, the instructor can rely on simulations to deliver the fundamental knowledge of robotics. As the courses evolve in practice, the instructors should consider the making or purchase of robotic manipulators, mobile robots, or other novel robot prototypes to complement the theoretical concepts delivered in class. The development of low cost robot prototypes based on model kits can serve both education and research positively. An example can be found in Ref. [11], where a prototype of a six degrees of freedom parallel manipulator, usually the subject of robot kinematics research, is built with Lego® kits.

Proposed Syllabus for a Graduate/Senior Level Introductory Robotics Course, Assessment and Future Plan

Based on the analysis conducted in previous sections, a graduate/senior dual level introductory robotics course was proposed to the ME department of Virginia Tech. This new course was first approved as a special study with a course number of ME 5984, and then delivered to ten graduate students and one senior by the authors Ping Ren and Dennis Hong in the spring of 2009. The syllabus used is presented in Appendix A.

As shown in the syllabus, the textbook of this course is the latest version of *Robot Modeling and Control.* Additional readings also come from complementary reference books, journals and magazines. The requirements on mathematics and programming are specified. The learning objectives, associated topics and materials are listed. The introductory topics include fundamental coordinate transformations, kinematics, trajectory planning, dynamics and control. Based on the instructors' expertise, the kinematics of mobile robots and parallel robots were taught as advanced topics. The course also briefly covered new branches of robotics. A faculty member with expertise in nanorobotics was invited to give a guest lecture. Since most students that signed up for this course were graduate students, the requirements of the course and objectives were the same for all students. If more senior students enroll in the future, then the requirements for these students could be slightly different, as the case of Course 5 in the table of Appendix B.

The final grade students received for this course was based on exams, assignments, projects and a presentation. An in-class quiz was used to test students' understanding of the knowledge just covered. Each student was required to lead a 5-minute discussion on most recent robot news, a method borrowed from Ref.[10]. This discussion was also counted as a quiz. The scores of the quizzes were mainly used to raise the students' percentage grades near the borderline of lettered grades. The presentation gave students an opportunity to consider the design of their own robots. Students were expected to illustrate the concept of their robots in a concise way. They were not required to perform in-depth analysis and present their results. Instead, they were required to establish the big picture of the research and the development scope. The potential challenges in the novel robot research should be described and students were required to consider how the knowledge learnt in this course could be synthesized to solve emerging problems.

During the instruction of this course, all students' reactions to the robot news presentation and robot design presentation were very positive. They used Power Point slides and Youtube videos to demonstrate the most recent robot news they collected through the Internet. The topics ranged widely from a survey on humanoid robots all over the world, novel applications of industrial robots in gas stations, spider-like legged robot that carried a person to Mars rover, space robots and so on. As for the robot design presentation, most graduate students used this opportunity to share with their classmates the robotics research fields they were very interested in or the robotics projects they would be working on towards their degrees, for example, surgical robots using smart materials, lightweight robotic manipulator design for the handling of nuclear materials and so on. During student presentations, the instructors led discussions between the presenter and the listeners, connecting the topic of the presentation with the lecture topics that were or would be covered and encouraging students to give inputs to their classmates' research.

Students were also required to accomplish a course project as part of their grades. This project was based on simulations. Basically, students used a model extracted from a PUMA 2 260 robot to study its inverse and forward kinematics, dynamics and control. Using the embedded graphics functions in Mathematica, real-time controlled animations were generated to verify their results of kinematics.

Based on the review of students' final reports, ten out of eleven students successfully accomplished the requirements of this project. They all agreed that the graphics functions in Mathematica or MATLAB could help them to identify and correct the errors in their equations and codes. Figure 1 shows a snapshot of the animation generated by one student's codes. The joints of the robot in the figure can be controlled by manipulating the six sliders above and correspondingly, the configuration will change in real time.

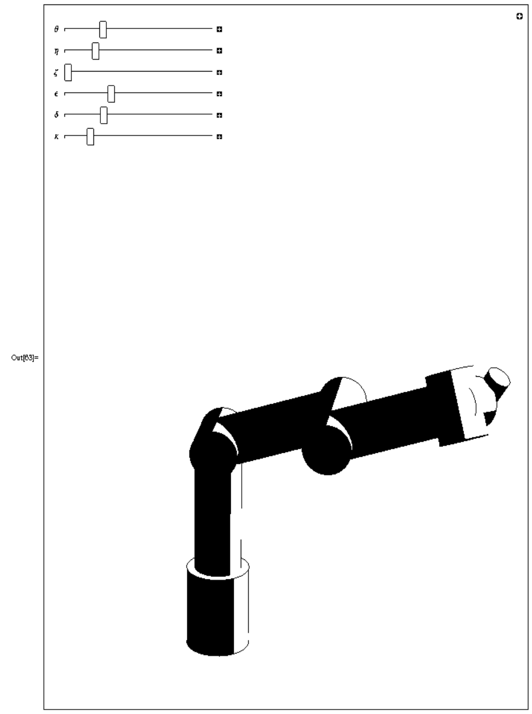

Figure 1: Snapshot of the real-time controlled robot model as a course project.

At the end of the spring semester of 2009, nine students evaluated this course. It received an overall rating of 3.2 out of 4. Most students indicated that their gains from the course that focused on theories, problem solving ability and appreciation of the discipline were above the average. Performance on in-class and out-of-class assignments and quizzes coupled with the term project provided strong evidence that learning objectives were achieved. Students were highly motivated after taking this course as indicatd by their final reports, in which a great portion of students produced more results using the model than the basic requirements. Comments collected on student evaluation forms, also suggest highly motivated and interested students with requests that the instructors increase the proportion of advanced topics in the future delivery of this course.

In the future, to satisfy students' desire for more advanced topics, other robot education platforms that can address the state-of-the-art trends in robotics will be investigated. The instructors are considering using the DARwIn LC humanoid robot shown in Figure 2, which is being developed in RoMeLa: Robotics and Mechanisms Laboratory at Virginia Tech, under the sponsorship of NSF [12]. With this type of low cost robot, graduate and senior students can advance and test their knowledge of kinematics, dynamics, control and motion planning as they study topics such as walking gaits, navigation and cooperative manipulation, thus obtaining experience in both theory and practice.

Future work related to this course will include the refinement of learning objectives, the improvement of delivery strategy and the evolution of the course through more practice. Design of course projects and labs based on robot hardware will also be investigated.

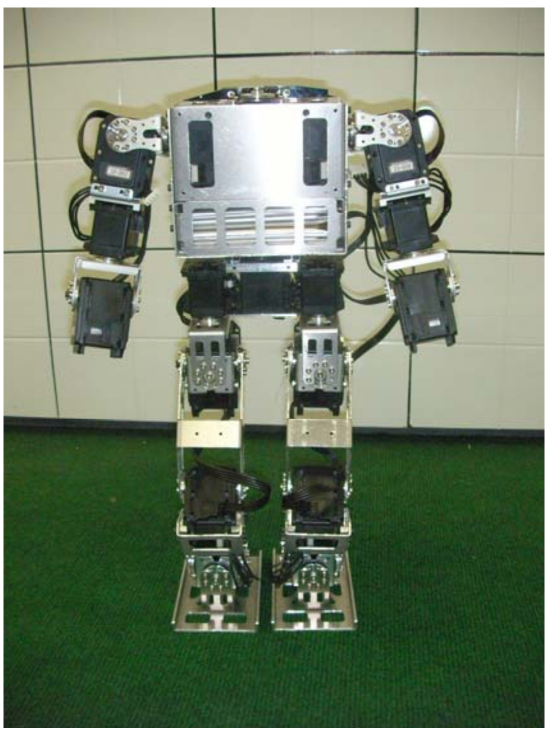

Figure 2: DARwIn LC humanoid robot (Dynamic Anthropomorphic Robot with Intelligent: Low Cost)

Bibliography

1. Rus, D., "Teaching Robotics Every where," IEEE Robotics & Automation Magazine, March, 2006.

2. Heywood, J., Engineering Education : Research and Development in Curriculum and Instruction, Wiley-IEEE Press, 2005.

3. Anon., Course List, Robotics Institute, Carnegie Mellon University, http://www.ri.cmu.edu/ri_static_content.html?menu_id=276, (accessed April 2010).

4. Anon., Ph. D Curriculum , GRASP, University of Pennsylvania, http://www.grasp.upenn.edu/education/phd, (accessed April 2010).

5. Anon., Ph.D Program in Robotics, Georgia Tech, http://robotics.gatech.edu/index.php/academics/phd-program.html, (accessed April 2010).

6. Anon., Master of Science in Robotics, GRASP, University of Pennsylvania http://www.grasp.upenn.edu/education/masters , (accessed April 2010).

7. Anon., MIT OpenCourseWare http://ocw.mit.edu, (accessed April 2010).

8. Anon., IEEE Robotics Course Ware http://www.roboticscourseware.org, (accessed April 2010).

9. Wood, R., "Robotic Manipulation Using an Open-Architecture Industrial Arm: A Pedagogical Overview," IEEE Robotics & Automation Magazine, September, 2008.

10. Piepmeier, J., et al., "Modern Robotics Engineering Instruction," IEEE Robotics & Automation Magazine, June, 2003.

11. Ebert-Uphoff, I., "Introducing Parallel Manipulators through Laboratory Experiments," IEEE Robotics & Automation Magazine, September, 2003.

12. Hong, D., "Collaborative Research: Development of DARwIn Humanoid Robots for Research, Education and Outreach," Award number: CNS 0958406,

http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0958406, (accessed April 2010).

Appendix A

Robot Modeling and Analysis

Level: Graduate/Senior

Course Description: This course covers both the fundamentals and the advanced topics in robotics, including homogeneous coordinate transformation, forward and inverse kinematics, Jacobian analysis, singularities, dynamics motion and path planning, and control. Various types of robotic manipulators with serial or parallel configuration, and mobile robots with wheeled or legged locomotion, are utilized as examples to illustrate the principles of robot analysis. New emerging areas of robotics in recent years are briefly introduced.

Textbooks:
Spong, M.W., Hutchinson, S., and M. Vidyasagar, *Robot Modeling and Control*. 2006, John Wiley & Sons, Inc.

Reference Books:
Spong, M.W. and M. Vidyasagar, *Robot Dynamics and Control*. 1989, John Wiley & Sons, Inc.
H.Asada and J-J.Slotine, *Robot Analysis and Control*, 1986
R.Siegwart and I.R.Nourbakhsh, *Introduction to Autonomous Mobile Robots*, 2004
R.M. Murray, Z.Li, and S.S. Sastry, *A Mathematical Introduction to Robotics*, 1994
L-W. Tsai, *Robot Analysis: The Mechanics of Serial and Parallel Manipulators*, 1999

Reference Journals:
IEEE Robotics & Automation Magazine, IEEE Transactions on Robotics and so on

Prerequisites:
Basic knowledge of linear algebra, differential equations, matrix theory. Programming and simulation with MATLAB, Mathematica, etc.

Learning Objectives:
1. Knowledge of basic robotics concepts, research subjects and applications
2. Analyses on the kinematics, dynamics and control of representative robots
3. Development of simulation tools for robots
4. Creative design of novel robots

List of Topics:
Robot definitions and classifications

Basic concept in kinematics
- Reference frames and rigid body representation
- Matrix representation of rotational and translational transformations

Forward kinematics
- Denavit-Hartenberg Representation of rotation and translation
- *Exponential coordinates for rigid motion and twists
- *Screws: a geometric description of twists
- Displacement analysis
- Velocity and acceleration problems

Inverse kinematics
- Analytical method
- Geometric method

Instantaneous kinematics
- Jacobian matrix
- Singularity conditions
- Inverse velocity and acceleration problems

Motion planning and trajectory generation
- Path planning using potential fields
- Trajectory planning

Dynamics Modeling
- Euler-Lagrange formulation
- Newton-Euler formulation

Robot Control
- PID control
- Model-based sliding mode control

*Kinematics of wheeled robots

- Forward wheel kinematic models
- Wheeled robot kinematic constraints

*Kinematics of parallel robots

- Mobility analysis
- Forward and inverse kinematics and singularities

*Introduction to emerging research areas in robotics

- Nanorobotics

*Advanced topics

Course Grading Policy:

1, Two exams, 40%
2, Assignments 25%
3. Simulation based project 25%
4. Presentation: the design of novel robotic systems 10%
5. In-class quiz ?%

Appendix B

List of the surveyed robotics courses

(SU: Senior Undergraduate; G: Graduate; AG: Advance Graduate)

	Course No.	*Course Name*	*Instructors*	*Department*	*University or Institute*	*Level*
1	*EML 6281*	*Robot Geometry I*	*Dr. Carl Crane*	*Mechanical and Aerospace Engineering*	*University of Florida*	*G*
2	*16-711*	*Kinematics, Dynamic System and Control*	*Dr. Chris Atkeson*	*Robotics Institute*	*Carnegie Mellon University*	*G*
3	*MEAM 620*	*Advanced Robotics*	*Dr. Vijay Kumar, et al.*	*Mechanical Engineering and Applied Mechanics*	*University of Pennsylvania*	*AG*
4	*EML 6834*	*Dynamics and Control of Robots*	*Dr. Gloria Wiens*	*Mechanical and Aerospace Engineering*	*University of Florida*	*G*
5	*ES 159/259*	*Introduction to Robotics*	*Dr. Robert Wood*	*Engineering and Applied Science*	*Harvard University*	*G/SU*
6	*N/A*	*Introduction to Mobile Robotics*	*Dr. Roland Siegwart*	*Institute of Robotics and Intelligent Systems*	*Swiss Federal Institute of Technology*	*G*
7	*CS 5247*	*Motion Planning and Application*	*Dr. David Hsu*	*Computer Science*	*National University of Singapore*	*G*
8	*CSAIL 6141*	*Robotics: Science and Systems*	*Dr. Daniela Rus, et al.*	*Electrical Engineering and Computer Science*	*Massachusetts Institute of Technology*	*G*
9	*CS 495/596*	*Software for Intelligent Robots*	*Dr Lynne Parker*	*Electrical Engineering and Computer Science*	*University of Tenessee*	*G/SU*
10	*ME 8204*	*Robotics: Analysis and Control*	*Dr. Hashem Ashrafiuon*	*Mechanical Engineering*	*Villanova University*	*G*
11	*ME 4524/ECE 4704*	*Robotics and Automation*	*Dr. Daniel Stilwell*	*Electrical and Computer Engineering*	*Virginia Tech*	*SU*
12	*2.12*	*Introduction to Robotics*	*Dr. Harry Asada*	*Mechanical Engineering*	*Massachusetts Institute of Technology*	*SU*

Biographical Information

Ping Ren is a PhD candidate working under the direction of Dr. Dennis Hong in RoMeLa (Robotics & Mechanisms Laboratory) of the Mechanical Engineering Department at Virginia Tech. He is passionate about advancing research in robot kinematics, dynamics, control, and innovations related to robotics education.

Dennis Hong is an Associate Professor and the Director of RoMeLa (Robotics & Mechanisms Laboratory) of the Mechanical Engineering Department at Virginia Tech. His research expertise lies in the area of mobile robot locomotion, humanoid robots, and autonomous systems. Dr. Hong is also the faculty advisor for Virginia Tech's team for RoboCup, and the co-team leader for team VictorTango for the DARPA Urban Challenge where they won third place and the $500,000 prize. He was awarded the prestigious NSF CAREER award in 2007 and has received numerous awards from ASME, NASA, and the College of Engineering at Virginia Tech for his research and work with students.

Janis P. Terpenny is a Professor with a joint appointment in the Departments of Engineering Education and Mechanical Engineering with an affiliate position in Industrial & Systems Engineering at Virginia Tech. Dr. Terpenny is the director of the multi-university NSF Center for e-Design. Her research focuses on design process and methodology, knowledge engineering, product families and platforms, methods to predict/respond to obsolescence and design education. She is a Fellow of IIE and a member of ASEE, ASME, and Alpha Pi Mu. She is also an Associate Editor for the Journal of Mechanical Design and an Area Editor for The Engineering Economist. At Virginia Tech, she is a Diggs Teaching Scholar and NSF Advance Professor.

Richard M. Goff is an Associate Professor in the Department of Engineering Education. He has been teaching engineering for over 30 years and is currently assistant department head and co-director of the engineering first-year program in the Department of Engineering Education. He is the director of the Frith Freshman Engineering Design Laboratory in operation since 1998. He is committed to creating interdisciplinary, innovative, sustainable, and engaging design projects in engineering education. His educational background is in Aerospace Engineering and has worked in the aerospace and motorcycle industries. He is an active member of ASEE, ASME, and SAE. Dr. Goff teaches first-year, senior and graduate design courses and is the faculty advisor of the VT Baja SAE Team. His research areas are in curricular design and design education.