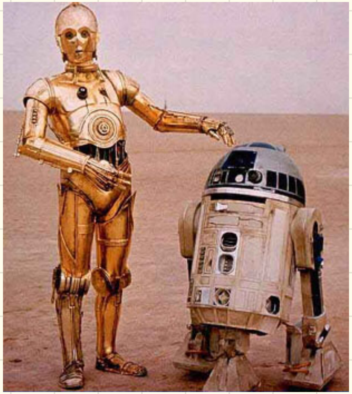
AME 50551

Introduction to Robotics



Welcome!

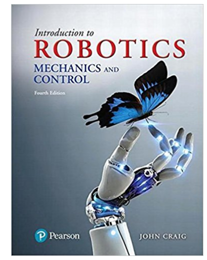
Spong +
Lynch & Park (Free PDF) +++

AME 50551 - Introduction to Robotics

Fall 2018, University of Notre Dame

Instructor: Dr. Patrick Wensing, pwensing@nd.edu
Office: 373 Fitzpatrick Hall, **ph:** 631-2652
Office Hours: M: 9:30-11:00 (373 Fitzpatrick), W: 4:30-6:00 (Room TBD), by Email
TRAD   Problem Solve

TA: Tan Chen, tchen8@nd.edu
Office Hours: Th: 1:30-3:30 (364 Fitzpatrick)



Required Text: Introduction to Robotics, Fourth Edition, J. J. Craig, Pearson, 2017
ISBN: 9780133489798
Bookstore Link: `www.bkstr.com/ProductDisplay?productId=76987441&storeId=10900`

Class Meetings: MWF 8:20 - 9:10 AM, Debartolo Hall, Room 129
Live Schedule: `https://goo.gl/bWruvU`

Learning Objectives: The objective of this course is for students to develop fundamental skills for the analysis, design, and control of robotic manipulators. Successful engineering of robotic systems is a multifactorial challenge, requiring competencies in kinematics, dynamics, design, control, mechatronics, and programming. This course will allow students to hone skills in each of these areas, but will place focus on aspects of kinematics, dynamics, and control.

Topics: Representations of orientation (Euler angles, angle-axis, rotation matrices), homogenous transformations, Denavit-Hartenberg convention for serial kinematic chains, direct and inverse kinematics of serial manipulators, differential kinematics and the Jacobian matrix, Newton-Euler and Lagrangian dynamics, trajectory planning, position control, force and impedance control, introductory nonlinear manipulator control.

Prerequisite: AME30314 Differential Equations, Vibrations, and Controls I

Prerequisite material: Newtonian dynamics in 2D, introductory linear algebra (general matrix operations, matrix inverses, determinants), linear differential equations and basic Laplace transforms, basic MATLAB.

Important Dates:

Wed. Aug. 22	First class meeting	Fri. Oct. 26	Last day for discontinuance
Tues. Aug. 28	Last date for class changes	Fri. Nov. 2	Exam 2
Fri. Sept. 21	Exam 1	Wed. Dec. 5	Last class meeting
Mon. Oct. 15	Mid-term deficiency reports submitted	Thur. Dec. 13	Final Exam

Grading:

Breakdown:	
Exam 1	25%
Exam 2	25%
Final Exam	35%
HWs/Projs.	15%

Grade Guarantees:			
A	90-100	B–	70-74.9
A–	85-89.9	C+	65-69.9
B+	80-84.9	C	60-64.9
B	75-79.9	C–	55-59.9

10 HWs 10%
2 Projects 5%

The class will be curved. With the curve, your final grade is guaranteed to be no worse than the one earned according to the scale above. I may further add up to 5 percent to your final score if I do not believe your grade adequately reflects your mastery of the material.

Exams: Exams will be closed book and you will be permitted to use your own notes sheets (one double-sided 8.5”×11” page for exam 1, two pages for exam 2, and three pages for the final). Providing or receiving aid from any students or unauthorized materials during an exam is strictly prohibited. If you have a legitimate reason to miss an exam, such as a documented illness or family emergency, contact me as soon as possible. In the case of an excused absence, a make-up exam will be administered for full credit. If the absence is unexcused, the opportunity for a make-up is left to the discretion of the instructor, but credit will not exceed 70%.

Homework:

- Homework is due at the beginning of class. *Late homework submissions will not be accepted for credit.* Late homeworks may still be submitted for feedback only. Your lowest homework score will be dropped.
- Homework should follow a number of technical guidelines:
  1. Homework should be done on 8.5 inch by 11 inch paper, using only one side. Edges should be clean.
  2. The top of the first page should list your name and the homework number.
  3. Pages should be stabled together.
  4. The top right of each page should be numbered, with total pages indicated (e.g. Page 3 of 6 or 3/6)
  5. Derivations should be supplemented with text explaining the procedure. Symbols must be defined.
  6. Numerical calculations must always be preceded by the algebraic form of the equation.
  7. Final answer(s) should be identified with a surrounding box. Identify nothing else with a box.
  8. Assignments should be clear and legible.

  Grade reductions may be imposed if any of the above guidelines are not followed.
- You are encouraged to collaborate on homework. However, submitted material must be your own work and accurately reflect your own understanding at the time of writing.
- Exact copying, wholly or in part, from another student or any outside resource is strictly prohibited.
- The use of outside resources (other text books, websites, academic papers, etc.) is allowed. However, previous homework solutions, solution manuals, or graded homeworks from a previous course are not permitted as outside resources. Any result/equation/etc. obtained from an approved outside resource must be cited in your homework submission. You do not need to cite AME50551 course materials.

Honor Code: (http://honorcode.nd.edu/the-honor-code/) The university community has a shared commitment to respect and honor the intellectual and creative contributions of each individual. As a precondition for admission to the University, all students pledge:

> *"As a member of the Notre Dame community, I will not participate in or tolerate academic dishonesty."*

Beyond this simple pledge, it is your responsibility to become familiar with the Academic Code of Honor, and to adhere to the responsibilities it outlines. Any suspected violation of this code, including but not limited to violation of integrity requirements detailed in this syllabus, will be reported through the procedure described in Section V.D of the Honor Code.

Regrade Requests: If there is an error in the grading of an exam or homework, students may submit a written regrade request. Requests must adhere to the following guidelines.

1. Regrade requests will *not* be accepted in the first 24 hours after an assignment/exam is returned.
2. Following this initial waiting period, regrade requests will be accepted for two business days.
3. Requests should make a clear case for where and why a regrade is being sought.
4. Requests should be placed in my mailbox within the AME main office, 365 Fitzpatrick.

Accommodations: Any student who has a documented disability and is registered with Disability Services should speak with the professor as soon as possible regarding accommodations. Students who are not registered should contact the Office of Disability Services - http://disabilityservices.nd.edu.

Preliminary Schedule

Class	Day	Date	Topic	Text
1	W	8/22	Introduction	Chapter 1
2	F	8/24	Representations of position and orientation	Chapter 2
3	M	8/27	Representations of position and orientation	Chapter 2
4	W	8/29	Representations of position and orientation	Chapter 2
5	F	8/31	Denavit-Hartenberg convention	Sections 3.1 - 3.4
6	M	9/3	Denavit-Hartenberg convention	Sections 3.1 - 3.4
7	W	9/5	Forward kinematics	Sections 3.5 - 3.10
8	F	9/7	Forward kinematics	Sections 3.5 - 3.10
9	M	9/10	Forward kinematics	Sections 3.5 - 3.10
10	W	9/12	Inverse kinematics	Chapter 4
11	F	9/14	Inverse kinematics	Chapter 4
12	M	9/17	Inverse kinematics	Chapter 4
13	W	9/19	Exam 1 Review	
14	F	9/21	**Exam 1 (Covers Lectures 1-9)**	
15	M	9/24	Velocity kinematics	Sections 5.1 - 5.7
16	W	9/26	Velocity kinematics	Sections 5.1 - 5.7
17	F	9/28	Jacobians	Section 5.1-5.8
18	M	10/1	Numerical inverse kinematics, Jacobian singularities	
19	W	10/3	Numerical inverse kinematics	
20	F	10/5	Static force analysis	Sections 5.9 - 5.11
21	M	10/8	Dynamics of a rigid body	Sections 6.1 - 6.4
22	W	10/10	Dynamics of a rigid body	Sections 6.1 - 6.4
23	F	10/12	Newton-Euler dynamics	Sections 6.4 - 6.8
			Midterm Break	
24	M	10/22	Newton-Euler dynamics	Sections 6.4 - 6.8
25	W	10/24	Newton-Euler dynamics	Sections 6.4 - 6.8
26	F	10/26	Newton-Euler dynamics	Sections 6.4 - 6.8
27	M	10/29	Lagrangian dynamics	Sections 6.9 - 6.13
28	W	10/31	Exam 2 Review	
29	F	11/2	**Exam 2 (Covers Lectures 10 - 26, no numeric IK)**	
30	M	11/5	Lagrangian dynamics	Section 6.9 - 6.13
31	W	11/7	Lagrangian dynamics	Section 6.9 - 6.13
32	F	11/9	Manipulator design	Chapter 8
33	M	11/12	Manipulator Design	Chapter 8
34	W	11/14	Trajectory planning	Chapter 7
35	F	11/16	Trajectory planning	Chapter 7
36	M	11/19	Linear position control	Chapter 9
			Thanksgiving Break	
37	M	11/26	Linear position control	Chapter 9
38	W	11/28	Nonlinear manipulator control	Sections 10.1-10.6, 10.8
39	F	11/30	Force control	Chapter 11
40	M	12/3	Review	
41	W	12/5	Wrap up	
	Th	12/13	**Final (Cumulative)**	

Kinematics

Dynamics in 3D

Control & Design

Getting to Know you:

www.pollev.com/ame50551

Project 0

shortening

AME 50551: Introduction to Robotics

Project 0: Introductions

Email to Dr. Wensing (pwensing@nd.edu) by Friday, Aug. 24th, 11:59 PM

The goal of this "project" is for me to get to know a bit about each of you. With a video recording device of your choosing, shoot a short (1-2 minutes) video of yourself that answers the following questions:

- What is your name? What year are you in school?
- What is your motivation for taking AME 50551? What are you hoping to get out of the course?
- What types of instruction have helped you learn best in the past? (straight lectures, examples in class, challenging homework, activities in class, etc.)
- What has been your favorite part of your time at Notre Dame?
- Optional: What is a fun fact about yourself? (e.g., What is something you are passionate about? Are you involved in any student activities? etc.)

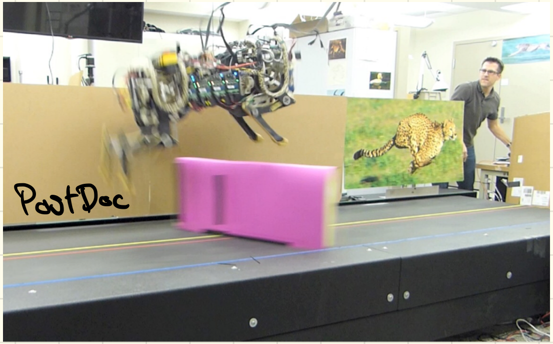
Your submissions will not be shared with the class. My intent is for you to spend no more than 10 minutes on this project (with the majority of the time reflecting before you record). It is perfectly acceptable if you, for instance, film the video on your phone on the way to your next class and email it to me right then. I'm not looking for something polished, just a quick introduction.

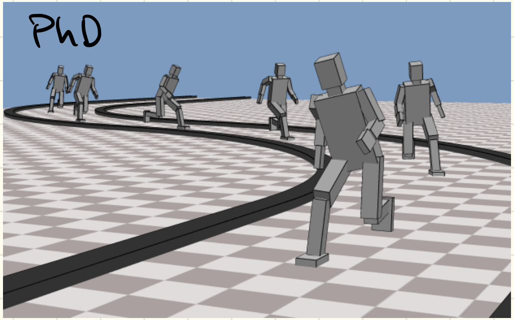
Getting to know me:

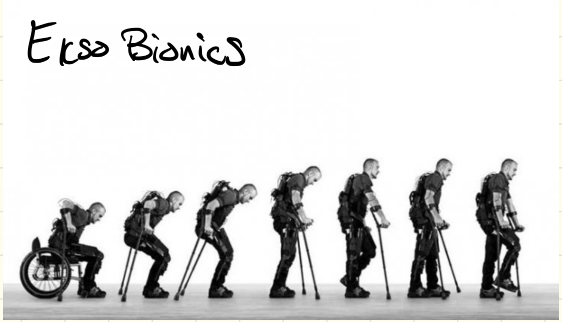
- Research
  - Humanoids
  - Quadrupeds
  - Exoskeletons

  } Dynamics/controls

- Cycling/Run







What is a robot?

(Autonomous)

automatically controlled

Sense, Think, Act

sensing, computation, actuators

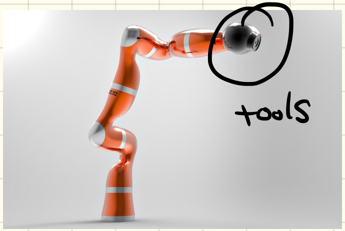
- Produce useful movement (physical work) in response to sensors

Fixed Automation

- Special purpose

Robot Manipulator

- Versatile
- New year, new cars

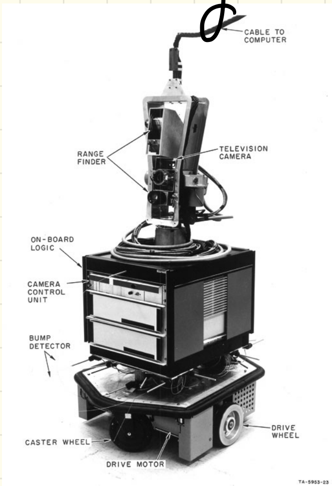


	Industrial Bots	Mobile Bots
Applications	• Assembly / Manufacturing Bottling • Transport • Casting • Measuring • Painting • Welder	• Transport / Driverless Cars/Trucks • Household cleaning • Healthcare Robots / Caregiver robots • Space exploration • Military / Surveilance
Challenges	• Workspace • Speed • Strength • Lifetime • Accuracy / Precision • Reliability / Repeatability Solutions well understood environment controlled	• Accurate Sensing • Safety • Adaptation • Size / weight • Energy Efficiency Solutions ongoing environment unknown

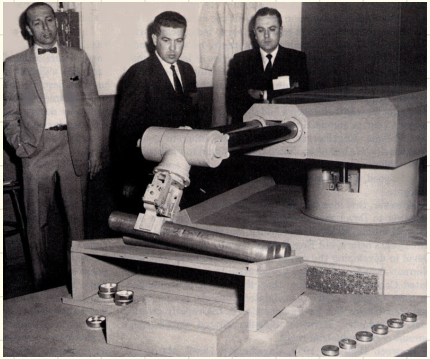
Bot History:

- "Robot" 1920's sci-fi play in Czech republic
- First inustrial robot - 1961 - Unimate ~ 4000 lbs
- Stanford Arm -1969- computer control
- Common - Design to minimize computation
- Mobile robot 1966 - AI

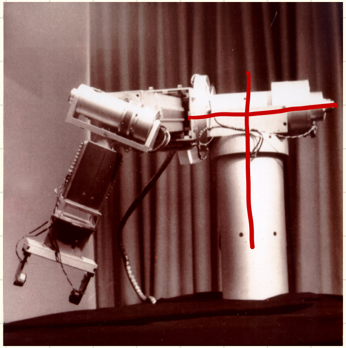
Shakey



Unimate -1961



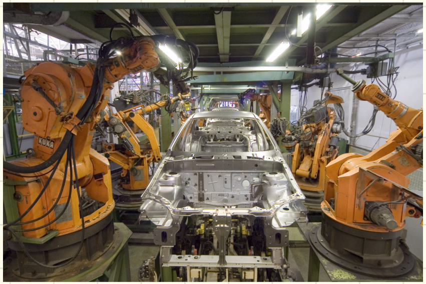
Stanford Arm 1969



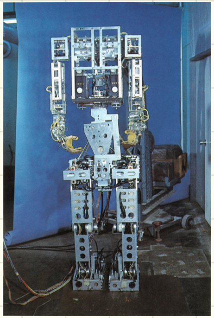
Bot History:

- 1970s – Legged locomotion research
- 1980s – Wide adoption of industrial bots
- Since 1970
    - Computers ~ 4 000 times faster
    - Actuators ~ about the same

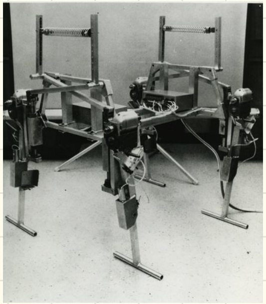
– Humans: 600 muscles / 200 DoFs – (100ms, 10Hz)
10s DoF – (50μs, 20KHz)



1983



WABOT
~1970s



Phony Pony
1966

Design: Mechanisms, Sensors, Actuators