UNIVERSITY OF WASHINGTON
ELECTRICAL ENGINEERING

EE543

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University of Washington

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Basics

MWF 1:30-2:20

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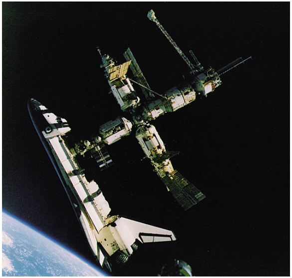
Course Web site: `http://https://canvas.uw.edu/courses/1021831`

- Spatial Serial Chain Mechanisms
- Mathematical Analysis
- Emphasis on computational issues
- Final Project (no final exam).

Fundamental Problems



Description of a positioning task

Q: How do we specify the position and orientation of robot arms and objects?

A: Frames, Homogeneous Transformations, and joint-space teaching.

Forward kinematics

Q: What is the position and orientation (configuration) of a robot end effector if joint positions are known?

A: A linear transformation (4x4 matrix) which is a function of the joint positions (angles, displacements) and specifies end effector configuration in the base frame. This matrix can also map a point in the end effector frame to its representation in the base frame.

Inverse kinematics

Q: What joint positions θ, do I need to achieve a given end effector configuration?

A: Form an equation by setting the 4x4 matrix of the foward kinematics problem equal to one specifiing the *desired* position and orientation. Then solve this equation for the joint positions. Be sure to watch out for existence of solutions and multiple solutions.

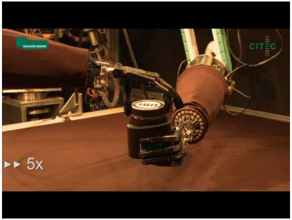
(Samtel Machines)

Velocity transformation

Q: What joint velocities, $\dot{\theta}$, do I need to achieve a given velocity of the end effector (both linear and angular velocity) in all three dimensions of a convenient reference frame?

A: Compute the "Jacobian Matrix", the matrix derivative, of the forward kinematic equations and invert it. Watch out for singular matrix in which case the inverse does not exist.

$$\dot{\theta} = J^{-1}\dot{x}$$



Force transformation

Q: What joint torques, τ, correspond to a given set of end effector forces and torques, F?

A: $\tau = J^T F$

Inverse dynamics

Q: For a given motion, $\ddot{\theta}, \dot{\theta}, \theta(t)$, what are the required joint torques?

A: We can derive a dynamic equation

$$\tau(t) = M(\theta)\ddot{\theta} + C(\theta, \dot{\theta}) + g(\theta)$$

by using the Recursive Newton-Euler or Lagrangian methods.

Position Control

Q: How can we command joint torques to achieve a desired end effector trajectory?

A: PID control, Feed-forward dynamic control (the method of computed torques).

Force Control

Q: How can we command joint torques to achieve a set of forces and torques at the end effector?

A: Open loop we can use $\tau = J^T F$. However because of friction and other losses in many typical manipulators we must use force sensing at the end effector and closed loop force control.

Trajectory Generation

Q: If we know a trajectory want to follow, how do we generate a time-function which is a quick but smooth and attainable trajectory between two configurations "A" and "B"?

A: Methods include polynomial splines and trapezoidal velocity profiles.

Motion Planning

Q: How do we decide the path to take between two configurations "A" and "B"?

A: Without considering obstacles, the most common approach is straight line interpolation. When obstacles and joint limits must be considered this becomes the AI motion planning problem.

Sensor Based Control

Q: How can I make use of non-joint sensor information (e.g. vision, proximity, etc.) to control robot motion (for example, to follow 1cm above an unknown surface).

A: Robot vision, vision servoing, sensor data fusion, world modeling, operational space control.

Telemanipulation

Q: How can a human operator control a remote manipulator in a "natural" and productive way to achieve a task goal?

A: Generalized bi-lateral teleoperation.

Youtube!

- Pick and Place http://www.youtube.com/watch?v=fizans6hCd8
- Robot Arm Tracking Conveyor Belt: http://www.youtube.com/watch?v=TMUWEx_zoHo
- ABB Fanta Can Challenge http://www.youtube.com/watch?v=PSKdHsqtok0
- ABB Fanta Can II http://www.youtube.com/watch?v=SOESSCXGhFo
- A robot, a bowling ball, and a Winnebago http://www.youtube.com/watch?v=LAtdsDTt__s

In-Class-Problems (ICPs)

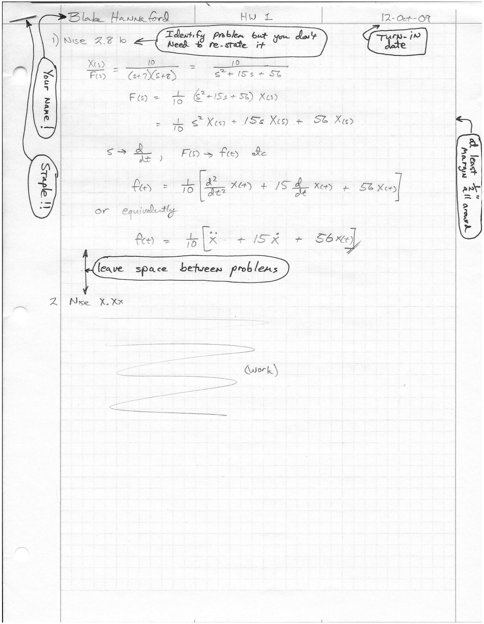
- Each week 50% of class time
- Work in class
- Small groups or individual
- Turn in work at end of class (no extensions)
- ICPs graded on **effort**

Homework

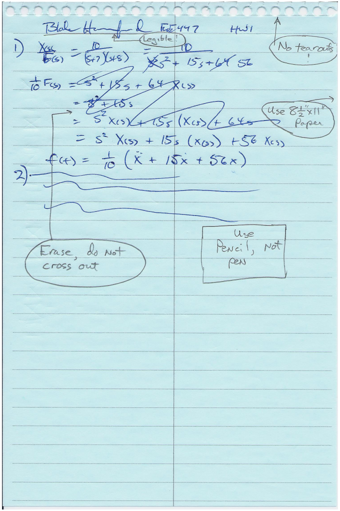
There will be 8 problem sets.
Homework will be collected in class on specified due dates.
Late homework will be accepted according to the following policy:

- up to one week late: -25%
- one to two weeks late: -50%
- two or more weeks late: **not accepted**.

GOOD Example



BAD Example



You are responsible for all content on Catalyst Be sure to check for revisions before starting your homework. Most useful stuff:

- "Files" section
- "Discussions" section

Anonymous Feedback:
`https://catalyst.uw.edu/umail/form/blake/4620`

Final Project

Create a robot example for the book "50 solved robots."

- Design your own robot arm
- Compute the forward kinematics equations
- Solve the inverse kinematic equations
- Derive the Jacobian Matrix
- If any step is too hard, redesign the manipulator

We will have access to a symbolic math toolkit in Python using the `sympy` and `numpy` packages.

We will use the toolkit for all problems of 5 DOF or greater, but do hand computations for < 5 DOF.

Grading

- 450 Total Points
- Divide by 100 and round
- Breakdown:

Homework (8 x 15)	120
ICPs (8 x 5)	40
Midterms (2 x 90)	180
Take Home Final	110
Total	450

Adjustment Policy

Grading is not an exact science. I reserve the right to check the average and make sure it is representative of the quality of the class as a whole. If it is not, I will add or subtract an appropriate offset to all class members equally.

Academic Integrity: ICPs

- Work together with people
- Ask questions
- Help each other (great way to learn)
- Share methods
- Create an open learning environment

Academic Integrity: Homework

- Turn in only your own work.
- Help each other with ideas and techniques but *not* answers.
- Examples:
  Some things it would be OK to say to a friend in the course:
  - "Use the complex conjugate"
  - "Try the method the book used in example 4.7"
  - "You made a sign error in the 3rd step of your solution. It should have been $-x$."
  - "You forgot to include units with your answer."

  Some things it would NOT be OK to say:
  - "Here's my solution" (showing / sending the document)"
  - "I'll take you through it step by step. Just copy down these equations."
- No copying or giving/loaning material to be copied.

Academic Integrity: Exams

- Turn in only your own work.
- No peeking at other's exams.
- No talking about any exam related information during the exam.
- Follow the Open/Closed book policy announced for the exam (EE447: Closed Book)

Criteria

Criteria for suspicion of cheating include:

- Identical work, especially when answers are wrong or wildly wrong.
- Similar work where an improbable wrong method has been used.
- Writing or graphics which can be found on the internet.
- Visual observation of copying (on an exam for example) by the professor or TA's.
- Other evidence that work has been copied.

Sanctions

- Any assignment or exam meeting the above criteria will have an automatic total grade assigned of zero.
- All suspected cheating will be reported immediately through the College of Engineering's academic misconduct procedure.
- See: `http://www.ee.washington.edu/academics/undergrad/AcademicMiscon` and `http://www.engr.washington.edu/mycoe/am/index.html`

If you have any questions or concerns about this policy, please communicate them to Prof. Hannaford through the annonymous feedback feature, by email, or in person at office hours.