1.1 Goals

Prepare to do research in future

- Primary Areas: nonlinear control, path planning, mobile robotics, grasping, soft robotics
- Secondary Areas: legged robotics, active safety, HRI
- Not Covered: learning, estimation, SLAM, vision, mechatronics

General Research Skills: reading papers (a lot), presenting work (at least three), and writing reports (for all four projects)

1.2 Logistics

Prerequisites

- 106A
- EE128
- Lin Alg
- Python and MatLab
- Curiosity
- Interest in experimental work

Staff emails on course website
Piazza for fastest response
Lectures: T/Th 3:30-5 pm
No exams :D
HWs are biweekly
Five slip days, max two for one hw
Must scribe at least one lecture
Paper presentation: one in lab (same as one hw), slide or word based, twenty minutes
Projects: four total, 40-60 hours, groups of three, at least one who took 106A and one with controls experience
Can reserve robot three hours at a time and can only make new reservation when current expires else five percent deduction from project grade
Project due dates on website
Proj 1: trajectory tracking with control on baxter/sawyer
Proj 2: path planning with turtlebots
Proj 3: grasping with baxter/sawyer
Proj 4: soft robotics
Final Proj:

- proposal due 3/20 and presentations will be on friday of RRR week
- should be research projects applying multiple parts of the course material including some sensing, planning, and actuation

Graduate students have more expectations that undergrads can do for extra credit

Disc

- W 2:00pm-3:00pm 237 Cory, Valmik and Amay
- W 4:00pm-5:00pm 293 Cory, Valmik and Amay

OH

- Prof. Bajcsy: Weds 11-12, Thursday 1-2 (SDH 719)
- Prof. Sastry: Tuesday 1:15-2:30 (Cory 333B)
- Tiffany: Tuesday 11-12 (Cory 111)
- Amay: Monday 4-5 (Cory 111)
- Jun: Monday 5-6 (Cory 111)
- Valmik: Tuesday 12-1, Wednesday 5-6 (Cory 111)

Labs

- Thursday 5-8pm Cory 111, Tiffany
- Friday 11am-2pm Cory 111, Amay
- Friday 2-5pm Cory 111, Jun

Should be 1.5-2 hours most days, rest will be OH

### 1.3 Announcements

- Look at website
- Join Piazza and Gradescope
- Disc 1 tomorrow
- Lab 0 in lab sec this week
- HW 1 assigned tomorrow
- Project 1a released this week and will be discussed during lab section
1.4 Expectations

- Emphasis on collaboration and exploration
- Ask a lot of questions
- It’s okay to be confused
- Expect to work hard

1.5 Rotational Matrices

will rotate any vector q about some axis w by an angle represented as linear transformations
\[ R: \mathbb{R}^3 \rightarrow \mathbb{R}^3 \]
\[ q_A = R_{AB} q_B \]

1.6 Linear Transformations

\( T_{AA} : A \rightarrow A \)
Left Multiplication: Change output frame \( R_{BAT_{AA}} : A \rightarrow B \)
Right Multiplication: Change input frame \( T_{AA} R_{BA} : B \rightarrow A \)
Change both input and output frames: \( R_{BAT_{AA} R_{BA}^{-1}} : B \rightarrow B \)

1.7 Groups

Rotations as a Group

\( SO(n) \) are a group of special orthogonal matrices under matrix multiplication which can represent any rotation

Properties of Rotation Matrices:
\[ R^{-1} = R^T \]
\[ \det(R) = +1 \]

Properties of Groups:

Closure: \( \exists P, Q \in SO(n) \rightarrow PQ \in SO(n) \)
Associativity: \( \exists A, B, C \in SO(n)(AB)C = A(BC) \)
Identity: \( \exists I \in SO(n) \text{s.t.} AI = IA = A \forall A \in SO(n) \)
Inverse: \( \forall A \in SO(n) \exists A^{-1} \in SO(n) \text{s.t.} AA^{-1} = I \)
1.8 Lie Group

Rotations as a Lie Group

SO(n) is a continuous, smooth group which means that it has a tangent space

SO(n) at any point can define a tangent or derivative space

1.9 Lie Algebra

so(n) = \( S \in \mathbb{R}^{n\times n} : S^T = -S \)

example: so(2) and so(3)

1.10 Exponential Map

elements in lie algebra are essentially velocities moving at some velocity \( \hat{w} \) for a time T to find any element in the group

\( \dot{R}(t) = \hat{w}R(t) \)

From \( t = 0 \) to \( T \):

\( e^{\hat{w}T}R(0) = e^{\hat{w}T} \)

1.11 Practice Problem

SO(2)’s lie group is a circle while a line tangent to the circle would be its lie algebra or so(2)

1.12 More Rotations

Other Parameterizations of Rotations:

Using Euler angles: \( R = R_x R_y R_z \)

Axis Angle same as exponential

Unit Quaternions:

also a Lie Group

rotations correspond to 2 quaternions

computationally efficient
1.13 Velocities

Rotational Velocities

When we take the derivative of a rotation, we get a tangent plane of $R$ at its current value, not $so(n)$

\[ q_a = R_{ab}q_b \]
\[ \frac{d}{dt} q_a = \dot{R}q_b \]
\[ \dot{R} : q_b \rightarrow q_a \]

1.14 Use Lie Groups for Rotational Velocities

Represent Rotational Velocities with $SO(n)$

body velocity:

\[ \hat{w}^b_{AB} = R_{AB}^{-1} \dot{R}_{AB} \]
\[ = R_{BA} \dot{R}_{AB} \]
\[ = \dot{R}_{BB} \]

spatial velocity

\[ \hat{w}^b_{AB} = \dot{R}_{AB}R_{AB}^{-1} \]
\[ = \dot{R}_{AB}R_{BA} \]
\[ = \dot{R}_{AA} \]