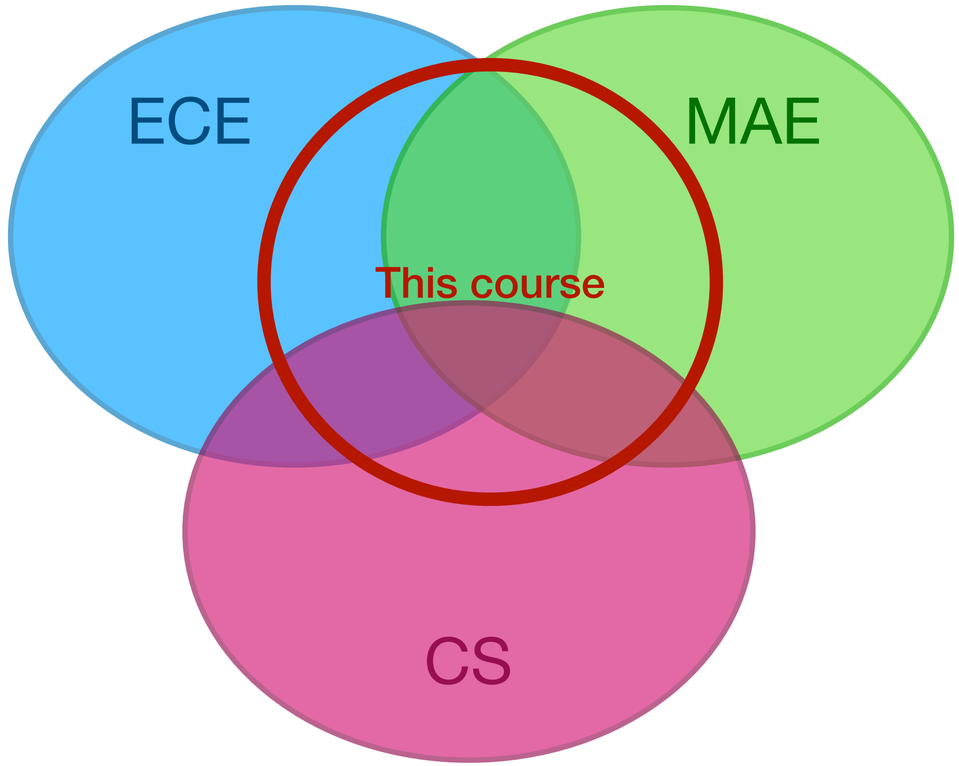
Introduction

Fast Robots, ECE4160/5160, MAE 4190/5190

E. Farrell Helbling, 1/21/25

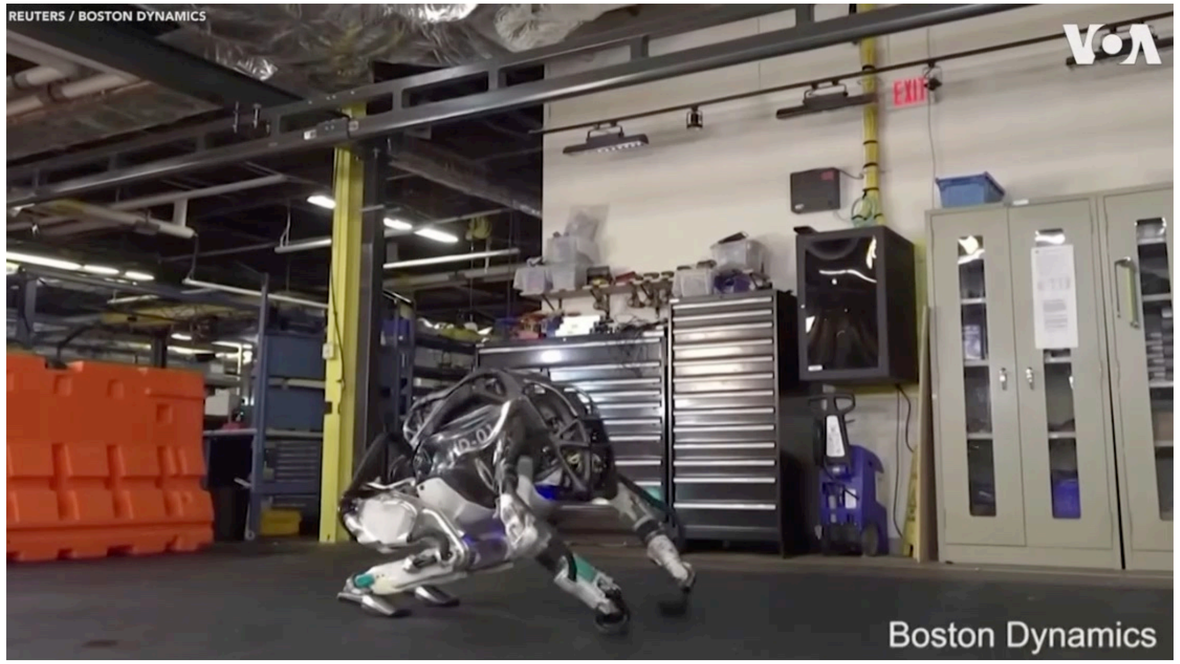
Why do you want to take this class?

- Exists somewhere between a CDE (learn through implementation)
- … and a foundations course
- Overlap with Autonomous Mobile Robots, Foundations of Robotics, and Feedback Control Systems



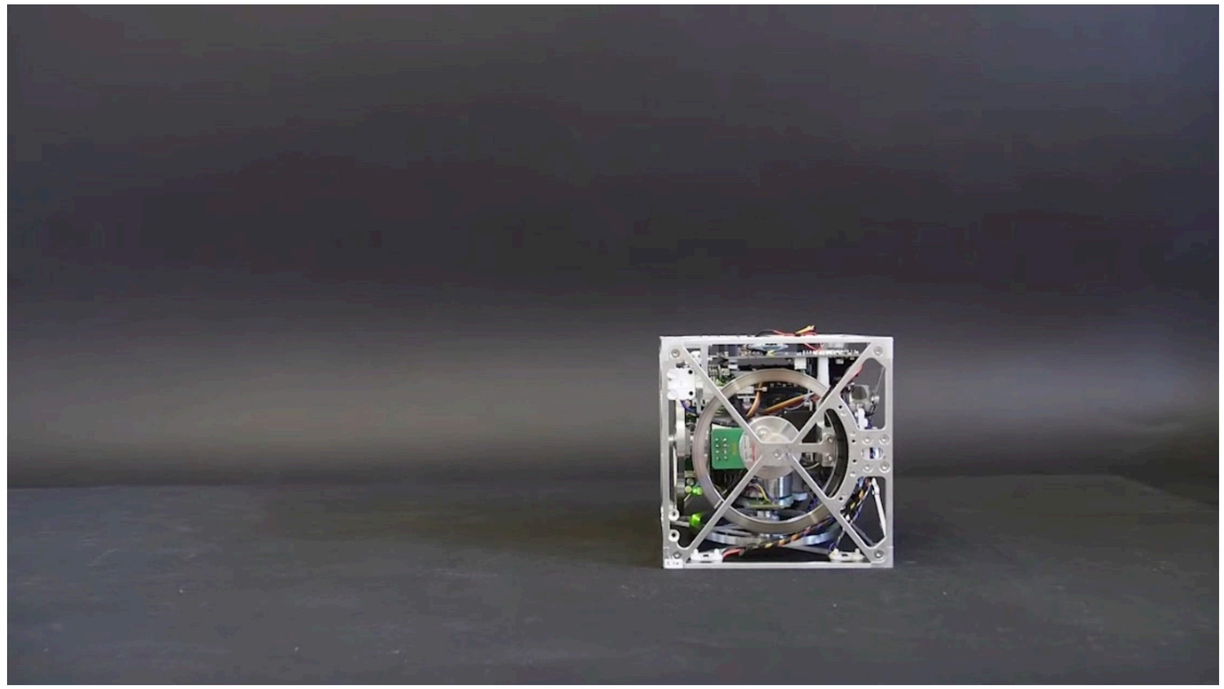
Fast Robots are fundamentally different

Kinematics — Dynamics



Fast Robots are fundamentally different

Stable — Unstable

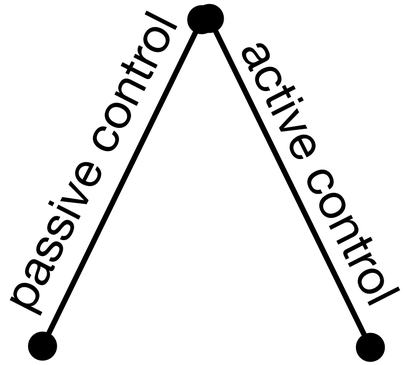


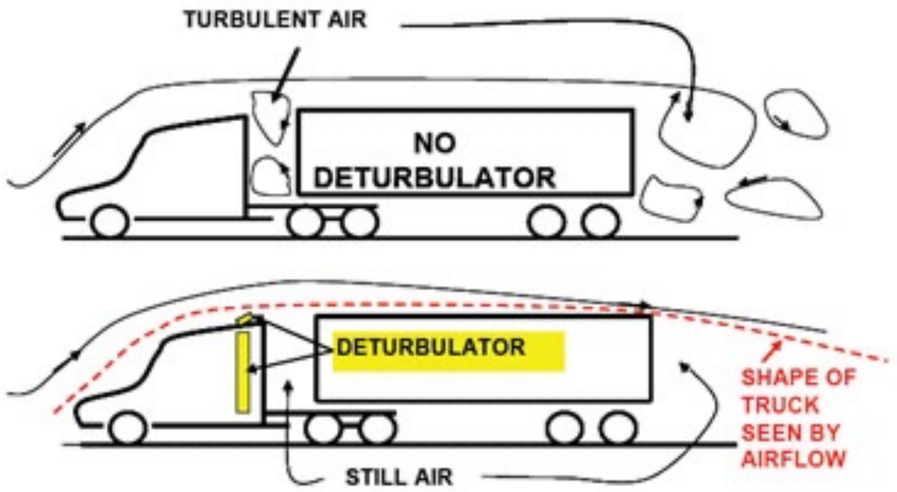
Fast Robots are fundamentally different

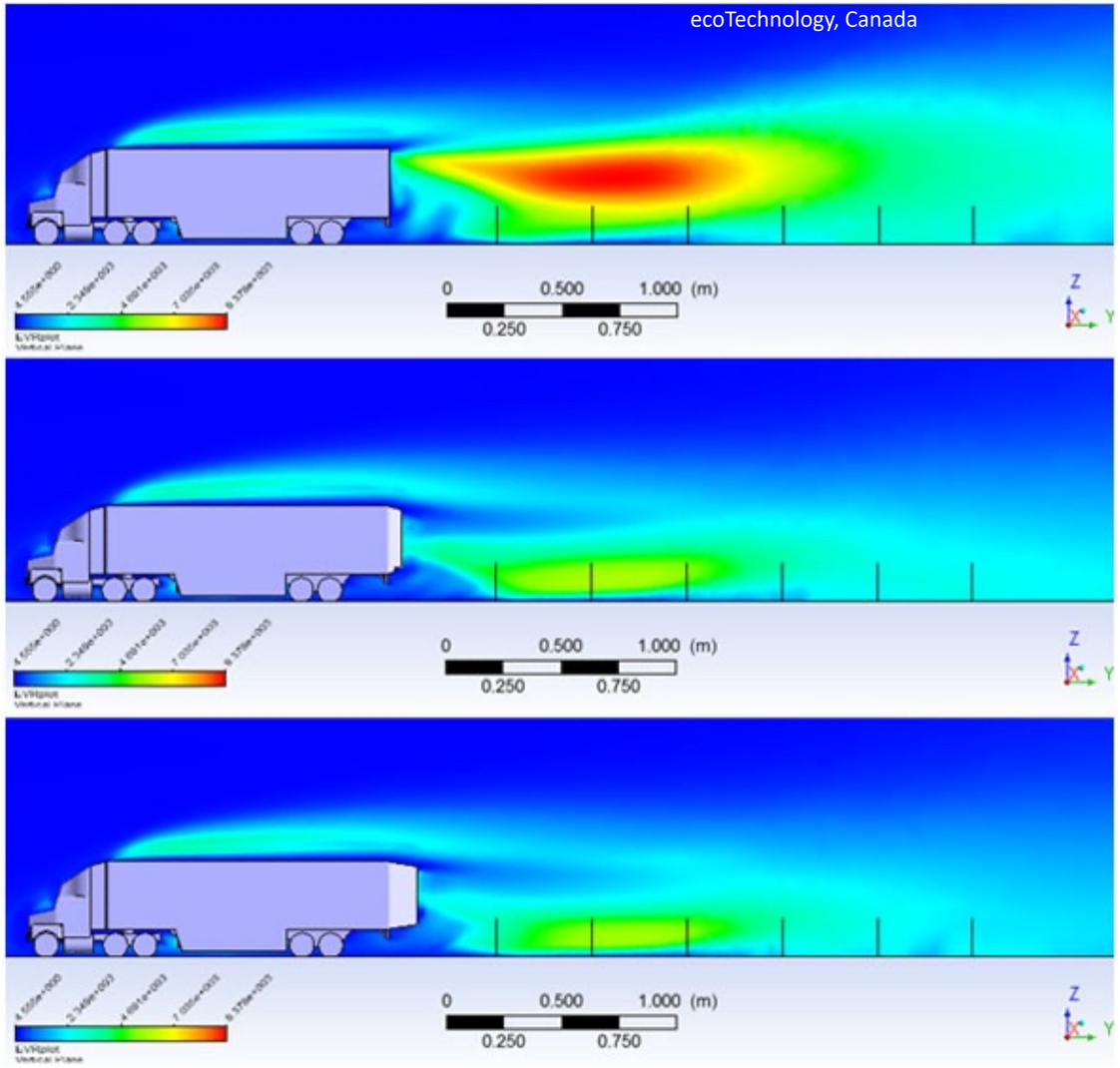
Design

- Requires more than good control theory and dynamic models
  - Practical implementation: mechanics, sensors, processing, estimation, etc.

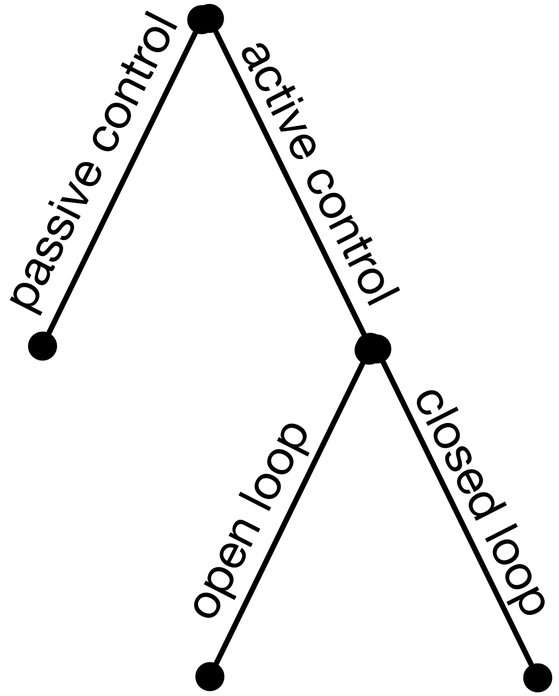
Control


passive control
active control


TURBULENT AIR
NO
DETURBULATOR
DETURBULATOR
SHAPE OF
TRUCK
SEEN BY
AIRFLOW
STILL AIR

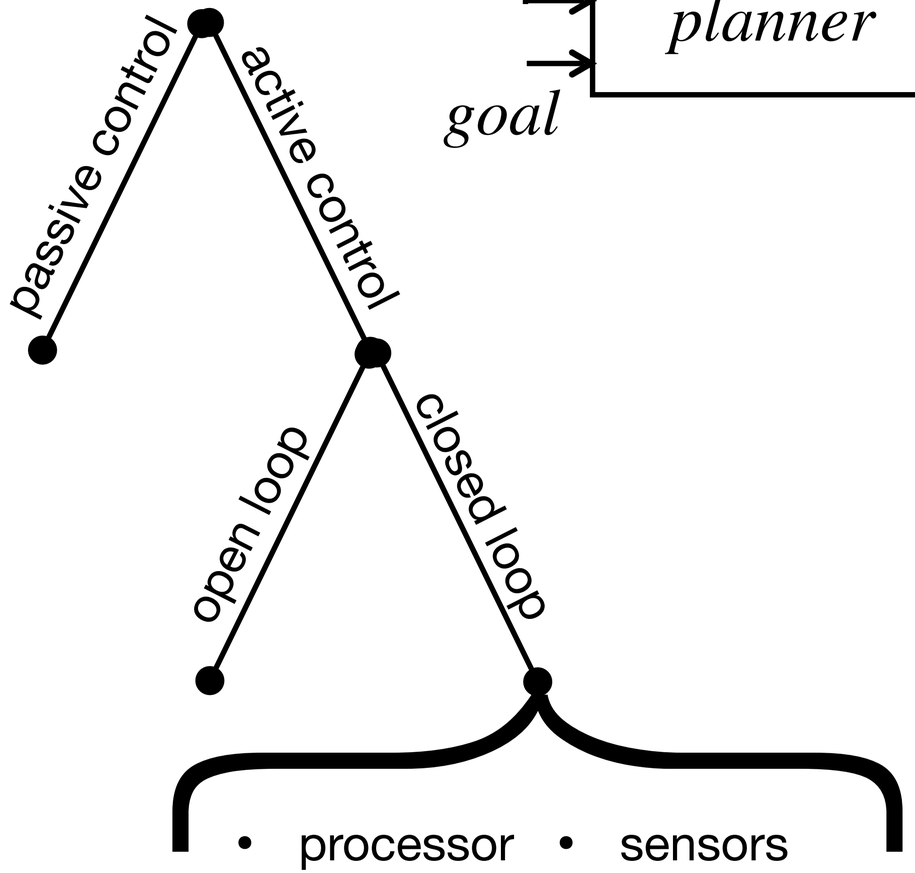

ecoTechnology, Canada
0
0.500
1.000 (m)
0.250
0.750

Control

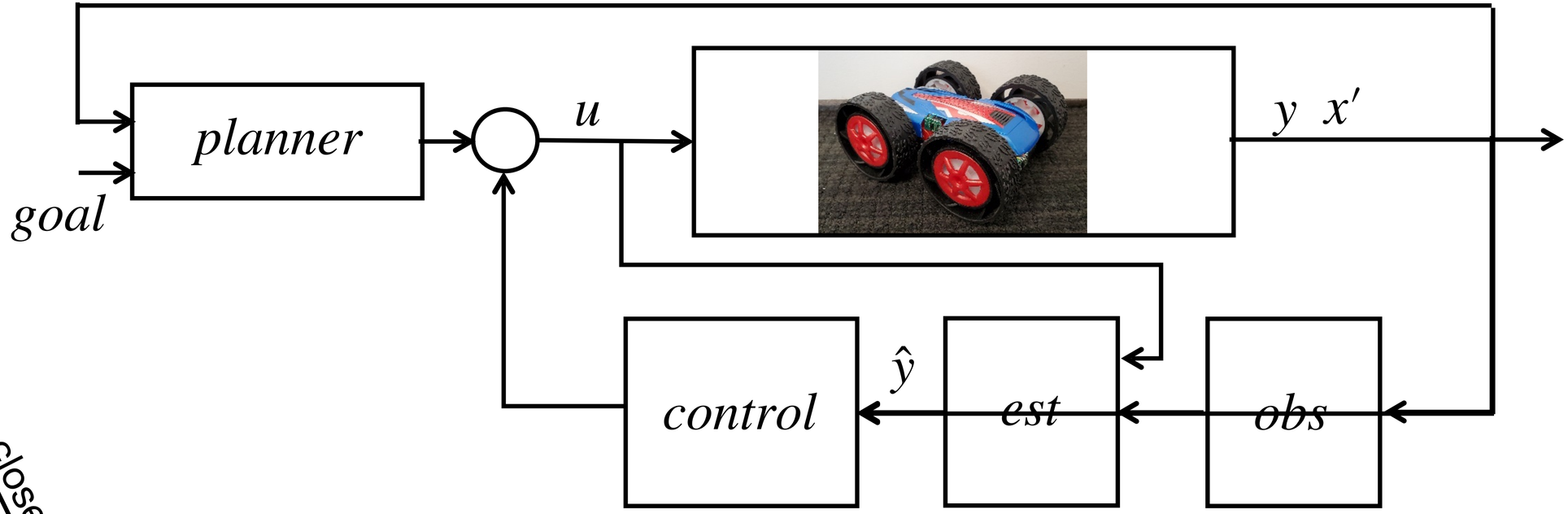


So why do we care about feedback?

Control



- processor
- drivers
- limits
- sensors
- noise/bias



Why do we need feedback control?

- System uncertainty
- Disturbances
- Instability
- Efficiency

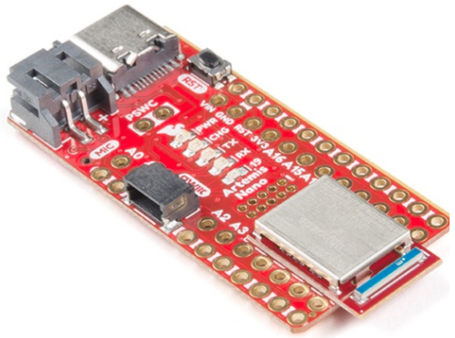
Class Layout

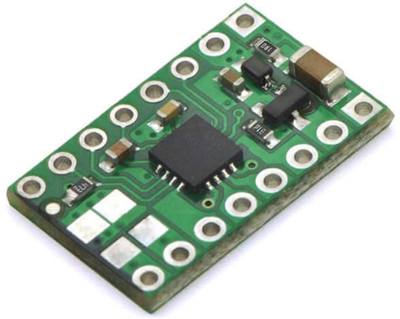
Lab 1-4: HW / Embedded SW	Lab 6-9: Feedback Control	Lab 10-12: Localization and Planning

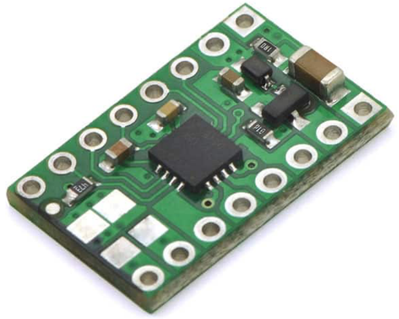
Lab 1-4: HW / Embedded SW	Lab 6-9: Feedback Control	Lab 10-12: Localization and Planning

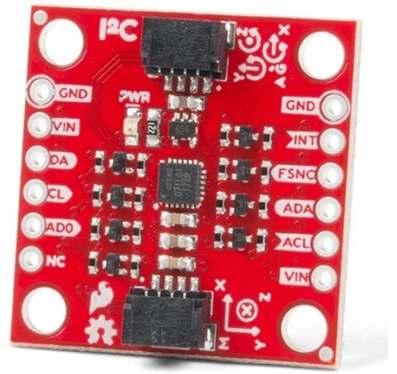
- Take the RC car base and combine with processor, sensors, and motor drivers
- Refresh on linear algebra and T-matrices
- Sensor modalities and types of sensors
- Actuators, drivers, circuits and routing, and EMI

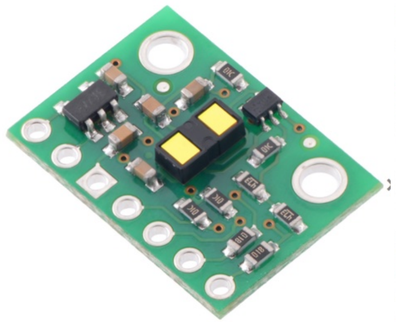
$125 lab kit! It’s yours!

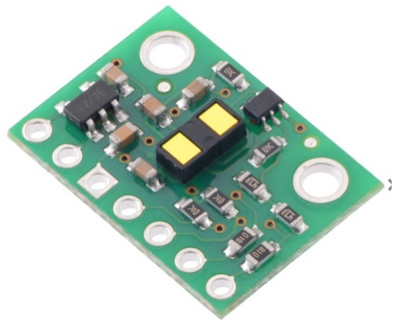










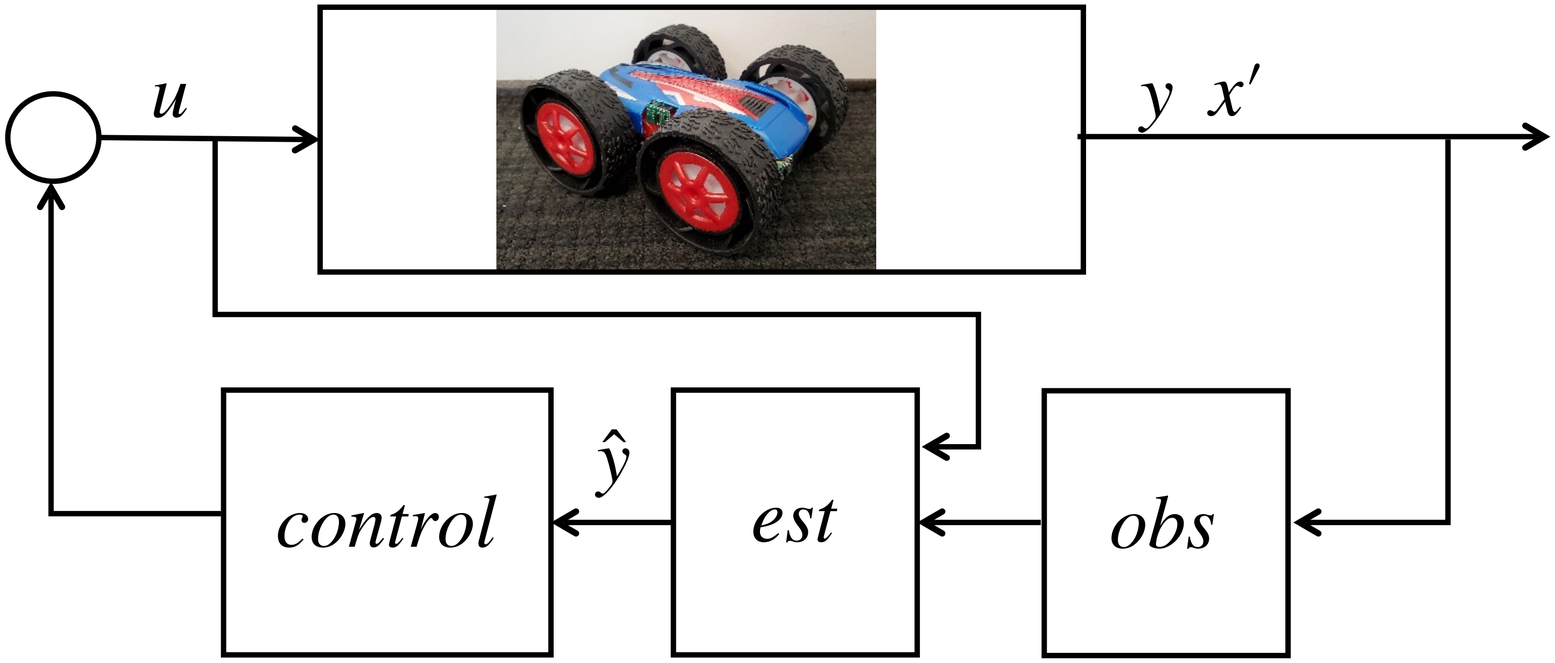


Lab 1-4: HW / Embedded SW

Lab 6-9: Feedback Control

Lab 10-12: Localization and Planning

- Linear systems, model-free and model-based control

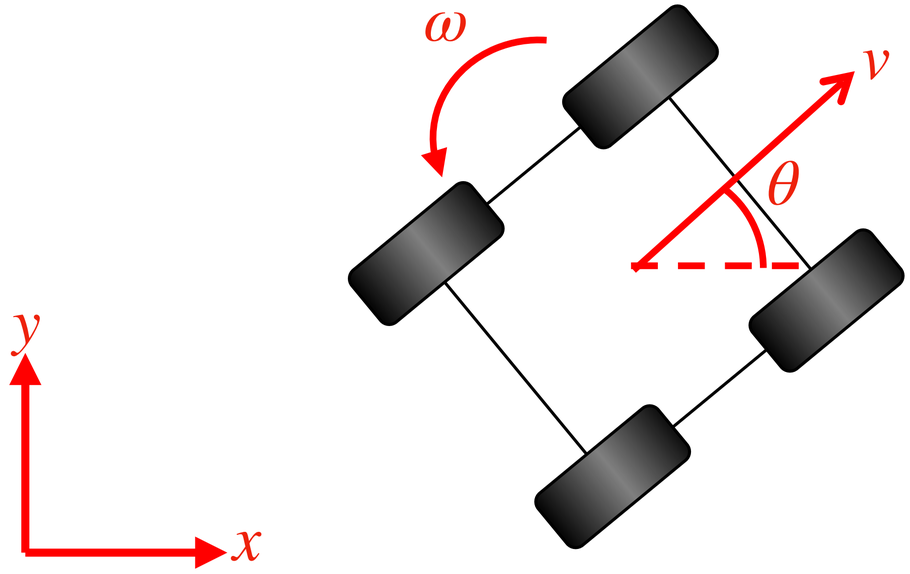


Lab 1-4: HW / Embedded SW

Lab 6-9: Feedback Control

Lab 10-12: Localization and Planning

- Linear systems, model-free and model-based control
  - PID controllers, theory, LQG control, Kalman Filters



$$\dot{x} = \cos(\theta)v$$
$$\dot{y} = \sin(\theta)v$$
$$\dot{\theta} = \omega$$

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & 0 \\ \sin(\theta) & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix}$$

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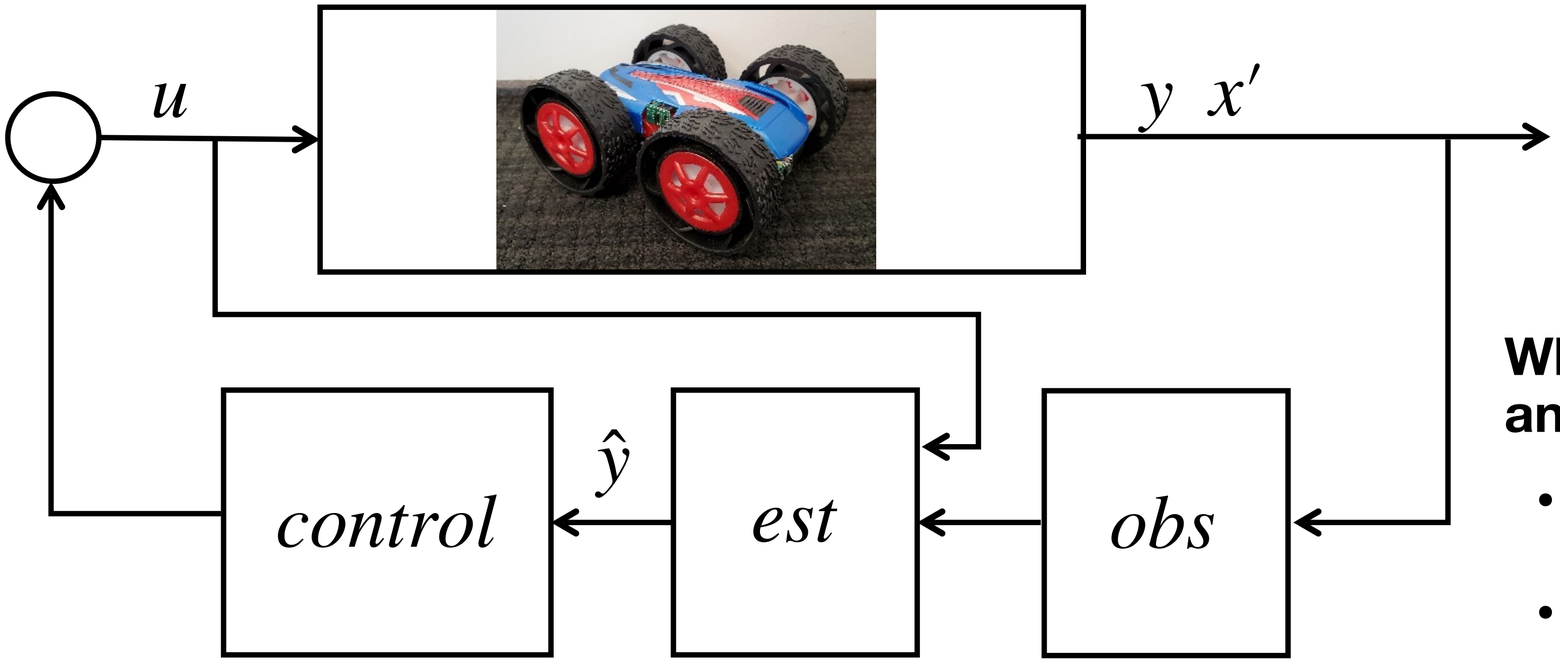


Why do we need feedback control and observers?

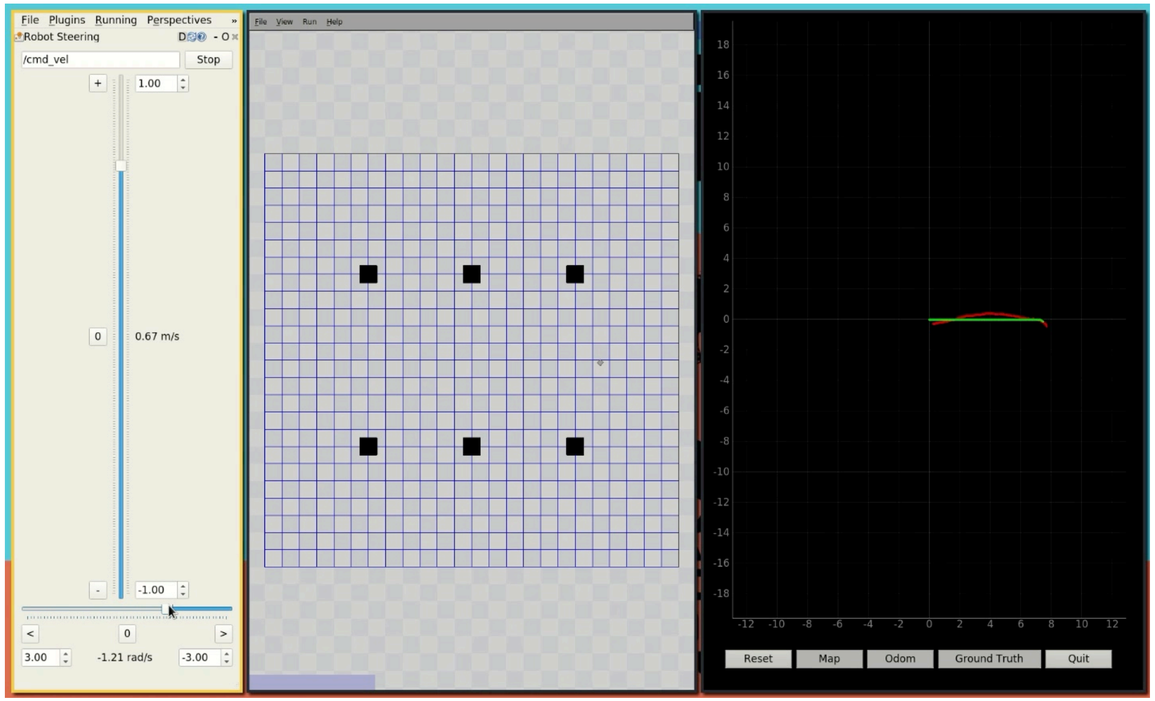
- Performance depends on the battery
- Sensing is slow (relatively)

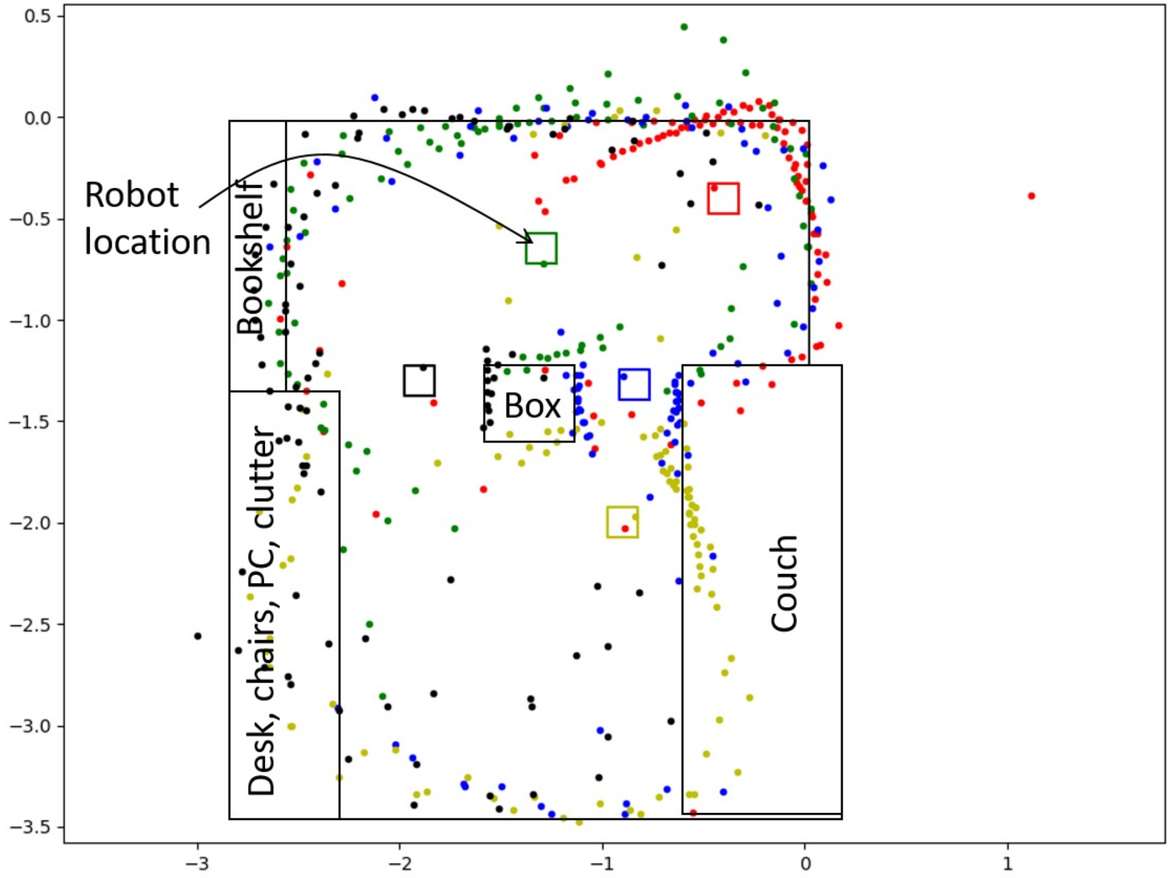
Lab 1-4: HW / Embedded SW

Lab 6-9: Feedback Control

Lab 10-12: Localization and Planning

- Map representations
- Search and planning



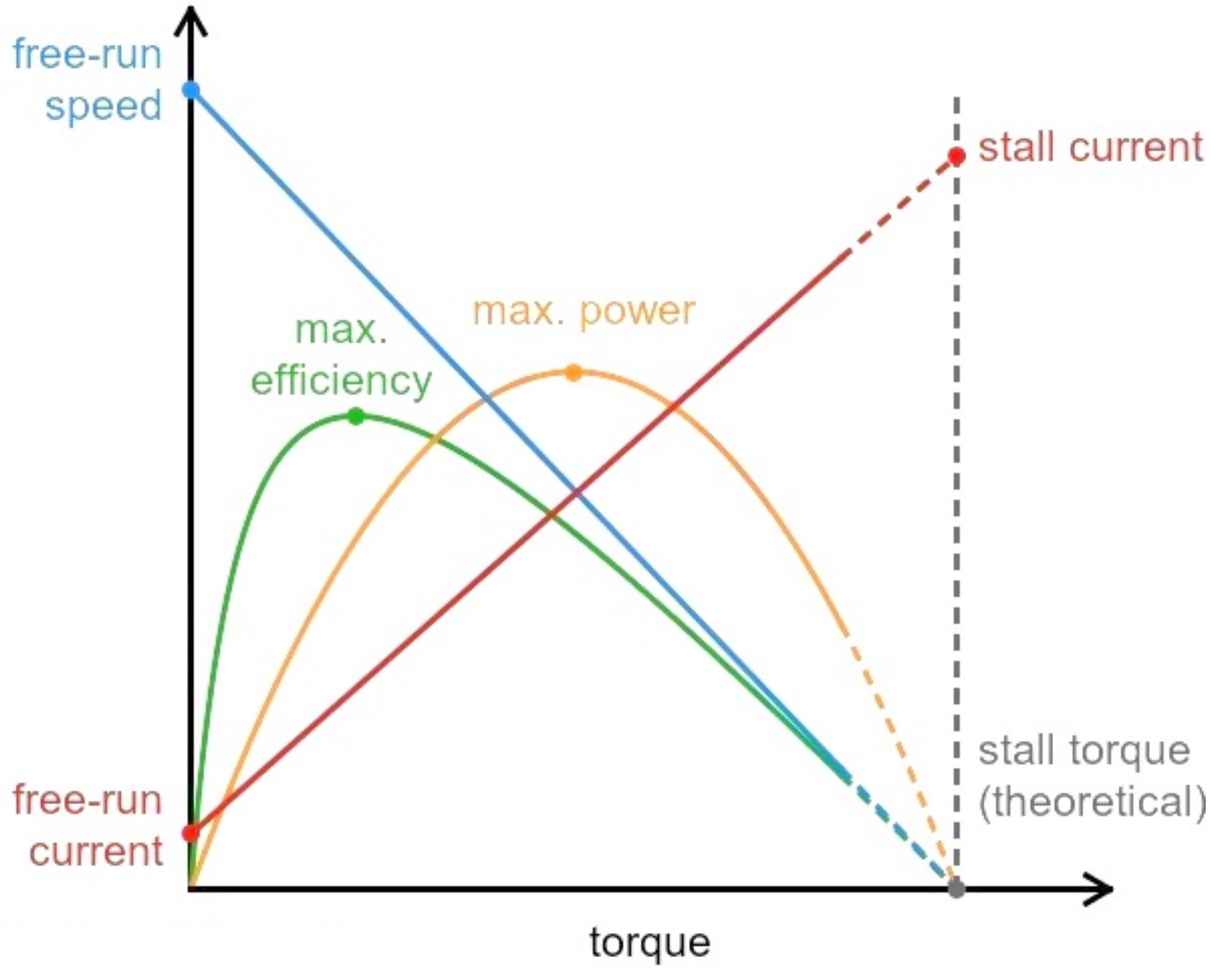


Lab 1-4: HW / Embedded SW	Lab 6-9: Feedback Control	**Lab 10-12: Localization and Planning**

- Map representations
- Search and planning
- Noise, discrete probability
- Motion and sensor models

What are sources of error?

- Sensor noise, resolution
- Momentum and slippage
- Weak motors



Lab 1-4: HW / Embedded SW	Lab 6-9: Feedback Control	**Lab 10-12: Localization and Planning**

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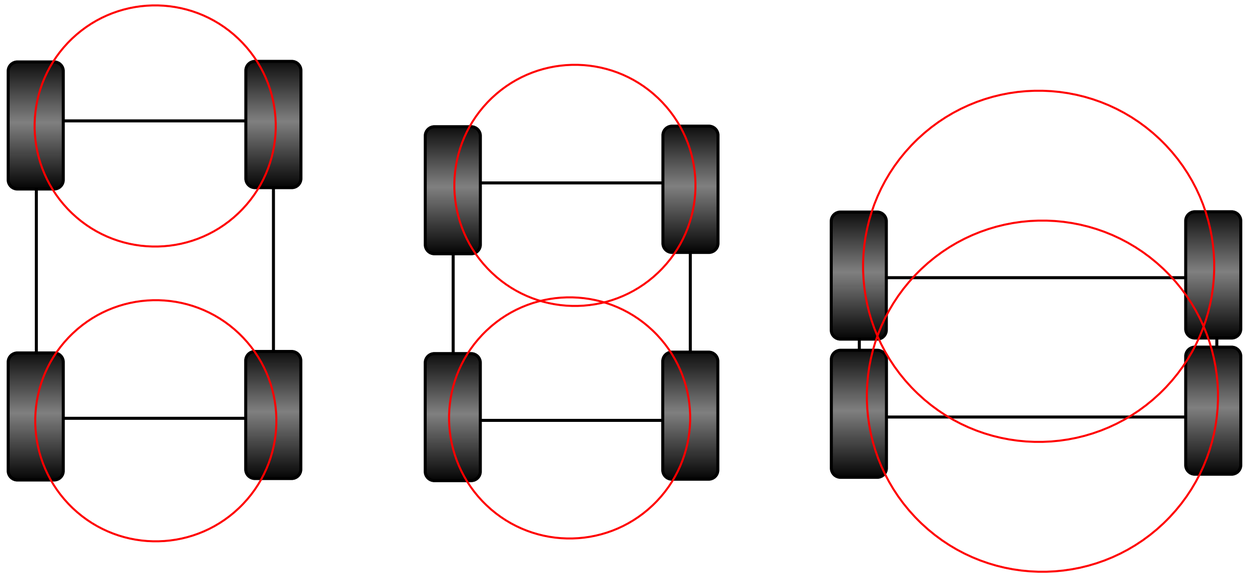
- Skid steering



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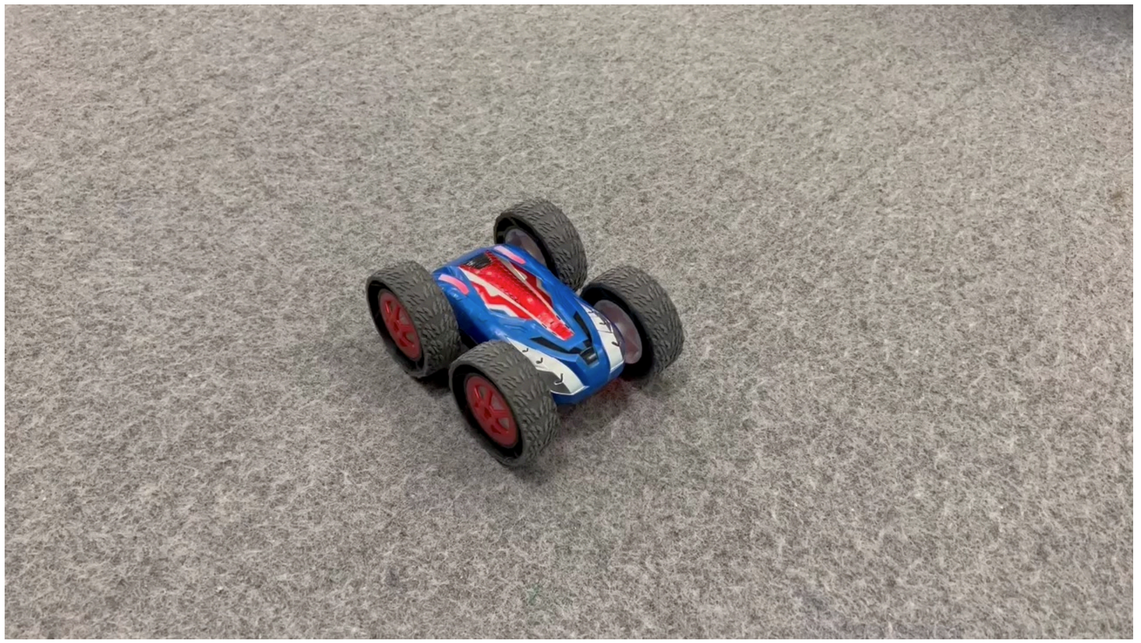
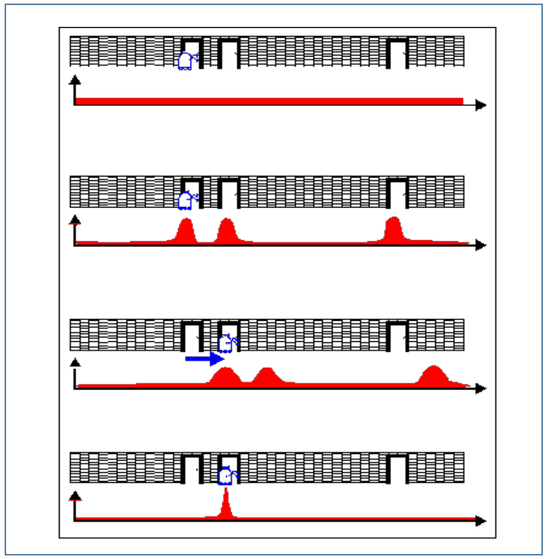


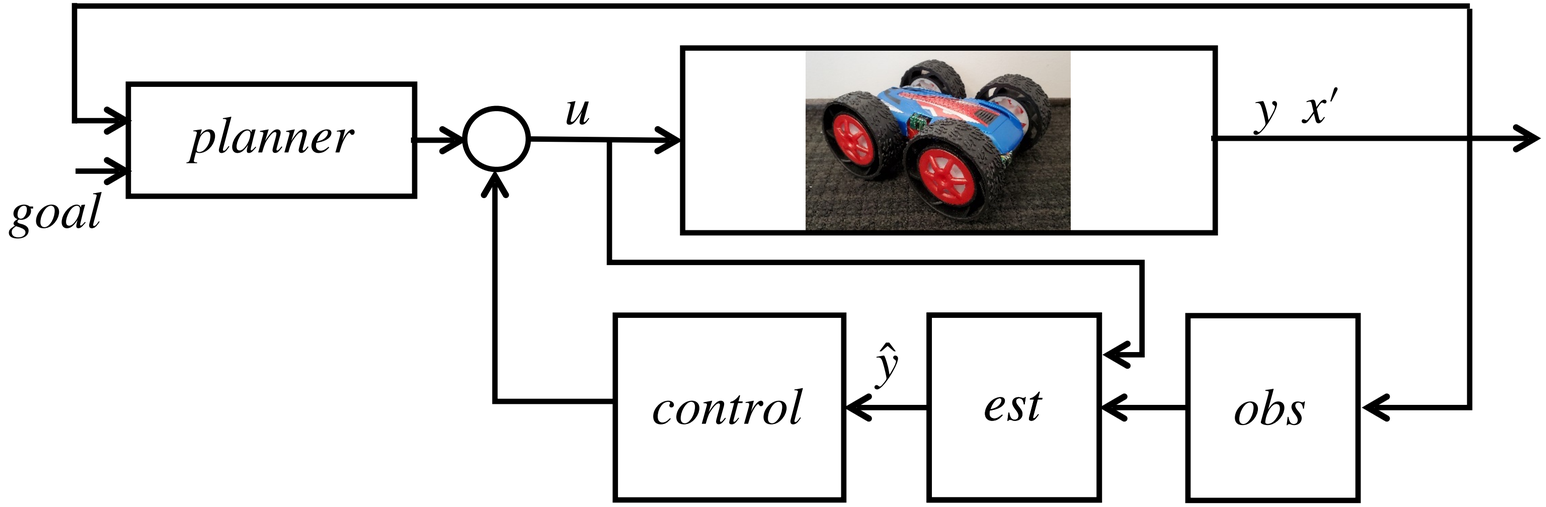
Lab 1-4: HW / Embedded SW

Lab 6-9: Feedback Control

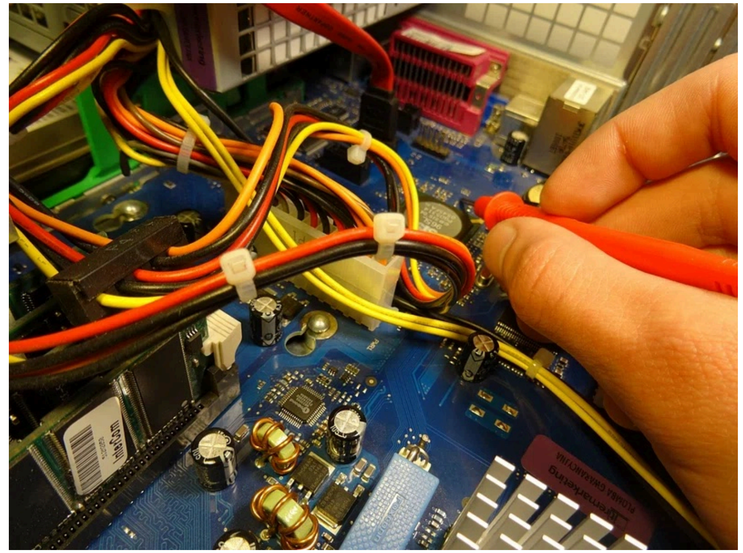
Lab 10-12: Localization and Planning



- Map representations
- Search and planning
- Noise, discrete probability
- Motion and sensor models
- Bayes theorem/ filters
- Localization, planning



Disclaimer



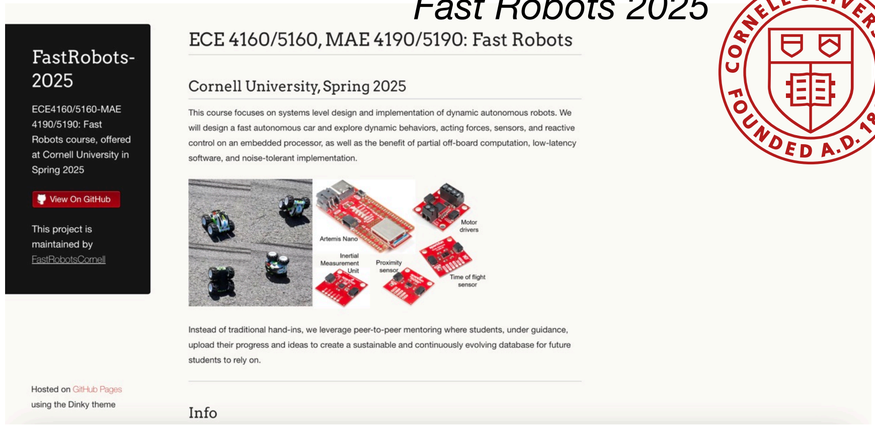
- We work with real hardware.
  - Everyone must build and operate a robot
  - We **break** things!
- Take this course if you want a highly interactive teaching team, fun and advanced challenges, experience with real robots, and an opportunity to build up an online portfolio
- **Do not take this class** if you prefer a deep dive into fundamentals, simulation-heavy work, or if you have a very busy schedule

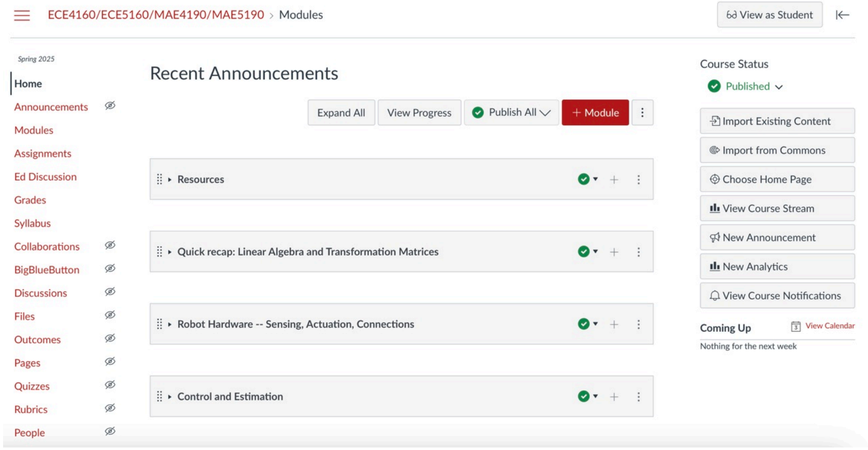
Logistics

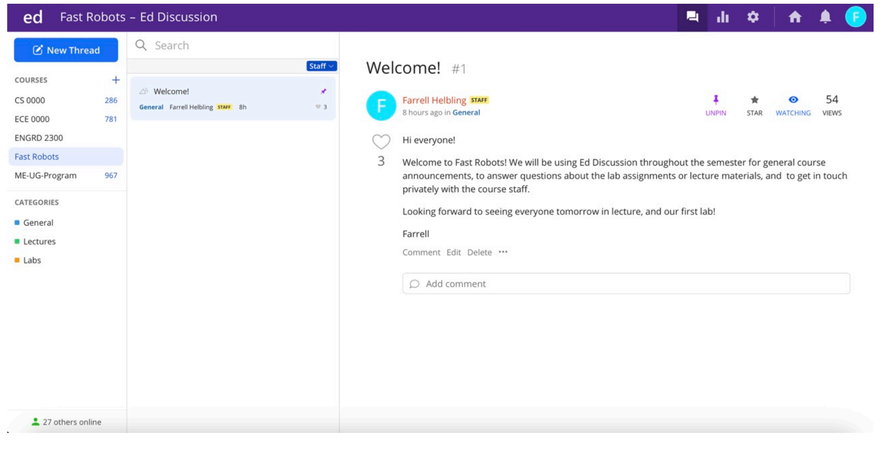
Logistics

Online resources

- Github page (https://fastrobotscornell.github.io/FastRobots-2025/)
  - Schedule, lecture slides, lab documents, tutorials, code examples, etc.
- Canvas
  - Lecture slides, deadlines, grades
- EdDiscussion
  - Post general questions to benefit all of your classmates, private messages to communicate with the course staff about extensions



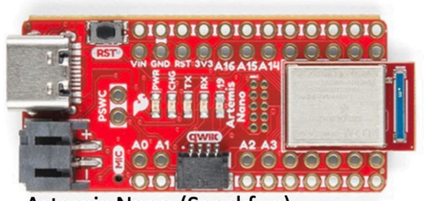




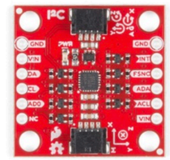
Logistics

Lab Kit

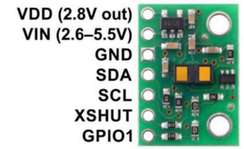
- Things will break, we have a small set of extra components, but please be careful. If you have never handled hardware before or are worried about breaking something, please ask the teaching staff for assistance.
- We will hand out all of the electronic components this week, and the RC cars we will hand out for Lab 2
- If you drop the class, we want these items back!

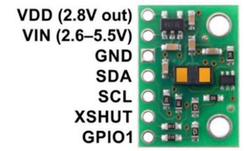


Artemis Nano (Sparkfun)



ICM20948 (Sparkfun)





VLX53L1X (Pololu)

DRV8833 (Pololu)

+ more cables

Logistics

Lab Software

- Guaranteed support on the 13 lab computers in PH427 (Windows 10 and 11)
- The teaching team has tested these labs on their personal machines (Mac Intel/M1/M1Pro and Windows 10/11) with minimal issues
- Minimum requirements:
  - Windows 10, MacOS 12, and Linux (bluez>4.58, kernel=4.15)
  - Processor: Core i3-8100 3.6GHz/AMD Risen 5 1400 or equivalent
  - Memory: 4GB RAM, Free Space: 8GB (Windows)/ 1GB (else)
- We are aware of an issue with MacOS Sequoia not recognizing the CH340 drivers. We have a solution (detailed in the Lab 1 documentation), but are looking for a better one. If you find one, please share with the rest of the class!

Logistics

Labs

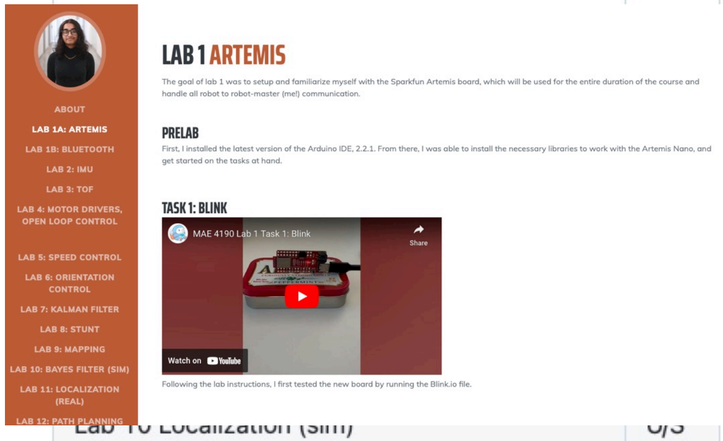
- Official lab times: T 2-4:30pm, W 8:30-11am, W 2-4:30pm. I will attend the first 60 minutes of every lab as my regular “office hours”
- Open lab times: TBD, will add a google calendar to the website later this week
- Time Commitment: 8-10 hrs/week
  - Spread this out over multiple days (batteries last 10-15mins).
  - These labs build on top of each other, start early and use each other/ the teaching staff/ past examples as resources.
  - If you run low on time, you have two one-week extensions to apply to any two labs throughout the semester (except lab 12).
    - You **must** let the teaching team know before the lab deadline through a private message on Ed.

Logistics

Grading

- All assignments and the respective deadlines are already outlined on Canvas.
- Lab write-ups are due one week after the lab session at 8am. Lab section 401 write-ups are due Tuesday at 8am, 402 and 403 due Wednesday at 8am.
- Specific grading policies can be found on the course website: https://fastrobotscornell.github.io/FastRobots-2025/Grading.html
  - 67% of the grade goes to technical solution, 33% goes to the write-up.
  - Many labs are graded on a curve, students that have more significant results score higher, even if all tasks are completed

Task	pts
Lab 1 Artemis + Bluetooth	5
Lab 2 ToF Sensors	7.5
Lab 10 Localization (sim)	0/5
Lab 11 Localization (real)	10
Lab 12 Planning and Execution	12.5
Participation	10
Bonus points for midterm and final course evals	2
Total:	**102**



Logistics

Collaborations

- You are welcome to check the write-ups from last year (links to the previous years student pages are clearly visible on our front page).
- You are welcome to work together, teams of 2-3 usually function best in this class. **Everyone is still responsible to implement the electronics/ software/mechanics and complete the write-ups on their own!**
  - Work/strategize
  - Complete prefabs
  - Debug
  - Compare results
  - Borrow teammates robot if yours fails (implement your own code).
- Include a collaboration/ resources statement in your write up. State who you worked with, resources you used, and **how you used them.** If (when) you used genAI, tell us how you used the resource.

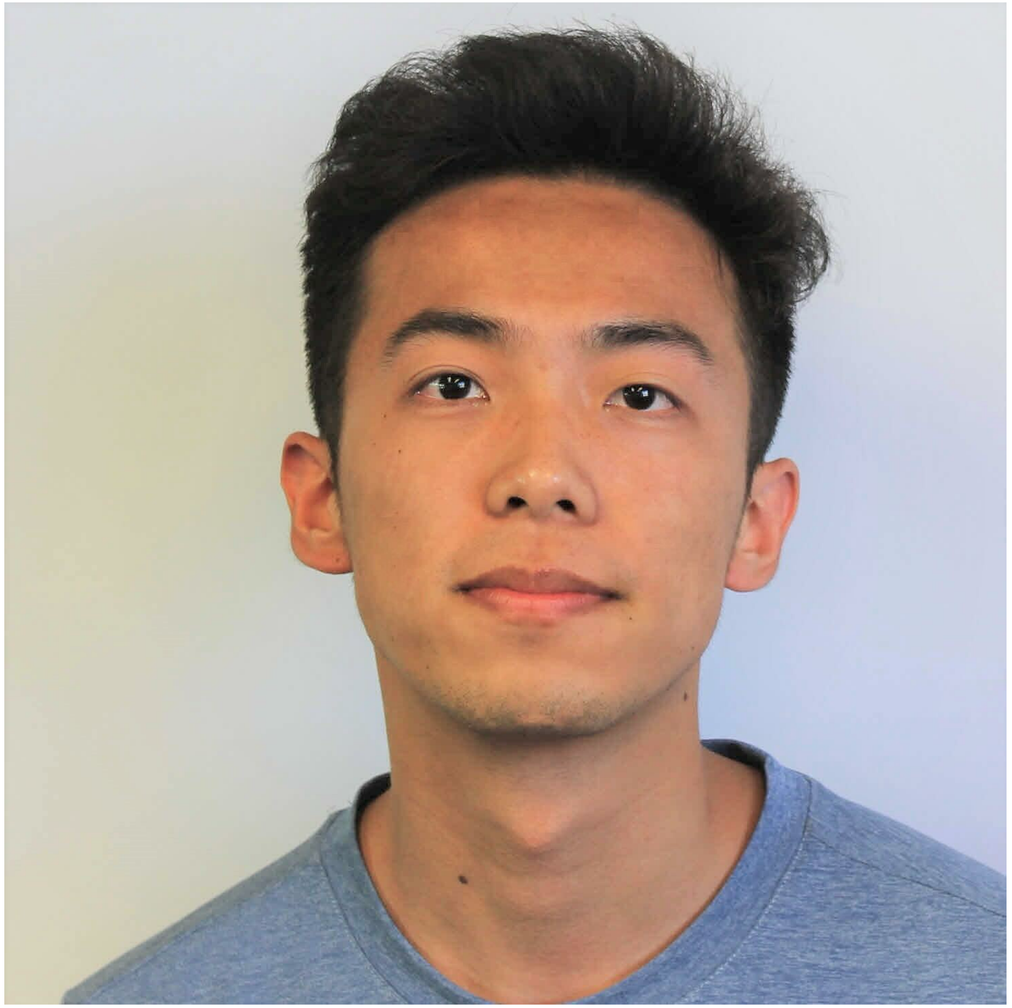
*Chatgpt created this image

Teaching Team

Teaching Team

Hang “Harry” Gao (he/him)

- **Wednesday Morning Lab**
- Graduate Student in the Helbling Lab
- Research focus on locomotion and autonomy at the water-air interface
- Enjoys skiing and reading (sci-fi)



Teaching Team

Cameron Urban (he/him)

- **Wednesday Afternoon Lab**
- Graduate Student in the Helbling Lab
- Research focus on locomotion and autonomy for underwater robots
- He enjoys contributing to open-source software projects, scuba diving, and getting beaten in chess.

Teaching Team

Chenyu “Cheney” Zhang (he/him)

- **Wednesday Afternoon Lab**
- Graduate student in the Helbling Lab
- Research focus on bio-inspired robotics
- He enjoys classical music, tennis, fossil hunting, and cross country

Teaching Team

Daria Kot (she/her)

- **Tuesday Afternoon Lab**
- Top student in the 2024 class, check out her website!
- CS major, Robotics and Fine Arts minor, member of the Cornell Rocketry Team.
- She enjoys painting and printmaking

Teaching Team

Mikayla Lahr (she/her)

- **Wednesday Morning Lab**
- Top student in the 2024 class, check out her website!
- Major/ research/ project team
- She enjoys rowing and has a corgi named Belle

Teaching Team

Nandita Nagarajan (she/her)

- **Tuesday Afternoon Lab**
- TA’d 2300 with me last year
- ECE major, ME minor, Electrical Subteam Lead of Cornell Rocketry
- She loves singing!

Teaching Team

E. Farrell Helbling (she/her)

Teaching Team

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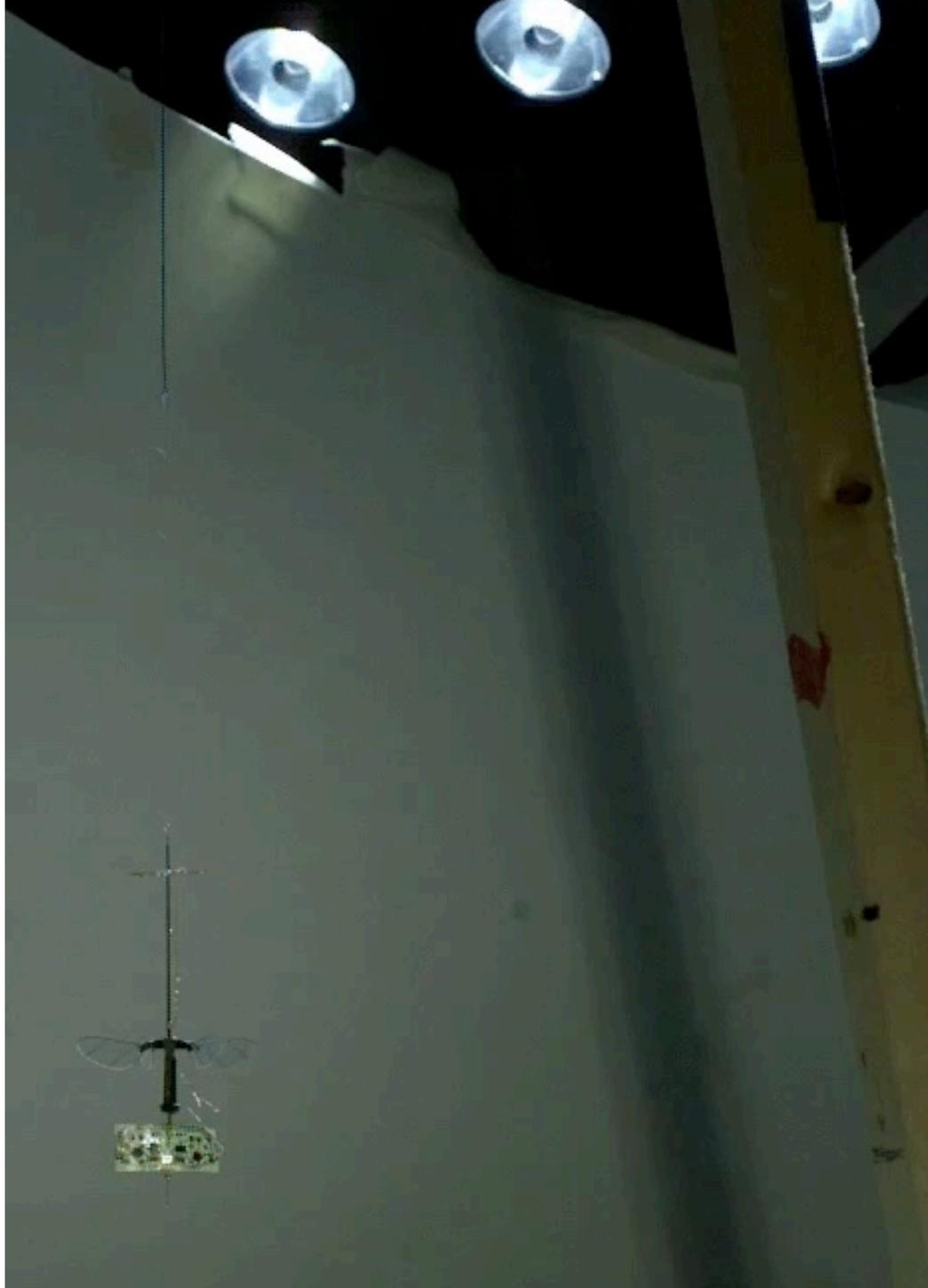

Teaching Team

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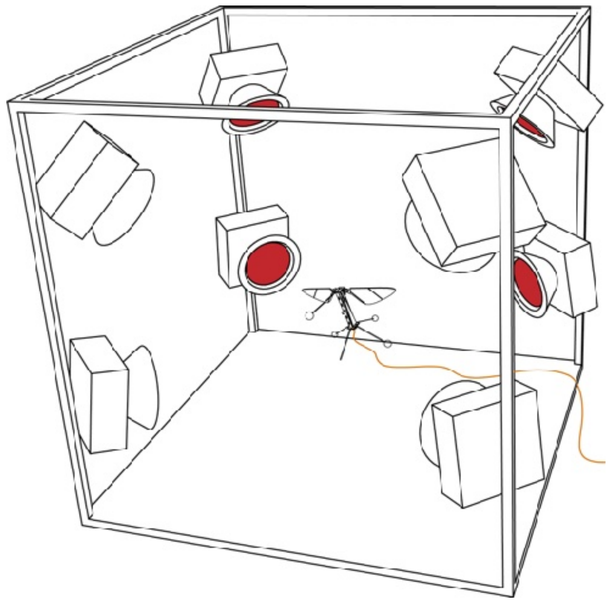
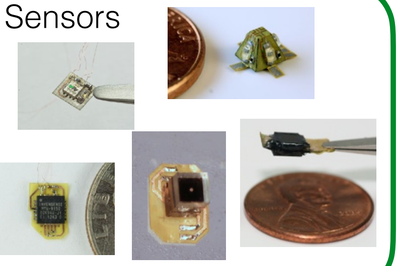
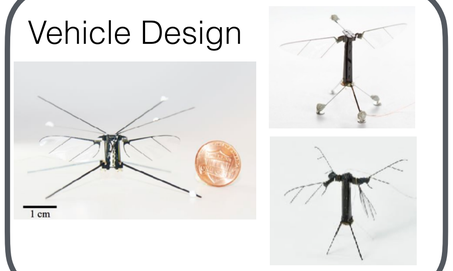


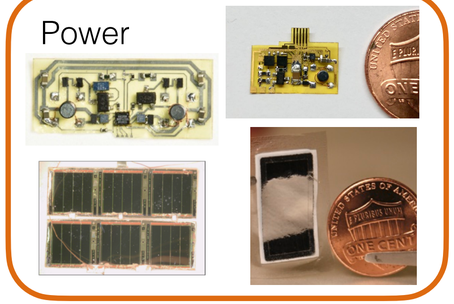
Sensors



Vehicle Design



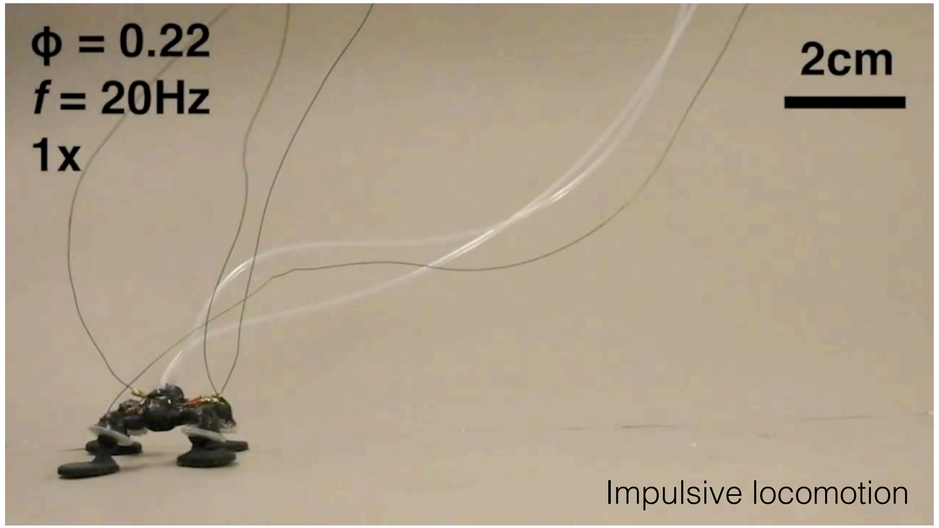
Power

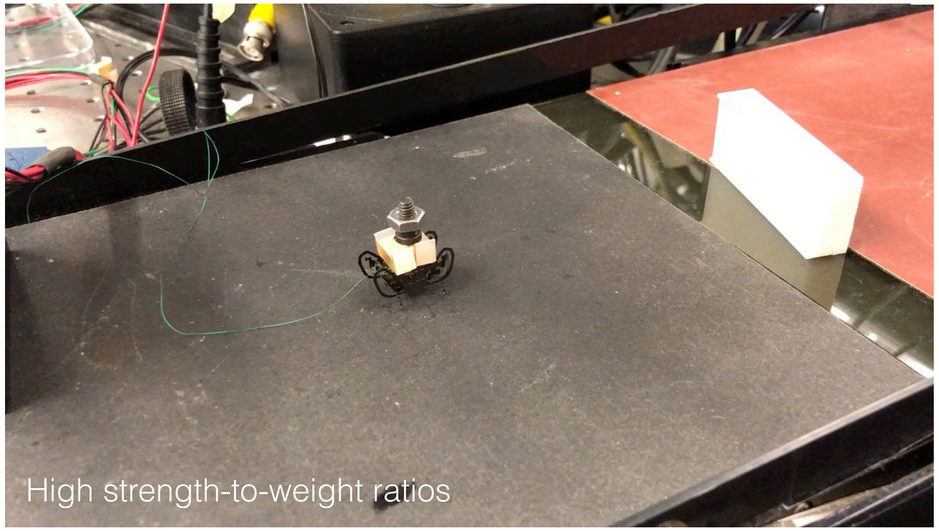


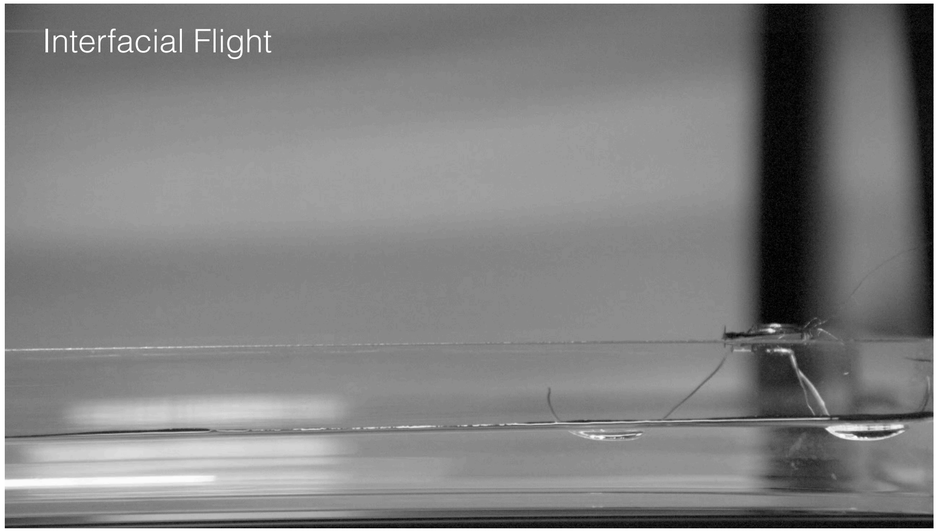
Real-time End-to-End System Demonstration

Teaching Team

E. Farrell Helbling (she/her)







Class Action Items

- Please if you have decided not to take the course, let me know ASAP. **Email farrell@cornell.edu.** We have 40+ people on the waitlist.
- **January 31st, midnight**: Make a GitHub repository and build your Github page
  - Include: name, photo, a small introduction, and the class number
  - Share **the page link** in the canvas assignment
- Labs start **TODAY**. You will pick up your electronics kit and start Lab1A. See some of you in Phillips 427 later today! The rest I will see tomorrow!

See you later today (or tomorrow)