

Implementing Flexible Evasion Dynamics with a Tuned Second Order Response

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MECHANICAL ENGINEERING
TEXAS A & M UNIVERSITY

Outline

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2. Design and Development

- i. Hardware Design
- ii. Dynamic Modeling
- iii. Software Architecture
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- vi. Final Implementation

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- iii. Human Test Subject

4. Discussion and Conclusions

5. Q&A and Demonstration



Objective & Significance



Ubergizmo.com

Objective & Significance



Roboticstrends.com

Objective & Significance



Totalfratmove.com: Young Mitt Romney

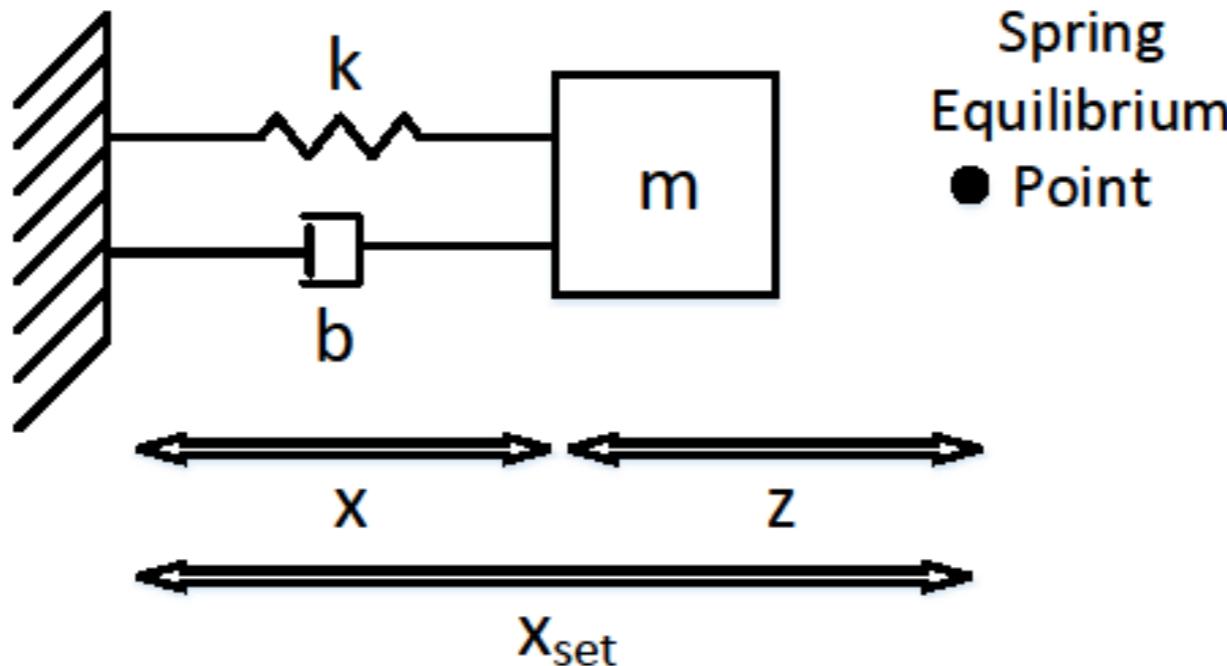


Objective & Significance



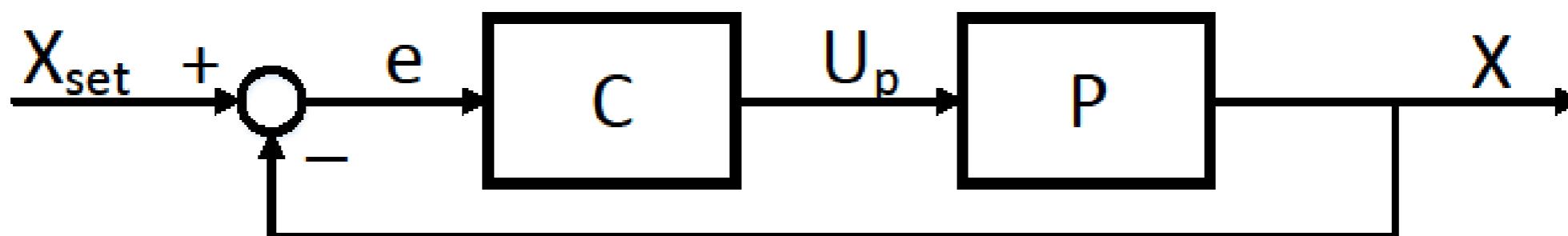
Uavexpertnews.com

Objective & Significance



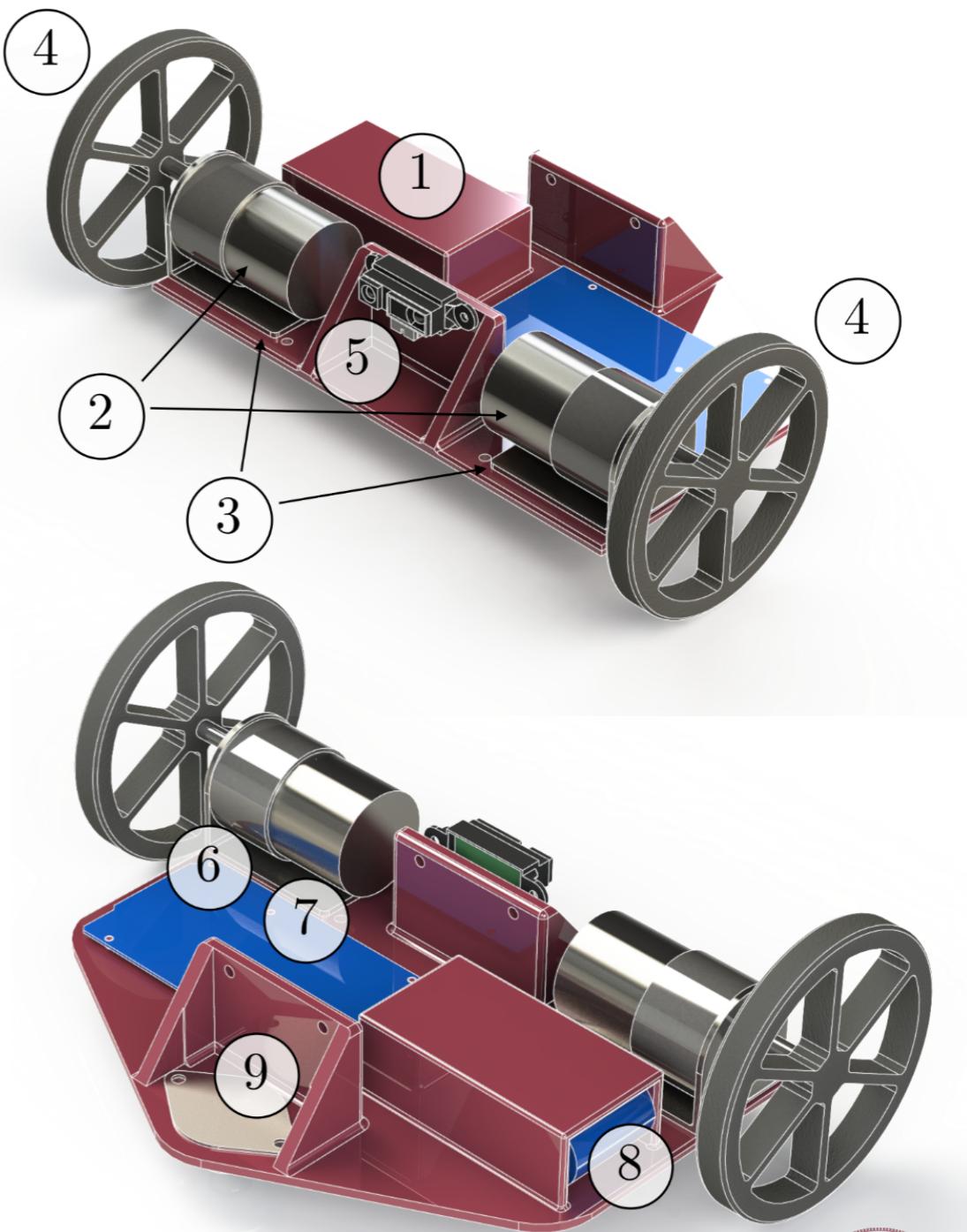
Desired Closed Loop Characteristic Equation:

$$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0$$



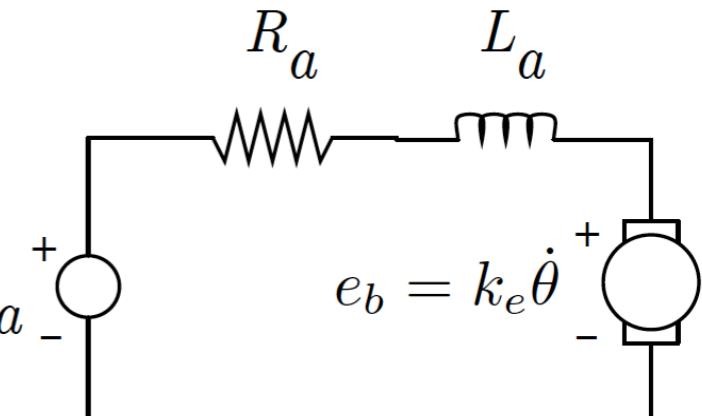
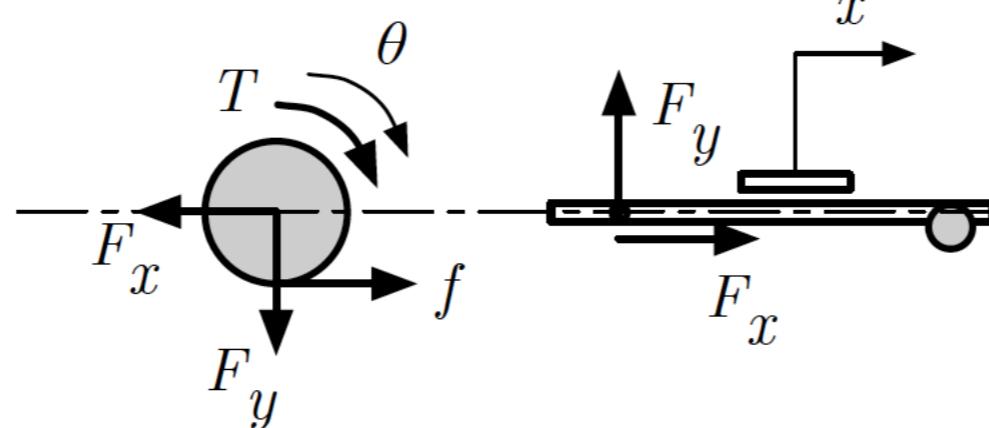
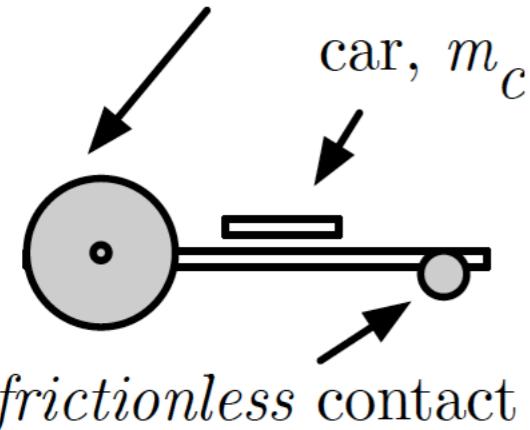
Hardware

| No. | Manufacturer | Model/Description |
|-----|--------------|----------------------------------|
| 1 | N/A | 3D printed chassis |
| 2 | Pololu | 12 V 120 RPM DC motors |
| 3 | Pololu | Aluminum L-bracket motor mounts |
| 4 | Pololu | Plastic wheels, Ø90mm, with hubs |
| 5 | Sharp | Long range IR sensor |
| 6 | Arduino | Uno |
| 7 | Adafruit | Motor shield v2.3 |
| 8 | Turnigy | 1500 mAh LiPo Battery |
| 9 | N/A | Ball and socket caster |



Dynamic Modeling

2 drive wheels, m_w



- Neglecting motor dynamics

$$X(s) = \frac{1}{Ms^2 + Cs} V_a(s)$$

$$M = \left[\frac{I_w}{r} + \left(\frac{1}{2}m_c + m_w \right)r \right] \frac{R_a}{k_t}$$

$$C = \frac{k_e}{r}$$

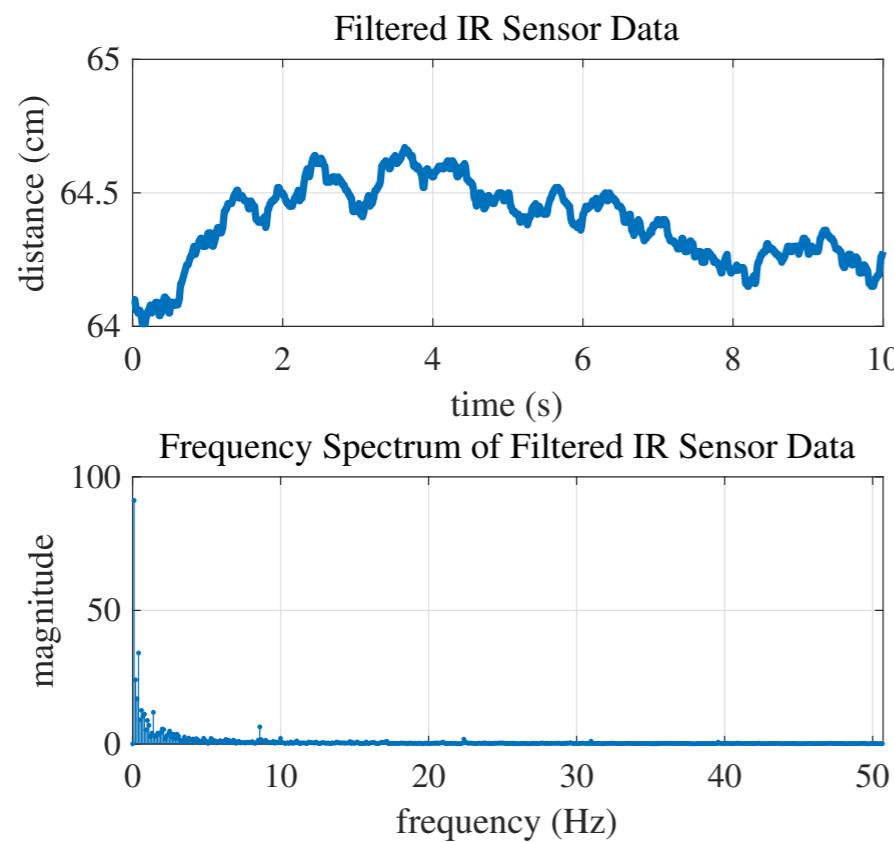
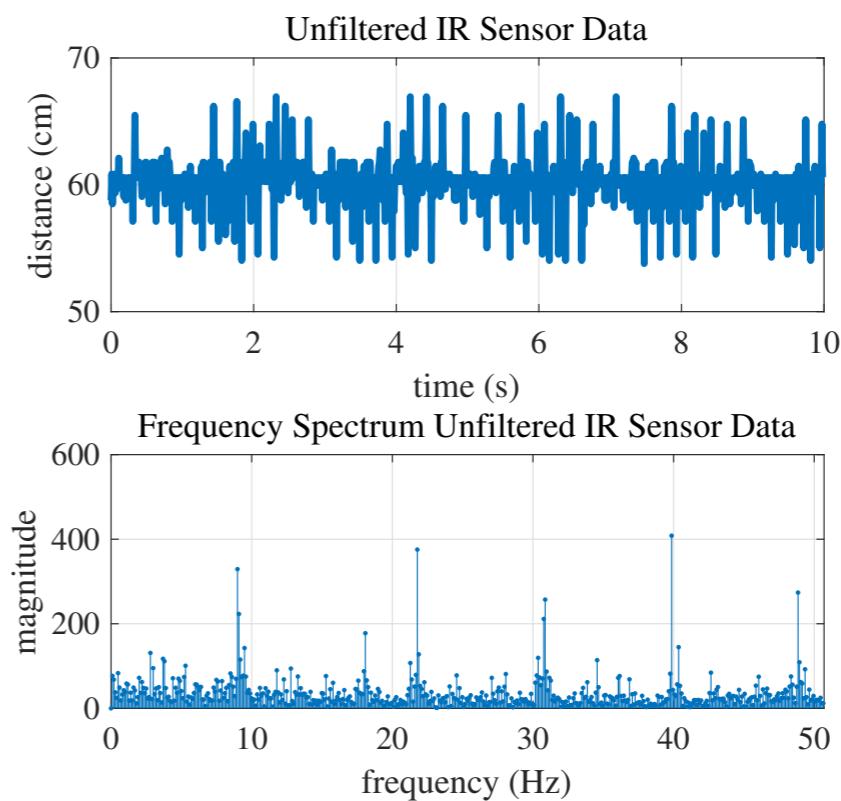
- Neglecting I_w and m_c ,

$$X(s) = \frac{1}{0.1728s^2 + 16.9778s} V_a(s)$$

Valid assumptions?

Filter Design

- Delay 1s (*why?*)
- To serial monitor
- Time interrupt: 11s
- Time + DFT
- Initial sensor response
- --> *Reset jumps*



- Digital filter (1 Hz)
- 15 cm -> 0.7 cm
- Inconsistent frequency
- One sensor? No!
- Closed-loop $\omega \downarrow bn$



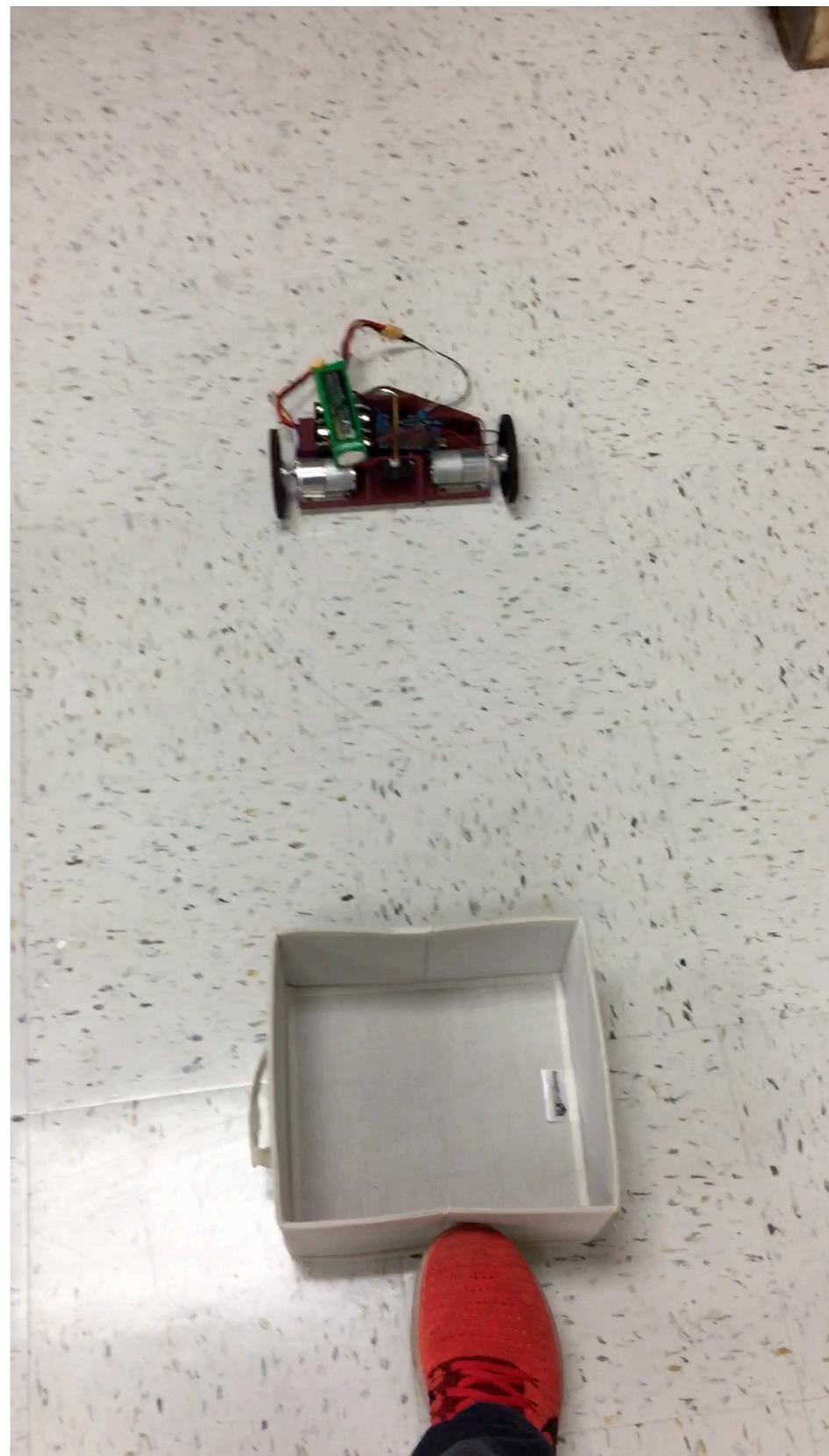
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Preliminary Test (Everything OK?)

- Controller + Filter
- Conservative (No saturation)
- Bandwidth: 3 rad/s
- Filter: 3x5 rad/s
- Coding: 100 Hz -> 180 Hz

Observations:

- ✓ *Dynamics, Implementation OK*
- Too conservative (1/3 motors)
- Open-loop stable -> Saturation

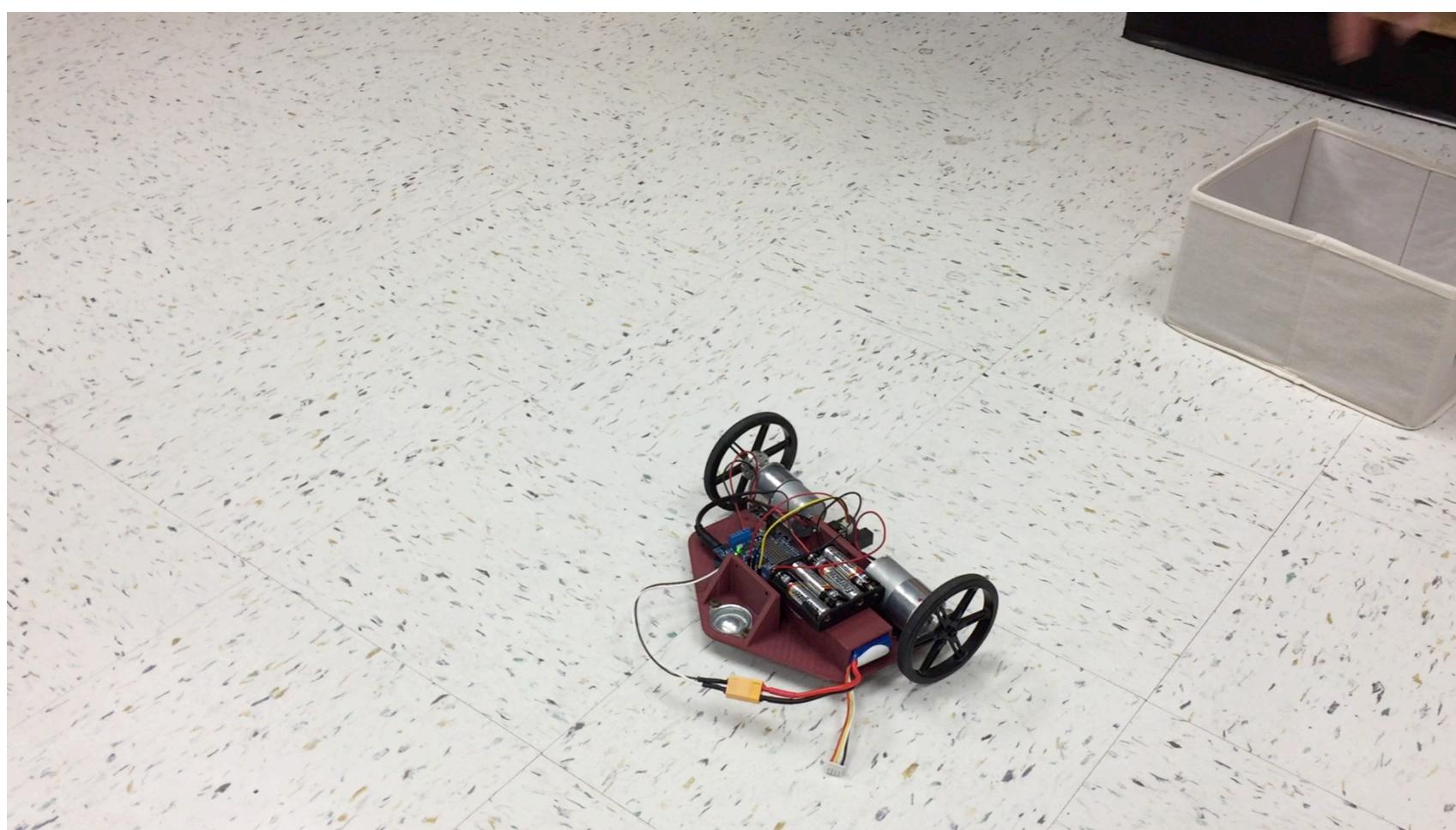


Additional Tests

- Saturation for $v \downarrow a > 12V$
- $\omega \downarrow bn$: 7 rad/s (1.1 Hz)

Verified →

- Filter speed: 3x7 rad/s (3.3 Hz)
- Filter avoids: 8 Hz, 22 Hz



Another fun test

- 2 DOF with 1 sensor?
- Radar?
- Scanning and tracking

Verified!
Good to go!

Controller Design

How to achieve tunable second-order closed-loop dynamics?

Controller:

$$D(s) = \frac{k}{s^2 + As + B}$$

Plant:

$$G(s) = \frac{X(s)}{V_a(s)} = \frac{1}{Ms^2 + Cs}$$

Actual C.L. Characteristic Equation:

$$a(s) = Ms^4 + (C + AM)s^3 + (AC + BM)s^2 + BCs + k$$

Desired C.L. Characteristic Equation:

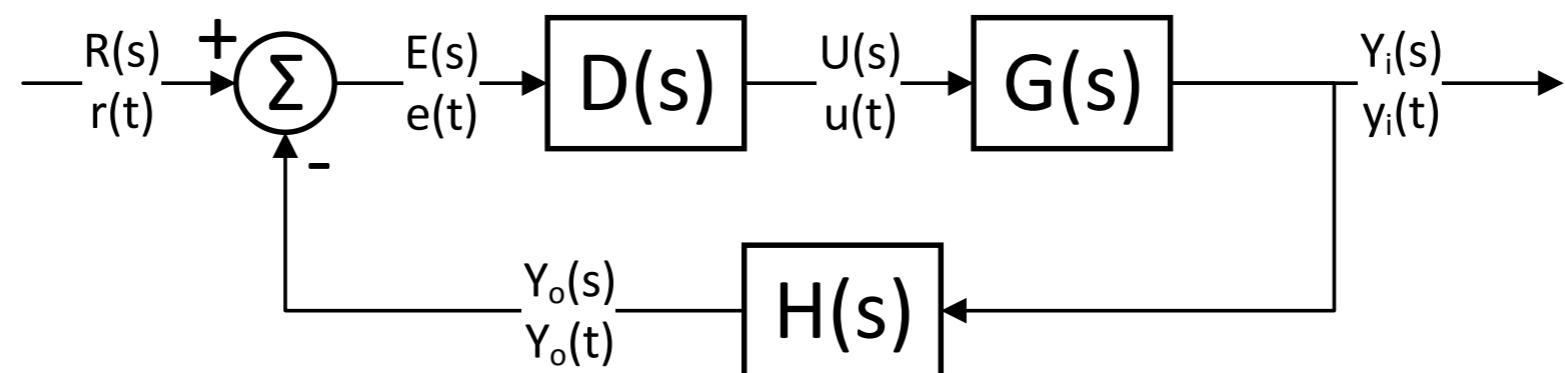
$$a_d(s) = \underbrace{\theta (s + \alpha)(s + \beta)}_{\text{fast poles}} \underbrace{(s^2 + 2\zeta\omega_n s + \omega_n^2)}_{\text{design poles}}$$

Let $\alpha = 10\omega_n$. Solve for A , B , k , and β .



Controller Design (CT)

Continuous Time Controller:



$$D(s) = \frac{k}{s^2 + As + B}$$

$$G(s) = \frac{X(s)}{V_a(s)} = \frac{1}{Ms^2 + Cs}$$

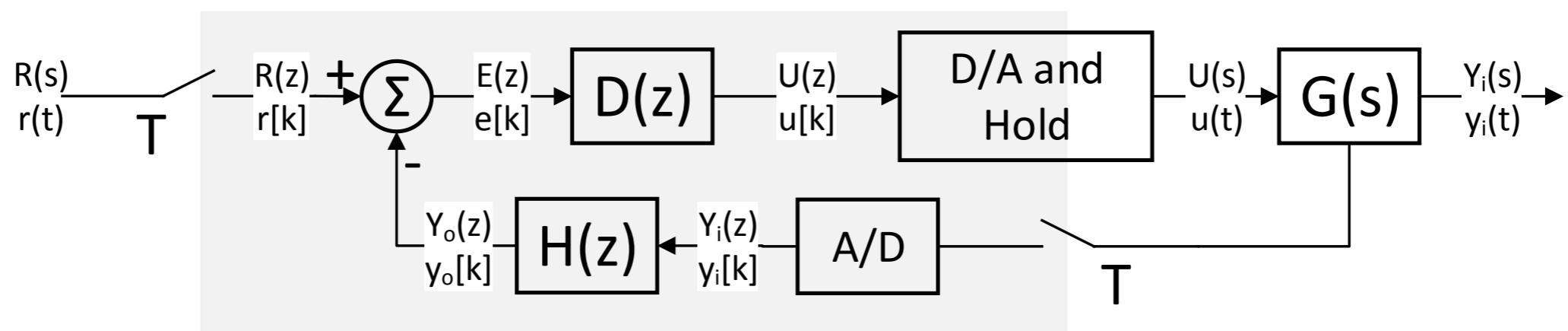
$$H(s) = \frac{1}{\frac{s}{\omega_c} + 1}$$



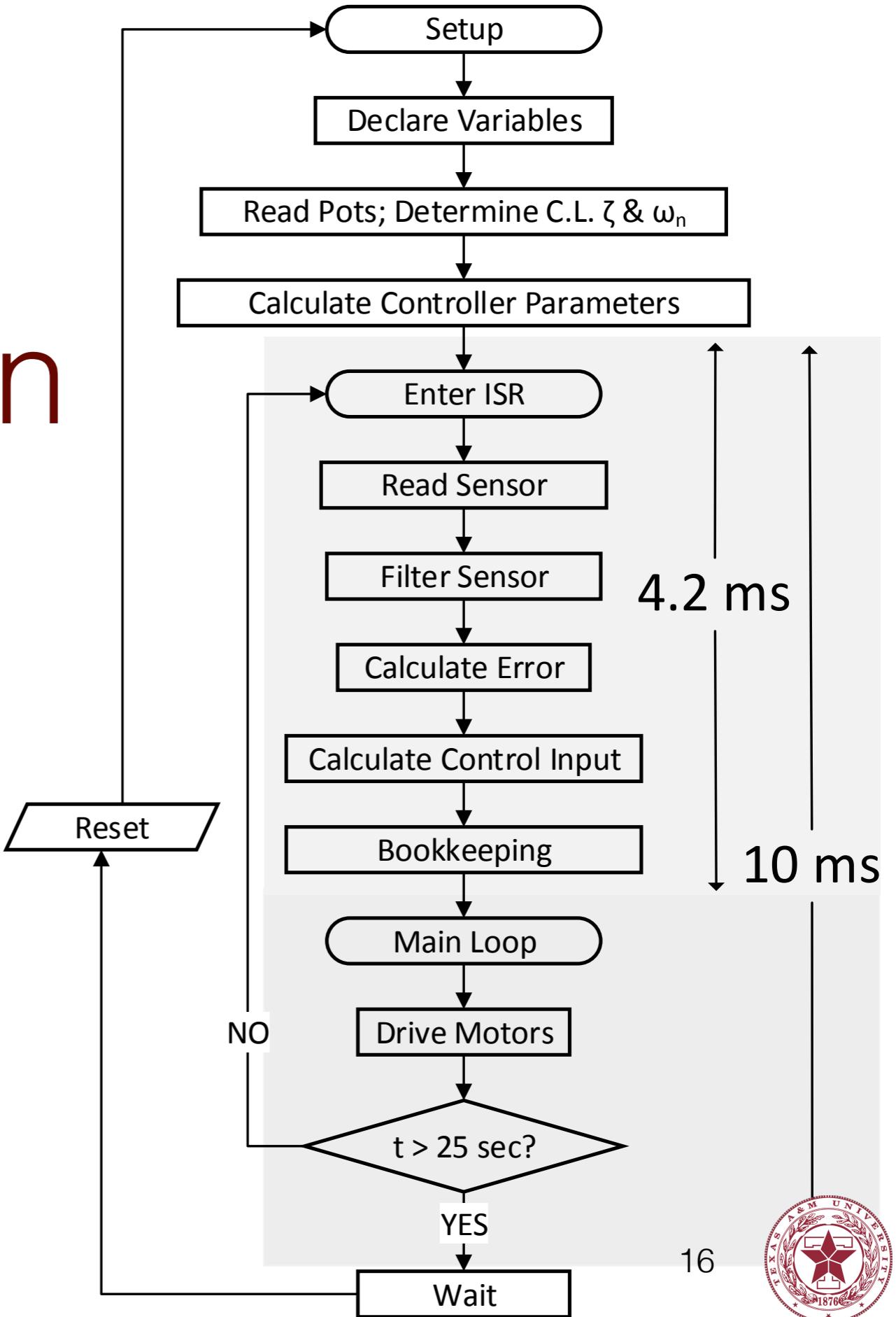
Discretization

Tustin's Transformation:

$$s = \frac{2}{T} \frac{z - 1}{z + 1}$$



Final Implementation



Object Tracking with Computer Vision

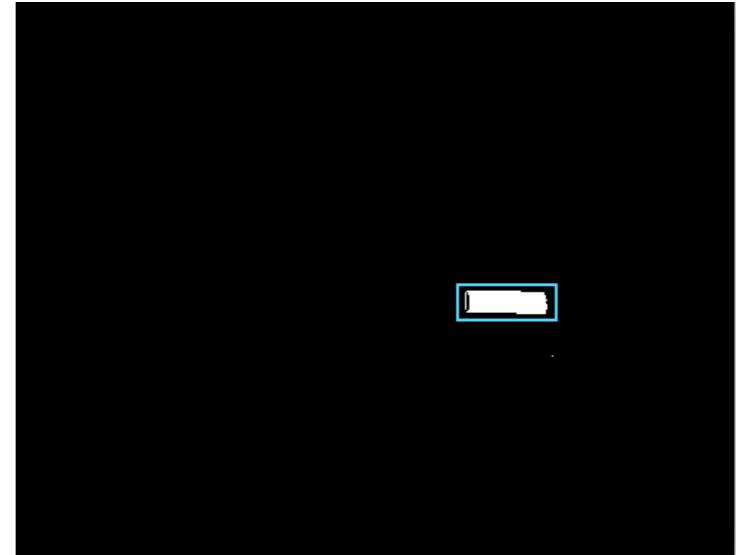
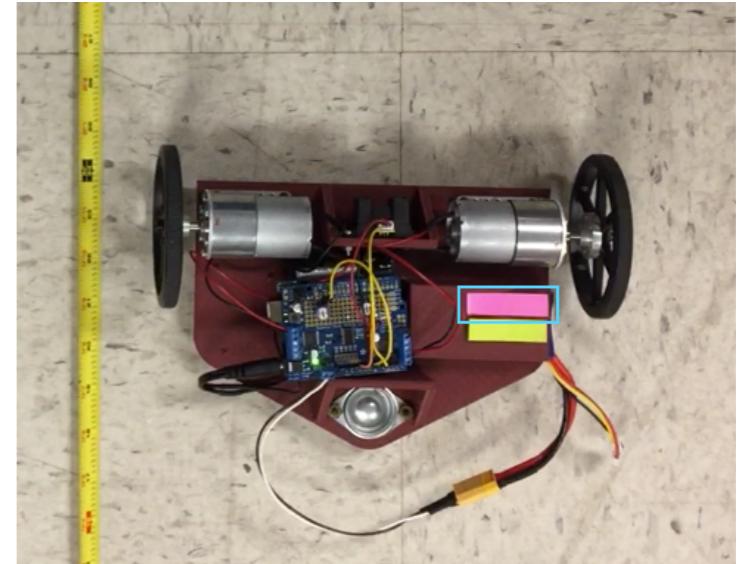
Need to experimentally validate.

Why CV?

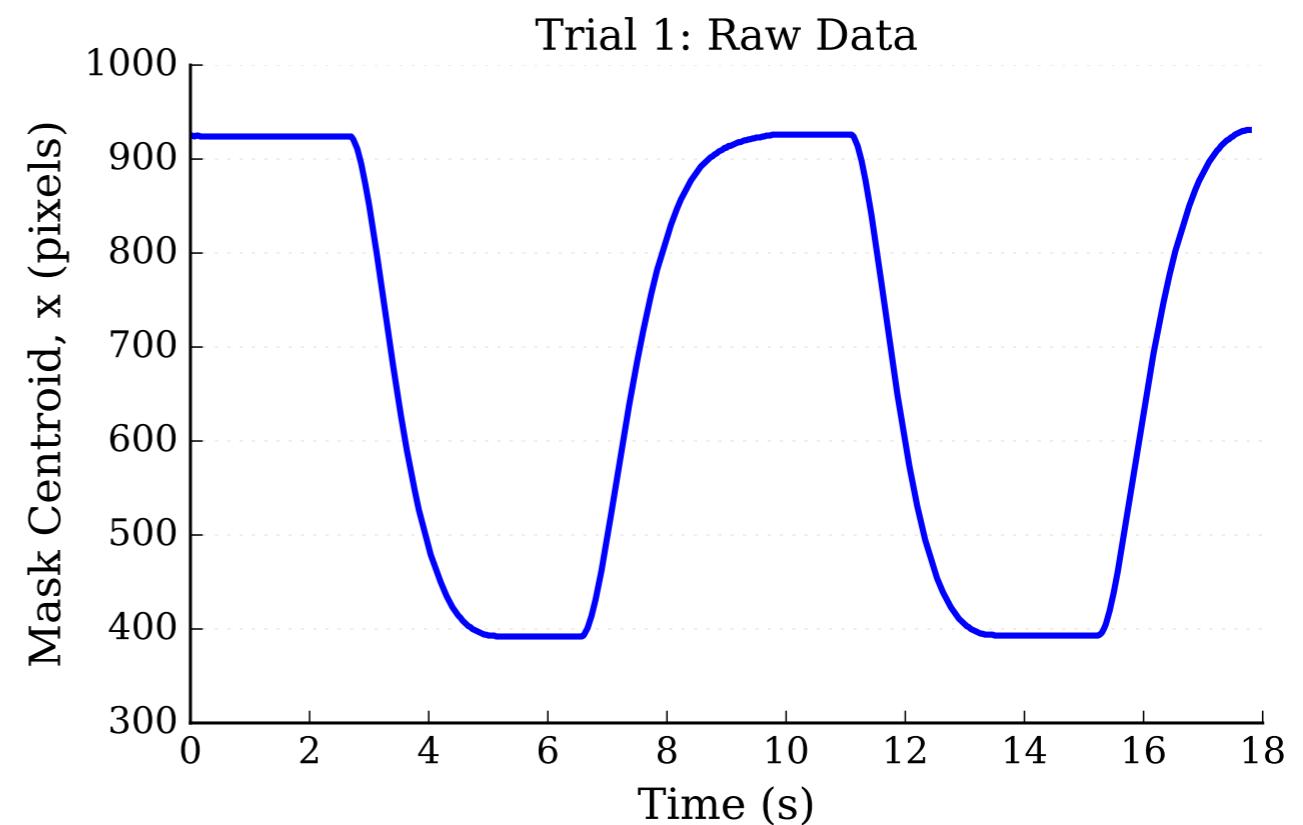
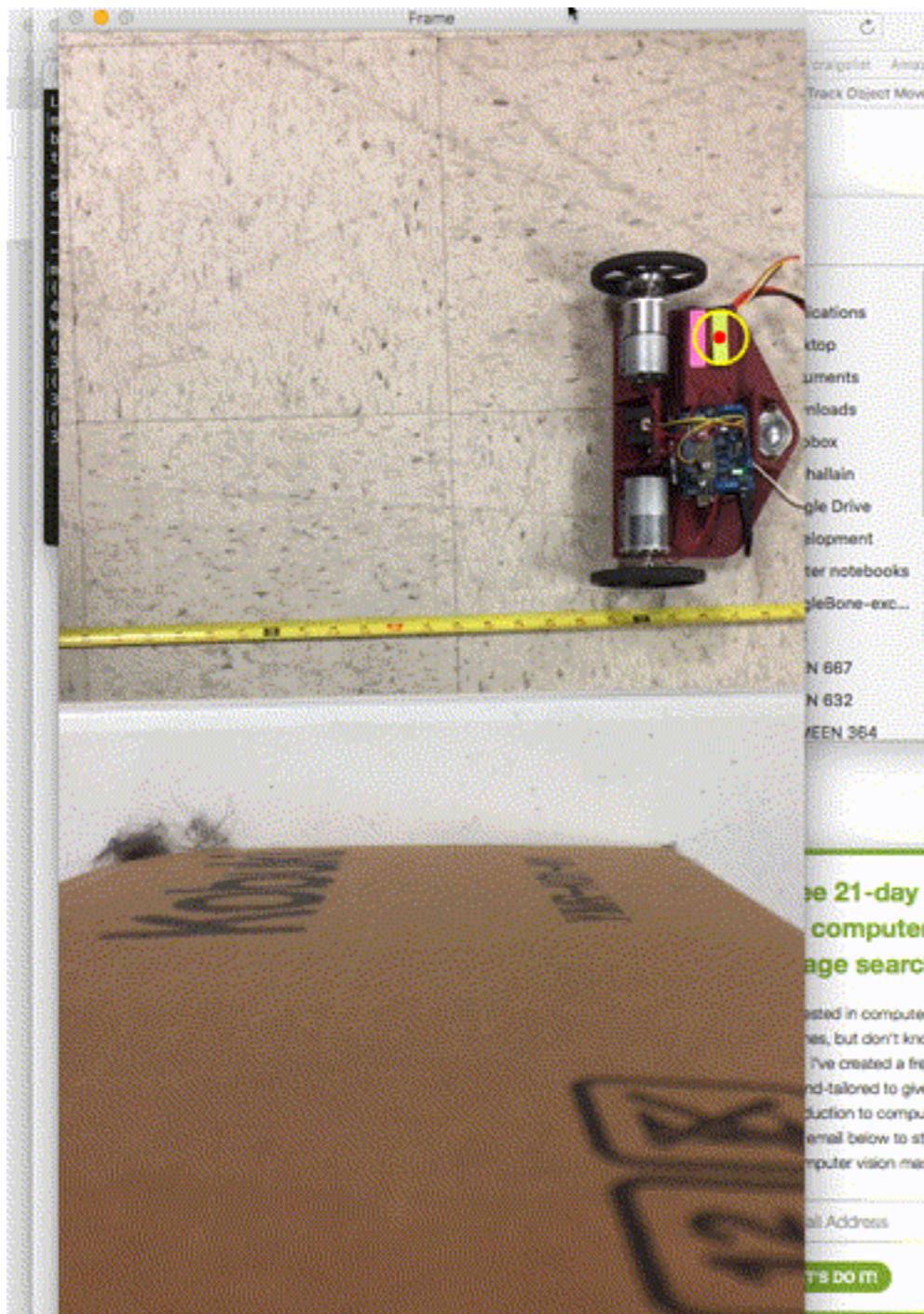
- IR data is noisy, logging is intrusive
- Quality sensor (iPhone Camera)

How?

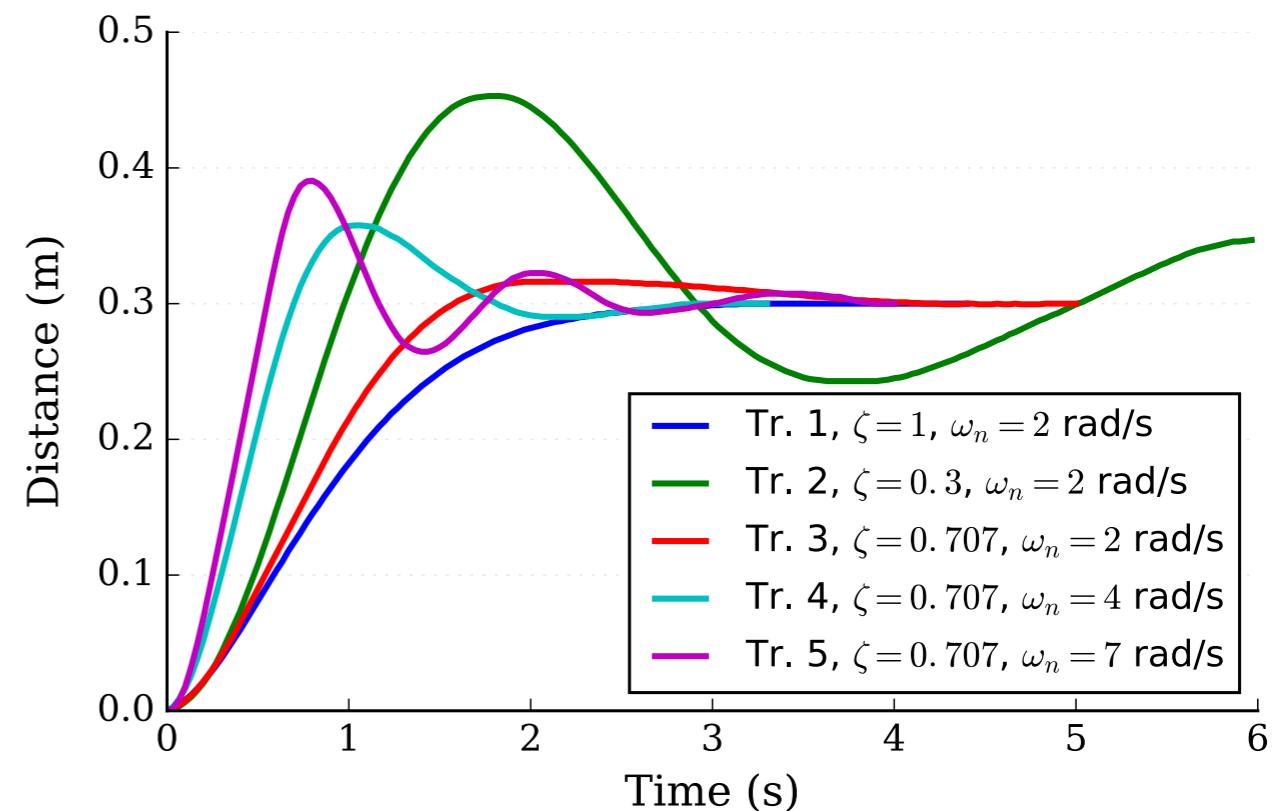
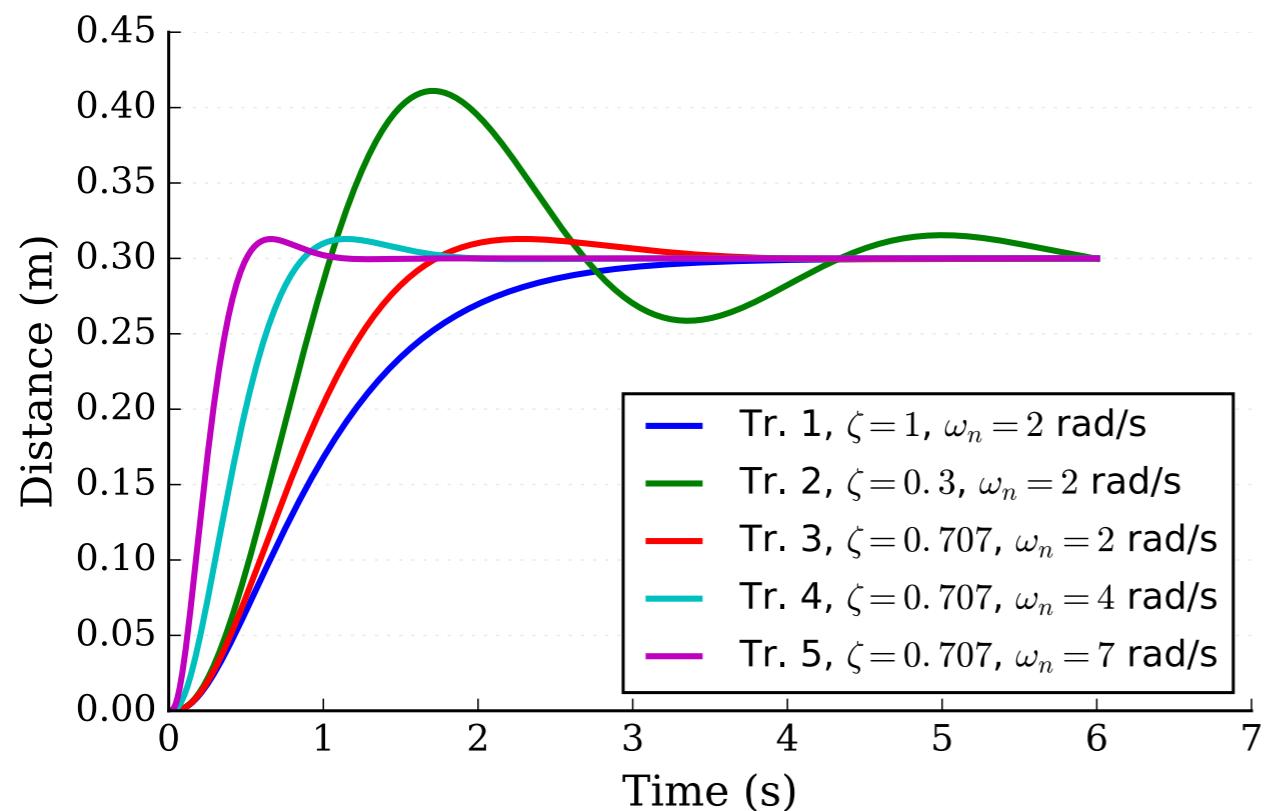
- OpenCV, Python
- Color Masking



Object Tracking - Sample Trial



Simulated vs. Measured



Human Test Subject



Discussion & Conclusions

Challenges

- Actuator saturation
- Zero introduced by filtering

$$CLTF = \frac{G(s)D(s)}{1 + G(s)D(s)H(s)}$$

Key Results

- Met proposed objectives
- Demonstrates 2nd order dynamics clearly
- Demonstrates the power of control theory



Questions & Demonstration

