Implementing Flexible Evasion Dynamics with a Tuned Second Order Response

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Outline

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2. **Design and Development**
   i. Hardware Design
   ii. Dynamic Modeling
   iii. Software Architecture
   iv. Filter Design
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4. **Discussion and Conclusions**
5. **Q&A and Demonstration**

Objective & Significance

Ubergizmo.com

Objective & Significance

Roboticstrends.com

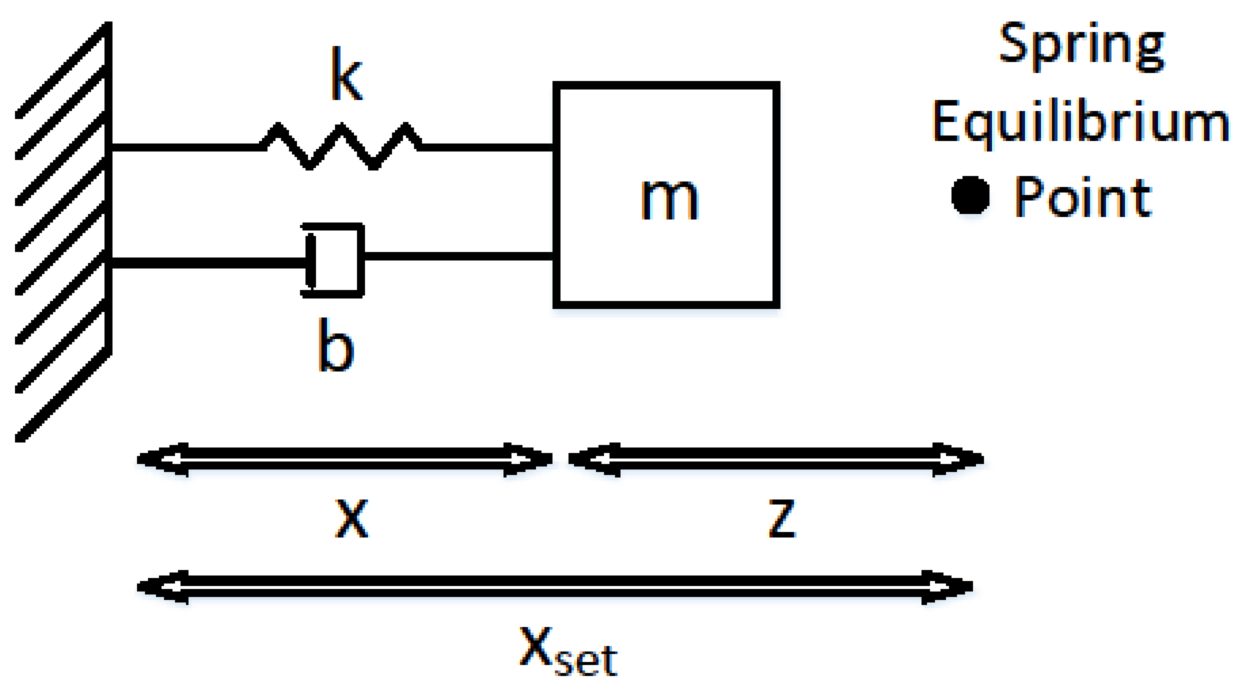
Objective & Significance

Totalfratmove.com: Young Mitt Romney

Objective & Significance

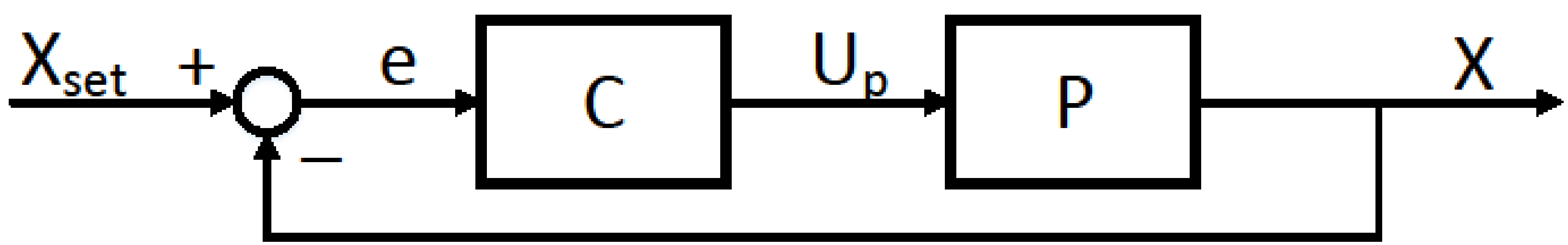
Uavexpertnews.com

Objective & Significance



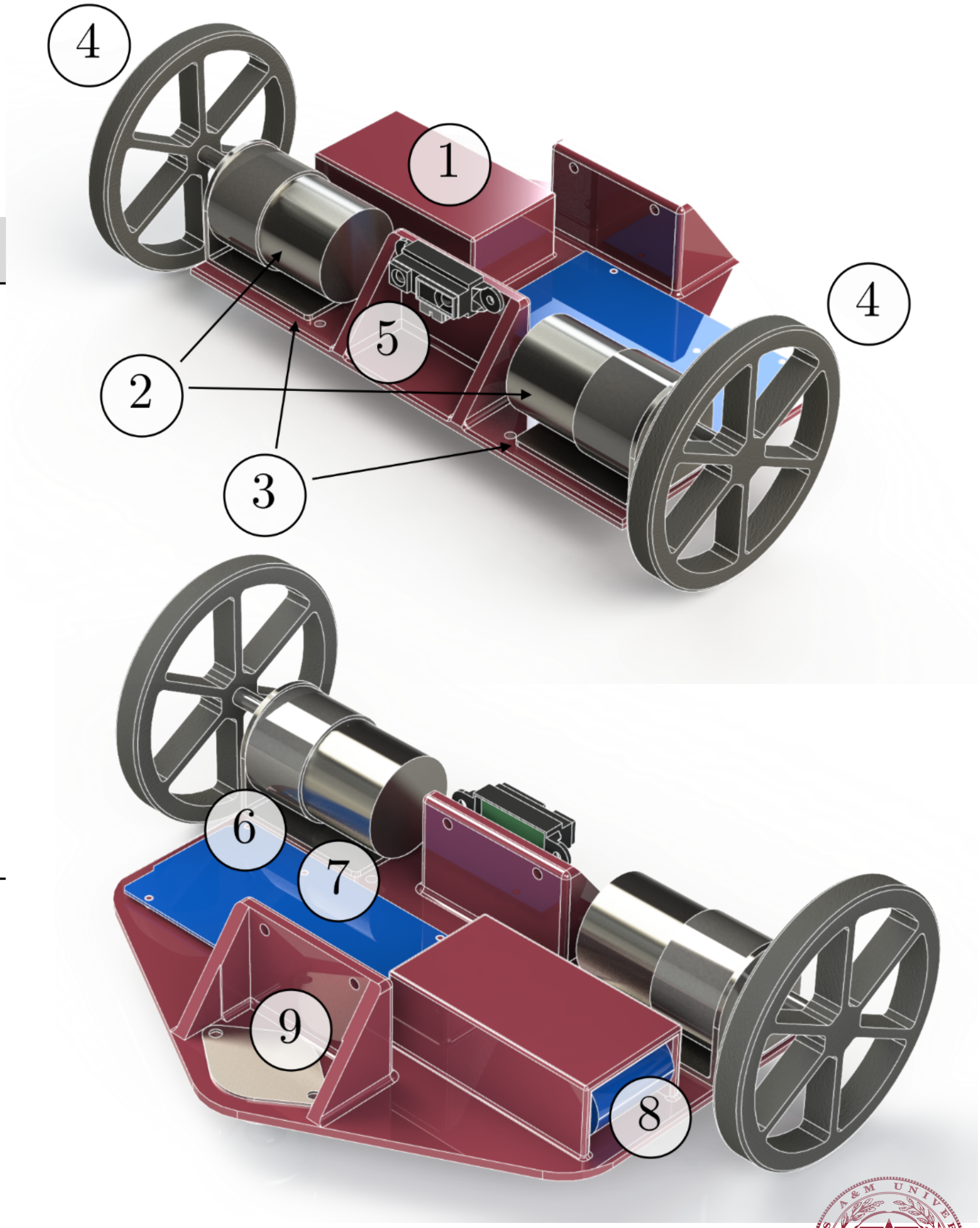
Desired Closed Loop Characteristic Equation:

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

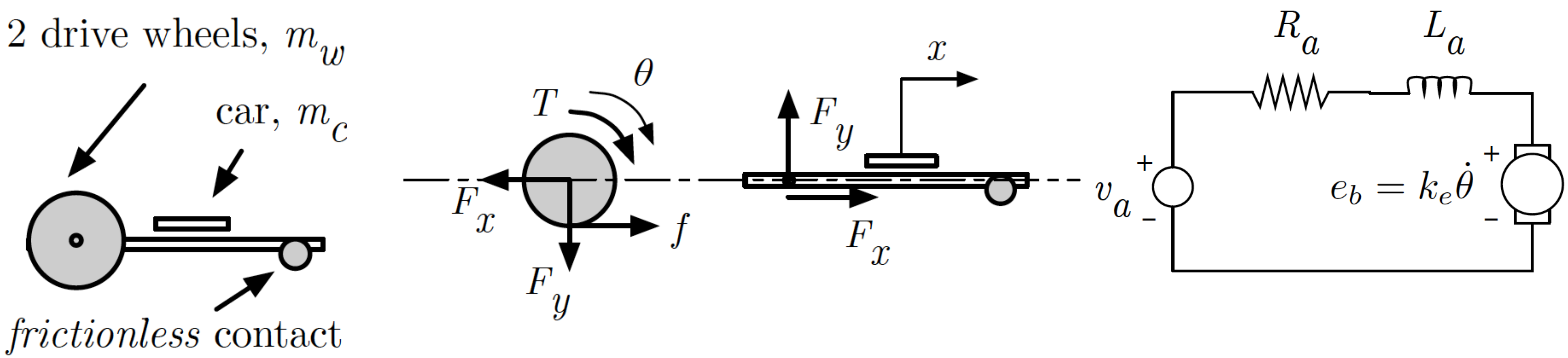


Hardware

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



- **Neglecting** motor dynamics

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

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

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

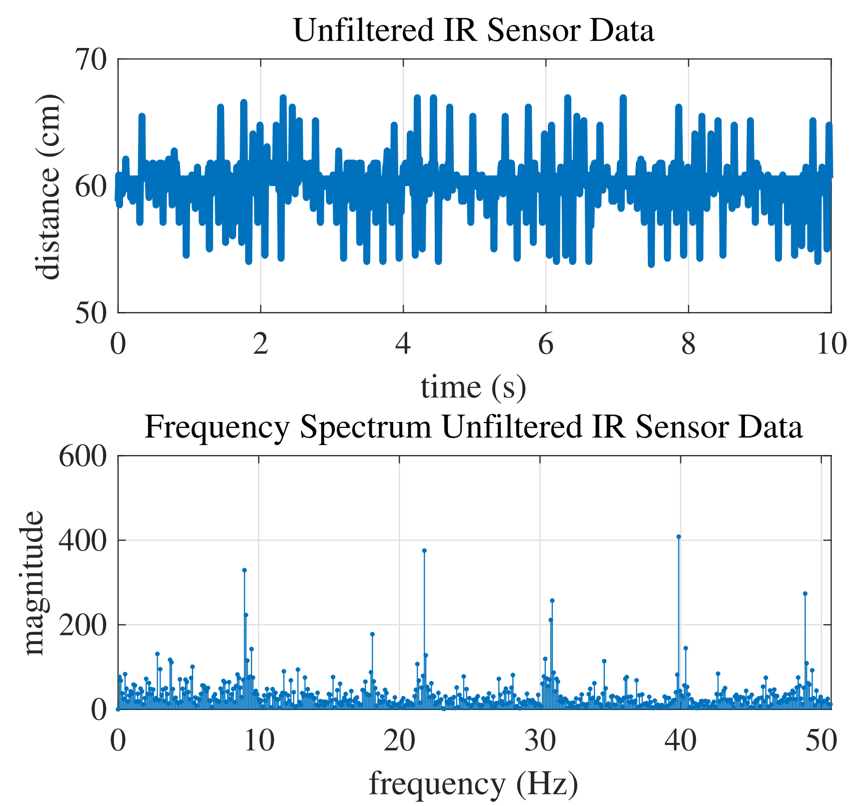
- **Neglecting** I_w and m_w

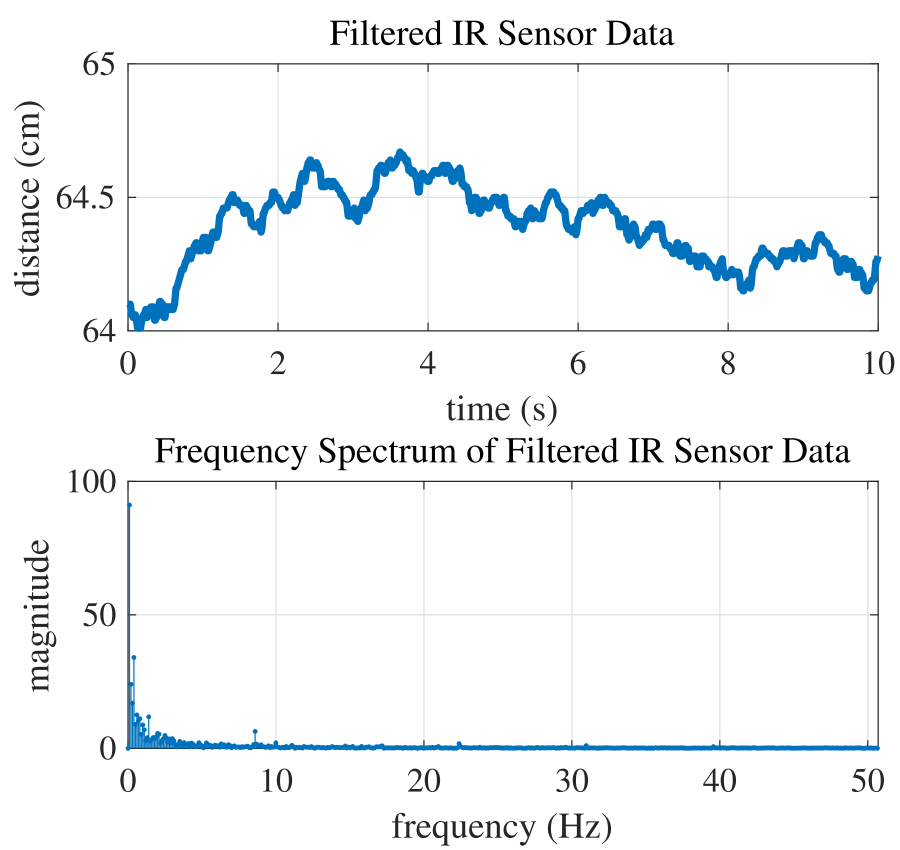
$$X(s) = \frac{1}{0.1728s^2 + 16.9778s} V_a(s)$$

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* ω_{bn}

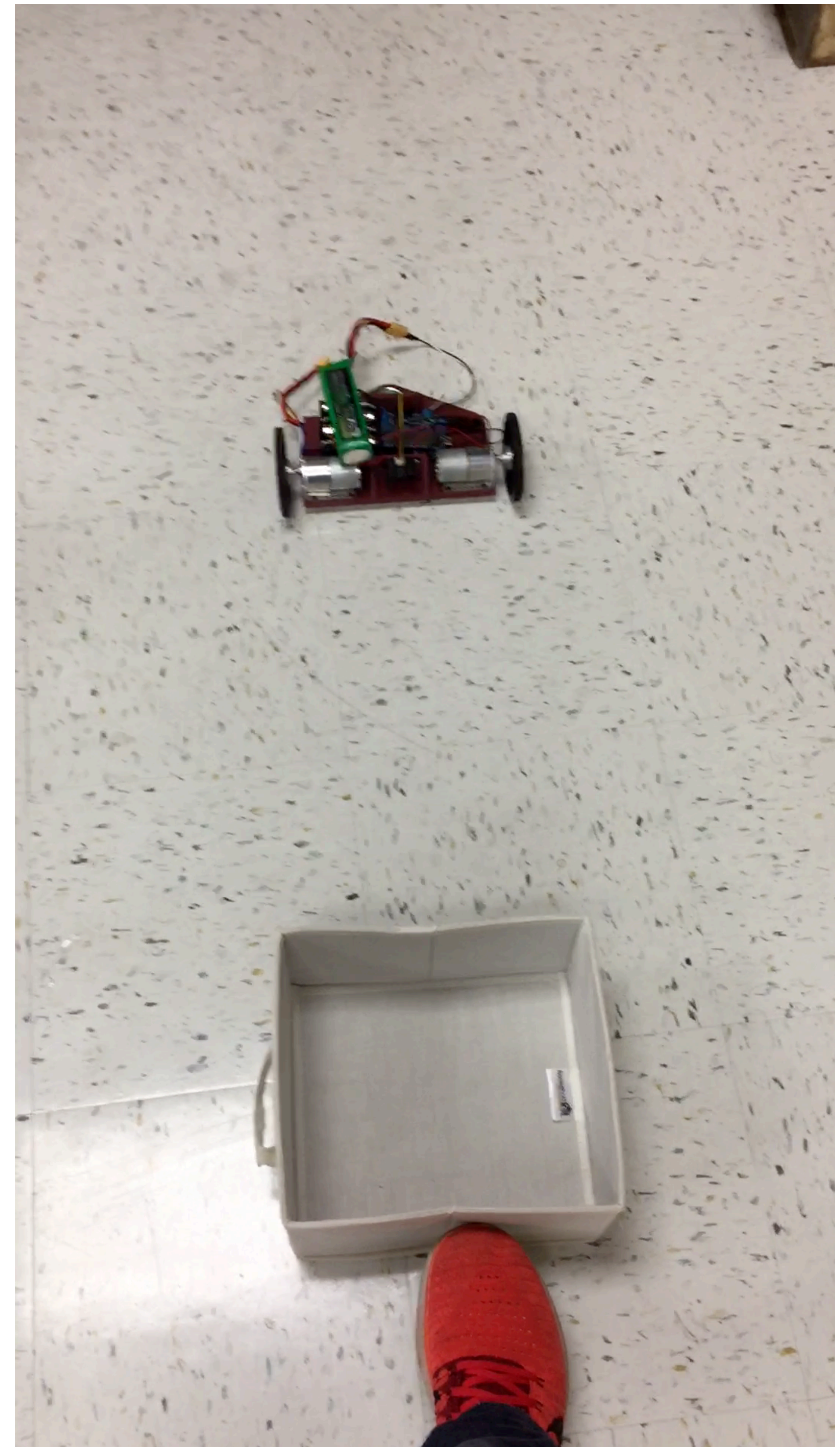
Preliminary Test (Everything OK?)

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

Observations:

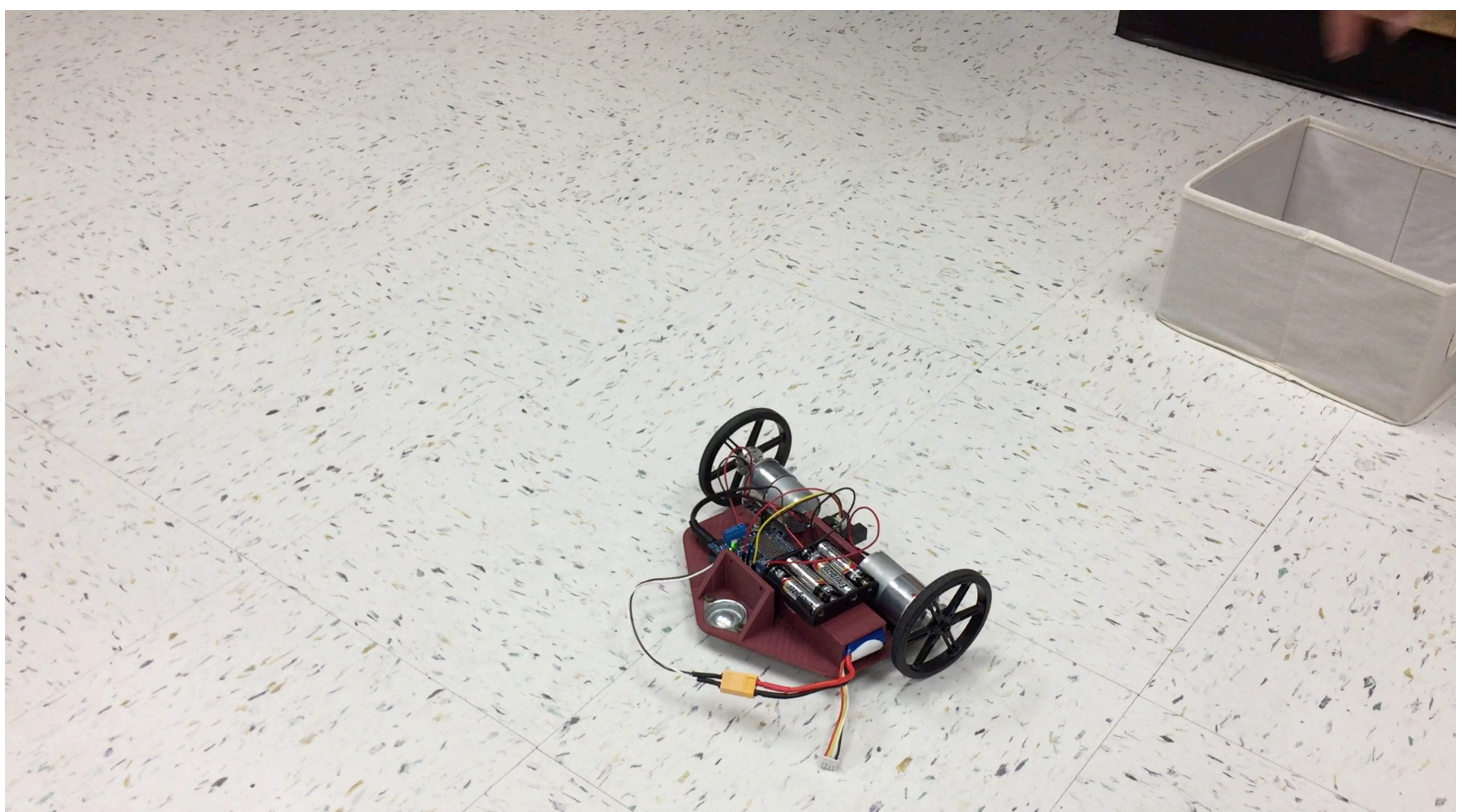
✓ *Dynamics, Implementation OK*

- Too conservative (1/3 motors)
- Open-loop stable -> Saturation



Additional Tests

- Saturation for $v_a > 12V$
- ω_{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:

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

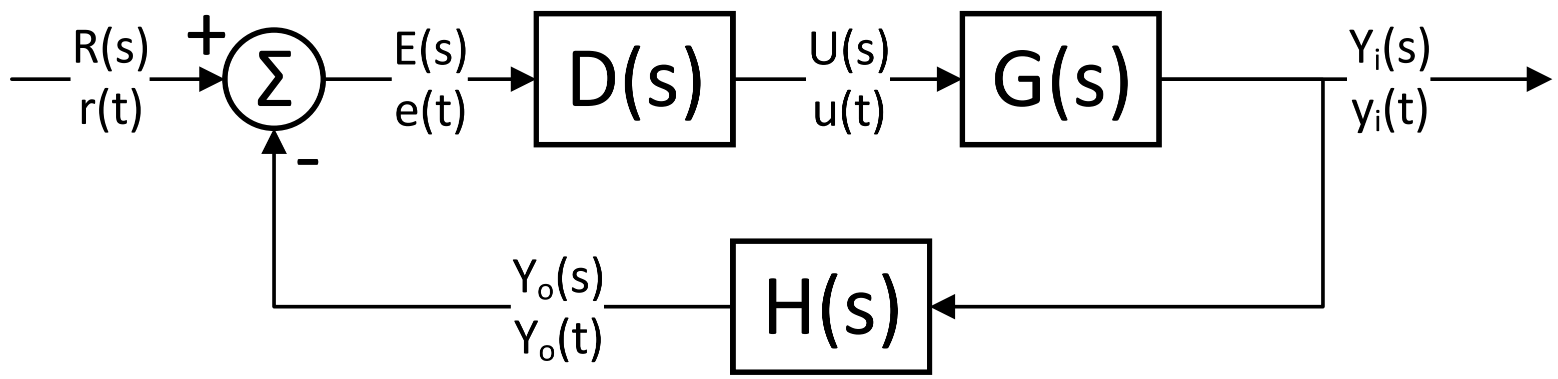
Desired C.L. Characteristic Equation:

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

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

Controller Design (CT)

Continuous Time Controller:



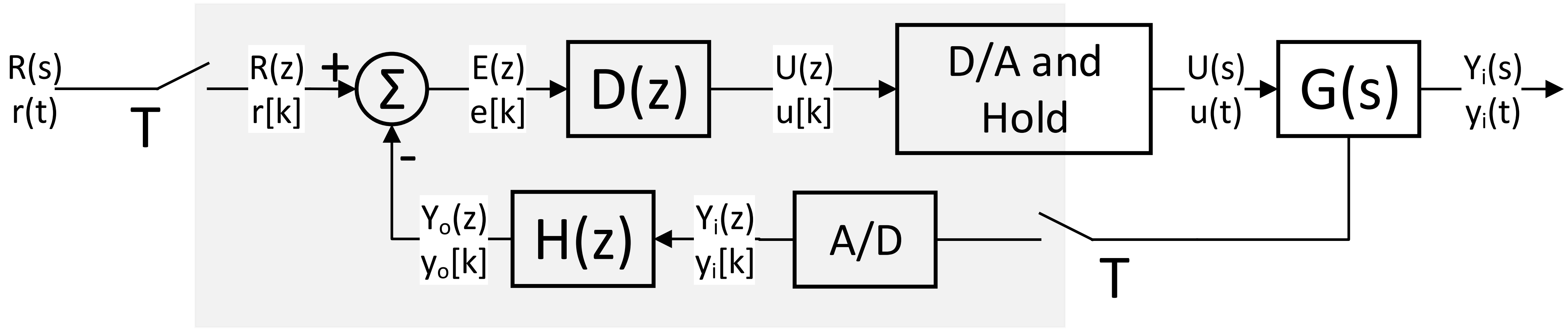
$$D(s) = \frac{k}{s^2 + As + B} \qquad G(s) = \frac{X(s)}{V_a(s)} = \frac{1}{Ms^2 + Cs}$$

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

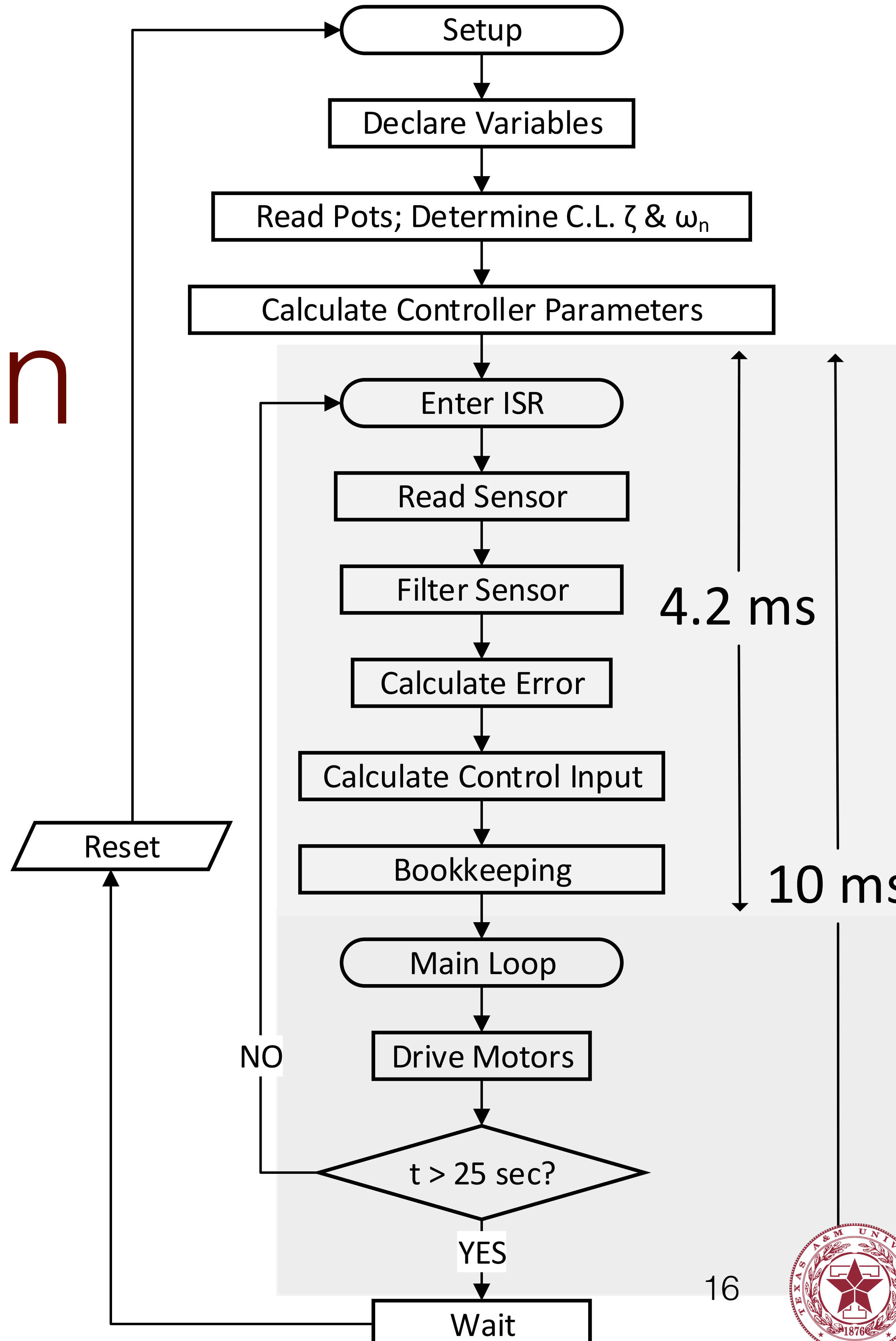
Discretization

Tustin's Transformation:

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



Final Implementation



Object Tracking with Computer Vision

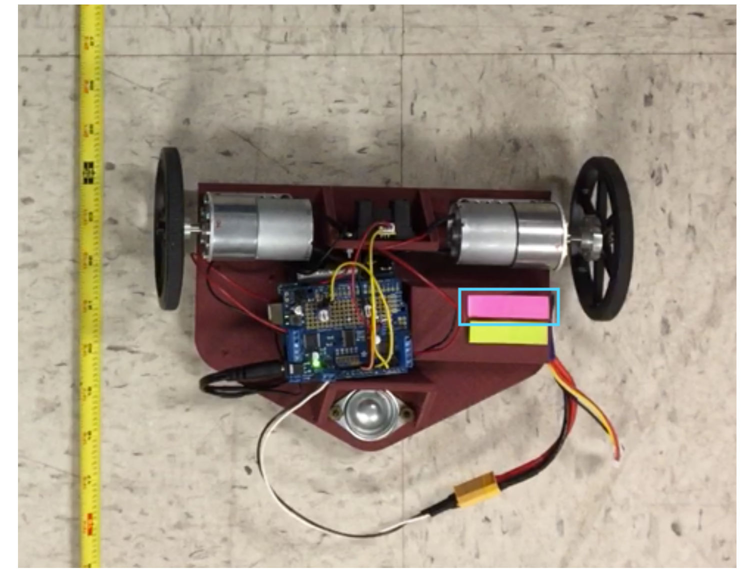
Need to experimentally validate.

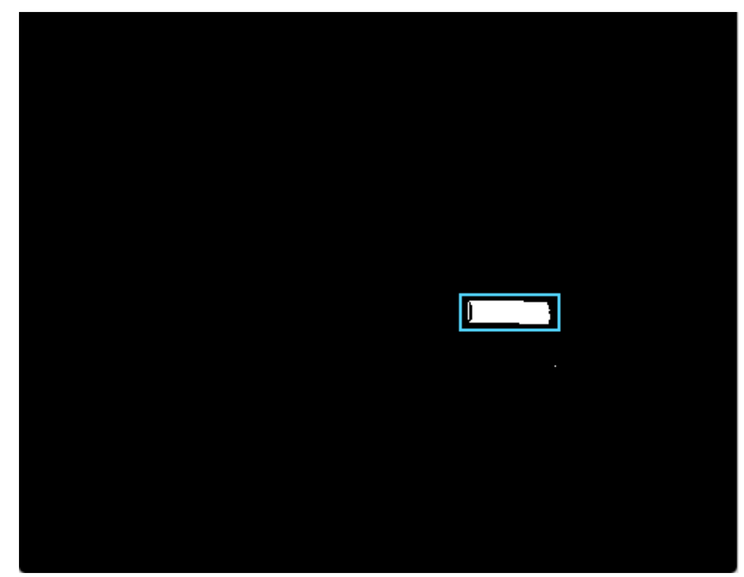
Why CV?

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

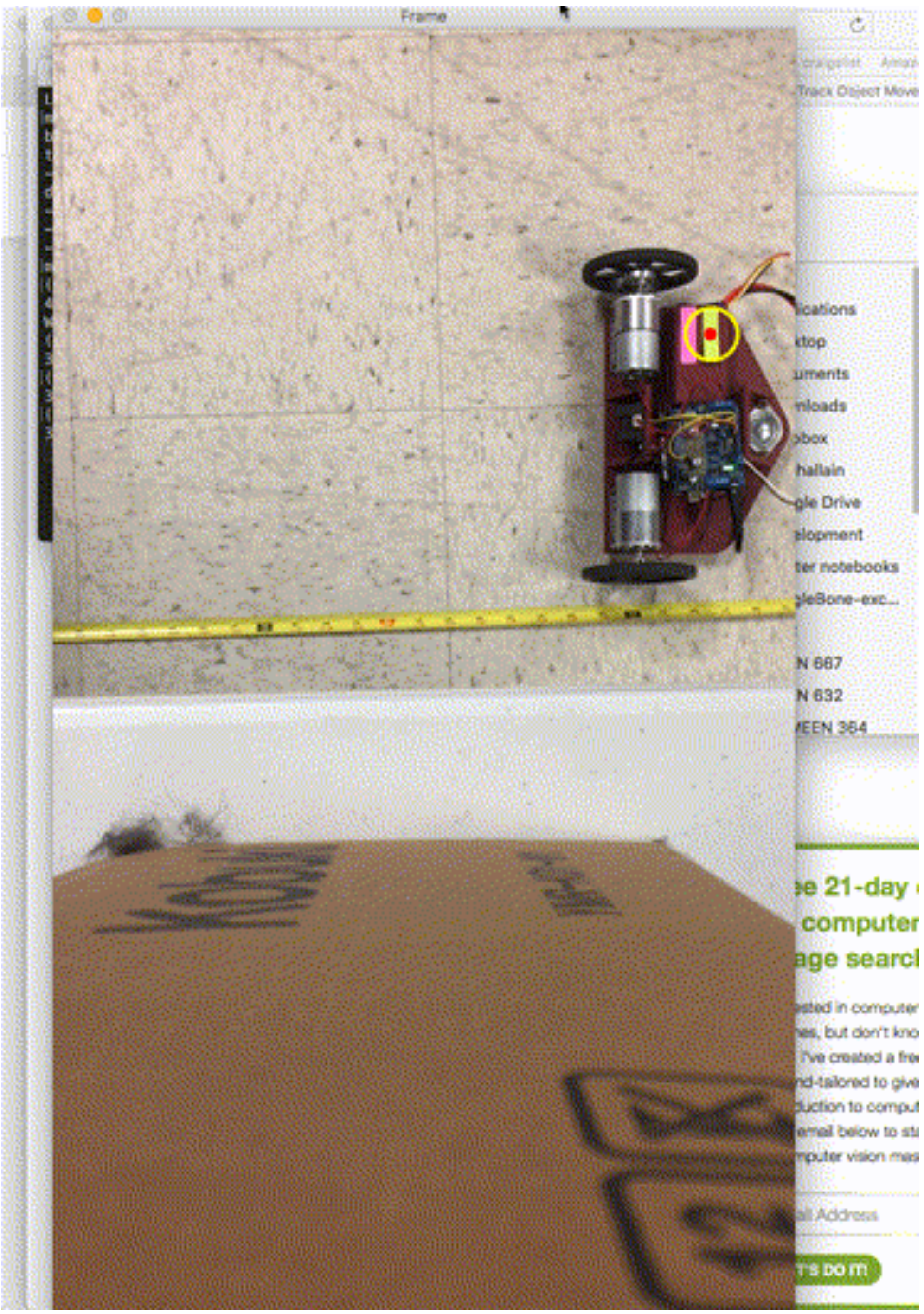
How?

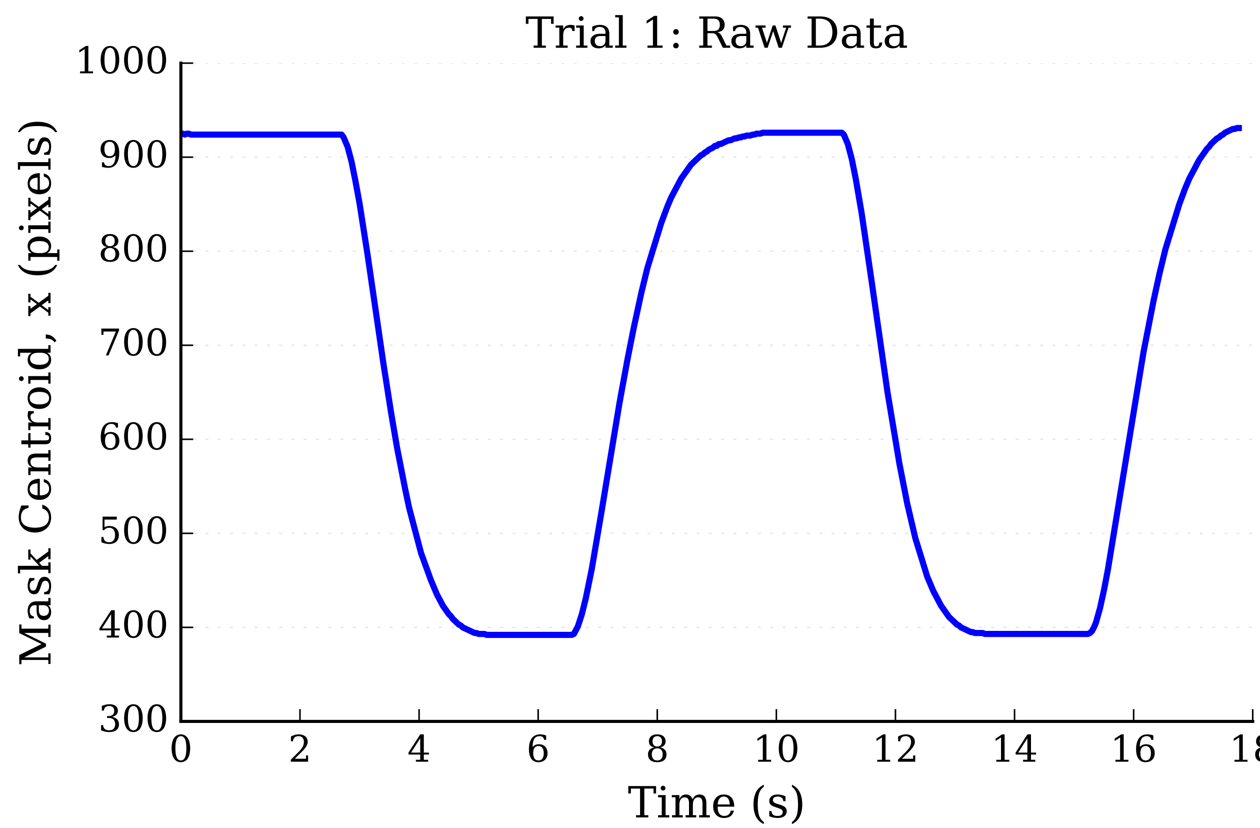
- **OpenCV, Python**
- **Color Masking**



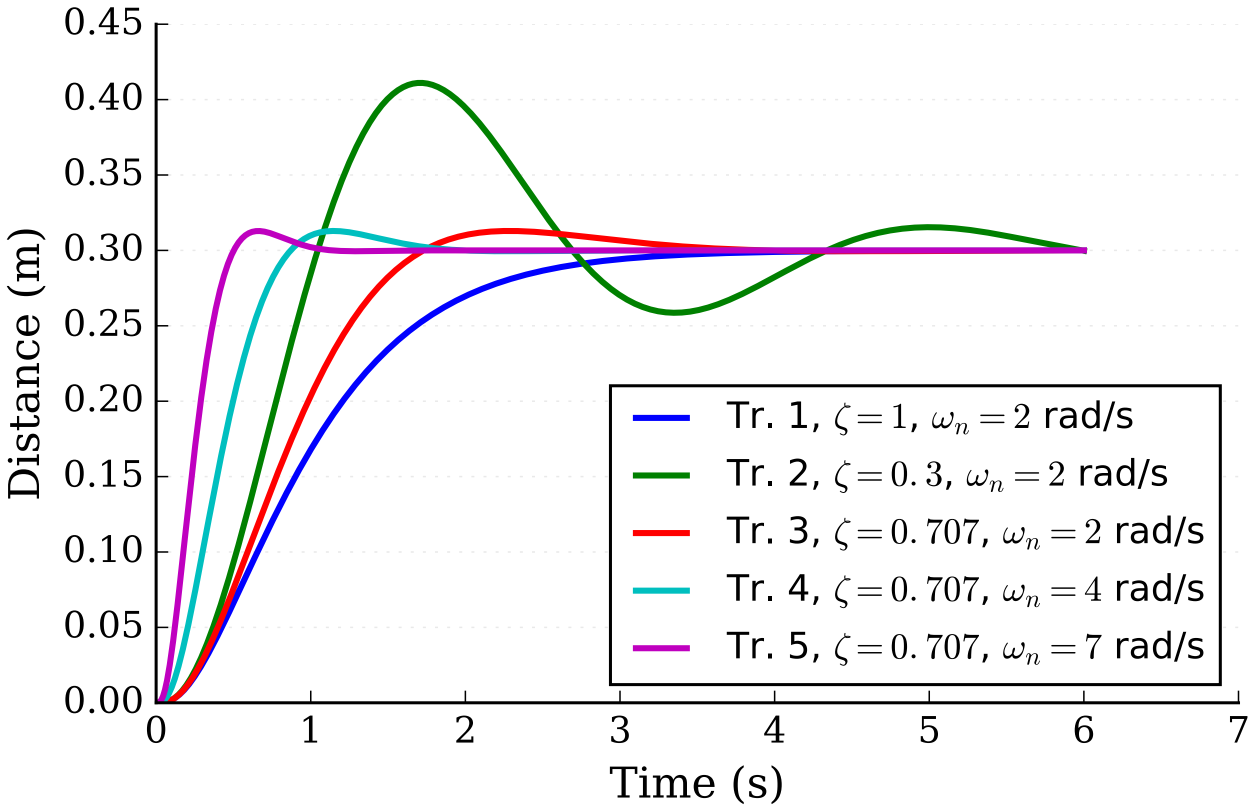


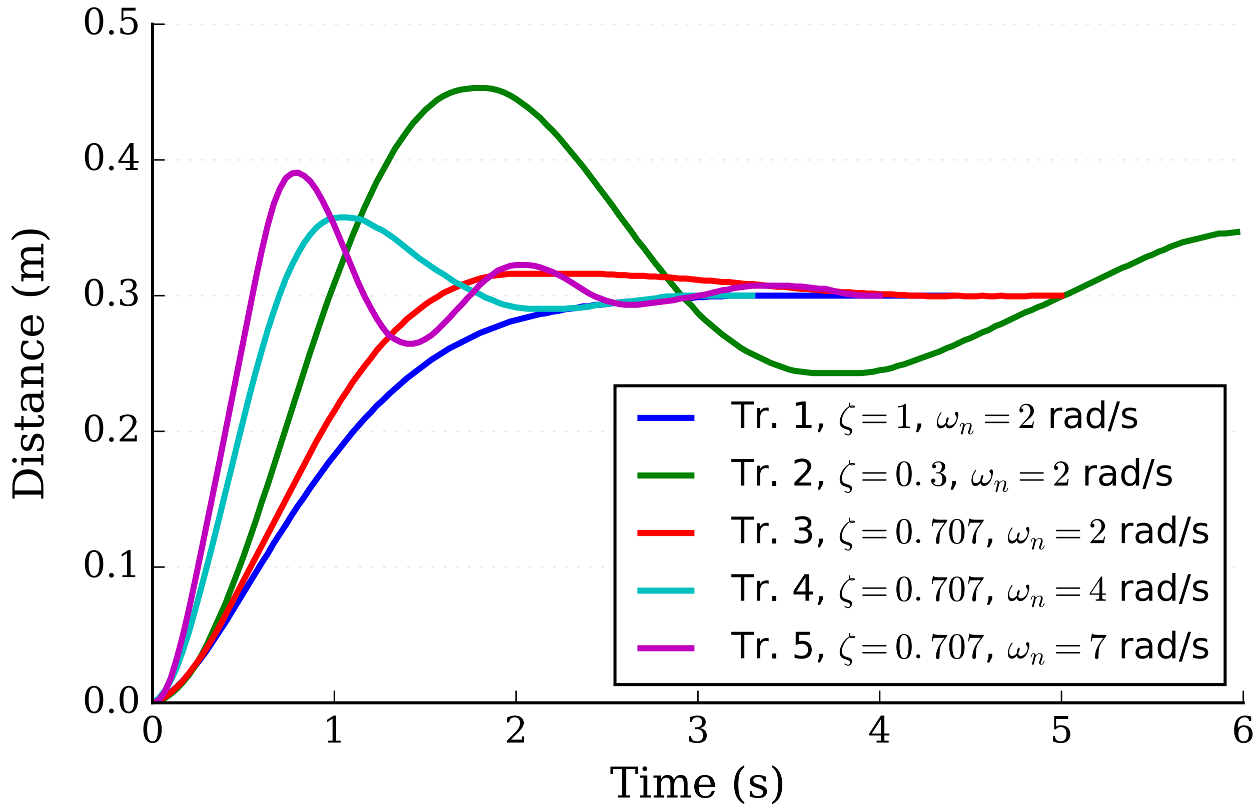
Object Tracking - Sample Trial





Simulated vs. Measured





Human Test Subject

Discussion & Conclusions

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

Challenges

- Actuator saturation
- Zero introduced by filtering

Key Results

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

Questions
&
Demonstration