# Active Aerodynamic Tail Enhances Agile Locomotion of Legged Robots

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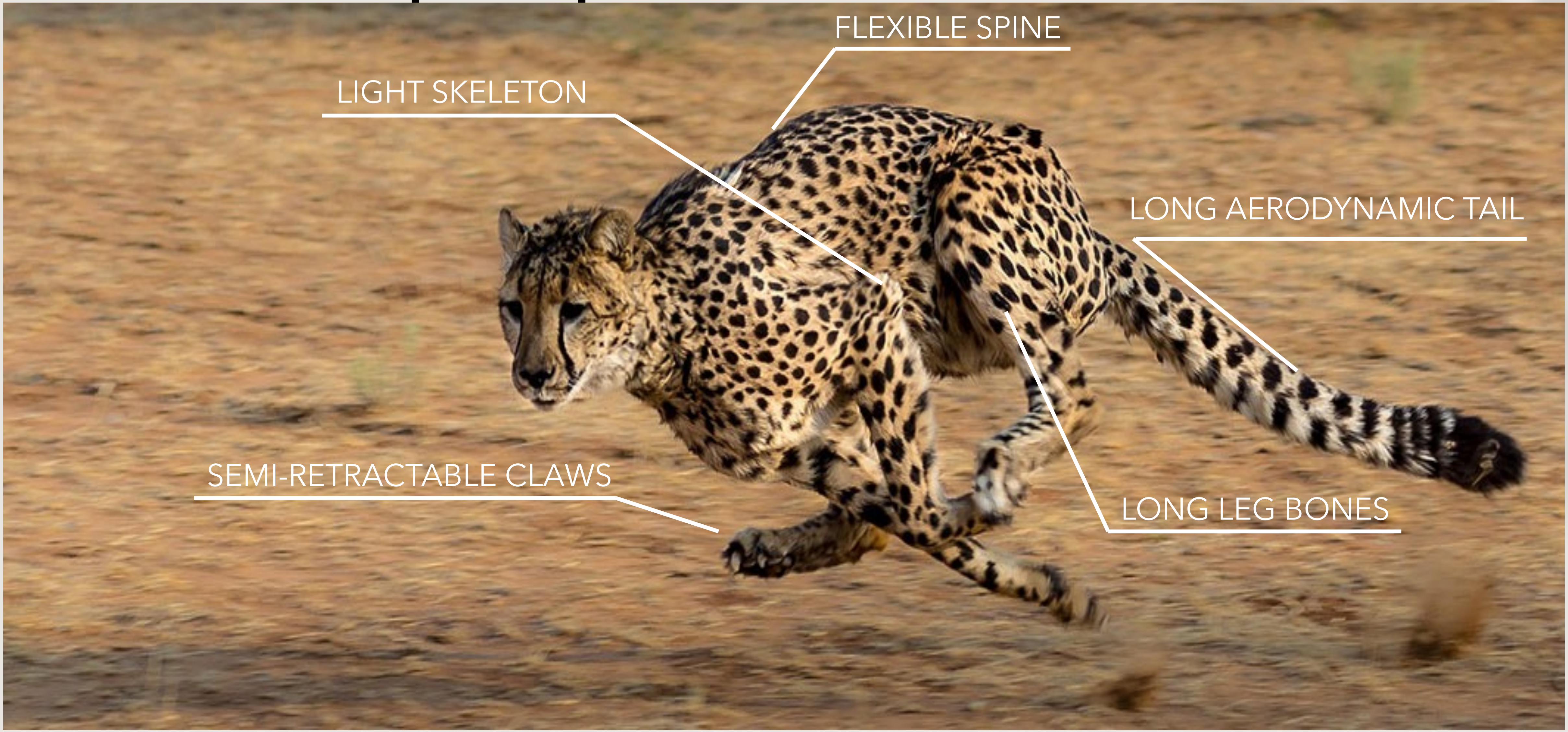
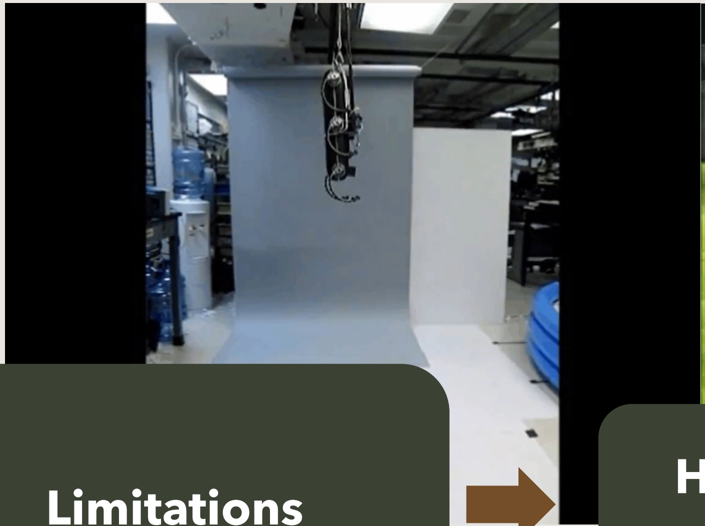
# Agility in animals enables complex adaptation mechanisms

**Agility** → **Dynamic Mobility** + **Speed**

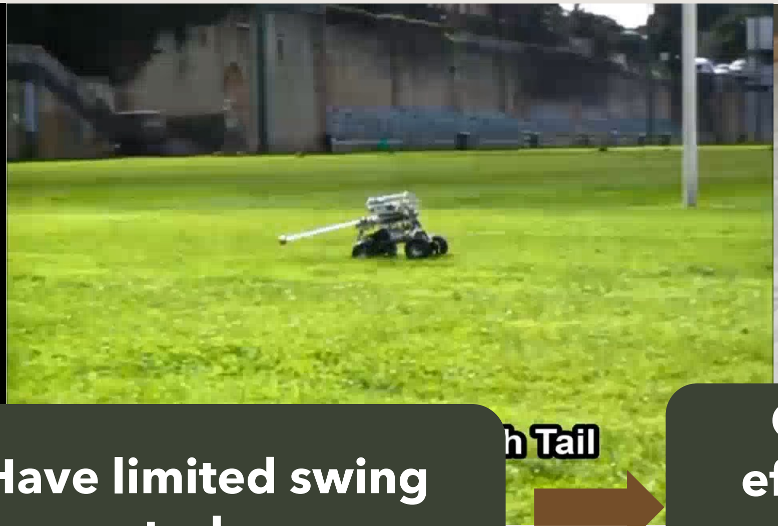
# Unique Adaptation features in cheetahs



# Investigate existing robotic tail designs



al, 2012



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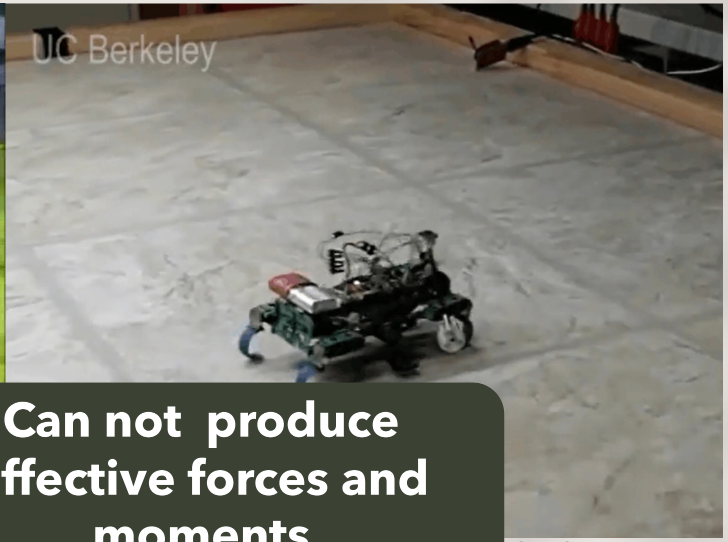


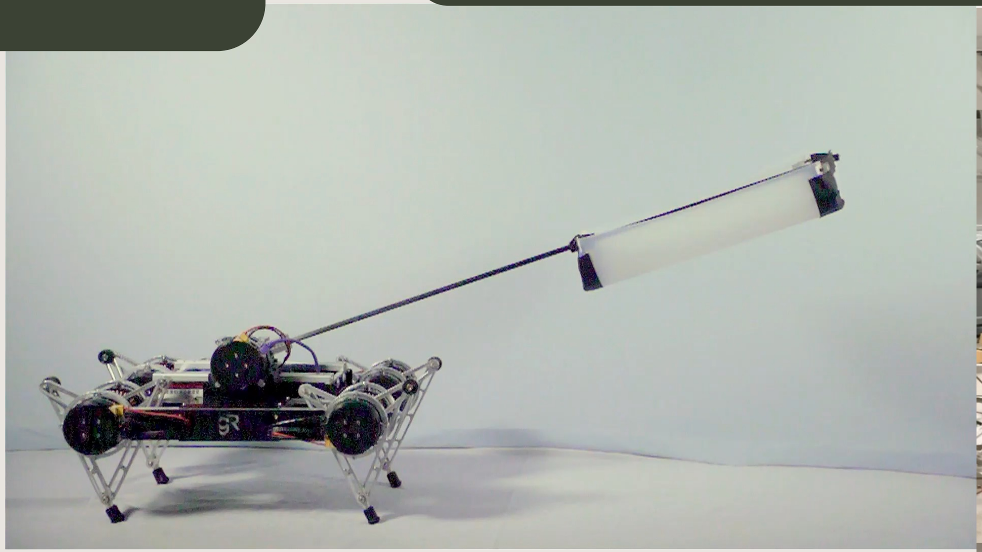

2013

**Limitations**

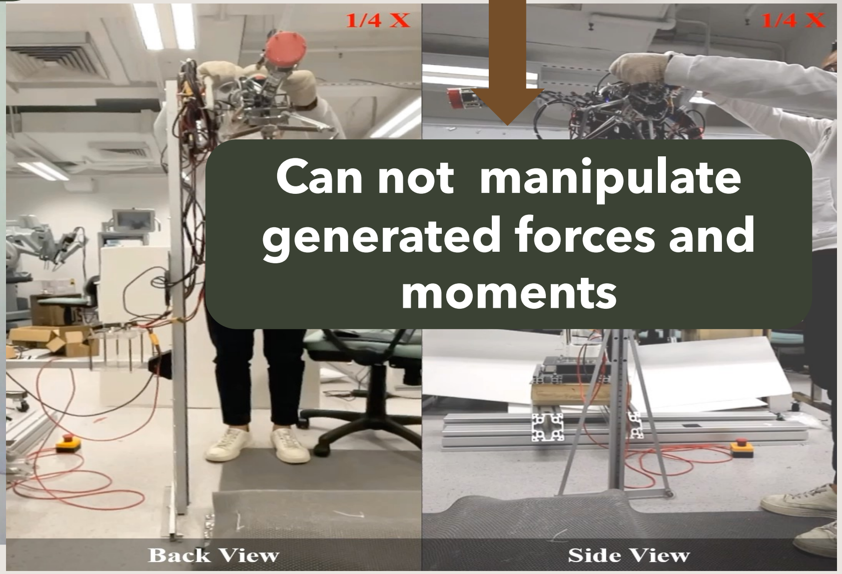
**Have limited swing strokes**

**Can not produce effective forces and moments**

**Can not manipulate generated forces and moments**



Joseph Norby et al, 2021

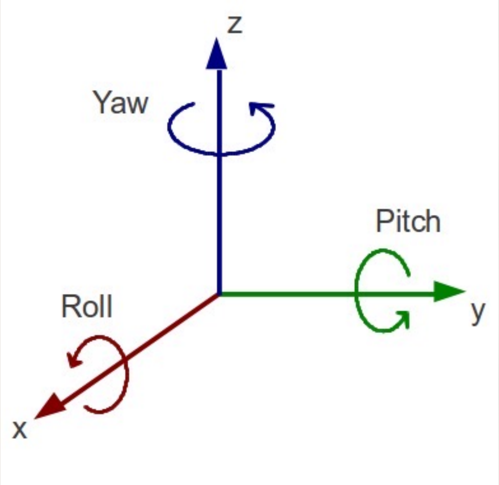


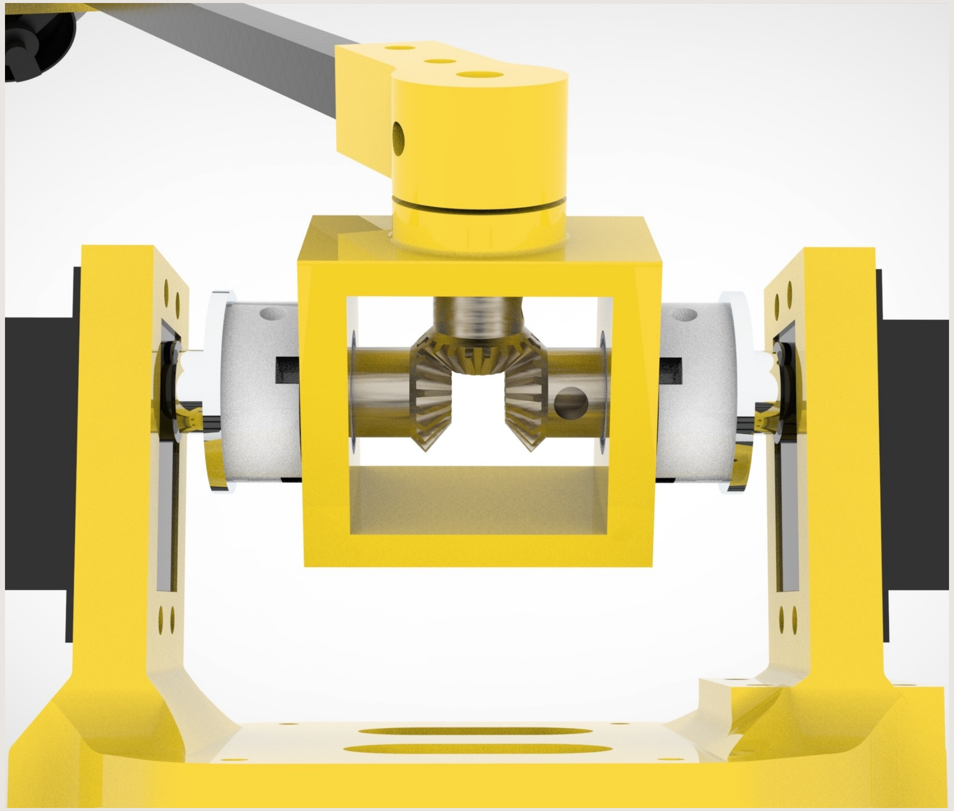

Jiajun An et al, 2023

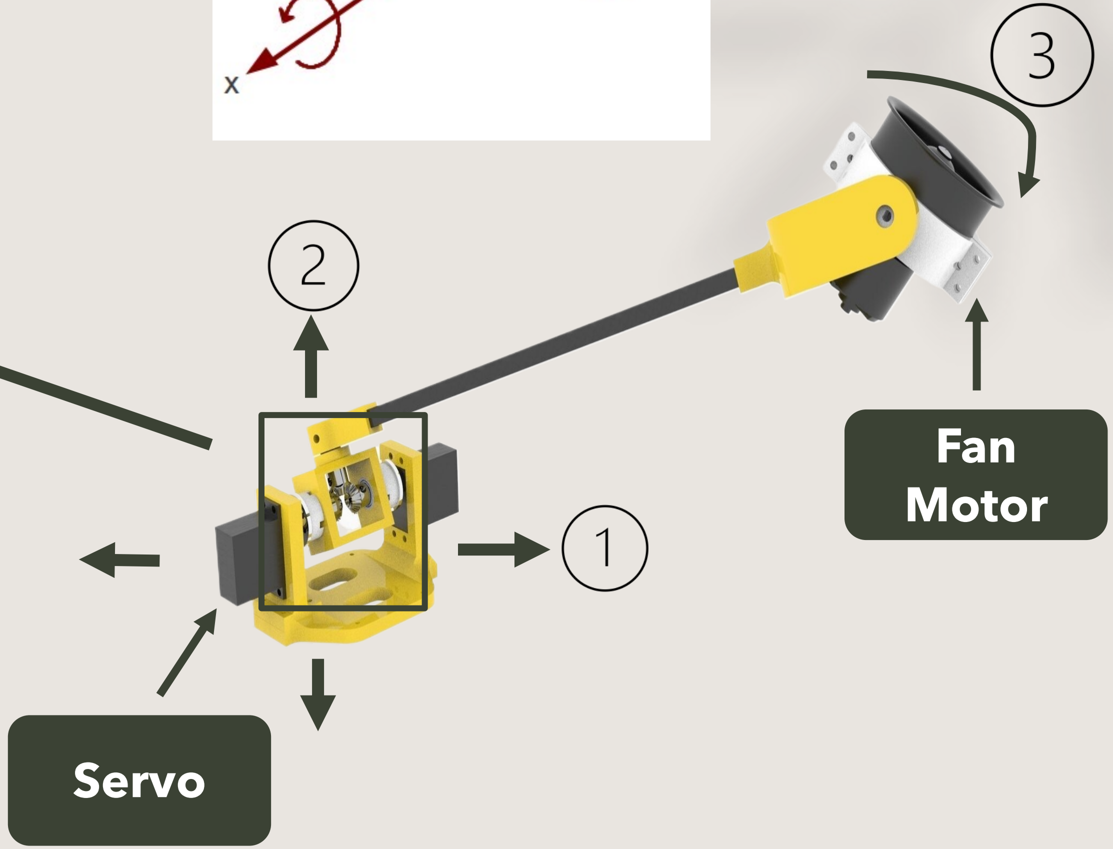
**Goal**: Design an active aerodynamic that generates continuous forces and moments, **without any stroke or direction limitations**, to enhance the agility of legged robots in complex movements.

# Tail Design

**3 Degrees of Freedom**

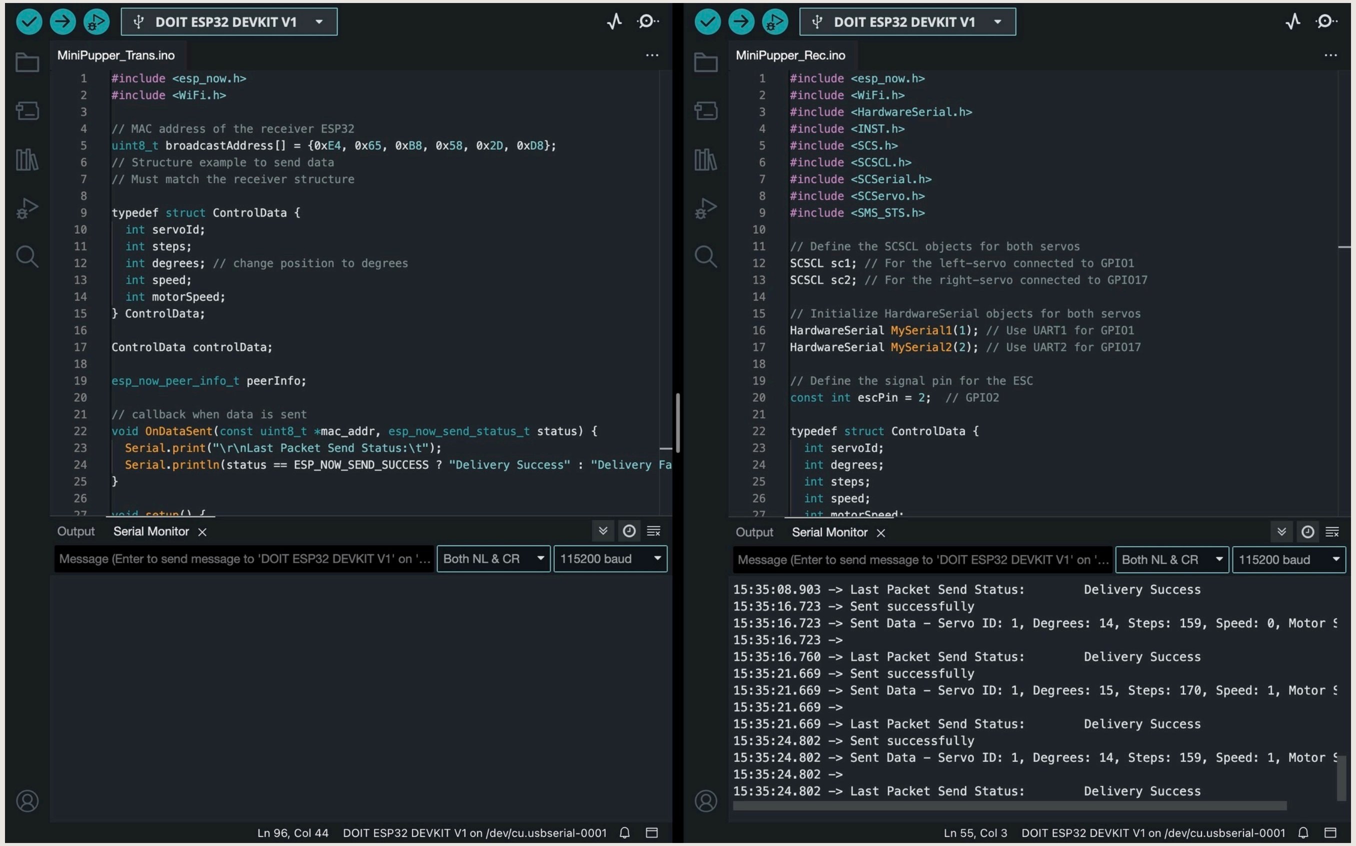




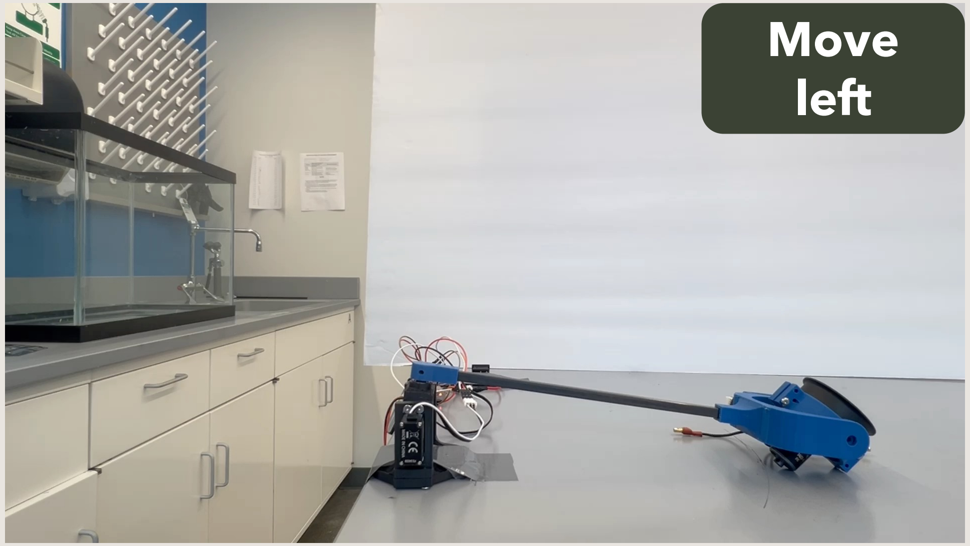
# Tail Control

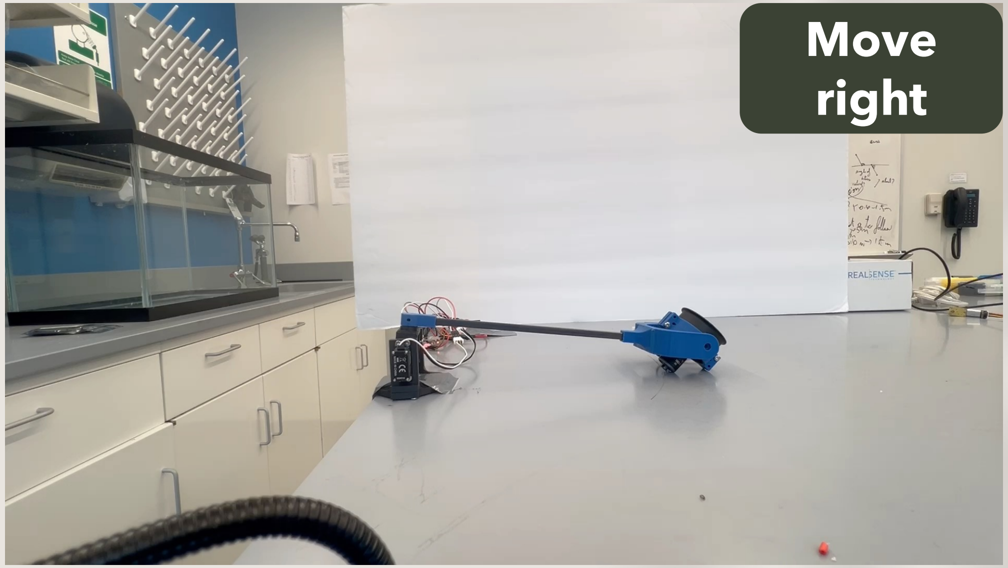
ESP_NOW protocol

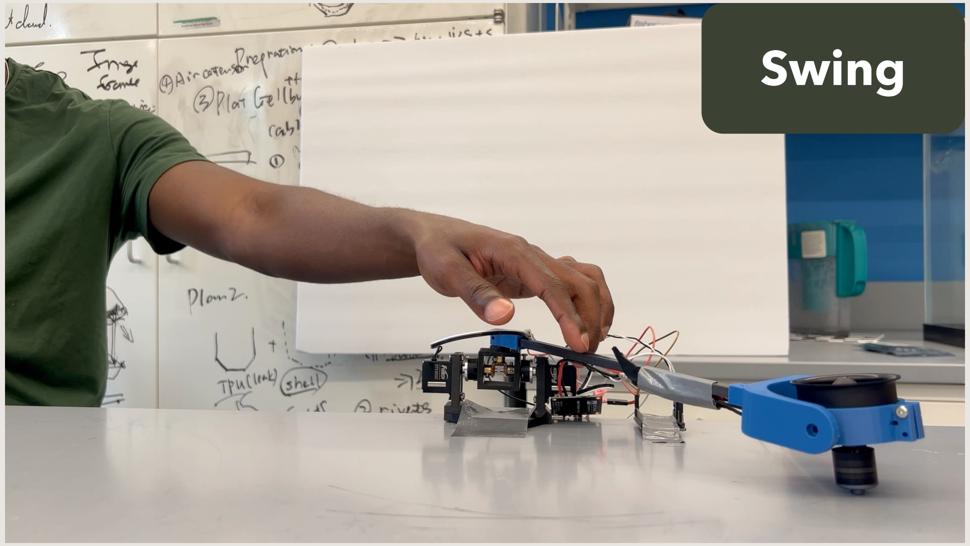


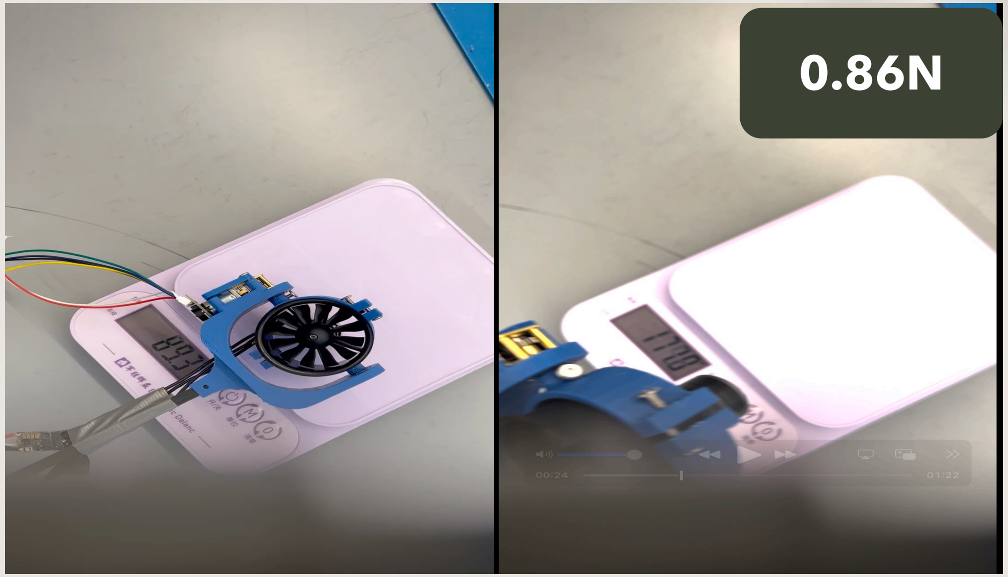

One-way communication

# Tail Experiments



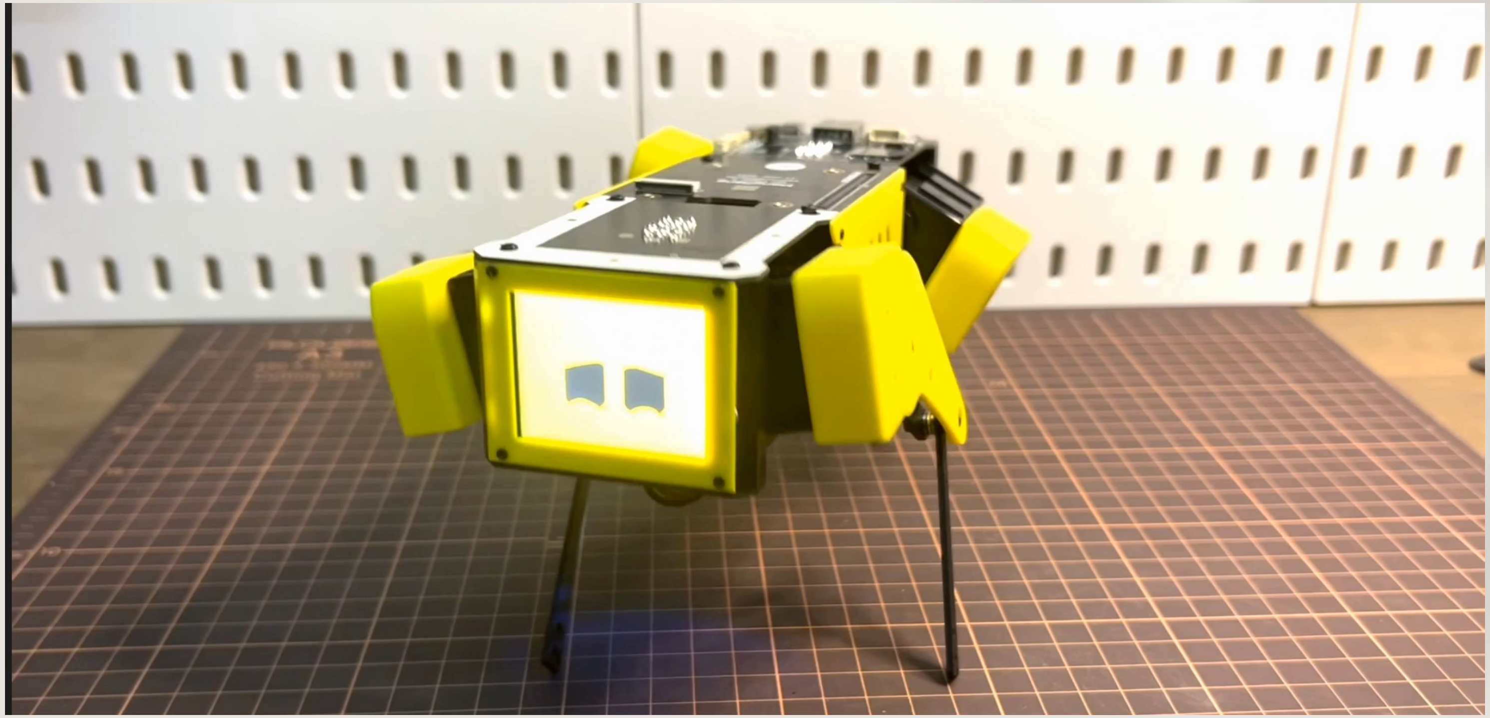



# Robot platform

- Mini Pupper 2, quadruped robot
- Reasons for choice:
  - 12 Degrees of Freedom
  - Open source
  - Ability to mount attachments
  - High quality servos
  - Small

**18cm x 11cm x 11cm**



# How do we measure agility?

Choose locomotion patterns → Design experiments → Gather agility scores

Design experiments ↓

- Forward Locomotion
- Backward Locomotion
- Sidestepping
- Slope running
- Jumping/Leaping
- Turning on Spot

# Experiments

# Results

**Equations from "Benchmark agility paper"**

**Calculate agility scores for Mini Pupper 2**

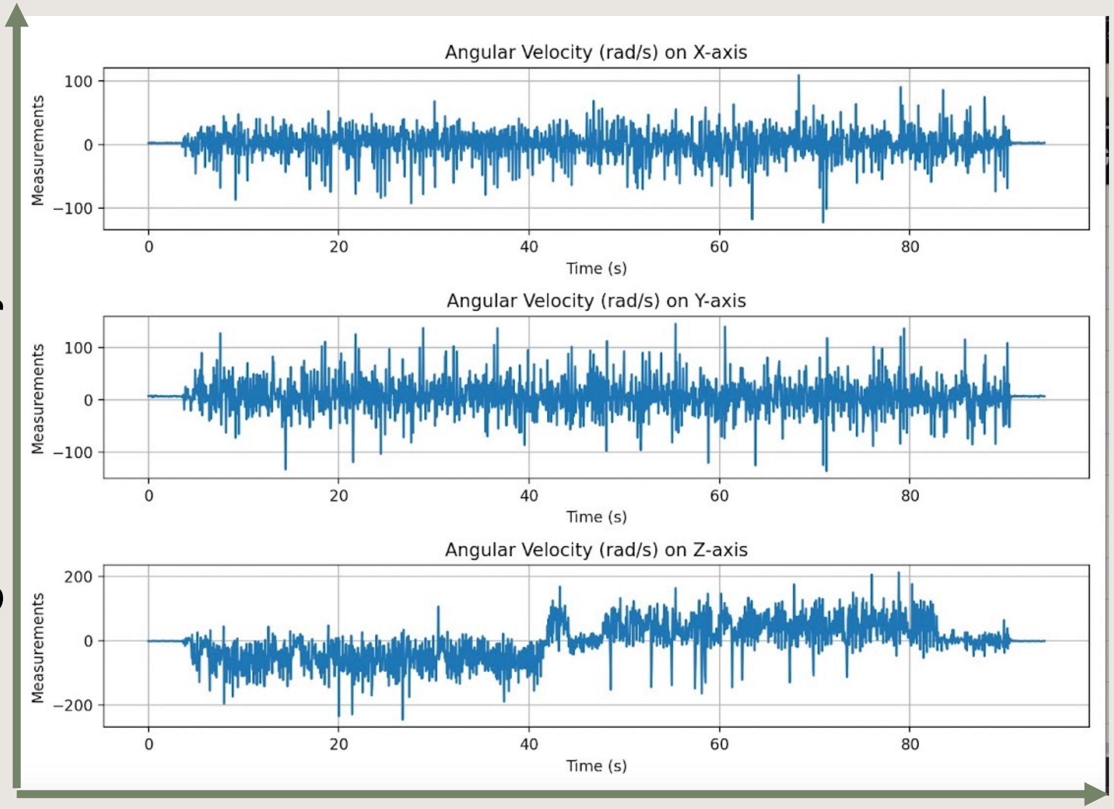
| Calculation | Variance |
|---|---|
| $A_{ts} = \frac{p}{t} \cdot \sqrt{\frac{h_R}{g}}$ | not needed |
| $A_{tr} = q_{tr} \cdot \frac{h_R}{r} \cdot \frac{p}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_{tr} = 1 - \left(\frac{\Delta r}{0.25 \cdot r}\right)$ |
| $A_j = q_j \cdot \frac{h_j}{h_R} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_j = 1 - \left(\frac{\Delta h_j}{0.25 \cdot h_j}\right)$ |
| $A_l = q_l \cdot \frac{l_l}{h_R} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_l = 1 - \left(\frac{\Delta l_l}{0.25 \cdot l_l}\right)$ |
| $A_{lv} = q_{lv} \cdot \frac{l_{lv}}{h_R} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_{lv} = 1 - \left(\frac{\Delta l_{lv}}{0.25 \cdot l_{lv}}\right)$ |
| $A_{s1} = q_s \cdot i_{s1} \cdot \frac{h_{com}}{h_R} \cdot \frac{l_s}{h_R} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_s = 1 - \left(\frac{\Delta w_s}{w_R}\right)$ |
| $A_{s2} = q_s \cdot (-i_{s2}) \cdot \frac{h_{com}}{h_R} \cdot \frac{l_s}{h_R} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_s = 1 - \left(\frac{\Delta w_s}{w_R}\right)$ |
| $A_{s3} = q_s \cdot i_{s3} \cdot \frac{h_{com}}{h_R} \cdot \frac{h_R}{w_R} \cdot \frac{l_{s3}}{h_R} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_s = 1 - \left(\frac{\Delta w_s}{w_R}\right)$ |
| $A_{st1} = \phi \cdot q_{st} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_{st} = \frac{m_{succes}}{10}$ |
| $A_{st2} = q_{st} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_{st} = \frac{m_{succes}}{10}$ |
| $A_{sstep} = q_{sstep} \cdot \frac{w_s}{h_R} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_{sstep} = 1 - \frac{\Delta l_s}{0.25 \cdot l_R}$ |
| $A_{fl} = q_{fl} \cdot \frac{l_{fl}}{h_R} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_{fl} = 1 - \frac{\Delta w_{fl}}{w_R}$ |
| $A_{bl} = q_{bl} \cdot \frac{l_{bl}}{h_R} \cdot \frac{1}{t} \cdot \sqrt{\frac{h_R}{g}}$ | $q_{bl} = 1 - \frac{\Delta w_{bl}}{w_R}$ |

| | | | |
|---|---|---|---|
| 8 | Ats | 0.015 | no q |
| 9 | Atr | x | |
| 10 | Aj | | |
| 11 | Al | | |
| 12 | Alv | | |
| 13 | As1(downslope) | 0.03274337 | q = N/A |
| 14 | As2(upslope) | 0.03016805 | q =N/A |
| 15 | As3(sagittal plane) | 0.03098841 | q = N/A |
| 16 | Ast1 | | |
| 17 | Ast2 | | |
| 18 | Asstep | | |
| 19 | Afl | 0.062 | q = N/A |
| 20 | Abl | 0.102 | q = N/A |
| 21 | Agav% | | |

# Results

Gyro data for turning on spot

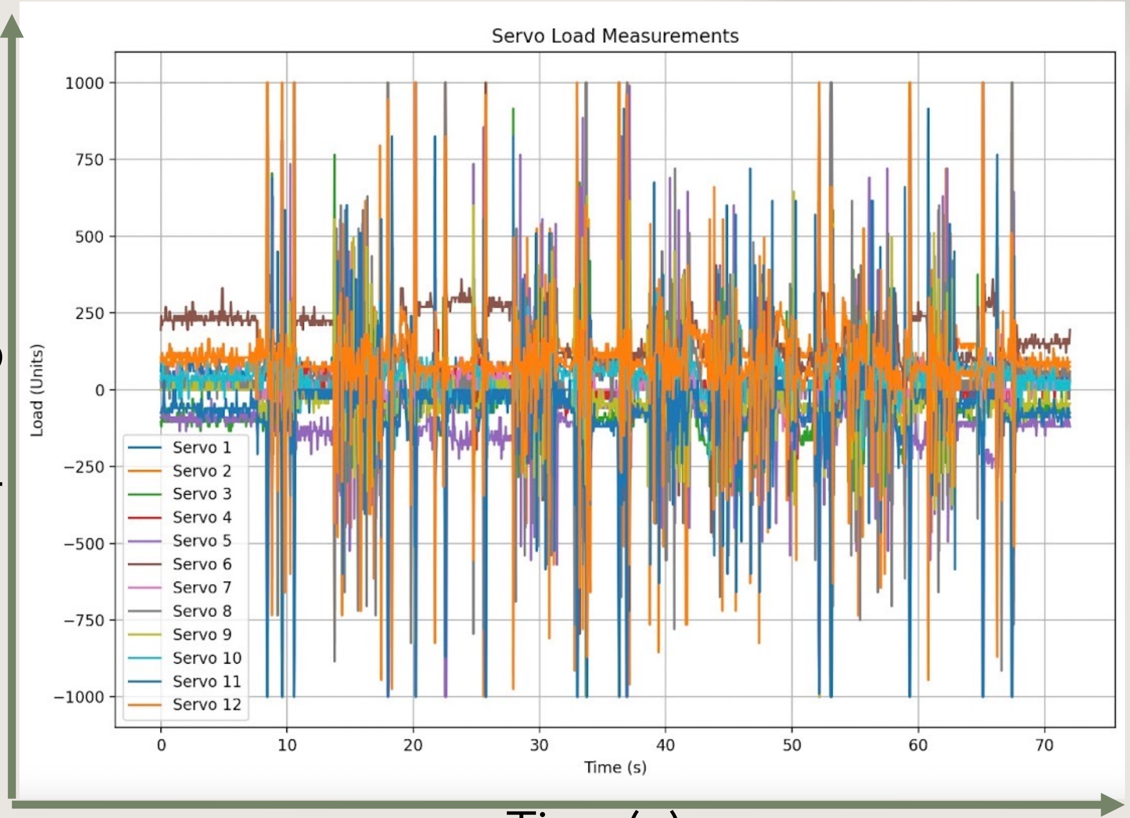
Angular Velocity(rad/s)




Time(s)

Load data for jumping

Torque(kg.cm)




Time(s)

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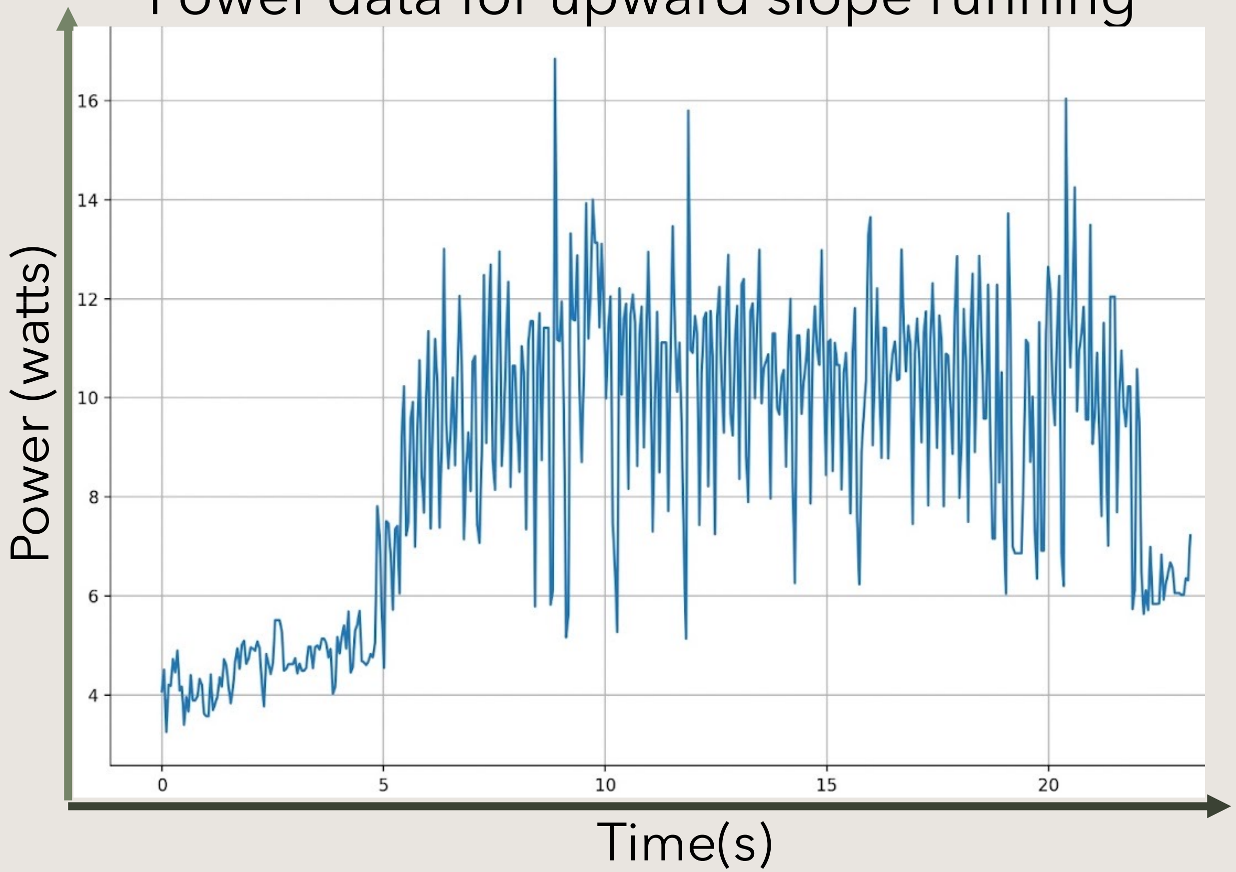
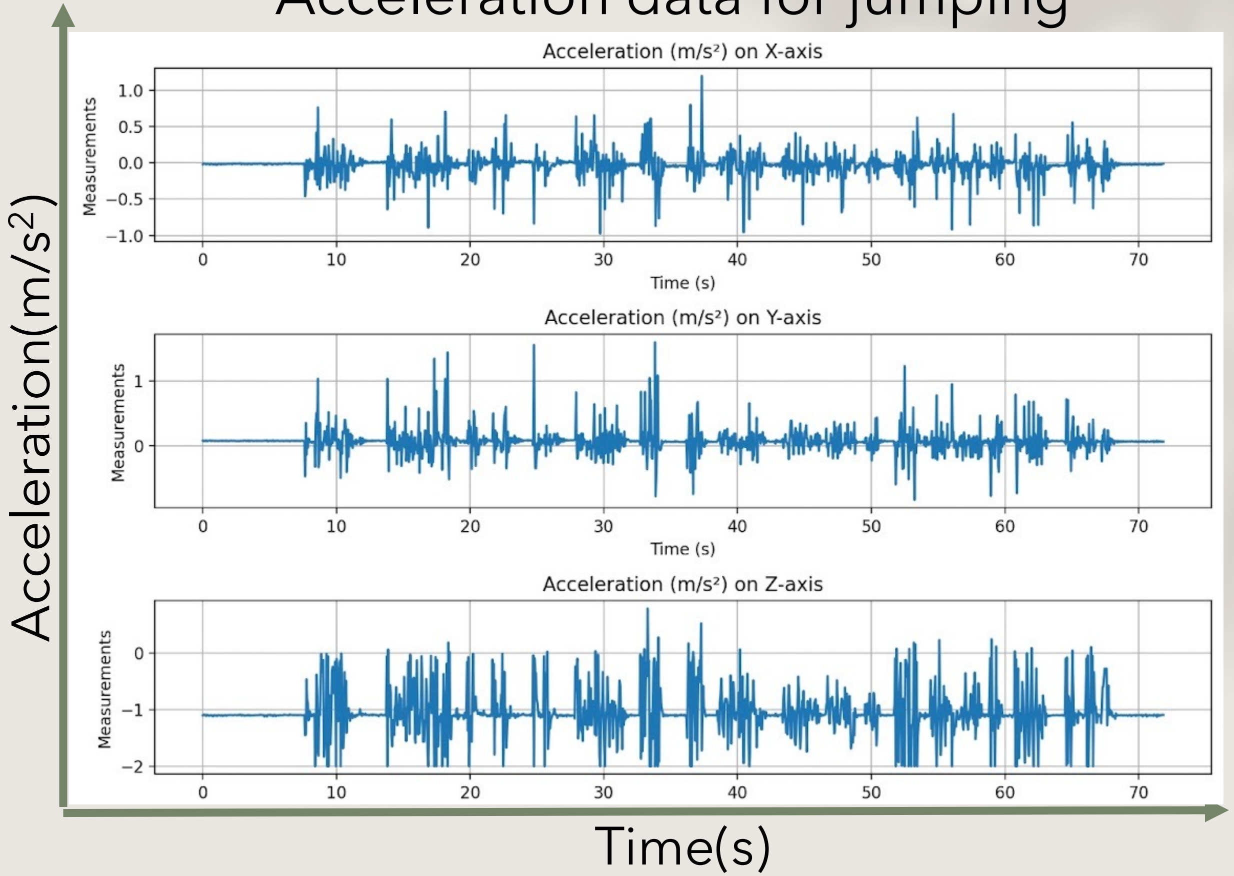
# Results

Power data for upward slope running




Acceleration data for jumping



# Conclusions & Future work

Conclusions:

- Designed an active aerodynamic tail
- Implemented tail control system
- Tested MiniPupper agility without tail

Future work:

- Simulate MiniPupper with tail
- Evaluate agility with tail
- Integrate Reinforcement Learning policy from cheetahs