SiMPLeR: A Series-Elastic Manipulator with Passive Variable Stiffness for Legged Robots

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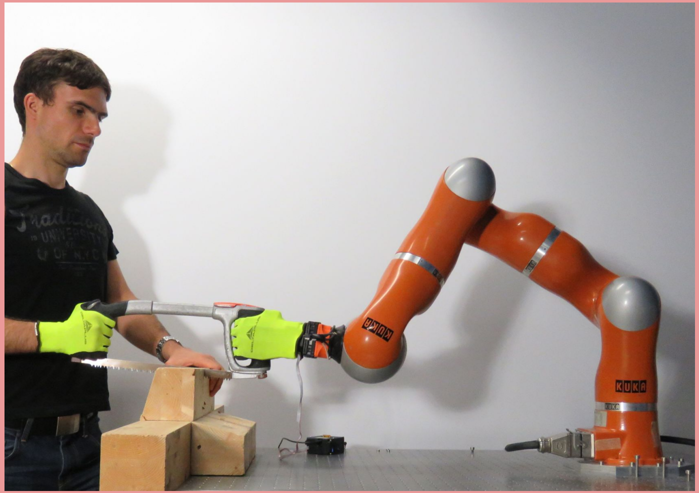
Introduction

- Collaborative environments are dangerous
- Compliant actuators address these issues'
  - Active compliance
  - Passive compliance
- Fixed compliance is limiting for robots
  - Payload
  - Speed
  - Energy efficiency
  - Tuned locomotion
- VSAs address these issues
  - Add in method for controlling stiffness



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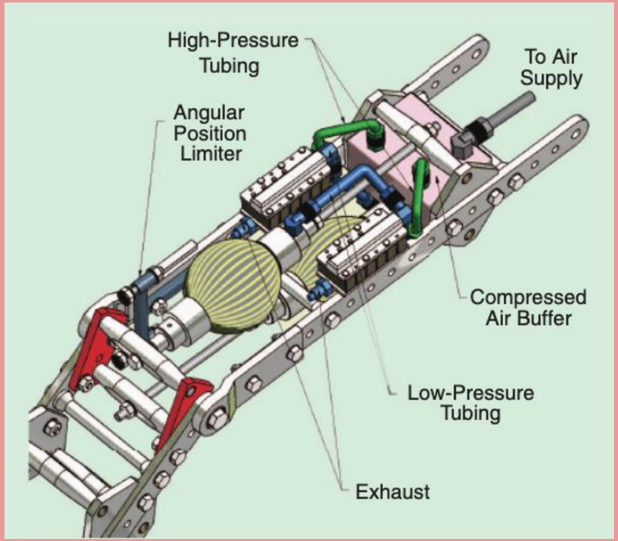
Previous Work

- Active VSA
  - Software based
  - Commercial robot: ASIMO
- Equilibrium controlled
  - Simulated through impedance control
  - SEA
  - Commercial arms: KUKA iiwa, Franka
- Antagonistic controlled
  - Non-linear springs, pneumatics
  - Additional actuator
  - VSA-cube, AMASC
- Structure controlled
  - Variation of material structure
  - Making spring coils inactive



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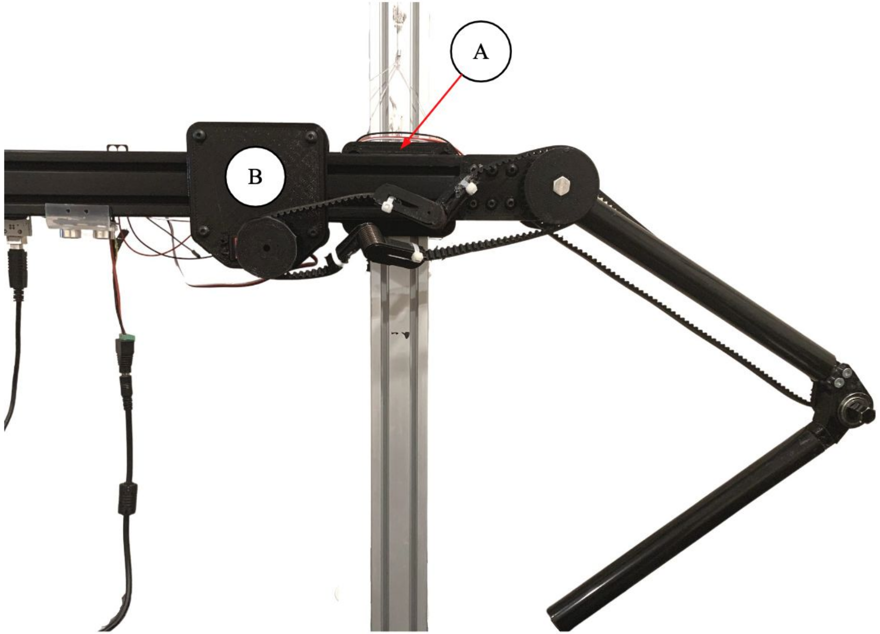
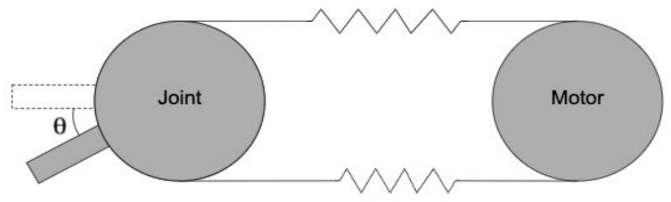
Contributions

- Passive VSA
  - Low-cost torsion springs
  - Biomimetic approach
  - Energy efficient stiffness control
- Simple Design
- Legged Robot Application



Traditional SEA

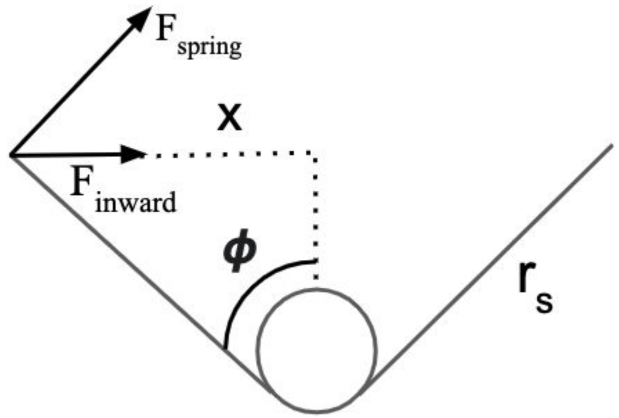
- Linear Springs
- Fixed Compliance
- Torque is reliant on 3 variables
    - pulley radius
    - spring constant
    - deflection
- To modify for VSA
    - Control k,r independently
    - changing radius would change torque characteristics



$$\tau(\theta) = k[(x_i + r\theta) - (x_i - r\theta)]$$
$$\tau(\theta) = k[2r\theta]$$

Torsion Springs

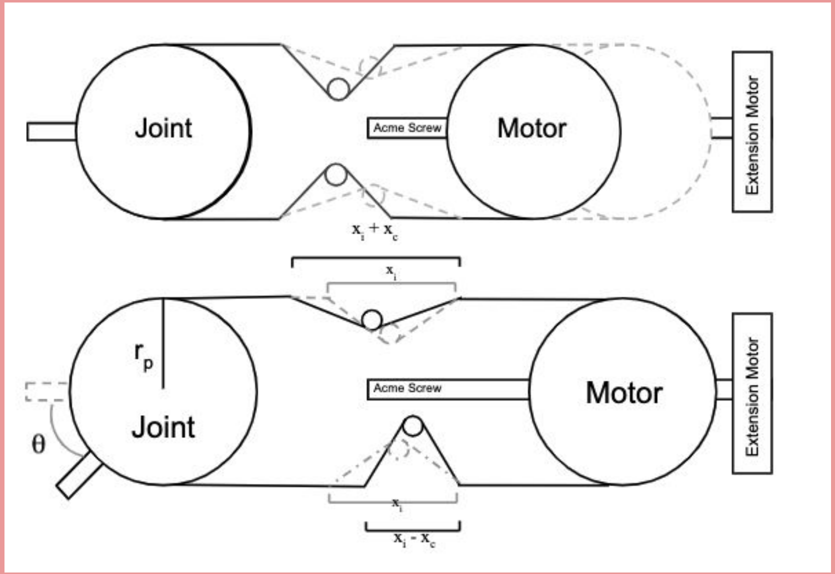
- Low-cost
- Linear torque/angular displacement relationship
- Non-linear inward force/horizontal displacement relationship
  - Can be applied in antagonistic fashion
- Acts analogous to rigid belt
  - When pulled 180, essentially a metal rod
- Stiffness can be varied by pretension of springs



$$\sigma(x) = \frac{\kappa \cdot \arcsin(\frac{x}{r_s})}{x \cdot \sqrt{r_s^2 - x^2}}$$

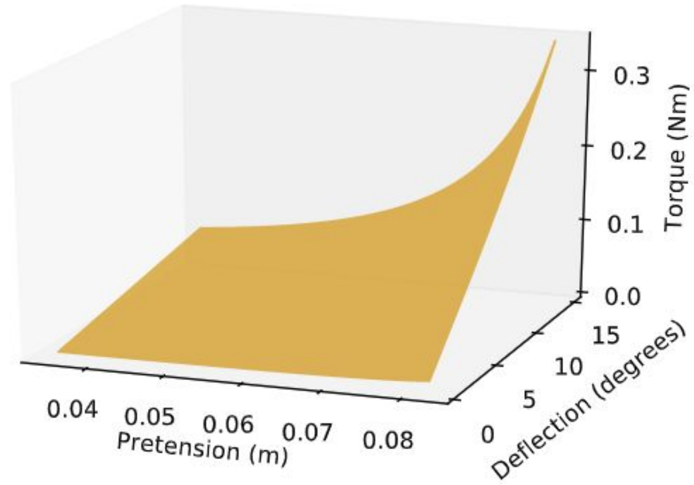
SiMPLeR Design

- Place torsion spring pair in belt transmission
  - Antagonistic
  - Similar to muscle-pair
  - Simple design
- Change pretension using additional actuator
  - Inefficient acme screw for low energy cost



Theoretical Model

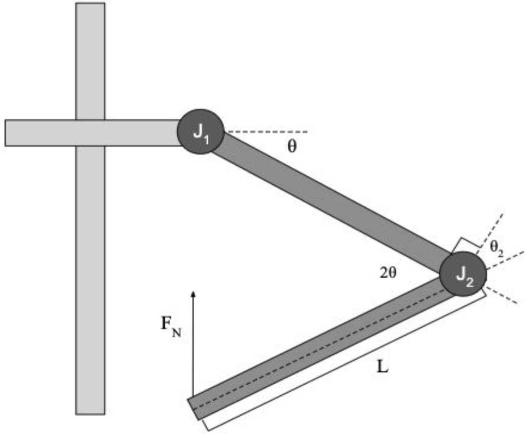
- Torque is varied by pretension
- As pretension approaches torsion spring length, actuator becomes rigid
    - Allows for actuation similar to standard belt transmission
- In low range, pretension has small impact
    - Inefficient to design for actuation in this stiffness range



$$\tau(\theta, x_i) = r_p[(x_i + r_p\theta)\sigma(x_i + r_p\theta) - (x_i - r\theta)\sigma(x_i - r\theta)]$$

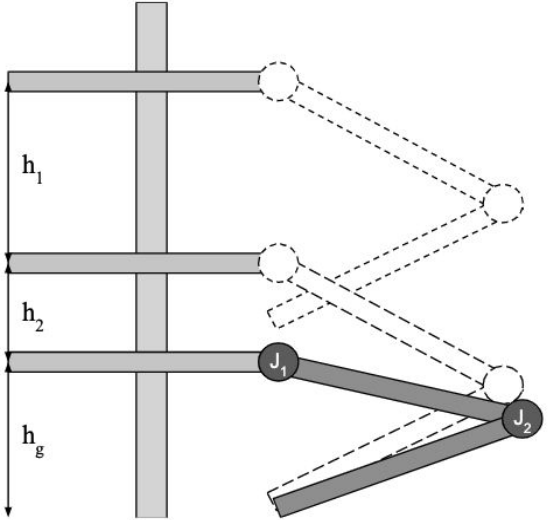
Application

Leg FBD



$$F_N = mg$$
$$\tau_1 = F_N L \cos(\frac{\pi}{2} - \theta_1)\cos(\theta_2)$$
$$\tau_2 = F_N L \cos(\theta_1)$$

Oscillation-less landing

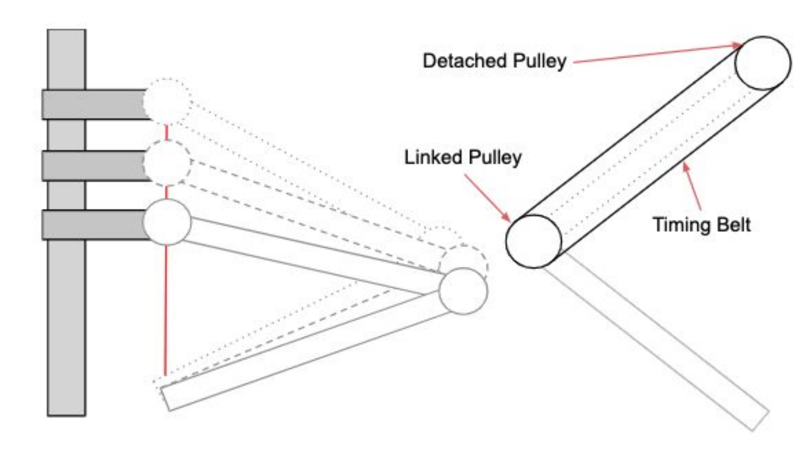


$$mg(h_1 + h_2) = \int_{x_i}^{x_i+x_c} x[\sigma(x)]dx - \int_{x_i-x_c}^{x_i} x[\sigma(x)]dx$$

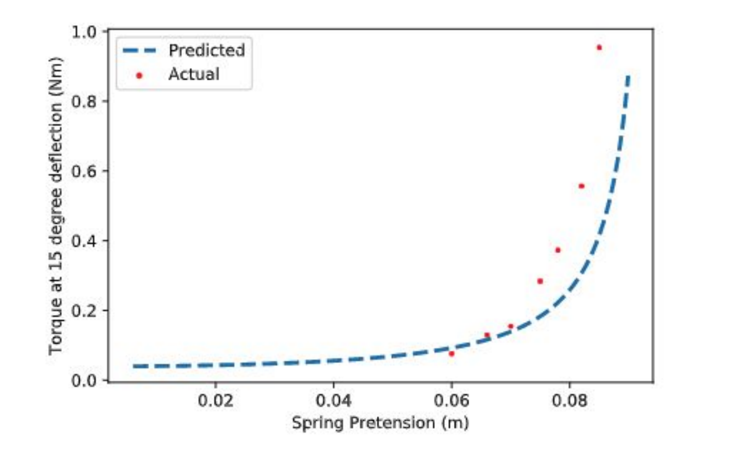
Experiments

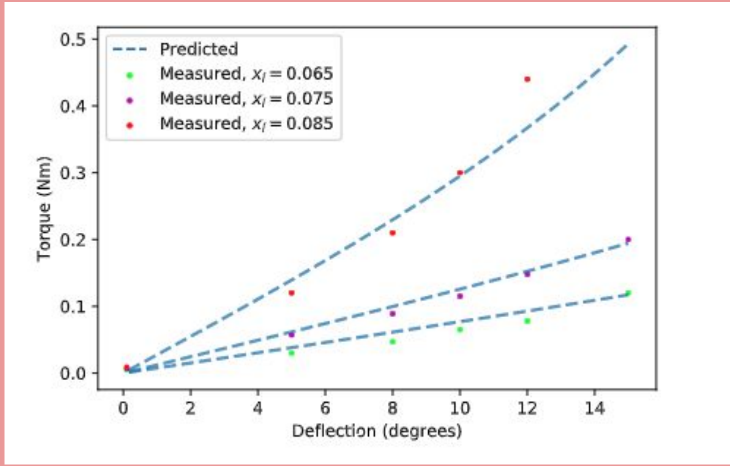
Robot Design

- Single legged platform
- Cardan gear system
    - Use one motor for two joints
    - keeps motion vertical
- Isolated movement in vertical direction

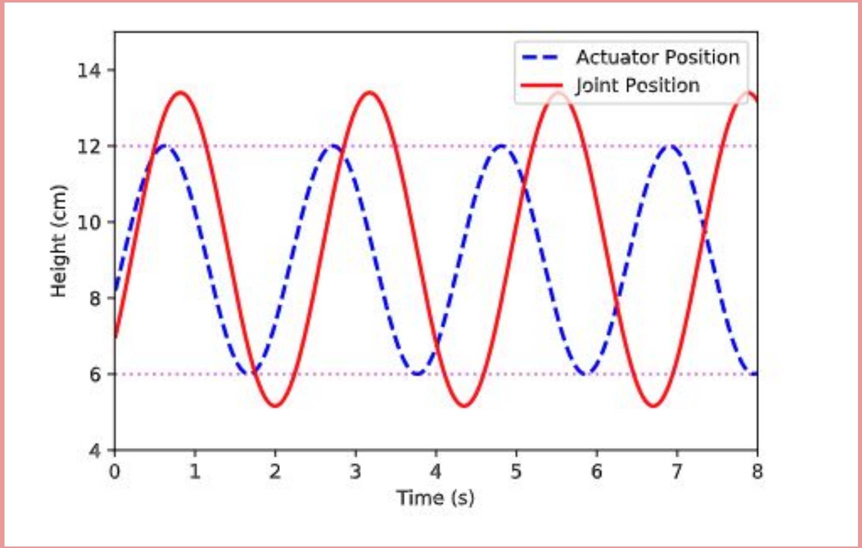


Characterization

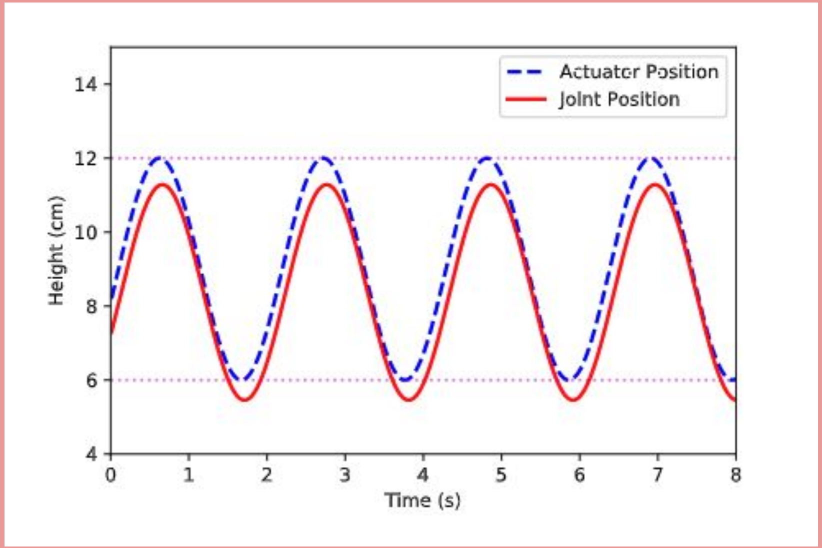




Hopping



Actuator Position
Joint Position
Height (cm)
Time (s)
14
12
10
8
6
4
0
1
2
3
4
5
6
7
8



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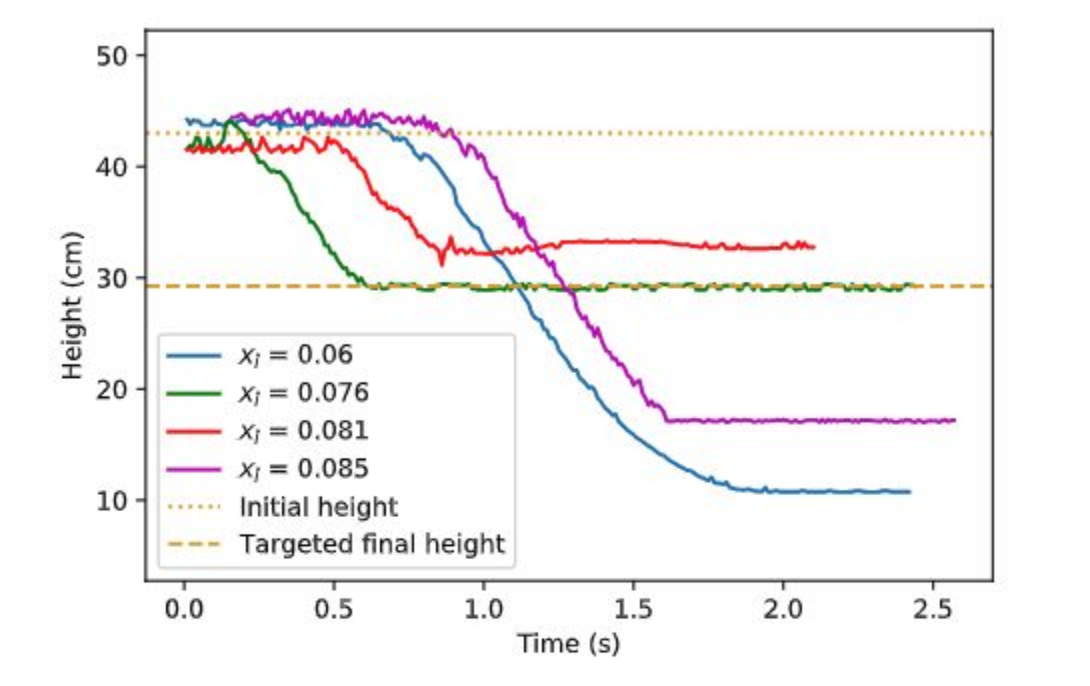

Thank You For Listening!
Email or contact me with questions!

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