COSMOS
UC Santa Cruz
California State Summer School for Mathematics and Science

APPLICATIONS OF SOFT ROBOTS IN SPACE

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OVERVIEW

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ABSTRACT

- Soft Robot Mechanics
  - Flexible materials and infinite degree of freedom
- Control System
  - Challenges with accuracy and modeling
- Conclusion
  - Current tech
  - Future research

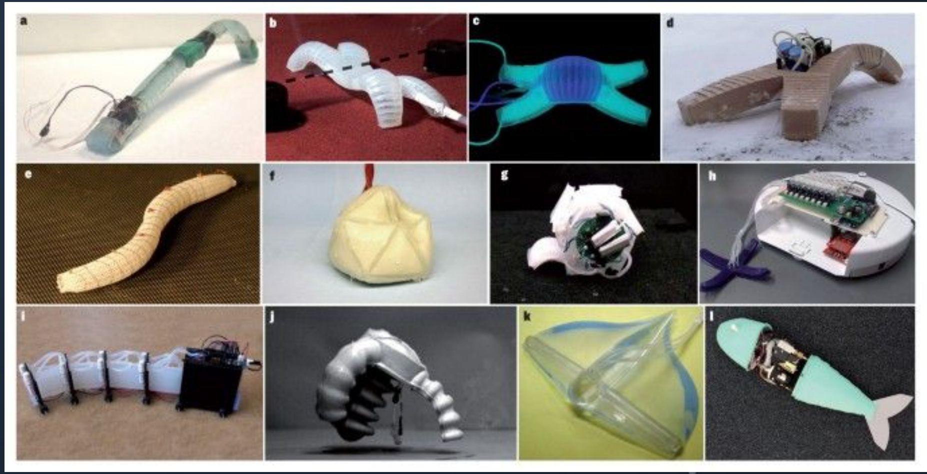
INTRODUCTION

Benefits

- Minimize risk of damage / injuries
- Versatile
- Wide range of motion

Uses

- Perform inspections
- Check conditions
- Third hand



CHALLENGES

SPACE BASED

- Zero-gravity
- Vacuum
- High radiation
- Temperature swings
- Lack of air resistance

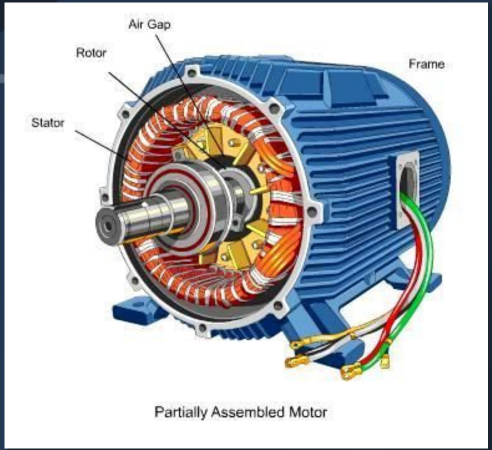
CONTROL BASED

- Unlimited movement
- Materials behave nonlinearly
- Relative internal position changes
- Vulnerable to noise

ACTUATION

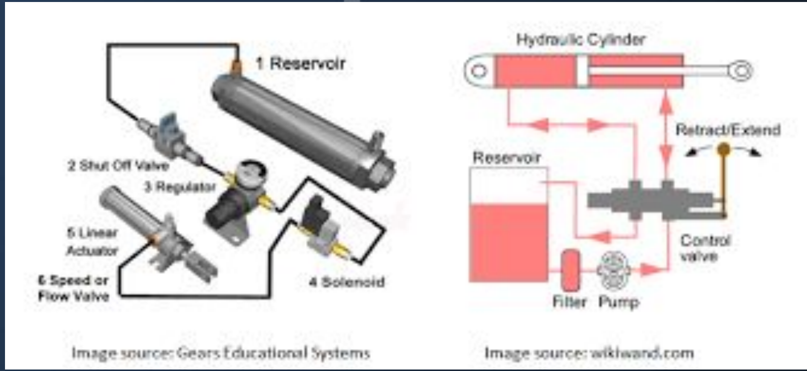
Motors

- Reliable
- Large & Rigid
- Depressurized
- Many variants



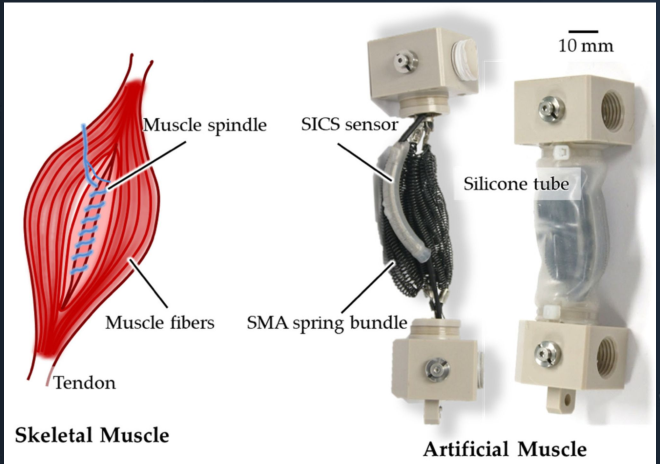
Fluid Actuation

- Pneumatics
  - Prone to leaking
  - Flexible & Large
- Hydraulics
  - Reliable
  - Flexible & Large

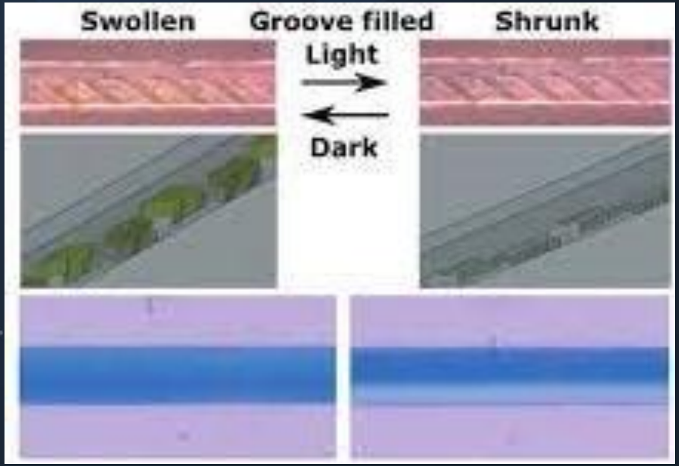


ACTUATION PT.2

- **Shape Metal Alloys(SMAs)**
  - Flexible
  - Sensitive
  - Small



- **Reactive Gels**
  - Unreliable
  - Flexible
  - Small
  - Sensitive



GRIP

Constraints:

- Zero-gravity
- Vacuum
- Tiny margin of error

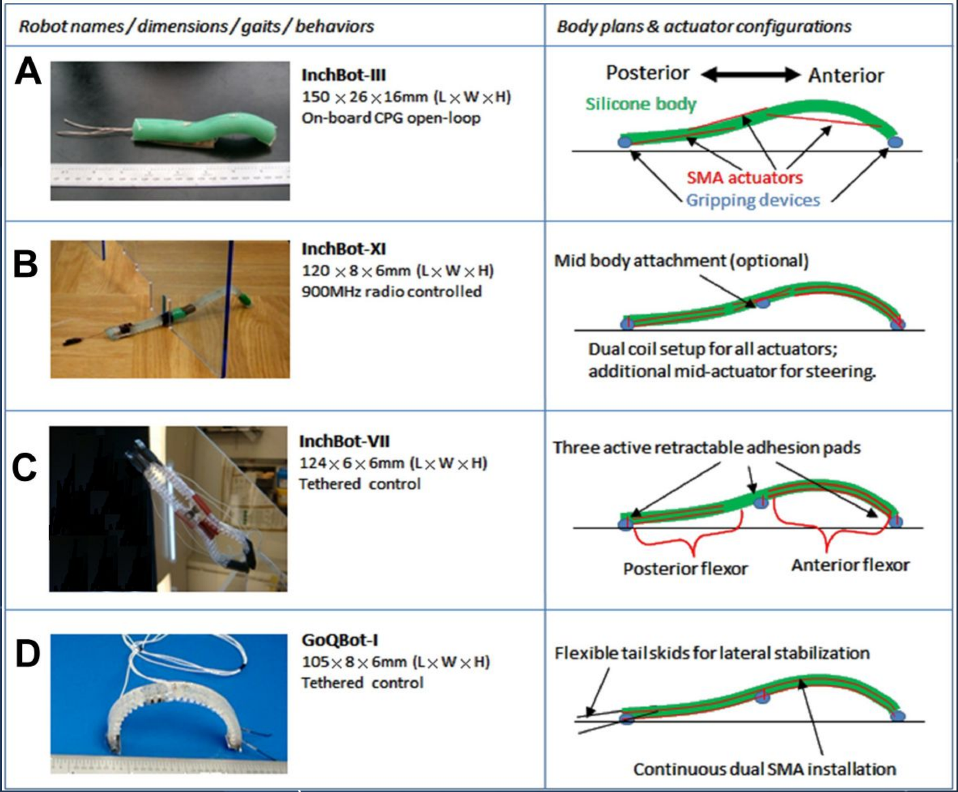
Options:

- Anchoring
- Rockets
- Adhesive pads

ROBOT BODY

Requirements:
- Flexible
- Resistant to impact
- Resistant to extreme temperature

Options discussed:
- Silicone based polymers
- Inflatable tubes



ARTIFICIAL MATERIALS

Silicon Polymers:

- Flexible
- Polymers' varying flexibilities
- Resilient to puncture/impact
- Stretches linearly
- Compresses nonlinearly

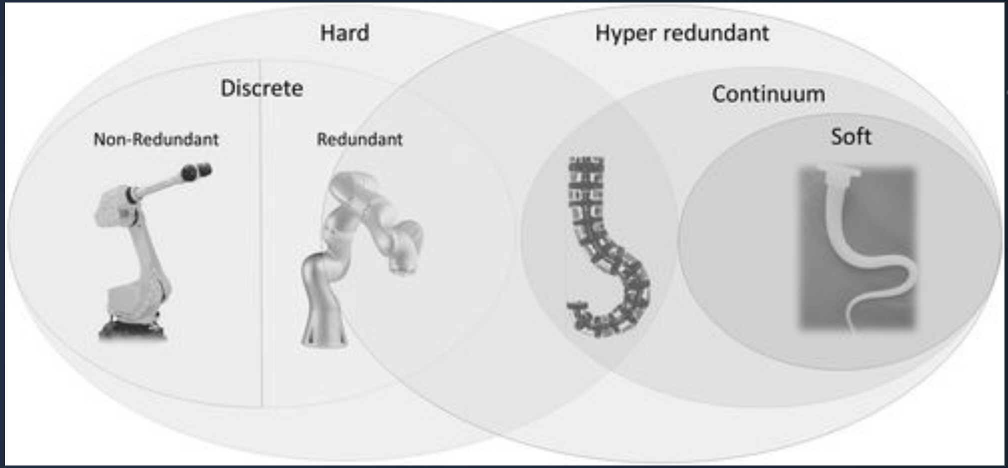
Inflatable Tubes

- Cheap and very compact
- Fairly simple to model due to pseudo-rigidity
- Must be sealed
- Highly susceptible to puncture

MODELING SYSTEMS

Issues:

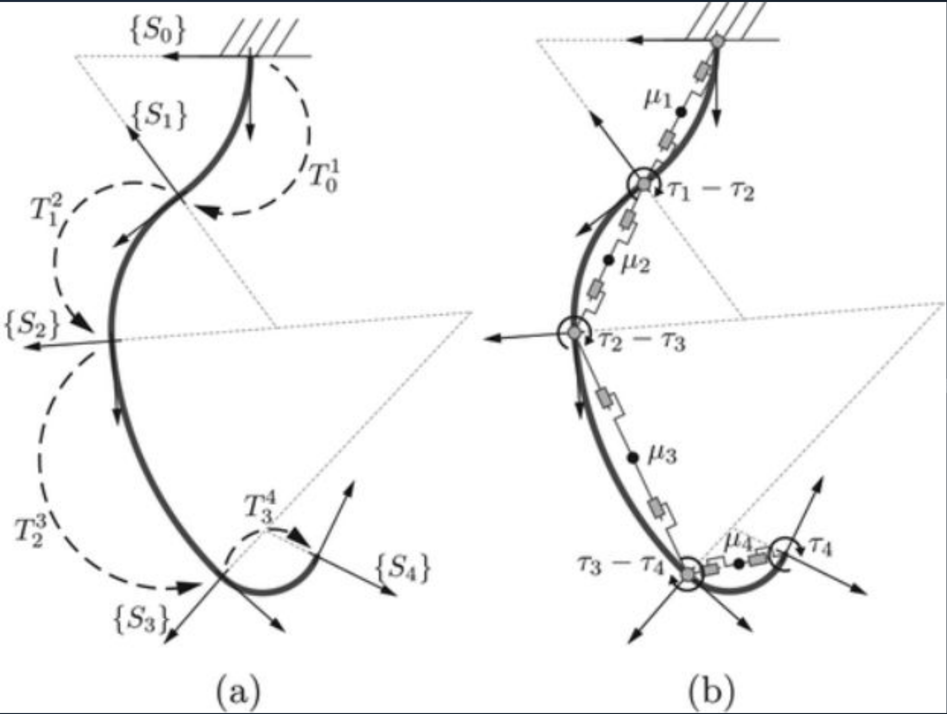
- Infinite State Space
  - Can move to any point in any way
- Can't use classical rigid robot modeling system



PIECEWISE CONSTANT CURVATURE

Solves Infinite Dimensionality

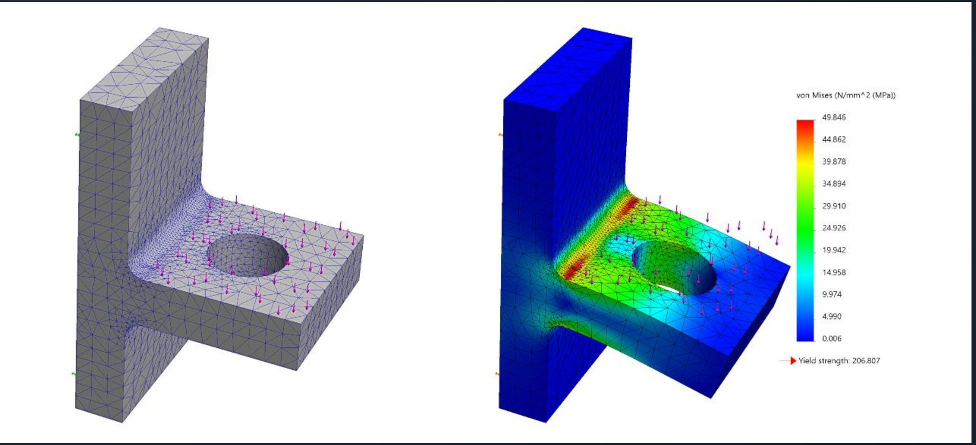
- Divides the robot into segments (like a rigid robot)
- 2 reference points placed on each segment
  - Finds relative rotation/angle
- Angles form dynamic rigid model giving us the state space
- Rigid model state space then used to find soft robot state space



FINITE ELEMENT METHOD

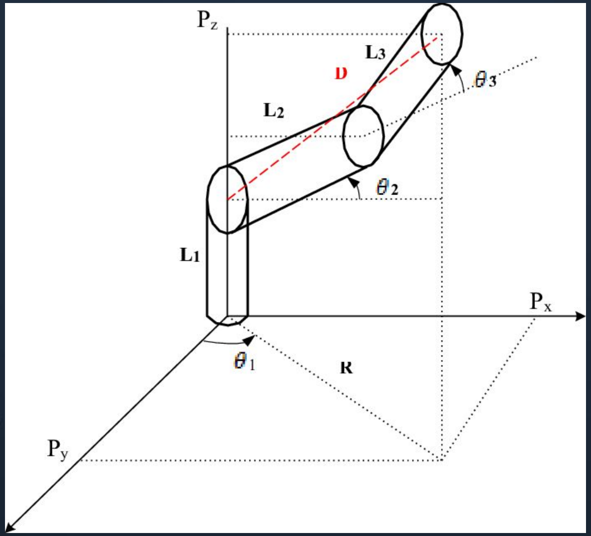
Splits robot into similar nodes

- Can be any shape
- Uses Mathematical relationships to model the relationship between nodes in order to model robot
- Physical and mathematical assumptions made to reduce the Degrees of Freedom (DOF)
- Heavy Computational burden



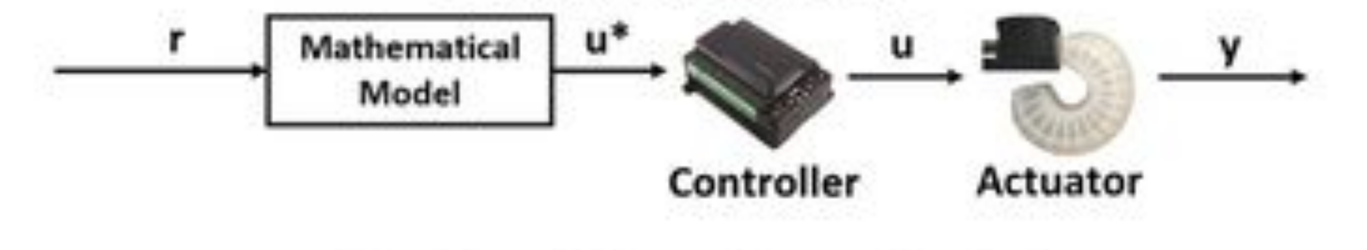
ANALYTICAL MODELS

- Case-By-Case Scenario
- Analyzes Physics
- Fast computation speed
- But limited in uses because only specific to a particular form of robot



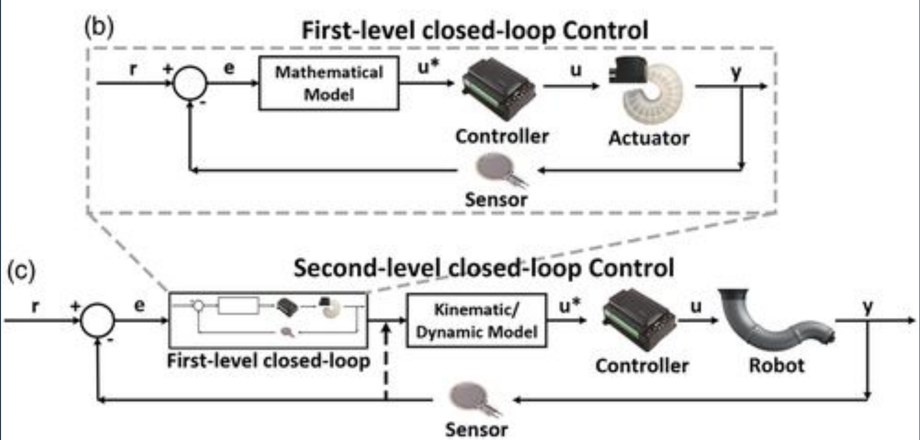
OPEN-LOOP CONTROL

- No feedback or sensors
    - No real time calculation or adjustment
- Requires total knowledge of robot and its environment
- In soft robotics actuators have 2 states: initial and final actuator state
- Add up to various deformation states
- Cannot account for a dynamic deforming body



CLOSED-LOOP CONTROL

- Uses sensors for feedback on the states of the robot and environment
- Involves 2 levels
  - First level: deals with individual actuator states
  - Second level: uses first level output and amodel to get state of whole robot
    - Static model
    - Dynamic Model
- Can only really be used for one robot/task



AUTONOMOUS CONTROL

- Controller is a “brain”
- Offline control uses machine learning to get parameters of robot
- Uses parameters to make kinematic and dynamic models
- Online control uses both Model Predictive Control(MPC) and model-free control
  - MPC repeatedly optimizes input for each timestep
  - Model-free control uses machine learning algorithms for decision making
- These methods dramatically increase robot adaptability

FURTHER CONTROL STRATEGIES

- Curvature Dynamic control (Closed-Loop)
  - Implement trajectory tracking in soft robots state space
  - Follows the curves in free space
- Preliminary robustness analysis (Closed-Loop)
- Cartesian Stiffness Control (Closed-Loop)
- Contact Planning (Closed-Loop)
- Above control methods performed at a higher accuracy than the PID (Proportional Integral Derivative) Controller on the Soft Robots
- Non-model On/Off Switch Control (Open-Loop)

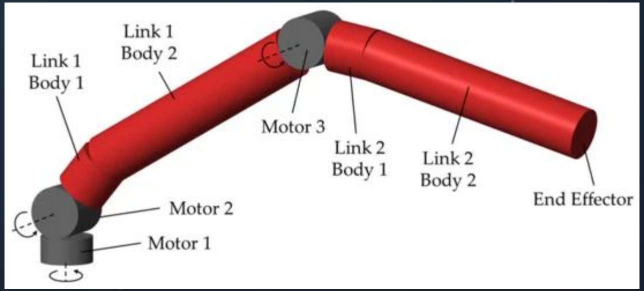
RESULTS

Robotic Arm System

- Ability to deflate to fit into small spaces
- Optimal formation tested
  - - inflatable links
  - - torque motors + pressurized tank
  - - adhesive pads vs silicon rubber

Control System Trials

- Used to balance movement
- Combination of algorithms to improve accuracy
- Addressing non-rigid movement

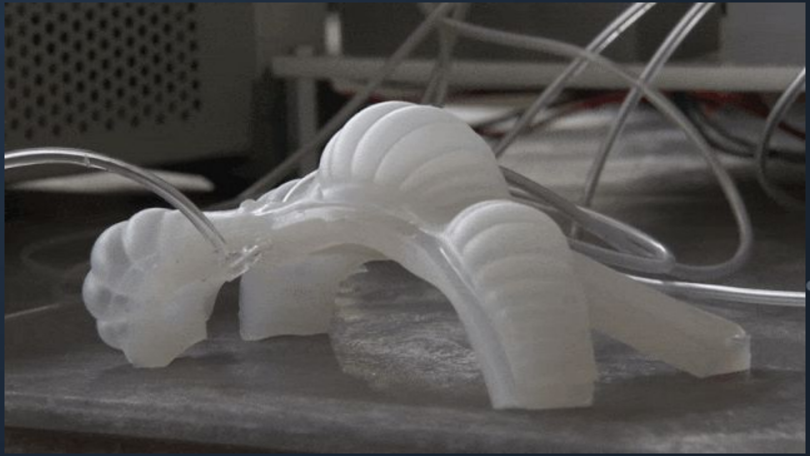


CONCLUSION

- Soft Robots' unlimited range of motion
- Improving soft robot control
- New ways to combat zero-gravity
  - Adhesive pads, anchoring robot, compressed gas
- Candidate for space exploration
  - Landing

FUTURE RESEARCH

- Novel Field
- Control strategies
  - Currently using ones meant for rigid robots
- Design
  - New materials
- 2-D → 3-D testing



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