Applications of Soft Robots in Space

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Cluster 11: Feedback Control with Applications to Robotics

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Abstract

The main problem facing soft robotics is the lack of suitable control systems. The flexibility of soft robots continues to confound attempts to model and control them, but progress is being made. Many current mechanical designs capitalize on the bleeding edge of material science. Methods for movement in zero gravity are also being tested with hopeful results. Currently, novel control systems and modified traditional systems are being used to control soft robots. In addition, advances in computing power and Artificial Intelligence techniques allow for greater semi-autonomous control. Overall, the progress in modeling and control systems has reached several milestones in accuracy and prediction while prototype robots are already being tested in labs.

Introduction

Soft robotics is garnering more and more attention due to its great potential in a wide variety of fields and disciplines. In particular, they are better suited for use in space because they are flexible, making them more resilient and adaptable to a variety of obstacles. However, the lack of air resistance and gravity in space means that any movement is amplified. As a result of this, precise control is very important in space. However, traditional approaches cannot be applied to soft robots due to an unlimited range of motion, making control a bottleneck in current applications.

Actuation

The unique environment of space, as well as the small size of the robot, severely limits actuator options. The following are options of actuators:

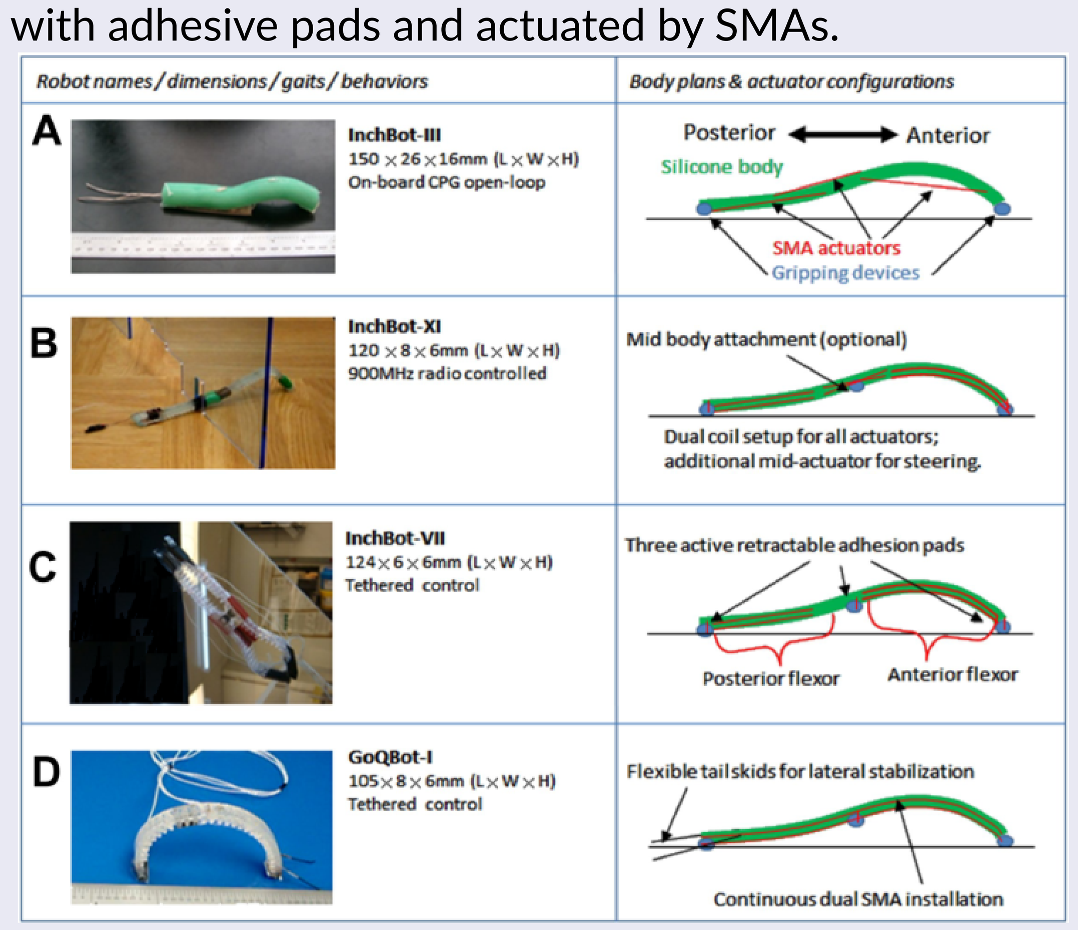
- Motors with tendons that can act as muscles - Downsides: fairly large and inflexible
- Pneumatics and Hydraulics - Downsides: They require fluids which need to be sealed. Both are inflexible, and pneumatics are prone to leaking
- Chemical Gels are a novel technology with reliability issues that uses internal chemical reactions to power itself
- Electroactive polymers (IPMCs and Dielectric Polymers): materials on the scale of molecule sheets that bend and deform when exposed to electricity
- Shape Memory Alloys (SMAs): soft alloys that can retain their original shape after being deformed

Example of pneumatic actuation in a soft robot

Grip and Locomotion

Regardless of actuator choice, many traditional movement options fail in zero gravity. Most wheels, treads, legs, wings, and suction cups rely on either air pressure or gravity, making them useless in space. Some alternative options are:

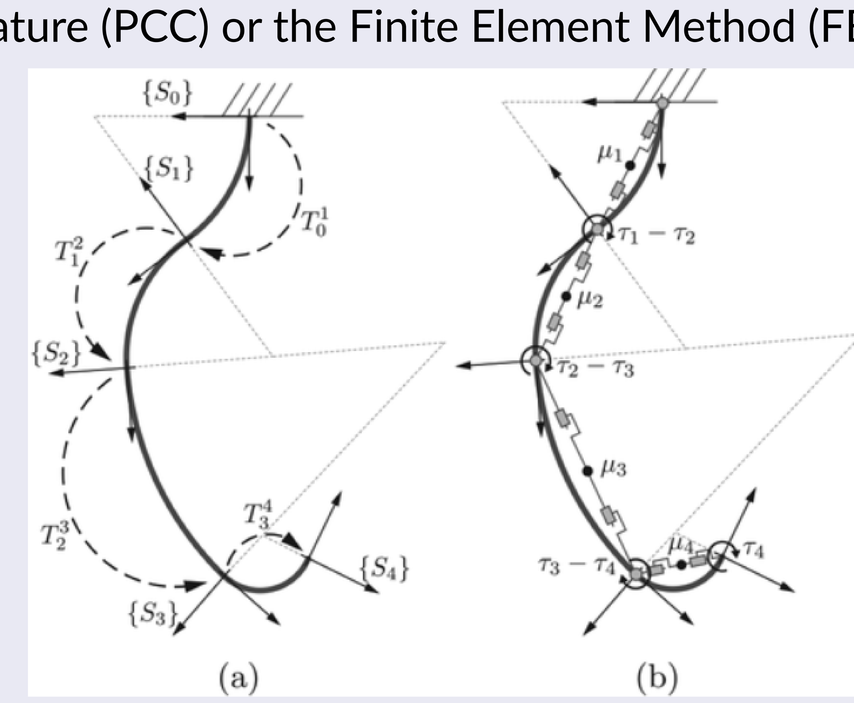
- Adhesive pads: have been tested and proven to work on a variety of rough and smooth surfaces
  - Caterpillar design: body made of silicon, equipped with adhesive pads and actuated by SMAs.



- Soft robots can be fixed to a point
- Movement can be controlled by the release of compressed gas

Modeling Systems

One of the main issues with controlling a soft robot is that it has an infinite state space, meaning that it can move in any way to any point, unlike a rigid robot. In order to combat this, soft roboticists often use Piecewise Constant Curvature (PCC) or the Finite Element Method (FEM).



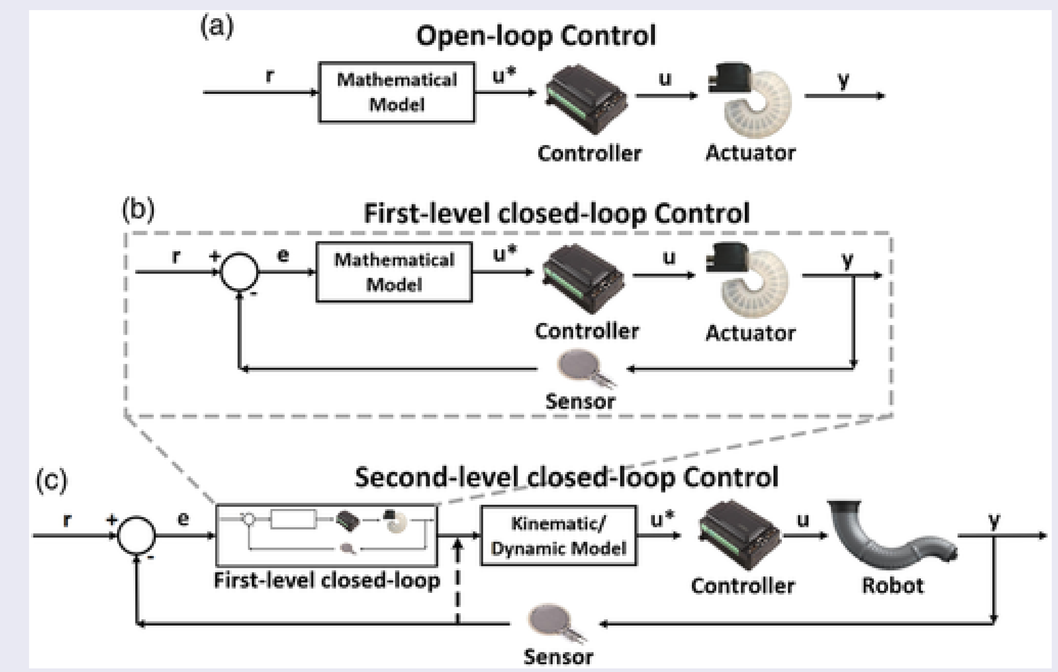
PCC Model: Continuous robot to Rigid robot

- PCC divides the soft robot into segments for modeling
  - 2 reference points on each segment to find angle
  - Angles form dynamic rigid model to map a soft robot
- Finite Element Method (FEM) splits robot into nodes
  - Mathematical relationships used to model the robot
  - Physical assumptions made to reduce DOF

Control Algorithms

Open Loop Control

- No feedback or sensors
- Requires total knowledge of robot and its environment
- In soft robotics, actuators have 2 states: initial and final actuator state
- Many of these add up to various deformation states



Closed Loop Control

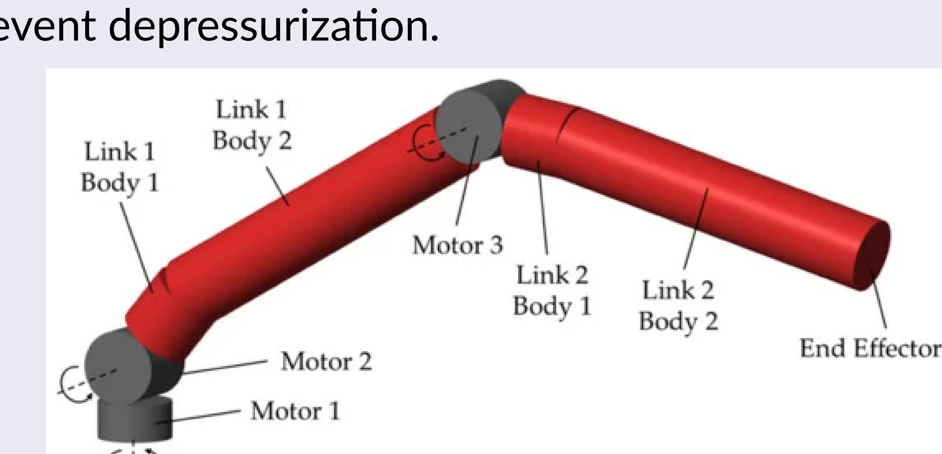
- Uses sensors for feedback on robot and environment
- Involves 2 levels
  - First level deals with individual actuator states
  - Second level uses first level and a model to get the state of the whole robot
- Can only really be used for one task

Autonomous Control

- Controller makes its own decisions
- Offline control uses machine learning to get parameters of the 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

Results

An example is a robotic arm system consisting of two inflatable links which are powered by motors. This system is connected to a pressurized tank used to inflate the soft robot. The robot consists of sealed PVC fabric tubes to prevent depressurization.

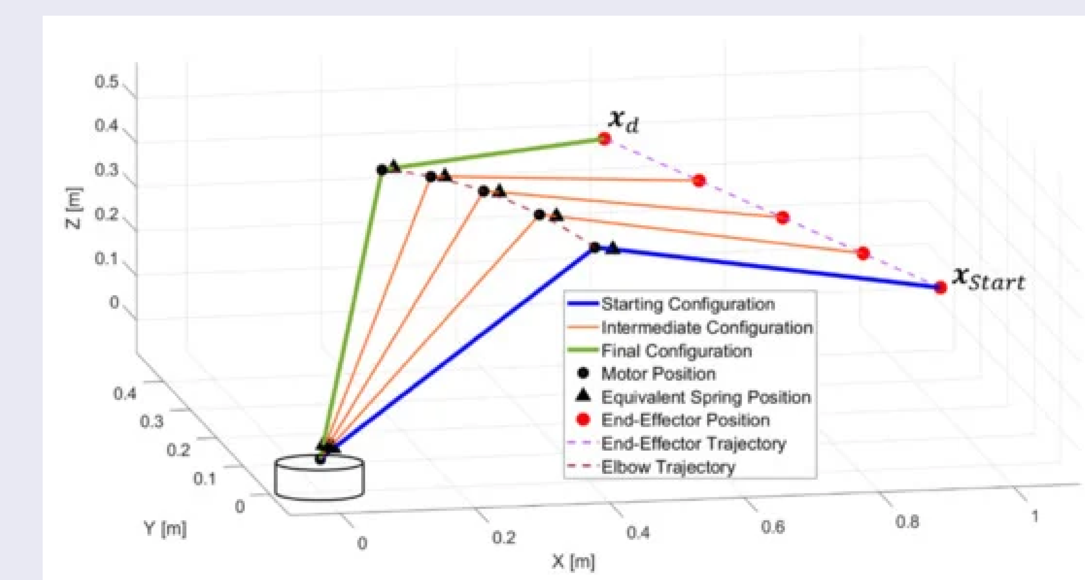


3D model of the inflatable soft robot

Results Cont.

- First modeled using a basic model that assumed rigidity across all joints.
- Model augmented with various formulas that calculate the pseudo-rigidity of the structure.
- Kinematic model used to determine small deformations like wrinkles.
- Load algorithm designed to determine the deformation from load.
- Elastostatic Kinematics used information from the first algorithm and the model to guide the arm to a determined state.

The robot trials demonstrated that the model followed the planned pathway and the algorithms worked as planned.



Predictable 3D Motion

The outcomes of these trials suggest that soft robotics is a capable of predictable control and space exploration.

Conclusion

Despite challenges, Piecewise Constant Curvature, Model Predictive Control, Machine Learning algorithms, and Open-Loop control are all being used to improve soft robot control. New ways to combat zero-gravity in space are being developed every day. These include using adhesive pads, anchoring the robot to a location, and controlling the release of compressed gas. Due to the success of current prototypes and the development of control systems, spacefaring soft robots are closer to reality than ever.

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