Modeling of Soft Manipulators Enabled by Twisted-and-Coiled Actuators

Adaptive Robotic Lab

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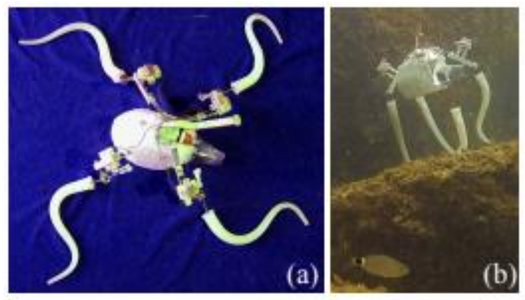
Background

Soft Robots:
- Interact more safely with people
- Adapt to uncertain environments and objects

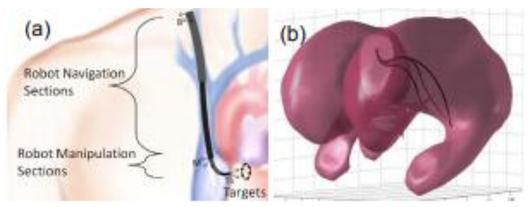
Applications:
- Medical devices
- Work with and alongside people
- Use in environment interaction

Towards a soft pneumatic glove for hand rehabilitation

Modeling:
- Most designs lack a model
- Models developed for specific manipulators
- Useful for design and control

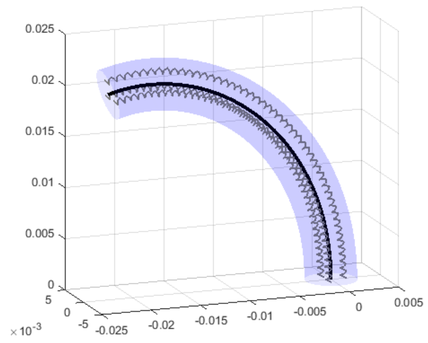


A Multi-Soft-Body Dynamic Model for Underwater Soft Robots

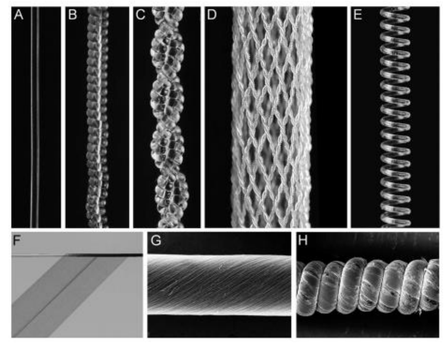


Concentric Tube Robots for Minimally Invasive Surgery

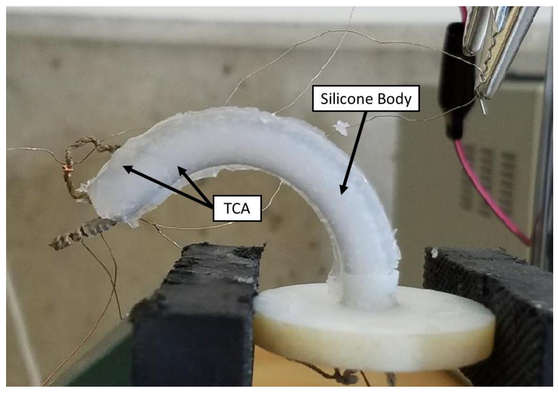
Twisted-and-Coiled Actuators (TCAs):
- Made from nylon, fishing line, etc.
- Actuated with temperature or electrical power
- Flexible
- Relatively large force exerted axially



A sample of a simulated soft manipulator with three TCAs



Artificial Muscles from Fishing Line and Sewing Thread

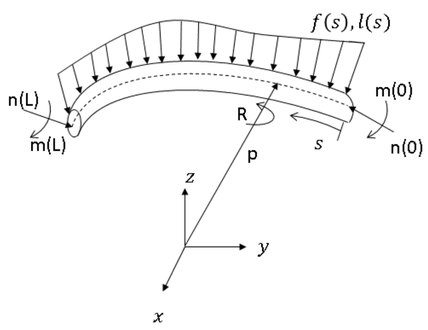


A soft manipulator made of EcoFlex with two embedded TCAs

Modeling

We want to establish a relationship between actuation values (temperature) and the shape of the manipulator.

Kinematics and Statics:
1. Model the statics and kinematics of the body of the manipulator
   - Slender -> Cosserat Rod model
   - Relate internal forces and distributed forces
     - Distributed forces are from actuators and external forces
2. Model the statics and kinematics of the actuators
   - Use Cosserat Rod or a string model
   - Relate actuation value to forces
3. Balance forces between body and actuators
4. Create configuration descriptions of body and actuators
5. Relate actuator and body strains
   - This is the main source of coupling in the model
6. Establish boundary conditions



Example setup for a Cosserat Rod

Cosserat Rod:
- Models most significant strains
- Extension
- Shear
- Bending
- Twisting/torsion

Results:
The model generalizes other established static models and matches their experimental results and predictions.

Control

Forward Kinematics:
- Predicting configuration from inputs to actuators
- Computations generally quick

Inverse Kinematics:
- Desired configuration to actuator parameters
  - Used for control
- Computations very slow

Solution:
Take advantage of fast forward computations to approximate inverse control.

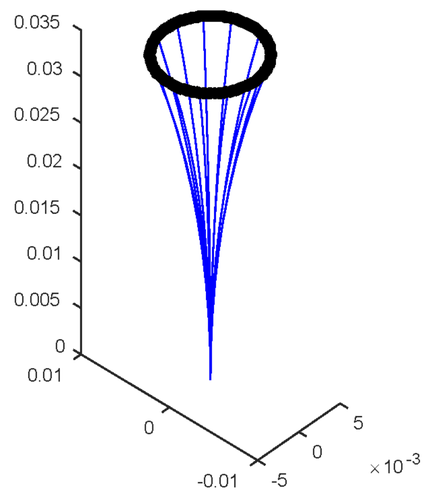
Static Controller:
The basic model for a static controller is a change in configuration x equals a local linear transformation of the change in actuation parameters q.

$$\Delta \boldsymbol{x} = \boldsymbol{J}\Delta \boldsymbol{q}$$

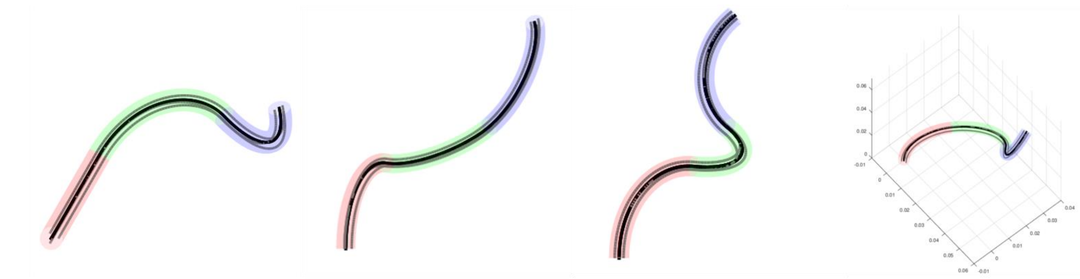
This can be rewritten to:

$$\boldsymbol{q_{next}} = \boldsymbol{q_{prev}} + \boldsymbol{J_{approx}^{-1}}(\boldsymbol{x_{desired}} - \boldsymbol{x_{current}})$$

Where J_{approx} is found by iterating the forward kinematics a few times.



A soft manipulator tracing a circle. All tip positions shown and a few curves shown.



An example of a multi-segment simulation of the TCA manipulator

Current & Future Work

Improvements
- Incorporate dynamics
- More general models of the soft, continuous manipulators and actuators
- Practical control schemes
  - Numerical solutions from analytic models are generally too slow

References

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