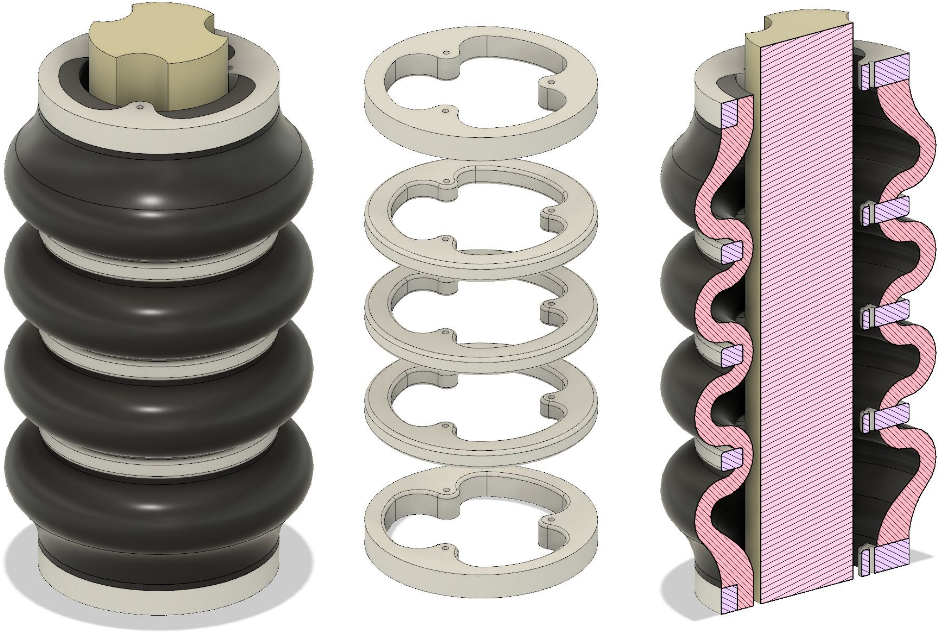
Thesis Visuals for Personal Website

Connex Design

- Soft Bellow Thickness: [1.5 2.0 2.5] mm

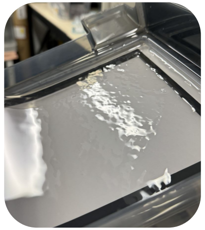
Next Steps:

- Characterize compression.
- Test functionality of tendon actuation.



FormLabs

- Troubleshooting
    - New Material + Tank on the way!



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Model Design

Vis Toolkit [Github Repo]

Segments
Lengths
Diameter

→

All Possible
Kappa, Phi, Ell

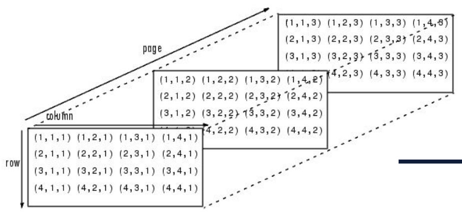
→

[function] robotindependentmapping

ell, kappa, phi → [n x 16] matrix

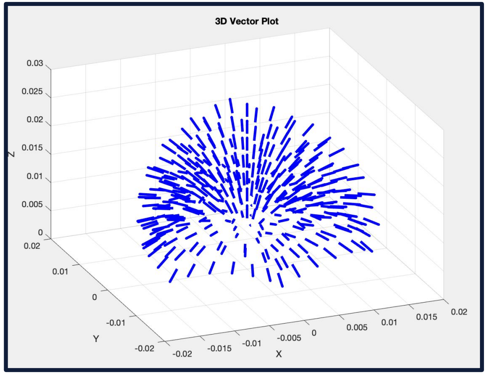
$$
T_w = \begin{bmatrix} \cos^2\phi(\cos\kappa s - 1) + 1 & \sin\phi\cos\phi\,(\cos\kappa s - 1) & \cos\phi\,\sin\,\kappa s & \frac{\cos\phi\,(1-\cos\kappa s)}{\kappa} \\ \sin\phi\,\cos\phi(\cos\kappa s - 1) & \cos^2\phi\,(1 - \cos\kappa s) + \cos\,\kappa s & \sin\phi\,\sin\kappa s & \frac{\sin\phi\,(1-\cos\kappa s)}{\kappa} \\ -\cos\phi\,\sin\kappa s & -\sin\phi\,\sin\kappa s & \cos\kappa s & \frac{\sin\kappa s}{\kappa} \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

All possible curves



Extract vectors and origins

```
for idx = 1:size(mapping_results, 3)
   g = mapping_results(:, :, idx);
   vx = g(end, 9); % Extract the components of the vector
   vy = g(end, 10);
   vz = g(end, 11);
   x = g(end, 13); % Extract the origin of the vector
   y = g(end, 14);
   z = g(end, 15);
   all_points = [all_points; x, y, z, vx, vy, vz];
end
```



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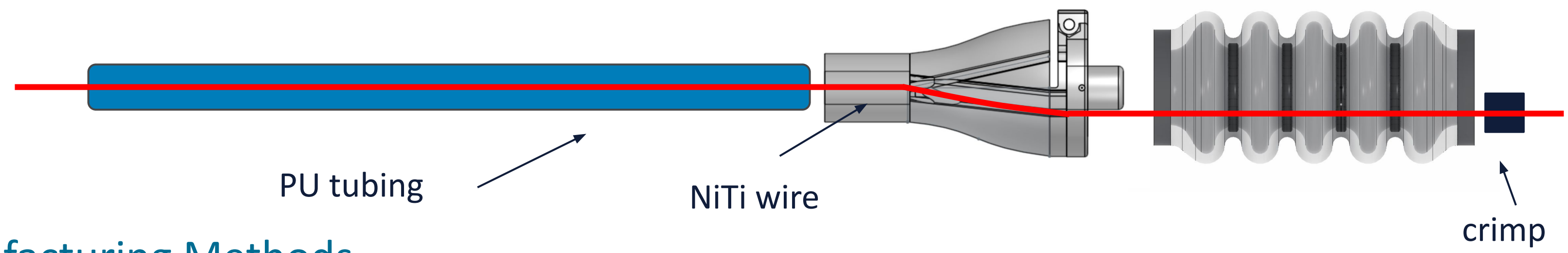
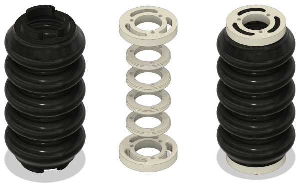
Prototype Testing: Goal = Maximize Curvature



Progress:

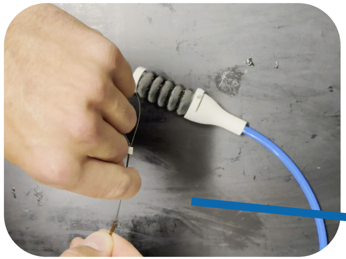
- Manufacturing Methods
- Bellow Geometry
- Tendon Guidance

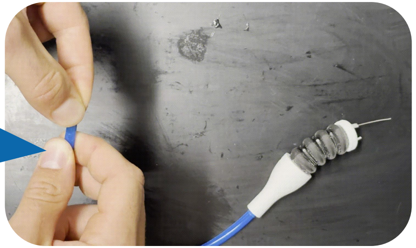


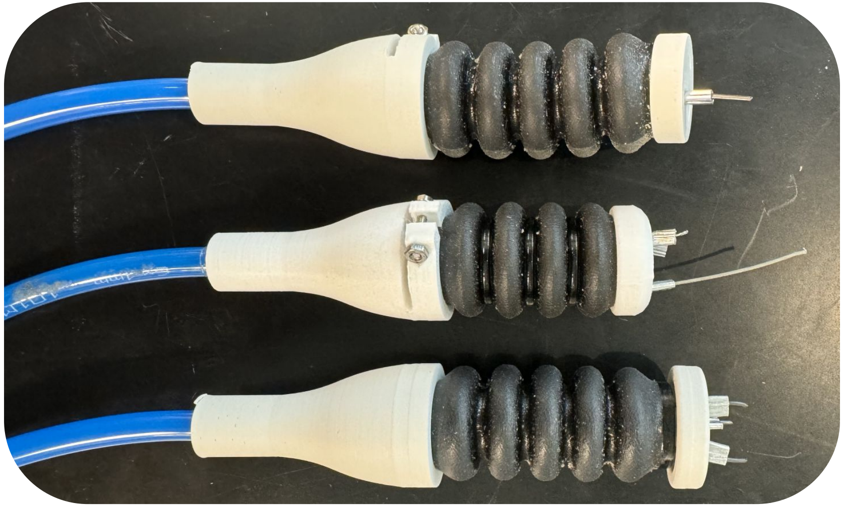
CAD of latest Connex Print

Challenges

- Push/Pull Tendons







Prints with Different Tendons Mounted

PROJECT AIMS

Aim 1. Design and model a soft 3D printed manipulator.

A 3D printed prototype capable of greater than **± 90º of pitch, steerable by tendons**. Also capable of **extending and compressing over 30% of its nominal length respectively using pneumatics**. The mechanism will have a 26mm outer diameter which is twice that of a standard colonoscope (2:1 scale). The overall length will be primarily influenced by the number of bellows, which are needed to ensure proper range of motion for steering.

Aim 2. Characterize the extension/compression/steering of the mechanism.

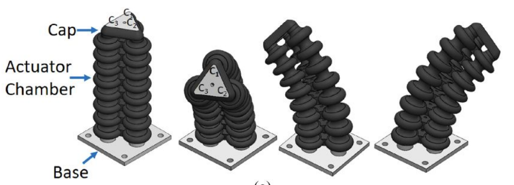
Characterize the scanning ability (in degrees of movement or using curvature) of mechanism using either **Motion Tracking or IMUs**. Provide comparisons of our characterization with the models that have been developed in Aim I. **Characterize extension and compression ratios** and map to tendon forces/air pressures that drive the respective movement.

Aim 3. Demonstrate potential use of mechanism.

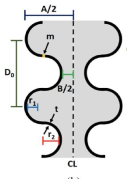
Mount the mechanism on a vine system designed for eversion and retraction. Develop a 2m long cylindrical demo environment that includes areas of interest that the mechanism can probe. This may be viewing with a camera or tracked using IMUs. **Challenges will be completed to show the capabilities of the system.**

PROJECT AIMS - FIGURES

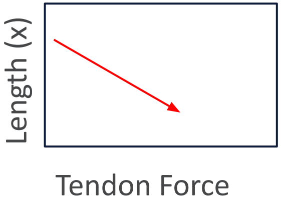
Aim 1. Design and model a soft 3D printed manipulator.

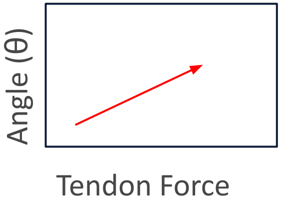


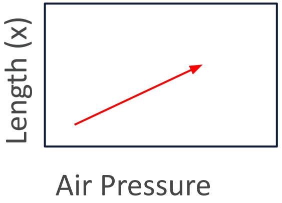
(a)



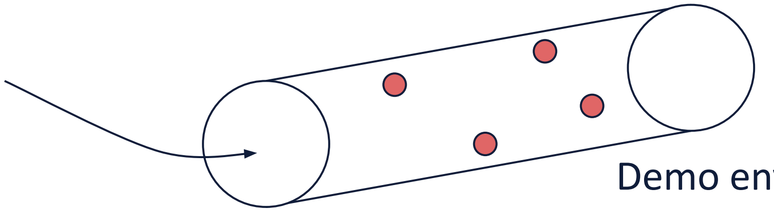
Aim 2. Characterize the extension/compression/steering of the mechanism.







Aim 3. Demonstrate potential use of mechanism.



Demo environment + challenges.

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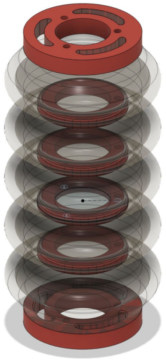
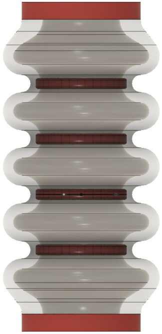
Connex Print V2 Design Changes

- Internal Clamps
  - Compression
- 1.5mm Wall
  - Flexibility
- Top Clamp Thick
  - Termination
- Top Clamp Inner Material Rigid
  - Easy to make air tight
- 1mm Guides

V1 → V2





3D Printed Bellow Mechanism for Vine Tip Scanning

Connex Design Testing

- 1.5, 2.0 ,2.5 mm
- Print Resolution, Bellow Thickness
- Elasticity

1.5mm wall thickness

Rings and walls restrict compression and steering...

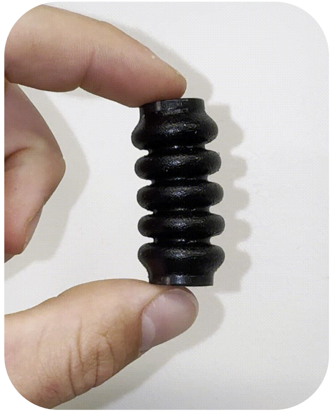
Wall Thickness	Nominal	Extended	Compressed	Force (Compression)
1.5	39.5	**50**	**27**	**8.8 N**
2.0	40	46	29	16.2 N
2.5	40	44	31	25.7 N

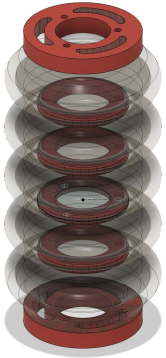
2.5mm wall thickness

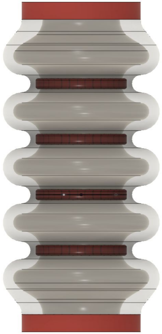
Connex Print V2 Design Changes

V1 → V2

- Top Clamp Thickness + Inner Material
- Internal Clamps
- 1.5mm Wall
- Added +1 Bellow
- 1mm Guides







Modeling Approach

Design and Kinematic Modeling of Constant Curvature Continuum Robots: A Review

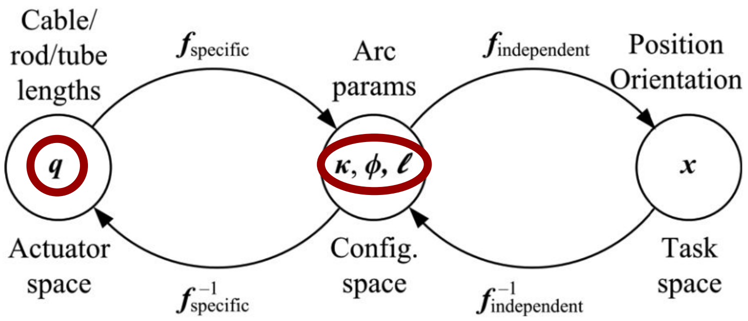
Robert J. Webster III[1] and Bryan A. Jones[2]

How to Model Tendon-Driven Continuum Robots and Benchmark Modelling Performance

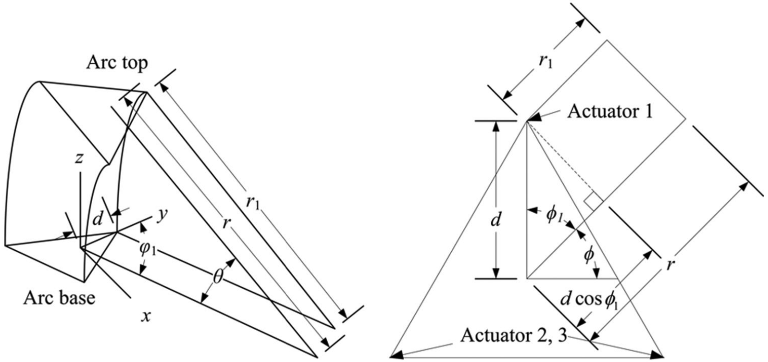
Priyanka Rao, Quentin Peyron, Sven Lilge and Jessica Burgner-Kahrs*

Kinematics for Multisection Continuum Robots

Bryan A. Jones, *Member, IEEE,* and Ian D. Walker, *Fellow, IEEE*



Mappings to define kinematics of constant-curvature robots… transforms actuator space variables q to configuration space variables k,l,psi.



Arc section in which various arc parameters are defined and a diagram of the base section seen from above.

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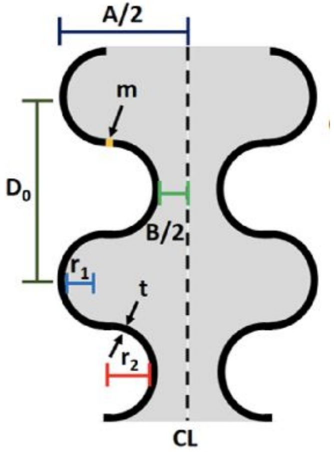
Modeling Considerations

How to consider max/min length of bellow



The deflection of the chamber is modeled using elemental load cases applied to a half- convolution of one of the bellows

The change in length of an individual bellows chamber Δl_i^e due to its internal pressure P_i is determined from

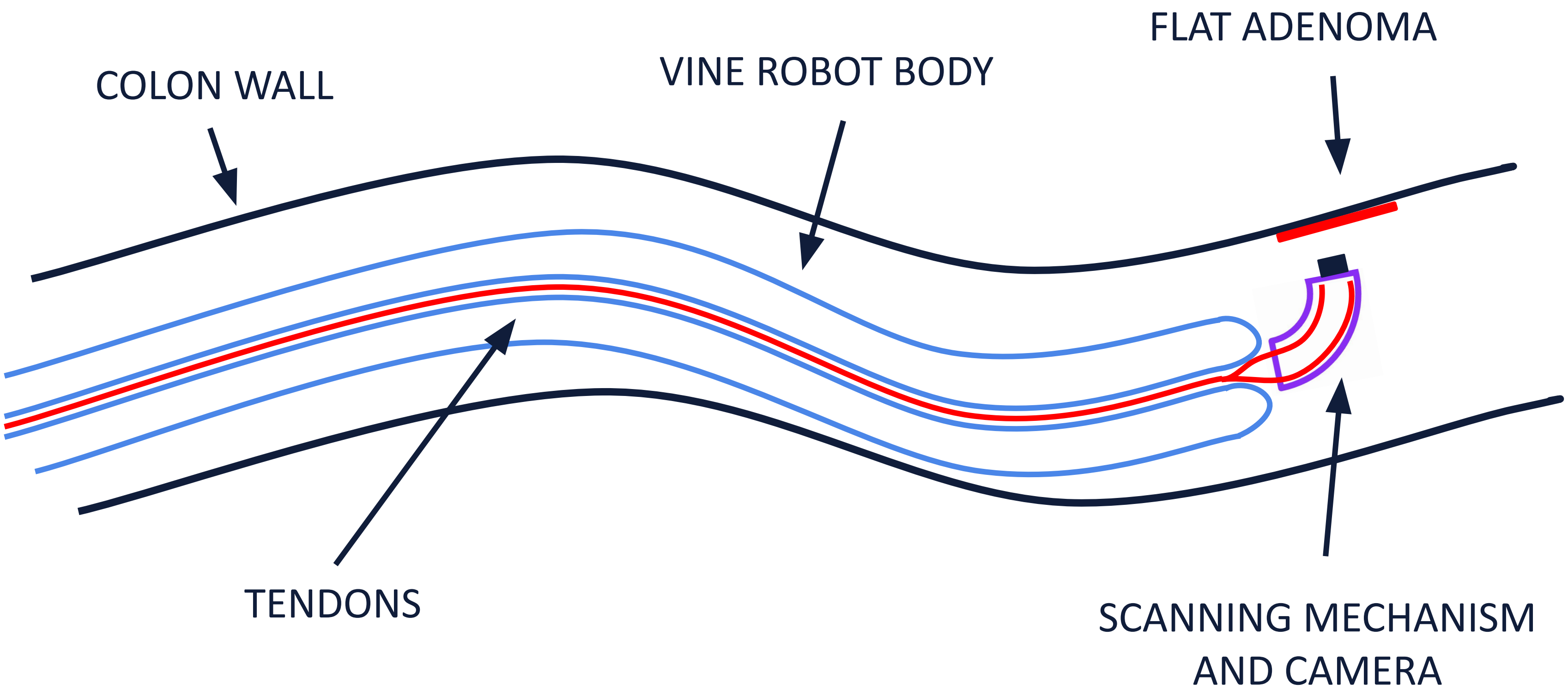
$$\Delta l_i^e = \frac{P_i A_p}{k_i} \tag{7}$$

$$l_i^e = \Delta l_i^e + l_0 \tag{8}$$

Assuming that the axial stiffness is similar in extension and compression, the stiffness k_i of chamber i is

$$k_i = \frac{1}{2n(\beta_1 + \beta_2)} \tag{5}$$

$$\beta_j = \frac{6\pi r_j^3 + 24 m r_j^2 + m^3 + 3m^2 r_j \pi \left(1 + \frac{t^2}{12 r_j^2}\right)}{24EI} \tag{6}$$



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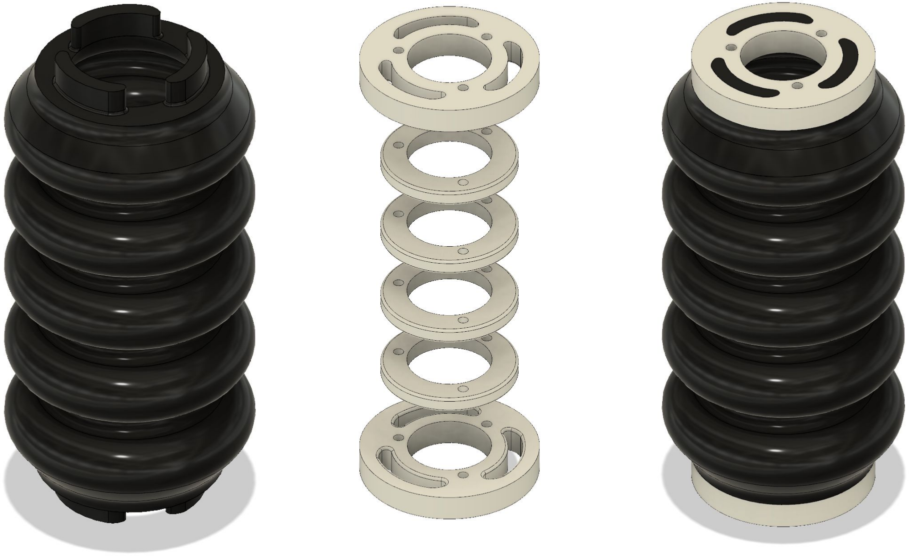
Tango Black
(flexible)

VeroClear
(rigid)



soft bellows

tendon guides

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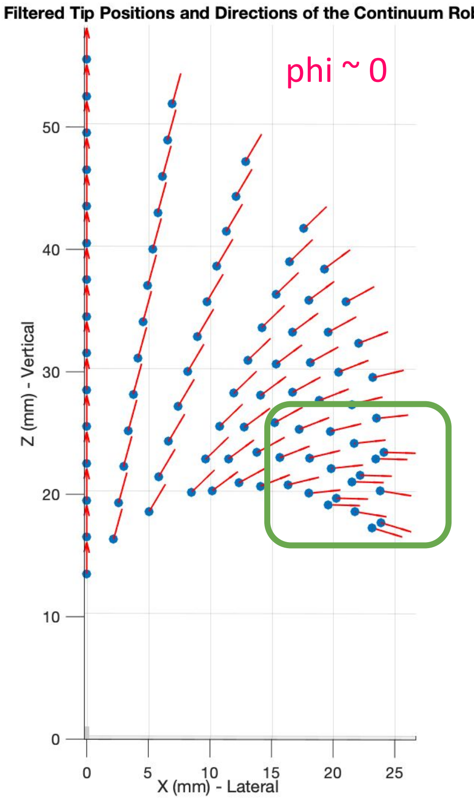
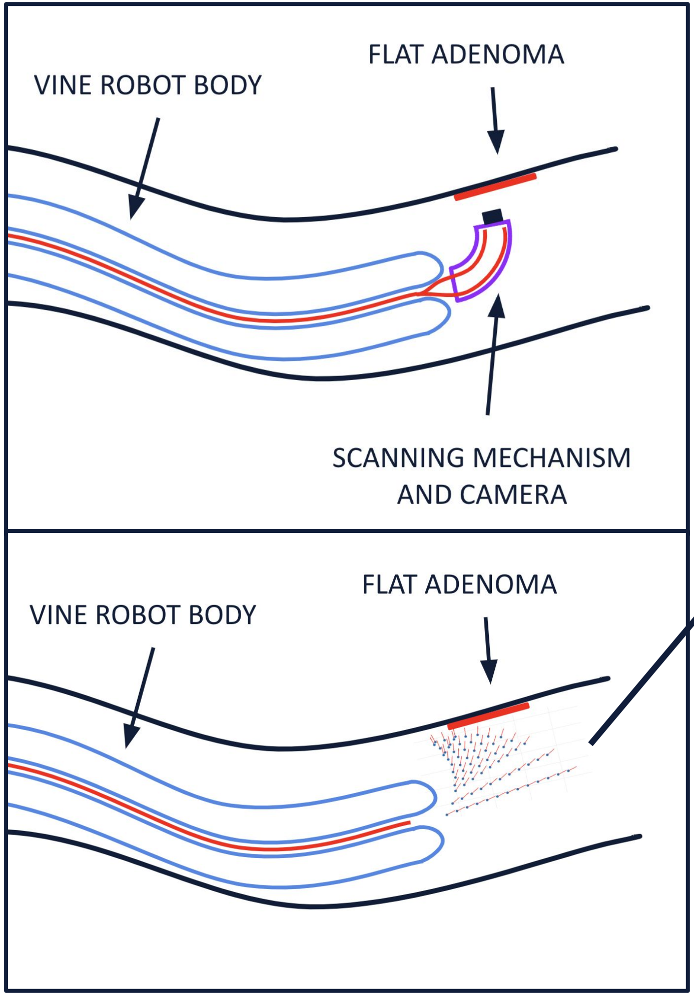
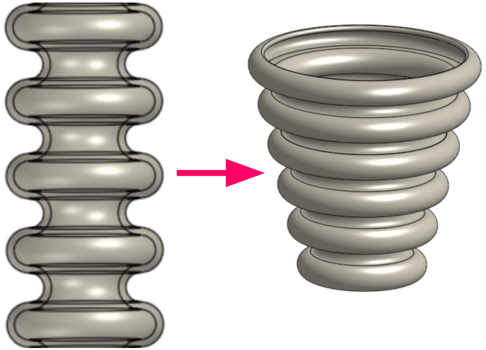
Modeling Progress







Workspace and viewing angles from bellow geometry

Could we increase desired workspace by using non-constant bellow design!?

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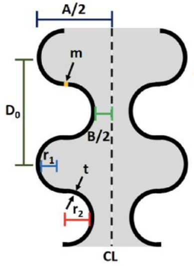
Modeling

- Estimated Bellows → Lengths
- Assume Constant Curvature

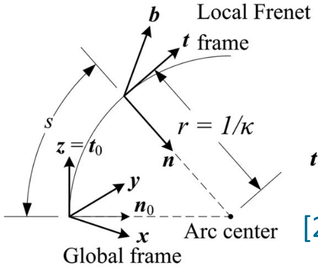


[1]

$$\phi(\boldsymbol{q}) = \tan^{-1}\left(\frac{\sqrt{3}(l_2 + l_3 - 2l_1)}{3(l_2 - l_3)}\right)$$

$$\ell(\boldsymbol{q}) = \frac{l_1 + l_2 + l_3}{3}$$

$$\kappa(\boldsymbol{q}) = \frac{2\sqrt{l_1^2 + l_2^2 + l_3^2 - l_1 l_2 - l_1 l_3 - l_2 l_3}}{d(l_1 + l_2 + l_3)}$$

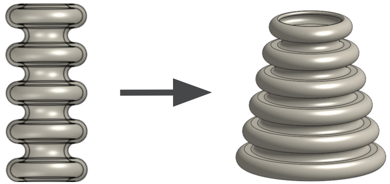


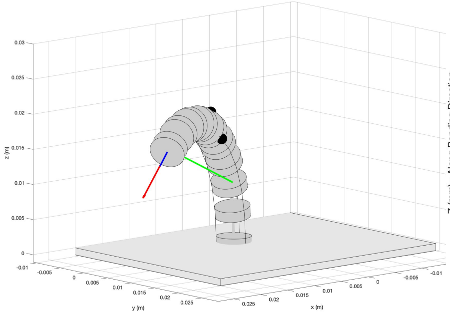
[2]

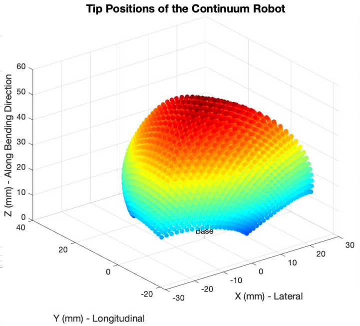
$$K(s) = \pi/2 - \phi$$
$$T(s) = \pi/2 - \kappa s$$

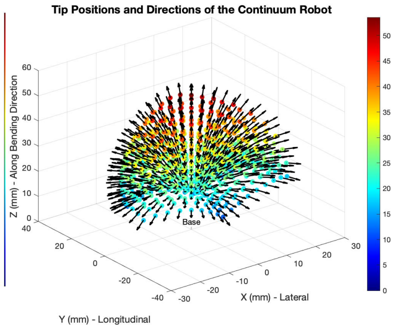
$$\boldsymbol{t}(s) = \begin{bmatrix} l(s)\sin K(s)\cos T(s) \\ l(s)\cos K(s)\cos T(s) \\ l(s)\sin T(s)\ ds \end{bmatrix}$$

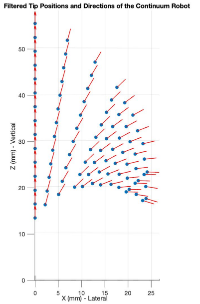
- Single Segment
- Frenet Frame **t**
- Maximize Lateral Reach







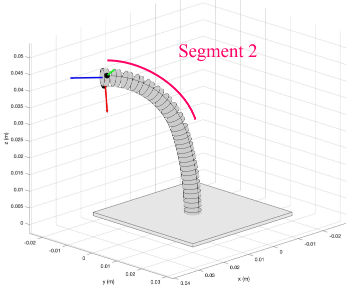


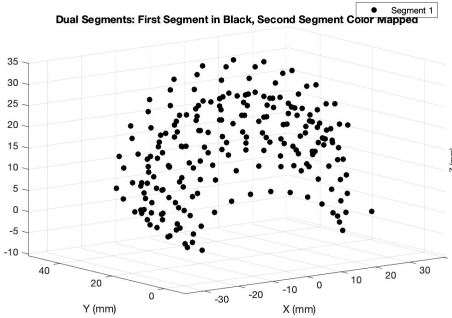


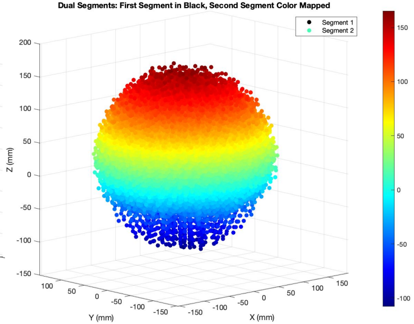
- Non-Constant Curvature
- Multi-Segment (Stepwise)

Challenge

- Select for Bending Plane
- Second Segment **length**







next…

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