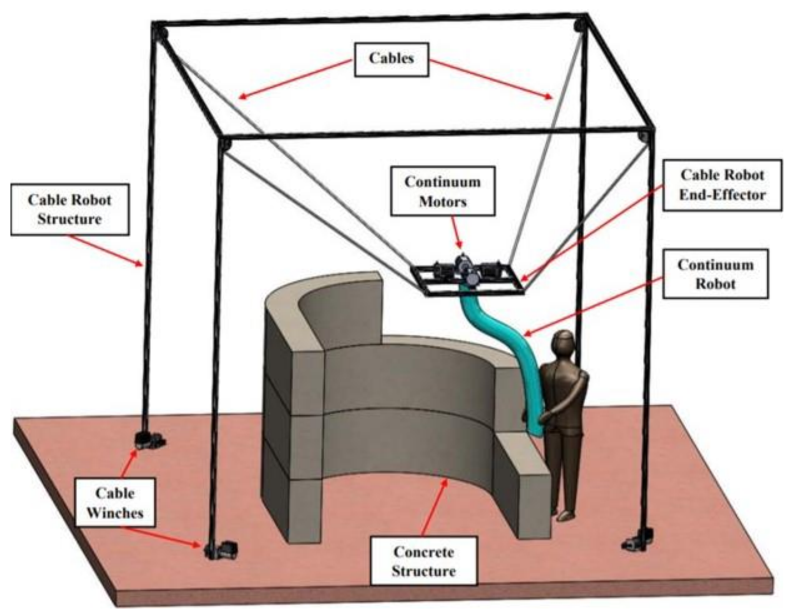
3D Printing of Concrete with a Continuum Robot Hose Using Variable Curvature Kinematics

Manu Srivastava, Jake Ammons, Abdul B. Peerzada, Venkat N. Krovi, Prasad Rangaraju, and Ian D. Walker, Clemson University

Motivation

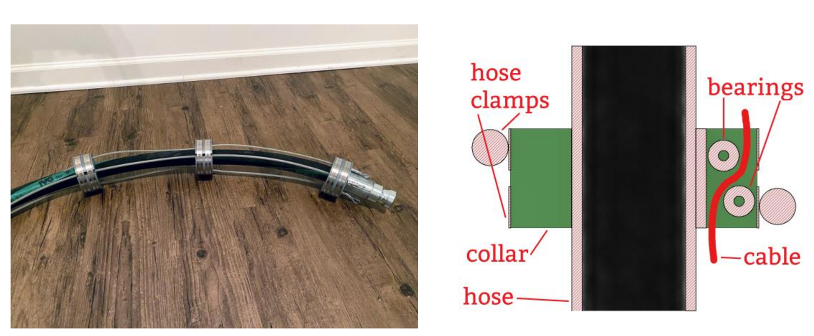
- Robotize the cement hose – a necessary component at all construction sites
- Ability to deposit material at an arbitrary angle
- Weight reduction



Continuum hose on a CDPR

Continuum Hose Prototype

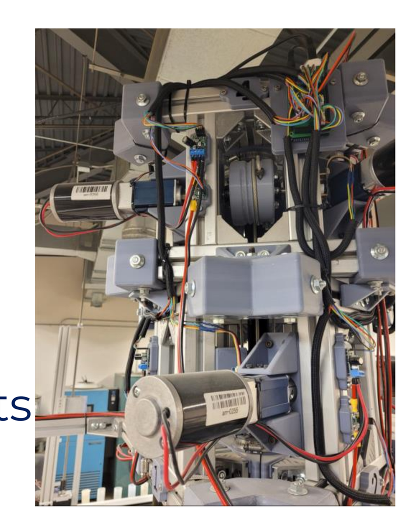
- 1" ID shotcrete hose backbone
- 2 sections, 6 tendons
- Section details:
  - 3 steel tendons/section
  - 2 DOFs/section
  - 5 collars/section
- Additional mass at the tip due to metallic nozzle



Hose assembly

Drive Assembly & Control

- 110V AC-12V DC 40A power supply
- 25A MOSFET H-bridge motor driver
- DC motor (5300RPM, 133A stall current)
- 100:1 gearbox
- 3-D printed capstan
- Position control based on encoder counts using an Arduino Mega



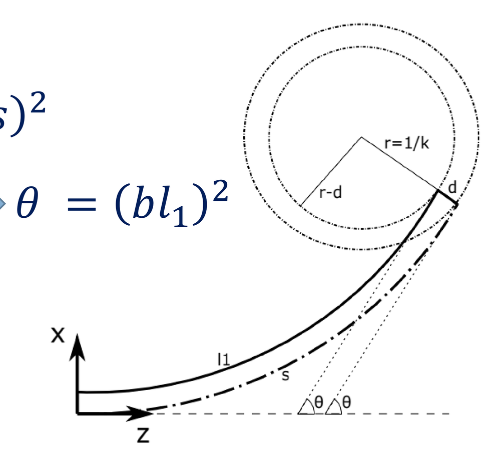
Drive assembly

Euler Curve Based Variable Curvature(VC) Inverse Kinematics

Backbone, $k = \frac{d\theta}{ds} = 2a^2 s \Rightarrow \theta = (as)^2$

Tendon 1, $k_1 = \frac{d\theta}{dl_1} = 2b^2 l_1 = \frac{1}{(r-d)} \Rightarrow \theta = (bl_1)^2$

$$l_1 = s - 2(as)^2 d = s - 2\theta d$$



Half section (split lengthwise)

Single Section 3-D Bending

$k_1 = (r - d\cos(\phi))^{-1}$

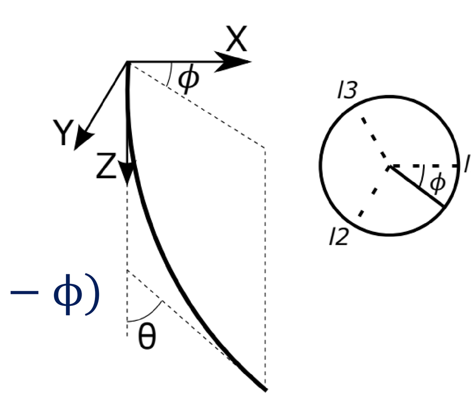
$\hookrightarrow l_{1,tip} = s_{tip} - 2\theta_{tip} d\cos(\phi)$

$k_2 = (r - d\cos(2\pi/3 - \phi))^{-1}$

$\hookrightarrow l_{2,tip} = s_{tip} - 2\theta_{tip} d\cos(2\pi/3 - \phi)$

$k_3 = (r - d\cos(4\pi/3 - \phi))^{-1}$

$\hookrightarrow l_{3,tip} = s_{tip} - 2\theta_{tip} d\cos(4\pi/3 - \phi)$



Coordinate frame and tendon local

Two Section 3-D Bending

$$l_4 = s_p - 2\theta_p d\cos(\pi/3 - \phi_p) + s_d - 2\theta_d d\cos(\pi/3 - \phi_d)$$

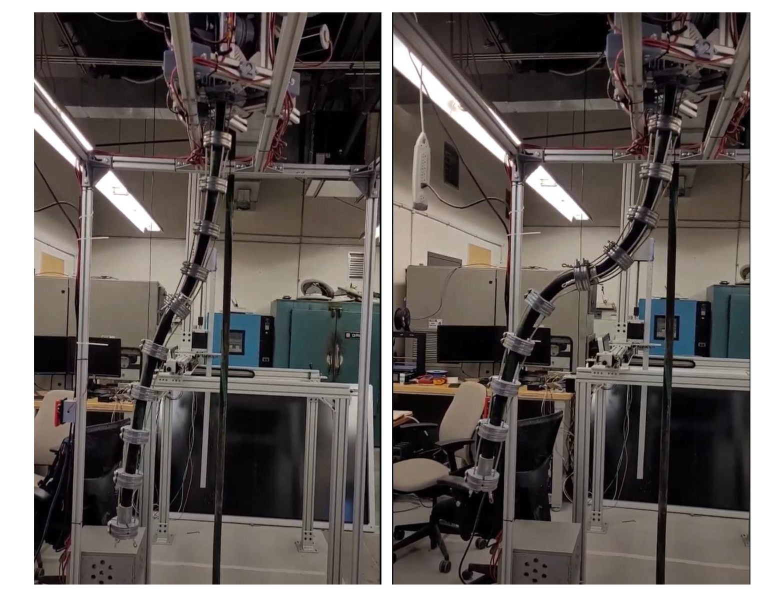
$$l_5 = s_p - 2\theta_p d\cos(3\pi/3 - \phi_p) + s_d - 2\theta_d d\cos(3\pi/3 - \phi_d)$$

$$l_6 = s_p - 2\theta_p d\cos(5\pi/3 - \phi_p) + s_d - 2\theta_d d\cos(5\pi/3 - \phi_d)$$

And, $\phi_d = \phi_p + \phi_{d,local}$

Where p and d denote proximal and distal sections, respectively.

Results



Constant curvature(L) vs VC(R) for two sections for $\theta_1 = \theta_2 = \pi/2$, depicting clear improvement in each section's orientation.

3-D printing concrete using VC kinematics with shape space interpolation with $\theta_1 = \theta_2 \approx 50°, \phi_d = \phi_p + \pi$, and $\phi_p \in [0, 2\pi)$. The loss of curvature in between the proximal tendon planes is due to unmodeled forces and moments.

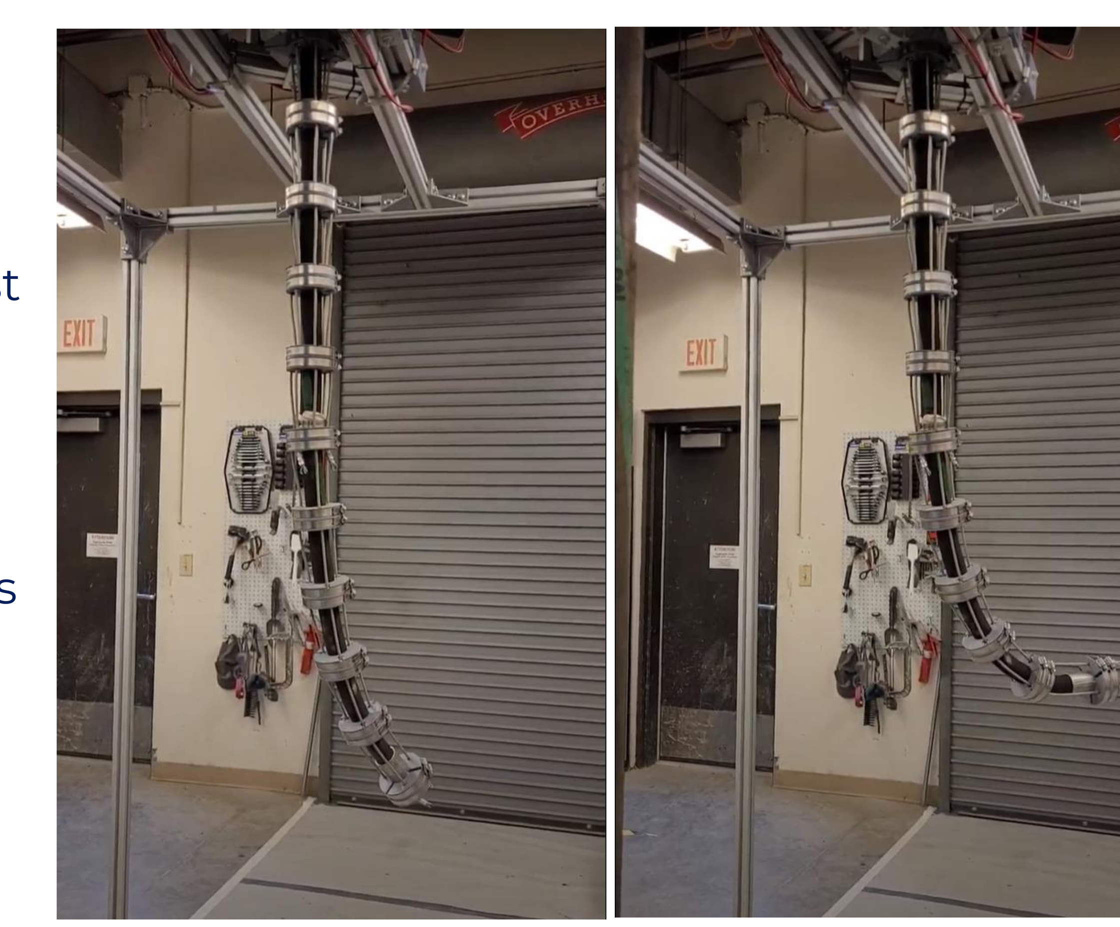
Contribution

A kinematic approach to account for the reduction in curvature when there is additional mass at the end effector (or when there are multiple sections in a continuum robot).

- More accurate description of sectional curvature than constant curvature kinematics
- No additional computational cost

Future Work

- Statics-based model that ensures uniform end effector velocity and curvature at all bending planes



Constant curvature(L) vs VC(R) for distal section for $\theta_d = \pi/2$

This work is supported by the U.S. National Science Foundation under grants 1924721 and 1718075.