Project Introduction

Team 5

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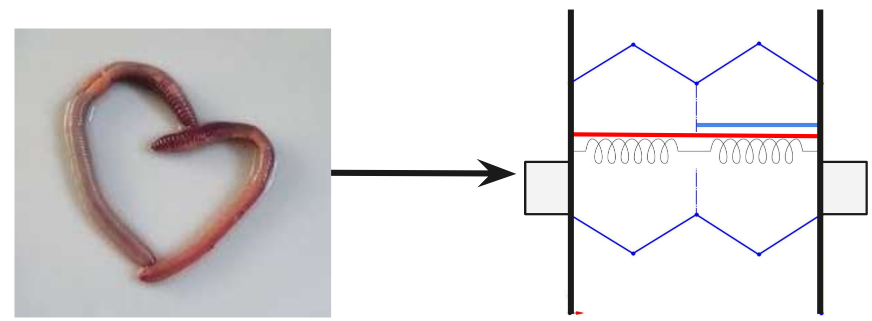

Refined Research Question:

“How can foldable techniques translate a small number of actuators into motion for a robot traveling through small spaces?”

Biomechanics-driven Inspiration

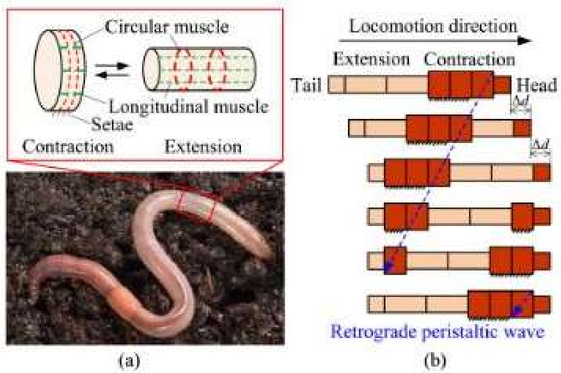

Figure 1. Lumbricus terrestris locomotion [1]

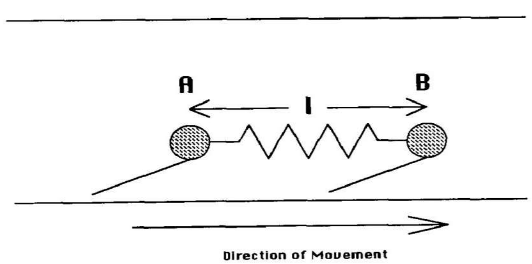

Figure 2. Free-body diagram [2]

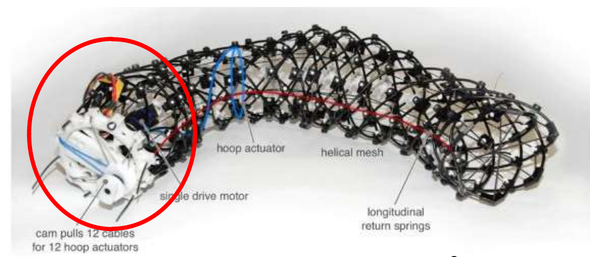

Figure 3. Cable driven worm [3]

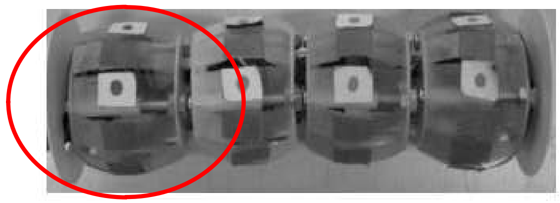

Figure 4. Four sarrus linkage worm with endplates [4]

Figure 5. "Feet" on existing Origami Inspired worm [5]

Table of max specifications

Parameter	*Value*
GRF	1.07×10^{-1} N
Mass	8.9×10^{-3} kg
Velocity	0.02 m/s
Kinetic Energy	1.78×10^{-6}J
Axial Acceleration	2.71 m/s^2
Radial Burrow Force	0.042 N
Axial Burrow Force	0.028 N
Mean Length	124×10^{-3} m
Mean Length/Mean diameter	18.1

Table 1. Max specifications

Proposed Mechanism

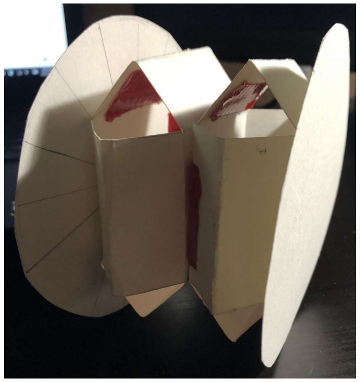

Figure 6. Paper mechanism concept.

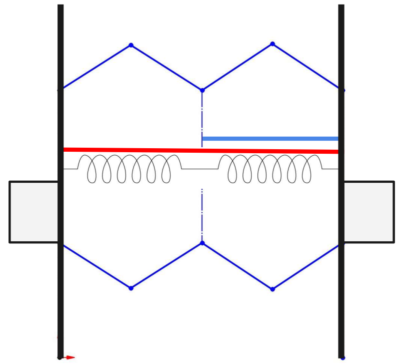

Figure 7. Final mechanism concept.

- Two sarrus linkages instead of four to reduce complexity.
- Endplates on front and back to keep system leveled.
- “Setae” on endplates to control direction of friction.

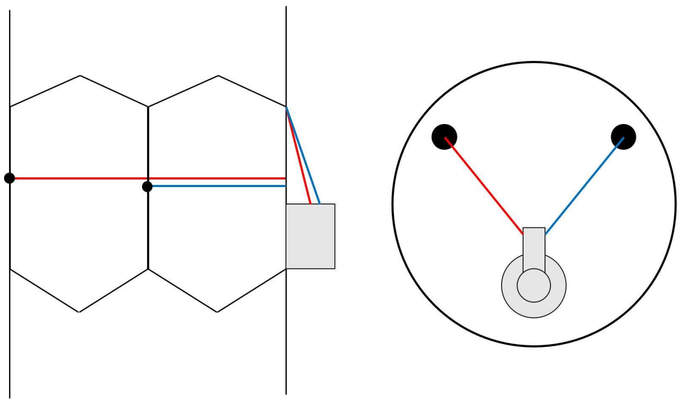

Figure 8. Cable + motor motion concept.

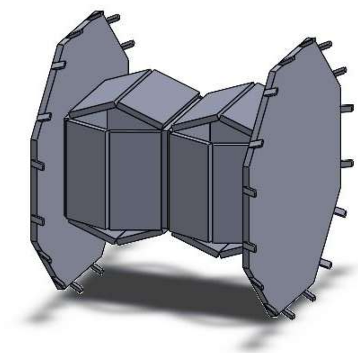

Figure 9. SOLIDWORKS 3D motion study.

Kinematics

Kinematic diagram

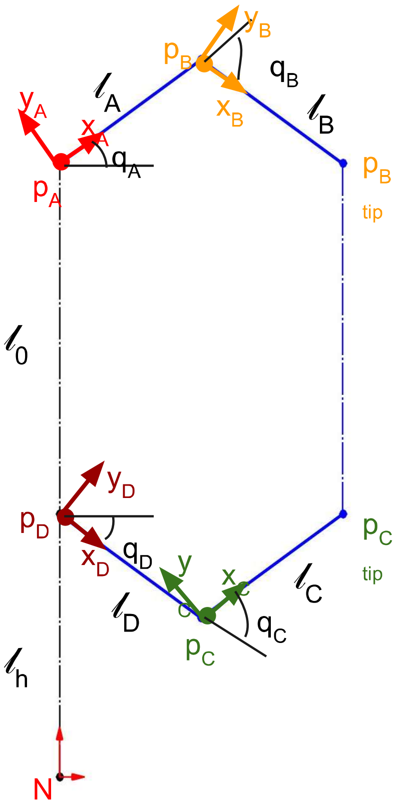

Figure 10. Kinematic diagram.

Python System Kinematics and Constraints

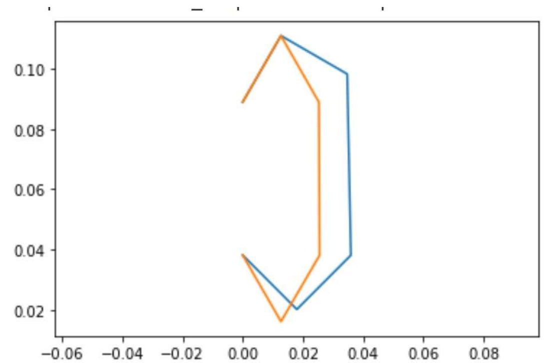

Figure 11. Python kinematics plot.

```
efine the closed loop kinematics of the four bar linkage.
_vector = pB - pC
_vector1 = pCtip - pBtip
```

```
: [] # eq -> equation

ıppend((eq_vector1).dot(N.x)) #same x value for B and C tip
ıppend((eq_vector1).length() - 10) #length constraint between B and C tip
ıppend((eq_vector).dot(N.x)) #B and C have same x

l=[(system.derivative(item)) for item in eq]
```

Figure 12. Kinematics vector constraints.

```
F_ee = numpy.array([-0.5, 0,0,0,0]).T # Arbitrary force vector on end effector;
F_in = J.T.dot(F_ee)
F_in
```

```
angA = 135*pi/180 #radians
angF = 45*pi/180 #radians
length0 = 0.0254 #meters
v_in = 0.02 # meters/sec
r = 0.0254
w = -v_in/r
v_out = length0 * w * m.cos(angA)/m.cos(angF)
v_out
```

Figure 13. Force and Velocity.

Future Plans

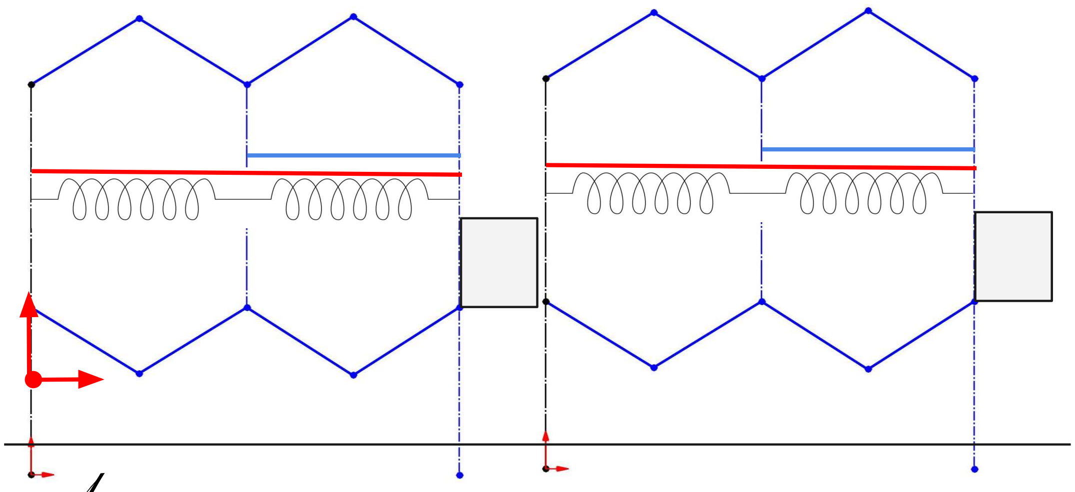

Figure 14. Next Steps diagram.

- Add springs, cables and an actuator. (vary spring stiffness to time compression cycle)
- Explore the sequence of compression so that two links touch the ground at specific times, allowing the system to 'step'

-Motion concept. As one expands, the other compresses

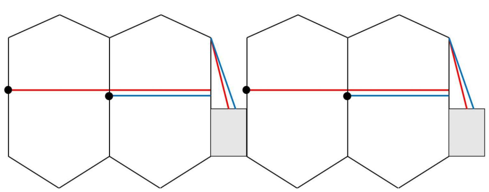

Figure 15. Next Steps cable motion concept.

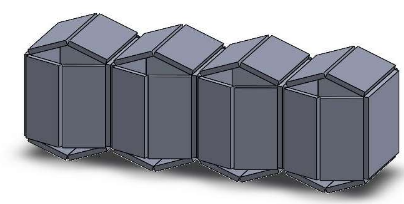

Figure 16. Next Steps 3D motion concept.

Bibliography

(1)R. Liu and Y. Yao, “A novel serial–parallel hybrid worm-like robot with multi-mode undulatory locomotion,” *Mech. Mach. Theory*, vol. 137, pp. 404–431, 2019.

(2)G. Miller, *The motion dynamics of snakes and worms*, vol. 22. 1988.

(3)K. A. Daltorio, A. S. Boxerbaum, A. D. Horchler, K. M. Shaw, H. J. Chiel, and R. D. Quinn, “Efficient worm-like locomotion: Slip and control of soft-bodied peristaltic robots,” *Bioinspiration and Biomimetics*, vol. 8, no. 3, 2013.

(4)C. D. Onal, R. Wood, and D. Rus, “An Origami-Inspired Approach to Worm Robots,” *Mechatronics, IEEE/ASME Trans.*, vol. 18, pp. 430–438, Apr. 2013.

(5)T. Nakamura, T. Kato, T. Iwanaga, and
and Yoichi Muranaka, “Development of a Peristaltic Crawling Robot Based on Earthworm Locomotion,” *J. Robot. Mechatronics*, vol. 18, no. 3, pp. 299–304, 2006.