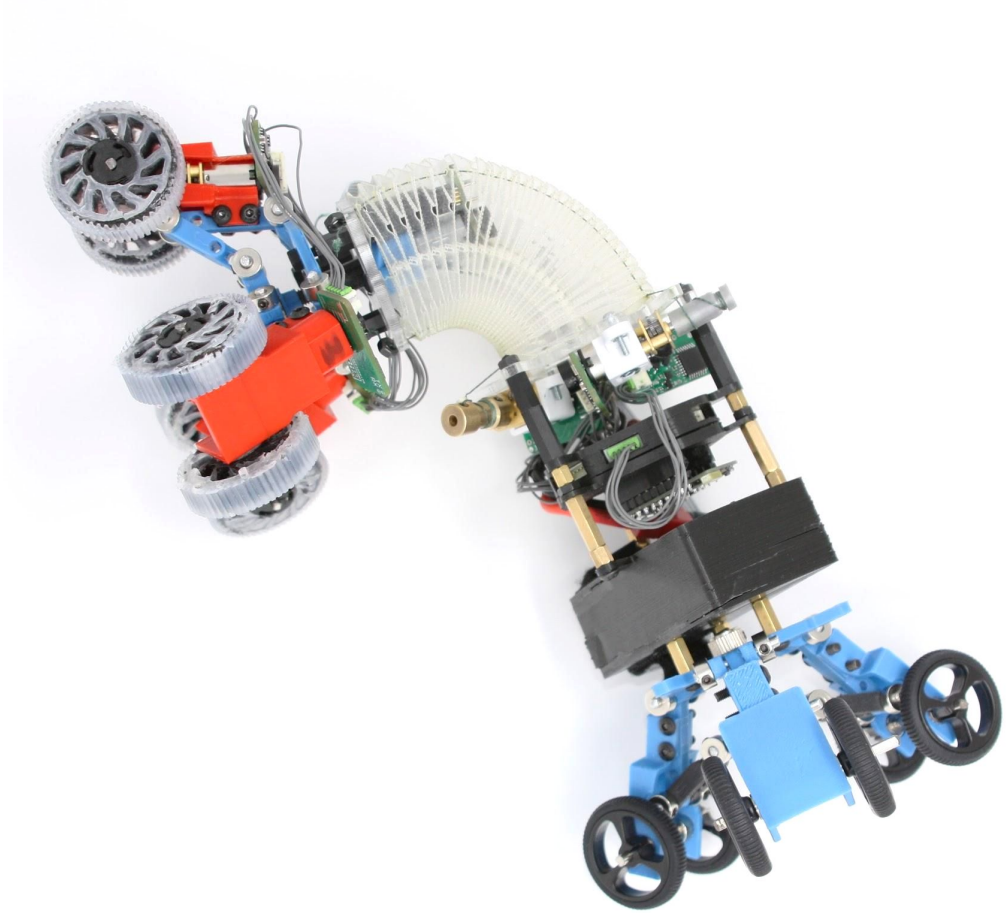
CLARA: Continuum Locomotive Alternative for Robotic Adaptive-exploration

Presented by:
Brian Katz (RBE/ME)
Kate Wheeler (RBE/ME)
Advised by:
Prof. Çağdaş Önal

Presentation Outline

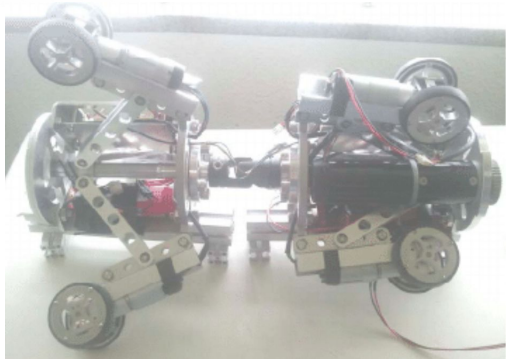
- Background & Motivation
- Project Objectives
- Mechanical System Design
- Control System Design
- Electrical Architecture
- Results and Conclusion
- Acknowledgements



Project Motivation & Background

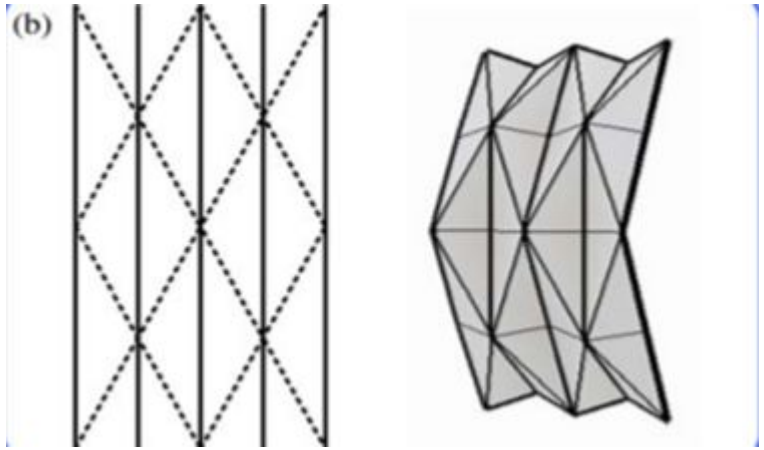
Project Motivations

- Pipe systems are prone to fouling, cracks, and leaks
  - Challenging for humans to explore entire pipe networks that span large areas
- Current forms of remote pipe inspection are limited in their maneuverability
  - Borescopes
  - Crawlers
  - Worms
- Expensive and cannot be applied to smaller diameters
- Tethering limits exploration

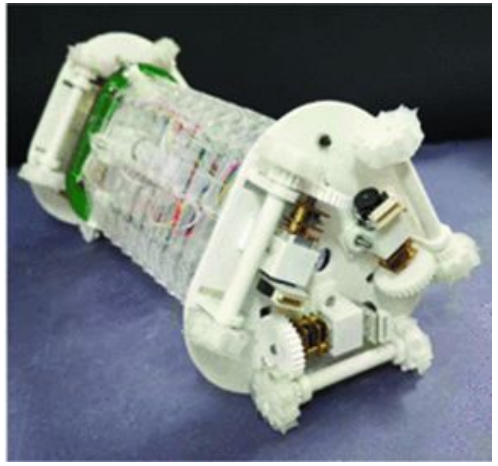


Grainger Video Boroscope, Deep Trekker DT340, Pukyong Pipe Inspection Robot, GE Pipe-worm [1][2][3][4]

Background



Yoshimura Fold Pattern (Santoso et al., IEEE ROS 2017) [5]



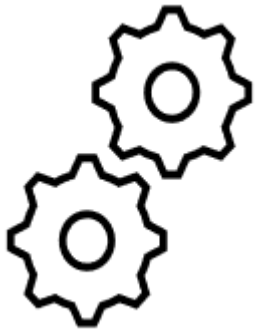
Salamanderbot (Sun et al., IEEE ICRA 2020) [6]

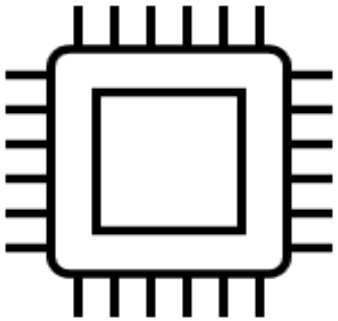
- Origami is a tool to create desired mechanical behavior when rigid mechanisms are insufficient
- Patterns produce varied behavior
  - Yoshimura pattern - axial compression
- Salamanderbot
  - Applied Yoshimura pattern with thread and motors to compress the module, climbing sharp inclines and navigating through turns

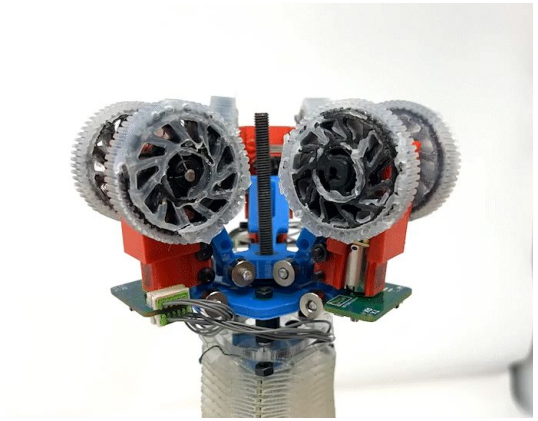
Project Objectives

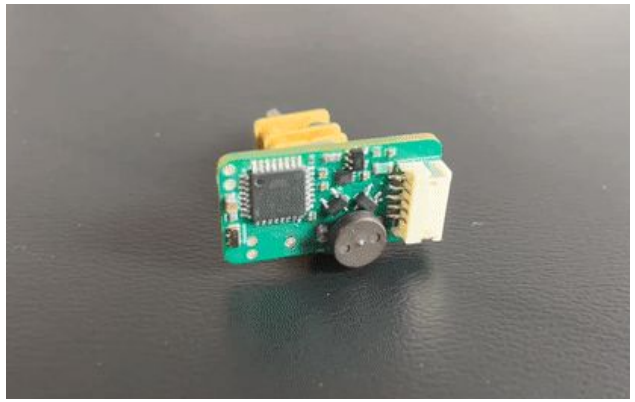
Project Objectives

Goal: Explore the capabilities of a soft robotic origami module in the inspection and exploration of pipe networks too small, expansive, or dangerous for humans.



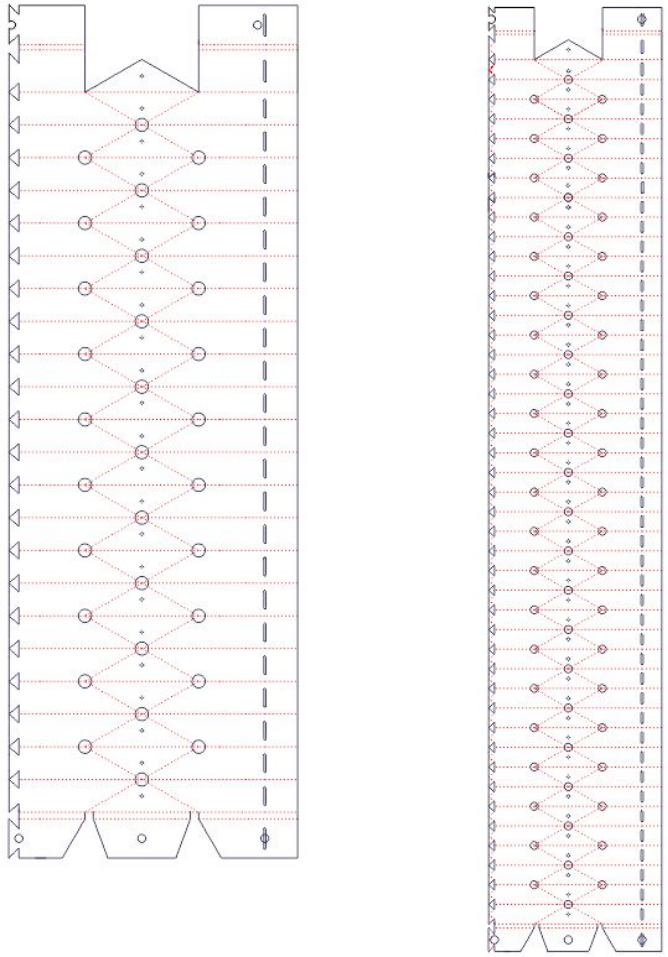






Mechanical Design

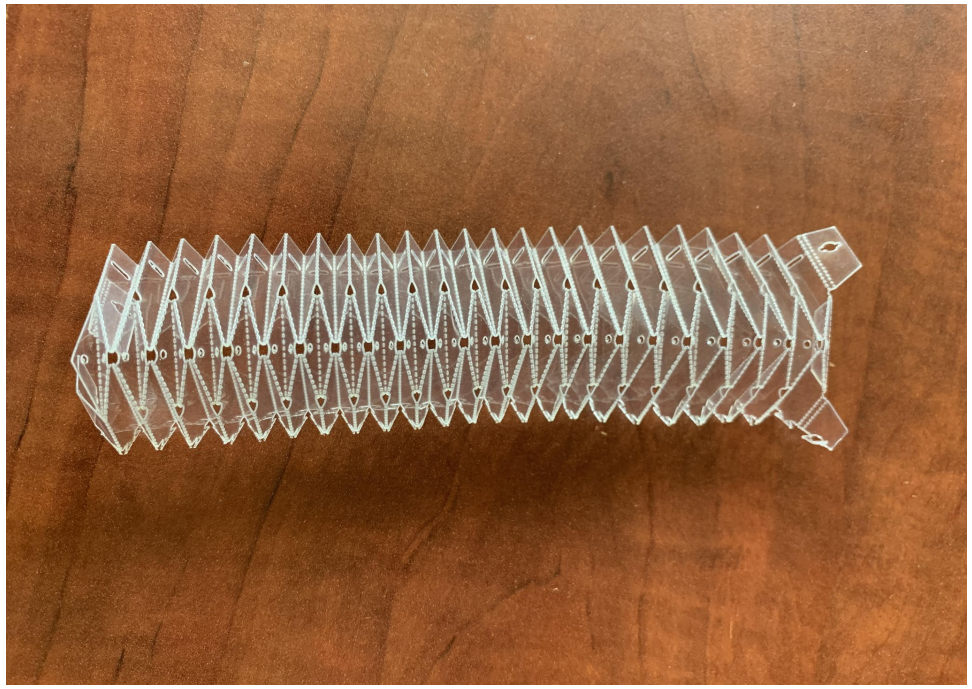
Yoshimura Crease Pattern



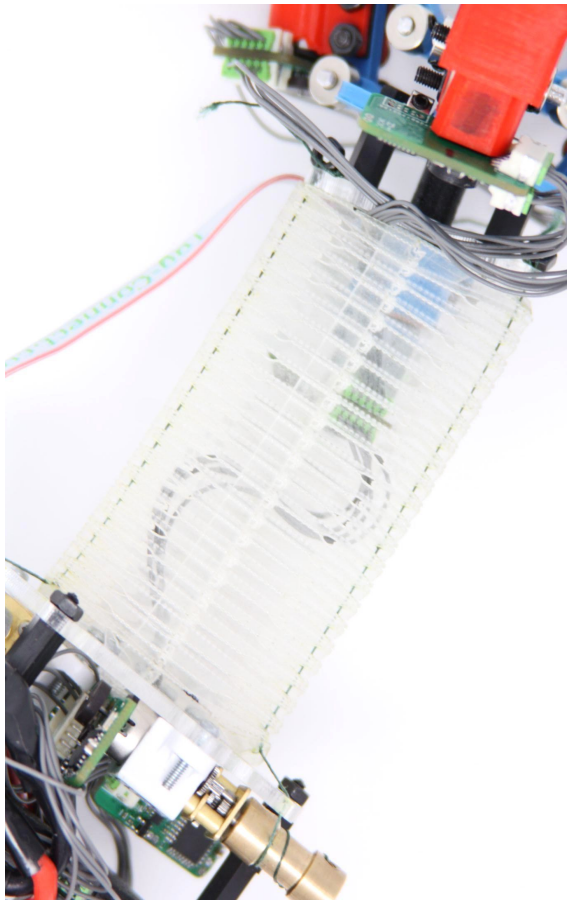
Salamanderbot Yoshimura pattern (left), CLARA Yoshimura pattern(right)

Key Benefits:

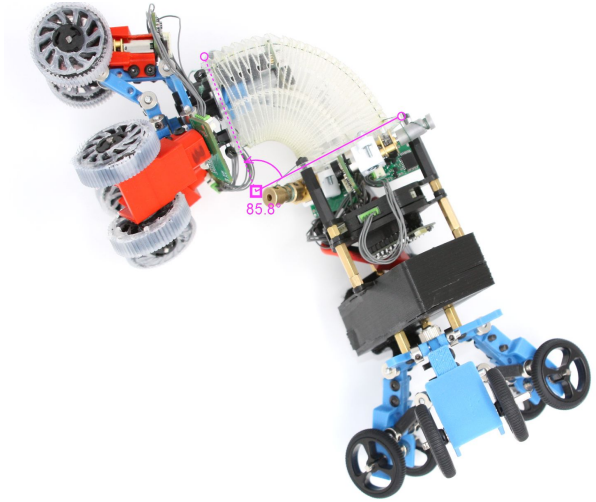
- Controllable linear compression
- Increased torsional stiffness



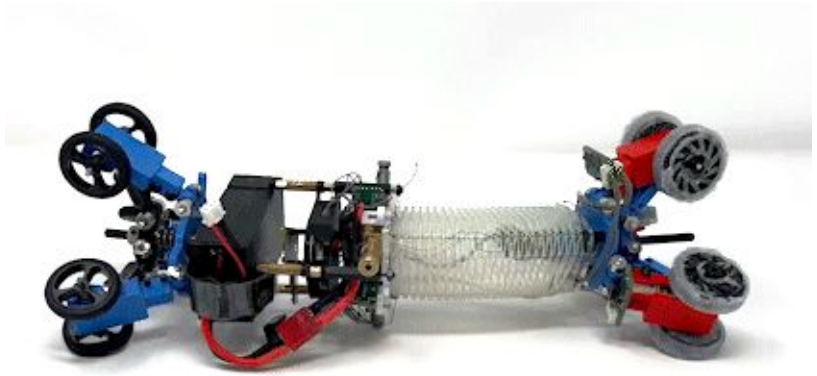
Yoshimura Continuum Module

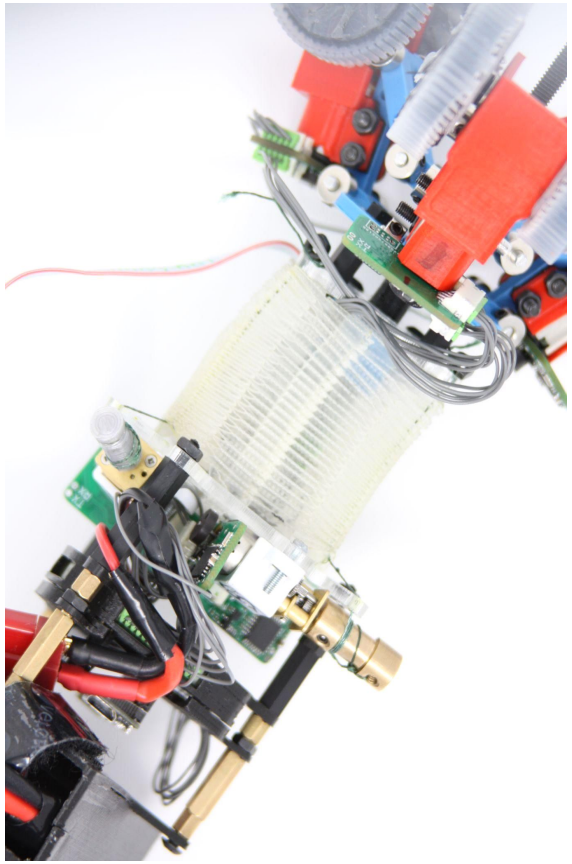


Fully Extended



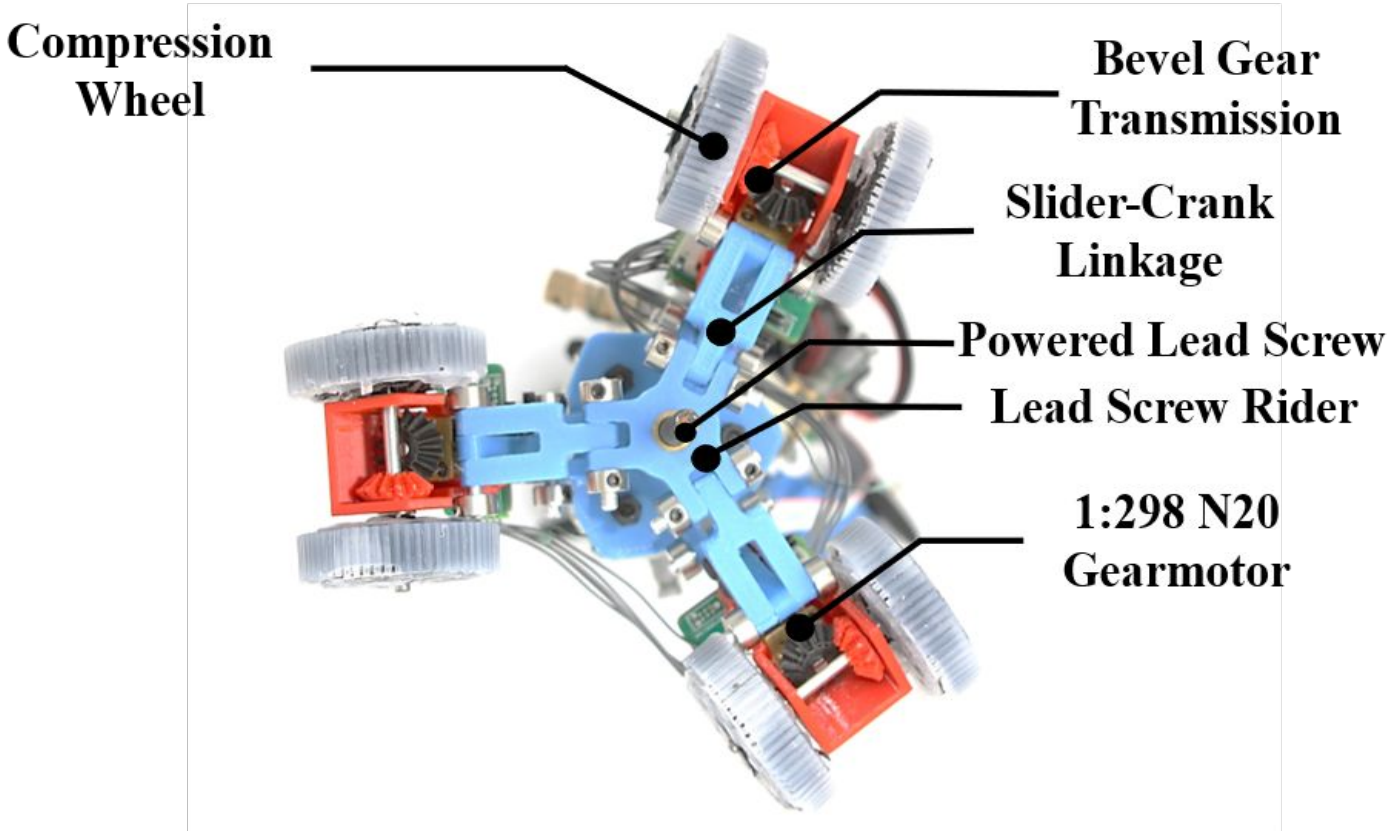
Maximum Bending

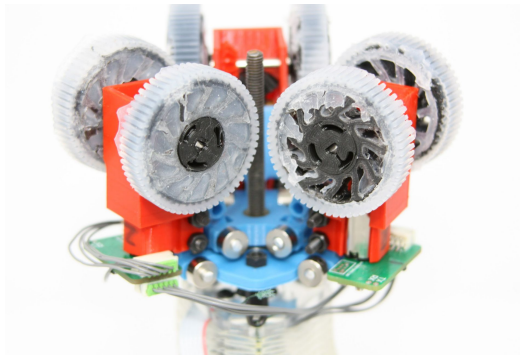


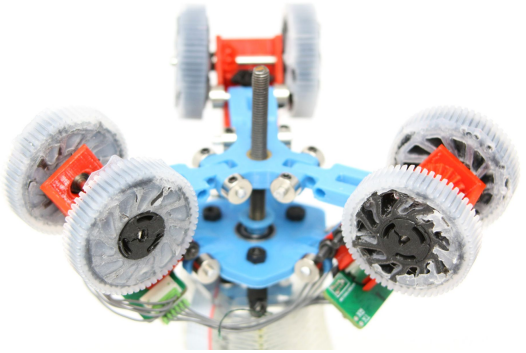


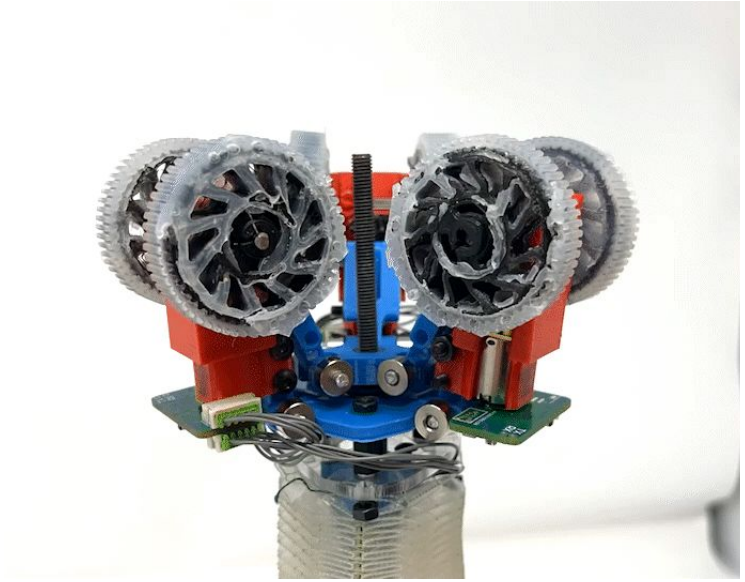
Fully Compressed

Active Variable-Diameter Suspension



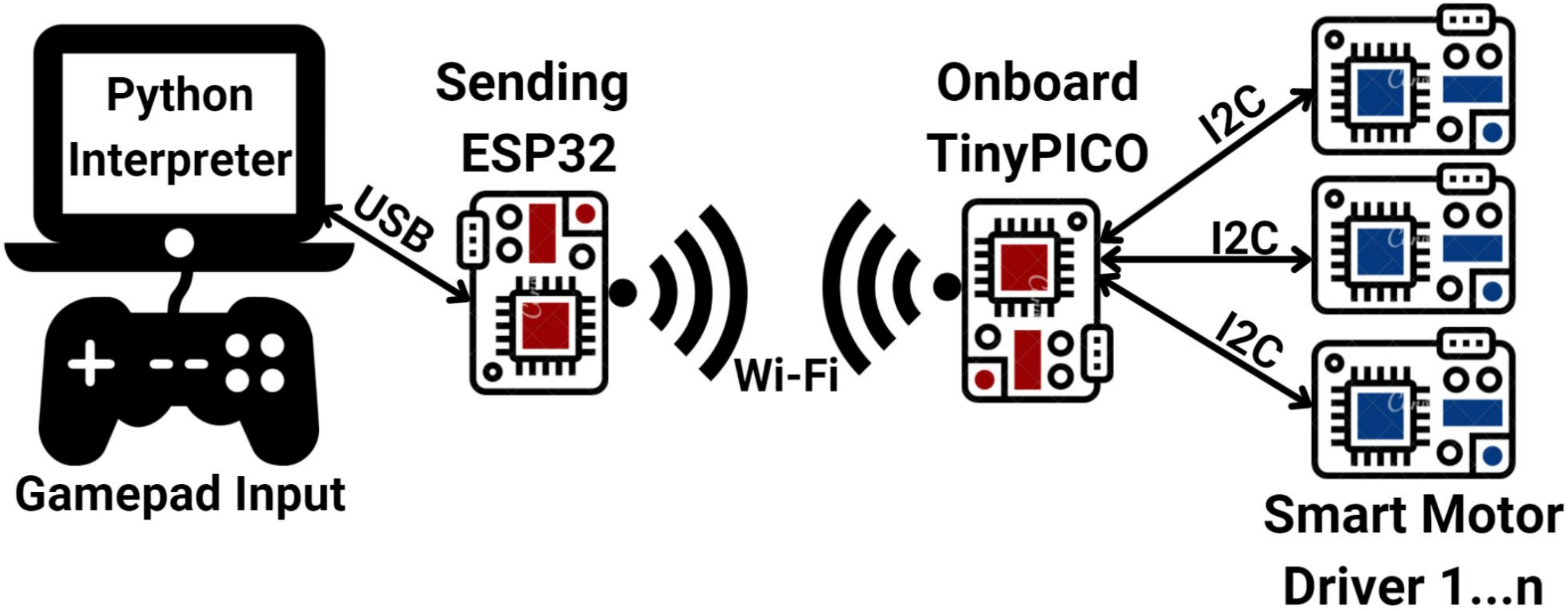






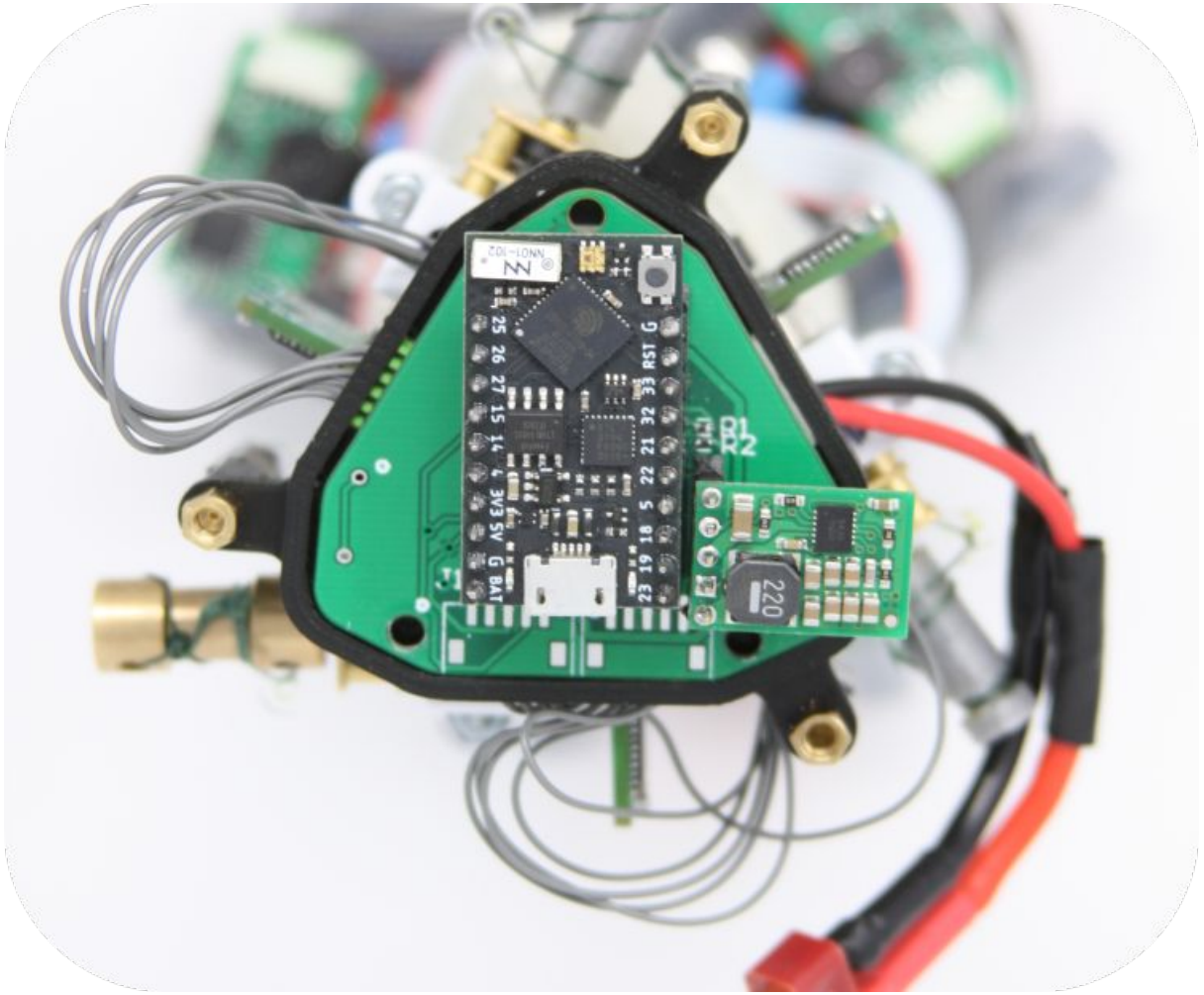
Electrical and Control Architecture

Control Architecture



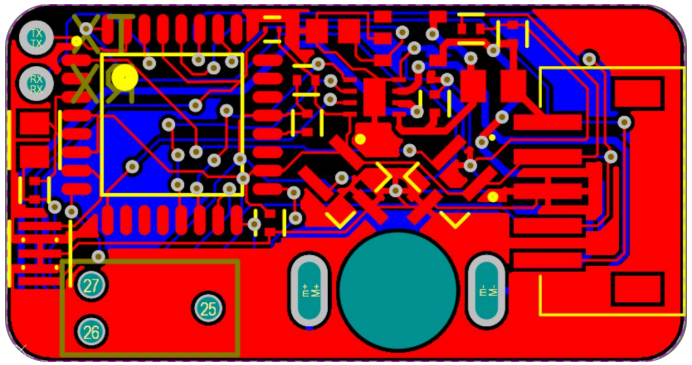
Mainboard PCB Design

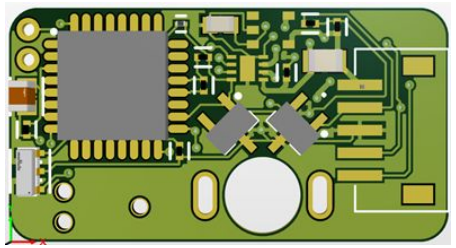
- TinyPICO (ESP32 microcontroller) enables untethered WiFi communication with ESP-NOW
- Onboard power regulation to step down 7.4V motor voltage to 3.3V for logic voltage

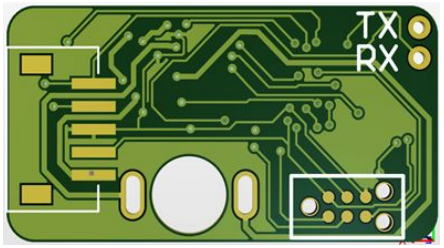


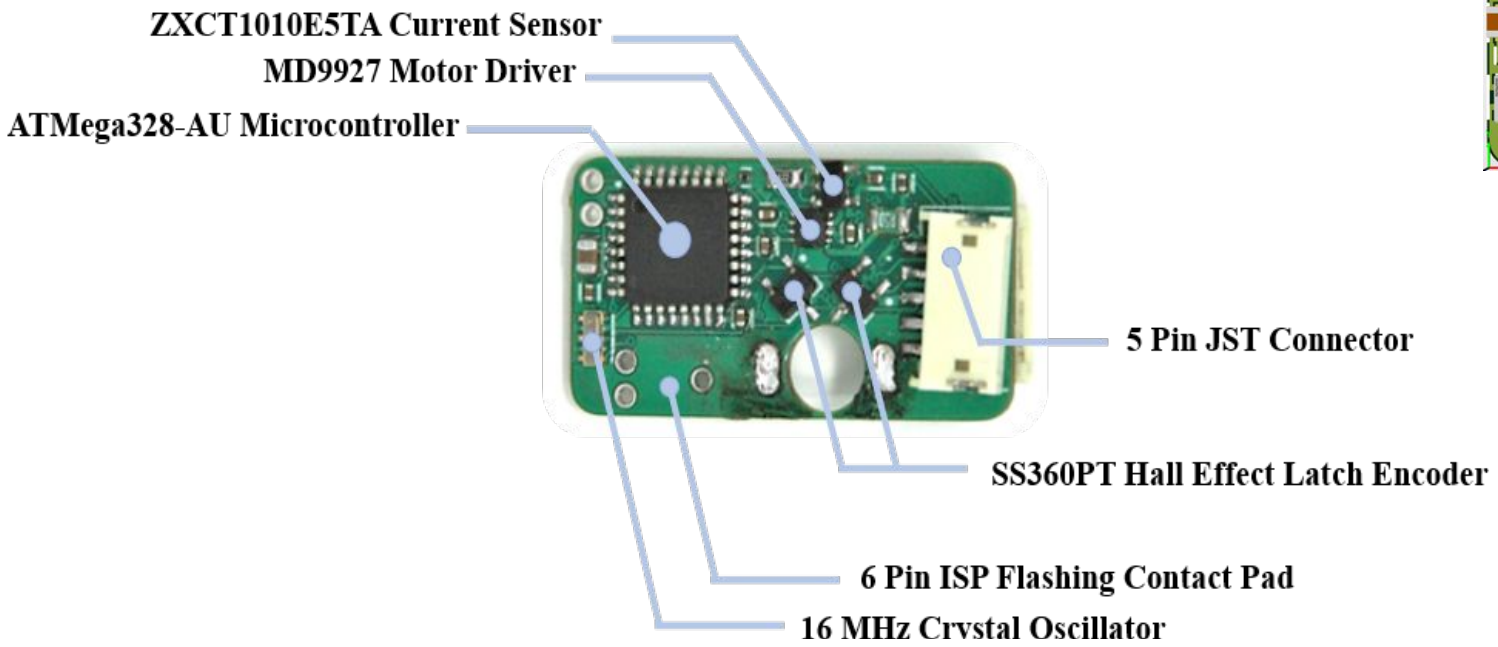
Smart Motor Driver PCB Design

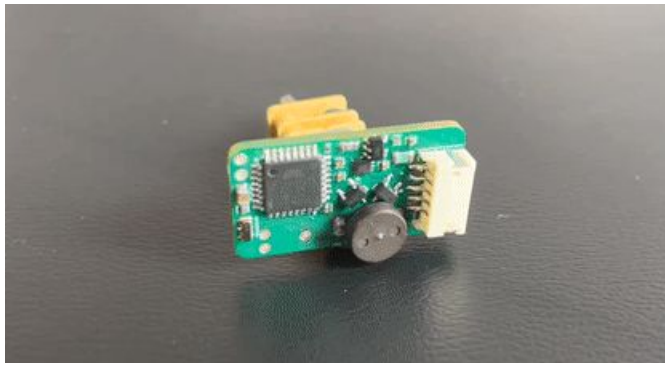
- Provides power, sensing and control with encoders, current sensors, motor drivers, and a microcontroller
- Daisy-chain compatibility using I2C, providing a scalable system





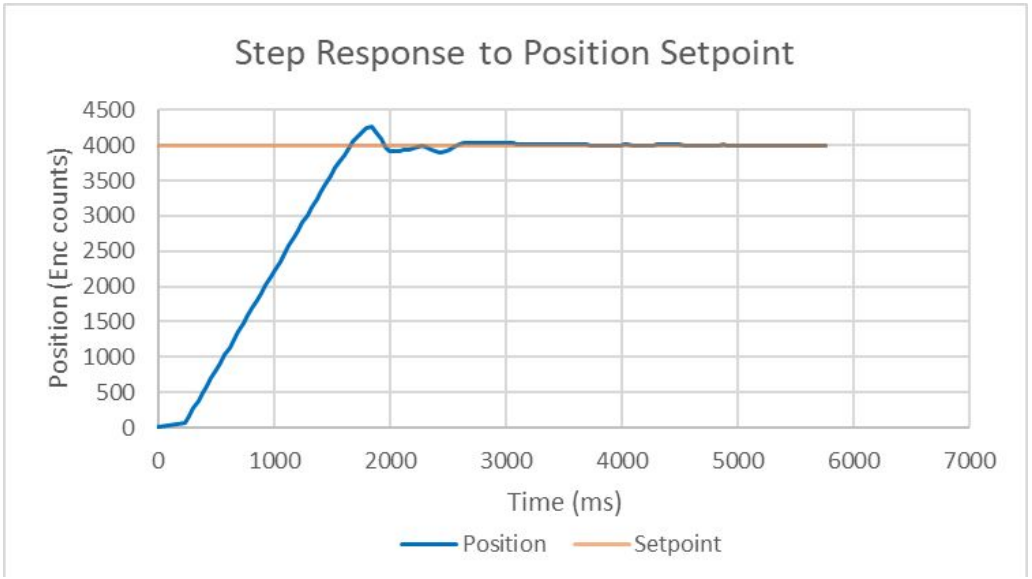




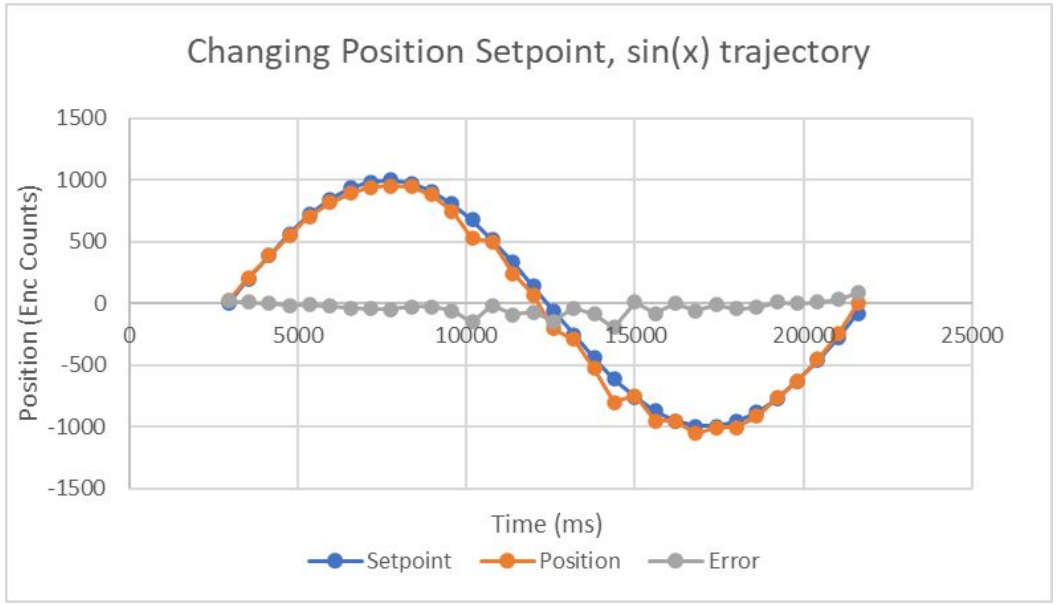


Results

Results: Motor Driver Performance

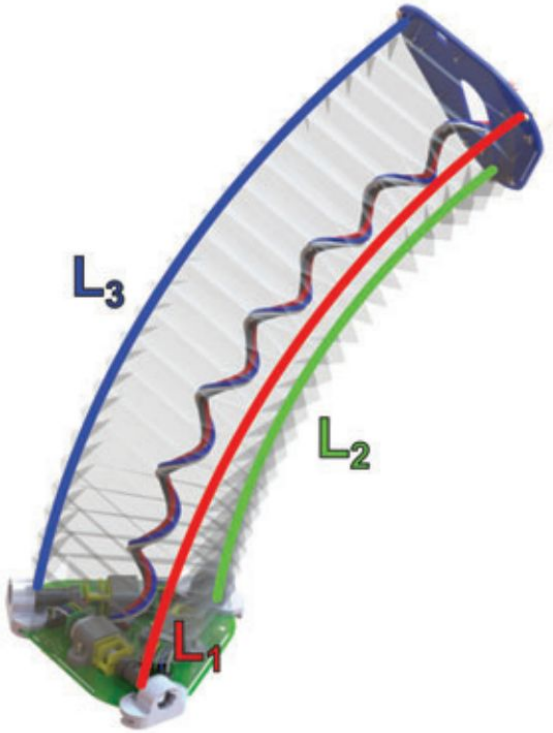


Motor step response to a position setpoint

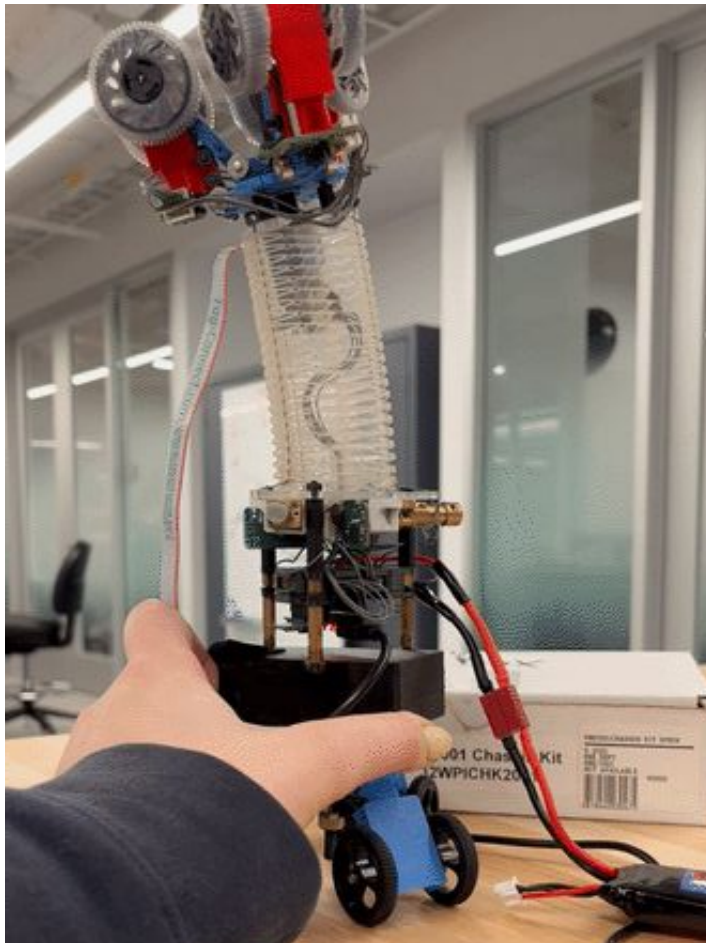


Motor response to sinusoidal position tracking

Results: Yoshimura Module Control

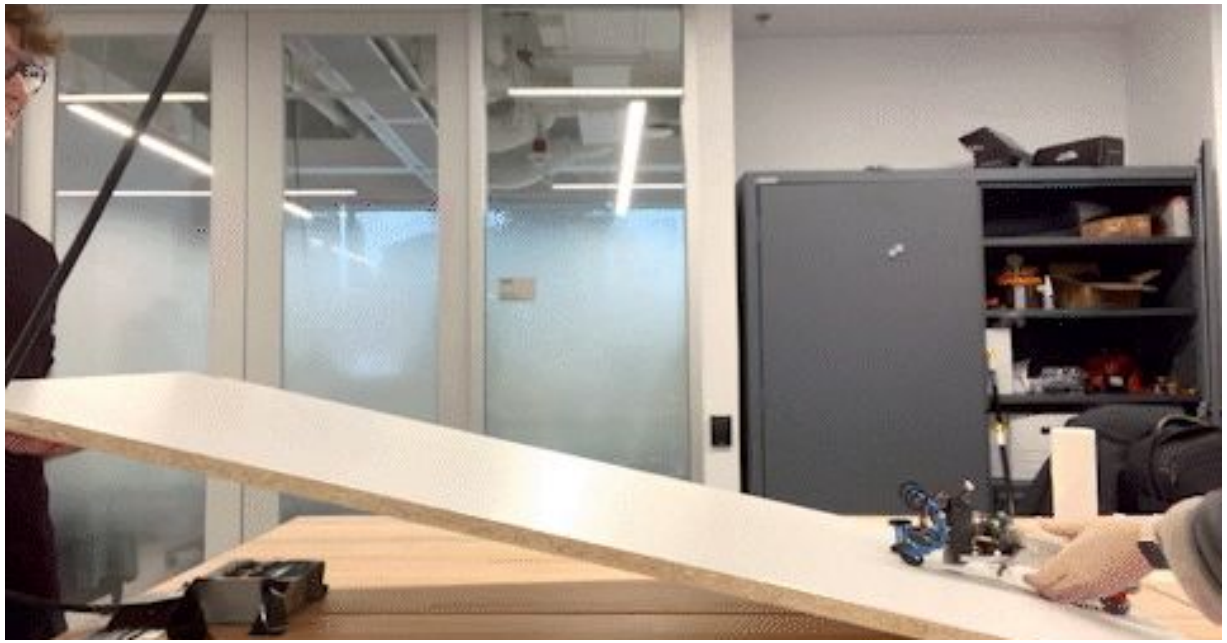


Joint Configuration (Santoso et al., Soft Robotics 2020) [7]

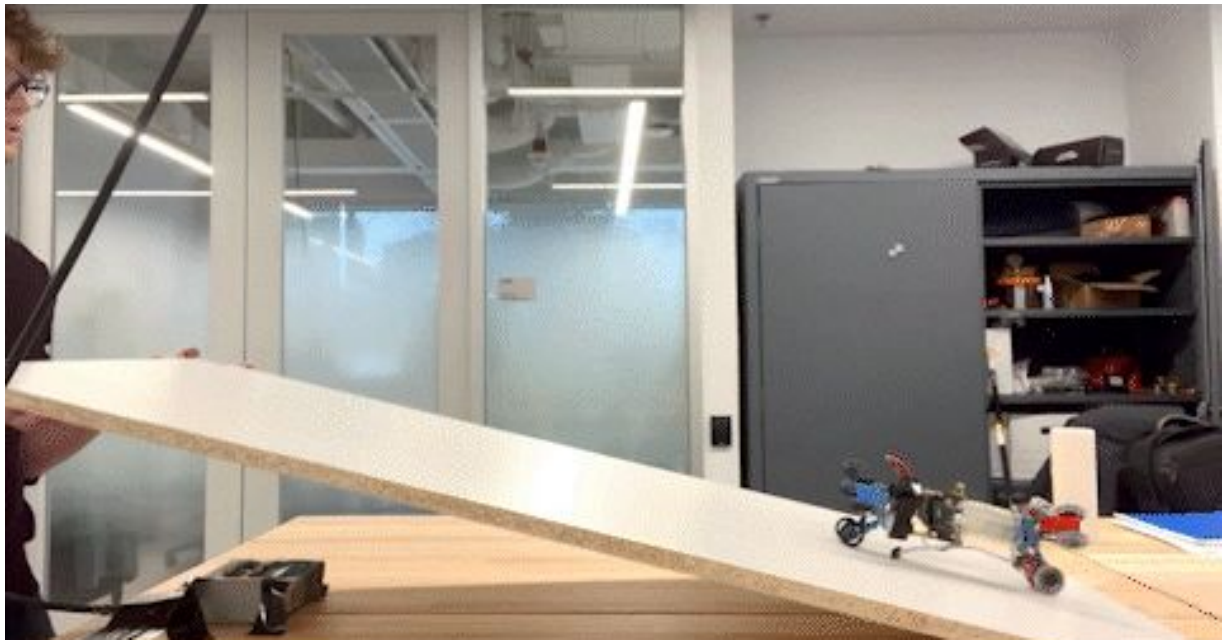


Results: Navigation and Steering

Results: Navigation and Steering



Two-Wheeled Incline Test - 1.5x Speed

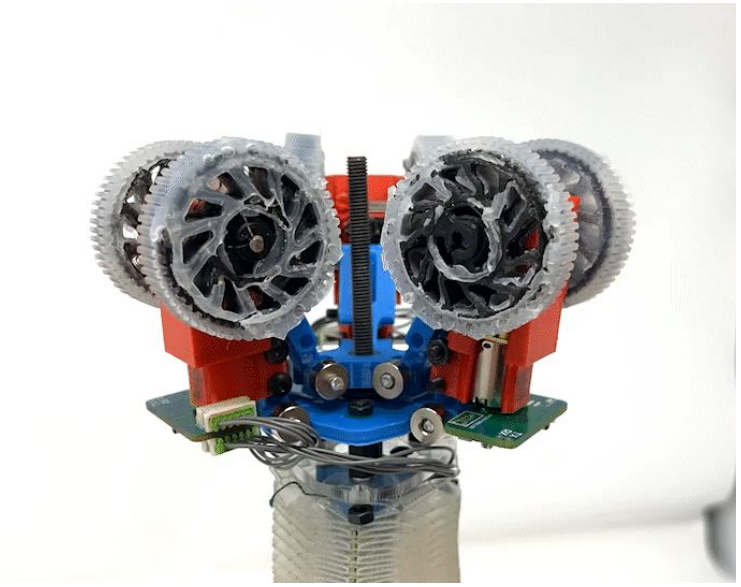


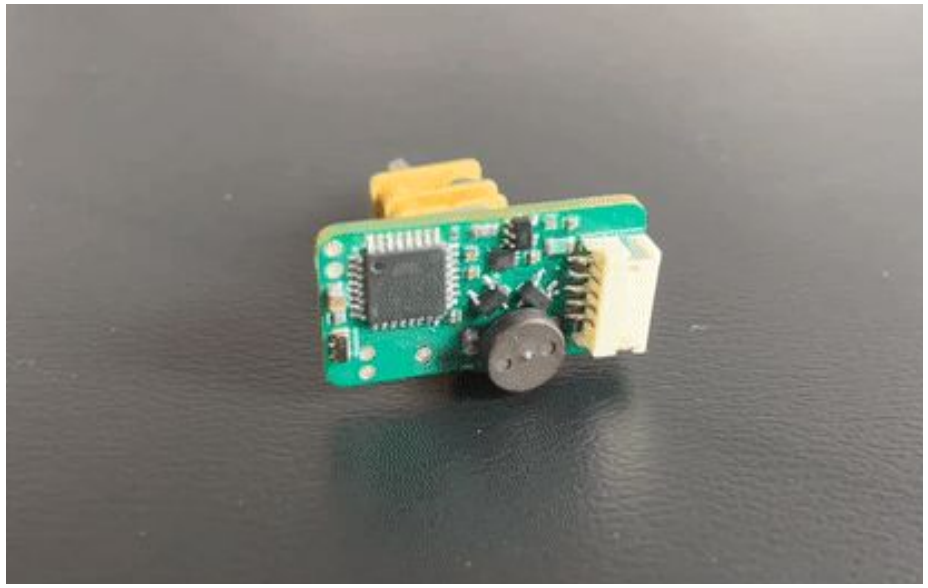
One-Wheeled Incline Test - 1.5x Speed

Results: Pipe Navigation

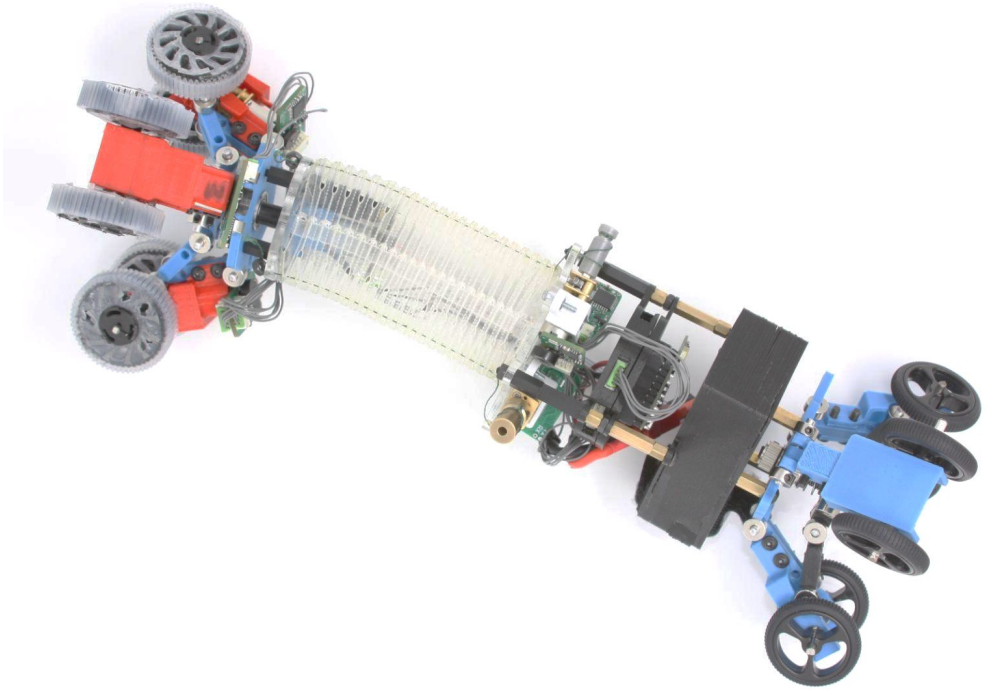
Fundamental Contributions

Goal: Explore the capabilities of a soft robotic origami module in the inspection and exploration of pipe networks too small, expansive, or dangerous for humans.





Results and Conclusion



Category	Value	Units
Weight	1.1	lbs
Yoshimura Module Length	1.5-6.0	in
Maximum Turning Radius	85.8	deg
Effective Diameter Range	3.6-5.2	in
Wheel Compression	0.3	in
Maximum Speed	6	in/s

Dedication & Acknowledgements

We dedicate this Major Qualifying Project to Jiyang "Jeffrey" Wu, our third partner, who passed away in the summer of 2021.

Special thanks to our advisor:

Professor Onal

Additional thanks to:

Professor Greg Lewin

Professor Markus Nemitz

Gabby Conard

Dan Moyer

Yinan Sun

Yoni Weiner

The OREO'd MQP team (Tyler Looney, Archie Milligan, Daniel Perno, Nathan Savard, Michael Scalise, Augustus Teran, Ryley Wheelock)

Questions?

Citations

[1] “Video Borescope, 5.2mm Camera Head,” Grainger. https://www.grainger.com/product/FLIR-Video-Borescope-60PT84

[2] “DT340L Pipe Crawler Package,” Deep Trekker. https://www.deeptrekker.com/shop/products/dt340l-pipe-crawler-package

[3] G. Hunt and I. Ario, “Twist buckling and the foldable cylinder: An exercise in origami,” Int. J. Non-Linear Mech., vol. 40, pp. 833–843, Jul. 2005, doi: 10.1016/j.ijnonlinmec.2004.08.011.

[4] Brian Heater, “GE’s worm robot sports roach-style whiskers to remove fat deposits from sewage pipes,” TechCrunch, Mar. 08, 2022. https://techcrunch.com/2022/03/08/ges-worm-robot-sports-roach-style-whiskers-to-remove-fat-deposits-from-sewage-pipes/

[5] J. Santoso, E. H. Skorina, M. Luo, R. Yan, and C. D. Onal, “Design and analysis of an origami continuum manipulation module with torsional strength,” in 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Sep. 2017, pp. 2098–2104. doi: 10.1109/IROS.2017.8206027.

[6] Y. Sun et al., “Salamanderbot: A soft-rigid composite continuum mobile robot to traverse complex environments,” in 2020 IEEE International Conference on Robotics and Automation (ICRA), May 2020, pp. 2953–2959. doi 10.1109/ICRA40945.2020.9196790.

[7] Santoso, Junius, and Cagdas D. Onal. "An origami continuum robot capable of precise motion through torsionally stiff body and smooth inverse kinematics." Soft Robotics 8, no. 4 (2021): 371-386.