Attritable Soft Robot for ERW Disposal

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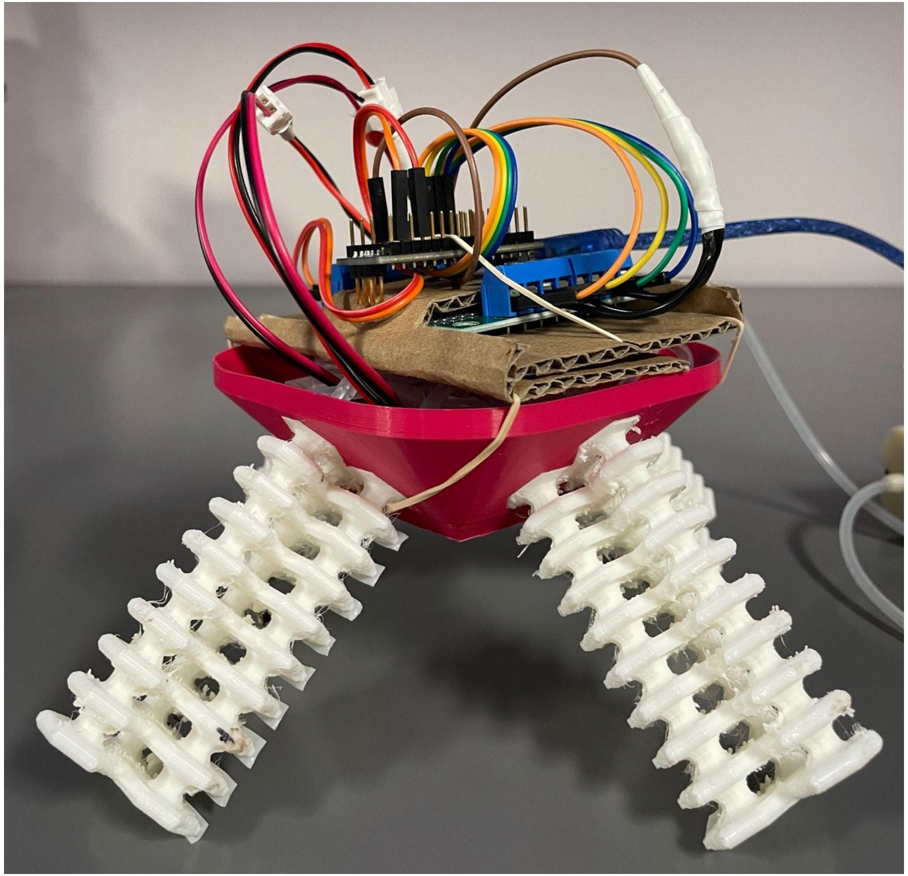
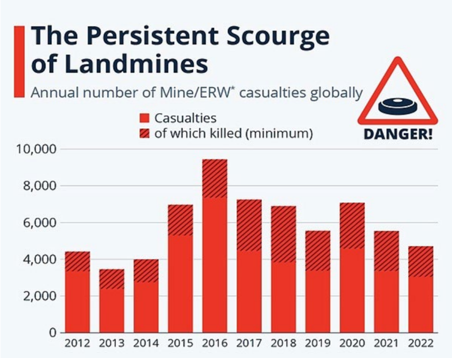


Problem

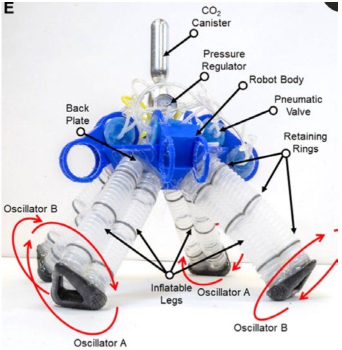
There are about 100 million active landmines worldwide, and civilians are frequently injured or killed by these remnants of war [1]. Removing landmines is currently dangerous, and costs more than it does to plant a mine, highlighting the urgent need for safer and low cost removal methods.



[1] Martin Armstrong, "Infographic: Casualties of Landmines," Statista Infographics, Nov 14, 2023.

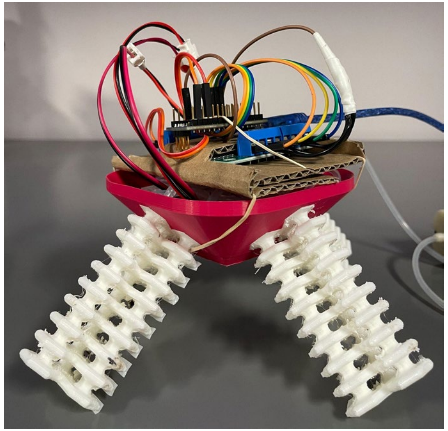
Approach

- We designed and 3D printed a soft robot with 3 parallel chambered actuators for omnidirectional leg movement.
- We tested different movement patterns to create gaits.



[3] D. Drotman, S. Jadhav, M. Karimi, P. de Zonia and M. T. Tolley, "3D printed so actuators for a legged robot capable of navigating unstructured terrain," *2017 IEEE International Conference on Robotics and Automation (ICRA)*, Singapore, 2017.

Results



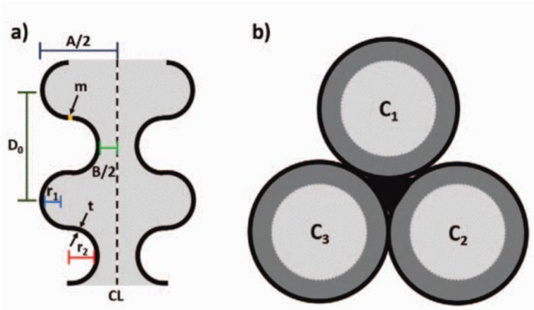
- Our robot consists of multiple actuators, controlled by electronics in a robot body.
- A fully FDM printed robot is tethered and able to walk with fluidic actuators.

Impact

- Our robot is inexpensive, tackling the economy of war; it costs less than $100 to plant a landmine, the printing of our robot and electronics should significantly undercut this cost.
- A walking robot is more adaptable to rough, uneven terrain.

[4] T. C. Looney et al., "Air-Releasable Soft Robots for Explosive Ordnance Disposal," IEEE Xplore, Apr. 01, 2022.

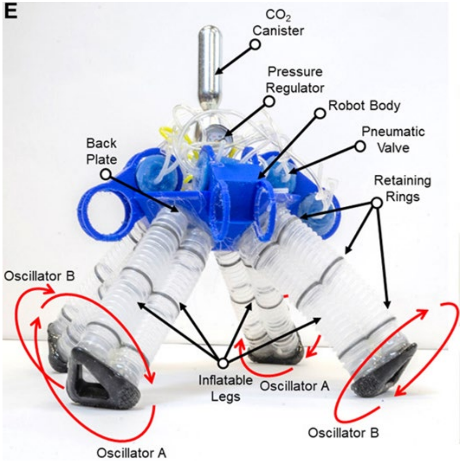
Initial research

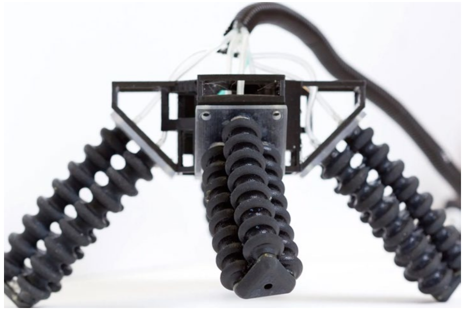


Initial design inspiration from paper which used a cylindrical chamber profile and smooth transitions [2]

Each actuator contains three pneumatic chambers which are pressurized independently through either a ring oscillator or electronic control

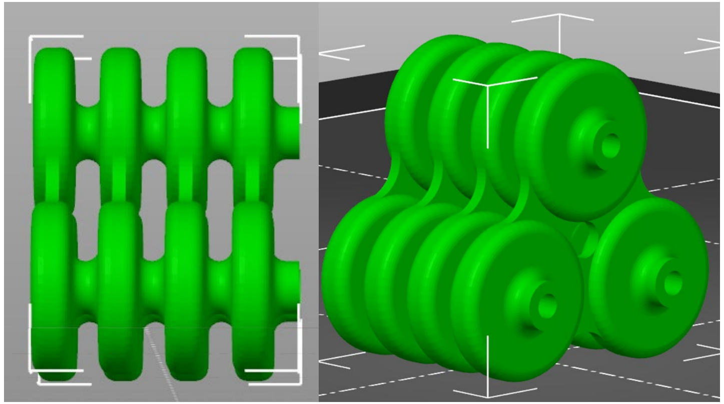
We were inspired by the CAD design of the actuator for a legged robot capable of navigating unstructured terrain [2]



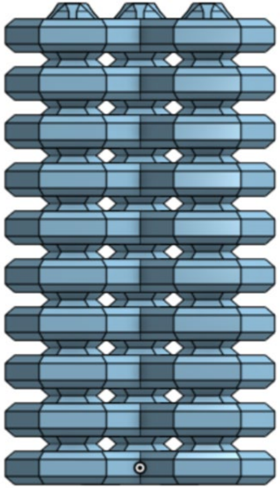


[2] Drotman, D., Jadhav, S., Karimi, M., de Zonia, P., & Tolley, M. T. (2017, May). 3D printed soft actuators for a legged robot capable of navigating unstructured terrain. In *2017 IEEE international conference on robotics and automation (ICRA)* (pp. 5532-5538). IEEE.

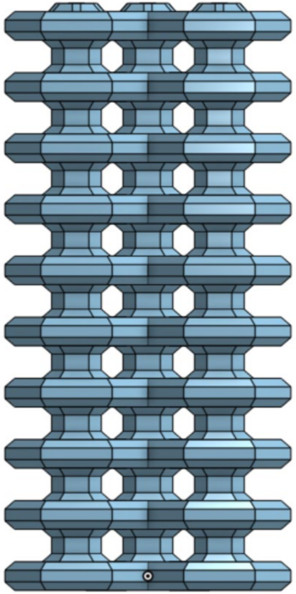
Design iterations of Trichamber Leg



Test CAD model to ensure significant bending angle and printability of the legs.

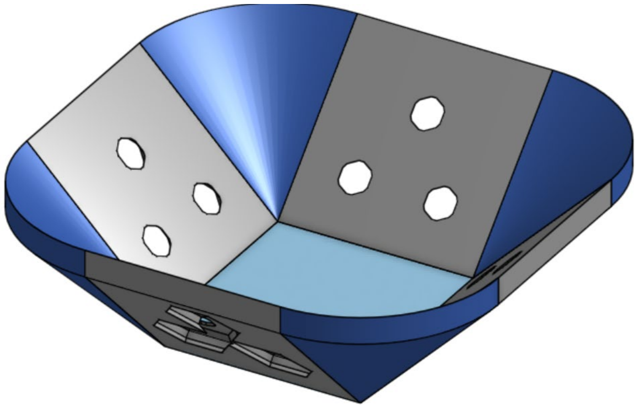


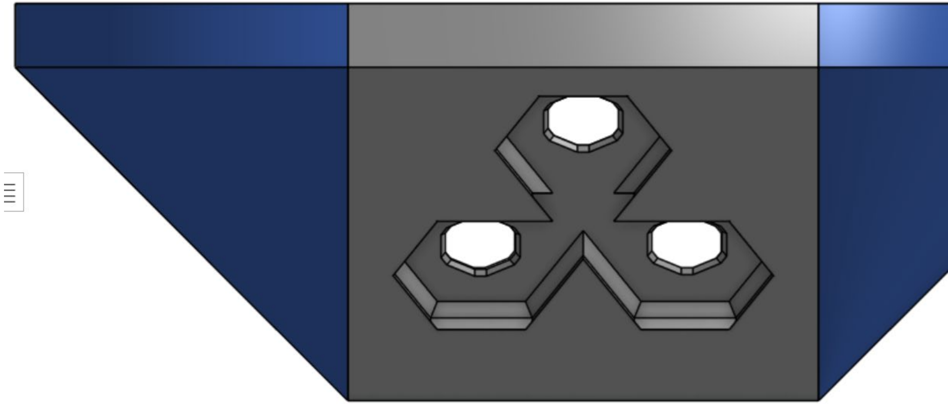
Hexagonal shaped chambers: reduced overhang leading to high quality and airtight print

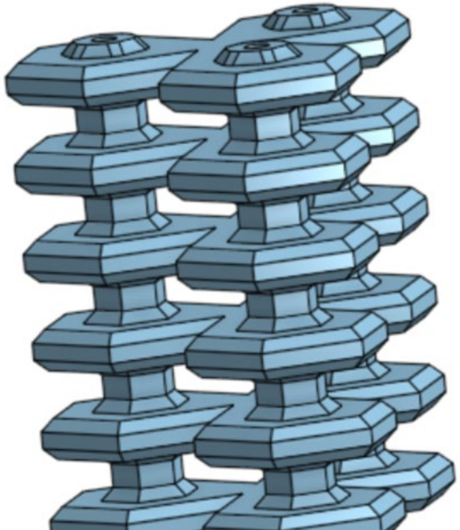


Thinner wall thickness (1.6 → 1.2 mm; 1.6 → 1 mm) to increase bending angle; Longer distance between chambers (2 → 4 mm)

Body







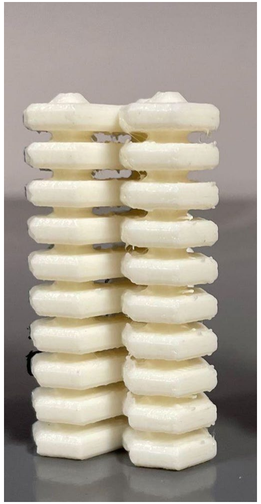
Diagonal sides are at 45 deg.

Extruded cuts of the same size as the chamber of the leg to keep the legs tightly fixed to the body while also easily being modular and adaptable.

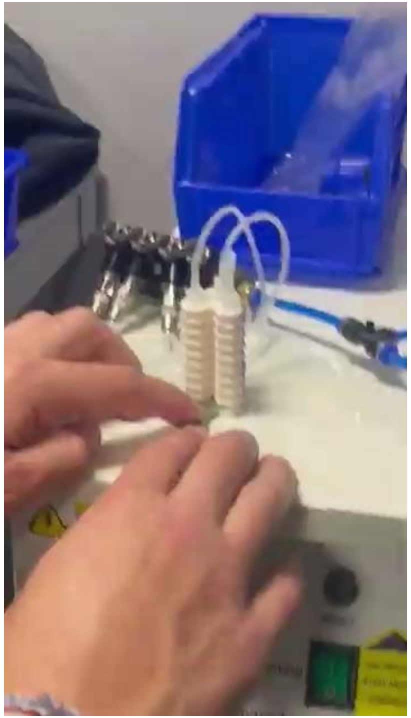
The holes allow for pressure lines to be run from inside the body.

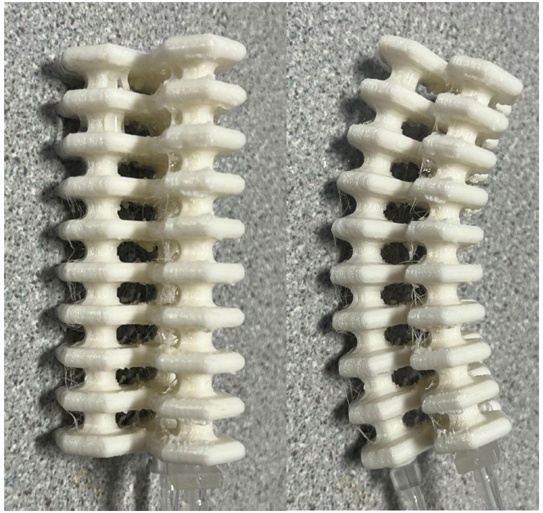
Prototypes and their performances

Test sample for proof of concept



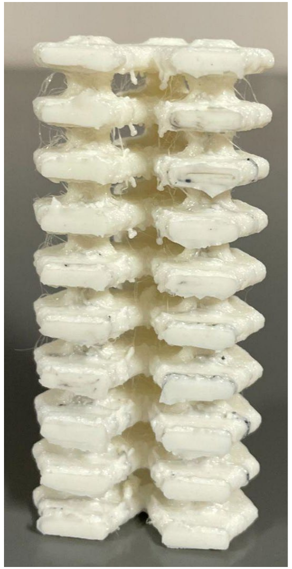
First scaled leg with hexagonal profile: too rigid for 12v pump

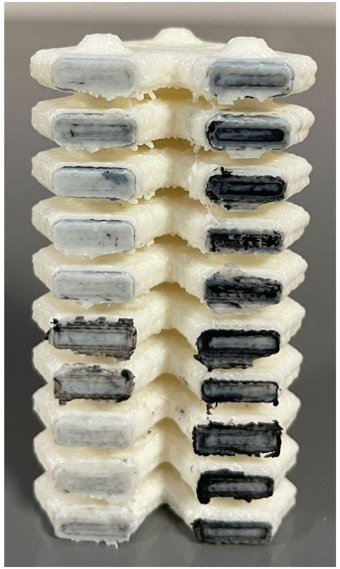


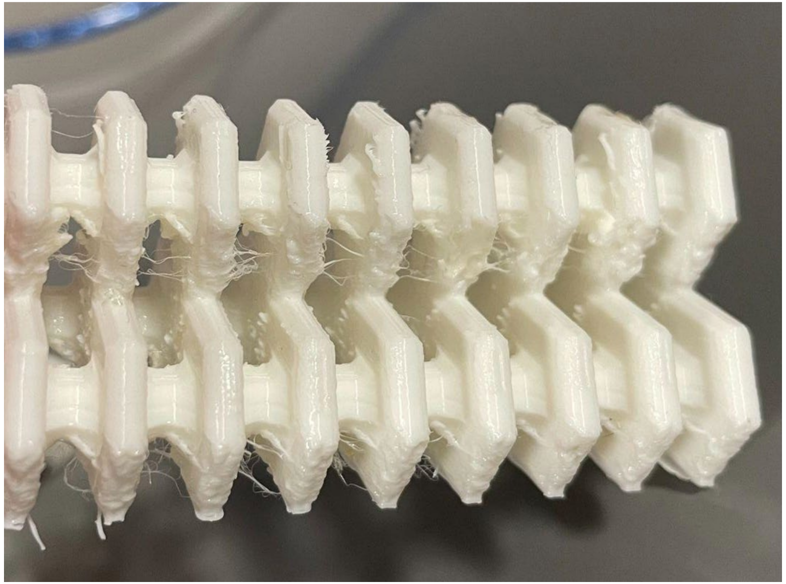


Redesigned full scale leg with thinner walls to increase bending angle at 100 kpa

Print Issues



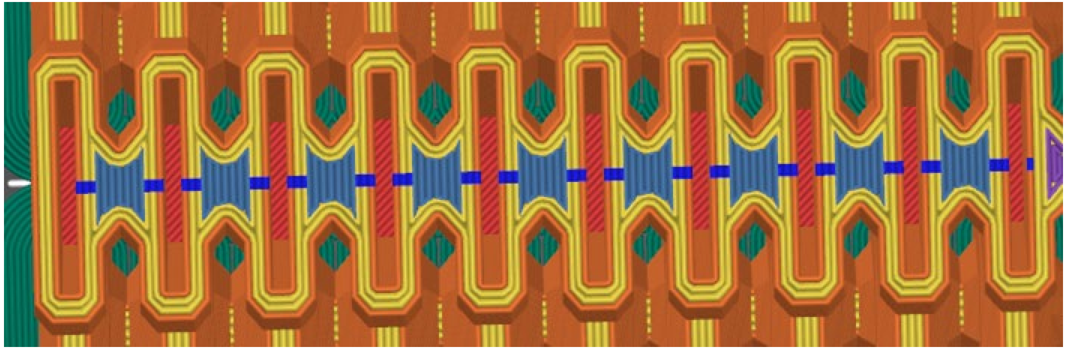


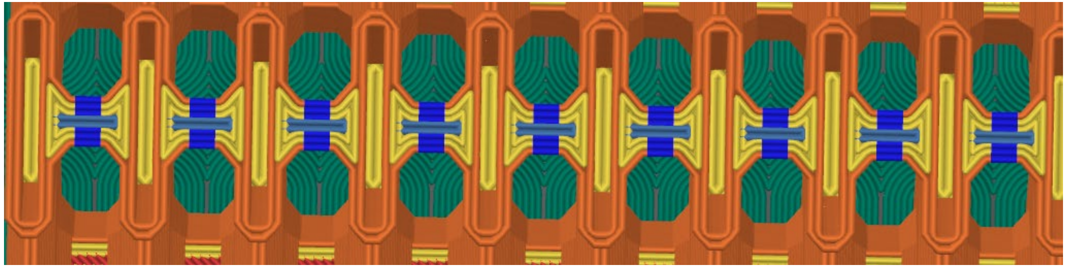


Layer shift and excessive stringing issues that we tried to address with retraction ultimately didn't affect final performance

- Leftover of conductive filament kept being extruded even after using cleaning filament
- Use of wrong filament material
  → less flexible structure

Print Issues cont.





- Overhang perimeter due to circular chamber geometry → fixed with hexagonal geometry

- Holes in the structure due to exceptionally thin walls → fixed with soldering iron

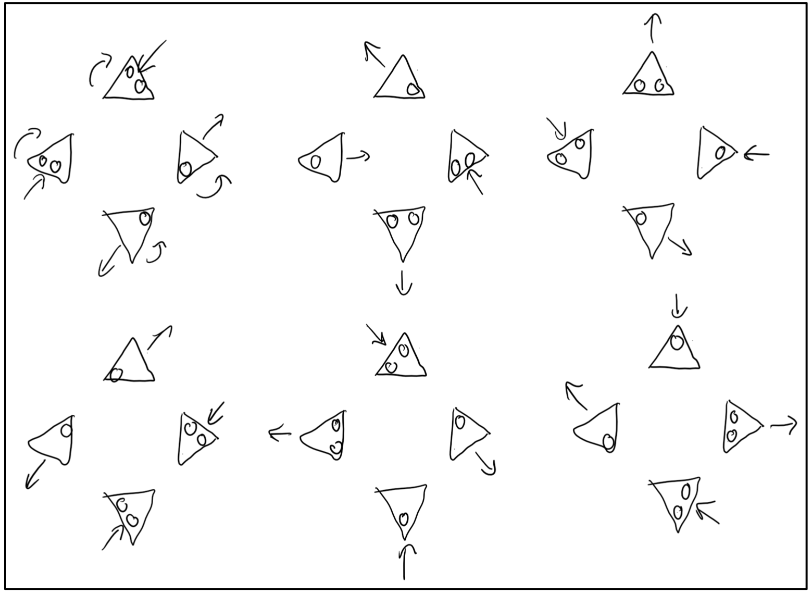
- Experimentation needed with retraction length and speed to see if legs can be printed more reliably without error

Control Implementation

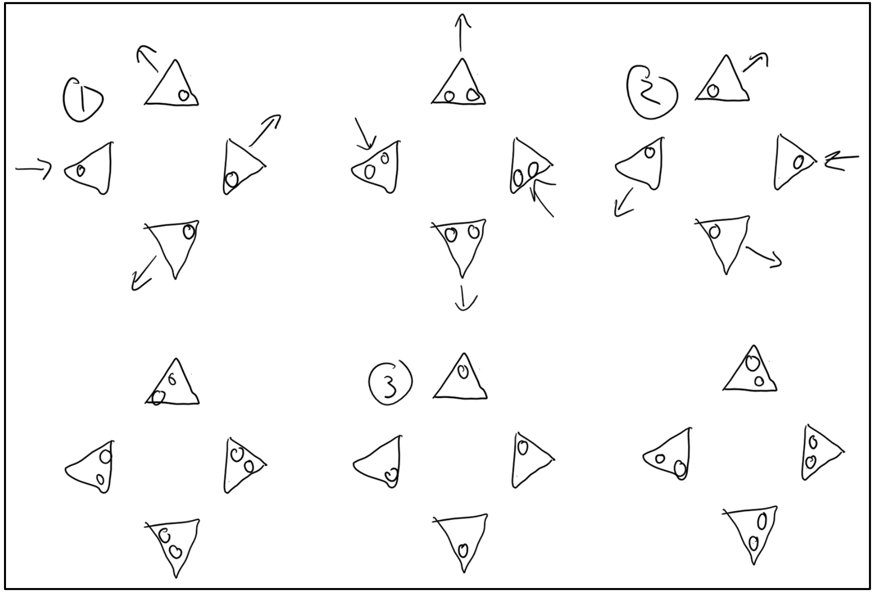
Theoretical control patterns and gaits were explored.

We found that for 3 solenoids we would have to compromise on the accuracy of the 4 legs' cycling by offsetting 2 of them to align the actuation cycle.

True Forward Gait

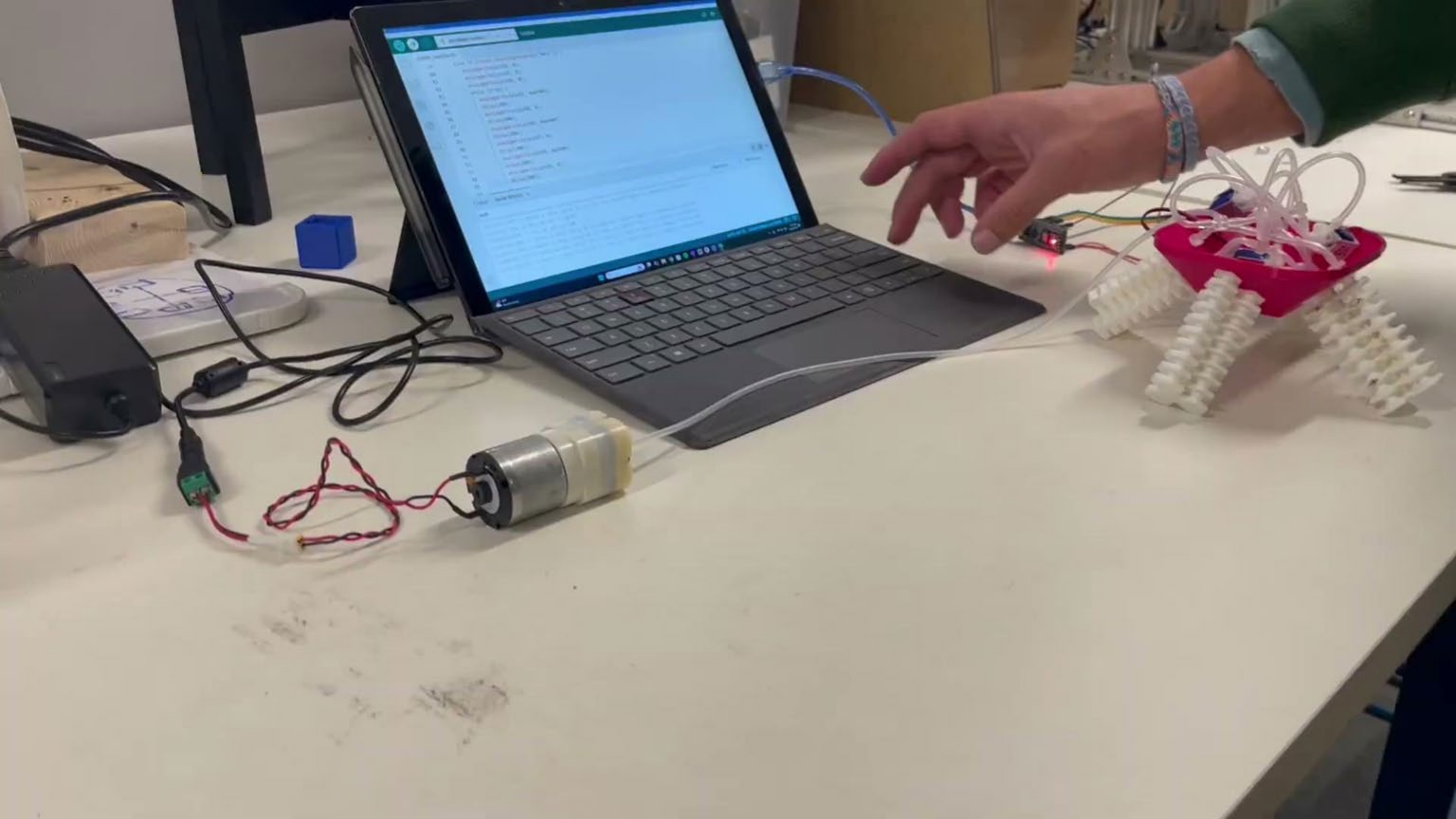


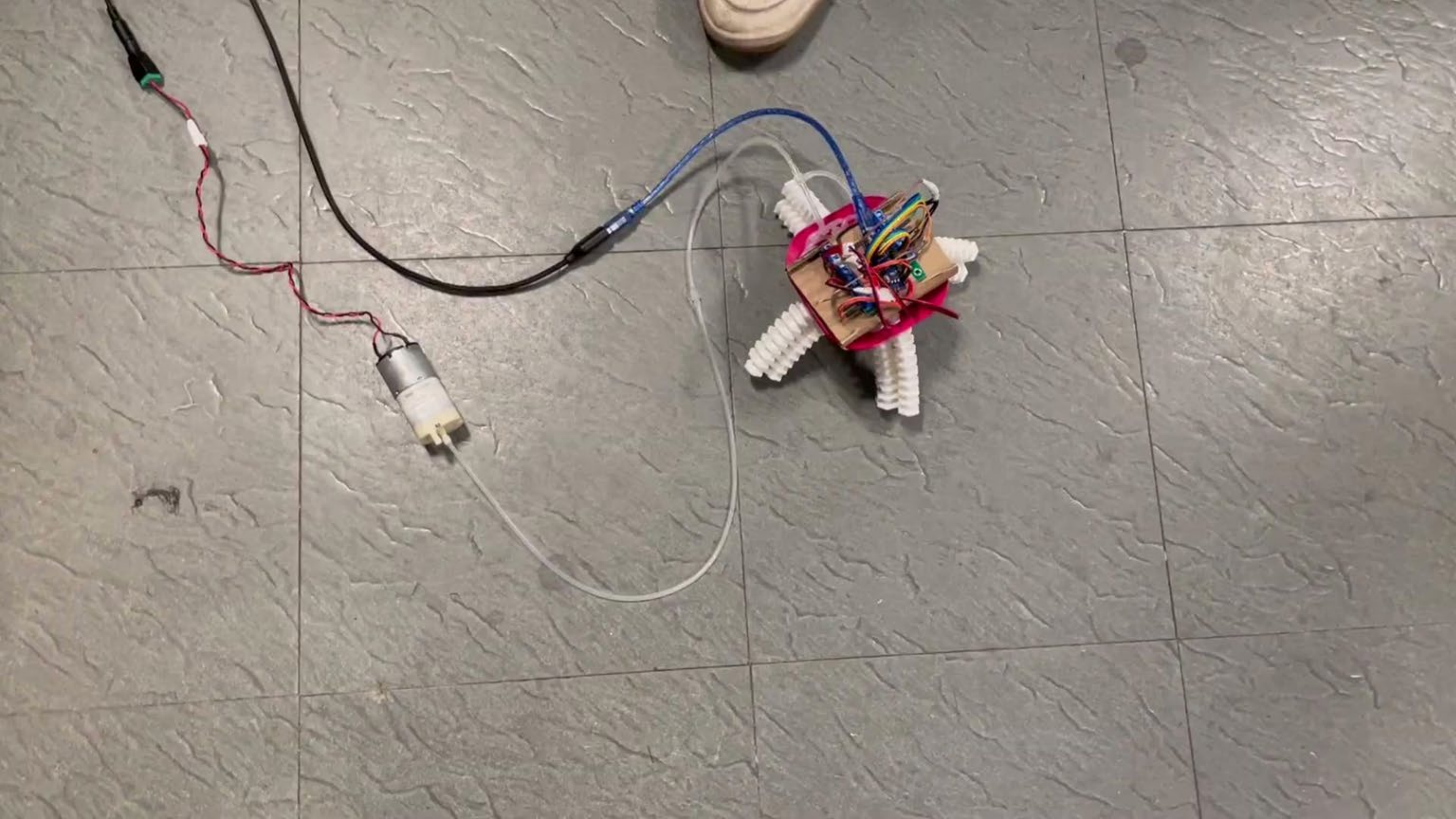
Modified Forward Gait



Key Takeaways

- Importance of prototyping and small step iteration
  - Through this project we found that prototyping our leg with different geometries and scales and physically testing them allowed us to see exactly how the leg could behave on the robot.
- Printer settings and slicing
  - We also learned how important print speed, temperature, retraction length, extrusion multiplier, infill percentage, layer height and many other parameters can play on print quality and air tightness. Additionally inspecting the traces in the slicer can provide insight on where a print might fail or errors could arise.
- Fluidic control schemes and electronics
  - This project showed us that accurate control of a fluidic system can require very complex electronics to achieve the desired movement. We decided on a 3 solenoid control system which limited our ability to create different gaits without moving pressure lines. In order to have total control of the robots movement we would need twice as many valves.





References

[1] M. Armstrong. “The Persistent Scourge of Landmines” Statista. https://www.statista.com/chart/20679/casualties-of-landmines-timeline/ (accessed Nov. 6, 2024).

[2] Drotman, D., Jadhav, S., Karimi, M., de Zonia, P., & Tolley, M. T. (2017, May). 3D printed soft actuators for a legged robot capable of navigating unstructured terrain. In *2017 IEEE international conference on robotics and automation (ICRA)* (pp. 5532-5538). IEEE.

[3] Drotman, D., Jadhav, S., Sharp, D., Chan, C., & Tolley, M. T. (2021). Electronics-free pneumatic circuits for controlling soft-legged robots. Science Robotics, 6(51):eaay2627.

[4] Looney, T. C., Savard, N. M., Teran, G. T., Milligan, A. G., Wheelock, R. I., Scalise, M., ... & Nemitz, M. P. (2022, April). Air-releasable soft robots for explosive ordnance disposal. In 2022 IEEE 5th International Conference on Soft Robotics (RoboSoft) (pp. 687-692). IEEE.

THANK YOU