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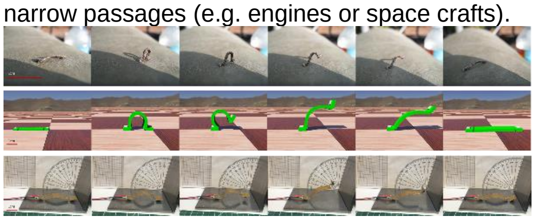
Self-assembling ferro-elastomeric soft-bodied robotic modules inspired by the Army ants self-assembling swarm

Jeremy Wanner

Professor : Alcherio Martinoli (EPFL), Radhika Nagpal (Harvard)
Assistant(s) : Faëzeh Rahbar (EPFL), Bahar Haghighat (Harvard)

Nowadays, more and more researches are going towards soft robots. They can have real advantages compared to the traditional rigid ones. Some examples can be to safely interact with human, to handle fragile objects or to adapt to their environment.

This thesis is the first step towards an envisioned swarm of autonomous small-scale soft robots that can climb on metallic surfaces, navigate into narrow spaces and work together to overcome obstacles (e.g. a gap). The inspirations of this project came from the Army ants (genus Eciton) self-assembling swarm. They are able to create 3D irregular structures by stepping over and latching onto each other's body, therefore crossing gaps that is not possible to pass alone. Here, we want to be able to imitate such swarm behavior, with soft robots that can navigate on metallic surfaces. Such system could have application for inspection of Metallic surfaces with narrow passages (e.g. engines or space crafts).



[top] Real Inchworm walking, [middle] Inchworming robot implemented in simulation (Webots), [bottom] Real inchworm robot prototype

During this thesis, a dual approach has been undertaken. It means that there was work done on both simulation and prototyping in parallel, using one to help to other. On the simulation side, due to the lack of powerful soft robot simulator, the first goal was to implement a soft body model in an open-source rigid-based robot simulator, Webots, using a mass-spring system. This was done to test different locomotion gaits for soft robot and decide the one to pursue for this project: inchworming. Then, the next step was to find a way to automatically calibrate the parameters of this soft body model to match a real soft body. It was done using a brute force search on the spring and damping constants of Webots HingeJoints.

On the prototype side, the first goal was to find the right actuation mechanism to replicate the inchworm locomotion gait, comprising three actions: latching, bending the body and foot-lifting. The bending and foot-lifting were done with three spring-shaped Shape Memory Actuator (SMA) wires mounted on a FR4/copper flex-pcb. Those SMA wires are flexible and soft when at room temperature but regain a spring shape when heated above a certain temperature. To heat those wires, a current is passed through them. Concerning the metallic latching, it was done with two Electro-Permanent Magnets (EPMs), developed in previous work[1].

Inchworm robot prototype

Then, this robot prototype was implemented in Webots and the following objectives were tried in both simulation and reality:

1) Walking on flat metallic surfaces
2) Climbing on metallic slopes
3) Transitioning between different slopes

In simulation, the robot was able to walk on flat metallic surface, to climb up to 45° slopes and to transition between slopes with up to 90° angle difference. Concerning the real prototype, it was able to walk on flat surface and to climb up to 80° slope. Unfortunately, the transitioning between slopes with the real robot could not have been shown because of a problem with the prototype at hand and lack of time to build new ones, because of the closing of laboratories due to the COVID-19. In both simulation and reality, when the robot tried to climb higher slopes than the one mentioned above, it would fall around its rear foot joint. This makes joint design one of the principal future work directions to be covered, along with an extensive analysis of spring-shape SMA wires.

[1] B. Haghighat, E. Droz, and A. Martinoli. Lily: A miniature oating robotic platform for programmable stochastic self-assembly. In 2015 IEEE International Conference on Robotics and Automation (ICRA), pages 1941{1948, May 2015.