EN4110 Mechatronics – Modular Robotic Snake

Building a modular robot in a chain-like formation that can perform several motions to make it adaptable to certain tasks and its environment

Supervisors: Ze Ji, Emmanuel Brosseau

Team members: Chian Sye Chia, Sara Djoudi, Jack Frampton, Thomas Alexander Hulse, Angelina Murphy, Nor Binti Mohd Ridzuan, Thomas Scammell and Toby Wright

Introduction

The main objective for this project was to create a modular robot that can replicate three methods of snake locomotion. By imitating these motions, snake-like robots can have numerous applications in an industrial context such as travelling over hazardous terrain for rescue missions[1] and exploring extra-terrestrial environments[2].

Types of Snake Locomotion:

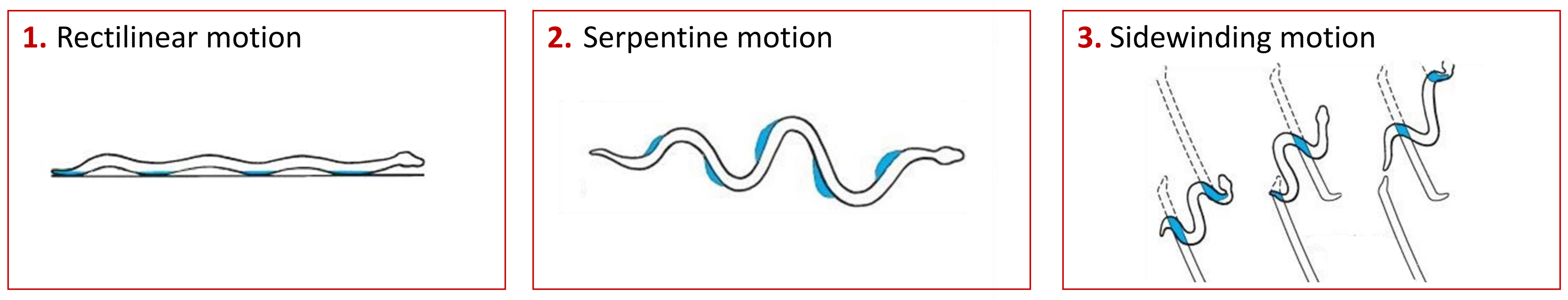

Figure 1. Methods of snake locomotion[3]

Project Aims:

1. **Design a housing**, to be 3D printed, able to contain all necessary components that can be connected in the same orientation or at 90˚ to each other.
2. **Create two prototypes** using these housings to replicate the aforementioned methods of snake locomotion:
   Prototype 1 - Linear actuators will be used to actuators to open and close scales cut into a skin wrapped around each unit to replicate rectilinear motion.
   Prototype 2 - Sinusoidal motions will propagate through the length of the robot using Dynamixel servomotors in each unit to replicate serpentine and sidewinding locomotion.
3. **One multi-functional robot:** If time permitted, it was planned to combine the two prototypes together and implement sensors with closed-loop feedback to allow the robot to detect objects and react to them accordingly.

Component Developments

Skin

The primary purpose of the skin design was to facilitate rectilinear motion through friction as is demonstrated by snakeskin scales in nature.

Features

- Made from Silicone - excellent flexibility and anti-adhesive by nature.
- Snake-scale pattern inspired by Kirigami art patterns.
- Specialised Sil-Poxy adhesive used for attachment to the housing.

Mechanism: Upon extension, embedded scales to pop out and provide anchorage to the ground. Upon contraction, the housings are propelled forwards and the skin layer becomes a flat sheet again (Figure 2 and 3).

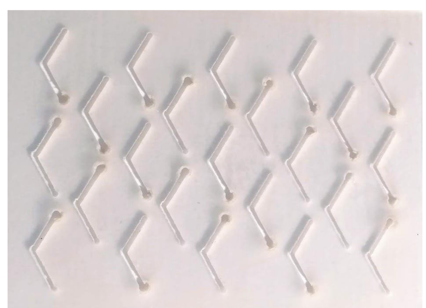

Figure 2. Silicone snakeskin layer sample

Figure 3. Demonstration of 'scale-buckling' effect when the skin layer is extended

Manufacture: SolidWorks used to design the snake scale patterns and the skin layer was then manufactured using a GlobalMAX waterjet cutting machine.

Skeleton

The role of the skeleton is to facilitate the three primary roles outlined:

Component housing

- A sliding mounting insert was designed and component layout was optimised to allow for necessary cable routing (Figure 4b).

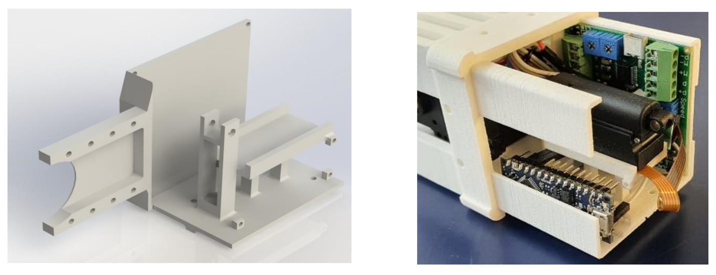

Figure 4. Component mounting insert a) Rendered CAD b) Internal components packaged

Robot motion

- The bracket was designed to allow for 180° rotation, enable unimpeded rotation on flat surfaces and provide structural rigidity under load.
- The housing is designed to slide over itself, allowing for the extension and contraction necessary for skin function.

Skin and sensor integration

- An external recess was added to accommodate the skin layer.
- At each end of the module, a region for sensor placement and skin layer bonding was implemented.
- Cable routing was incorporated to accommodate component connections.

Control, Sensors and Software

Sensors provide a closed-loop feedback (Figure 5) to detect contact with obstacles then reroute itself around the object.

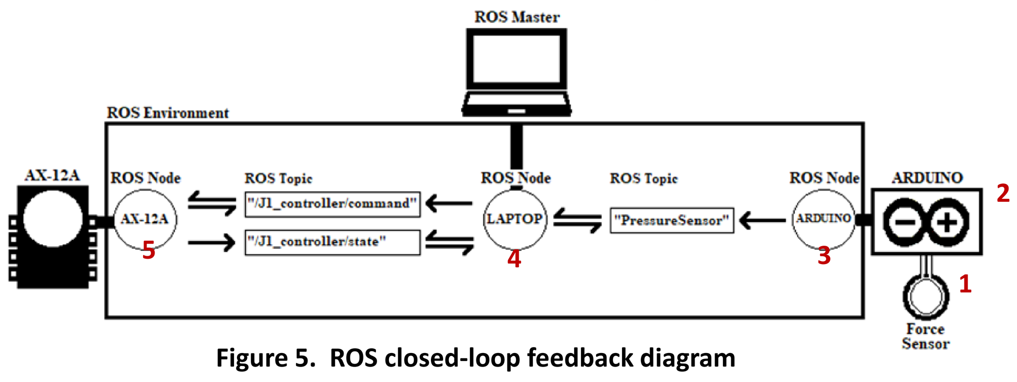

Figure 5. ROS closed-loop feedback diagram

Sensors: Changes in the resistivity of the sensors of a force applied are converted to a voltage using a voltage divider circuit.

Arduino: The micro-controller reads the voltage of the sensor and converts into a value from 1 – 1023.

Arduino ROS Node: These values are published to the Arduino ROS node 10 times per second as a digital 16-bit called "PressureSensor".

Laptop ROS Node: The values are interpreted. If deemed a collision a ROS Topic is sent to the AX-12A ROS node.

AX-12A ROS Node: The ROS Topic is received and the motors reroute the robot around the obstacle.

Prototypes - Integration

Prototype 1 – Rectilinear motion

- **Purpose:** To simulate the contracting muscles of the snake during rectilinear motion.
- **Method:** To control the movement of the scales from the skin layer using micro linear actuators (*step 1 & 2*).
- **Working Principle:** Higher friction coefficient in one direction caused by the scales protruding (*step 3*), propelling the robot forwards.
- **Methodology:** The following steps lead to the robot being propelled forwards.

Figure 6. Prototype 1 Motion Flow Chart

Prototype 2 – Serpentine and Sidewinding motion

- **Purpose:** Simulate the serpentine and sidewinding motions of a snake.
- **Method:** Coordinate movement of motors in the form of matrices, executed in Python under ROS (*step 2 & 3*).
- **Working Principle:** Motors, with alternating time-delays, follow triangle-wave motion (*step 1*) between two angular positions, lifting sections of the snake and propelling the robot in the desired direction (*step 4*).
- **Methodology:** The following steps lead to the robot performing 6 different movements, based on step 1.

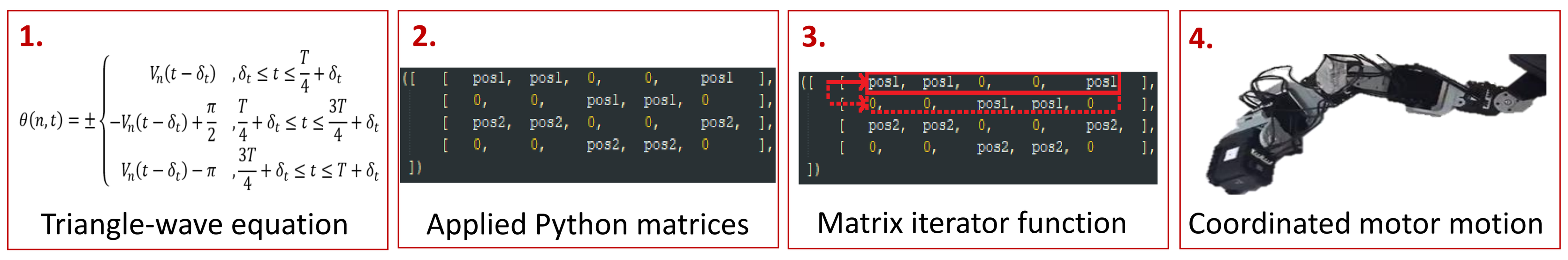

Figure 7. Prototype 2 Motion Flow Chart

Results and Discussion

Prototype 1 – Rectilinear motion

Skin design tests

1. Tension testing
Seven samples (Figure 8) uniaxially extended to select the optimal snakeskin layer; Sample 3 was chosen.

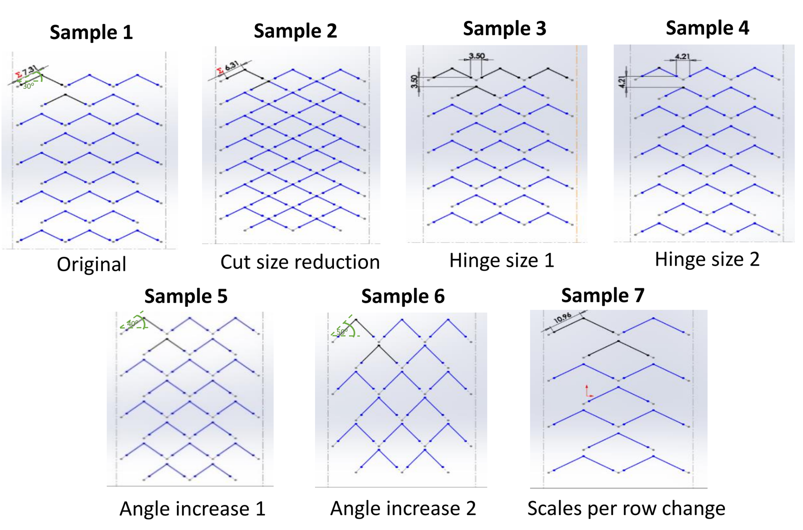

Figure 8. Snake-skin samples (height=70 mm and width=48 mm)

2. Frictional testing
To investigate the skin layer interaction with different surfaces - the skin layer travels across rough surfaces more effectively.

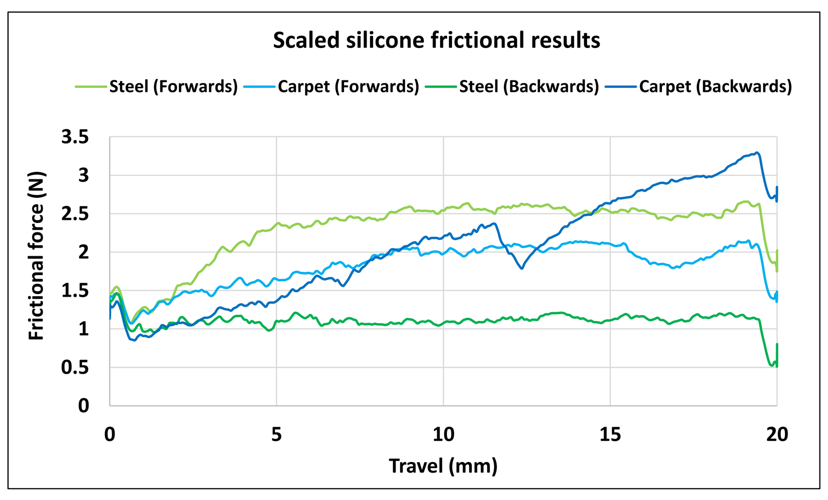

Figure 9. Frictional testing results for Snake-skin layer

Skin mechanism tests

1. Actuator retraction-extension motion - Software validated to produce in-sync actuator motion.

2. Housing retraction-extension motion - Housing assembly with actuator validated module extension and retraction.

3. Function of the scales during housing motion - Skin attachment withstood the tension force of the housing extension and the scales flattened at normal state and protruded at extension (Figures 2 and 3).

Outcome: The following tests proved that one module housing enclosed within a skin layer was capable of producing rectilinear motion and adding further modules would increase the speed of robot movement.

Prototype 2 – Serpentine and Sidewinding motion

Servo motor tests

1. 5-motors with standard motor brackets – Testing software developed for the 6 motions (Figure 10).

2. 5-motors with 3D printed SLS brackets – Assessment with increased weight and size of the modules (Figure 11).

Objectives tested: Ease of assembly, full range of motion and motion stability.

Figure 10. Stage 1: Standard brackets

Figure 11. Stage 2: SLS brackets

6 motions tested:

- Forward Serpentine
- Right Sidewinding
- Backwards Serpentine
- Clockwise Rotation
- Left Sidewinding
- Anti-clockwise Rotation

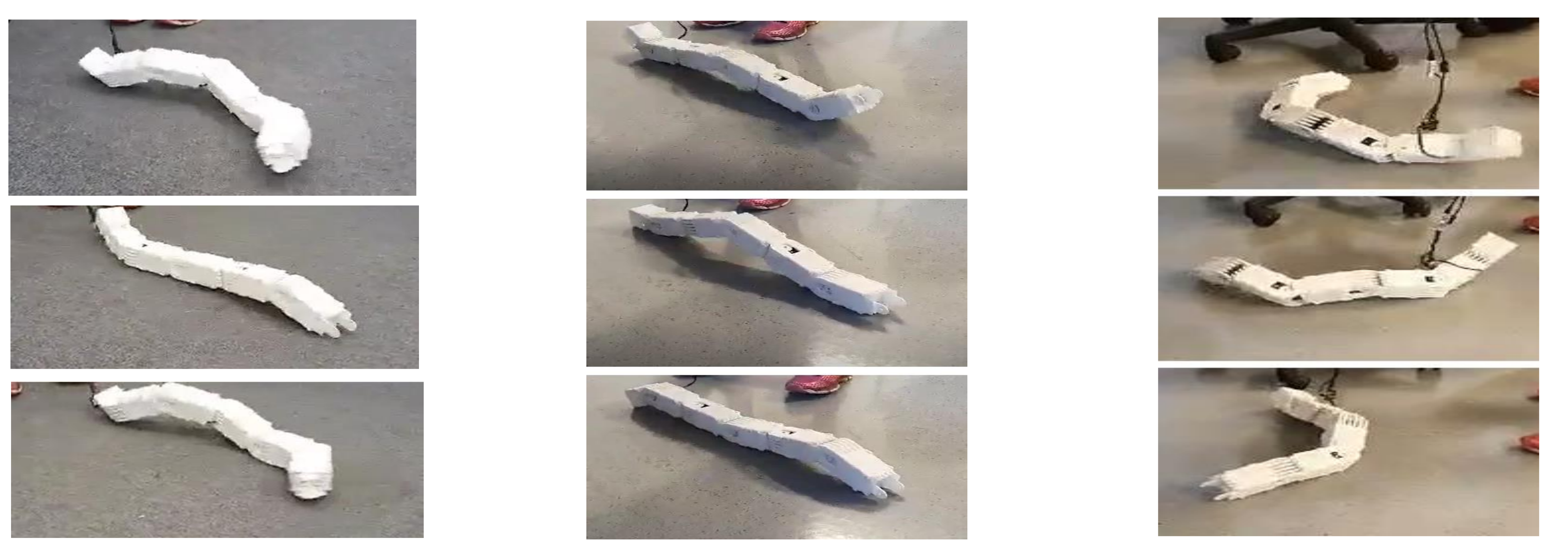

Figure 12. Stage 2 video capture motions a) Right Sidewinding b) Backwards Serpentine c) Anti-clockwise Rotation

Outcome: Both stages successful in producing robot movement: stage 1 successful in all objectives, stage 2 had minor stability issues.

Future Work and Conclusion

Prototype 1

- **Achieved:** A single module can extend/contract, propelling the module housing forwards.
- **Future steps:** Assemble more modules in a chain formation to enhance the rectilinear motion.
- **Industrial application:** The rectilinear motion enables the robot to travel through narrow, hazardous environments.

Prototype 2

- **Achieved:** Housings assembled into chain formation to perform serpentine and sidewinding motion.
- **Future steps:** Incorporating the closed feedback loop will create a smart robot can reroute itself around obstacles.
- **Industrial application:** Explore extra-terrestrial environments to retrieve critical scientific data.

References

[1]. Carnegie Mellon University, 2017. Carnegie Mellon Snake Robot used in search for Mexico Quake Survivors. [Online] Available at: https://www.cmu.edu/news/stories/archives/2017/september/snakebot-mexico.html [Accessed 18 April 2020].

[2]. Liljeback, P., Pettersen, K. Y., Stavdahl, O. & Gravdahl, J. T., 2013. Snake Robots: Modelling, Mechatronics, and Control, s.l.: Springer.

[3]. Encyclopaedia Britannica. 2020. Snake Locomotion. Available at: https://kids.britannica.com/students/assembly/view/171904 [Accessed 30th March 2020]