Designing and Optimizing Snake Robot Locomotion

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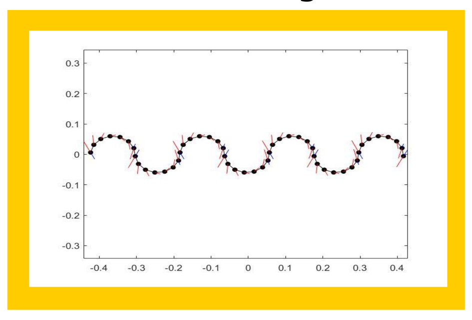
Introduction

In the field of robotics, many models use legs or wheels to get around; however, both usually rely on flat, steady surfaces in order to achieve high mobility, meaning that these types of robots struggle on narrow and cluttered terrain. From nature, we can see that a snake can conquer both kinds of terrain, which is a useful application in robot locomotion.

The goal for this project is to model the snake's intricate movement into a robot, giving it the potential to explore hard reaching places where humans cannot. The snake robot can be used to aid in search and rescue operations, exploring unknown worlds with intricate terrain, or medical/surgical uses to navigate through narrow areas of the body. Like how a biological snake can alter its gait in response to the type of terrain, the robot snake can do so as well and can be controlled by humans to achieve a desired goal.

Goals to Build a Snake Robot

Goal #1:
Build a Working Model



Goal #2:
Simulate Snake Movement

Goal #3:
Optimize Speed & Efficiency

http://clipartfan.com/free-clipart/turtle-fast-speed-clipart-71/ https://www.opuc.texas.gov/energyefficiency.html

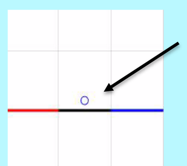
Methods to Accomplish Each Goal

Simulate Kinematics

In MATLAB, basic physics equations such as kinetic and potential energy are modeled as well as conservative and non-conservative forces of the entire system of interest.

Use Animations to…

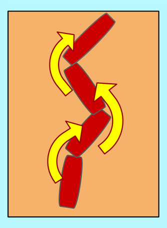
Look for errors in code to determine if the physics is correct



What to look for:
1. Center of Mass Location
2. Conservation of Angular Momentum

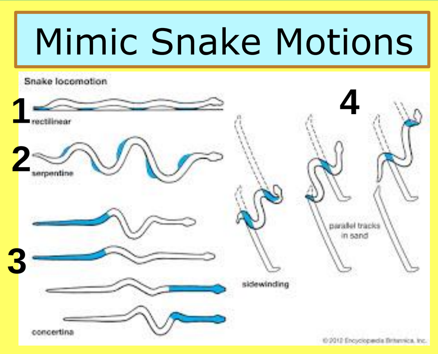
These two properties can show if the simulation physics is correct. In the example above, we can see that the center of mass location is incorrect as it should lie in the middle of the three-link segment. Once the bugs are fixed, all future simulations can be done confidentially.

Apply torque to joints



By programming the joints, we can achieve any motion the snake can physically make: ideally snake motions.

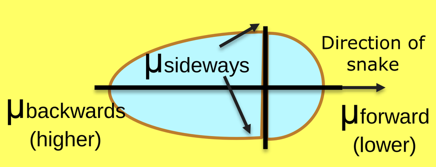
Mimic Snake Motions



In order to have the robot move like a snake, natural movements must be studied. The blue areas on the snake's body represent more pressure on the ground at those areas.

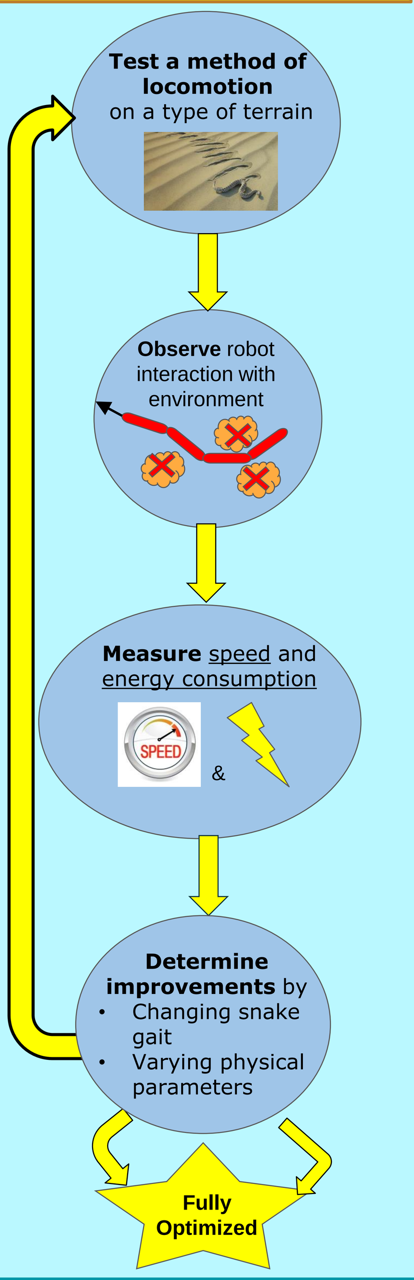
1. **Rectilinear**: The snake scrunches vertically to "inchworm" forward.
2. **Serpentine**: The traditional sine movement of a snake pushing off the curves of its body to move forward.
3. **Concertina**: The snake anchors its rear and pushes its front up, then anchors the front to pull is back up.
4. **Sidewinding**: The snake sends both a vertical and horizontal wave through the body, moving diagonally.

Asymmetrical Friction



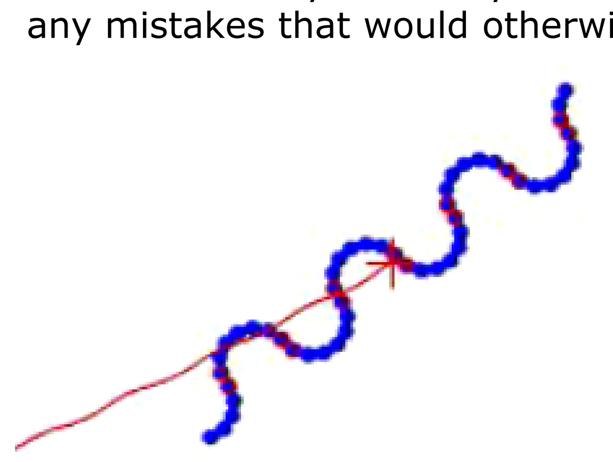
In nature, snakes have unique (ventral) scales that create more friction sliding backwards and sideways, and less so forward, which is modeled using the figure above. We can use this to further mimic how snakes move efficiently in nature.

Mimic Snake Motions

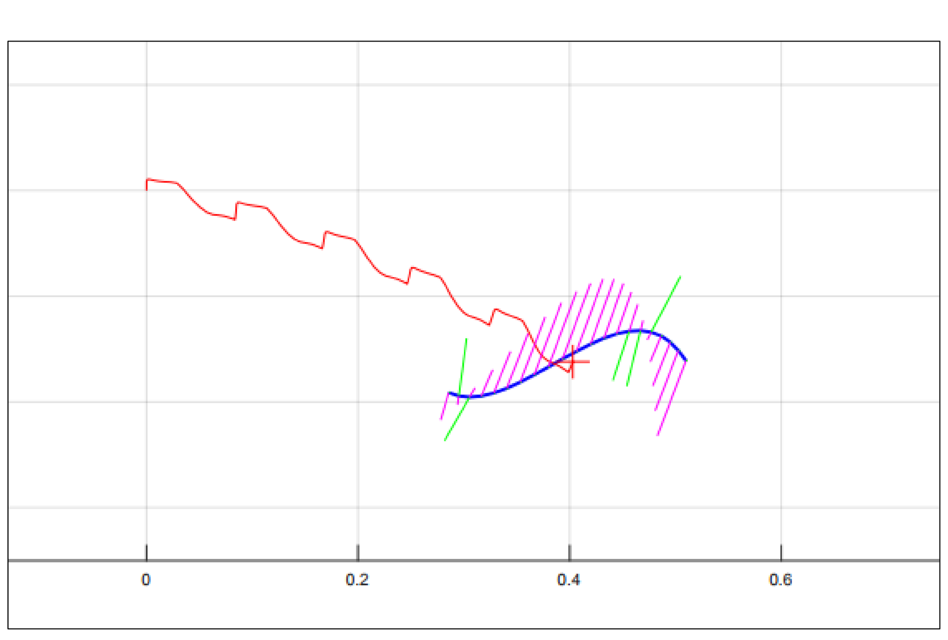


Animations: Visualizing the Model

Animations are the end product of coding physics into MATLAB and running the simulation. They allow anyone to see what is happening in the code, and to detect any mistakes that would otherwise be hidden.



On the **left**, this model uses half-circle curves and each blue dot represents a point mass of the link. The red dots indicate where the snake is touching the ground, while the blue points indicate lifted areas. The red trailing line shows the path of its center of mass.



On the **right**, this model uses a sinusoid curve to achieve movement.

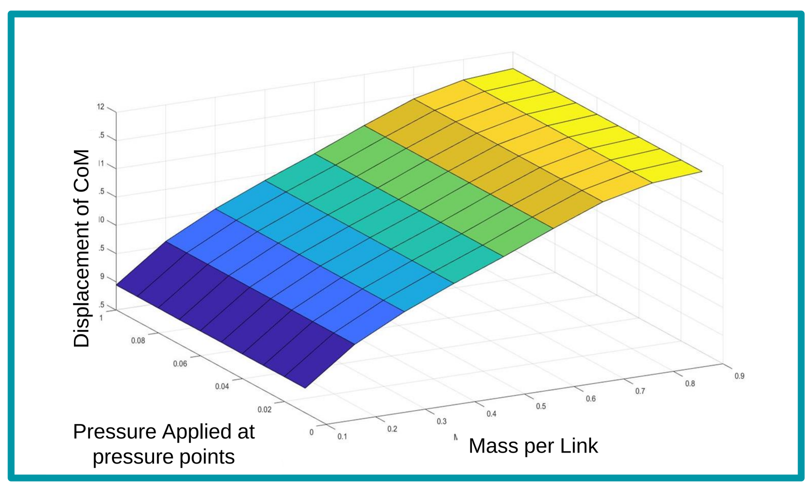
- The pink lines show the velocity vectors at each point mass
- The green lines show friction vectors, pointing in the opposite direction of velocity
- Easy to see where friction is helping the snake move

Actual animations will supplement the poster to see these models in action.

Optimization Results: Speed

Because the robot has dozens of physical parameters that can be varied, it's hard to visualize local maxima or minima in more than three dimensions. So we can choose two parameters that may or may not have an effect on each other to give a 3D surface plot where optimal points can be easily recognized. By keeping every other parameter constant, varying two parameters can show how they affect each other and show if there are significant relationships.

In these plots, the z-axis will be the displacement of the center of mass, and the x and y axes represent the changing variables. Displacement is a good indicator of speed as every simulation has the same timespan, so each maxima shows optimal speed when varying parameters. Furthermore, energy should be isolated as a factor in determining speed because inputting more power would clearly make a faster snake. What is desired is optimizing physical conditions so that less power is required to move further.

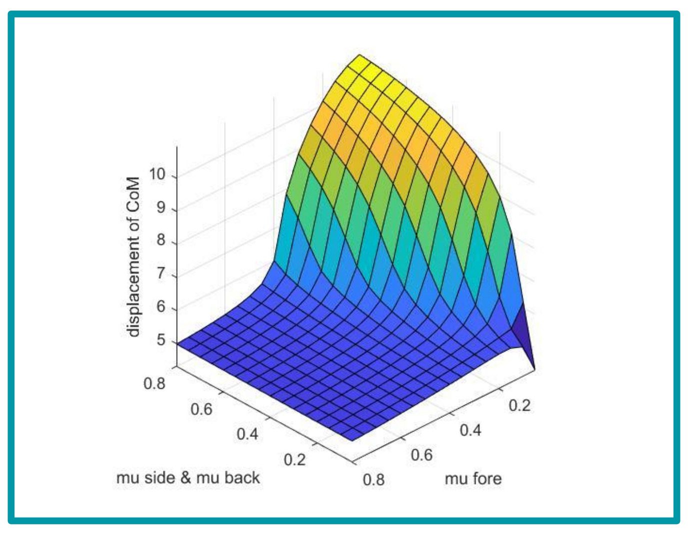


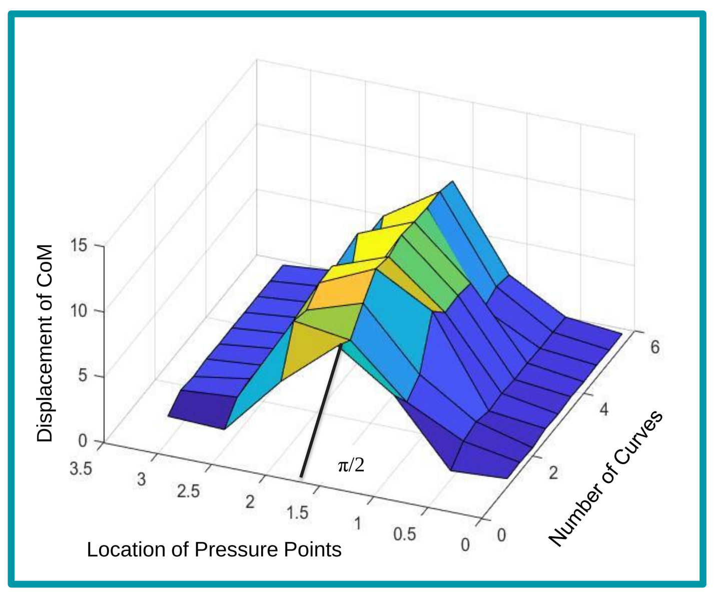
Mass per Link vs. Pressure Applied at Pressure Points

- From plot, it is shown that higher mass means higher speed
- The amount of pressure, however, does not have any effect on speed
- Although more mass per link is faster, it uses more energy to move more mass which means energy is not isolated
- Because of these last two points, these parameters are not useful in optimizing the physical properties of a snake

Friction Forward vs. Friction Backwards and Sideways

- Mu means the direction's coefficient of friction
- Can be seen that a low friction forward and higher friction backwards and sideways lead to higher speed
- Obvious since making it easier to move forward should lead to a faster snake
- Less obvious that this implies more power is needed for terrain with more friction to move at the same speed
- It is possible to change the frictional properties of the snake to lean towards the maxima point





Location of Pressure Point vs. Number of Curves on Snake

- There is a peak in speed where the location of the pressure point is about π/2
- Number of curves on snake does not affect speed
- Location at π/2 means the snake touches the ground where two opposite half-circles meet
- These parameters do not implicate more energy is needed
- Therefore, we can use these physical optimizations to make the snake faster without increasing energy consumed

Conclusions

From Animation Results:

- The physics of the system appear correct in the simulation because the Center of Mass is in the right location and angular momentum appears to be conserved
- The overall normal force of the snake remains the same when lifting parts of its body, which indicates that the friction modeling and lifting modeling is correct, as normal force relates to frictional force:

$$F_{friction} = \mu_{coeff} F_{Normal}$$

- The snake moves in a wide variety of ways depending on the physical properties (i.e. number of curves) which still needs more looking into as to why that happens

From Optimization Results:

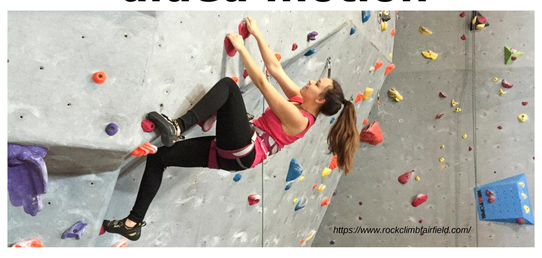
- Parameters such as mass per link can not be changed as it uses more energy to move faster
- The amount of pressure applied and number of curves has no effect on the speed, but can contribute to a different kind of movement in the snake, as seen in animations
- Having pressure points in the middle of the snake is most optimal for speed as it is in nature
- Varying friction is tricky because it is largely situation-dependent, so this should be looked more into as well

Future Improvements

Continue Optimization

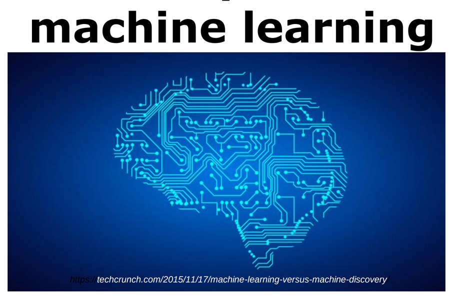
Gather results for energy efficiency optimization using a "gradient descent" method

Incorporate object aided motion



Like a rock climber, the robot can push and pull off of obstacles to aid movement

Incorporate machine learning



This allows robot to make more autonomous decisions in the absence of human command

References

R. A. Berthé, G. Westhoff, H. Bleckmann, S. N. Gorb, (2009), Surface structure and frictional properties of the skin of the Amazon tree boa *Corallus hortulanus* (Squamata, Boidae), Journal of Comparative Physiology A, March 2009, Volume 195, Issue 3, pp 311–318

Acknowledgements

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