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Modular Snake Robot - Simulation, Design, and Control

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Motivation

A snake robot consists of several long, slender links connected by motorized joints. Because these robots have many degrees of freedom, they have the potential for greater mobility than traditional wheeled vehicles [1]. By contorting its body into many different shapes, the snake robot is able to use different gaits to traverse rough terrain, climb, and tunnel through pipes.

Potential applications of snake robots are environmental monitoring and search and rescue. For search and rescue missions, the robot can be fitted with a GPS tracking device and a thermal imaging camera to look for survivors of natural disasters. Once a victim is found, their location would be sent to rescue personnel.

Project Goals

A prototype snake-robot will be built to demonstrate the capability of this type of vehicle over flat and moderate terrain. Point to point navigation is to be demonstrated with manual control and completely autonomously.

The prototype will also be designed to be modular. Modular robots are able to reconfigure themselves based on their mission. This could allow the snake-robot to be later reconfigured into a loop, worm, or other form.

Kinematic Simulation

Biologists have identified several modes of locomotion in snakes [2]. One of the simplest is lateral undulation which can be approximated by a sine wave. The motion of a snake robot consisting of *i* links connected by (*i*-*1*) revolute joints can be approximated by the formula

$$\theta_i(t) = A * \sin(\omega t + \varphi * i) + \delta$$

where the angle, θ, of each link given as a function of time, *t*. *A* represents the amplitude of oscillation, ω is the angular frequency, φ is the phase angle and δ is the turning angle.

A simulation in MATLAB of lateral undulation for a twenty link snake robot is shown in Figure 1.

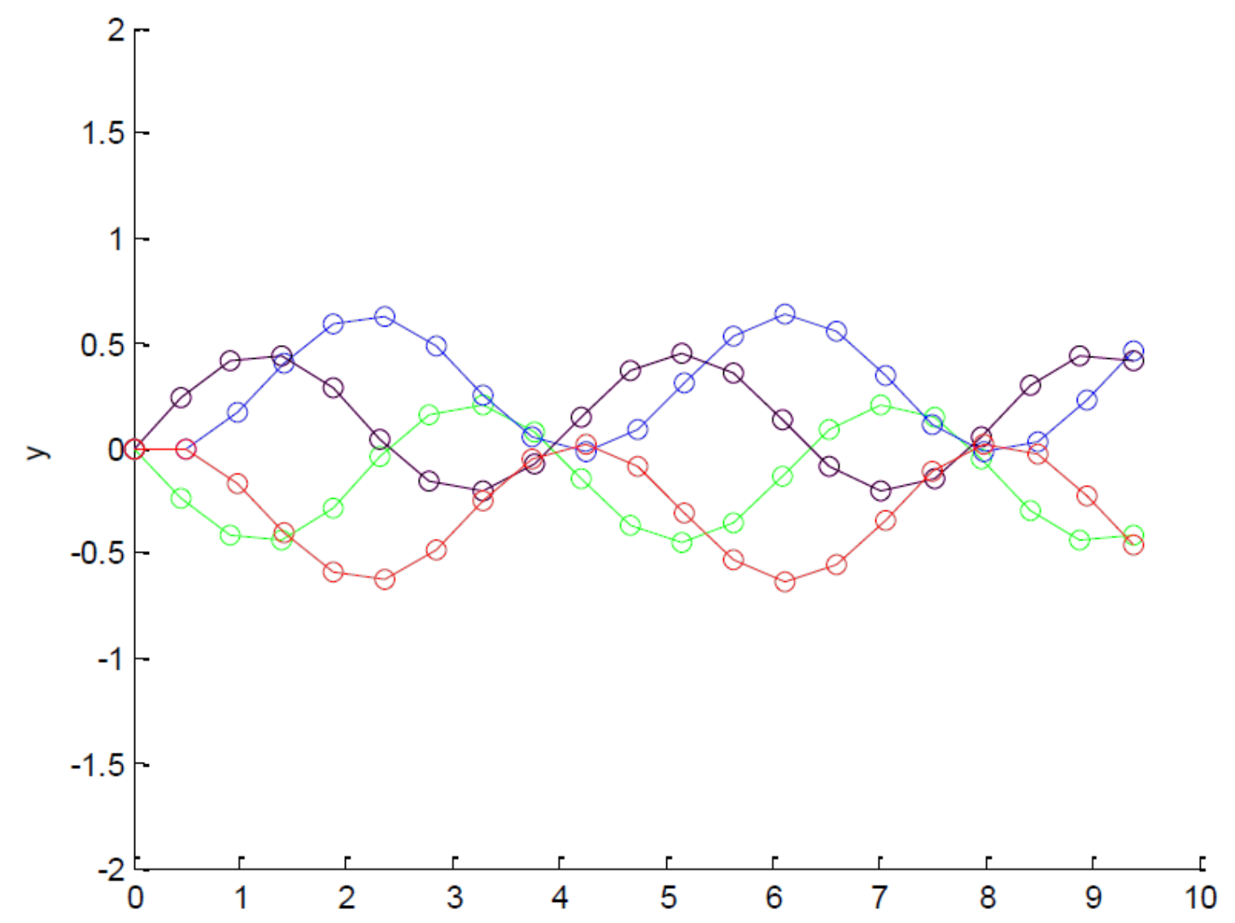

Figure 1: Kinematic simulation of 20 link snake robot

Dynamic Simulation

The kinematic analysis can be used to determine the torque required to power each revolute joint. The snake robot can be modeled in MATLAB SimMechanics as a series of links connected by revolute joints, as shown in Figure 2.

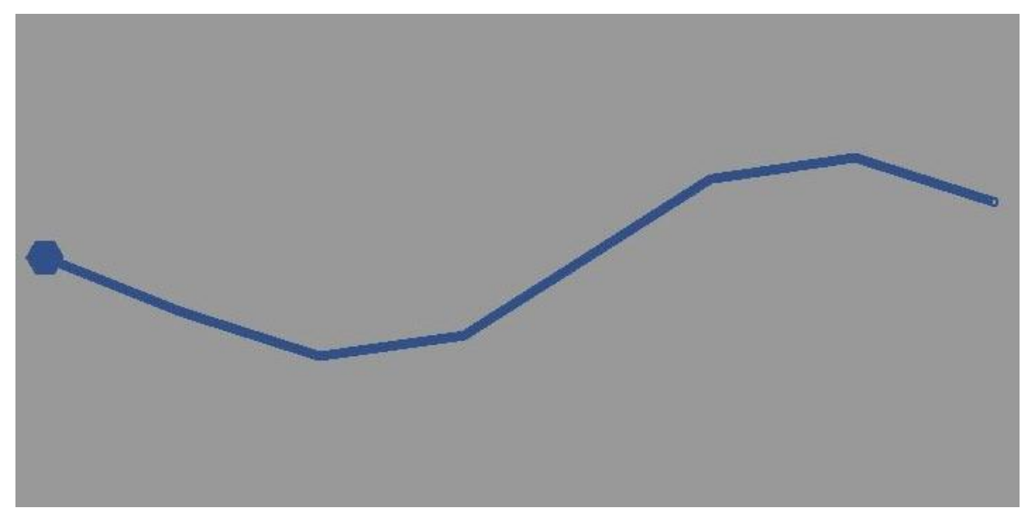

Figure 2: Dynamic model of snake robot with 10 links

By applying the kinematic motion of the snake-robot to the dynamic model, the required torque in each joint as a function of time can be solved for. First, the mass of each link and a torsional spring coefficient for each joint must be estimated. Figure 3 shows the required torque in each motor over two cycles.

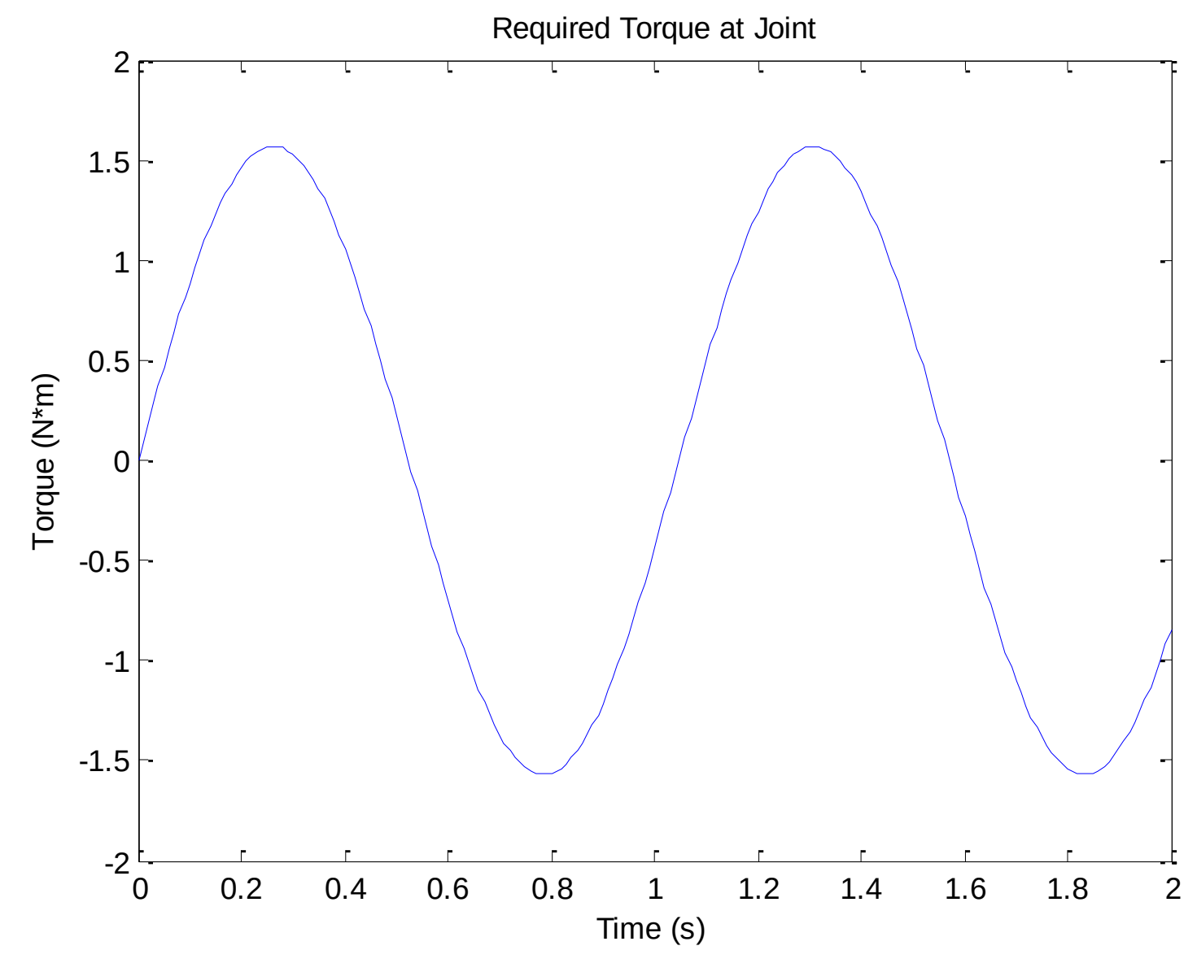

Figure 3: Required torque in revolute joint

This conservative simulation reveals that the maximum required torque is about 1.55 N*m.

Motor Sizing

After completing dynamic simulation, the robot design process can begin. Given the required torque at the revolute joints, the Dynamixel RX-24F (Figure 4) was chosen.

Figure 4: Dynamixel RX-24F servo

The RX-24F provides 2.55 N*m of torque and can be linked together in a “daisy chain,” eliminating excess wiring [3].

Structural Design

Custom links, shown in Figure 5, were designed to connect the servo motors. The snake-robot is formed by a chain of identical links connected together. Each link has four passive wheels that reduce friction in the direction of motion while increasing lateral friction, allowing for efficient propulsion by lateral undulation.

Figure 5: Structural Link

As part of the modular design, the snake-robot can be assembled with one or two axes of rotation (Figure 6).

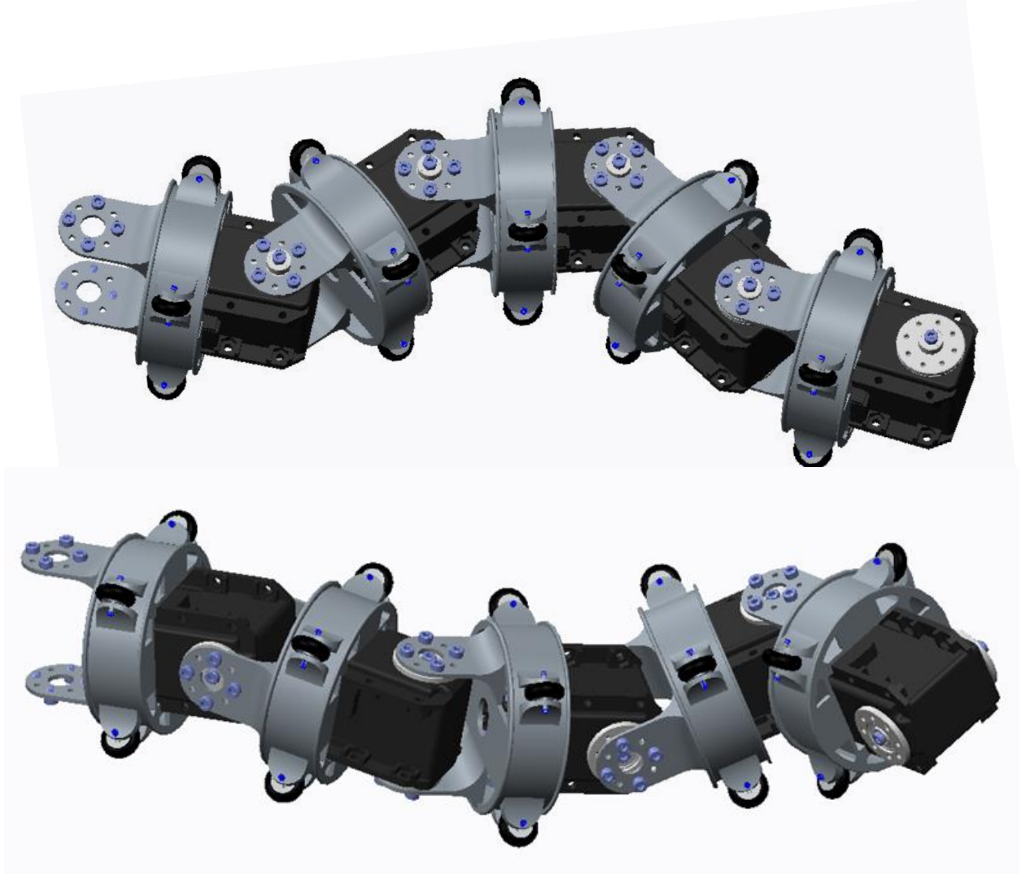

Figure 6: One axis of rotation (top) and two axes of rotation (bottom)

Construction

Each link was created using 3D-printing on the *Formlabs* Form 1 printer, shown in Figure 7.

Figure 7:*Formlabs* Form 1 3D-printer

Then, components were assembled with purchased hardware. Figure 8 shows an assembled section of the snake-robot.

Figure 8: Assembled section of snake robot

Control

Goal positions for each joint are generated in MALAB based on the kinematic analysis of lateral undulation. A simple GUI, shown in Figure 9, was developed to adjust the control formula to allow for steering.

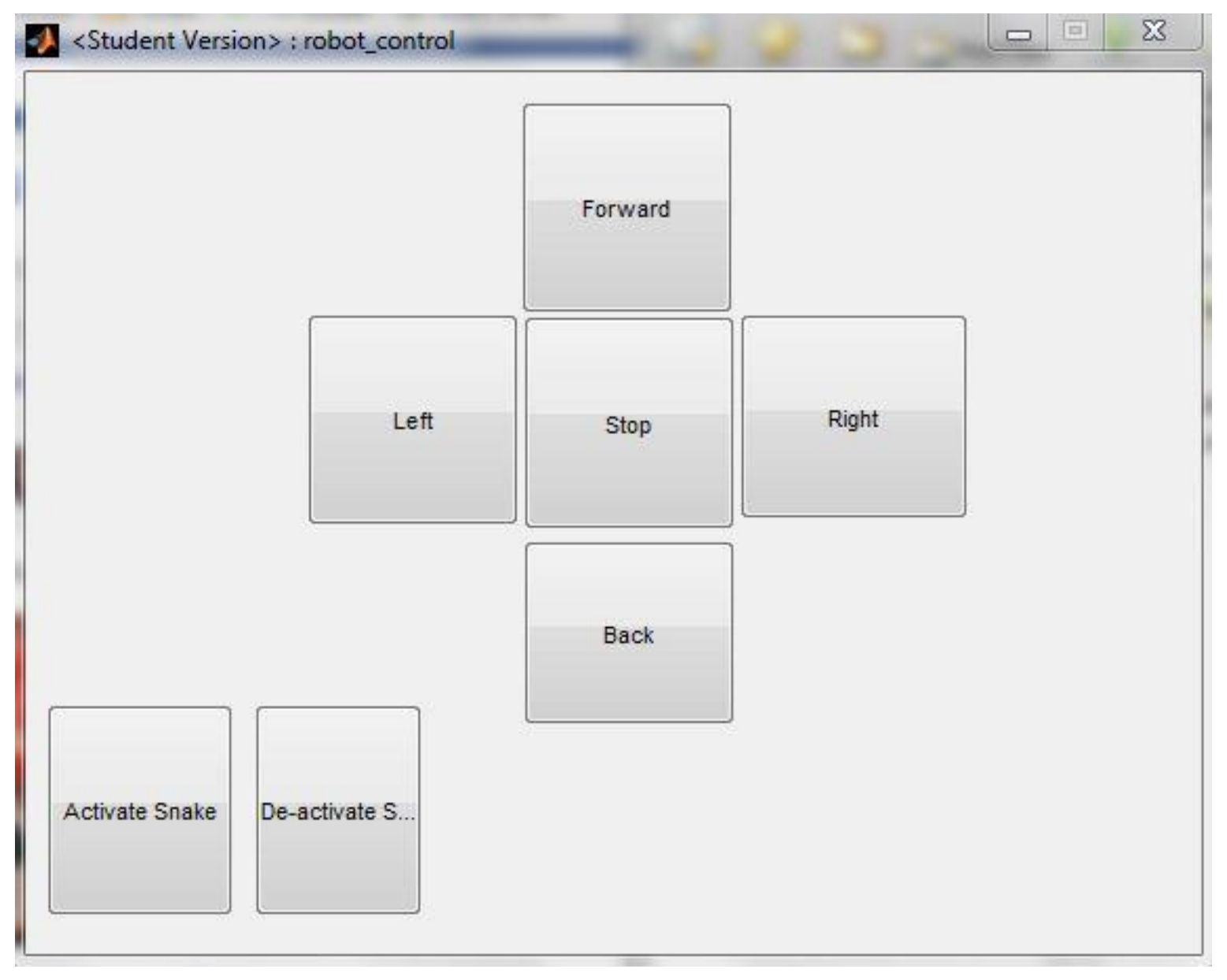

Figure 9: MATLAB GUI for robot control

Currently, the goal positions are generated in MATLAB on a laptop computer and are sent to the snake-robot via a cable. Wireless transfer of this data via RS-485 transceivers is being implemented

Future Work

Several components will be added to the snake-robot over the next month. Transceivers will allow commands to be sent to the robot wirelessly. Also, battery packs will replace the external power source. Unique head and tail structures will be designed and 3D-printed to accommodate these features.

Also, sensors will be added for autonomous control. These will include cameras and range finders in the head and tail pieces. Data from these sensors will be sent wirelessly to the laptop computer and processed in MATLAB by modified control algorithms.

Finally, additional gaits will be analyzed and programmed to allow the snake-robot to travel over moderate obstacles.

Conclusions

Thus far, manual control of a snake-like robot over a flat surface has been successfully completed. Over the next month, demonstration of autonomous control over varied terrain is likely.

References

[1] Eustis, Susan. *Snake Robots: Market Shares, Strategies, and Forecasts*, Worldwide, 2012 to 2018. *Research and Markets*, August 2013.

[2] Jayne, B.C. *Kinematics of Terrestrial Snake Locomotion*. *Copeia*, vol. 4, pp. 915-927, 1986.

[3] *RX-24F Manual*. http://support.robotis.com/.

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