ARMY RESEARCH LABORATORY

Creation of Robotic Snake to Validate Contact Modeling in Simulation

by Mark Hoppel

ARL-CR-0725 **December 2013**

prepared by

American Society for Engineering Education
1818 N. Street NW
Washington DC, 20036

under contact

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Army Research Laboratory
Aberdeen Proving Ground, MD 21005

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14. ABSTRACT
The objective of this project was to create a robotic snake that could be compared to an identical snake in a simulation program called LMS Virtual Lab. The robotic snake would then be able to confirm the effectiveness of the simulation program and would help determine the coefficient of friction in contact modeling. The snake body was roughly based on the design of the Carnegie Mellon University snake robots. It was constructed using a series of links made of polycarbonate and acrylonitrile butadiene styrene **(**PC-ABS) plastic connected by MX-28 Dynamixel motors. The links were designed so that the robot could be tracked using a VICON motion tracking system. Slots were cut into the sides of the skin so that the number of contact points with the ground could be adjusted in order to find out how many contact points were needed to create an adequate simulation. The robot was fed a tapered sine wave in order to simulate a slithering motion.

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Student Biography

I am a rising junior attending the University of Maryland, College Park, MD. I am currently working toward a Masters in Mechanical Engineering and a minor in Computer Science. I have participated in three years of the Gains in Education of Mathematics and Science (GEMS) program, two years of the Science and Engineering Apprentice Program (SEAP) at the Weapons and Materials Research Directorate (WMRD), and am completing my second year in the College Qualified Leaders (CQL) student program at the Vehicle Technology Directorate (VTD). I plan to finish my current major at University of Maryland before moving on to obtain a PHD in Mechanical Engineering and maybe a major in Computer Science. I am still trying to determine what to work on in graduate school. After graduating from college, I plan to work in a research laboratory, possibly in robotics or a robotics-related field.

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1. Introduction and Background

The goal of this project was to create a slithering snake robot based roughly off of the snake robots at Carnegie Mellon University (CMU), Pittsburg, PA, in order to test a simulation program called LMS Virtual Lab (LMS). While LMS is effective at modeling changes in a robot's center of mass, it is difficult to use it to model surface-ground contacts. For instance, LMS has limited contact types, the most robust being point-to-extruded-body contacts. This makes it difficult to model other types of contacts, such as plane contacts. Within LMS, it is better to model friction using a dynamic coefficient defined by an equation rather than a static value. Dynamic coefficients of friction need to be characterized for different materials. The snake robot is meant to address both problems. By comparing the real snake robot with the simulation, an optimal number of contact points can be discovered so that the simulation is able to model the real world. This process can also be used to test the coefficient of friction by modifying it in the program until the snake motion in the simulation matches up with the real snake robot.

Another purpose of the snake robot was to make progress toward the Army's goal of creating an "agile robot." An agile robot is one that is easily maneuverable, can adapt to changes in terrain, can avoid or overcome obstacles, and is fast. The final goal of the agile robot is to have a robot version of parkour, practitioners of which aim to move quickly and efficiently past the obstacles in their environment, using only their bodies and their surroundings to propel themselves. The snake robot is a part of this trend. Snake robots have several advantages over more traditional wheeled or legged robots. For instance, snake robots are much smaller than other robots, allowing them to fit in tight spaces and go where other robots cannot. They are also very maneuverable and feature many degrees of freedom. Snake robots have been shown to be very effective in exploring and working in otherwise unreachable areas, such as the piping of a nuclear power plant. There are many areas where cramped spaces and twisting passages make snake robots ideal for exploration. Howie Choset, a roboticist and mechanical engineer at CMU, has designed snake robots for many purposes, including search and rescue operations, plane construction, and even minimally invasive surgery. Given the potential of snake robots as highly maneuverable and dynamic robots, it would be advantageous to have one that could be experimented with.

2. Experiment and Calculations

The robotic snake constructed was based roughly on the robotic snakes designed by CMU. It consists of a series of links designed using SolidWorks CAD software joined together by MX-28 Dynamixel motors (figure 1). The diameter of the links was chosen so they would be close to the diameter of the original CMU links and still be able to contain the Dynamixel motors being used to drive the snake. After an acceptable diameter was selected, the piece was cut so that it had room to mount a motor on one side and accept a motor on the other. The two positions were offset by 90° in order to allow the snake to move in two orthogonal directions. Then the motor carriage itself was cut out, and screw holes were made so that the motor could be held in place after it was inserted. Tap holes were also added so that VICON beads could be attached to the robot, allowing it to be tracked by a VICON system.

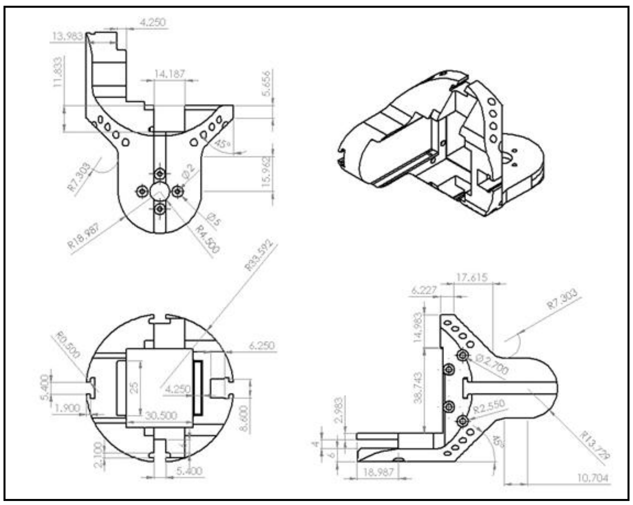

Figure 1. Snake link diagram.

Slots were added on all four sides of the skin so that inserts could be placed on the snake link. These inserts featured different numbers of bumps in order to vary the number of contact points with the ground (figure 2). Four different types of inserts were created for this purpose: one bump, two bumps, three bumps, and five bumps. The bumps were placed in two parallel rows along the sides of the inserts in order to make sure that the robot was able to balance properly. The last addition made to the snake link was another set of slots that allowed the motors to be wired without snagging on anything. After the snake link was constructed, it was placed into a SolidWorks assembly and connected to the motor. After ensuring that the two fit together properly, another SolidWorks assembly was created using the two-link subassemblies to form a twelve-link snake. When it was certain that the snake link would be satisfactory, it was printed using a FORTUS three-dimensional (3-D) printer using polycarbonate and acrylonitrile butadiene styrene (PC-ABS) plastic. After all of the pieces had been printed, the snake was assembled and driven.

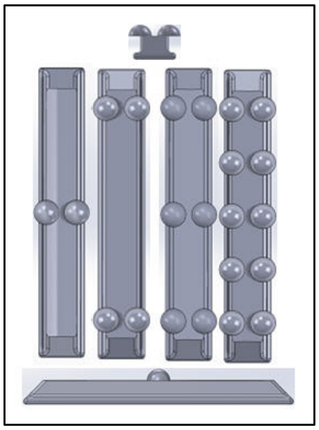

Figure 2. Inserts.

In order to drive the snake, it was fed a tapered sine wave across each of its horizontal motors (figure 3). This resulted in the snake passing a sinusoidal wave down the length of its body, propelling it forward. Each motor operates at a different amplitude, which is determined by the formula (equation 1, sine wave amplitude):

$$A = 0.4 \times \frac{Motor\ Index}{\#\ of\ motors} + 0.15 \times \frac{\pi}{2} \tag{1}$$

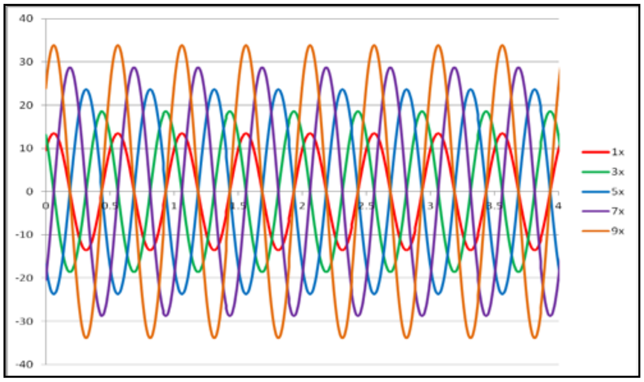

Figure 3. Tapered sine wave.

Where Motor Index goes from 0 to number of motors –1. The minimum amplitude through which the link at the "head" of the snake oscillates is arbitrary (0.15 × pi/2 radians=13.5°). The amount the sine wave amplitudes increase with each successive link toward the tail is set by the arbitrary term 0.4 radians/motor position. These values have been used to successfully drive a CMU snakebot and were thus chosen for this project.

After finding the amplitudes of the individual waves, the tapered sine wave is generated using the formula (equation 2, motor position):

$$X = A \times \sin(xPPM \times module\ \# \times 2 \times \pi + 2 \times time/period \times 2 \times \pi) \times \frac{180}{\pi} \quad (2)$$

The wave was generated and sent to the snake using LabVIEW. Several factors were varied in order to make the robot move more efficiently. These include: xPPM, the spatial period, the rate at which the motors updated themselves and the direction of the wave across the snake. There was a function to read and record the position information returning from the robot, but it was made optional after it was noticed that it slowed the update speed significantly. Several other modifications were made in order to help the robot move, such as coating the snake in duct tape in an effort to improve the coefficient of friction. Eventually, the robot was able to move under its own power.

3. Results and Discussion

While attempting to get the robot to slither properly, the gait parameters were varied and other factors changed and as a result three different types of gaits were discovered. The first effective gait to be discovered was the inchworm gait. This involves the robot crawling in an inchworm-like fashion. This gait was relatively fast and ended up making the robot travel opposite the direction it was supposed to travel; it was found when xPPM was set to 0, or 0.5xk, since the pattern of gaits repeats itself at intervals of 0.5 along xPPM. The second gait to be discovered is a “flop” gait. The first time the robot was run with the modules coated in duct tape, it was observed to be moving rather quickly forwards. However, further observation revealed that this was because the speed with which the robot was moving caused it to lift itself partway off of the ground, resulting in a gait that was half inchworm gait and half slither gait. This gait is difficult to duplicate and collect data from, due to the fact that the act of collecting data slows down the robot, making its actions choppier and preventing it from generating enough inertia to mimic the gate. The “flop” gait was found by setting xPPM to 0.125 and then doubling the amplitude. The final gait type to be discovered was the slither gait. (Refer to table 1 for gait data.)

Table 1. Gait data.

Reversed?	xPPM	Amplitude (scale)	Period (scale)	Gait	Notes
No	0.125	2	–1.3	Slither	Robot moved slowly on rubber mat. Robot appeared to be moving on carpet, but was probably just rotating. The drag caused by the cable may play a significant part in how the robot moves.
No	0.04	1	–1.3	Slither	Robot moved forwards slowly but perceptibly on carpet. Amplitude is very small. Robot is moving forward this time.
No	0.04	1	–1.2	Slither	Robot still moves forward slowly. Cord comes out the front of the robot, and the robot appears to steer towards the cord. Robot won't move much at all if cord is dragging on ground and facing behind it.
Yes	0.04	1	–1.2	Slither	Reversed robot. Cord comes out of the back now, and robot either rotates or moves sideways. Cord seems to affect robot less, although it may have made the difference between the robot rotating and translating.
No	0.01	1	1.2	Inchworm	Robot inchworms backwards. Speed is better when reversed, but that's probably because it is moving towards the cord. Robot moves opposite way of how it should, regardless of whether it is reversed or not.
No	0.12	1	1.3	Slither	Robot occasionally seems to be moving backwards very slowly.
Yes	0.35	1	–1.4	Slither	Robot slithered forward slowly but noticeably. A little faster than earlier. Works both ways. Always goes right direction.
Yes	0.35	1	–1.3	Slither	Same run as 2nd.
Yes	0.04	1	–1.3	Inchworm	

The slither gait was found by increasing xPPM to 0.14 and slowing down the robot by about 23%. Although the slither gait is not as fast as could be desired, it does move the robot forward while maintaining perfect contact with the ground. Several different slither gaits have been found, all operating at different speeds and on different surfaces. The program for operating the robot has been modified in order to make it easier to modify gaits and then record which gait works best.

4. Summary and Conclusions

Although the robot would not move very quickly under its original specifications, it was able to move when those specifications were modified a bit. Still, the maximum speed of the robot is very slow unless it reverts to one of the two other gaits. The slowness of the normal slither gait may result from a number of different factors. First, the motor to part weight ratio is much higher on this robot than on the CMU robot, which has smaller motors and is composed of heavier parts. This change in weight distribution may have affected how the robot moves. Also, the out-of-plane motors on the robot were not used, as lifting parts of the robot would change the number of contact points with the ground, and make them inconsistent. Instead, those motors were just set level. Although this allows the robot to make more of a slithering motion, it makes it different from the CMU snake robot, which makes more of a spiraling than slithering motion. Slithering motion has been achieved in LMS simulation and attempts were made to do this on the physical robot to validate the simulation. Finally, there is a strong difference in materials between this snake robot, the CMU snake robot, and actual snakes. Snakeskin is scaly. Snakeskin scales are much smoother on the front than the back. This results in a very high friction force pointing backwards, which overcomes the friction in the opposite direction. This makes slithering relatively easy, as the snake can push off of the ground in order to move forward. This robot, on the other hand, has a single coefficient of friction driving it forwards and pushing it back. Because of this, it only moves forward based on the geometry of its motion. Although this can still be done, it is much slower than normal. The CMU snake robot, meanwhile, has a rubbery skin. This allows it to grip the floor better, giving it a higher coefficient of friction. Since friction is defined discretely rather than continuously, and is much higher statically than dynamically, a higher coefficient of friction could result in a different pattern of motion than a lower one. The snake robot was coated in duct tape in an effort to mimic this, but it was not enough to entirely replicate the effect of the CMU robot's skin. Finally, there is a problem faced when comparing the LMS simulation and the robot resulting from the fact that LMS treats friction coefficients as continuous rather than discrete. While friction coefficients vary between different substances, they follow a general trend of being high when the objects remain still, and then falling once one of the objects moves away from the other. This results from the fact that stationary objects are better able to grip each other while moving objects do not have enough time to grip properly. If either surface is moving, it becomes impossible for them to grip and the coefficient of friction goes down. Even though LMS follows this to an extent, it models the coefficient of friction as continuous rather than discrete. This results in the simulation experiencing a different coefficient of friction than the actual snake, causing the simulation and the actual model to deviate further.

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