Robotic Origami Worm

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Introduction and Motivation

Applying the ancient art of origami to engineering has gained lots of attention in academia. Origami robots offer great advantages include low weight, compliance, modularity, ease of manufacturability, transportation and storage, and of course, aesthetic. In researching we design an origami worm structure using mylar.

Robot Design

Origami Structure

A common problem with previous worm designs is that their structures were not "rigidly foldable", that is, the faces of the structure need to stretch to actuate. As the origami structure is to act as a spring, non-rigid foldability may lead to undesirable nonlinear responses in the spring. The structure used in this project addresses this issue. We are calling this the Rigiscordion because of its repeating accordion like structure, and rigid foldability. The developed structure has the following advantages:

- High stiffness
- Linear stiffness
- Ability to deform omnidirectionally to allow for turning (only 1 DoF analysis were performed in this project).

Rigid Structure

The robot has 2 3D printed parts attached to its front and back ends for motor interface. To control friction, electromagnets are also installed at the bottom of each rigid structure.

Robot Controller

The robot was controlled using an Arduino Uno microprocessor located outside the robot. The Arduino used the Fermata library to communicate with other programs on our laptops. The robot receives commands from an Xbox controller, which is interpreted by the Arduino through the Game Control Plus library. Inputs given were:

- Electromagnet trigger (ON/OFF)
- DC motor pulse width modulation (PWM)

Future works

To expand the use-cases of this project, alternative means of friction control need to be investigated including:

- Suction (negative pressure)
- Expansion mechanisms and morphological techniques

A proposed example of the latter is the use of a ‘magic ball’ origami structure at the ends of the robot to produce outward radial forces on the surfaces of a pipe, thus increasing the normal force, which in turn increases friction.

The proposed magic ball design is shown in the figure below:

Experimental Measurements

The coefficients of friction of each part of the robot were measured experimentally. The values are shown in the table below.

<table>
<thead>
<tr>
<th>Body Segment</th>
<th>Static Friction</th>
<th>Kinetic Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>0.497</td>
<td>0.373</td>
</tr>
<tr>
<td>Tail (part with motor)</td>
<td>0.489</td>
<td>0.419</td>
</tr>
<tr>
<td>Body</td>
<td>0.537</td>
<td>0.322</td>
</tr>
</tbody>
</table>

Robot Kinetics

The only external force acting on the robot is friction, which controls the direction of motion. During the robot’s motion, energy is stored in the spring and then released to allow only one part of the robot (front or back) to move. The moving part is chosen based on friction, which is modulated using the electromagnet.

For this project, it was necessary to find the minimum torque required from the motor. Additionally, optimizing the compression of the spring body after each motion would likely cause the robot to move faster. To reveal this tension force from the motor as well as the spring force from the body, kinematic analysis was done by slicing the robot in half. The amount the spring can be compressed is mostly determined by the dynamics of the back half of the robot in the compression stage. Summing forces in the horizontal direction:

\[ F = T - f \mu_N \]

Thus, the maximum spring compression is:

\[ \Delta x_{\text{max}} = \frac{T}{k} \left( 1 - \mu_N \right) \]

Similarly, we could use the same kinetinetics to find how much torque we need our motor to provide. Derived from equation (1), we find:

\[ T = Nk\Delta x_{\text{max}} \left( 1 - \mu_N \right) \]

Results

The robot was tested on a horizontal table with a metal sheet on top. During testing the maximum spring compression was found to be 1.18. The speed of the robot was also recorded during numerous trials. A maximum speed of 1.07in/s was recorded. These results match closely with the kinetic analysis. Additionally, 1.07in/s is very fast compared to other worm robots in the literature.

Acknowledgment

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REFERENCES