Preliminary Study on Locomotion Performance of WaveBot on Different Surfaces Using Traveling Waves

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1 Introduction

Many inspiring works on bioinspired soft robots and their terrestrial locomotion abilities have been recently published [1]. Soft robots operating in variable surface condition demonstrate adaptation in order to overcome obstacles in unstructured terrains [1]. Invertebrates with hydrostatic skeletons show a close relation to soft robots due to their soft/adaptable body and have amazingly different principles of locomotion based on traveling waves [2] given their simplicity in design and efficiency [3]. Moreover, invertebrates like worms have higher deformation by body length [4] and demonstrate strong surface interaction to their habitable environment. Preliminary study on traveling wave locomotion has been investigated and studied based on their role of using friction [6] to different surface condition. The notable feature of this robot is its peristaltic wave-like locomotion, which can mimic locomotion pattern of traveling waves on different surfaces by exploiting the presence of setae at the ventral side of the worm to interact varying surfaces. We name this robot 'WaveBot'. WaveBot stabilizes its motion by increasing the friction to the surface and actuation period of its waves oriented towards the direction of motion. The role of anchoring is obtained by generating friction between the robot body and the environment by introducing setae-like spikes. In order to observe the effect of such waves, we tested the robot with different surface material and roughness in order to understand the behavior of the modular structure and evaluate its locomotion performance.

2 Design and Prototyping

WaveBot is a worm-like modular robot with three pneumatically actuated soft modules. The modular platform described here uses two thin discs of Plexiglas (2 mm thickness and diameter of 30 mm) as a base that keeps the actuators in position. A series of McKibben actuators (external diameter of 7 mm and length of 45 mm) have been fabricated by mounting latex balloons inside an insulating braided sleeves. These actuators are activated through a positive air pressure, which makes them to contract. The use of McKibben permits to amplify the deformation with a strong force [7]. The actuators are placed at an angle of 120° respect to each other on a circular pattern alongside the central axis (Figure 1). Due to this configuration, a symmetric contraction at the same time permits a straight shortening of the module while by a differential contraction the capability of bending in any desired direction is achievable. The terrestrial locomotion of soft robots remains a challenge, since the focus has been mainly on actuators and their control; yet, soft robot design has to consider surface interaction as one of its characteristic features (e.g., kirigami [6], worm with spike). In WaveBot the base disc of each module hosts a symmetric spiky ring with eight triangular spikes fabricated using kirigami technique by laser cutting and manual folding of a PET sheet of 0.5mm. These spikes enhance the frictional interaction of the robot with environment during the locomotion. In parallel to frictional interaction, another major factor in terrestrial locomotion is the transition period of contact between the body and its environment. This paper presents the design consideration and discusses the preliminary results of an experimental study of WaveBot locomotion on different surfaces.

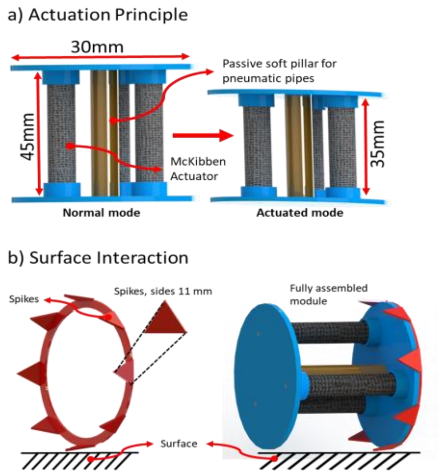

Figure 1: a) Actuation principle during initial state (normal mode) and compressed state (actuate mode). b) Spikes to enhance the friction to the interacting surface.

2.1 Control Unit

The three WaveBot modules are connected in series and actuated by electro-valves (EV) controlled by a custom electronic board. Each actuator is individually controlled and connected to a constant input pressure of 1.5 bar using an air compressor to the actuators (actuated mode) or connected to the ambient pressure (released mode). Depending on the period of actuation of the modules each of the EV's gate is turned on/off to have a better understanding of the actuator's performance by deforming under different wave patterns and the surfaces.

3 Experiments and Results

We tested the robot under different actuation frequency (100 ms, 300 ms and 500 ms) and surface properties. As reported in Table 1 (below), these tests were performed on a wide range of surfaces (mainly abrasive sheets) with different surface roughness’s and patterns. The surface roughness of each substrate was measured using ZEISS SURFCOM 130A mobile surface measuring instrument. The modules were actuated following a linear sequence from the anterior end to the posterior end of WaveBot (green boxes in Figure 2) and the direction of locomotion is opposite to the direction of the wave. As depicted in Figure 3, the robot demonstrated different locomotion performance by varying both actuation period and surface properties. During the experiments, we underwent visual analysis which showed that the design of spikes in anchoring to variable surfaces increases the frictional forces to enhance the locomotion. The speed of the WaveBot was calculated based on distance travelled by the robot to the time recorded. In general, we observed a better locomotion performance when the surface roughness was increased. In the other hand, we recorded a faster velocity in the case of faster actuation period. As a result, the robot had the best performance in P40 substrate with the highest roughness of Ra = 29.2μm under all sequence of actuation. The locomotion speed in this condition was decreased with increase in time sequence of 100, 300 and 500 ms between the modules from 0.8 cm/s to 0.6 cm/s as shown in Figure 3. Likewise, the same for other roughness materials used as a locomotion and surfaces corresponding to their sequence of actuation. The experiment in tubular environment also demonstrated the importance of environment type to the performance of locomotion. During the experiments on flat terrain, just two spikes of each module interact with the surface. At the same time when crawling inside the tube all the spikes on the WaveBot interact with the tube wall and provide a high frictional force for assisting forward locomotion by preventing sliding backward motion. Inside the tube, the robot succeeded to move faster in comparison to flat terrain Plexiglas with similar roughness and even faster than abrasive paper P1200 which had a roughness higher than the tube (Refer table 1 for surface roughness).

Table 1: Surface roughness of the terrain used for experiments

Surface Roughness	Surface Material						
	Plexiglas	PET (tube)	P1200	P180	P80	P40	Mesh
R_a (μm)	0.023	0.177	5.589	18.473	25.688	29.298	2mm *2mm
R_z (μm)	0.384	1.545	33.023	94.305	112.100	119.192	

*P1200, P180, P80, P40 are abrasive (sand paper) sheet.

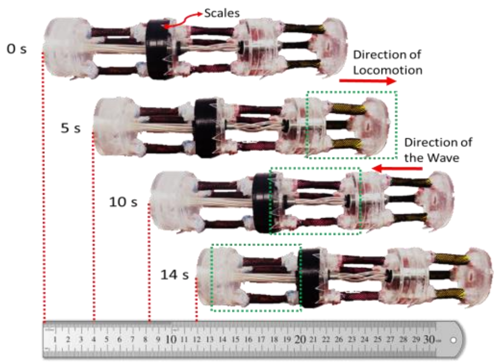

Figure 2: Strategic locomotion modes of modular robot (WaveBot). A series of frames captured from video is shown with three actuator modules. (Here we show a sample sequence of 100 ms)

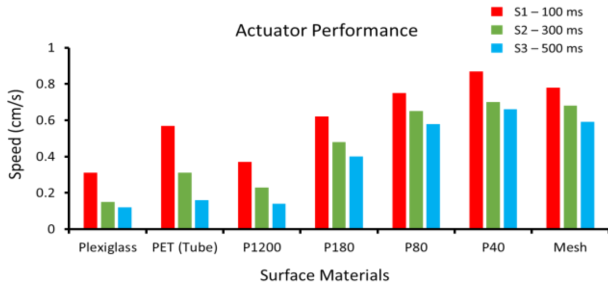

Figure 3: Actuator performance by different actuation sequence under varying surface roughness

4 Conclusions

We designed and developed a simple, fast, and modular robotic platform to explore new approaches in bioinspired soft robots, especially for the traveling wave locomotion. The individual modules can be independently controlled to have a different sequence of actuation with different traveling wave patterns. Considering the surface features as a design approach motivated us to understand the role of friction between the interacting surface and spikes (in earthworm biology setae plays the role of spikes). These are initial studies to explore the advantages and limitations of considering frictional interaction as an approach for soft robots in complex environments.

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