אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev

לשכת המהנדסים
האדריכלים והאקדמאים
במקצועות הטכנולוגיים
בישראל
AEAi

The 35th Israeli Conference on Mechanical Engineering – ICME 2018
Beer-Sheva, 9-10 October 2018

Wave Robotic Locomotion in Compliant Tube-Like Surfaces

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1 Abstract

This research presents the design, manufacturing and analysis of a miniature wave-producing robot named SAW – a Single Actuator Wave robot, which is destined to be used as a self-propelled probe of the intestines, for medical diagnostic inside the digestive system. We present the mechanical design of the miniature robot, its structure and main components, as well as experimental synthetic tube-like compliant surfaces, which we created to test the robot. We performed multiple experiments both inside flexible tubes and in pig's intestines, which proved the capability of the robot to advance inside these challenging environments.

Keywords: Wave robot, Wave locomotion, Medical robot, Endoscopy, Compliant surfaces.

2 Introduction

The recent technological advances in the fields of electronics and imaging have led the way to creating revolutionary miniature medical equipment, including robotic devices capable of performing minimally invasive procedures. One of the most revolutionary devices is the PillCam [1], which is a capsule camera that films the digestive system as it moves using the peristaltic motion of the intestines. As such, it requires on average 8 hours to film the small intestine. Still, while the pill records a video along its voyage, it lacks the ability to stop for further inspection or to indicate the whereabouts of interesting findings. Many researchers engaged in creating miniature medical robotic devices capable of crawling inside the body [2], [3], but none of these devices has reached the operational stage.

The single actuator wave robot (SAW), which is the subject of this work, is designed as an untethered device, which can crawl inside the intestines while controlled by a doctor in real time. The control of the locomotion will allow substantially faster procedures, the ability to stop at a desired location for further inspection and to locate the position of interest by finding the robot itself (using ultrasound for example).

3 Contribution

Robotic device: The mechanical design of SAW (see Zarrouk et al. [4]) is simple and based on a rotating helix and a series of links attached using R joints (Figure 1). The robot is actuated using a DC motor, which rotates the helix, and the links attached in series produce the advancing wave motion during the actuation of the robot. The length of the robot is 58 mm, its maximum width is 15 mm and it weighs only 3.4 g including the motor.

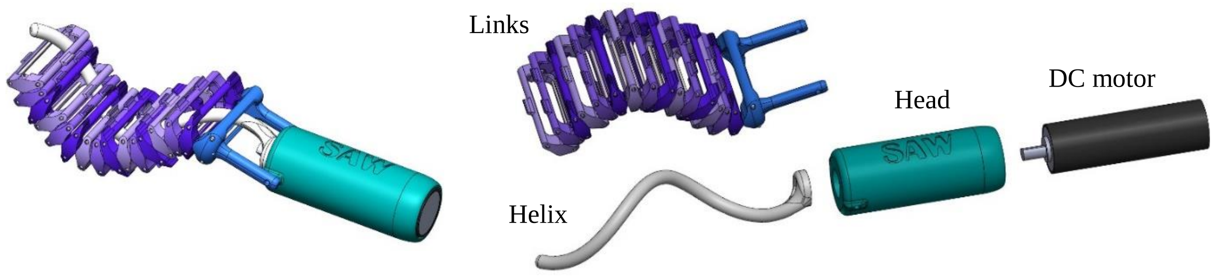

Figure 1: Left – the assembled robot. Right - components of the robot.

The mechanical parts of the experimental prototype are all 3D printed using an Objet350 Connex3 3D printer, with VeroWhitePlus printing material (polymer).

Synthetic surfaces: Along the research, we developed experimental synthetic surfaces using DragonSkin silicone rubber. We designed multiple molds to cast silicone tubes that have a diameter of 15 mm and wall thicknesses of 1 and 2 mm (Figure 2).

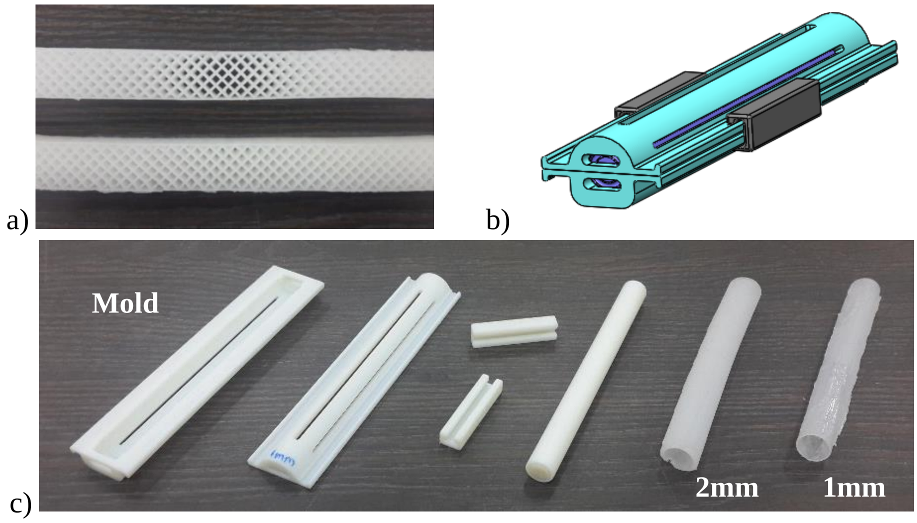

Figure 2: a) Flexible surfaces with a mesh structure. b) 3D design of the mold. c) The mold and the casted silicone tubes

Experimental results: We performed several experiments with the robot crawling between two compliant synthetic surfaces and inside synthetic compliant tubes (see Figure 3). The robot crawled at a maximum speed of 20.4 mm/sec and successfully advanced in curved systems (Figure 3b).

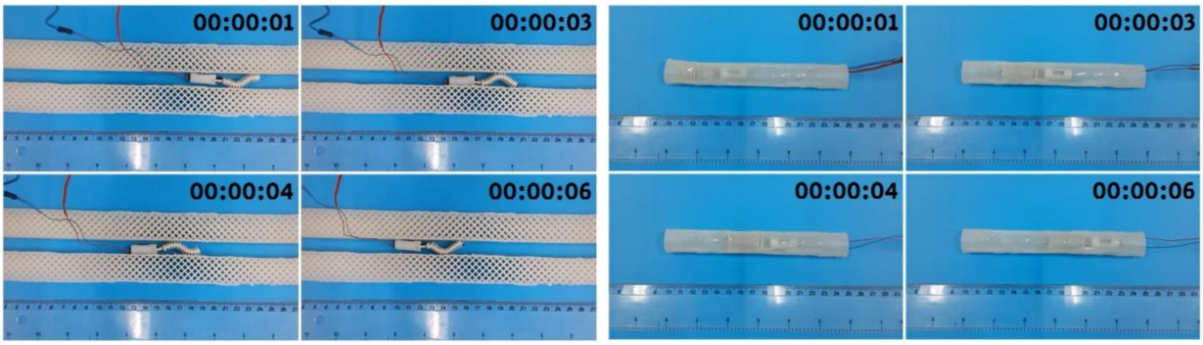

Figure 3a: Experiments between flexible surfaces (left) and a flexible tube (right).

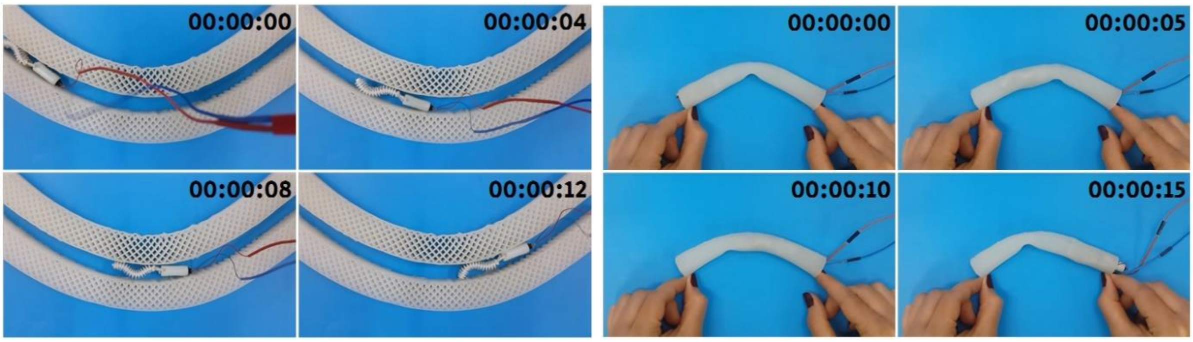

Figure 3b: Experiments with curved surfaces (left) and in a curved tube (right).

We additionally performed experiments in pig's intestines to check the ability of the robot to advance in a more realistic scenario in which the surfaces are extremely flexible and slippery (see Figure 4). The robot successfully advanced at a speed of 3.4 mm/sec.

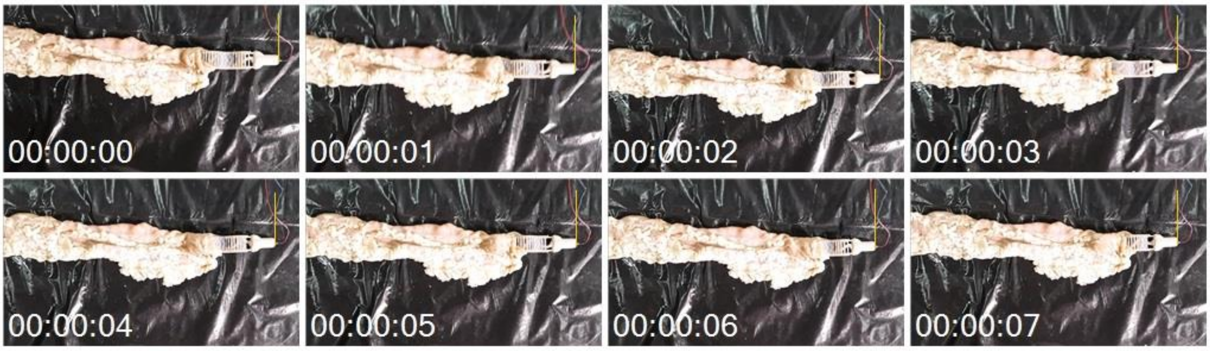

Figure 4: Experiment in a pig's intestine.

4 Conclusions

We presented the innovative design of a medical device producing a wave motion that enables it to advance in a compliant environment. The robot's mechanism is simple and shrinkable, allowing the miniaturization and adaptation of the robot to be used inside intestines. We have shown the successful results of multiple experiments of the robot's motion, crawling with maximum velocity of 20.4 mm/sec.

5 References

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