Wireless force sensing of a micro-robot penetrating a viscoelastic solid

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Abstract. The penetration of biological soft tissues is an essential prerequisite for micro-robots to perform useful biomedical tasks, such as targeted drug delivery and minimally-invasive surgery. However, most wirelessly-driven micro-robots do not exert large enough force to penetrate solid tissues. It is therefore important to understand the fundamental mechanics of tissue fracture at micro-scale to facilitate the optimization of micro-robots. Here, we report the force sensing and modelling of a magnetic micro-robot in a viscoelastic solid. The robot is actuated by a homogeneous magnetic field gradient and its dynamics are analyzed to calculate the resistive forces in a phantom gel. Multiple shapes and surface topology of the micro-robots are compared to identify an optimized design for soft tissue penetration.

Introduction

Micro-robots show great potential for minimally-invasive medicine. Many efforts have been made to power and actuate them, for example, by a magnetic field [1], an ultrasonic field [2], or a light field [3]. The magnetic field is one of the most promising power source for biomedical applications, as the magnetic field is safe for humans and offers a large penetration depth and a higher actuation force comparing to the other fields. As the device gets smaller, the magnetic driving force scales with the volume of the device, but the resistive forces scale with only the surface area. Therefore, it becomes even more difficult for micro-/nano-devices to exert high enough forces to penetrate biological soft tissues. In this work, we report a wireless force sensing system based on magnetic micro-robots. With the new system, the dynamics of the robots moving in viscoelastic phantom gels are measured and modelled.

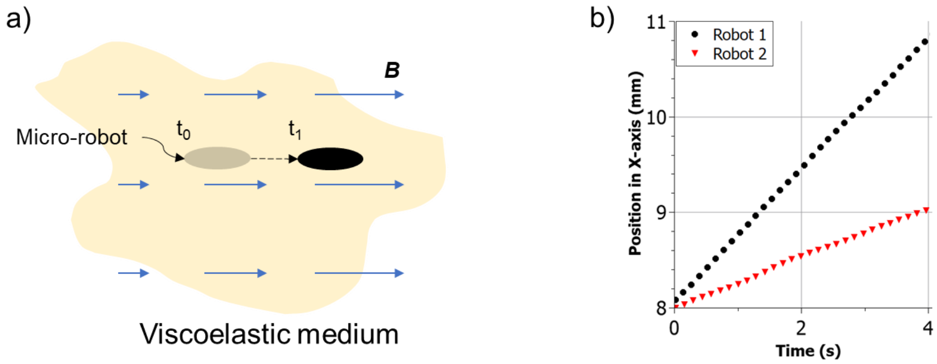

Figure 1: a) Schematic of a micro-robot moving in a viscoelastic medium. The robot's motion is captured while it is actuated by a homogeneous magnetic gradient. b) The displacement curves of two robot designs.

Results and discussion

Experimental results show that the customized system generates a controllable homogeneous magnetic field gradient. A micro-robot moves through a transparent viscoelastic medium actuated by the magnetic gradient, as shown in Figure 1a. The displacement curves of different micro-robots' designs are shown in Figure 1b. The optimization of the robot's shape and surface increases the velocity of 20 %. Moreover, air bubbles were observed that were left on the path of the micro-robot, indicating the fracture of the viscoelastic solid. Future study lies in the modelling of the gel mechanics and optimizing the interaction between the robot and the gel to facilitate an effective penetration with a low actuation force. Furthermore, we expect the experimental results contribute to the understanding of nonlinear fracture mechanisms.

References

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