Numerical investigation of a piezoelectric wrinkled film-based vibration sensor for the vibro-impact capsule robot

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Abstract. Monitoring the velocity of the vibro-impact capsule robot [1] during the gastrointestinal endoscopic procedure can enhance diagnosis' controllability and accuracy. To understand the movement of such a robot in the small intestine, a piezoelectric wrinkled film-based vibration sensor is proposed to attach to the outer shell of the capsule. Based on the energy method [2], the mathematical model of this sensor is established. Taking the hoop pressure of the small intestine into account, by utilising the extended Lagrangian principle, the equations of motion of the capsule and the sensor are derived. The effects of the capsule-intestine dynamics on the amplitude of the wrinkled structure are discussed. Findings of this study can be used as the guidelines for sensor fabrication and testing.

Introduction

Pill-sized capsule endoscopes are swallowable for non-invasive diagnosis of the small intestine [3], which is an anatomical site previously considered inaccessible to clinicians due to its small diameter and length. Measuring the physical parameters of the small intestine (e.g., intestine's rigidity) is a key to diagnose potential lesions and determine their locations in the small intestine. Another issue of the capsule endoscopy is the lack of active locomotion [1]. Current endoscopic capsules are passive devices and their locomotion relies on the natural peristalsis of the small intestine, which may lead the risk of missing visualisations at the places of interest of clinicians. To avoid these two problems, a piezoelectric (PZT) wrinkled film-based vibration sensor which can be attached to the outer shell of the vibro-impact capsule robot [1] was studied. A wavy configuration of thin films of PZT on a pre-strained polydimethylsiloxane (PDMS) was conceived, which can make the PZT structure more stretchable by changing its wave amplitudes and wavelengths [2]. A recent study showed that the buckled regions of the structure may enhance the piezoelectric response. Hence, it is essential to investigate the dynamics of this wrinkled structure for predicting the mechanical parameters of the small intestine and the velocity of the capsule robot.

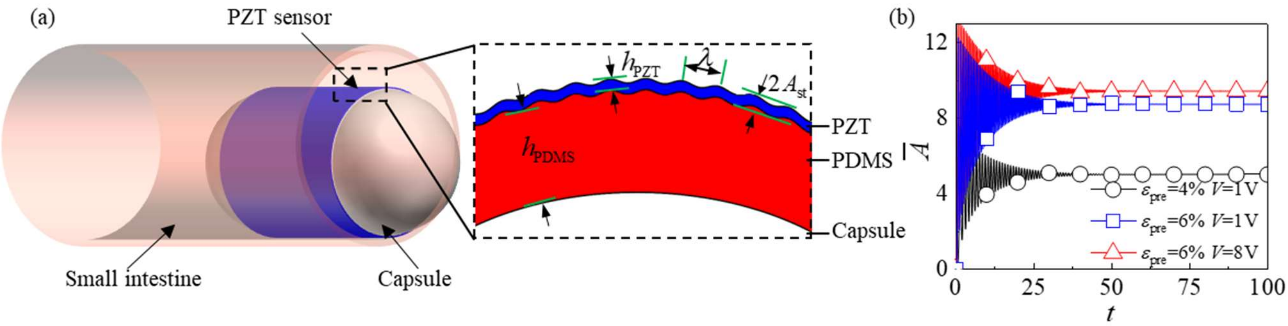

Figure 1: (a) Schematic diagram of the vibro-impact capsule robot in the small intestine; (b) Effects of various pre-strains and applied voltages on the dimensionless time histories of dimensionless displacement $\bar{A}$ of the PZT wrinkled structure. This structure vibrates around the static dimensionless buckling amplitude A_{st}, and the large pre-stain ε_{pre} or applied voltage V enhances the static dimensionless buckling amplitude of this structure.

Results and discussions

Fig. 1(b) illustrates the dimensionless time histories of the PZT wrinkled structure at different pre-strains and applied voltages. The velocity of the capsule robot was set at 4 mm/s. It can be observed that the motion of the wrinkled structure is non-periodic, and the structure vibrates around the static buckling amplitude. As time progresses, the vibration magnitude decreases to the static buckling amplitude. It is also noted that the greater the pre-strain, the greater the amplitude of static buckling. In addition, the applied voltage of the PZT wrinkled structure has a significant influence on the dynamics of this structure. As the applied voltage increases, the static buckling amplitude becomes greater.

References

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