Locomotion of a vibro-impact capsule robot for colon examination: Multibody dynamics simulation and experimental verification

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Abstract. To study the locomotion of a vibro-impact capsule robot self-propelling in the large intestine for colonoscopy, this work concerns the dynamic modelling of capsule-colon interaction by using three-dimensional (3D) multibody dynamics (MBD) simulation. The anatomy of the colon, in particular the haustral fold, was considered to test the performance of the robot for self-propulsion. Preliminary results suggest that at sharp turns or when encountering high haustral folds, the capsule may slow down, and different control parameters, e.g., frequency of the external excitation, should be applied.

Introduction

Conventional colonoscopy, a very common procedure for colorectal cancer diagnosis, often results in insertion-related anxiety, pain, and nonadherence, necessitating local anesthesia for patients. Capsule endoscopy, as an alternative technique, provides a wireless, minimally invasive, sedation-free, patient-friendly and safe diagnostic modality [1]. However, due to its passive nature and uncontrollable progression speed by intestinal peristalsis, the procedure of capsule endoscopy is time-consuming and cumbersome for both the patients and clinicians. Our team, the Exeter Small-Scale Robotics Lab at the University of Exeter, has developed a controllable capsule by using the vibro-impact self-propulsion technique [2] to address these difficulties. Our previous work [3] mainly focused on the small intestine. In this work, we investigate the locomotion of the self-propelled capsule in the large intestine via MBD simulation using MSC Adams. In order to depict the entire large intestine, rectum, sigmoid colon, descending colon, transverse colon, ascending colon and cecum were modelled with haustral folds. The model of the colon was assumed to be inflated, which is a key treatment during colonoscopy, so the capsule will only be in contact with the lower surface of the intestine. The model was simplified as a half symmetric model with an underneath supporting base as shown in Figure 1(a). The capsule, with a diameter of 19 mm and a length of 47.6 mm, moved in the large intestine with a wall thickness of 3 mm. The capsule was driven by an external square-wave excitation, and its amplitude, frequency and duty cycle were adjustable. By using the proposed Adams model, one can obtain the capsule's displacement, moving speed, resistance force and contact pressure between the capsule and the large intestine, which can be used for prototype design and control strategy optimisation.

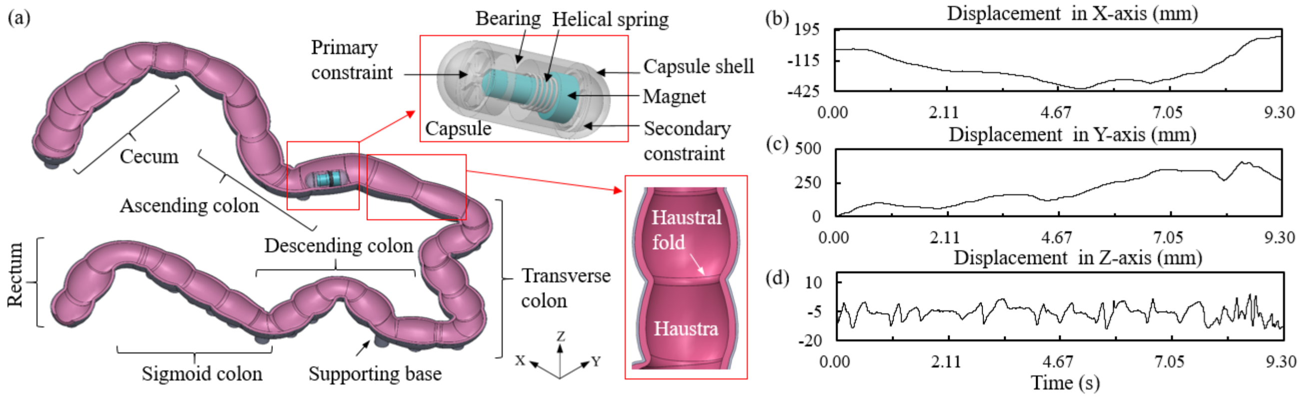

Figure 1: (a) Geometric model of the vibro-impact capsule moving in the large intestine, where the on-board magnet in the capsule interacts with a helical spring and concomitantly impacts with a primary and a secondary constraints under the square-wave excitation from an external magnetic field; time histories of the capsule displacement in the direction of (b) X-axis, (c) Y-axis and (d) Z-axis at the excitation amplitude of 0.2 N, frequency of 30 Hz and duty cycle of 0.8.

Results and Discussion

The preliminary results presented in Figures 1(b) and (c) show that the capsule's displacement changed when encountering the curved sections of the large intestine. The capsule fluctuated up and down along the Z-axis as shown in Figure 1(d) due to the haustral effect. The total moving duration of the capsule from the rectum to the cecum was 9.3 s. More studies will be carried out by considering the effect of different dimensions and geometries of the large intestine based on the gender and age of the patients on the locomotion of the capsule.

References

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