Development of a Vibro-Impact Self-Propelled Capsule in Millimetre Scale

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Abstract. This paper studies the development of the vibro-impact capsule prototype in millimetre scale for small-bowel endoscopy, which is controlled via external magnetic field using the pulse-width-modulation signal. Identification procedure of physical parameters of the prototype is introduced and compared with analytical predictions. Preliminary experimental investigation of the prototype by changing the frequency, magnitude and duty cycle of the driving signal is presented to show the capability of the prototype moving at different progression speeds in forward and backward directions in a controllable manner.

Introduction

In this work, the development of a standard-sized vibro-impact capsule prototype (26 mm in length and 11 mm in diameter) for small-bowel endoscopy is presented. The driving principle of the prototype was inspired by the non-smooth dynamical system using the vibro-impact self-propulsion method studied in [1]. Conceptual model of the capsule is presented in Figure 1(a), and its prototype is shown in Figure 1(b), where the rectilinear motion of the capsule is generated using a periodically driven permanent magnet interacting with the capsule's main body as a hammer via the primary and the secondary constraints.

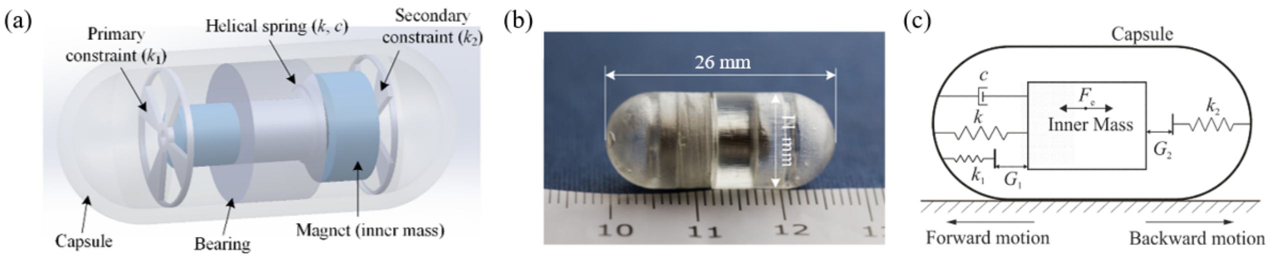

Figure 1: (a) Conceptual design, (b) 3D-printed prototype, and (c) physical model of the vibro-impact self-propelled capsule.

A mathematical model showing an inner vibrational mass M_m, a total capsule mass M_c, a helical spring with the stiffness k and the damping ratio c, two constraints' stiffness k_1 and k_2, is presented in Figure 1(c). Other identified parameters include the friction coefficient between the capsule and the synthetic intestine μ, the gaps between the inner mass and two constraints G_1 and G_2, the magnetic driving force F_e, and the duty cycle of the external excitation D. All the parameters were measured and used in both numerical simulation and experiment.

Results and Discussion

Schematics of the experimental setup and its photograph are shown in Figure 2(a) and (b), respectively, where the coils were controlled by a drive circuit triggered by a pulse-width modulation (PWM) signal. A video camera was used to record the locomotion of the capsule, and the recorded video clips were analysed by using Tracker [2], a real-time tracking software for visualizing the time histories of capsule's displacement as illustrated in Figure 2(c) and (d).

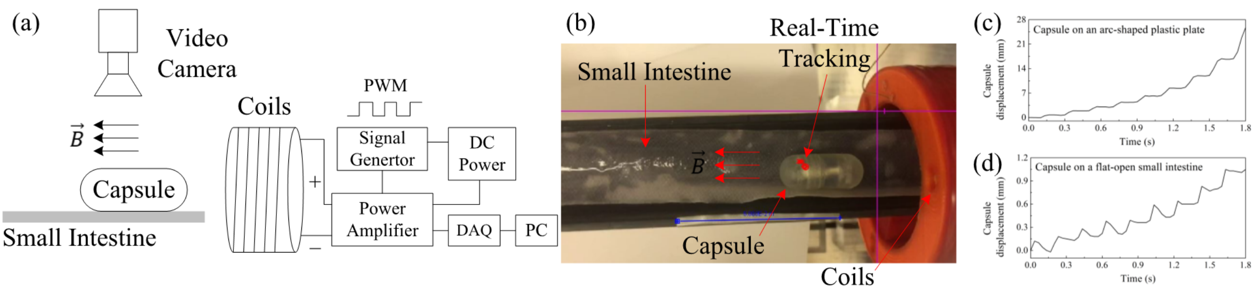

Figure 2: (a) Schematics and (b) photograph of the experimental setup. Time histories of capsule's displacement (c) on an arc-shaped plastic plate and (d) on a flat-open small intestine.

References

[1] Liu Y, Pavlovskaia E, and Wiercigroch M. 2015 Experimental verification of the vibro-impact capsule model, *Nonlinear Dynamics*, 83, 1029–1041.

[2] Tracker, website https://physlets.org/tracker/