Optimisation Verification for a Millimetre-Scale Vibro-Impact Capsule System

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Abstract. A self-propelled capsule endoscope moving inside patient's gut is a promising means of minimising patient's painful investigation and improve the diagnostic efficiency. This paper presents the study of a millimetre-scale capsule prototype that can be propelled by external magnetic field via vibration and impact, from both mathematical modelling and experiment, showing a high progression speed up to 5.3 mm/s. Good agreement between numerical simulation and experimental investigation demonstrates the feasibility of the proposed driving method for small-bowel capsule endoscopy.

Introduction

Inspired from inchworm's locomotion, the rectilinear motion of the system can be obtained through overcoming external resistance using a periodically driven internal mass interacting with the main body of the capsule [1]. To demonstrate this principle, a capsule prototype was implemented at the standard dimension of the marking-leading capsule endoscope [2], which is 26 mm in length and 11 mm in diameter as shown in Figure 1(a).

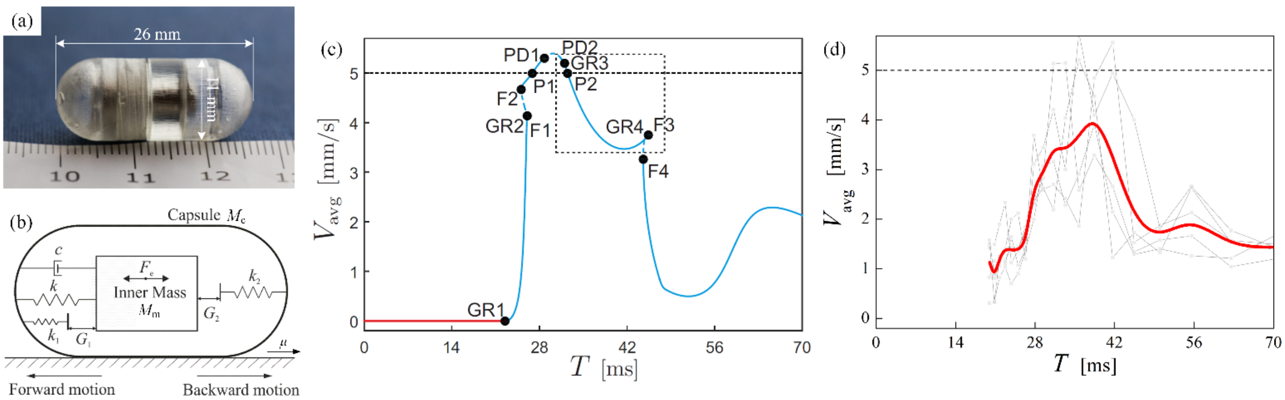

Figure 1: (a) Photograph and (b) physical model of the capsule prototype. (c) Numerical continuation of the periodic response of the prototype: the average speed of the prototype V_{avg} with respect to the excitation period T, computed for M_m = 1.8 g, M_c = 1.67 g, μ = 0.23, G_1 = 1.6 mm, G_2 = 0 mm, k = 0.062 kN/m, k_1 = 27.9 kN/m, k_2 = 53.5 kN/m, c = 0.0156 Ns/m, with the duty cycle D = 0.8 and the amplitude of excitation F_e = 6.8 mN [3]. (d) Experimental results: red line shows the averaged progression speed with respect to the excitation period T, and grey dot-lines indicate each individual test.

Results and Discussion

By using nonsmooth multibody dynamics [4], mathematical modelling of the prototype shown in Figure 1(b) was carried out for speed and propulsive force optimisation. Our analysis presented in Figure 1(c) shows that the prototype can achieve a high progression speed up to 5.3 mm/s while avoiding the collision between the inner mass and the capsule, which could reduce the propulsive force on the capsule, hence minimising the possibility of any harm to the patient [5]. Finally, experimental results are provided in Figure 1(d) to validate the efficiency of the proposed model as well as the feasibility of the technique for the potential of a 'live' and controllable small-bowel endoscopy.

References

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