Parameter identification of a vibro-impact capsule robot through optimisation

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Abstract. When studying the non-smooth dynamics of a vibro-impact capsule robot, parameter identification of an equivalent theoretical model is of practical significance. However, for such a small-sized robot, the direct measurement of its inner forces, such as the damping force between mass-capsule interaction, will be very difficult, leading to challenges in model parameter identification. Based on the partial information obtained from the robot, this paper presents parameter identification analyses for the vibro-impact capsule robot by defining a trajectory-tracking problem and solving it via optimisation. To ensure the robustness of the identified parameters, three independent cases subjected to different excitation parameters are integrated and solved together. By using the simulated annealing algorithm, the values of damping, spring stiffness, constraint stiffness and intestinal friction coefficient can be identified. Finally, the simulated capsule trajectories in all cases have good agreements with the known data.

Introduction

The strongly nonlinear systems involving impact and friction can be widely found in many engineering applications, e.g., self-propelled locomotion robots, percussive drilling systems and rotor/stator rubbing systems. The nonlinear dynamics of such non-smooth systems, including oscillation patterns and bifurcations, should be thoroughly studied to uncover their underlying instability mechanisms. For example, Guo et al. [1] experimentally studied a vibro-impact self-propelled capsule in mesoscale and revealed some hidden dynamics of the prototype by identifying a theoretical model. The vibro-impact capsule robot, a potential solution for the next-generation active capsule endoscopy shown in Fig. 1(a), is a non-smooth dynamical system driven by its internal vibration and impact in a rectilinear manner in the presence of environmental resistance. From a practical point of view, identifying an equivalent theoretical model of such a robot is vital. However, the direct measurement of its inner forces (e.g., mass-capsule damping force) will be very difficult due to its dimension. Thus, it is very challenging to identify the robot's theoretical model by using only partially known information. This work will study the parameter identification of the vibro-impact capsule robot by defining a trajectory-tracking problem and solving it through optimisation.

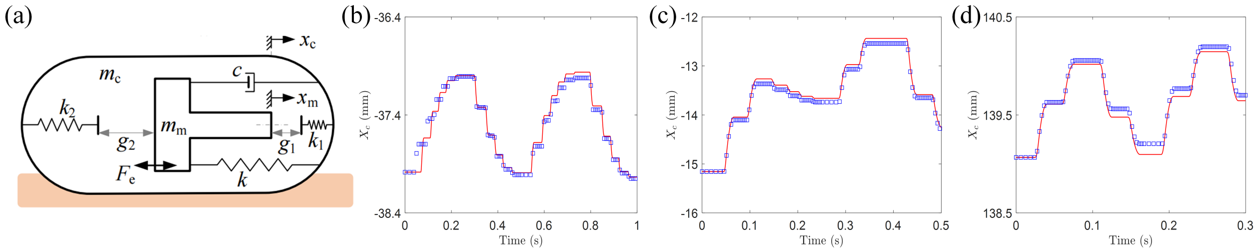

Figure 1: (a) Schematic diagram of the vibro-impact capsule robot self-propelling on an intestinal substrate. (b) Case 1: excitation amplitude 1.5 N and frequency 2 Hz. (c) Case 2: excitation amplitude 1.8 N and frequency 4 Hz. (d) Case 3: excitation amplitude 2 N and frequency 6 Hz. Blue squares indicate the known capsule displacements, and red lines stand for the identified trajectories.

Results and Discussion

To validate the developed parameter identification method, this work adopted the theoretical model shown in Fig. 1(a) to produce the known capsule displacements and velocities, and three independent cases were considered. To identify the model's damping, spring stiffness, constraint stiffness and intestinal friction coefficient, the above three cases were integrated and solved by using the simulated annealing algorithm [2]. After 334 iterations of the algorithm, the defined optimisation problem converged to the neighbourhood of the pre-specified parameter sets. Comparisons between the known data and the identified trajectories of the capsule are shown in Fig. 1(b-d), where good agreements can be observed. Considering the real-world application of the vibro-impact self-propelled capsule robot, it is believed that such a method can provide essential guidance for the identification of capsule-environment interaction, e.g., [3], and will further advance the potential functionality for the capsule robot.

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References

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