The closed-loop controller optimization of a discontinuous capsule drive with the use of neural network in the uncertain frictional environment

Sandra Zarychta*, Marek Balcerzak*, Artur Dąbrowski* and Andrzej Stefański*

*Division of Dynamics, Lodz University of Technology, Lodz, Poland

Abstract. This short paper presents the novel method of designing the closed-loop controller for a nonlinear, discontinuous capsule system. As a foundation of the controller, an optimized open-loop control function is used, based on which the neural network determines the dependencies between the output and the system's state. The robustness of a neural controller is verified in the uncertain frictional environment and compared with the original control function. It is expected that the method can facilitate the design of the systems' closed-loop controllers, especially for non-smooth and discontinuous ones, where typical approaches are not efficient enough.

Introduction

The pendulum capsule drive (Fig. 1a) is an example of a nonlinear, discontinuous system, exhibiting rich and interesting dynamical behaviour. It is not only caused by the pendulum's inherent nonlinearity, but also due to the frictional interactions between the capsule and the underlying surface, resulting in stick-slip discontinuity. Last but not least, the dependence of the contact force on oscillations of the pendulum can be noticed [1]. Control design methods applicable to capsubots systems with discontinuities such as the pendulum capsule drive considered in this paper, use various approaches, such as the open-loop [2, 3], closed-loop [3], as well as neural networks (NN) [4] and others. However, very little research is dedicated to the NN applications in optimal control drives. One possibility is the use of Reinforcement Learning. Nevertheless, it requires a lot of time and resources [5]. In this case, the authors propose a simpler approach. The open-loop optimal control approximation of a pendulum capsule drive, obtained within the method described in [2], is the base for the NN model created with a specified structure that can determine the dependencies between the open-loop output values and the corresponding states of the capsule system. In such a manner, a closed-loop controller is obtained. The purpose of this study is to test and evaluate the robustness and efficiency of the NN closed-loop controller comparing with the original open-loop one, in an uncertain frictional environment.

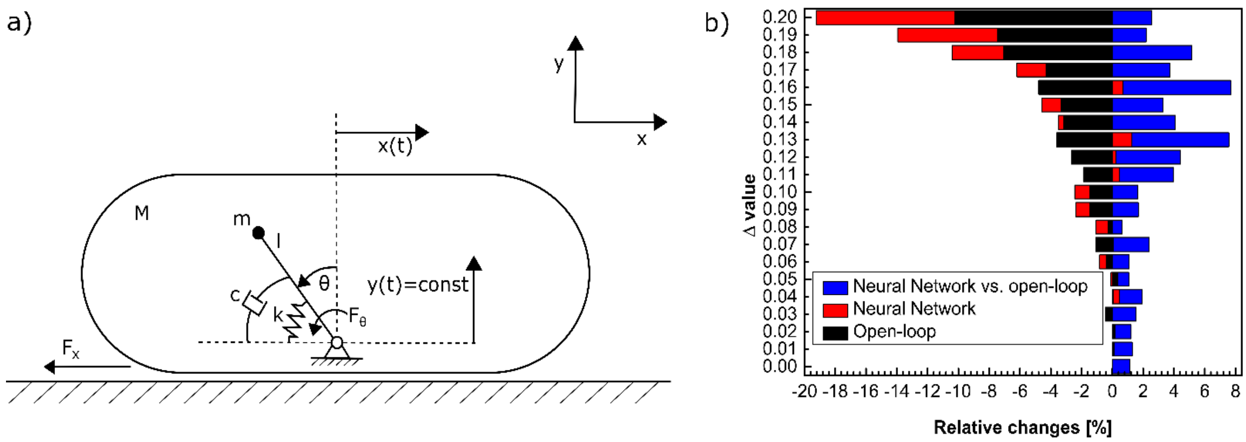

Figure 1: Scheme of the pendulum capsule drive (a) [2] and the robustness comparison of the open-loop and neural controllers (b)

Results and discussion

The controllers' robustness studies revealed a 1.16% higher performance and 7% better resistance of the NN closed-loop controller comparing to the original open-loop, in the constant frictional environment and the uncertain one, respectively (Fig. 1b). Obtained results confirm that the NN controller works more efficiently, offering better robustness against uncertainties appearing in the environment with the varying coefficient of friction, which is one of the main limitations in the open-loop controllers. Moreover, the novel NN closed-loop controller seems to be an interesting option for designing and optimization of the systems controllers, particularly for discontinuous ones, where the open-loop approach is only available.

References

[1] Liu, P., Yu, H., & Cang, S. (2018). On the dynamics of a vibro-driven capsule system. *Arch. Appl. Mech.* **88(12)**:2199–2219.
[2] Zarychta, S., Sagan, T., Balcerzak, M., Dabrowski, A., Stefanski, A., & Kapitaniak, T. (2022). A novel, Fourier series based method of control optimization and its application to a discontinuous capsule drive model. *Int. J. Mech. Sci.* **219**:107104.
[3] Liu, Y., Yu, H., & Yang, T. C. (2008). Analysis and control of a capsubot. *IFAC Proc. Vol.* **41(2)**:756-761.
[4] Liu, P., Yu, H., & Cang, S. (2019). Adaptive neural network tracking control for underactuated systems with matched and mismatched disturbances. *Nonlinear Dyn.* **98(2)**:1447–1464.
[5] Ketkar, N. (2017). Deep Learning with Python - A Hands-on Introduction. Apress Berkeley, CA.