Control of a Soft Redundant Manipulator Under Variable Loading Through Localized Online Learning

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Summary—Commonly used model-based approaches often have low tolerance to unmodelled loading, resulting in significant error. In this study we employ a nonparametric learning-based method that can approximate and update the inverse model of a redundant two-segment soft robot in an online manner. The performance of the control framework was evaluated by tracking of a 3D trajectory with an unknown mass added to the robot tip. The results indicate that the proposed controller could effectively adapt to the disturbance and continue to track the desired trajectory accurately.

I. INTRODUCTION

The introduction of robots constructed from hyper-elastic materials and embedded with fluidically driven chambers have given rise to a new class of robots that have gained prevalence in specialized applications like surgical intervention [1]. Subsequently, the growth of soft robotics field has sparked research focused on modelling the behaviour of soft robots.

The piecewise constant curvature (PCC) approach is commonly used to approximate the kinematic mapping of soft robots [2]. Although the use of PCC still remains predominant, any loading to the robot that results in non-circular bending invalidates the PCC assumption. Fully utilizing the conformability and maneuverability of soft continuum robots while also maintaining end-effector accuracy is still technically challenging.

A path towards this goal is through learning-based approaches, which have gained popularity in soft robotics for their ability to bypass the difficulties in modelling uncertain internal and external dynamics. A number of NN-based approaches have been used to learn the inverse kinematics of soft continuum robots [3], however the presence of external disturbances was not accounted for in these studies.

II. METHODS

A. Implementation of Online Learning Algorithm

The objective is to control the soft robot accurately in the task space motion transition coordinate \(\Delta s_k\), while under unknown loading. For this reason, an online learning algorithm based on the work found in [5] is adapted for usage on our...
Chambers per segment, which were equally spaced around the section perimeter. Each segment was able to bend approximately 100 degrees omnidirectionally. The x-y-z robot tip and base position was tracked by an electromagnetic (EM) tracking system (NDI Medical Aurora) with an update rate of 40 Hz. The online learning algorithm was implemented in the Matlab environment, applying the open-source library for LWPR [7]. In order to effectively generate a functional global controller, pre-training data that sufficiently characterizes the robot’s workspace and possible configurations was obtained. Initially, 80 random waypoints were used to pre-train the global inverse model. The proposed system architecture is shown in Fig. 2.

B. Trajectory Tracking Experiment with Tip Load

An additional tip mass was added to the robot tip, as illustrated in Fig. 1(a). The total additional mass was 14.2 g and was not previously presented to the model during pre-training. The real-time data obtained from the tracked tip position and actuator volumes were input to the online learning algorithm, enabling incremental improvements to the overall learned inverse model. The average frequency of the online updates was 23 Hz. Improvements to tracking could be observed in the results presented in Fig. 3. The mean absolute tracking error of every cycle could be seen to decrease significantly, starting at ±4.42 mm in the first cycle and reducing to ±1.63 mm in the third cycle.

IV. CONCLUSIONS AND FUTURE WORK

Overall, online learning of the original pre-trained model could be seen to improve the tracking performance through continuous online updating of the inverse model, even in the presence of a previously unknown external disturbance. Our future work includes further extension of the proposed control framework to three or more segments of a soft robot and incorporation of a greater number of task space variables to improve the manipulability of the robotic system. We also aim to integrate alternative sensing modalities such as FBG-based fiber optics in place of the heavily tethered EM system.

REFERENCES