Modeling and Advanced Control for Designing a Soft Material Robot

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EXTENDED ABSTRACT

Soft material robots are an emerging and fast-growing field of research with potential application in various areas. In contrast to conventional robots, which are usually fabricated out of high-stiffness materials such as steel, soft robots are mostly fabricated out of soft materials like, silicone or foam. Soft robots are mainly used in newer areas of robotics, such as human-machine interaction, medical applications, or gripping sensitive and differently shaped objects. Their soft design allows for very flexible use, e.g. for different gripping tasks, while their softness also protects sensitive objects from damage. Due to the soft structure, conventional components and design methodologies are not applicable. Therefore, new actuators, sensors, modeling and control concepts are currently developed.

Modeling rod-like structures with large deformations is especially important for soft robots because soft robots are often of long, slender shape. In contrast to rigid robots and flexible link robots, large elastic deformations occur in soft robots. Therefore, established modeling methods in traditional robotics, such as modeling with rigid multibody systems or flexible multibody systems using the floating frame of reference approach, are unsuitable for soft robots. For soft robots methods such as ANCF, the Cosserat rod theory or piecewise constant curvature approaches are necessary. Piecewise constant curvature approaches are most popular in soft robotics [2]. These only model bending and torsional deformations as these are usually dominant for soft material robots. Also, the Cosserat Rod theory is very popular. Besides bending and torsion also elongation is modeled. Both modeling approaches are suitable for real-time model-based control. They are shown in Figure 1 and Figure 2.

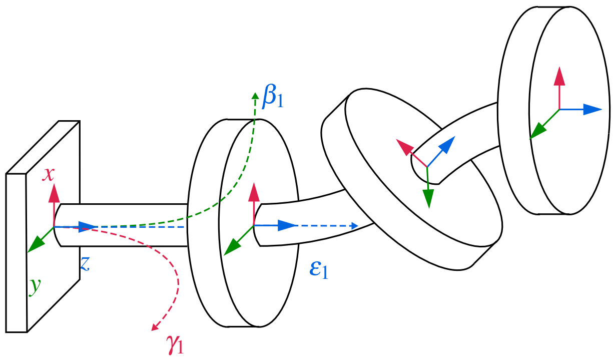

Figure 1: Soft robot segment modeled with a piecewise constant curvature model.

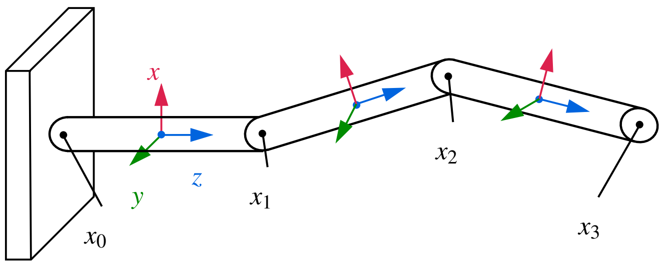

Figure 2: Soft robot segment modeled with a Cosserat rod model.

For practical applications of soft robots, reliable control and positioning is important. Especially gripping force control as well as trajectory tracking control are relevant to soft robotics. Here, the focus will be on trajectory tracking control. In soft robotics so far mainly so called "kinematic controllers" are used. These controllers neglect the dynamics, which often makes them very simple. Especially, no dynamic model of the soft robot is required. However, neglecting the dynamics also limits the achievable agility and accuracy. Therefore, considering the dynamics with "dynamic controllers" usually results in a much better performance [1]. In soft robotics most kinematic control approaches use machine learning techniques to learn either the forward or the inverse kinematics of the soft robot to be controlled. For dynamic control more often model-based control techniques such as model predictive control are used as learning the dynamics requires much more training data and effort than learning just the kinematics.

In this contribution modeling and trajectory tracking control of a simple tendon-actuated beam-shaped soft robot is presented. In Figure 3 the soft robot used for trajectory tracking control is shown. It is fabricated out of silicone and is therefore highly flexible. This allows large nonlinear bending deformations. The soft robot is actuated by servomotors via three tendons. An external camera tracking system based on AprilTags attached to the end effector is used for reference measurements. The soft robot is simulated with a simulation model based on the Cosserat rod theory. For control an open-loop model-free kinematic controller is used. The forward kinematics are thereby approximated with a small neural network. This saves computational costs and allows to compensate modeling inaccuracies of the physical robot. The controller is first examined in simulations and then in experiments. In Figure 4 the trajectory tracking of a flower-shaped trajectory with the soft robot is shown in simulation. In addition, also experimental results will be presented.

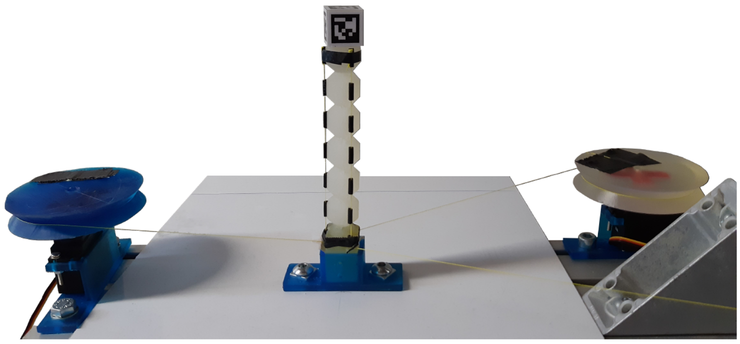

Figure 3: Tendon actuated soft material robot for trajectory tracking.

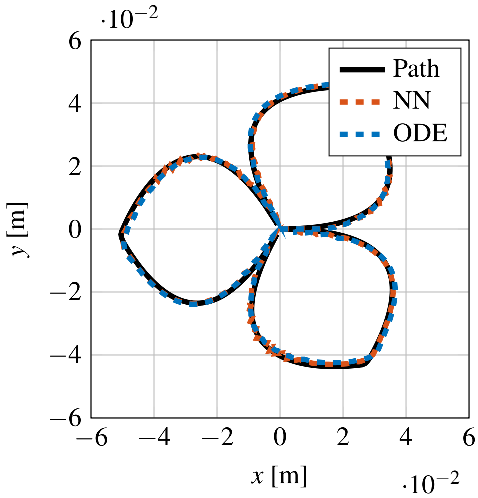

Figure 4: Trajectory tracking result in simulation with neural-network based feed forward control.

References

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