LULEÅ TEKNISKA UNIVERSITET

Assignment: Pneumatic Actuation Controller
Robotics and AI Research Group

Description

The objective of this assignment is to test programming capabilites, control theory and simple material knowledge. This will include setting up the soft simulation software on your computer, completing the Python simulation file and giving small descriptions on the given questions.

You will work with a state-of-the-art reduced-order model for soft robots and explore how optimal control can be applied using this model. You are expected to read the following research paper and implement the corresponding code base:

- Article: Soft Robot Optimal Control via Reduced Order Finite Element Models
- Code Repositories: SOFA Framework

In this assignment, your goal is to simulate and control a soft robotic arm using SOFA framework. The segment of the robot is made of a soft, bendable material and actuated to produce in-plane deformation. The system is modeled with the intention of guiding the robot's end-effector to reach a specific target point within its reachable workspace under quasi-static equilibrium conditions.

The robot comprises one link measuring $150mm$ in length, $16mm$ in diameter and $115mg$ in weight. The entire robot moves freely on every axis but its fixed in space at its base. Each segment is modeled as a continuous, deformable beam made from a soft hyper-elastic material. Gravitational effects can be neglected.

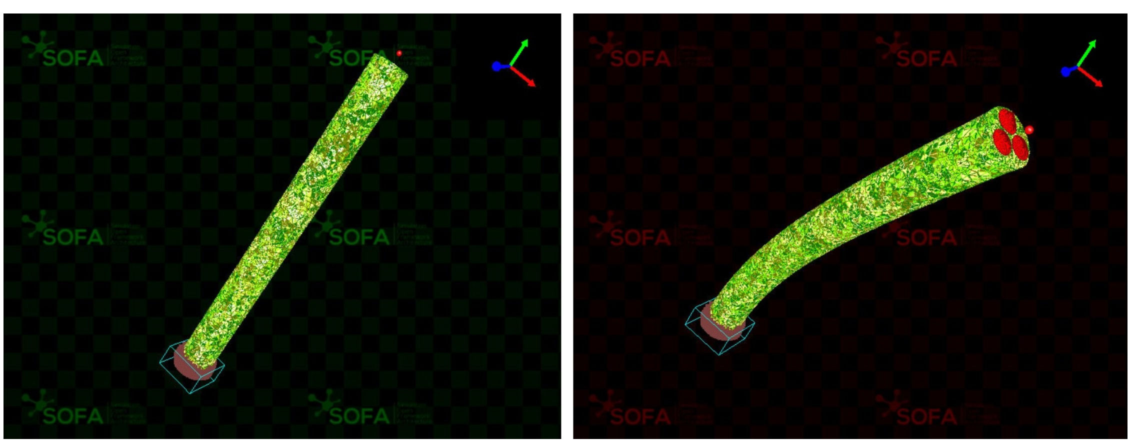

Figure 1: Example screenshots from SOFA simulation tool.

Each segment is actuated using three internal pneumatic chambers, symmetrically arranged around the central axis. By applying different pressures to these chambers, the segment bends in different directions: **top-right** towards $(-x, +z)$, **top-left** towards $(+x, +z)$ and **bottom** towards $(-z)$.

You will have to install the simulation framework and configure the actuation by using PID feedback control mechanism. Find an appropriate set of chamber pressures as control input, so that the robot's end-effector (the tip of the segment) reaches every target position in space. No considerations are done towards the y axis.
A deviation within $\pm 5mm$ from this point is acceptable. You are required to simulate the robot in SOFA framework for different target positions, compute the resulting deformation, and determine the position of the tip. You must visualize (and screenshot) both the initial and final robot configurations. Additionally, plot the input pressure values you used to reach the final configuration.

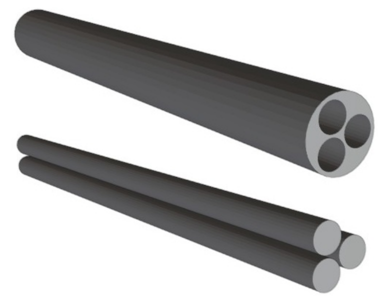

Figure 2: Mesh objects.

The maximum allowed pressure for each cavity is $0.0015MPa$ and no negative pressures are allowed. The system's masses shall be in tonnes ($10^3 KG$). If any parameters or information are missing, you may make reasonable assumptions and clearly state them in your submission.

The PID controller is ruled by the following equation:

$$u(t) = MV(t) = K_p\ e(t) + K_i \int_0^t e(\tau)\ d\tau\ + K_d \frac{de(t)}{dt} \tag{1}$$

where

- K_p is the proportional gain, a tuning parameter.
- K_i is the integral gain, a tuning parameter.
- K_d is the derivative gain, a tuning parameter.
- $e(t) = SP - PV(t)$ is the error (SP is the setpoint and $PV(t)$ is the process variable).
- t is the time or instantaneous time (the present).
- τ is the variable of integration (takes on values from time 0 to the present t).

Such dynamic simulations require very small gain factors.

The result of this exercise will be a zip file with a .txt containing the best achieved positions together with screenshots for each target where the strain and the coordinate frame of the simulation are clearly visible. The zip will also contain the assignment.py and a controller.py where your implementation of a SoftBodyController class shall be present. Finally, plots for the cavity pressure values to reach the target positions shall be included. This zip will be named lastname.firstname.zip.

Research interest and directions

The candidate should discuss among the various research directions highlighted in the advertisement:

- Which core area(s) you are most interested in exploring during your PhD?
- What do you see as the key open challenges or limitations in those areas.
- Based on your current background and interests, what is your personal research vision?
- What kind of problems excite you, and what would you like to contribute over the course of your PhD?