Bending angle prediction for Soft Pneumatic Actuator using Neural Networks.

Aryan Sharma
Radhika Agwan
Nihal Pushkar
Mentor: Debjit Hore

Introduction

1. Soft robots are flexible and adaptable, and can be used in areas where hard/non malleable robots cannot be used (For eg: prosthetics or disaster relief scenarios)
2. In 4D printed robots, the robot responds to external stimuli such as heat, electricity, magnetism and pressure
3. One of the main challenges associated with the analytical and FE modelling approaches is the need for accurate material models and relevant material coefficients, which can accurately describe the nonlinear behaviour of the hyperelastic materials used.

Problem statement

1. Predicting and modeling motion of an actuator is complicated due to the material's non linearity.
2. A linear model fails to predict the actuator's movement correctly.
3. Doing simulations that use non linear materials enhance accuracy of the model.

Experimental setup

1. The original work uses soft pneumatic actuators(SPAs) embedded with resistive flex sensors
2. They are made of finger like structures that expand when compressed, thus making them flexible
3. When a PneuNet actuator is inflated, areas that have the least stiffness expand first
4. They can be programmed to achieve the desired motion by changing the wall thicknesses

Fig. 1. A cross-sectional illustration through a typical bending SPA featuring a ribbed morphology

1. The input is supplied as different input pressures and orientations and the resulting output is noted from the flex and pressure sensors
2. A calibrated high speed camera captures image frames during the actuation, which are then analysed using an image processing program to calculate the actual bending angle and synchronise it with the recorded sensory feedback.
3. A purely data-driven modelling approach was proposed that utilises feedback from inexpensive commercially available sensors, to derive empirical models that can be used for predicting and controlling the free bending response of soft actuators.
4. The approach isn’t constrained to a specific actuator morphology or input, and hence is only based on the generated data.

Input parameters and method used

1. Input parameters are geometrical parameters(length, width, height), pneumatic pressure and material parameters(shear and bulk modulus)
2. The bending angle of the actuator is calculated as $\theta(P) = \frac{L_i A^2 e}{A_w E^2 I} P^2 + \frac{L_i A e}{EI} P = CP^2 + DP$
3. If the cross sectional area is regular, the actuator expands uniformly without any bending
4. However, if there is an offset between the centre of pressure and the neutral axis of the actuator, it bends towards the side of the neutral axis
5. The centre of pressure is the centroid of the cross section of the air chamber

Linear regression

1. Previously deflection angle was modelled by using linear regression but while implementing that, large values of error were observed.

MSE values for the linear regression models.

Shapes	MSE	R-Squared
Rectangular	148.4003	0.74
Circular	54.586	0.90
Triangular	88.973	0.84
All Shapes	108.4	0.81

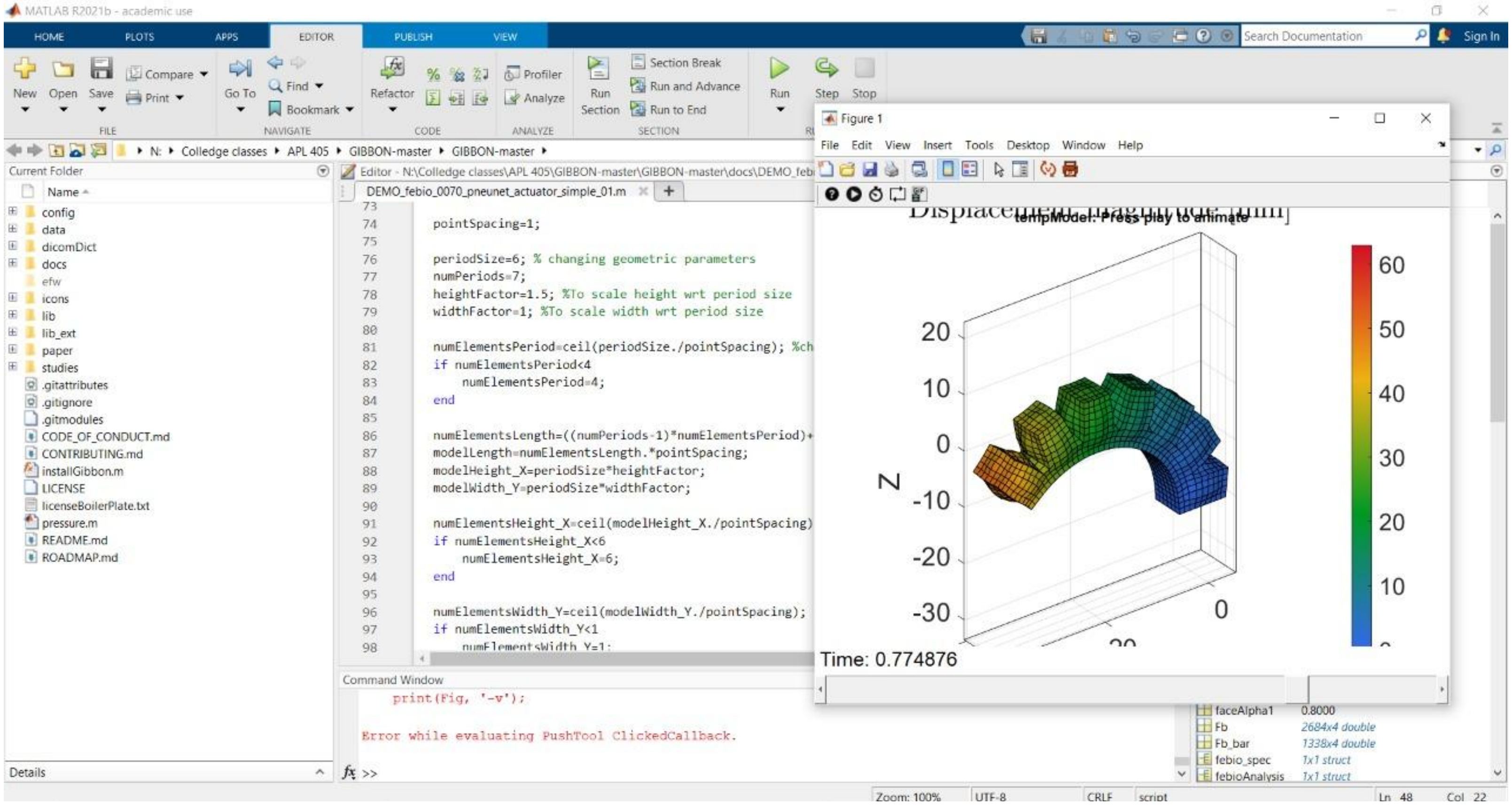
2. Since they tried a linear relation with Pressure input thus this model failed, analytical solution showed that the variation is with square of input pressure (keeping other parameters constant).

Data Extraction Method

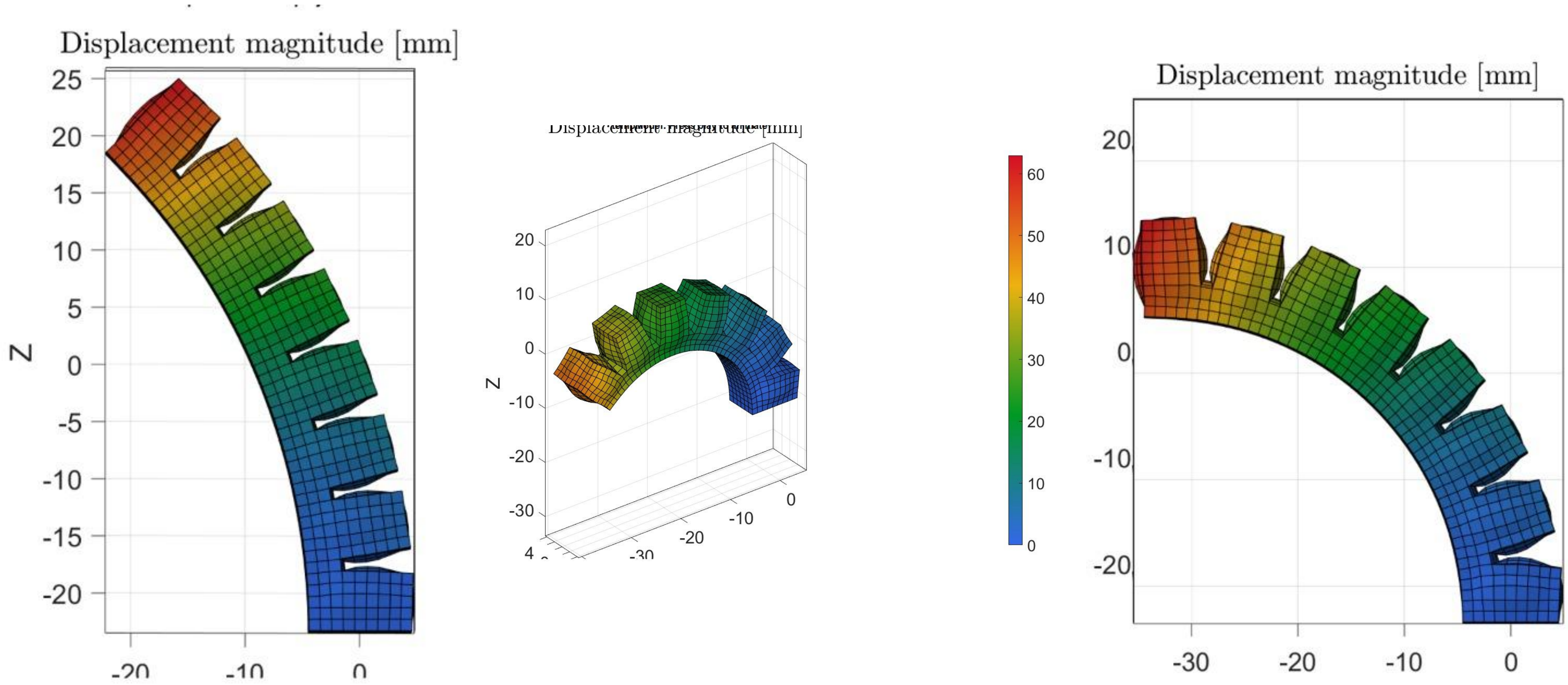
The data for this project has been extracted using the following softwares:-

1.) MATLAB - Running Simulations
2.) FEBio - Finite Element Analysis
3.) Gibbon - Offers image filtering and smoothing methods, and has a graphical user interface for 3D image segmentation
4.) AutoCAD Inventor - For measuring bending angle for the images produced

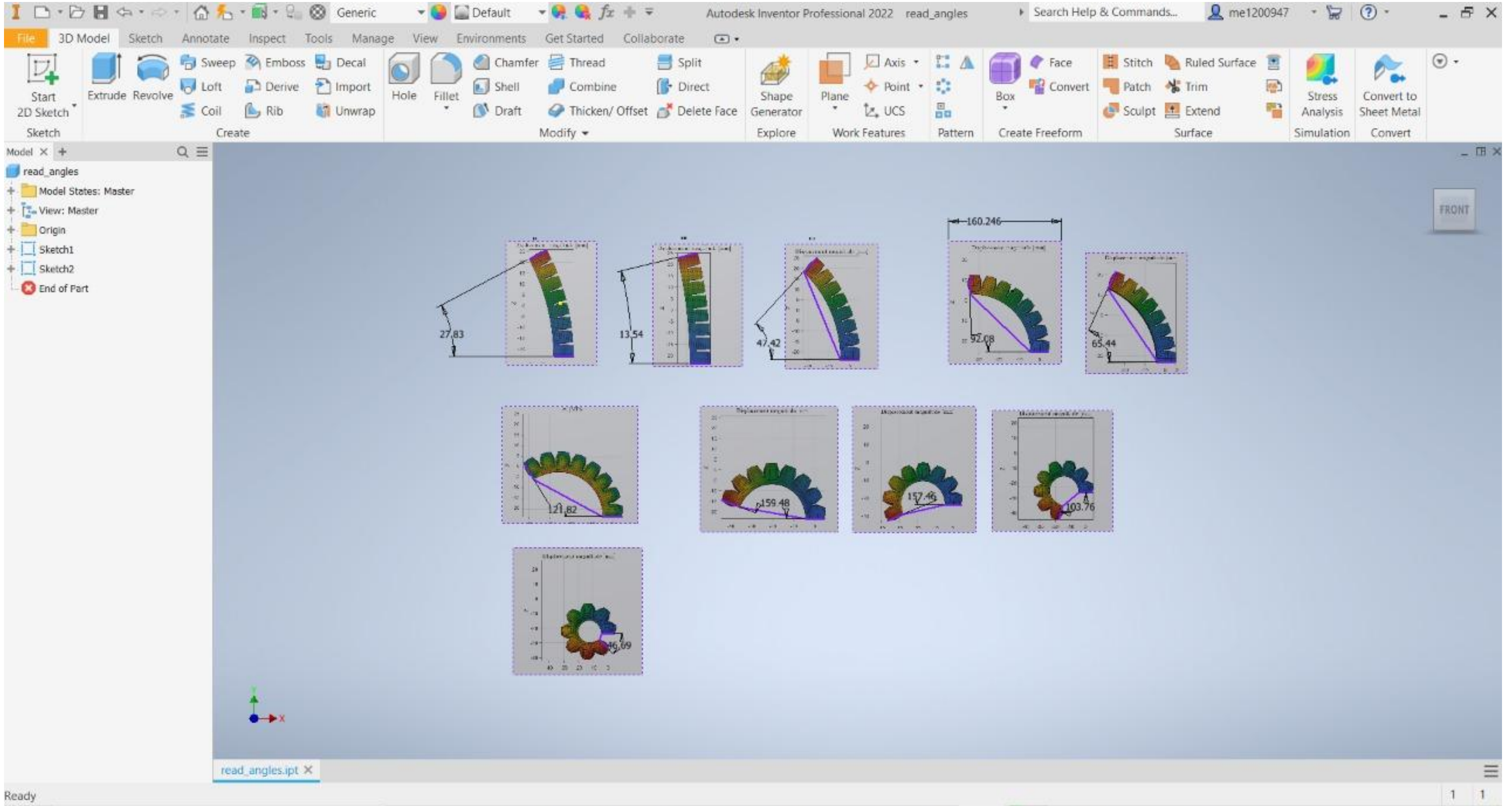
Using MATLAB and FEBio to Run Simulations at different pressures



SPA positions captured at different input pressure



Measuring Bending Angle using AutoCAD



Why to use image

1. The software for simulation is calibrated for displacements, not for bending angle.
2. The meshing in FEBio is physics based, however the meshing we need is terminal based. Since we don’t have a method of changing the meshing, we’re using an image based method.

Neural networks

1. The data is divided in three sets, namely training, validation and test sets
2. The neural network has 2 hidden layers, no. of input parameters = 8 , no. of output parameters =1
3. The finite element model is simulated a lot of times with different actuation profiles to get the final results
4. The error is minimised using a gradient based algorithm and the weights and biases are updated using backpropagation

	Geometrical Parameters(mm)			Material Parameters(MPa)				Input Pressure (MPa)	Bending Angle (output/degrees).
Serial Number.	Length	Width	Height	c1	k1	c2	k2		
1	47	6	9	1	50	50	2500	0.5	313.3074597
2	47	6	9	1	50	50	2500	0.45	256.2392149
3	47	6	9	1	50	50	2500	0.4	202.5384498
4	47	6	9	1	50	50	2500	0.35	159.4775408
5	47	6	9	1	50	50	2500	0.3	121.8218075
6	47	6	9	1	50	50	2500	0.25	92.0757569
7	47	6	9	1	50	50	2500	0.2	65.4412224
8	47	6	9	1	50	50	2500	0.15	47.4231918
9	47	6	9	1	50	50	2500	0.1	27.8312913
10	47	6	9	1	50	50	2500	0.05	13.5432489

5. Steps sizes can be made smaller to get more precision in results, intervals can be made more smaller, that will generate more data and we can get more generalized result.

Approach for NN

- The MSE must be reduced using a **gradient-based technique** while the weights and biases are updated to optimize the algorithm. Backpropagation is the word used to describe the process of improving the weights and biases of a network in order to improve the model's performance.
- To get training results, the FE-Model is simulated numerous times using randomly generated actuation profiles, which are grouped into three sets: training, validation, and test set.
- In this work, Matlab Machine Learning was used to find the best machine learning model for predicting the bending angle of a 4D-printed soft pneumatic actuator, using the multilayer ANN using Euclidean distances between inputs and weights of a neuron, multiplied by bias.
- As a training algorithm, the Bayesian Regularization method will be used.
- We will be using tan-sigmoid activation function to produce low MSE values.

Novelty

1. Apart from the input parameters of pressure and geometrical lengths, we also provide material parameters such as shear and bulk modulus as input.
2. By changing shears and bulk we can model cases for anisotropic materials also.
3. Previous paper only worked with second order of nonlinearity, we will try to generate a parameter for non linearity which can make the model more generalized.

Future work

Two possible solution for more accurate results:

1. Digging into the meshing and marking the terminal nodes and modify our mesh such that it outputs the bending angle
2. Use image processing to calculate the bending angle rather than doing that manually.(which is less accurate)

References

1. 4D printing soft robots guided by machine learning and finite element models - ScienceDirect
2. Bending angle prediction and control of soft pneumatic actuators with embedded flex sensors – A data-driven approach | Elsevier Enhanced Reader
3. Reference Data Set: FEM will be used to generate datasets for a SPA using an automated MATLAB routine.