Mesh Based Machine Learning Algorithms for Use in Deforming Solids Simulations

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Purpose

The purpose of this research is to determine the effectiveness of graph based neural networks in predicting the motion and deformation of solids. Specifically, this research focuses on deformation of beams with varying elasticities under their own weight. While this is a very simple example, the end goal is to apply the models and methods developed to soft robot movements and deformations. By computing these deformations with neural networks, it should be possible to greatly reduce the computation time compared to traditional simulations enabling more adaptive control systems.

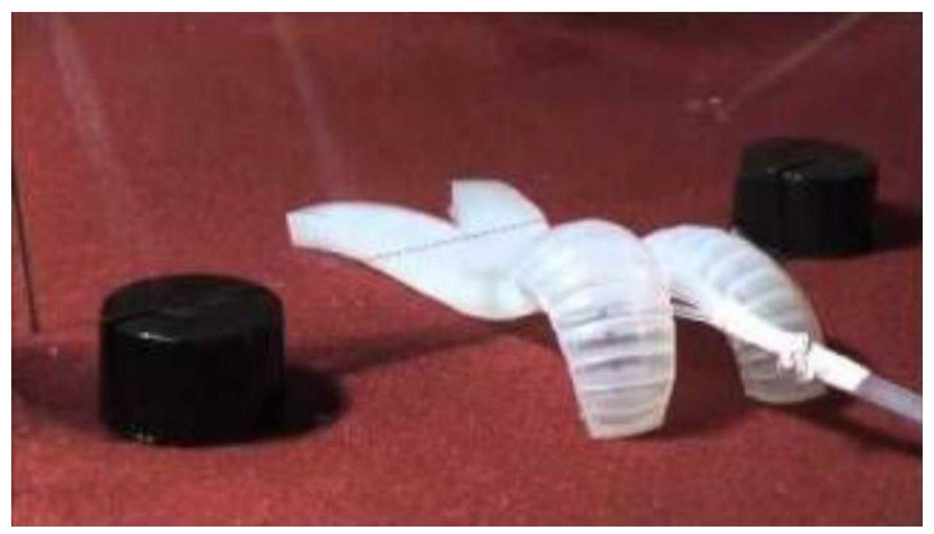

Fig. 1 walking multigate soft robot [1]

What is a Graph Neural Network (GNN)

Graph neural networks or GNNs are a type of neural network that function on a collection of nodes and edges called a graph. Within a graph each of these nodes and edges store a collection of values known as features. The way nodes features change and effect nearby nodes can be trained to create a graph model that simulates physical motion.

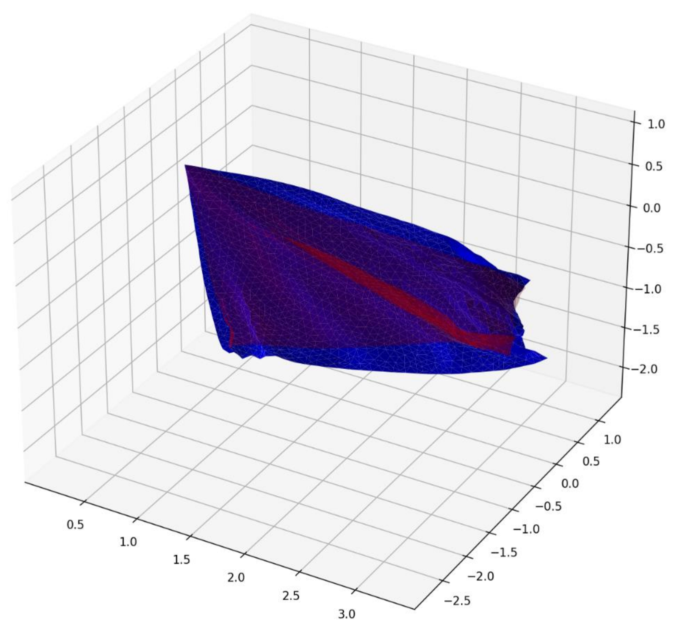

Fig. 2 GNN Cloth Model [2]

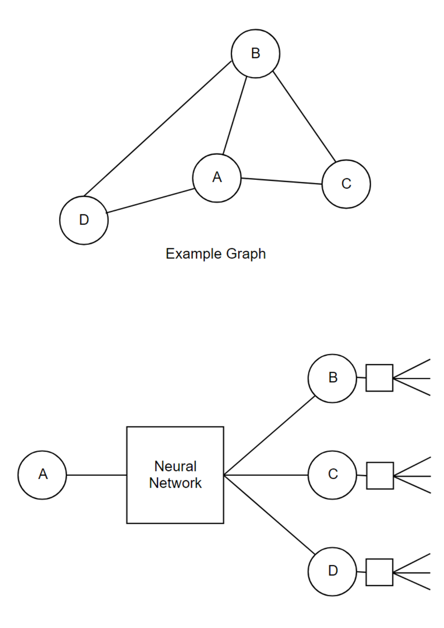

Fig. 3 Graph and Encoding

Graph Network Beam Model

Loss Optimization of the Model:

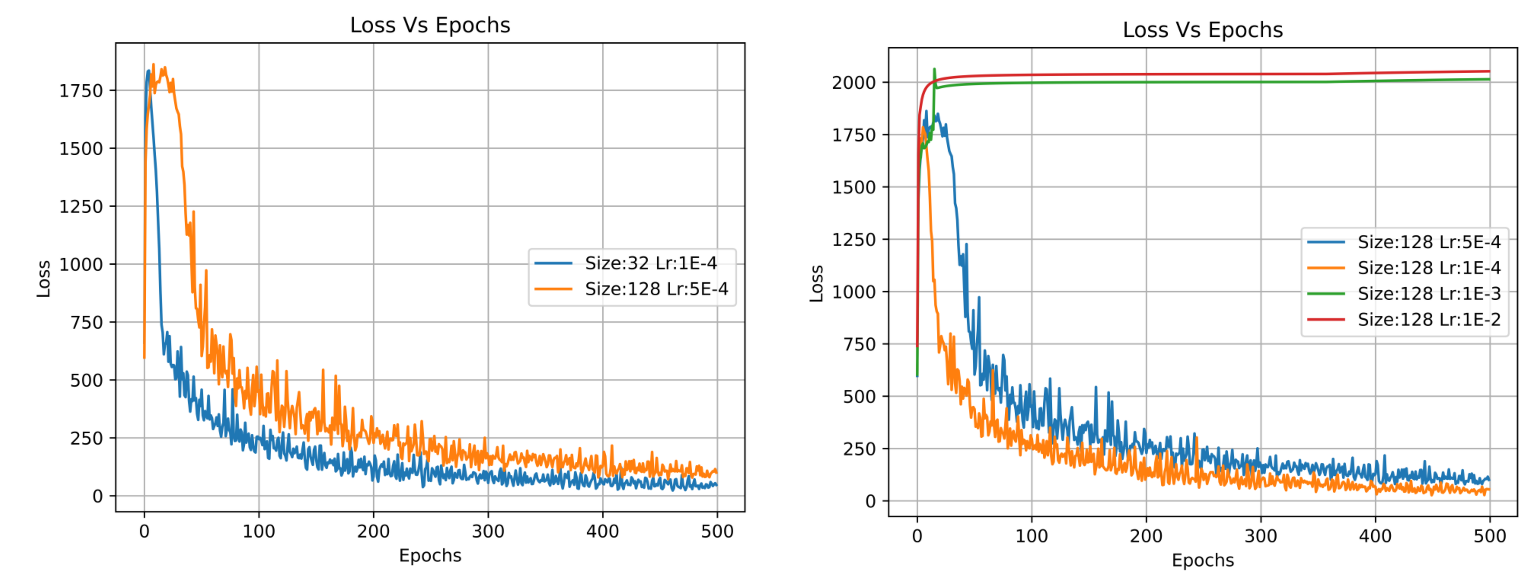

Fig. 4 Loss Plots

Findings:

- Loss increases marginally with decreased latent size
- Loss increases marginally with increased learning rate up to a point where it converges on a high loss solutions
- Learning rate of 5E-4 with a latent size of 64 was chosen to be used for all future training

Final Deflection Model Predictions Trained With 20 Beam Datasets over 2000 Epochs:

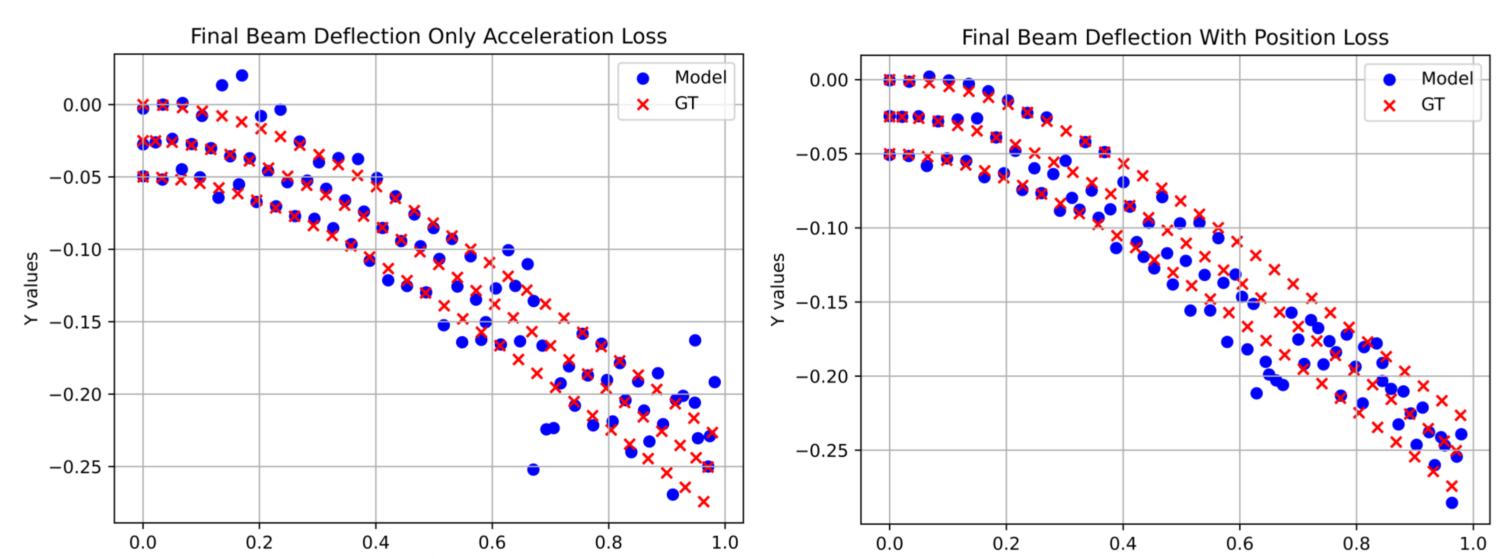

Fig. 5 GNN Beam Deflections

Findings:

- Both loss functions can create reasonable predictions for a beam's deflection with a young's modulus that was not part of the training data
- The additions of positions loss appears to reduce the scattering of data points

Convolutional Network Beam Model

Although further testing is required a basic convolutional neural network (CNN) has also been created to compare to the GNN. CNNs are much simpler than GNNs which would make them more appealing if they could offer similar results. However, expanding the use of CNNs to more complex solids may prove difficult.

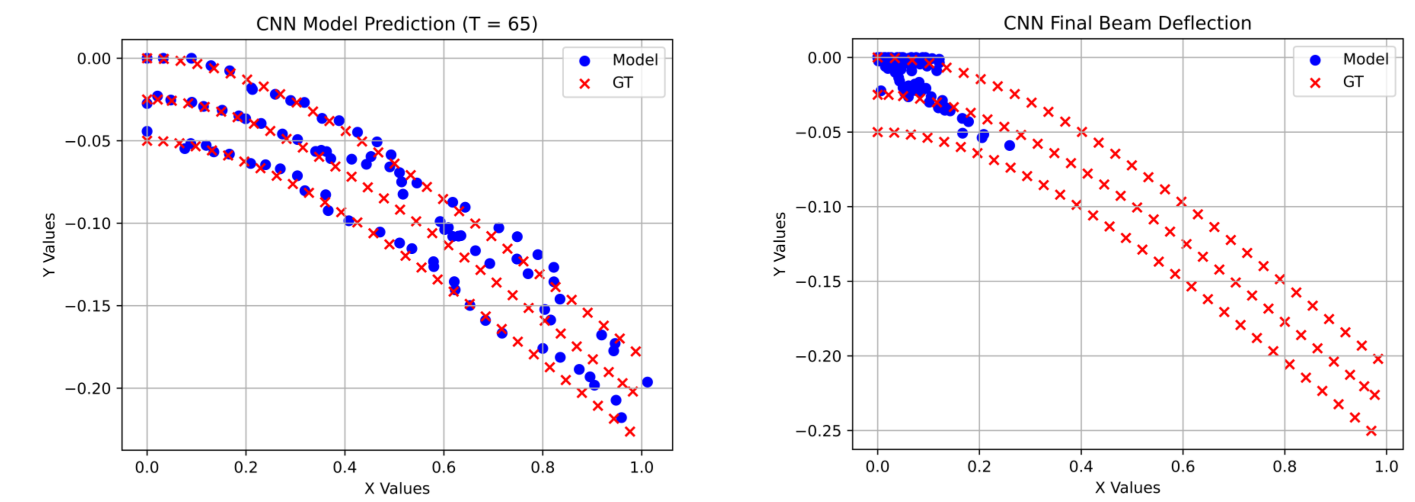

Fig. 6 CNN Beam Deflection

Findings:

- The current CNN model can predict deflections after a small amount of time but breaks down when predicting the final deflection.

Future Work

- Adjust weights of acceleration and position loss for GNN model for best result
- Continue to develop CNN model
- Train on three-dimensional data and soft robot models
- Integrate into soft robotics control systems

Acknowledgments

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References

[1] Shepherd, R.F., Ilievski, F., Choi, W., Morin, S.A., Stokes, A.A., Mazzeo, A.D., Chen, X., Wang, M. and Whitesides, G.M., 2011. Multigait soft robot. Proceedings of the national academy of sciences, 108 (51), pp.20400-20403.

[2] Pfaff, T., Fortunato, M., Sanchez-Gonzalez, A. and Battaglia, P.W., 2020. Learning mesh-based simulation with graph networks. arXiv preprint arXiv:2010.03409.

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