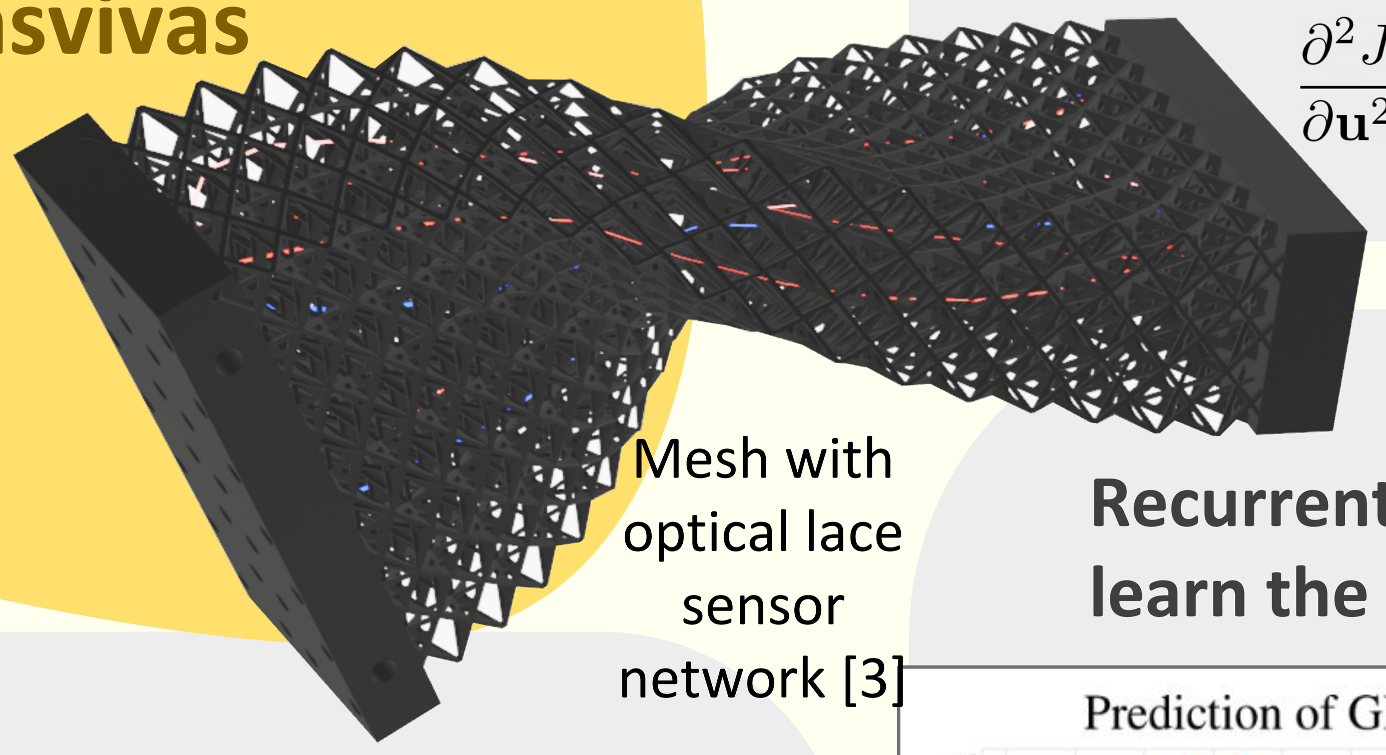
Nonlinear Online Controller for Biomimetic Soft Muscles

by Sarah Aguasvivas Manzano
University of Colorado Boulder



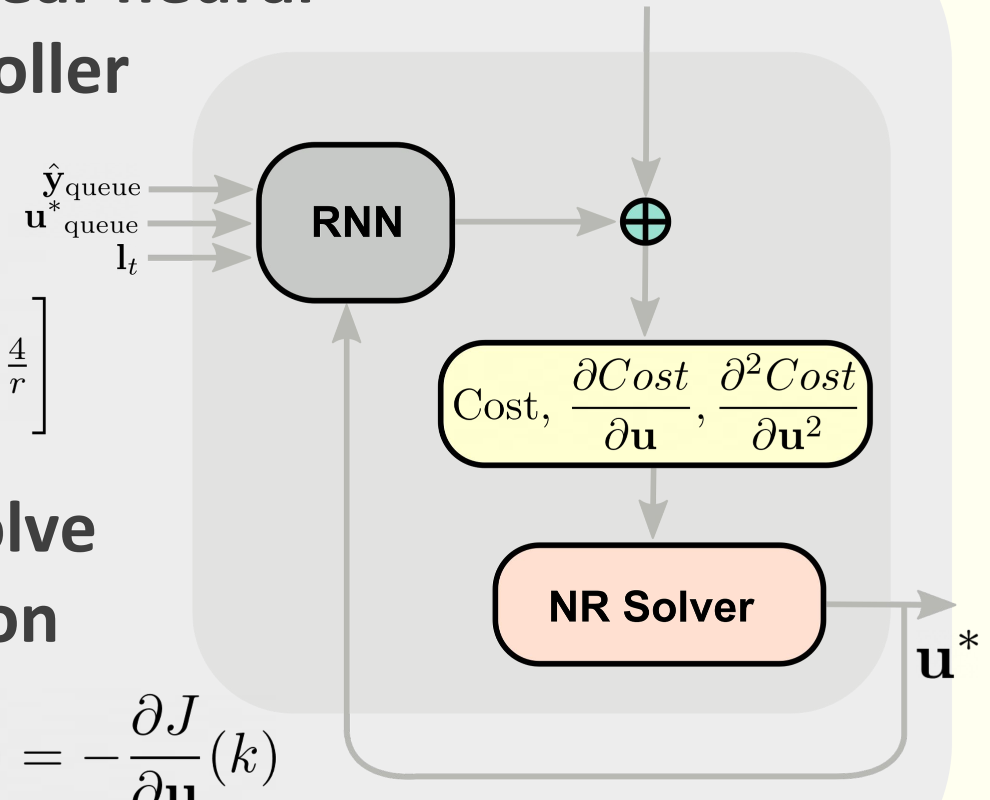
Mesh with optical lace sensor network [3]

We developed a fully nonlinear neural network-based online controller

$$J = \sum_{j=N_1}^{N_2} \|\mathbf{y}_{ref,j} - \hat{\mathbf{y}}_j\|^2_{\mathbf{Q}} + \sum_{j=0}^{N_u} \|\Delta \mathbf{u}_j\|^2_{\Lambda} + \sum_{i=1}^{m}\sum_{j=1}^{N_u}\left[\frac{s}{u(n+j,i)+\frac{r}{2}-b} + \frac{s}{\frac{r}{2}+b-u(n+j,i)} - \frac{4}{r}\right]$$

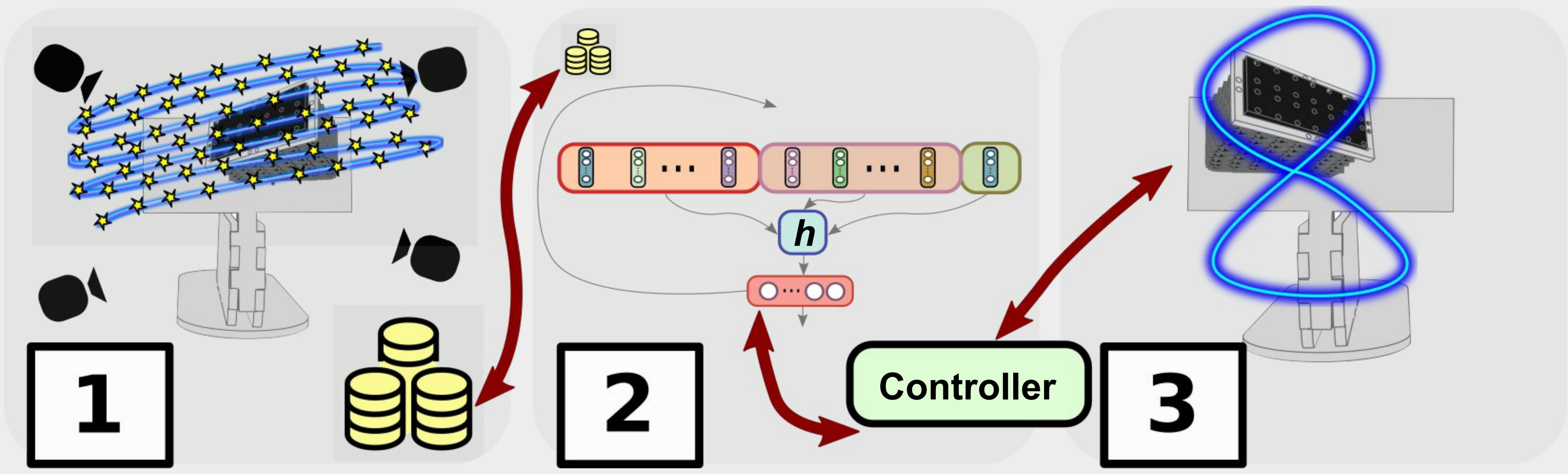
We use Newton Raphson to solve the following algebraic equation

$$\frac{\partial^2 J}{\partial \mathbf{u}^2}(k)(\mathbf{U}(k+1)-\mathbf{U}(k)) = -\frac{\partial J}{\partial \mathbf{u}}(k)$$



Controller Overview

This controller is lightweight and can be embedded in off-the-shelf microcontrollers



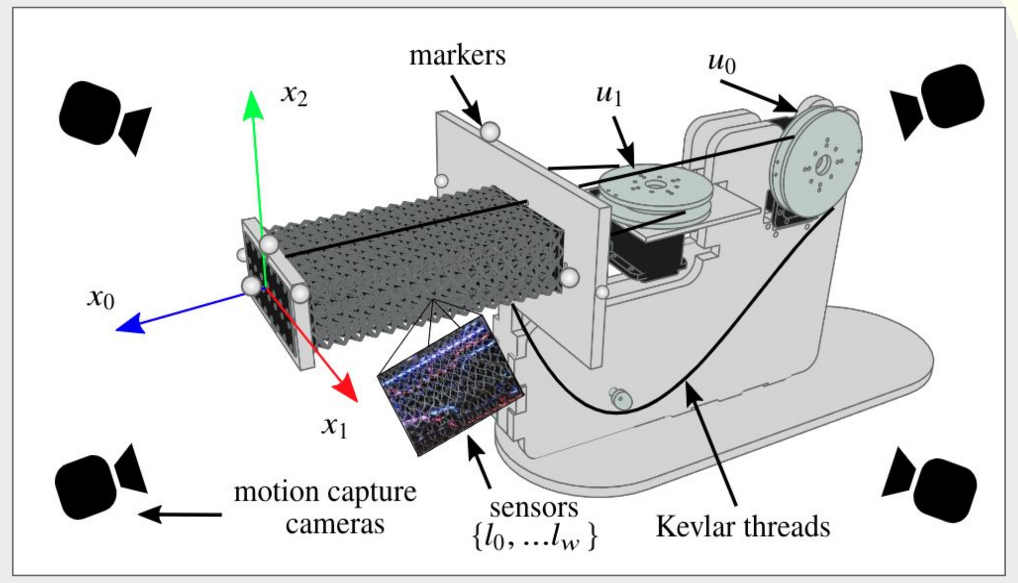
Step 1. Data collection (we collect at about 125 Hz)

Step 2. Training model to predict from *t* to *t+1*

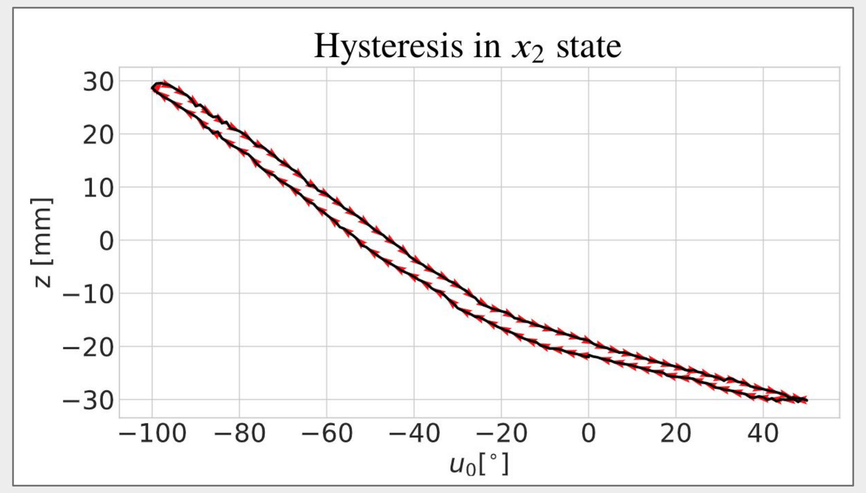
Step 3. Offload the open source controller

Motivation

Soft flexible muscle-like objects with embedded sensors are great biomimetic mechanisms...



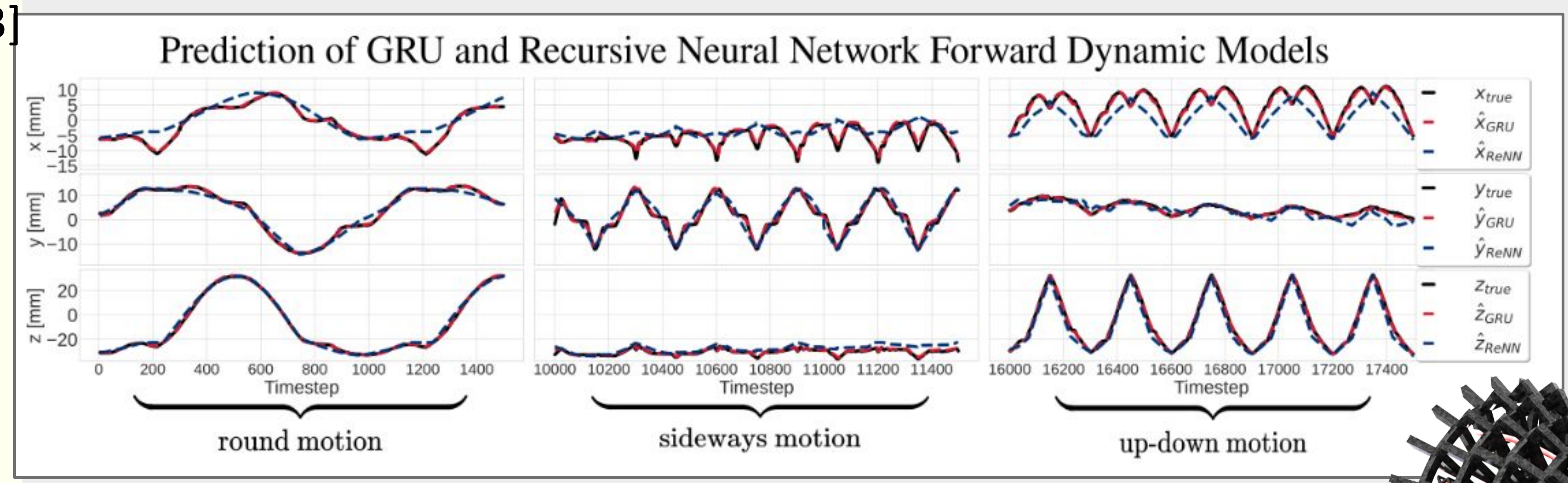
We build this tendon-based experimental rig



There is hysteresis in the motion and sensor reading of this system

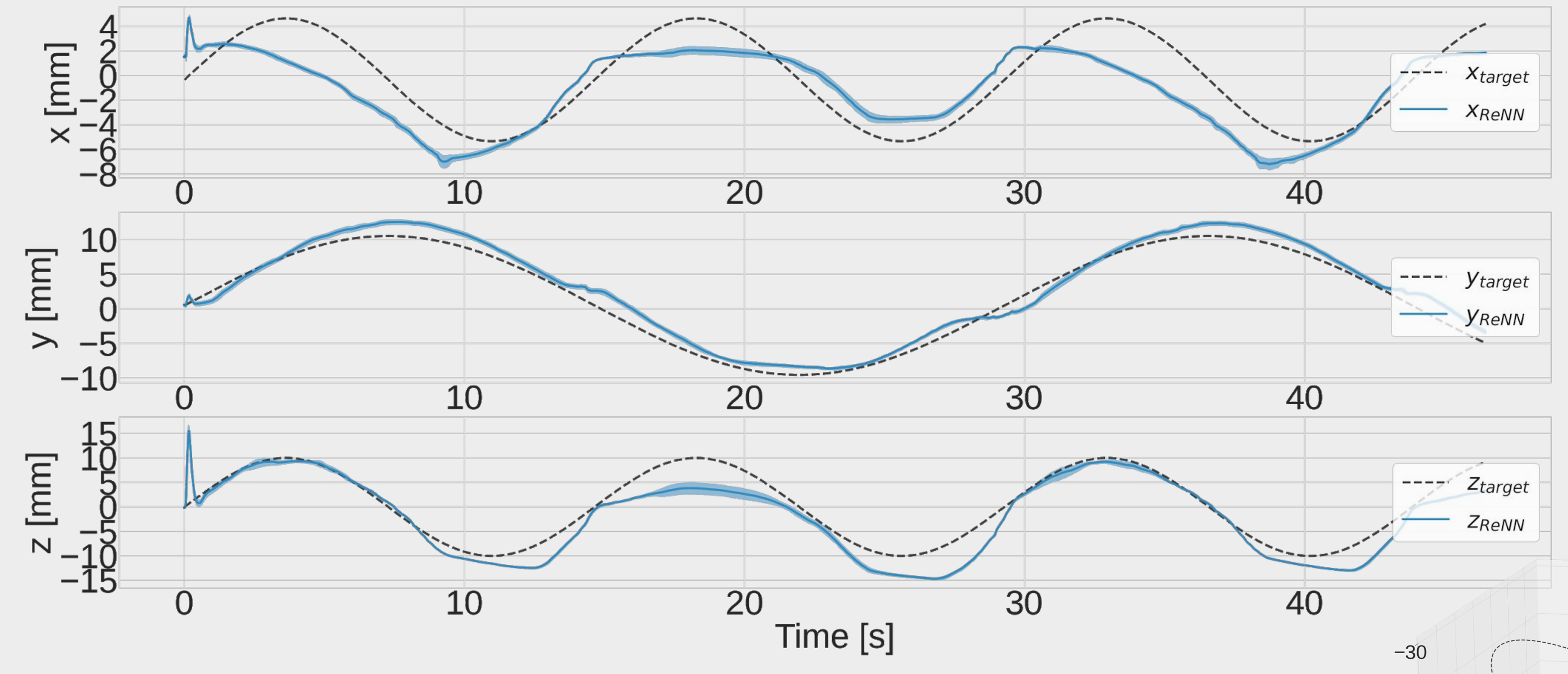
... but it is hard to formulate controllers that exploit their complex sensor readings and nonlinearities

Recurrent Neural Networks (RNNs) are able to learn the forward kinematics of the system

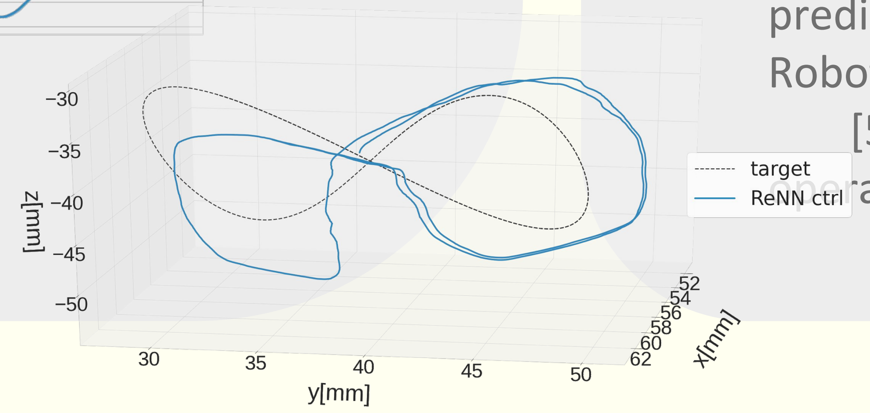


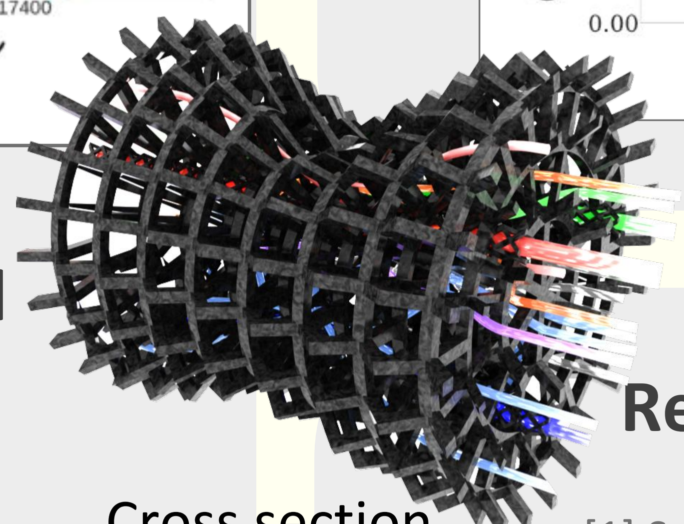
Testing set prediction (5-fold cross-validation)

We achieve 5.1% average absolute error and a control loop frequency of about 70 Hz



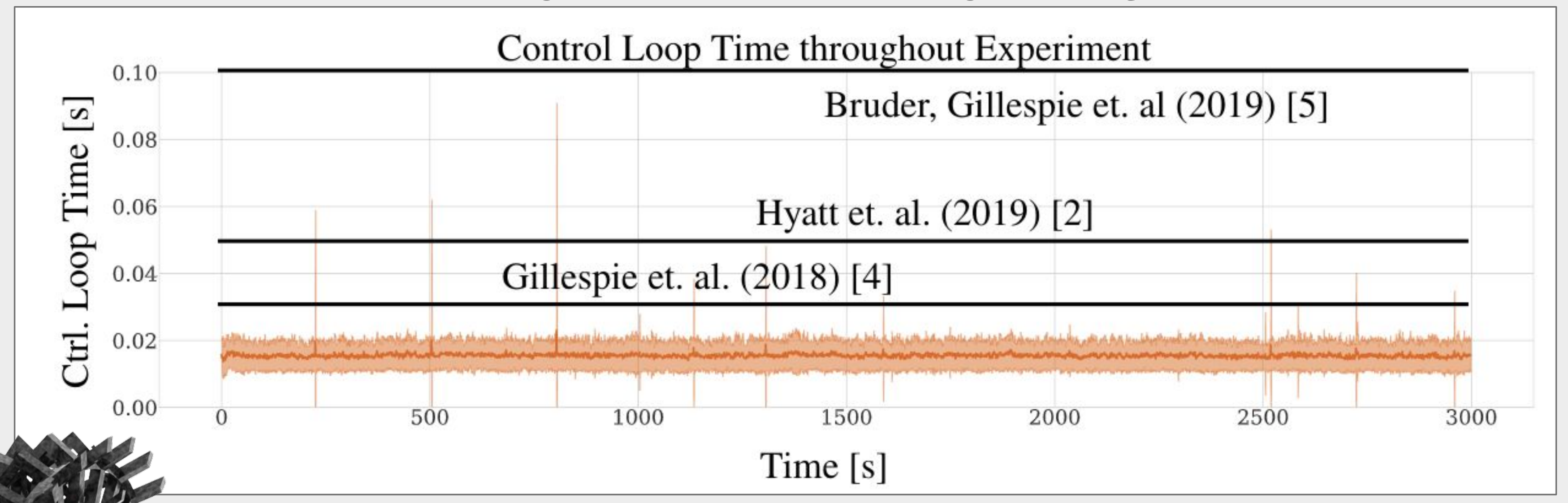
Aggregated path following results over 100 runs





Cross section of the sensor network layout [3]

Our lightweight approach offers reduced computational complexity



Average control loop time over 100 runs of this controller

References

[1] S. Aguasvivas Manzano, *et. al.*"Embedded Neural Networks for Robot Autonomy," in 2019 International Symposium on Robotics Research (ISRR), Hanoi, 2019.

[2] Hyatt, P., *et. al.* (2019), Model-Based Control of Soft Actuators Using Learned Non-linear Discrete-Time Models. Frontiers in Robotics and AI, 6, pp 2296-9144. doi: 10.3389/frobt.2019.00022

[3] Xu, P. A., *et. al.* (2019). Optical lace for synthetic afferent neural networks. Science robotics, 4(34).

[4] M. T. Gillespie, *et. al.* "Learning nonlinear dynamic models of soft robots for model predictive control with neural networks," 2018 IEEE International Conference on Soft Robotics (RoboSoft), Livorno, 2018, pp. 39-45, doi: 10.1109/ROBOSOFT.2018.8404894.

[5] Bruder, D., *et. al.* (2019). Modeling and control of soft robots using the koopman operator and model predictive control. arXiv preprint arXiv:1902.02827.

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MFM Multi-functional Materials