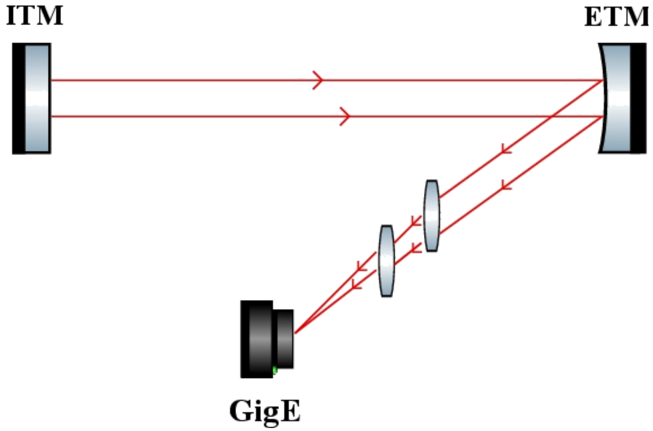
Optical loss characterization at the 40m prototype lab

Pooja Sekhar
Mentors: Gautam Venugopalan, Koji Arai, Rana Adhikari

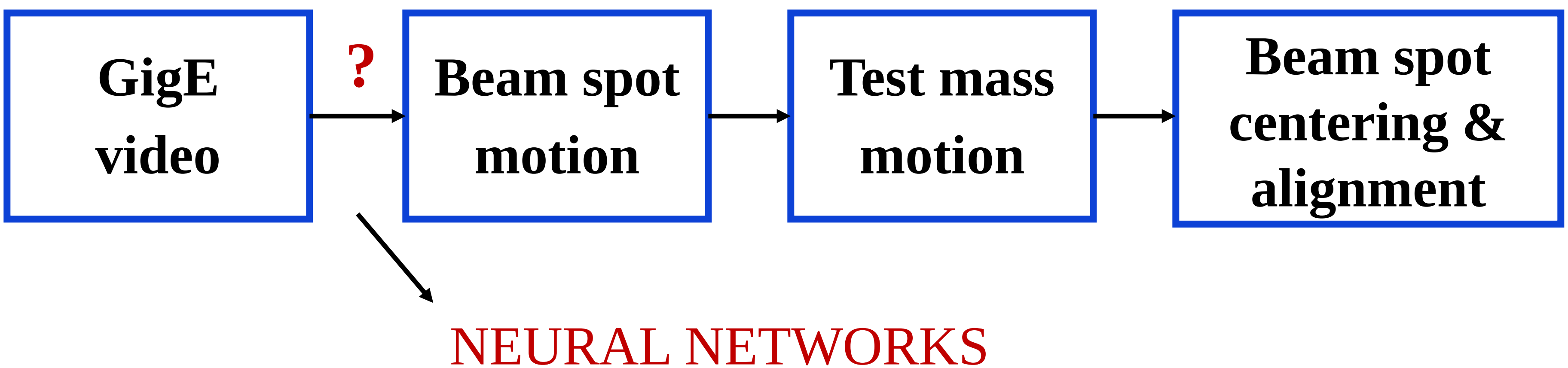
Objectives

- Develop neural network to resolve test mass motion from the video
- Develop simulated video of beam spot motion
- Capture video of scattered light from test mass using GigE camera
- Other image processing techniques to resolve test mass motion from the video

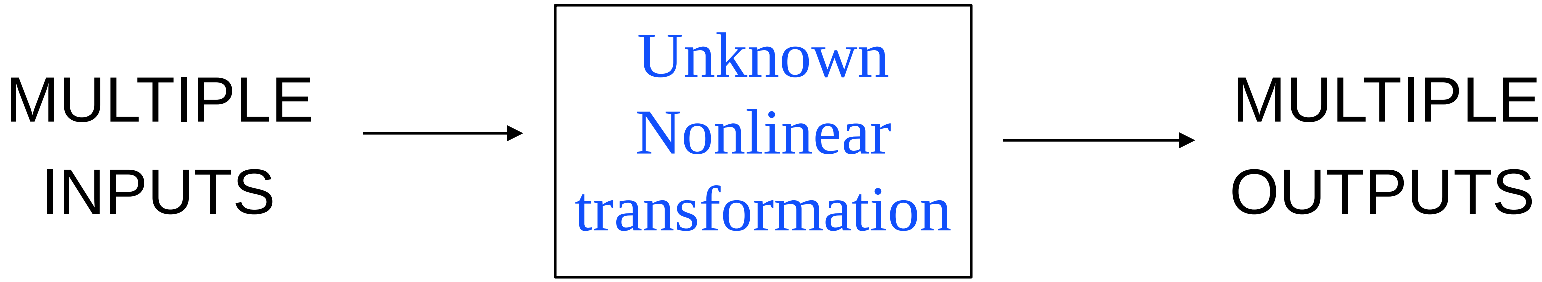


Why analyze video ?

- To center the laser beam spot on the test mass
- To resolve test mass motion from the video of scattered light captured
- Additional tool for alignment control

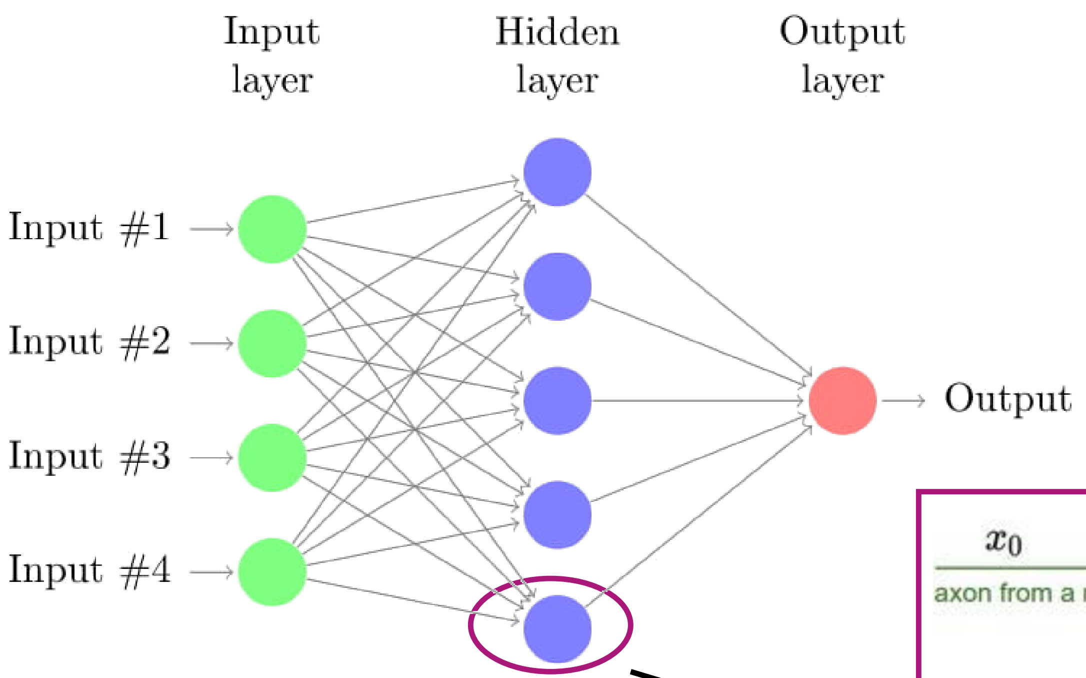


Why neural networks ?

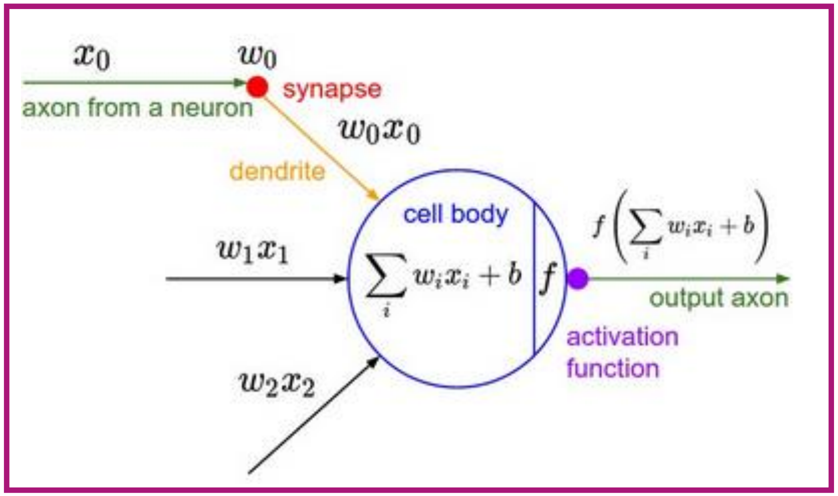


Random movement of beam spot on the test mass due to seismic motion & other noise sources can be identified by neural network since it updates the weights of the inputs during training.

Neural networks

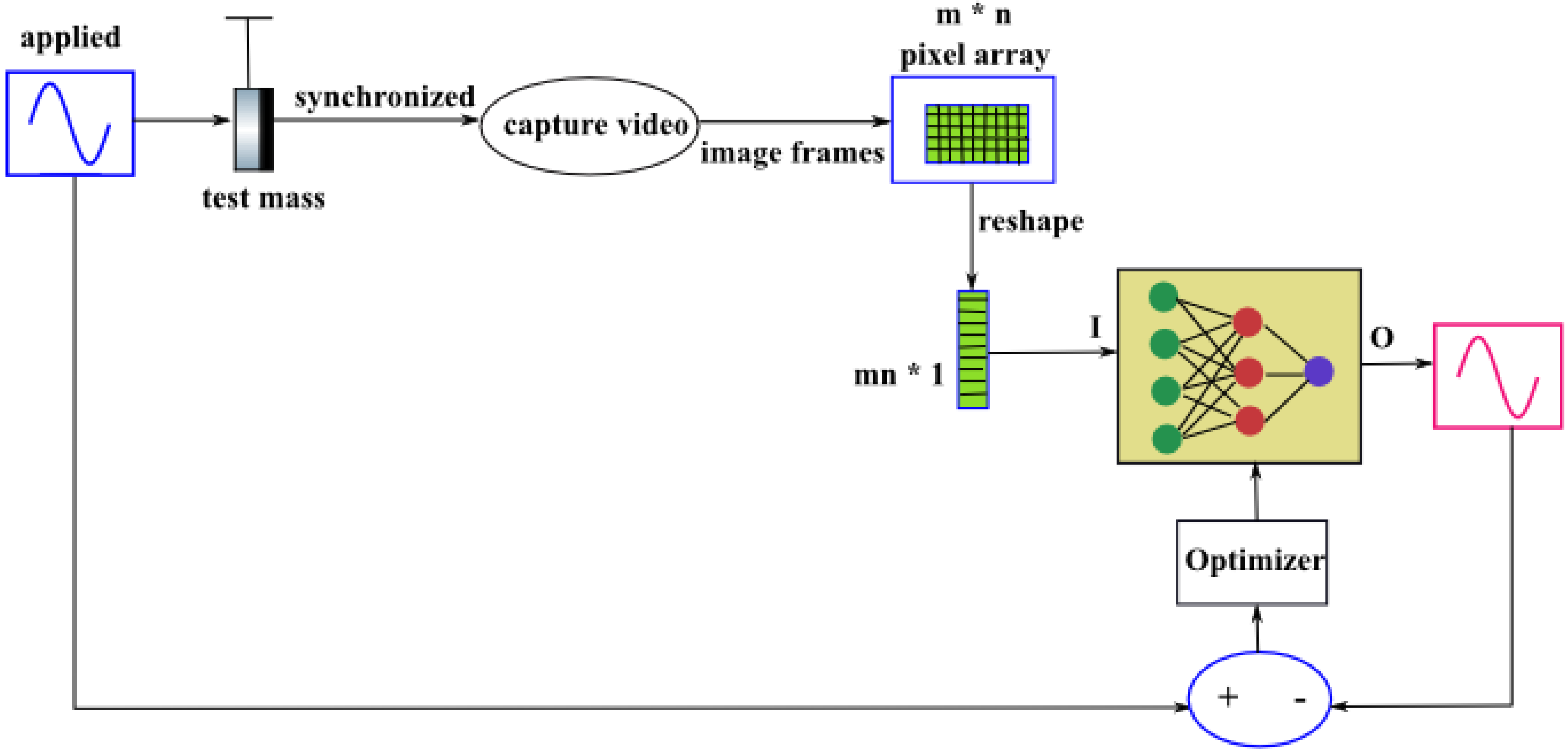


GENERAL TOPOLOGY

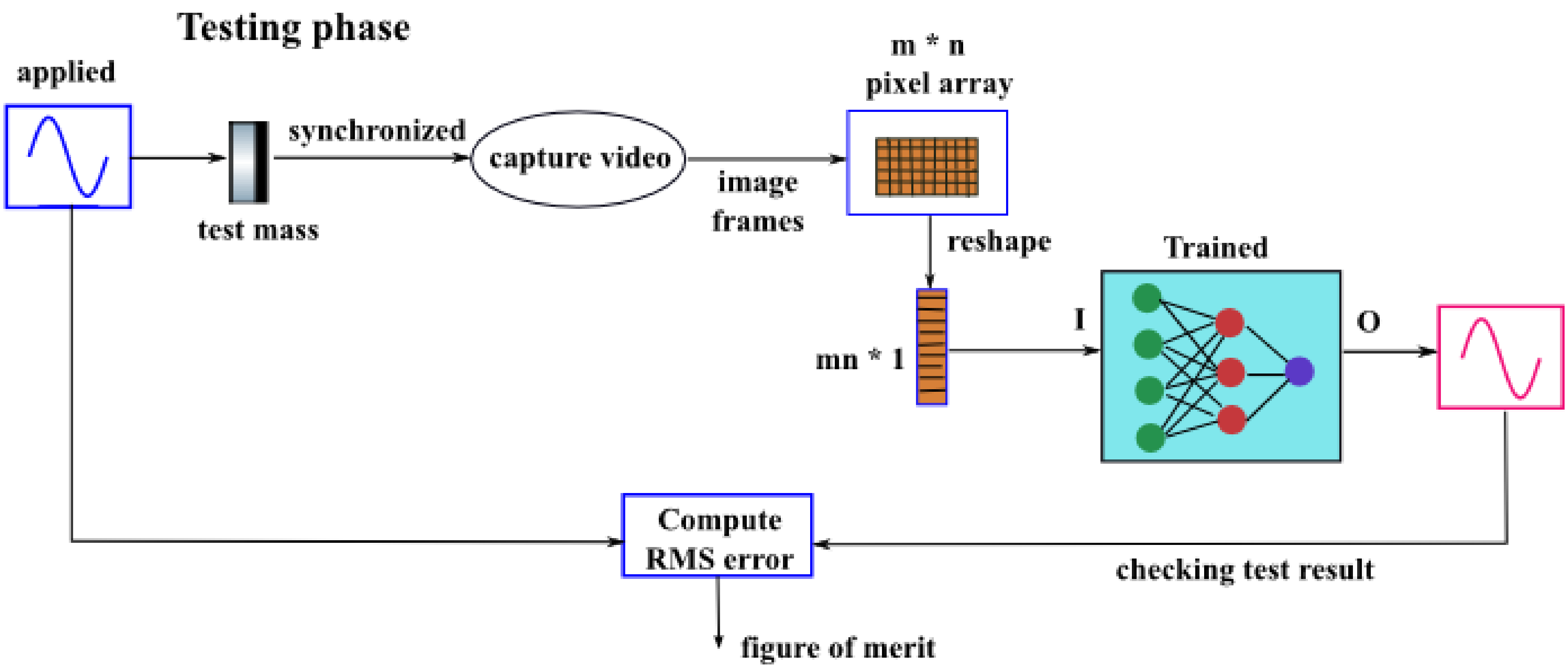


Implementing NN - Supervised Learning

TRAINING



Testing NN

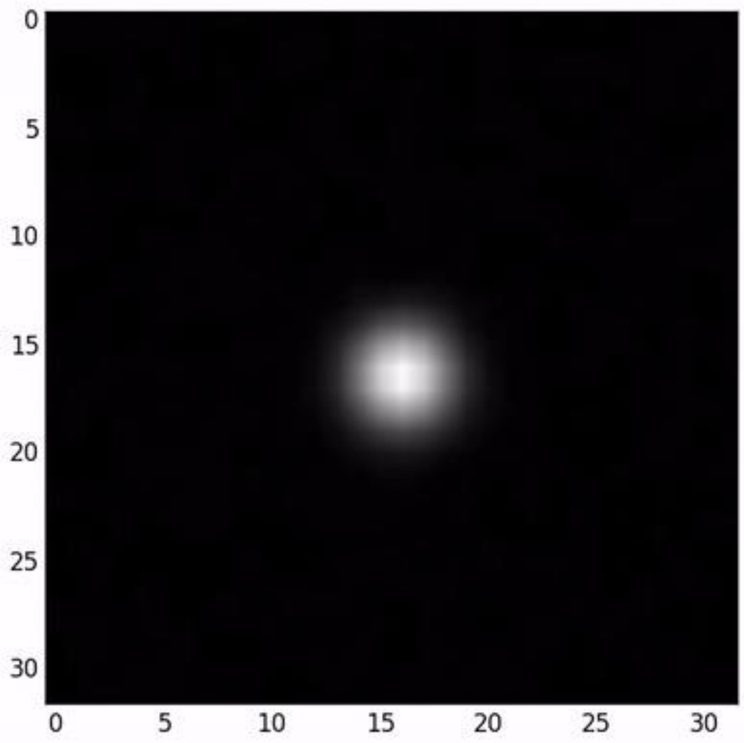


Testing phase
applied
synchronized
capture video
test mass
m * n
pixel array
image
frames
reshape
Trained
mn * 1
I
O
Compute
RMS error
checking test result
figure of merit

Advantage of camera over sensor networks at 40m

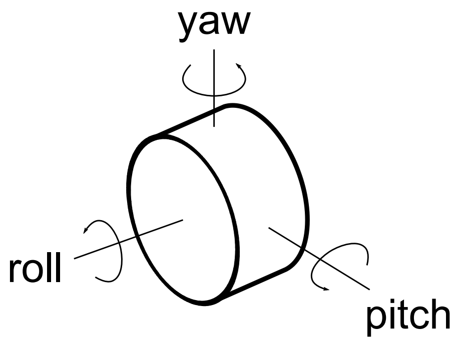
- Neural network training on videos captured using cameras has **larger usable range** for alignment as compared to the sensor network using photodetector at transmitted end.

Simulated video



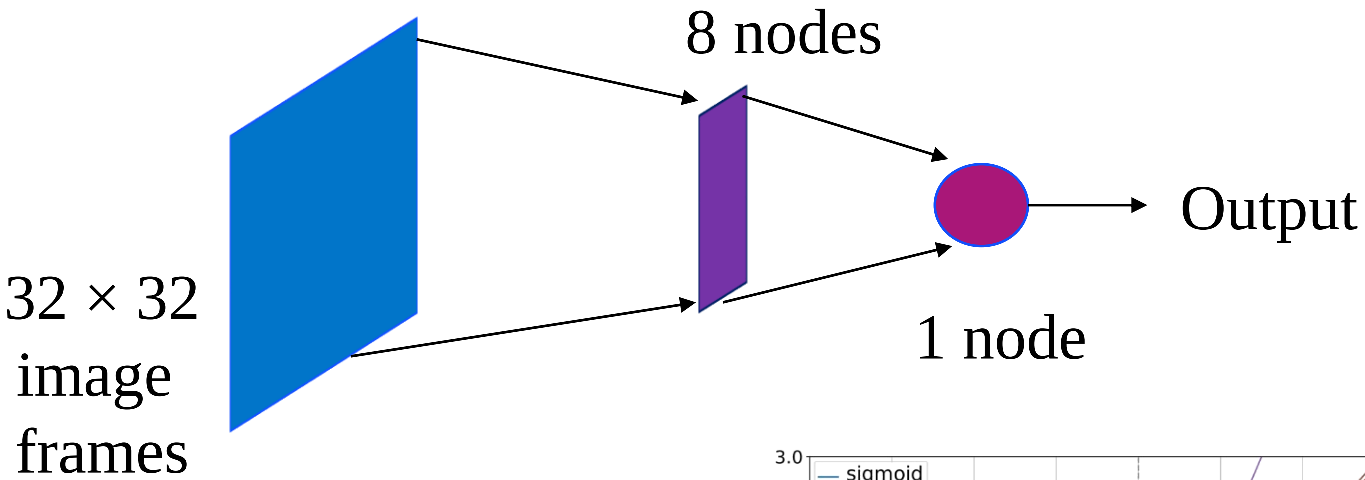
Beam spot moves vertically by applying a sinusoidal signal,

$$s = 3 \times \sin(2\pi\ 0.2\ t)$$

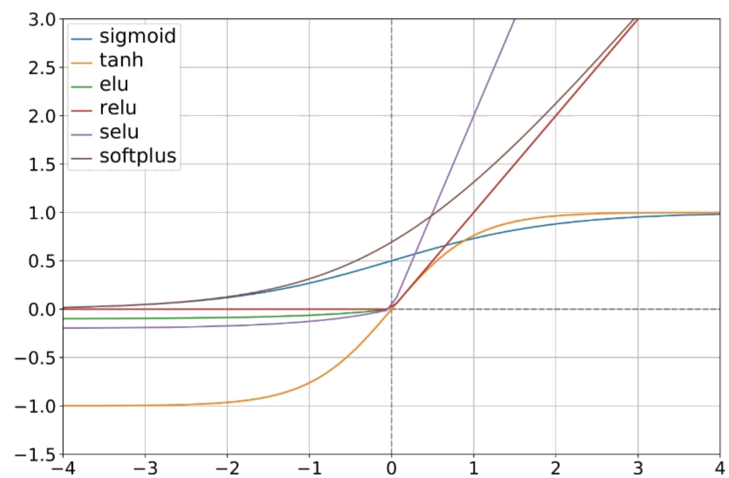


Model topology

Keras

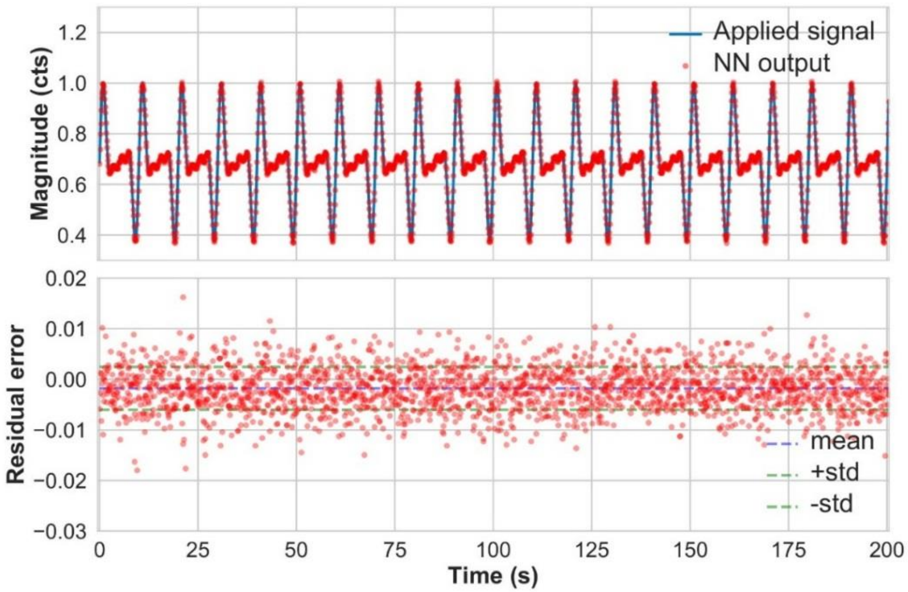


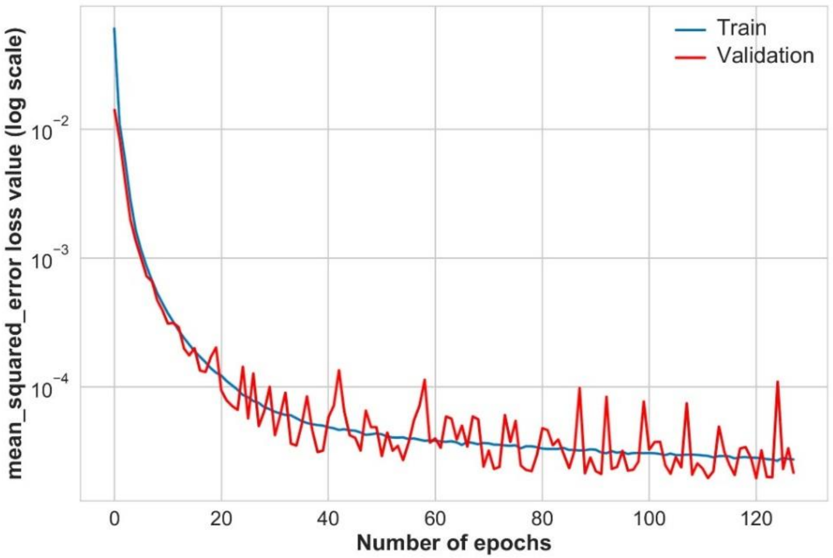
Loss function : mean squared error
Optimizer : Nadam
Activation function of hidden layer : selu
Activation function of output layer : linear



https://keras.io/

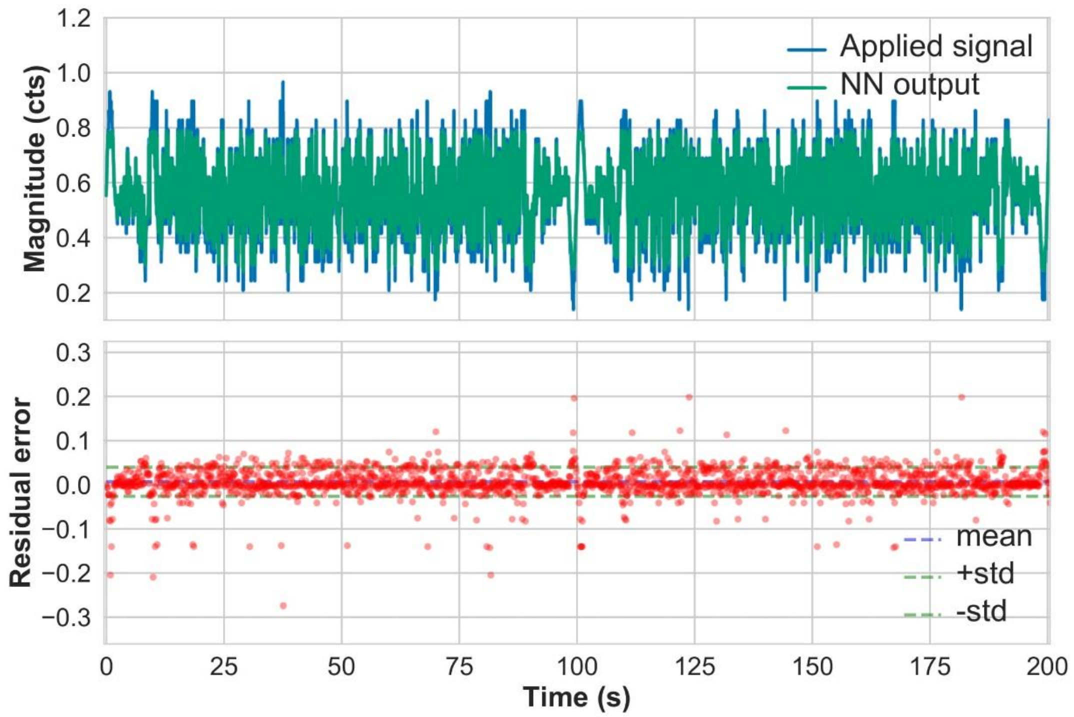
Training NN with multiple sine waves





Testing this trained NN

- Testing with simulated video of beam spot motion by applying 4 sine waves with their amplitudes and frequencies varying with time by random uniform noise ranging from 0 to 0.05



Future Work

- Tried Monte carlo simulation to find the set of hyperparameters that gives minimum loss value but needs to be further explored.
- Train neural network with simulated video of random beam spot motion in pitch & yaw that resembles practical case.
- Convolution neural networks (CNNs) can be used over these for feature extraction and weight sharing. This can even be combined with recurrent neural networks (RNNs) since it stores information about previous trial. This may be advantageous over DNNs for tracking the beam spot since it moves in only a confined space under seismic disturbance.
- Test the trained network with real video data from GigE camera and calibrate test mass motion with the beam spot motion.

Acknowledgement

- I would like to thank my mentors **Rana Adhikari**, **Gautam Venugopalan** and **Koji Arai** for their guidance and support throughout the project.
- Special thanks to Steve, all members at the 40m and my friends.
- Holger Wittel and Gabriele Vajente for their help
- LIGO and Caltech.

THANK YOU!

Hyperparameters

Parameter	Description
Loss function	Difference between actual & predicted output **Mean squared error**, log cosh, mean squared logarithmic error
Optimizer	Optimization algorithm that updates weights & biases. SGD, RMSprop, Adam, **Nadam**
Activation function	tanh, sigmoid, softmax, relu, **selu**, **linear**
Batch size	Number of training inputs in 1 pass Default = **32**
Epochs	Number of times entire dataset passes through NN
No. of nodes in dense layer	Equals the number of bias values
Dropout	To reduce overfitting, randomly selected number of nodes ignored during training

Activation Functions