Laser beam position tracking for LIGO interferometers

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A Brief Overview

- Motivation - the what and why of the beam tracking project

- Methods and results-
  - » Weighted pixel sum
  - » OpenCV based image processing
  - » Major thrust: Neural networks - CNN and LSTM based approach

- Future work

Beam tracking - what and why?

- To detect gravitational waves we would like the LIGO interferometers to operate at highest sensitivity.

- Need laser beam spot to be positioned at particular positions despite seismic noise.

- Therefore, the objective is to build a black box that can look at video feed of scattered light from optic and predict position of beam spot on the optic.

Beam tracking - more of the why

- Why a camera feed? Why not a QPD? Why not A2L measurements?
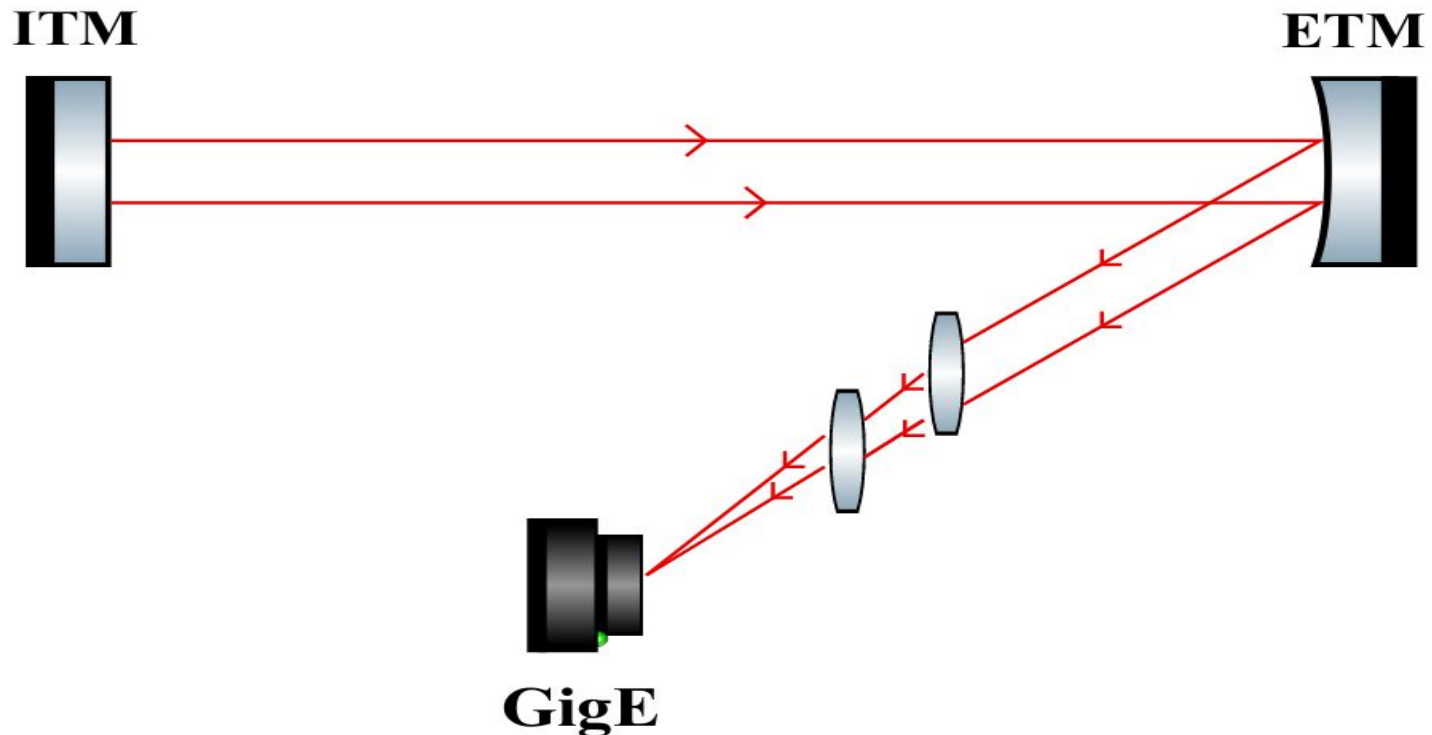
Methods

- Simple techniques
  - » Weighted pixel sum
  - » Image processing

- More sophisticated/general approach
  - » CNNs
  - » CNN-LSTMs

Methods
Simple pixel sum

The centroid of the beam spot is calculated as the weighted sum of the pixel coordinates with the pixel intensities as weights. This is essentially a center of mass calculation.
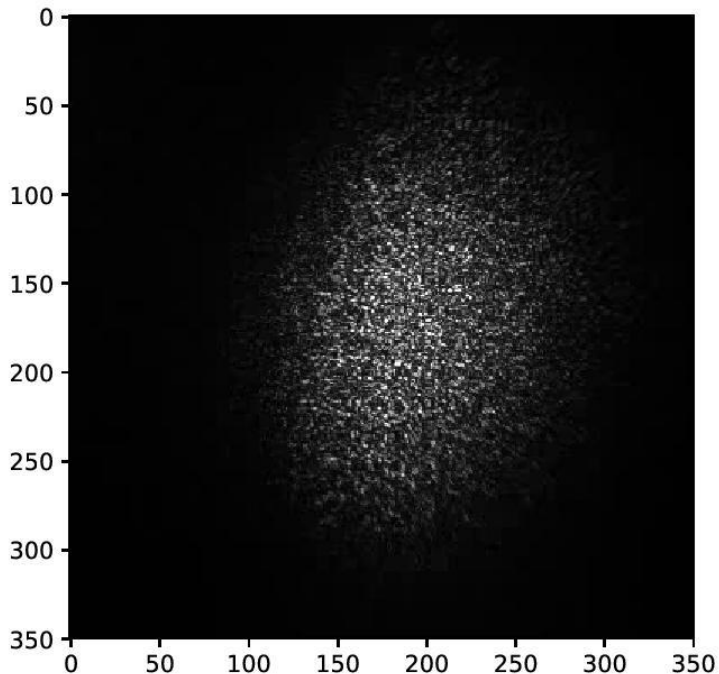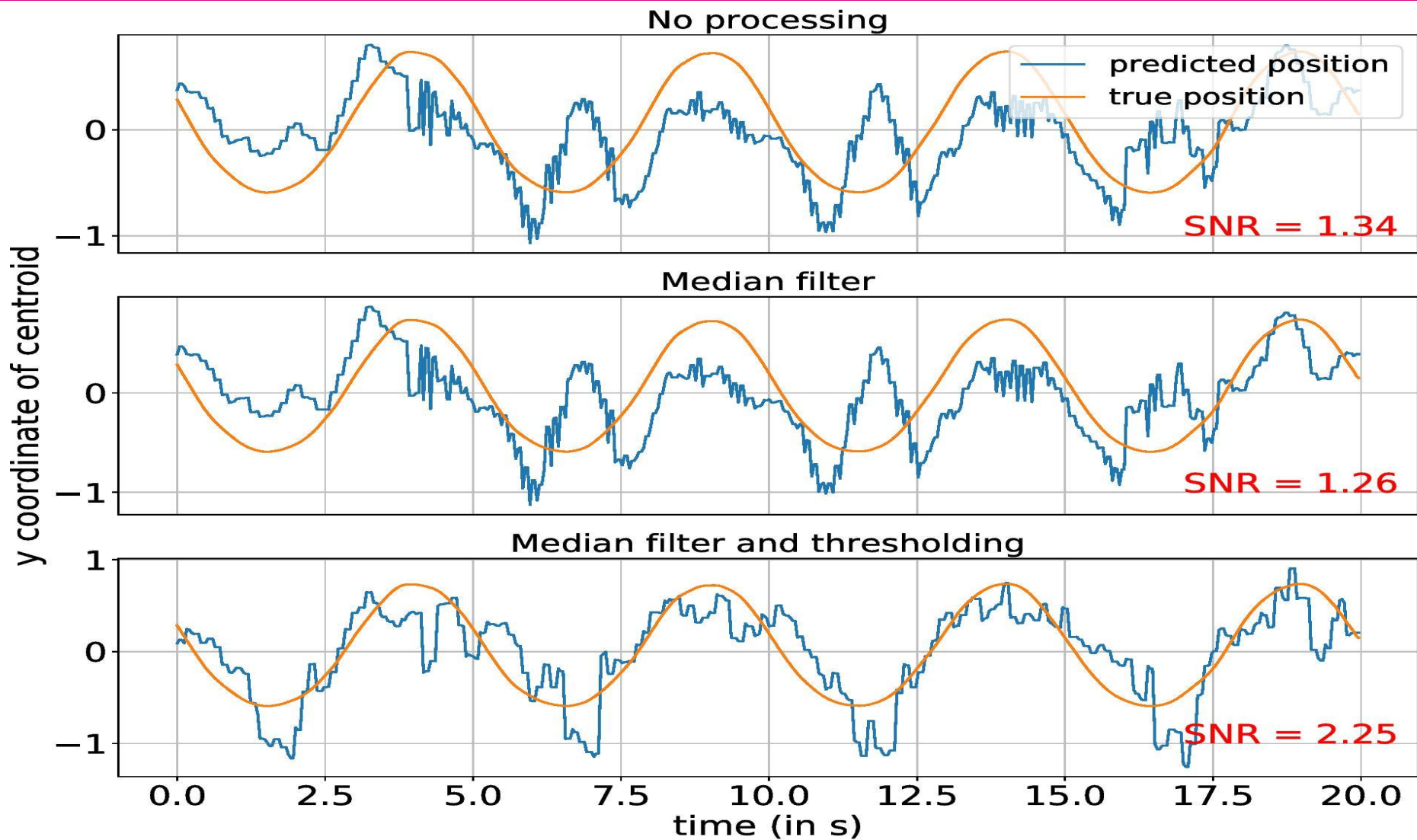

$$X_{centroid} = \frac{\sum\limits_{pixels} X_{pixel} \times (\text{pixel value})}{\sum\limits_{pixels} (\text{pixel value})}$$

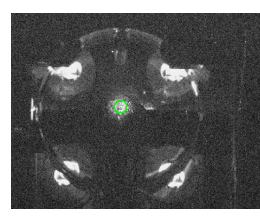$$Y_{centroid} = \frac{\sum\limits_{pixels} Y_{pixel} \times (\text{pixel value})}{\sum\limits_{pixels} (\text{pixel value})}$$
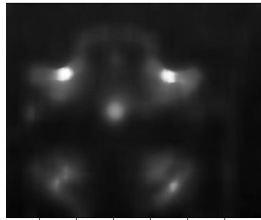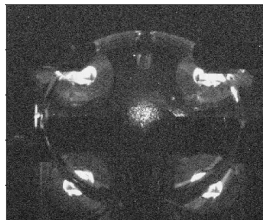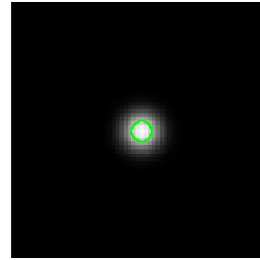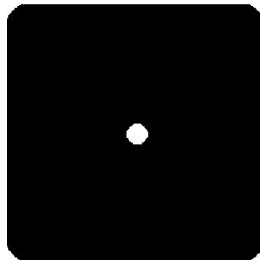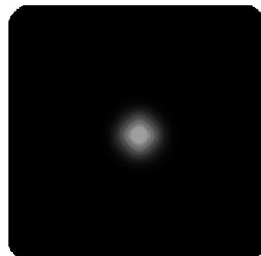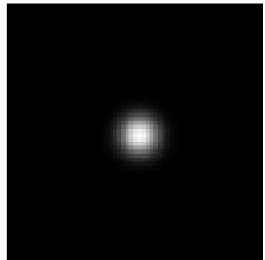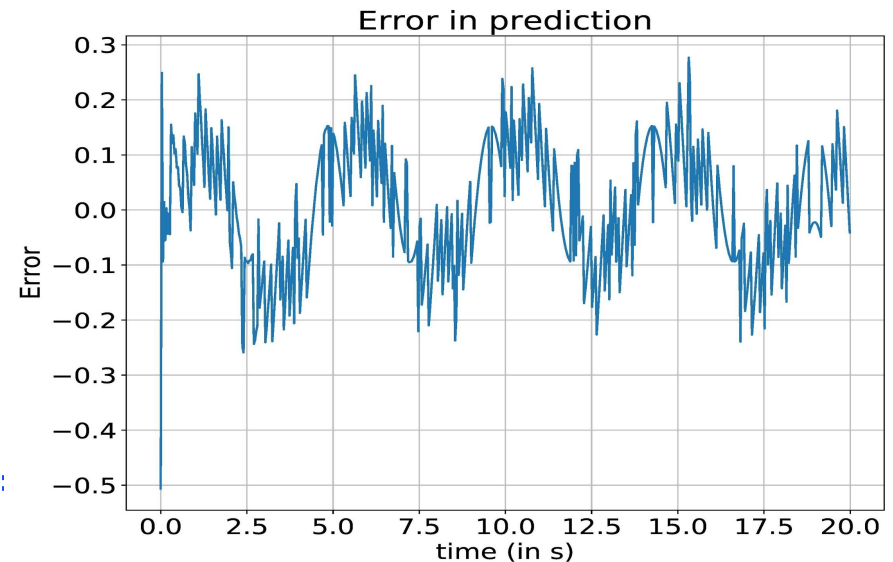
Methods
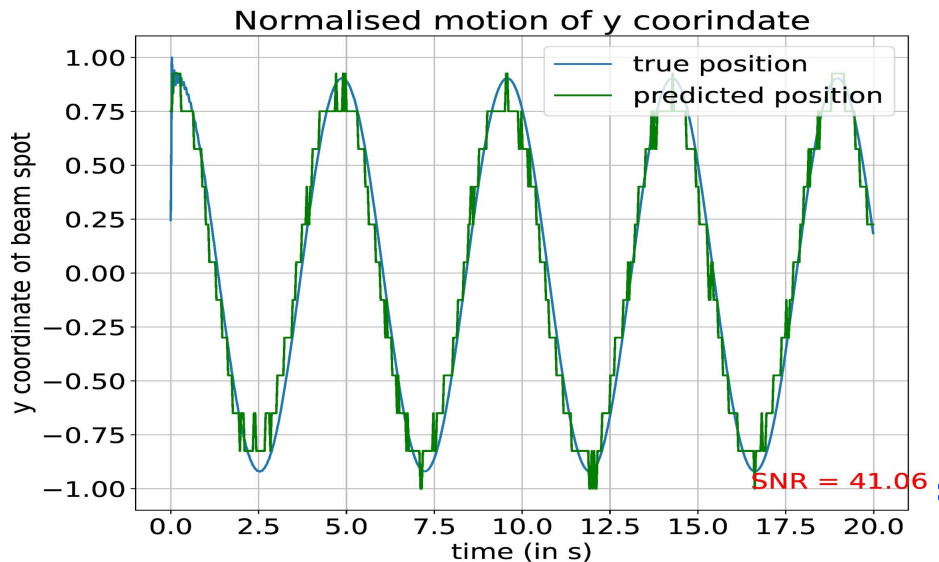## Simple pixel sum
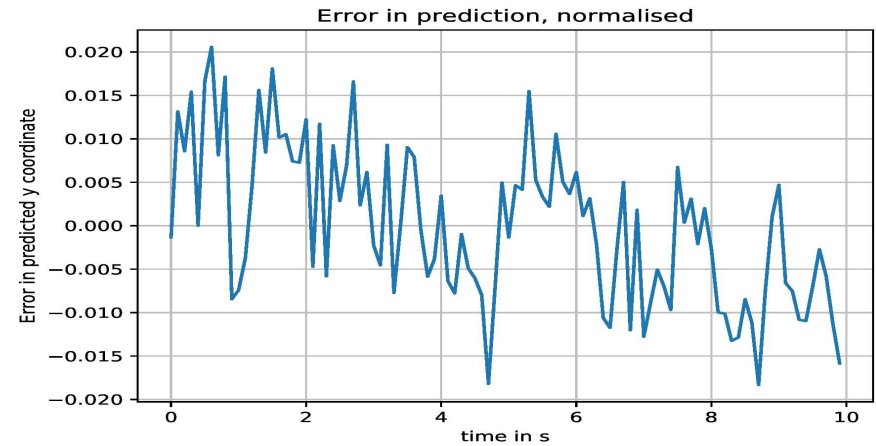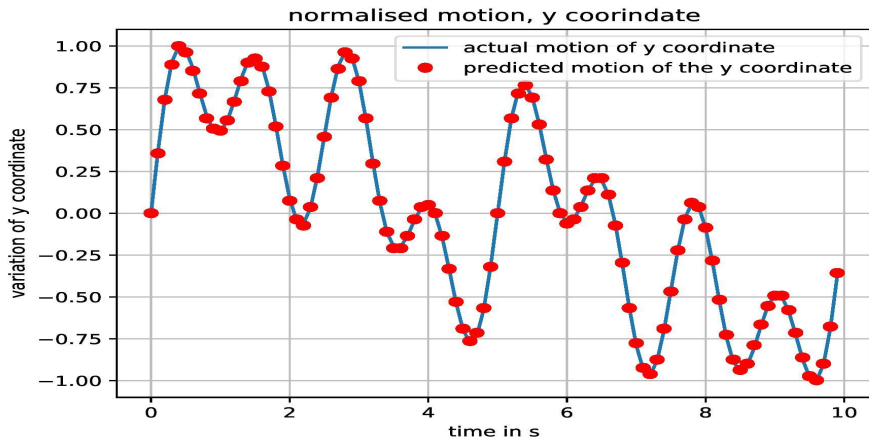
Methods
OpenCV based approach

Methods

OpenCV based approach

Works well for simulated Gaussian beam spot data! Fails for real video data.
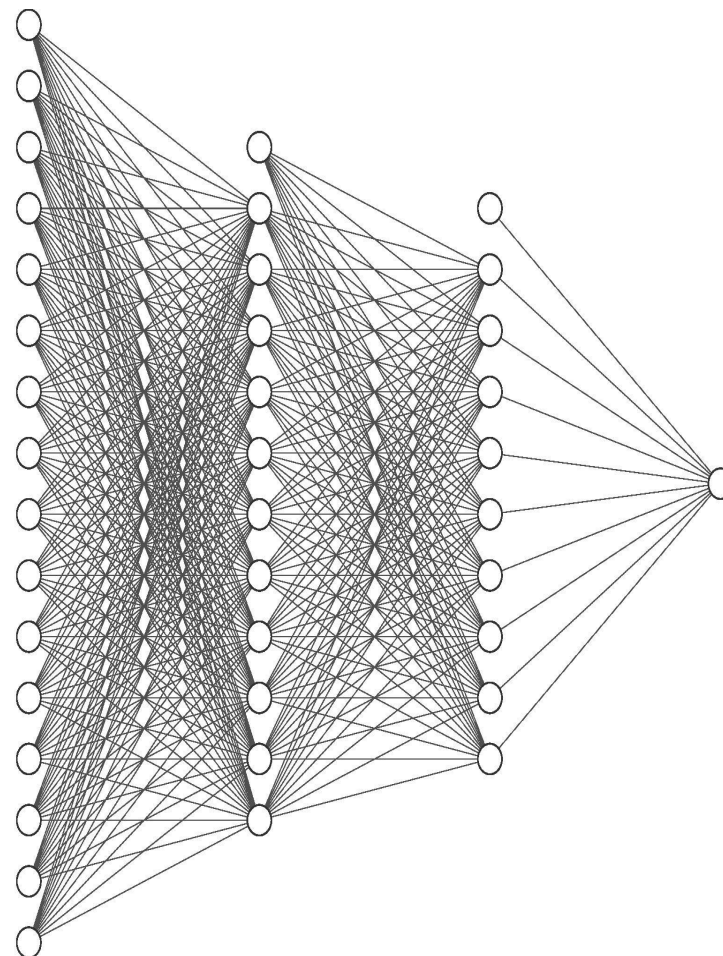
Methods
Why do simple techniques fail?

- The intensity profile of the beam spot is no longer Gaussian.
- The relation between video of beam spot motion and position of the spot is complex and nonlinear.
- Further, these methods are not general and require a degree of hard coding- threshold value for instance.

Methods
Neural Networks
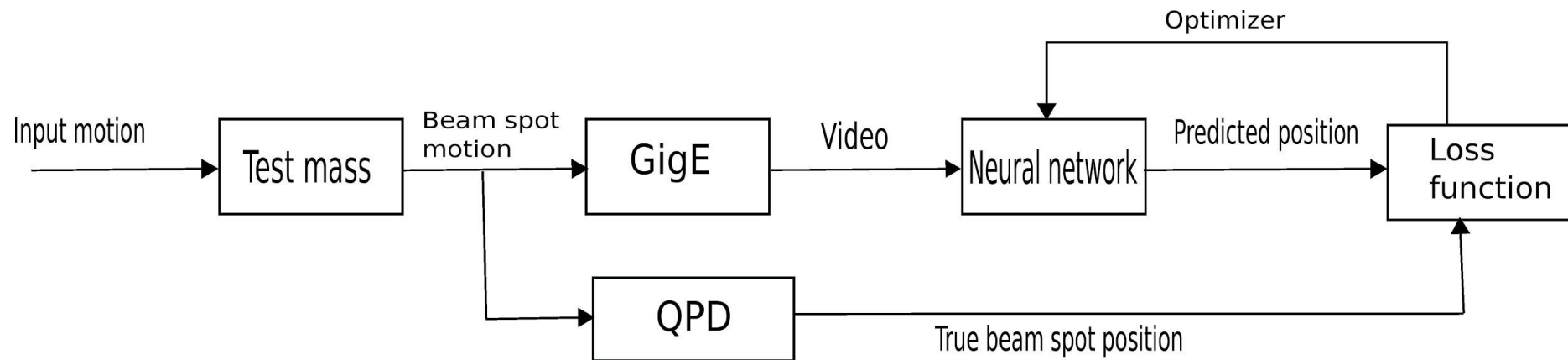
- What are neural networks?
  y = f(x;**W,b**)

- These weights and biases can be "learnt" using optimization algorithms.

- CNNs are used as this is an image processing task. They are better suited to handling images because of weight sharing.

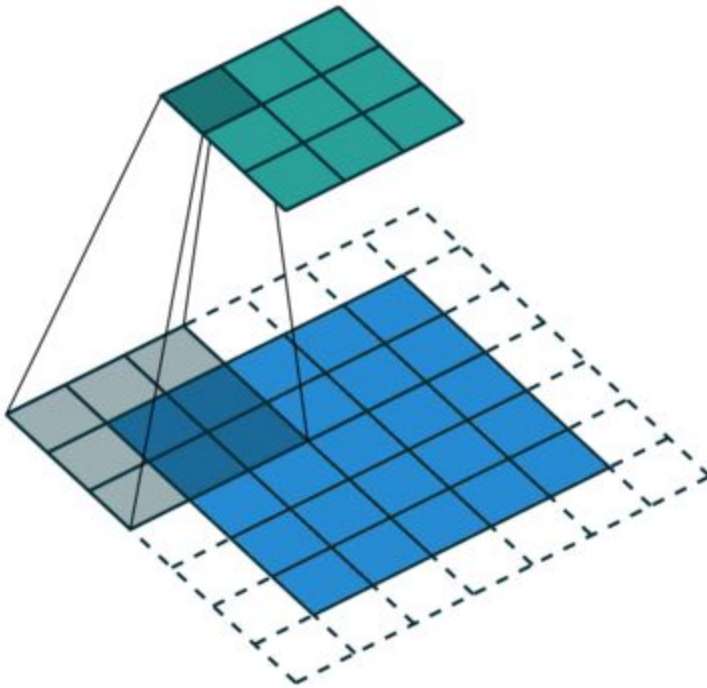# Methods
Neural Networks - the training

- **Optimizer**: Adam
- **Loss function**: Mean squared error
- **Framework**: Keras with tensorflow backend
- **Hidden layer activation**: relu
- **Output layer activation**: linear
- **Regularization**: Dropout
- **Preprocessing**: crop and apply median blur
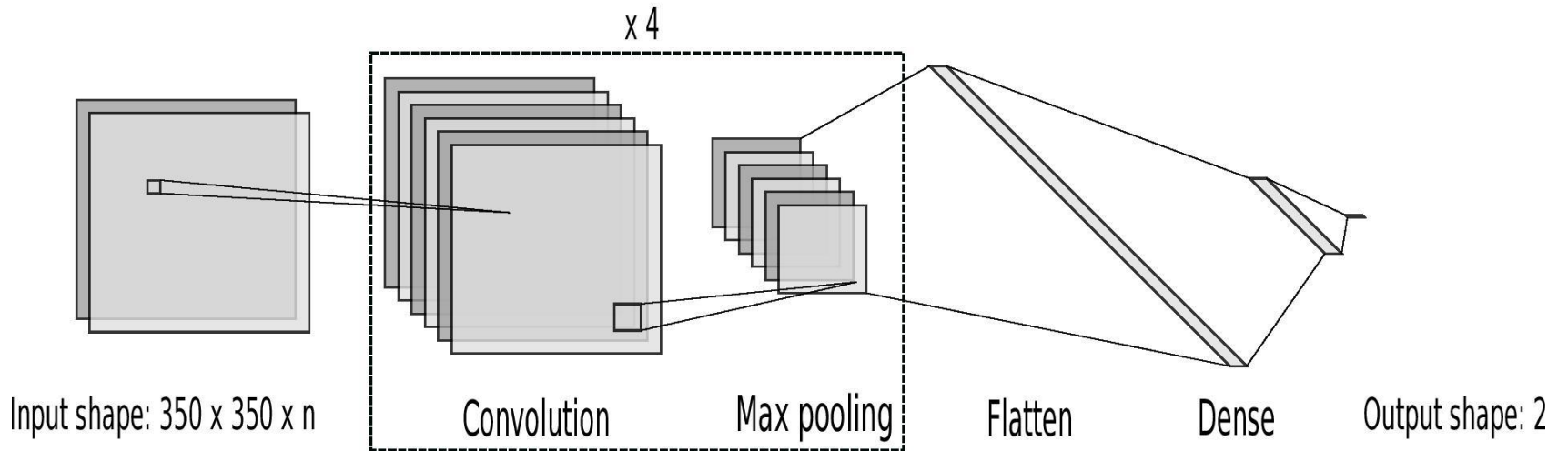
Methods
Neural Networks - CNNs

2D convolution

Max pooling

Graphics retrieved from
https://towardsdatascience.com/a-comprehensive-guide-to-co
nvolutional-neural-networks-the-eli5-way-3bd2b1164a53

Methods
Neural Networks - CNN architecture

x 4

Input shape: 350 x 350 x n | Convolution | Max pooling | Flatten | Dense | Output shape: 2

Methods
Neural Networks- testing

After much hyper parameter tuning, the following learning curves.

Learning curves

Methods

Neural Networks- testing

Y coordinate motion

SNR = 51.92

Error in Y coordinate prediction
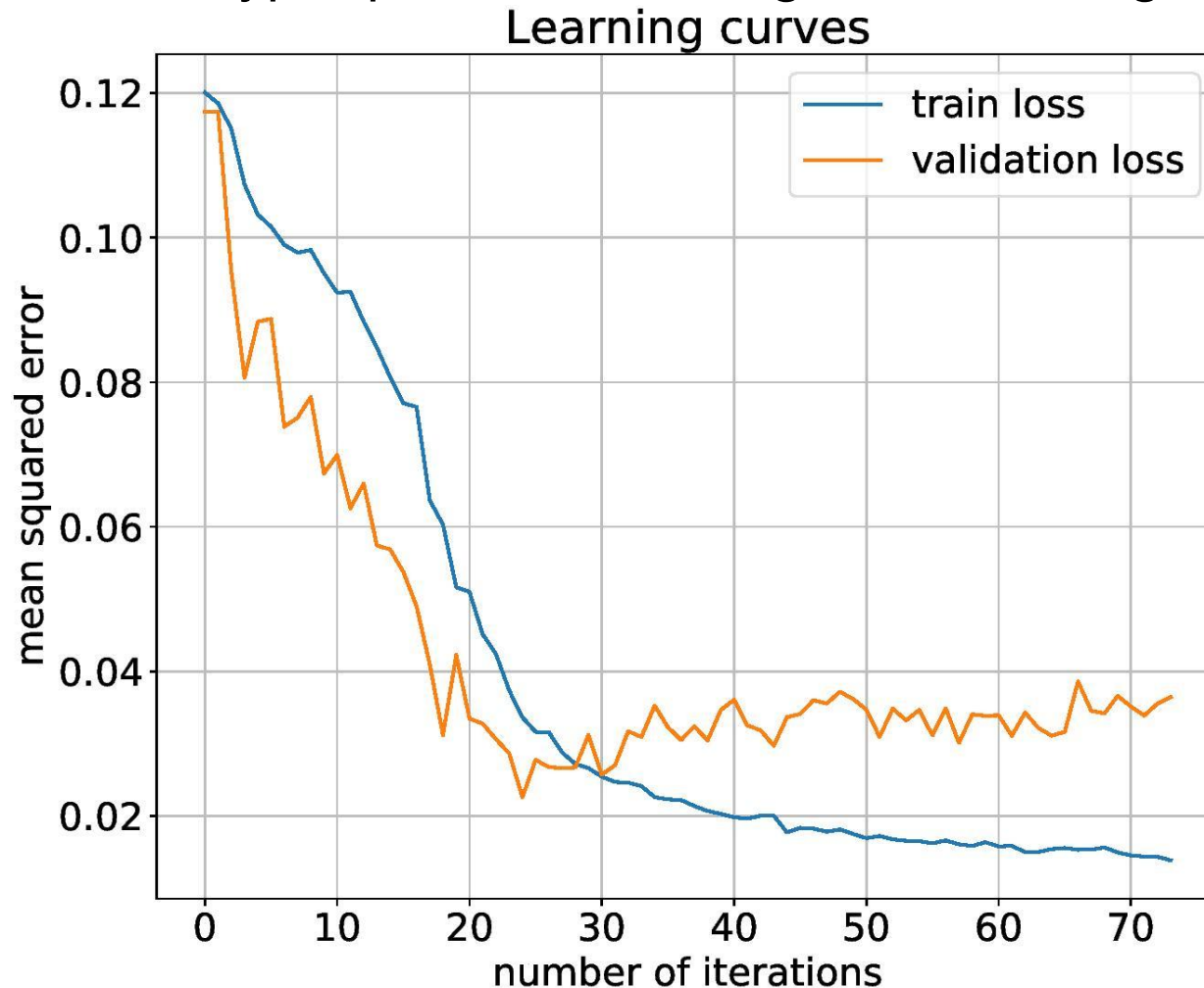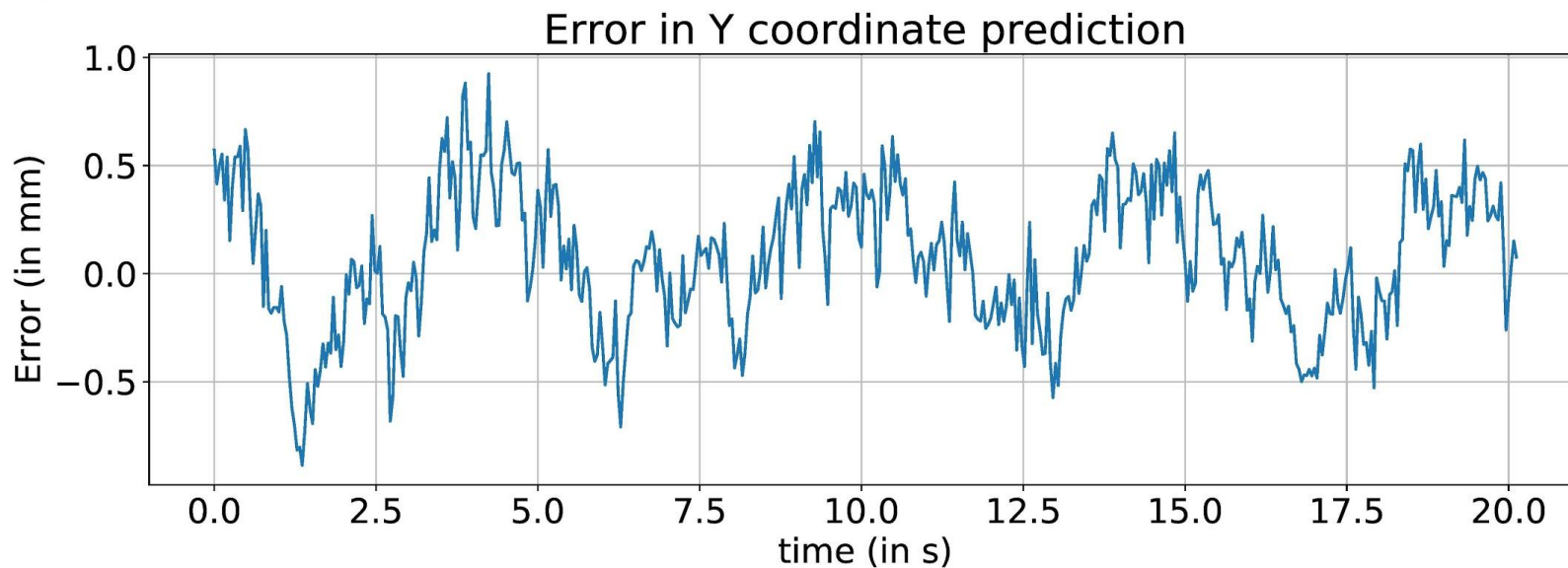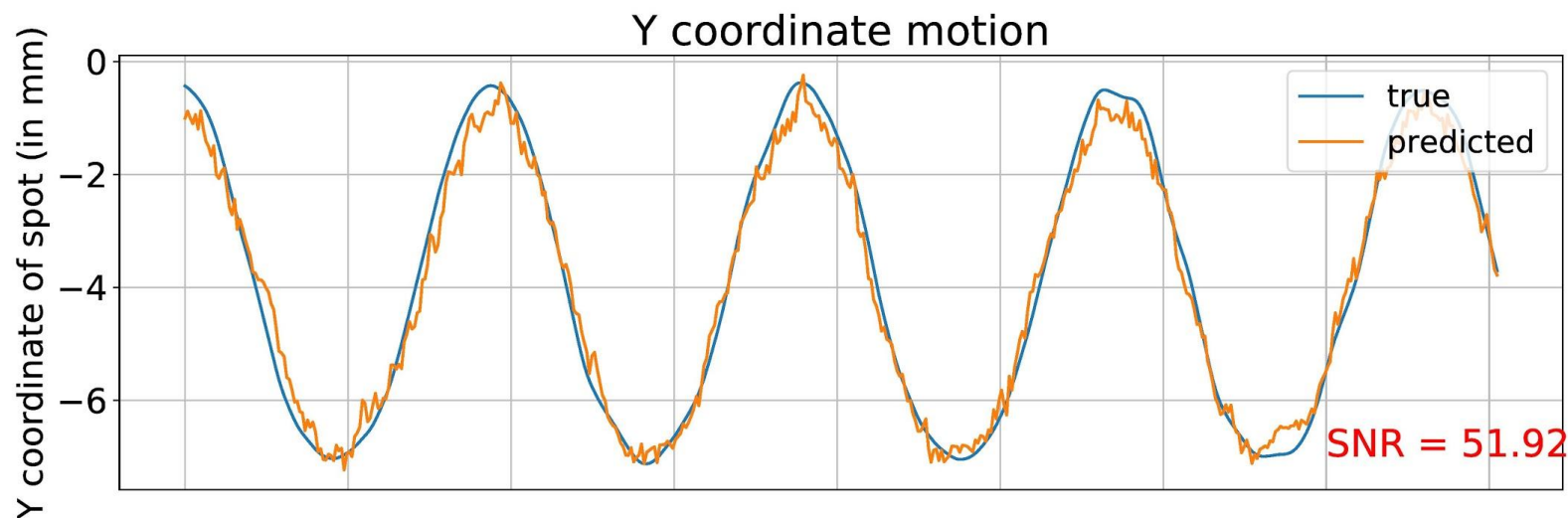
Future work

- Collect and train on data at different frequencies, amplitudes and exposure times.
- GANs for simulation- data generated is similar to real data.
- Transfer learning using weights from the previous experiments.

Summary

- Need for beam tracking

- Traditional image processing

- Deep learning for beam tracking

Thank You!