Report 5

Traditional Filter applied so far:

1. Convolution smoothing

2. Wavelet Smoothing

3. Moving averages

4. Exponential Smoothing

5. Finite Impulse Response filters

6. Infinite Impulse Response filters

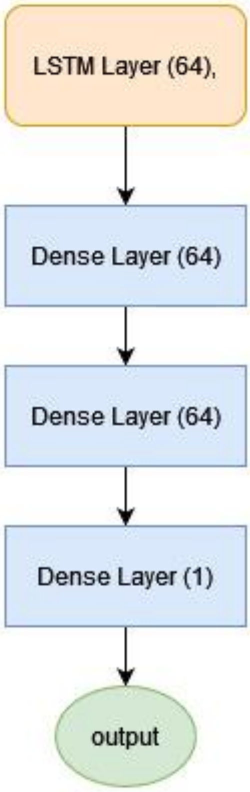
INPUT SAMPLES: 20, 000 input 1D signals of length 512 were used

TESTING: 5,000 samples were used for testing , 6,000 were used for validation.

DEEP LEARNING FILTERS

Below are some neural nets from the past 2 years proven to be effective in signal denoising (mainly 1D ECG signals)

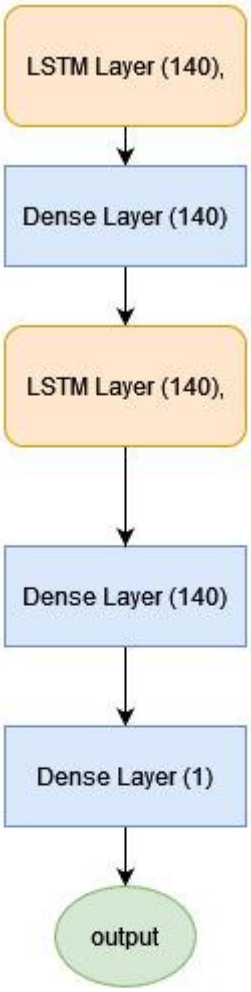
1. DRNN (Deep Recurrent Neural Network)



https://arxiv.org/abs/1807.11551 (July 2018)

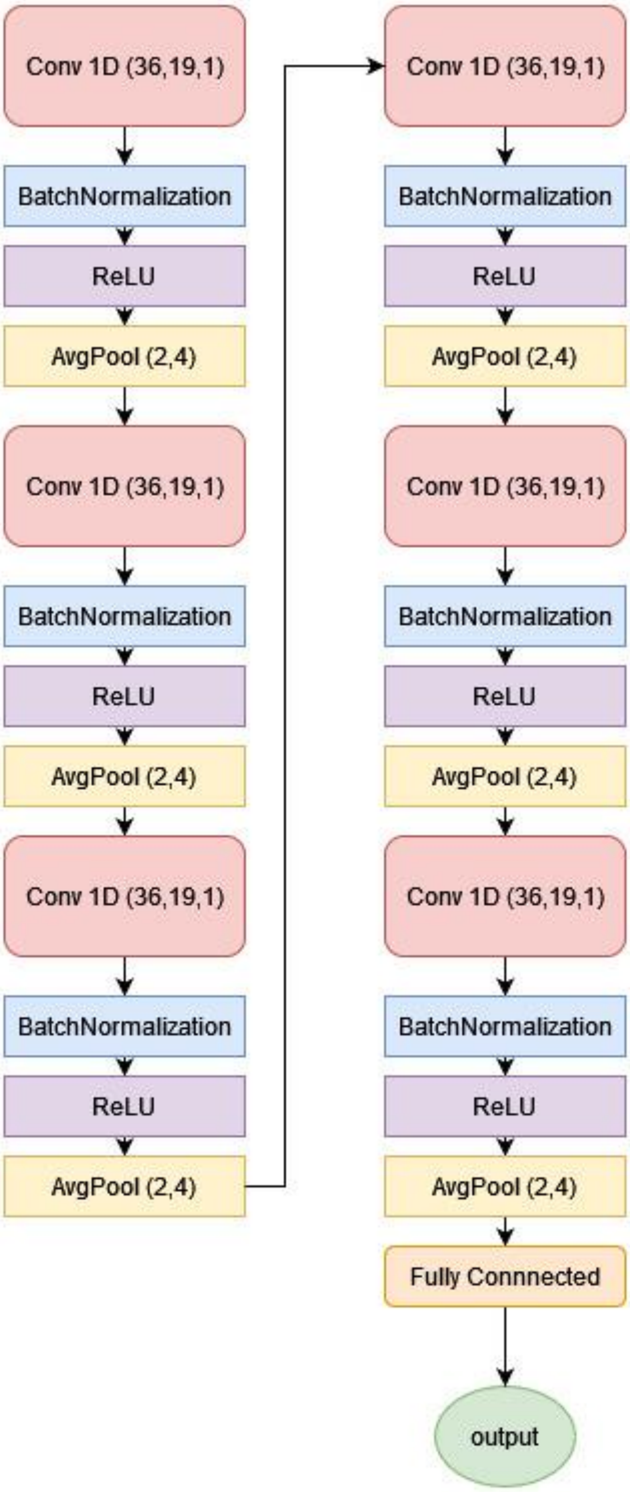
2. LSTM neural network for denoising.

https://ieeexplore.ieee.org/document/8902833 (Sept 2019)



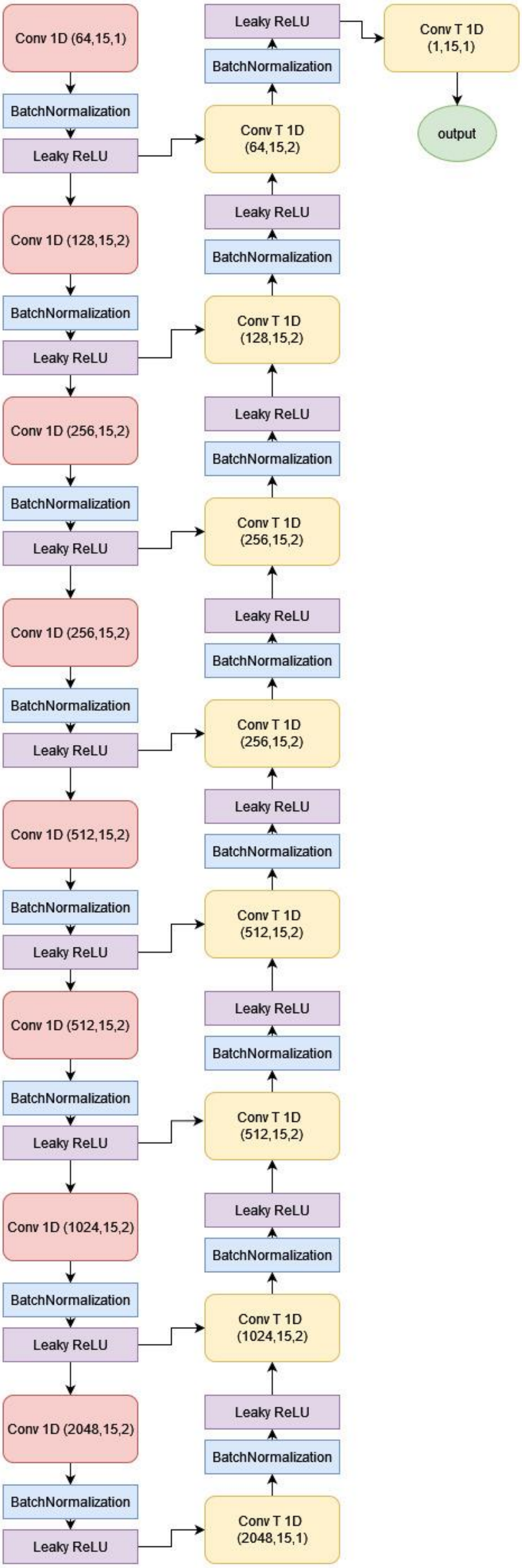
3. CNN Deep learning model for denoising.

https://ieeexplore.ieee.org/document/8902833 (sept 2019)

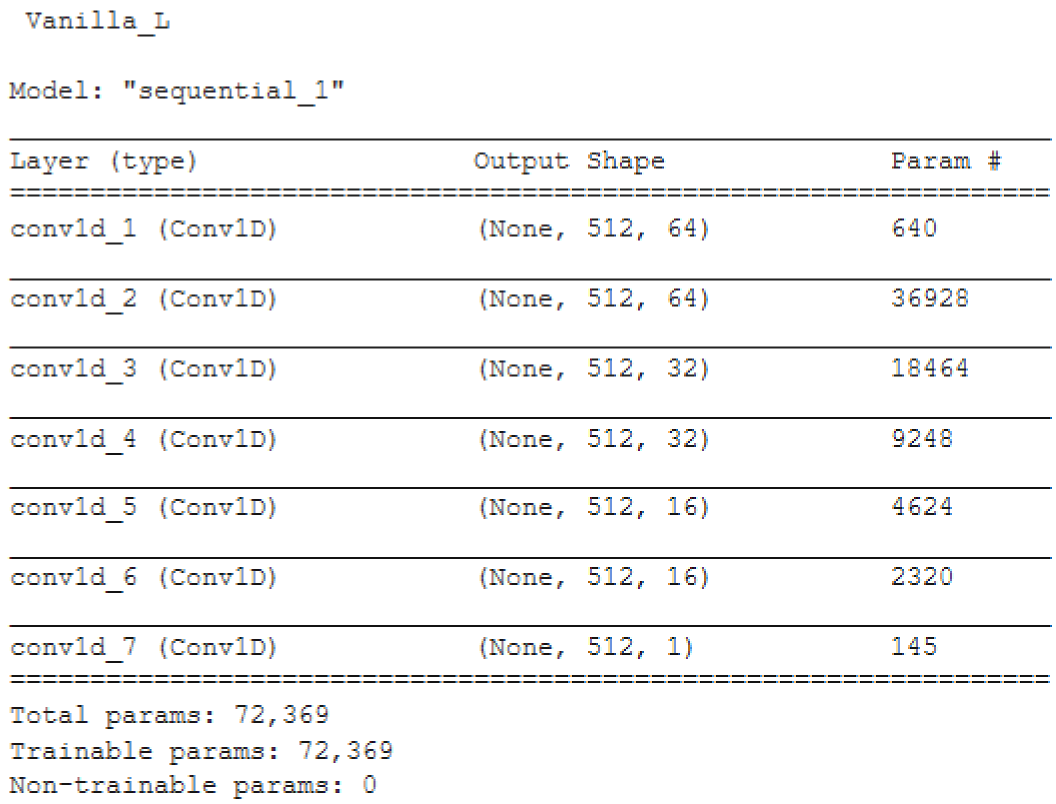


4. CNN encoder decoder

https://pubmed.ncbi.nlm.nih.gov/31918422/ (Feb 2020)


Conv 1D (64,15,1)
BatchNormalization
Leaky ReLU
Conv 1D (128,15,2)
BatchNormalization
Leaky ReLU
Conv 1D (256,15,2)
BatchNormalization
Leaky ReLU
Conv 1D (256,15,2)
BatchNormalization
Leaky ReLU
Conv 1D (512,15,2)
BatchNormalization
Leaky ReLU
Conv 1D (512,15,2)
BatchNormalization
Leaky ReLU
Conv 1D (1024,15,2)
BatchNormalization
Leaky ReLU
Conv 1D (2048,15,2)
BatchNormalization
Leaky ReLU
Leaky ReLU
BatchNormalization
Conv T 1D (64,15,2)
Leaky ReLU
BatchNormalization
Conv T 1D (128,15,2)
Leaky ReLU
BatchNormalization
Conv T 1D (256,15,2)
Leaky ReLU
BatchNormalization
Conv T 1D (256,15,2)
Leaky ReLU
BatchNormalization
Conv T 1D (512,15,2)
Leaky ReLU
BatchNormalization
Conv T 1D (512,15,2)
Leaky ReLU
BatchNormalization
Conv T 1D (1024,15,2)
Leaky ReLU
BatchNormalization
Conv T 1D (2048,15,1)
Conv T 1D (1,15,1)
output

5. Vanilla Filter

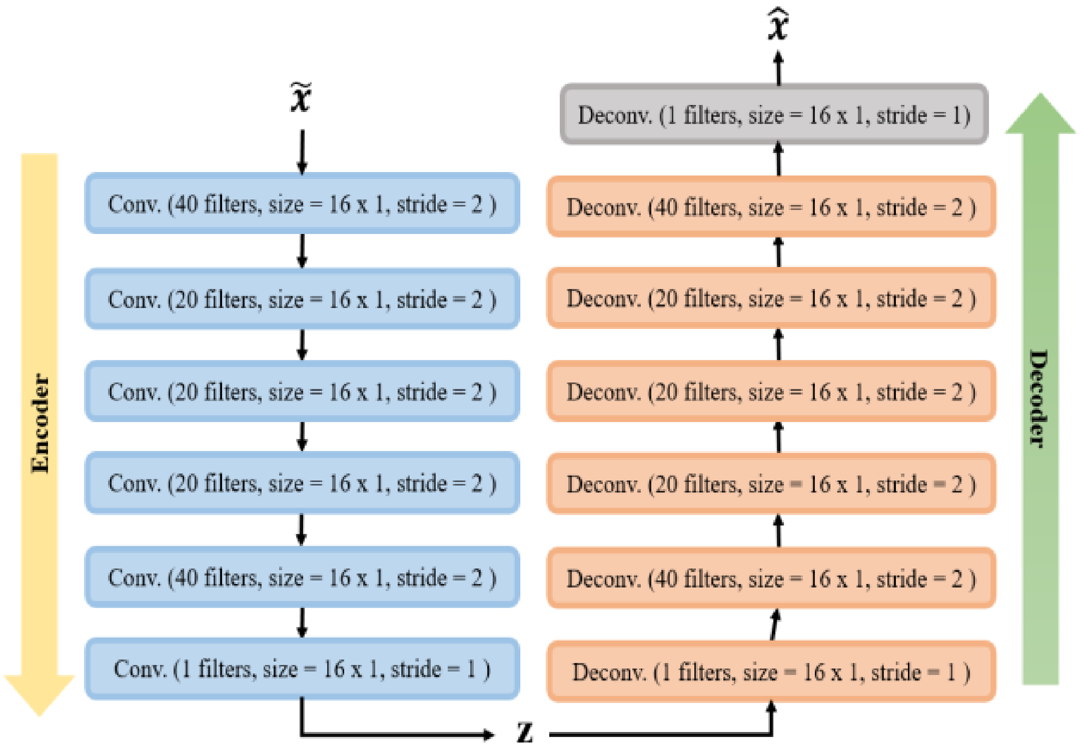


```
 Vanilla_L

Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv1d_1 (Conv1D)            (None, 512, 64)           640       
_________________________________________________________________
conv1d_2 (Conv1D)            (None, 512, 64)           36928     
_________________________________________________________________
conv1d_3 (Conv1D)            (None, 512, 32)           18464     
_________________________________________________________________
conv1d_4 (Conv1D)            (None, 512, 32)           9248      
_________________________________________________________________
conv1d_5 (Conv1D)            (None, 512, 16)           4624      
_________________________________________________________________
conv1d_6 (Conv1D)            (None, 512, 16)           2320      
_________________________________________________________________
conv1d_7 (Conv1D)            (None, 512, 1)            145       
=================================================================
Total params: 72,369
Trainable params: 72,369
Non-trainable params: 0
```

https://arxiv.org/pdf/2101.03423.pdf   (Jan 2021)

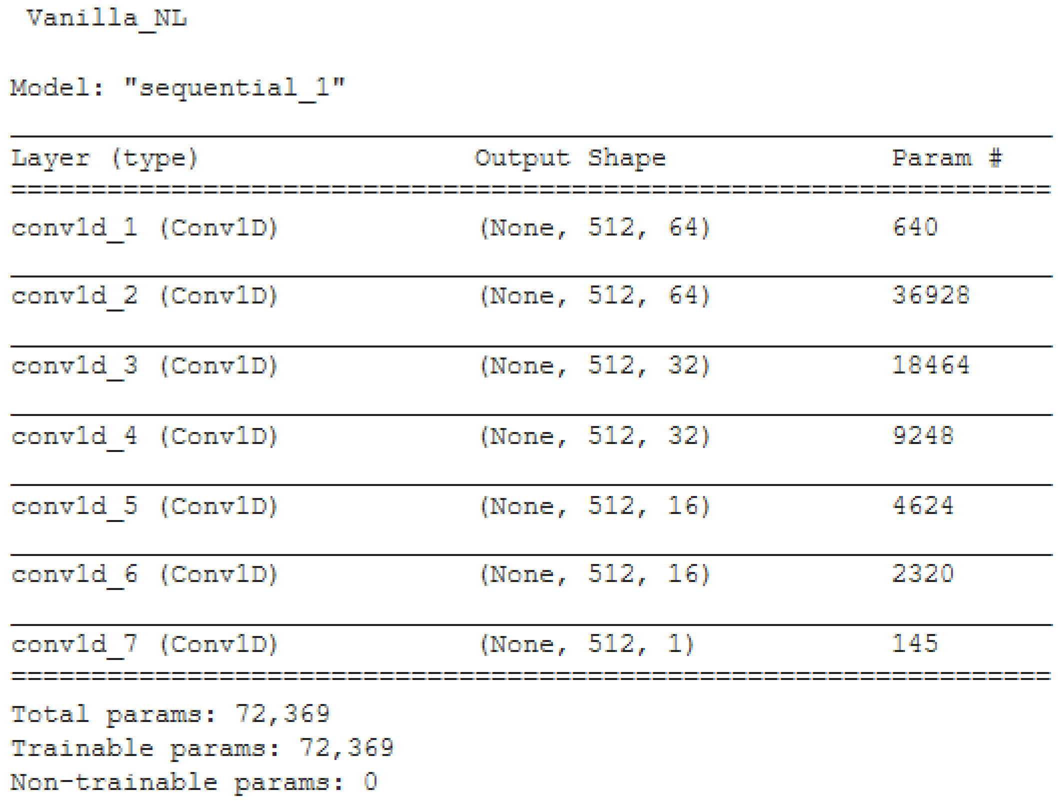
6. Full Convolution Net Denoising Autoencoders.



$\tilde{x}$
Conv. (40 filters, size = 16 x 1, stride = 2)
Conv. (20 filters, size = 16 x 1, stride = 2)
Conv. (20 filters, size = 16 x 1, stride = 2)
Conv. (20 filters, size = 16 x 1, stride = 2)
Conv. (40 filters, size = 16 x 1, stride = 2)
Conv. (1 filters, size = 16 x 1, stride = 1)
Encoder
Z
$\hat{x}$
Deconv. (1 filters, size = 16 x 1, stride = 1)
Deconv. (40 filters, size = 16 x 1, stride = 2)
Deconv. (20 filters, size = 16 x 1, stride = 2)
Deconv. (20 filters, size = 16 x 1, stride = 2)
Deconv. (20 filters, size = 16 x 1, stride = 2)
Deconv. (40 filters, size = 16 x 1, stride = 2)
Deconv. (1 filters, size = 16 x 1, stride = 1)
Decoder

https://ieeexplore.ieee.org/document/8693790   (April 2019)

7. Vanilla NL Filter



```
 Vanilla_NL

Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv1d_1 (Conv1D)            (None, 512, 64)           640
_________________________________________________________________
conv1d_2 (Conv1D)            (None, 512, 64)           36928
_________________________________________________________________
conv1d_3 (Conv1D)            (None, 512, 32)           18464
_________________________________________________________________
conv1d_4 (Conv1D)            (None, 512, 32)           9248
_________________________________________________________________
conv1d_5 (Conv1D)            (None, 512, 16)           4624
_________________________________________________________________
conv1d_6 (Conv1D)            (None, 512, 16)           2320
_________________________________________________________________
conv1d_7 (Conv1D)            (None, 512, 1)            145
=================================================================
Total params: 72,369
Trainable params: 72,369
Non-trainable params: 0
```

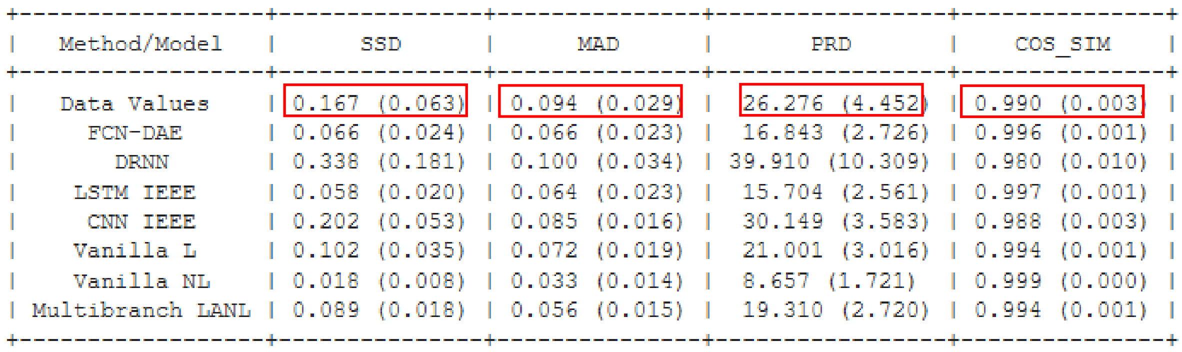
https://arxiv.org/pdf/2101.03423.pdf (Jan 2021)

8. Deep Filter

--model photo.

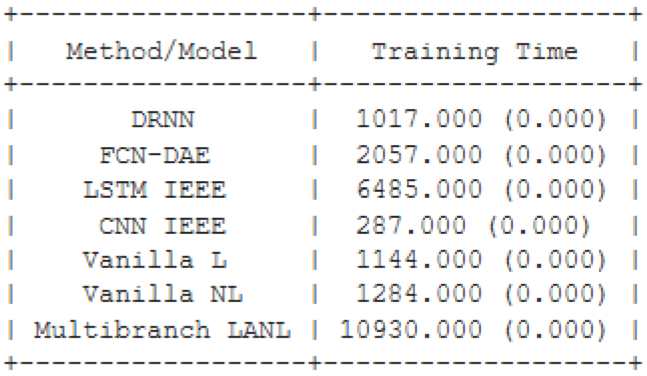
Results:

Sum of Square Differences, Mean Absolute Differences, Percent Root Mean Square Differences, Cosine-Similarity.



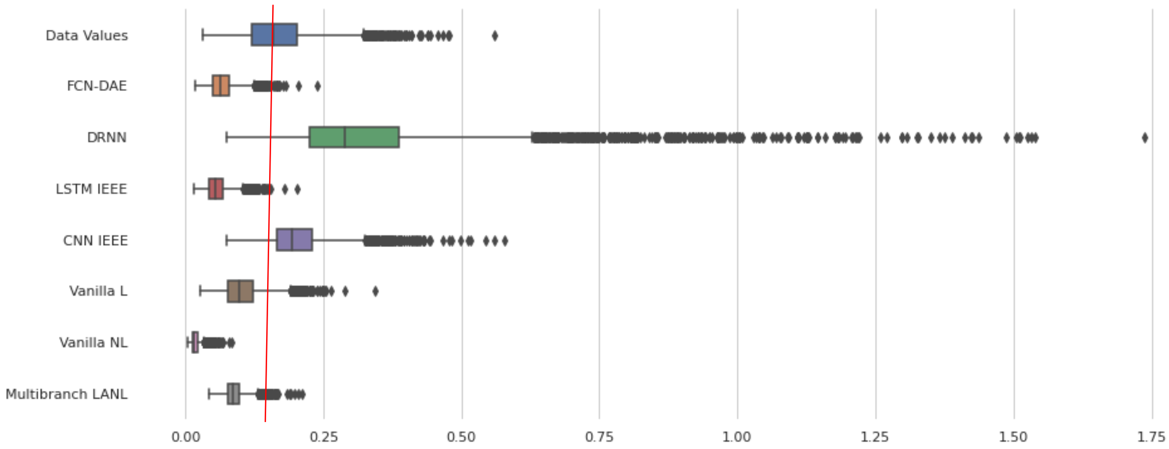
```
+-----------------+---------------+---------------+-----------------+---------------+
|   Method/Model  |      SSD      |      MAD      |       PRD       |    COS_SIM    |
+-----------------+---------------+---------------+-----------------+---------------+
|   Data Values   | 0.167 (0.063) | 0.094 (0.029) |  26.276 (4.452) | 0.990 (0.003) |
|     FCN-DAE     | 0.066 (0.024) | 0.066 (0.023) |  16.843 (2.726) | 0.996 (0.001) |
|       DRNN      | 0.338 (0.181) | 0.100 (0.034) | 39.910 (10.309) | 0.980 (0.010) |
|    LSTM IEEE    | 0.058 (0.020) | 0.064 (0.023) |  15.704 (2.561) | 0.997 (0.001) |
|     CNN IEEE    | 0.202 (0.053) | 0.085 (0.016) |  30.149 (3.583) | 0.988 (0.003) |
|    Vanilla L    | 0.102 (0.035) | 0.072 (0.019) |  21.001 (3.016) | 0.994 (0.001) |
|    Vanilla NL   | 0.018 (0.008) | 0.033 (0.014) |  8.657 (1.721)  | 0.999 (0.000) |
| Multibranch LANL| 0.089 (0.018) | 0.056 (0.015) |  19.310 (2.720) | 0.994 (0.001) |
+-----------------+---------------+---------------+-----------------+---------------+
```

Training Time for Models: (in secs)

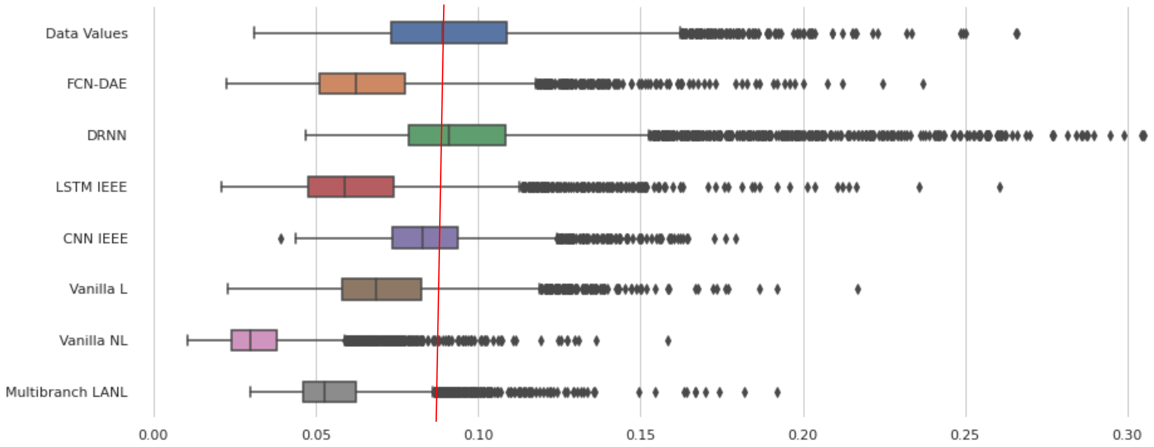


```
+------------------+-------------------+
|   Method/Model   |   Training Time   |
+------------------+-------------------+
|       DRNN       |  1017.000 (0.000) |
|     FCN-DAE      |  2057.000 (0.000) |
|    LSTM IEEE     |  6485.000 (0.000) |
|     CNN IEEE     |  287.000 (0.000)  |
|    Vanilla L     |  1144.000 (0.000) |
|    Vanilla NL    |  1284.000 (0.000) |
| Multibranch LANL | 10930.000 (0.000) |
+------------------+-------------------+
```

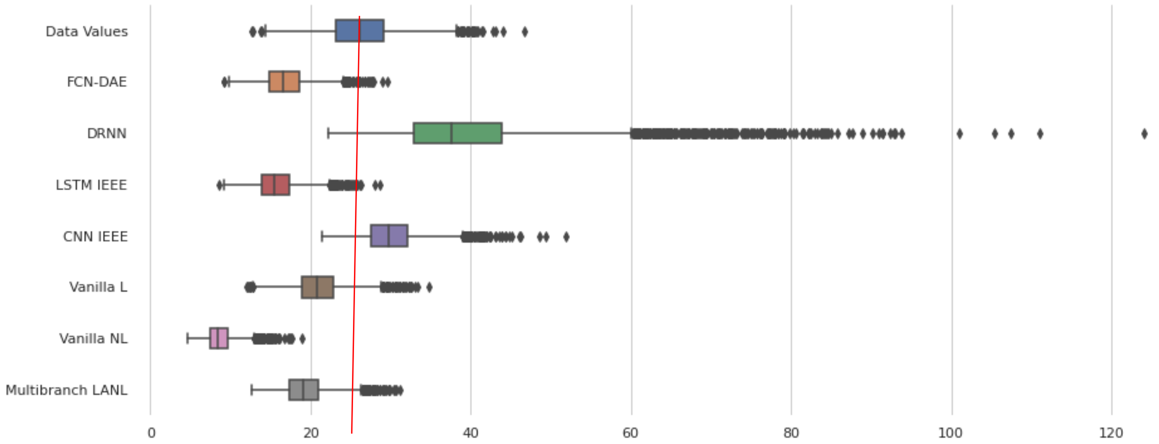
Sum of Squared Distances



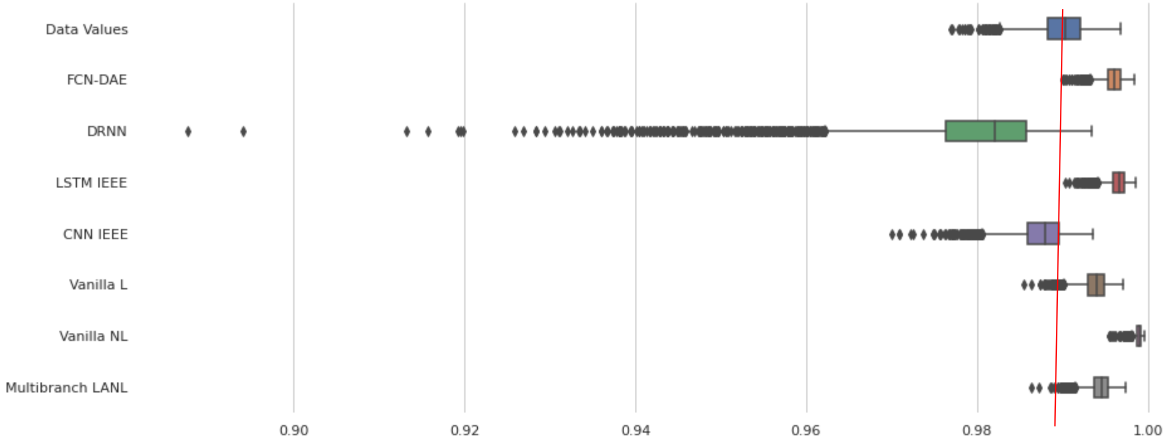
Mean Absolute Deviations



Percent Root Mean Square Differences

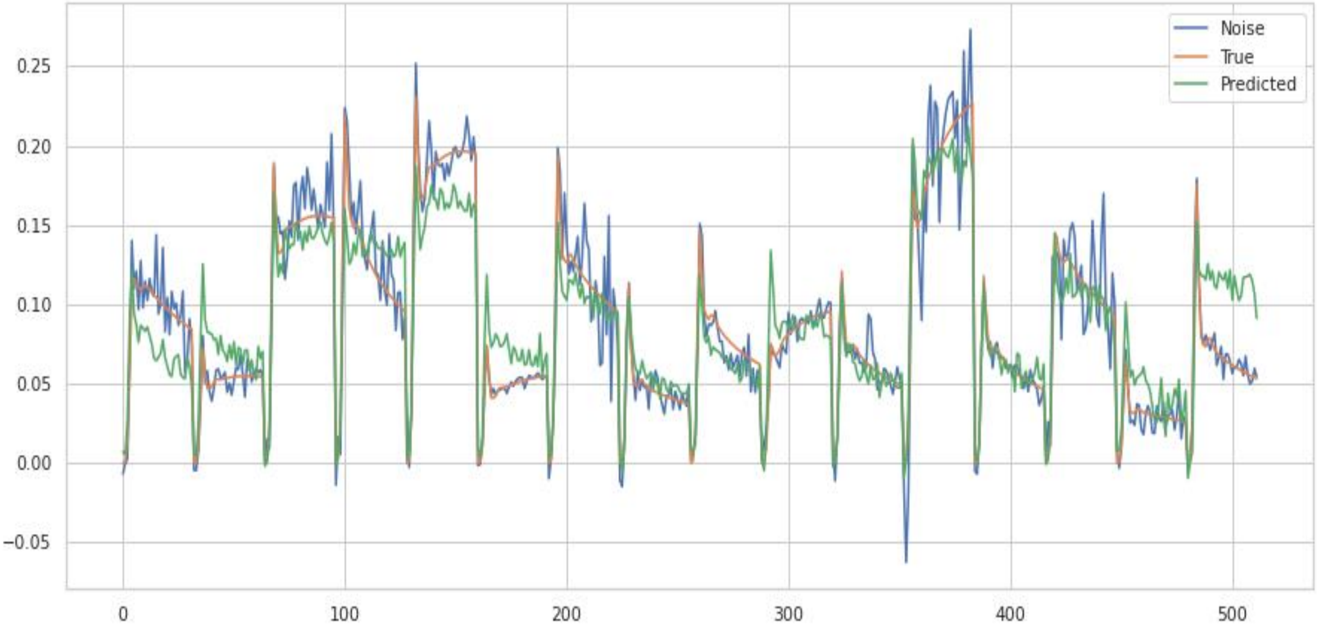


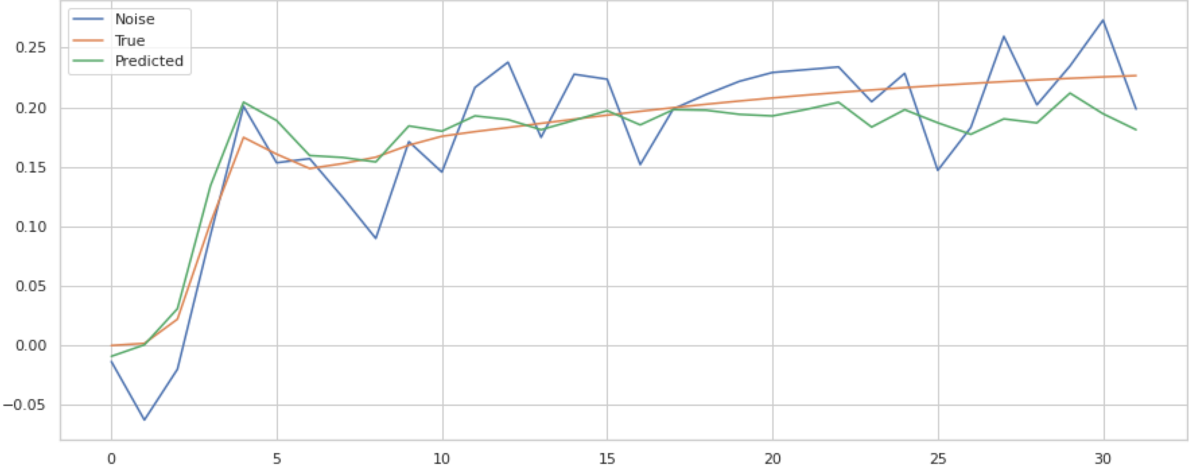
Correlation Box plots



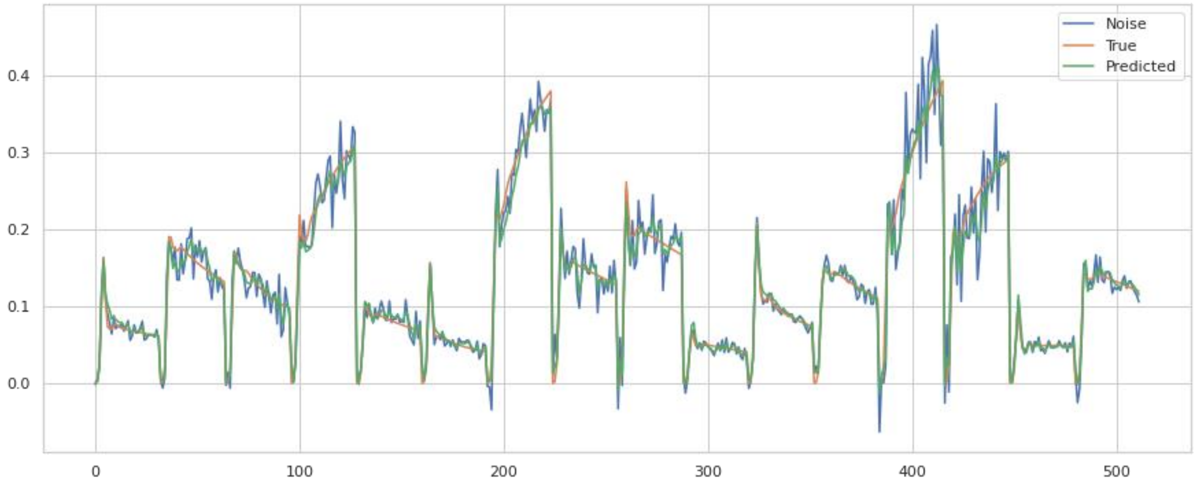
From the above graphs, we can see that some models perform much better than the others for our purpose. Like FCN-DAE, LSTM_IEEE, Vanilla_NL and Deep Filters(multibranch LANL).

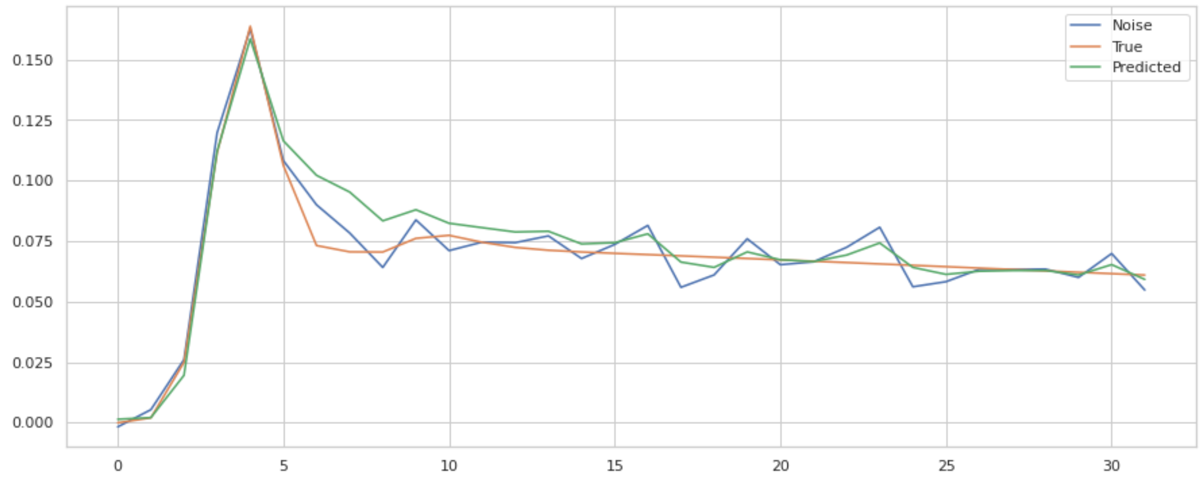
Denoised Results: DRNN



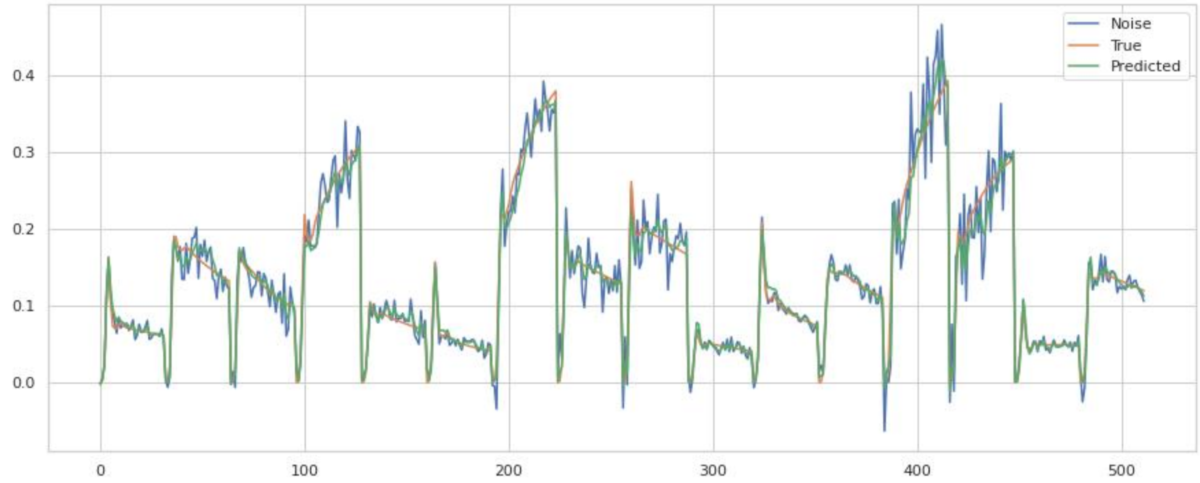


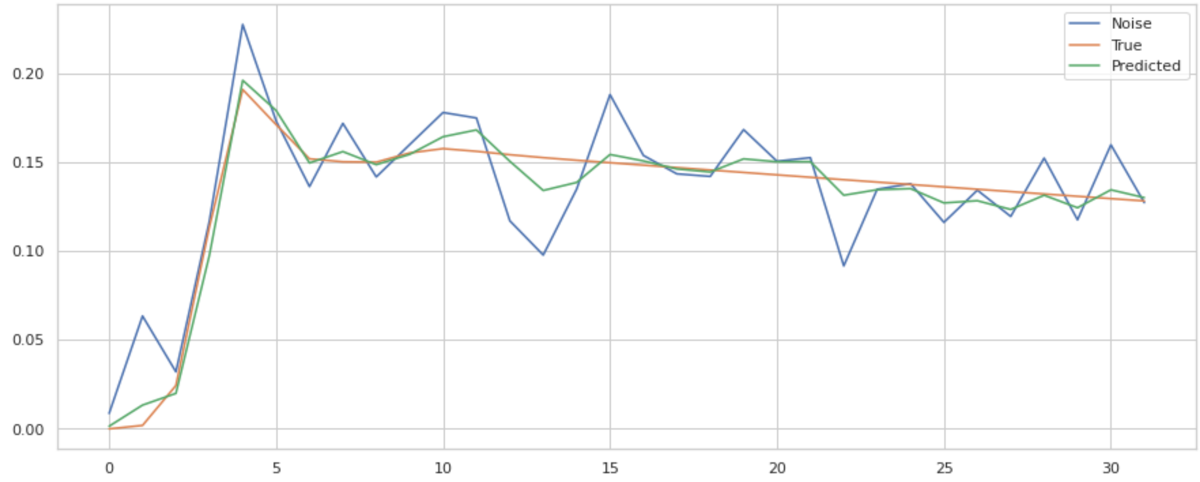
FCN-DAE



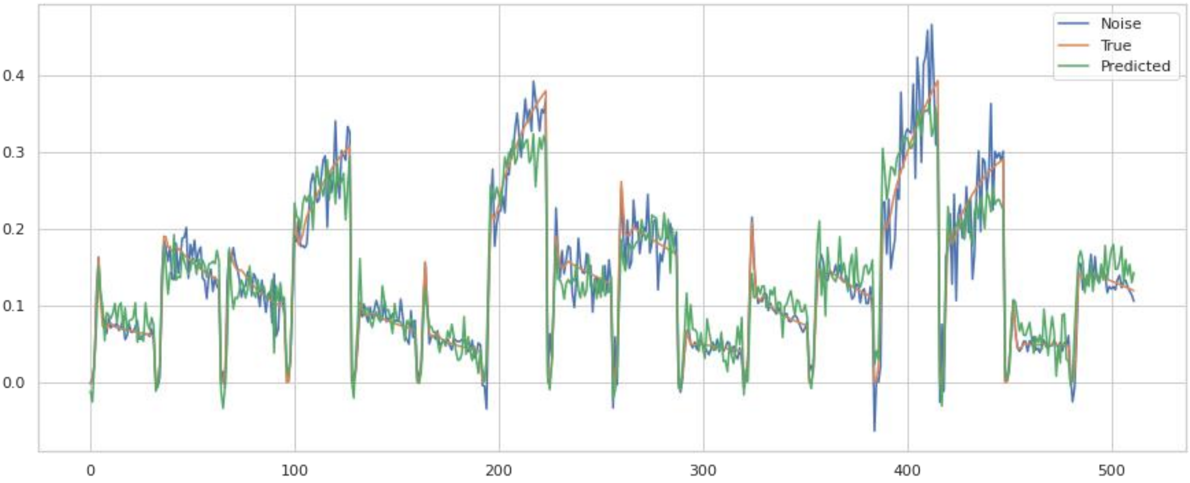

Noise
True
Predicted
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
5
10
15
20
25
30

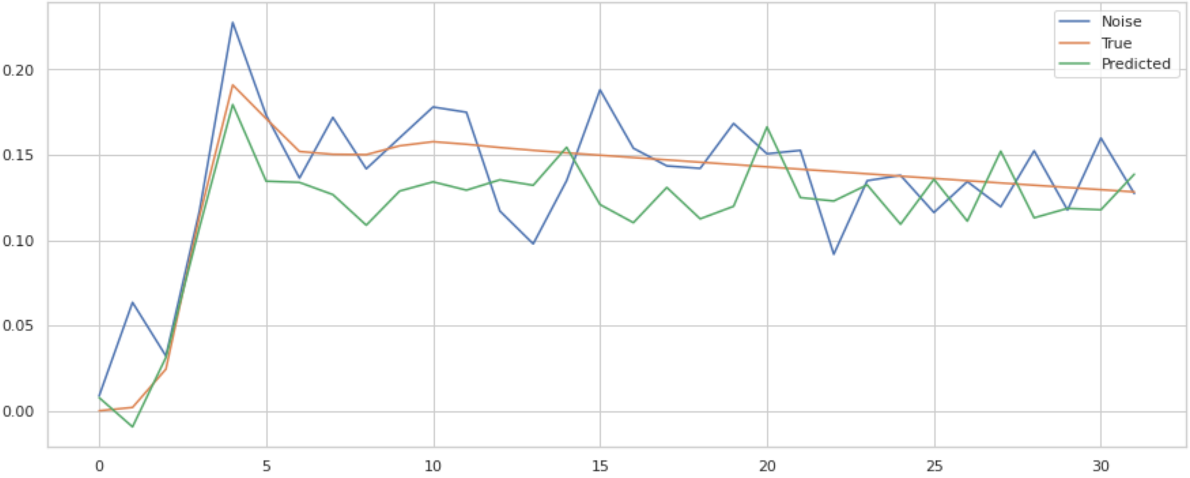
LSTM IEEE


Noise
True
Predicted
0.4
0.3
0.2
0.1
0.0
0
100
200
300
400
500

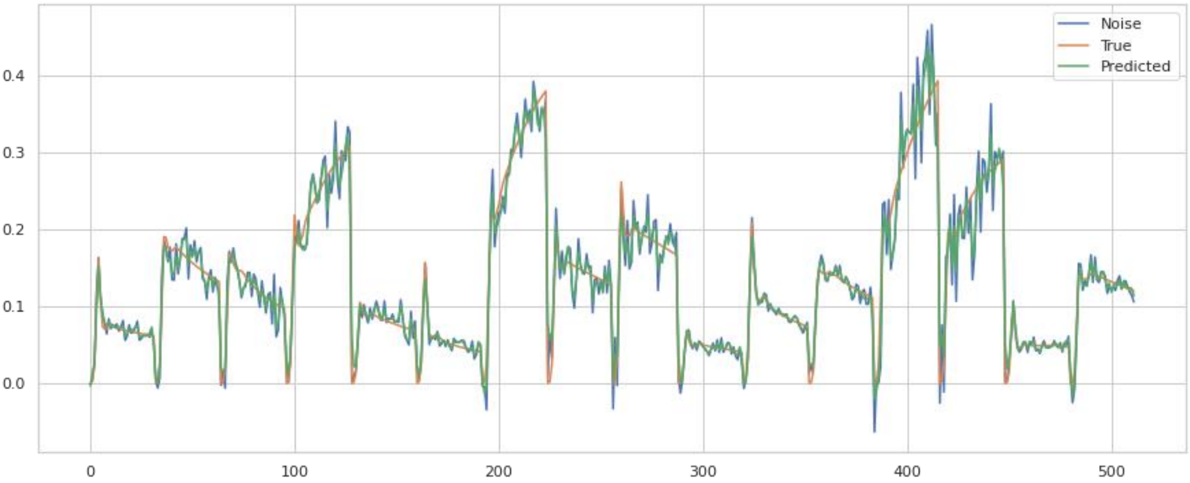

Noise
True
Predicted
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
30

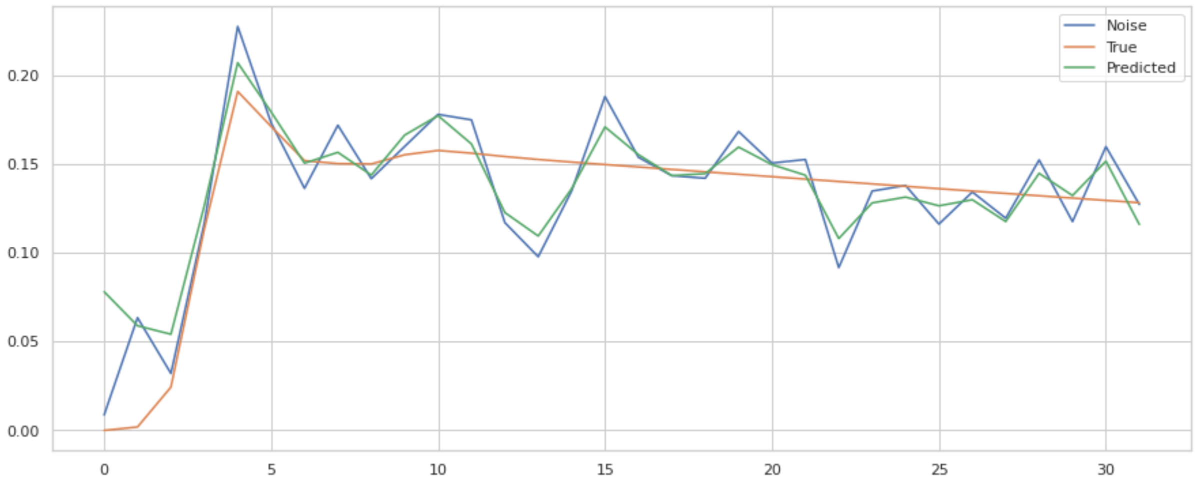
CNN IEEE



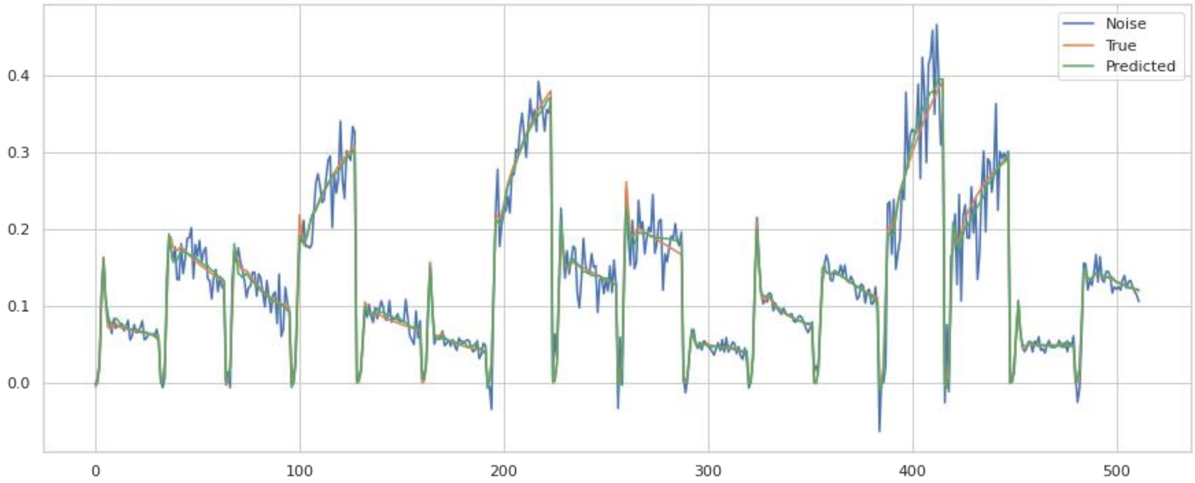


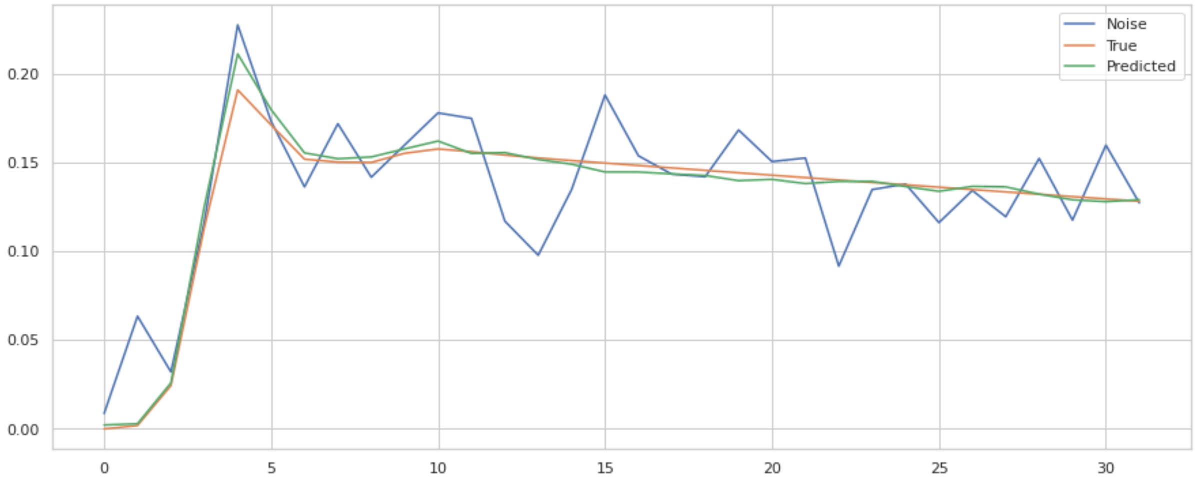
Vanilla L



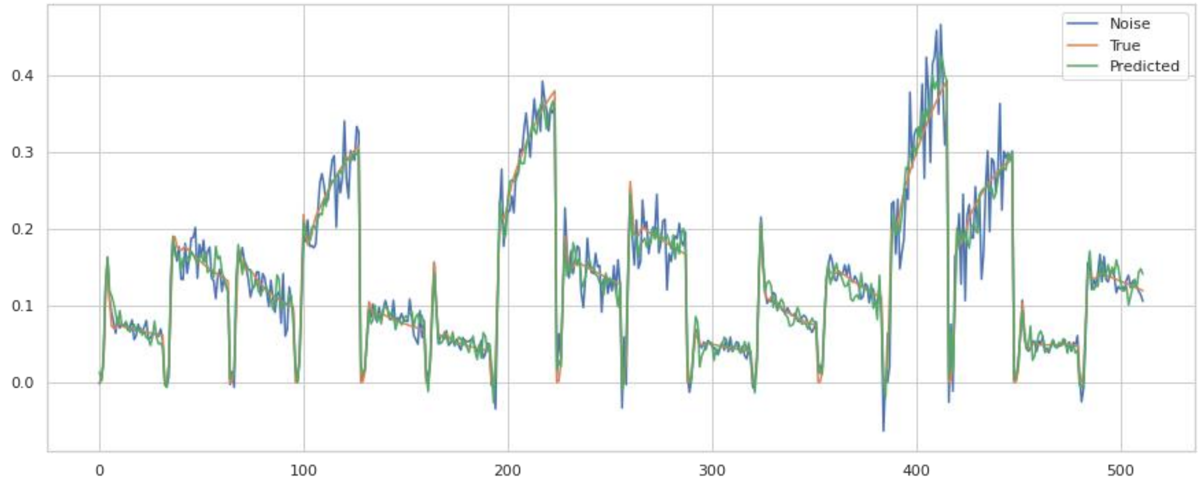

Noise
True
Predicted
0.00
0.05
0.10
0.15
0.20
0
5
10
15
20
25
30

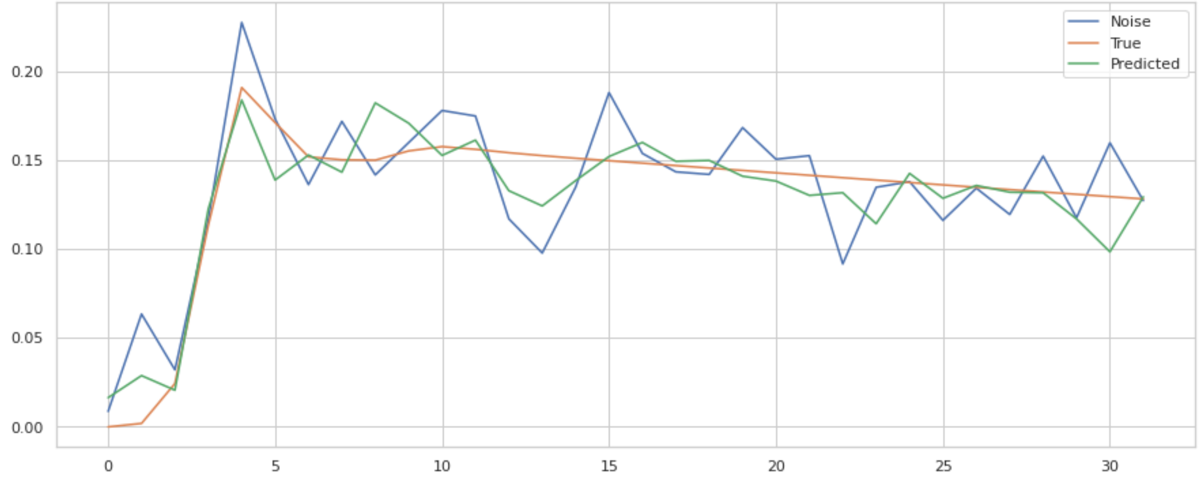
Vanilla NL


Noise
True
Predicted
0.0
0.1
0.2
0.3
0.4
0
100
200
300
400
500


Noise
True
Predicted
0.00
0.05
0.10
0.15
0.20
0
5
10
15
20
25
30

Deep Filter





SOME QUESTIONS----------------------------

1. Why we are not denoising the images directly.

2. Can we do some kind of data pre-processing before-hand.

3. Instead of adding random noise can we add some specific noise (ECG noise paper).