CAP 6615 - Neural Networks

Programming Assignment 2 – Deep Learning

Group member:

Bowei Wu (UFID: 75825722)

Haowen Chen (UFID: 81411485)

Tao Zhang (UFID: 76366624)

Xichen Li (UFID: 49287968)

Yangbo Yu (UFID: 29077422)

Yuwei Xia (UFID: 28267331)

Spring Semester 2022

18 Feb 2022

Table of Contents

1 Network Parameters

In this section, the parameters of our well-trained 3-layer Deep-Neural-Network (DNN) will be specified.

- Inputs: A vector with size 256, containing 256 input values.
- Hidden layers: 3 hidden layers in total. All layers are linear layer, with input size 256 and output size 256.
- Weights: Each layer contains 64K weights, in the form of a matrix with size [256, 256].
- Bias: Bias of each layer is a vector of size 256.
- Activation function: Layer 1 and 3 use Rectified Linear Unit (ReLU) as activation function, while layer 2 and output layer use Sigmoid as activation function.
- Optimizer: Adaptive Moment Estimation (Adam) is used as our optimization method, where the learning rate is 0.00001.
- Output: Output is a vector including 256 values.

2 Python Code for DNN

In this part, we will display Python code generated for DNN. Before showing the code, there are a few details that we need to explain first.

We use a sequential container to construct this network. Unlike the container in assignment 1 which only contains two modules, this container includes 8 modules. Also, instead of using only Sigmoid as activation function, we replace Sigmoid in layer 1 and 3 with ReLU. The reason is that when we use Sigmoid function as activation function for all layers, the training loss does not decrease and our DNN cannot converge. We did some research and noticed that Sigmoid function sometimes has the problem of vanishing gradient. So we modify our network by using ReLU in layer1 and 3. Also, Sigmoid function is kept as activation function of the output layer of our neural network because it exists between 0 and 1. By setting a threshold, for example, 0.5, we can replace all outputs smaller than 0.5 with 0 and for those equal to or larger than 0.5, we replace them with 1. In this way, we can regenerate output as an image with only black and white. Adam is used as optimization method and learning rate is 0.001. Figure 1 is the DNN we designed and developed in Python using PyTorch.

```
# Construct a fully-connected network using torch.nn.Sequential.
# Sigmoid() used as a activation function in neural networks to map variables between 0 and 1.
training_model_dnn = torch.nn.Sequential(nn.Linear(256, 256), nn.ReLU(),
                                         nn.Linear(256,256),nn.Sigmoid(),
                                         nn.Linear(256,256),nn.ReLU(),
                                         nn.Linear(256,256),nn.Sigmoid())
# Use Adam as our optimization method
optimizer_dnn = optim.Adam(training_model_dnn.parameters(), lr=1e-5)
# Mean-Square-Zero (MSE) Loss function
criterion_dnn = nn.MSELoss()
all_loss_dnn = []
executed in 25ms, finished 16:56:39 2022-02-12
```

Figure 1: DNN generated using PyTorch

After designing the DNN, we train and test it using 36 16*16-pixel images, where each image corresponds to a character from A to Z or 0 to 9.

We first run some preliminary tests on the number of epochs that should be used for backpropagation procedure. We randomly pick 100, 1000 and 5000 as the number of epoch and the output results are shown in Figure 2, Figure 3, Figure 4 respectively. When epoch equals to 100, the output results looks like random generated image. This means that doing backpropagation only one time is far from enough to train this DNN. When epoch is increased to 1000, some features are learned by DNN, but it cannot tell the difference among pictures. When epoch is 5000, the outputs can form the basic shape of each character, although the images look obscure.

Figure 2: Testing results for epoch = 100

Figure 3: Testing results for epoch = 1000

Figure 4: Testing results for epoch = 5000

But by observing the tendency of loss as shown in Figure 5 where the epoch equals to 5000, we think there might still be improvement by using a larger number of epoch. Hence, in our formal experiment, epoch is set as 15000. The Python code for DNN training is in Figure 6.

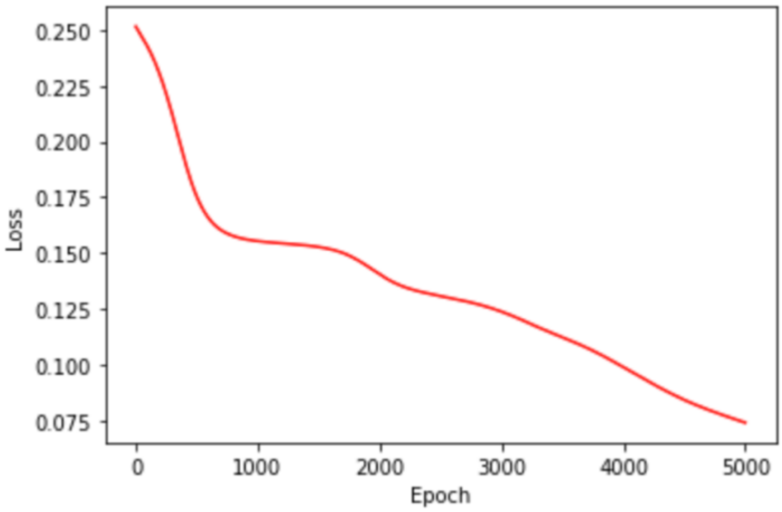

Figure 5: Loss of DNN training when epoch = 5000

```
# Begin training
epochs = 15000
for epoch in range(epochs):
#   Change numpy to tensor
    input_data = torch.from_numpy(train_dataset_reshaped)
    output_data = torch.from_numpy(train_dataset_reshaped)
#   Prediction
    predict_out = training_model_dnn(input_data)
    loss = criterion_dnn(predict_out, output_data)
#   Sampling
    if epoch % 1000 == 0 :
        print("Epoch: " + str(epoch) + " --- "+ "Loss: " + str(loss.item()))
    all_loss_dnn.append(loss)
    optimizer_dnn.zero_grad()
#   Backward propagation
    loss.backward()
    optimizer_dnn.step()
executed in 44.0s, finished 21:27:24 2022-02-12
```

Figure 6: Python code for DNN training

3 Training Set Configuration

In this section, the training set generated by us is displayed. Figure 7 is a screenshot of printed training images in jupyter notebook, which is the Dataset #1. Figure 8 shows Dataset #2.

Figure 7: Training set (Dataset #1)

Figure 8: Dataset #2

4 DNN Output Results for Noiseless Inputs

4.1 DNN output results for dataset #1

Figure 9 is the output results for dataset #1, which is also the dataset that DNN used for training. X-coordinate denotes value of Ffa and Y-coordinate is Fh.

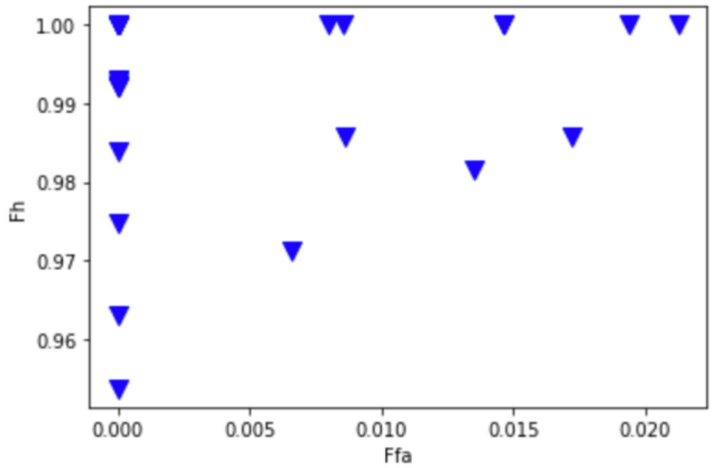

Figure 9: DNN output results on Dataset #1

4.2 DNN output results on dataset #2

Figure 10 is the output results of dataset #2, which is slightly different from dataset #1 and is not used for training. The output figures are shown in Figure 12. Comparing output figures with original input figures, as in Figure 11, we could see that some characters are obscure and not recognizable. For instance, the first character should be ‘A’, but the output looks like ‘4’ instead. Output figure of ‘M’ is similar to ‘N’, while ‘Q’ is similar to ‘O’. ‘W’ is also obscure and ‘8’ as well as ‘9’ are unable to recognize.

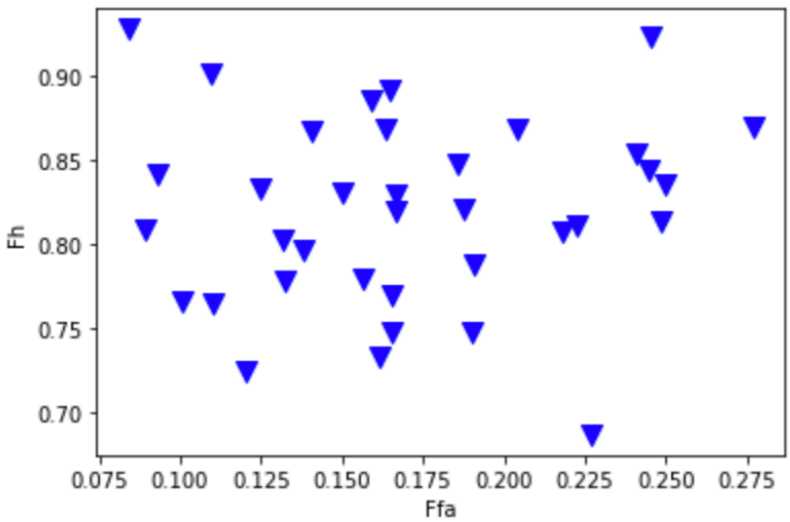

Figure 10: DNN output results on Dataset #2

Figure 11: Original dataset #2

Figure 12: DNN output using dataset #2 as input

However, as for the question that “should we use Y’ with dataset #1(instead of dataset #2) as the reference dataset”, the answer is no. Because the input in dataset #2 and we are testing the performance of our DNN on dataset #2, then we should compare the output results with dataset #2 and see the difference. If there’s small difference, for instance, the values of Fh are almost 1 and Ffa almost 0, then we could say our DNN can perform well on dataset #2. We could also say that our DNN has generalization to some extent. Moreover, we could regard X as training set and X’ as testing set. After training the DNN with X, we use X’ to test the performance of our DNN.

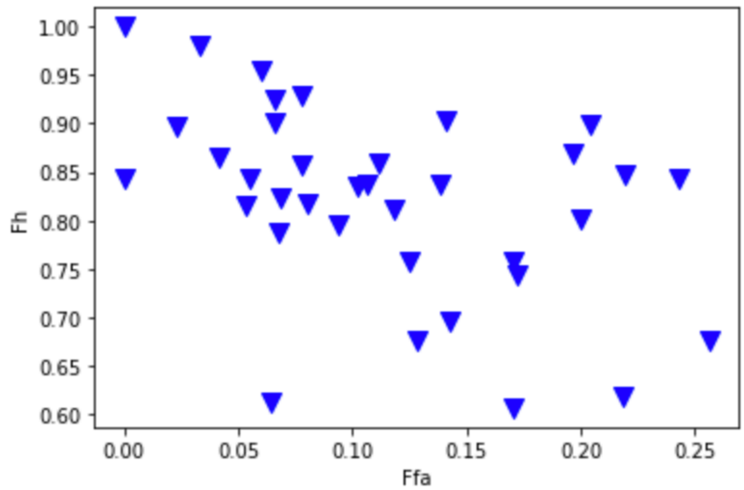

Figure 13: Output results of Y' with dataset #1

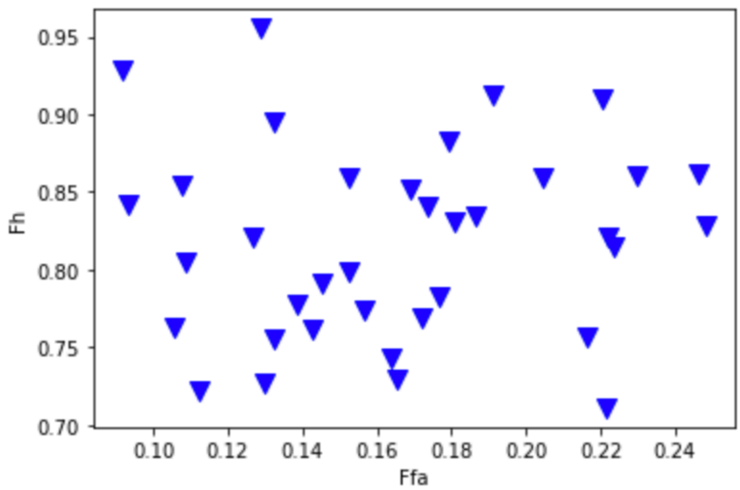

Figure 14: Output results of images with size 32*32

We also run another experiment, where we increase the size of test images from 16*16 to 32*32. We also train the dataset with epoch equivalent to 15000. The results are shown in Figure 14. Comparing Figure 14 with Figure 10, we find that the output results of images with size 32*32 are slightly better than images with size 16*16. We think the reason might be that when the size of an image is 32*32, it has 1024 features instead of 256. Then there's a large chance that DNN could learn more from extra 728 features.

5 Figure 10Pseudocode and Python Code for Fh and Ffa

In our project, we use 0 to represent black and 1 to represent white.

5.1 Pseudocode

Suppose cal_values is a list containing all 36 test results and true_values is a list of 36 inputs.

Algorithm 1: Computing Fh and Ffa

Inputs: cal_values, true_values

Outputs: Fh, Ffa

1 $for\ i\ =\ 0\ to\ 35:$

2 $$Fh[i] = \frac{number\ of\ 0\ in\ cal\_values[i]\ in\ correct\ place\ comparing\ with\ true\_values[i]}{total\ number\ of\ 0\ in\ true\_values[i]}$$

3 $$Ffa[i] = \frac{number\ of\ 1\ in\ cal\_values[i]\ in\ wrong\ place\ comparing\ with\ true\_values[i]}{total\ number\ of\ 1\ in\ true\_values[i]}$$

5.2 Python code

We define a function called "metrics" to compute Fh and Ffa. As shown in Figure 15, this function has two input parameters, where true_value is input and cal_value is real test result.

```
# define Fh and Ffa
# 0 refer black and 1 refer white
def metrics (true_value, cal_value):
    Fh = sum((true_value == 0) & (true_value == cal_value))/ sum(true_value == 0)
    Ffa = sum((true_value == 1) & (true_value != cal_value))/ sum(true_value == 1)
    return Fh, Ffa
executed in 5ms, finished 22:15:11 2022-02-12
```

Figure 15: Python code for computing Fh and Ffa

6 DNN Output Results for Noise-corrupted Input

In this section, we display output results after adding noise at 10, 20, 25, 30 and 35 percent cross-section to the dataset in the form of table as well as graph. Because the charts are large, we use a smaller font to display data. All data are copied from Jupyter Notebook.

```
Table of Autoassociative Deep Neural Network Response to Noisy Input
Number of Inputs  = 16x16   = 256
Number of Weights in an Equivalent Single-Layer Perceptron = 256x256 = 64K
Number of Hidden Layers in This DNN = 3
Number of Weights in Hidden Layer 1 = 256x256 = 64K
Number of Weights in Hidden Layer 2 = 256x256 = 64K
Number of Weights in Hidden Layer 3 = 256x256 = 64K
Number of Outputs = 16x16   = 256
```

6.1 Noise at 10 percent cross-section

	stdev = 0.001		**stdev = 0.002**		**stdev = 0.003**		**stdev = 0.005**		**stdev = 0.01**		**stdev = 0.02**		**stdev = 0.03**		**stdev = 0.05**		**stdev = 0.1**	
	Fh	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**
A	0.81	0.14	0.83	0.14	0.80	0.15	0.84	0.15	0.81	0.14	0.81	0.13	0.83	0.15	0.80	0.14	0.81	0.15
B	0.79	0.22	0.81	0.24	0.81	0.22	0.81	0.26	0.79	0.22	0.79	0.24	0.80	0.22	0.80	0.23	0.82	0.24
C	0.83	0.15	0.84	0.15	0.84	0.16	0.85	0.14	0.85	0.15	0.83	0.16	0.83	0.16	0.84	0.17	0.85	0.14
D	0.80	0.13	0.80	0.15	0.79	0.15	0.79	0.14	0.81	0.14	0.79	0.13	0.81	0.15	0.77	0.14	0.81	0.14
E	0.73	0.09	0.75	0.10	0.73	0.09	0.74	0.08	0.75	0.09	0.74	0.10	0.73	0.09	0.75	0.10	0.75	0.11
F	0.83	0.15	0.82	0.14	0.84	0.13	0.84	0.16	0.84	0.16	0.81	0.15	0.83	0.14	0.82	0.14	0.85	0.15
G	0.83	0.22	0.84	0.19	0.82	0.19	0.82	0.19	0.84	0.22	0.84	0.20	0.84	0.20	0.84	0.22	0.83	0.21
H	0.78	0.21	0.76	0.20	0.77	0.19	0.77	0.21	0.78	0.21	0.77	0.21	0.78	0.20	0.76	0.20	0.78	0.22
I	0.89	0.13	0.91	0.12	0.89	0.14	0.91	0.13	0.89	0.13	0.91	0.11	0.89	0.13	0.92	0.11	0.92	0.14
J	0.86	0.10	0.87	0.11	0.86	0.11	0.86	0.09	0.85	0.12	0.87	0.11	0.87	0.11	0.86	0.12	0.86	0.09
K	0.74	0.20	0.75	0.19	0.75	0.18	0.76	0.18	0.75	0.17	0.75	0.19	0.76	0.18	0.76	0.19	0.75	0.18
L	0.75	0.12	0.74	0.11	0.74	0.11	0.77	0.12	0.77	0.09	0.74	0.10	0.77	0.11	0.78	0.11	0.76	0.11

M	0.71	0.16	0.71	0.15	0.70	0.16	0.71	0.16	0.69	0.15	0.69	0.15	0.68	0.14	0.70	0.17	0.70	0.14
N	0.65	0.20	0.66	0.21	0.66	0.21	0.68	0.20	0.66	0.21	0.65	0.22	0.66	0.21	0.68	0.21	0.68	0.20
O	0.82	0.12	0.81	0.12	0.82	0.11	0.82	0.11	0.84	0.09	0.81	0.10	0.82	0.11	0.83	0.11	0.81	0.11
P	0.77	0.15	0.76	0.17	0.80	0.15	0.79	0.15	0.80	0.15	0.77	0.17	0.77	0.17	0.77	0.17	0.79	0.15
Q	0.83	0.09	0.83	0.09	0.82	0.08	0.83	0.10	0.82	0.10	0.83	0.10	0.83	0.10	0.81	0.09	0.85	0.10
R	0.87	0.16	0.87	0.15	0.87	0.16	0.88	0.15	0.87	0.16	0.89	0.14	0.86	0.14	0.88	0.14	0.85	0.14
S	0.80	0.24	0.81	0.23	0.80	0.22	0.79	0.22	0.79	0.22	0.81	0.20	0.81	0.23	0.78	0.22	0.81	0.22
T	0.84	0.08	0.84	0.10	0.84	0.07	0.85	0.08	0.84	0.10	0.86	0.10	0.84	0.07	0.83	0.10	0.85	0.08
U	0.73	0.14	0.71	0.14	0.71	0.14	0.73	0.14	0.71	0.14	0.70	0.14	0.71	0.13	0.72	0.13	0.72	0.14
V	0.79	0.14	0.79	0.15	0.78	0.15	0.81	0.15	0.80	0.15	0.78	0.14	0.80	0.13	0.79	0.15	0.80	0.16
W	0.80	0.15	0.78	0.15	0.77	0.15	0.82	0.16	0.79	0.17	0.77	0.16	0.78	0.17	0.76	0.16	0.79	0.16
X	0.75	0.19	0.76	0.19	0.75	0.19	0.75	0.22	0.76	0.20	0.79	0.20	0.75	0.19	0.75	0.21	0.78	0.21
Y	0.74	0.14	0.74	0.14	0.75	0.12	0.74	0.12	0.76	0.13	0.74	0.13	0.76	0.13	0.76	0.13	0.74	0.14
Z	0.84	0.16	0.85	0.18	0.85	0.18	0.82	0.19	0.83	0.18	0.84	0.18	0.83	0.18	0.84	0.18	0.83	0.15
0	0.85	0.13	0.84	0.14	0.86	0.14	0.84	0.13	0.86	0.13	0.85	0.14	0.86	0.12	0.86	0.13	0.84	0.14
1	0.92	0.10	0.92	0.09	0.92	0.08	0.93	0.10	0.92	0.09	0.92	0.09	0.92	0.09	0.92	0.09	0.92	0.08
2	0.80	0.23	0.84	0.21	0.83	0.22	0.81	0.23	0.81	0.22	0.80	0.23	0.83	0.23	0.80	0.23	0.82	0.22
3	0.82	0.19	0.84	0.20	0.85	0.20	0.85	0.19	0.87	0.22	0.84	0.17	0.82	0.20	0.84	0.21	0.83	0.21

4	0.81	0.16	0.79	0.17	0.83	0.16	0.80	0.17	0.81	0.18	0.78	0.17	0.80	0.18	0.79	0.17	0.80	0.16
5	0.83	0.27	0.83	0.26	0.82	0.27	0.86	0.28	0.84	0.25	0.84	0.29	0.85	0.29	0.84	0.27	0.84	0.29
6	0.85	0.17	0.86	0.16	0.87	0.16	0.87	0.16	0.85	0.15	0.88	0.16	0.87	0.16	0.87	0.17	0.86	0.16
7	0.88	0.15	0.88	0.17	0.86	0.18	0.86	0.17	0.90	0.20	0.88	0.16	0.91	0.18	0.90	0.18	0.87	0.19
8	0.83	0.25	0.83	0.25	0.82	0.25	0.82	0.26	0.82	0.25	0.83	0.25	0.83	0.25	0.80	0.25	0.82	0.22
9	0.87	0.18	0.85	0.17	0.86	0.18	0.86	0.17	0.87	0.19	0.85	0.16	0.85	0.18	0.84	0.18	0.85	0.18

Chart 1: Fh and Ffa table of noise at 10 percent cross-section

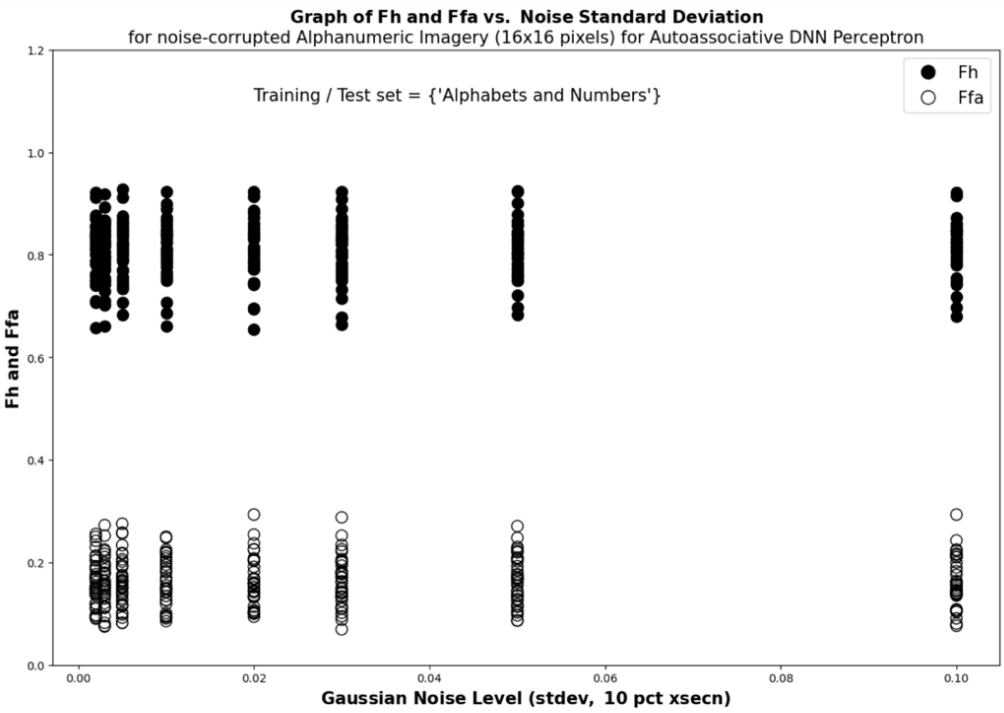

Figure 16: Fh and Ffa graph of noise at 10 percent cross-section

6.2 Noise at 20 percent cross-section

	stdev = 0.001		**stdev = 0.002**		**stdev = 0.003**		**stdev = 0.005**		**stdev = 0.01**		**stdev = 0.02**		**stdev = 0.03**		**stdev = 0.05**		**stdev = 0.1**	
	Fh	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**
A	0.83	0.17	0.86	0.18	0.84	0.15	0.79	0.16	0.80	0.16	0.84	0.14	0.80	0.16	0.79	0.14	0.85	0.16

B	0.80	0.23	0.80	0.23	0.83	0.25	0.78	0.21	0.80	0.22	0.78	0.26	0.80	0.24	0.78	0.24	0.80	0.22
C	0.87	0.13	0.85	0.16	0.85	0.17	0.87	0.15	0.84	0.15	0.84	0.15	0.83	0.16	0.86	0.14	0.84	0.12
D	0.79	0.15	0.81	0.15	0.81	0.14	0.76	0.15	0.77	0.12	0.78	0.10	0.80	0.14	0.81	0.14	0.79	0.16
E	0.73	0.11	0.75	0.09	0.70	0.09	0.74	0.09	0.73	0.11	0.72	0.10	0.74	0.12	0.73	0.11	0.74	0.08
F	0.88	0.14	0.84	0.13	0.85	0.16	0.81	0.16	0.86	0.11	0.83	0.15	0.85	0.15	0.82	0.16	0.84	0.15
G	0.83	0.19	0.83	0.22	0.83	0.19	0.85	0.22	0.81	0.20	0.82	0.17	0.81	0.20	0.80	0.22	0.81	0.17
H	0.77	0.21	0.77	0.19	0.78	0.14	0.79	0.25	0.79	0.15	0.76	0.22	0.77	0.19	0.77	0.20	0.74	0.20
I	0.88	0.11	0.91	0.11	0.89	0.11	0.90	0.12	0.92	0.13	0.90	0.14	0.91	0.12	0.90	0.12	0.88	0.14
J	0.86	0.13	0.87	0.10	0.84	0.10	0.88	0.12	0.88	0.12	0.87	0.10	0.91	0.12	0.86	0.11	0.86	0.11
K	0.73	0.19	0.79	0.18	0.75	0.20	0.76	0.20	0.74	0.18	0.73	0.16	0.75	0.20	0.72	0.21	0.77	0.18
L	0.77	0.11	0.79	0.09	0.75	0.11	0.76	0.08	0.77	0.11	0.78	0.11	0.72	0.10	0.73	0.11	0.72	0.08
M	0.72	0.14	0.75	0.15	0.69	0.14	0.72	0.15	0.72	0.13	0.68	0.15	0.70	0.16	0.68	0.17	0.69	0.17
N	0.68	0.22	0.65	0.19	0.64	0.21	0.63	0.23	0.66	0.17	0.62	0.21	0.67	0.22	0.64	0.21	0.62	0.23
O	0.83	0.11	0.86	0.12	0.82	0.11	0.83	0.10	0.84	0.12	0.83	0.10	0.82	0.12	0.83	0.09	0.83	0.10
P	0.82	0.15	0.81	0.15	0.84	0.15	0.81	0.15	0.78	0.15	0.79	0.15	0.74	0.17	0.80	0.17	0.80	0.12
Q	0.80	0.09	0.82	0.12	0.83	0.11	0.82	0.08	0.82	0.09	0.81	0.11	0.83	0.08	0.82	0.08	0.84	0.09
R	0.86	0.12	0.87	0.14	0.86	0.16	0.86	0.14	0.86	0.15	0.89	0.17	0.88	0.14	0.86	0.12	0.86	0.15
S	0.81	0.20	0.81	0.19	0.79	0.22	0.82	0.20	0.81	0.22	0.79	0.16	0.80	0.19	0.80	0.19	0.80	0.17

T	0.80	0.08	0.80	0.08	0.85	0.09	0.83	0.08	0.84	0.11	0.81	0.11	0.85	0.10	0.85	0.11	0.86	0.11
U	0.72	0.16	0.70	0.15	0.71	0.13	0.74	0.14	0.71	0.14	0.74	0.13	0.72	0.14	0.73	0.12	0.75	0.15
V	0.78	0.16	0.82	0.15	0.76	0.12	0.77	0.15	0.82	0.15	0.78	0.16	0.77	0.14	0.76	0.14	0.81	0.14
W	0.78	0.15	0.77	0.14	0.77	0.16	0.77	0.14	0.79	0.18	0.78	0.15	0.77	0.13	0.79	0.15	0.81	0.17
X	0.75	0.20	0.76	0.23	0.82	0.21	0.76	0.19	0.76	0.23	0.76	0.20	0.75	0.19	0.73	0.19	0.77	0.19
Y	0.75	0.12	0.73	0.15	0.71	0.12	0.76	0.15	0.71	0.15	0.74	0.13	0.79	0.13	0.75	0.14	0.76	0.13
Z	0.85	0.19	0.84	0.19	0.85	0.14	0.81	0.18	0.84	0.16	0.82	0.17	0.82	0.19	0.86	0.16	0.85	0.19
0	0.87	0.13	0.87	0.14	0.86	0.14	0.85	0.13	0.85	0.14	0.86	0.12	0.86	0.16	0.85	0.11	0.84	0.11
1	0.94	0.09	0.95	0.08	0.91	0.09	0.96	0.11	0.92	0.09	0.92	0.07	0.94	0.10	0.92	0.10	0.92	0.08
2	0.80	0.21	0.79	0.23	0.83	0.24	0.79	0.18	0.82	0.24	0.81	0.20	0.84	0.21	0.82	0.22	0.78	0.24
3	0.82	0.17	0.84	0.20	0.86	0.19	0.84	0.16	0.85	0.21	0.85	0.20	0.86	0.23	0.85	0.20	0.81	0.21
4	0.81	0.18	0.80	0.18	0.81	0.18	0.81	0.18	0.82	0.17	0.81	0.18	0.84	0.17	0.79	0.18	0.79	0.17
5	0.83	0.28	0.84	0.27	0.85	0.25	0.85	0.26	0.84	0.28	0.85	0.28	0.89	0.30	0.90	0.30	0.82	0.26
6	0.88	0.15	0.85	0.15	0.86	0.17	0.89	0.18	0.88	0.16	0.87	0.17	0.89	0.15	0.85	0.17	0.87	0.17
7	0.89	0.15	0.89	0.18	0.88	0.17	0.88	0.18	0.88	0.19	0.85	0.17	0.88	0.18	0.86	0.16	0.86	0.18
8	0.83	0.25	0.84	0.22	0.85	0.22	0.84	0.26	0.83	0.24	0.88	0.25	0.87	0.26	0.86	0.24	0.79	0.26
9	0.87	0.19	0.85	0.16	0.85	0.18	0.89	0.19	0.85	0.19	0.85	0.19	0.86	0.16	0.90	0.18	0.82	0.18

Chart 2: Fh and Ffa table of noise at 20 percent cross-section

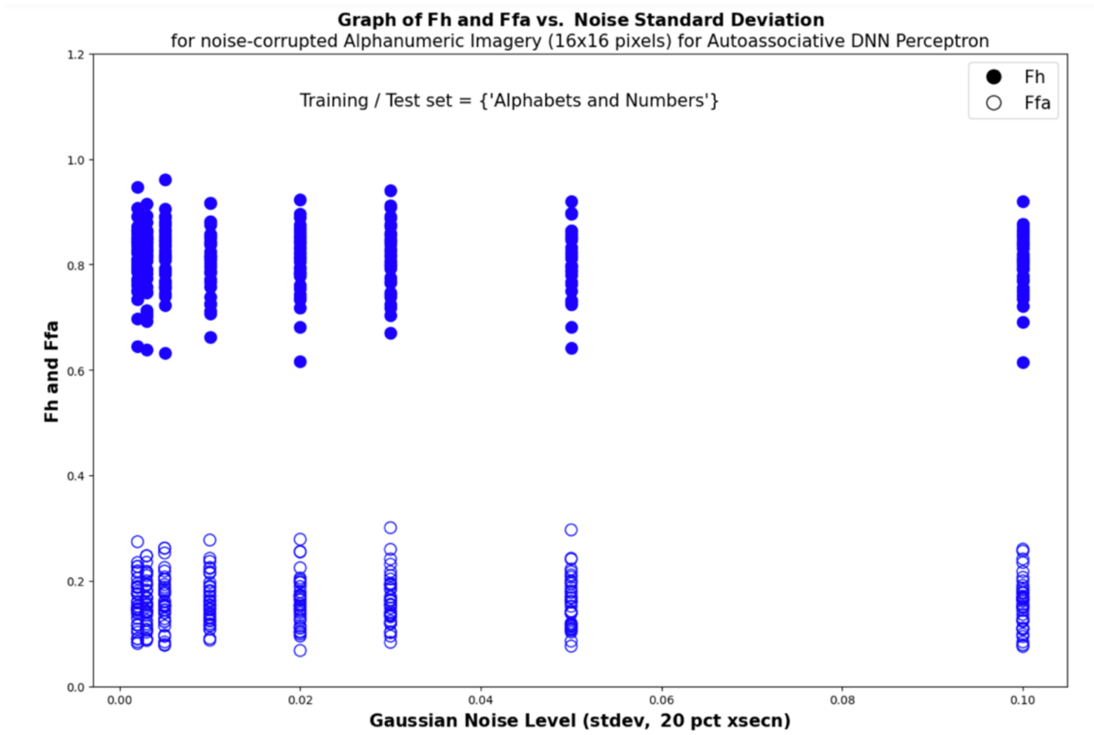

Figure 17: Fh and Ffa graph of noise at 20 percent cross-section

6.3 Noise at 25 percent cross-section

	stdev = 0.001		**stdev = 0.002**		**stdev = 0.003**		**stdev = 0.005**		**stdev = 0.01**		**stdev = 0.02**		**stdev = 0.03**		**stdev = 0.05**		**stdev = 0.1**	
	Fh	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**
A	0.82	0.13	0.85	0.15	0.84	0.15	0.82	0.16	0.83	0.14	0.78	0.15	0.81	0.14	0.82	0.17	0.83	0.15
B	0.81	0.24	0.80	0.21	0.81	0.23	0.81	0.26	0.81	0.20	0.80	0.22	0.79	0.22	0.81	0.26	0.79	0.26
C	0.87	0.16	0.84	0.15	0.86	0.15	0.83	0.15	0.89	0.15	0.86	0.14	0.84	0.14	0.84	0.15	0.83	0.14
D	0.82	0.13	0.82	0.14	0.85	0.14	0.77	0.12	0.81	0.13	0.78	0.12	0.77	0.14	0.80	0.12	0.79	0.17
E	0.78	0.10	0.73	0.08	0.71	0.06	0.74	0.09	0.73	0.08	0.80	0.10	0.77	0.09	0.71	0.11	0.75	0.09
F	0.82	0.17	0.84	0.10	0.83	0.15	0.89	0.12	0.83	0.16	0.82	0.17	0.82	0.16	0.81	0.14	0.82	0.15
G	0.84	0.23	0.83	0.21	0.86	0.21	0.79	0.21	0.84	0.20	0.83	0.20	0.86	0.19	0.75	0.17	0.81	0.20

H	0.78	0.17	0.78	0.20	0.77	0.21	0.76	0.19	0.80	0.22	0.78	0.21	0.79	0.22	0.78	0.19	0.77	0.21
I	0.90	0.12	0.92	0.15	0.90	0.13	0.92	0.14	0.91	0.13	0.90	0.13	0.89	0.14	0.90	0.13	0.91	0.11
J	0.89	0.12	0.88	0.08	0.89	0.08	0.87	0.12	0.88	0.12	0.87	0.12	0.88	0.12	0.88	0.13	0.85	0.12
K	0.76	0.17	0.76	0.22	0.73	0.16	0.76	0.19	0.72	0.17	0.79	0.19	0.74	0.19	0.75	0.20	0.75	0.19
L	0.74	0.09	0.72	0.09	0.78	0.13	0.75	0.11	0.74	0.13	0.76	0.12	0.71	0.11	0.79	0.09	0.73	0.11
M	0.74	0.15	0.73	0.12	0.66	0.15	0.73	0.17	0.75	0.18	0.70	0.17	0.71	0.20	0.69	0.19	0.67	0.17
N	0.70	0.19	0.66	0.25	0.67	0.19	0.67	0.24	0.65	0.15	0.63	0.16	0.66	0.20	0.64	0.22	0.64	0.20
O	0.80	0.12	0.86	0.12	0.85	0.12	0.81	0.10	0.84	0.14	0.84	0.08	0.83	0.12	0.85	0.08	0.84	0.09
P	0.75	0.14	0.81	0.14	0.80	0.16	0.78	0.15	0.80	0.14	0.82	0.13	0.84	0.16	0.78	0.16	0.81	0.13
Q	0.84	0.09	0.82	0.10	0.83	0.10	0.82	0.07	0.82	0.12	0.79	0.10	0.87	0.09	0.86	0.09	0.83	0.10
R	0.86	0.18	0.86	0.17	0.87	0.15	0.88	0.16	0.84	0.13	0.90	0.12	0.89	0.15	0.88	0.14	0.83	0.13
S	0.80	0.20	0.79	0.21	0.82	0.24	0.82	0.18	0.81	0.16	0.78	0.21	0.82	0.22	0.80	0.22	0.82	0.17
T	0.87	0.08	0.85	0.08	0.81	0.10	0.88	0.10	0.84	0.10	0.86	0.10	0.87	0.10	0.81	0.06	0.84	0.09
U	0.74	0.16	0.73	0.14	0.68	0.14	0.71	0.15	0.71	0.17	0.76	0.14	0.74	0.16	0.70	0.15	0.71	0.11
V	0.77	0.14	0.81	0.14	0.81	0.18	0.79	0.16	0.81	0.17	0.79	0.14	0.78	0.16	0.78	0.16	0.74	0.14
W	0.74	0.16	0.77	0.18	0.80	0.12	0.77	0.11	0.77	0.16	0.78	0.17	0.82	0.14	0.77	0.16	0.78	0.15
X	0.81	0.19	0.74	0.19	0.76	0.21	0.78	0.19	0.76	0.18	0.76	0.21	0.75	0.21	0.75	0.17	0.75	0.22
Y	0.71	0.13	0.75	0.13	0.74	0.10	0.76	0.14	0.74	0.14	0.76	0.15	0.76	0.09	0.74	0.14	0.75	0.11

Z	0.87	0.14	0.84	0.18	0.84	0.19	0.83	0.15	0.85	0.15	0.84	0.18	0.80	0.22	0.82	0.21	0.84	0.15
0	0.88	0.15	0.85	0.14	0.82	0.14	0.88	0.12	0.84	0.15	0.85	0.14	0.84	0.13	0.85	0.12	0.85	0.14
1	0.91	0.11	0.93	0.09	0.94	0.09	0.93	0.08	0.93	0.10	0.93	0.08	0.92	0.09	0.94	0.09	0.92	0.11
2	0.85	0.25	0.82	0.23	0.79	0.23	0.81	0.22	0.82	0.23	0.81	0.22	0.83	0.23	0.79	0.23	0.81	0.19
3	0.81	0.20	0.84	0.19	0.85	0.20	0.85	0.21	0.86	0.18	0.80	0.24	0.83	0.24	0.81	0.19	0.81	0.21
4	0.85	0.20	0.79	0.17	0.79	0.17	0.77	0.19	0.78	0.16	0.79	0.18	0.79	0.16	0.81	0.15	0.76	0.16
5	0.83	0.25	0.83	0.29	0.84	0.23	0.87	0.29	0.85	0.26	0.81	0.25	0.83	0.25	0.82	0.25	0.82	0.30
6	0.84	0.16	0.86	0.19	0.86	0.13	0.87	0.19	0.89	0.17	0.85	0.18	0.83	0.16	0.87	0.18	0.87	0.17
7	0.89	0.14	0.88	0.17	0.88	0.18	0.87	0.16	0.85	0.16	0.85	0.19	0.90	0.19	0.87	0.17	0.87	0.18
8	0.88	0.27	0.86	0.25	0.82	0.23	0.82	0.25	0.83	0.23	0.78	0.21	0.85	0.22	0.80	0.24	0.79	0.29
9	0.86	0.18	0.86	0.19	0.84	0.13	0.87	0.15	0.82	0.17	0.84	0.19	0.90	0.15	0.91	0.15	0.89	0.19

Chart 3: Fh and Ffa table of noise at 25 percent cross-section

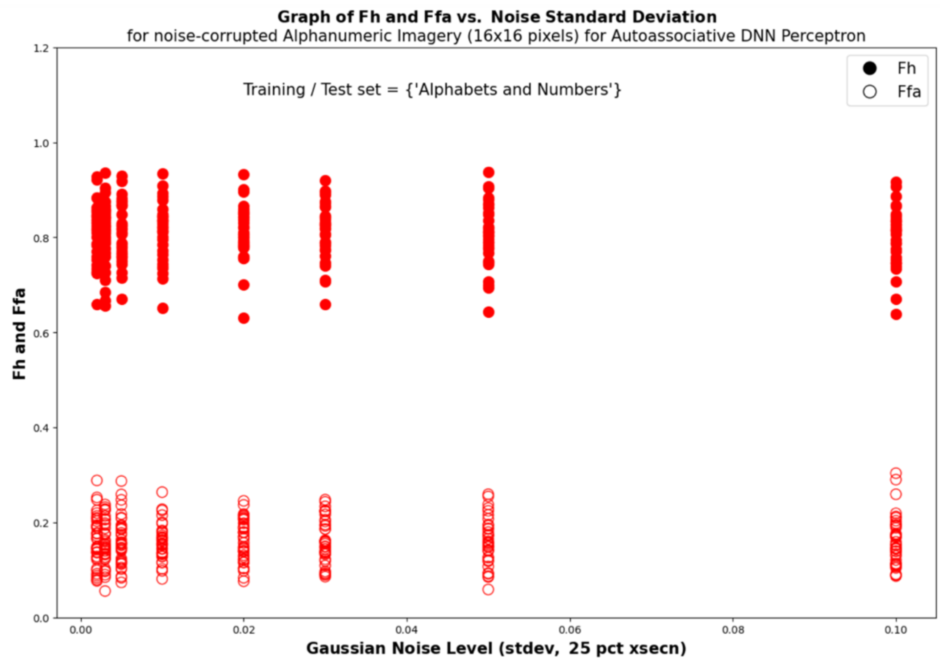

Figure 18: Fh and Ffa graph of noise at 25 percent cross-section

6.4 Noise at 30 percent cross-section

	stdev = 0.001		stdev = 0.002		stdev = 0.003		stdev = 0.005		stdev = 0.01		stdev = 0.02		stdev = 0.03		stdev = 0.05		stdev = 0.1	
	Fh	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**
A	0.79	0.14	0.83	0.12	0.77	0.17	0.82	0.12	0.78	0.09	0.81	0.13	0.84	0.18	0.79	0.11	0.76	0.11
B	0.79	0.25	0.80	0.26	0.80	0.23	0.82	0.19	0.80	0.21	0.77	0.22	0.75	0.19	0.81	0.21	0.82	0.20
C	0.85	0.12	0.84	0.17	0.88	0.16	0.85	0.14	0.84	0.13	0.84	0.17	0.86	0.16	0.84	0.16	0.87	0.14
D	0.79	0.11	0.76	0.14	0.81	0.11	0.78	0.18	0.83	0.15	0.79	0.15	0.80	0.15	0.77	0.17	0.77	0.14
E	0.77	0.11	0.74	0.07	0.77	0.11	0.75	0.08	0.76	0.10	0.68	0.13	0.73	0.10	0.77	0.09	0.70	0.10
F	0.82	0.13	0.83	0.13	0.79	0.13	0.86	0.16	0.85	0.15	0.81	0.15	0.86	0.15	0.82	0.18	0.84	0.16
G	0.82	0.20	0.80	0.20	0.83	0.21	0.83	0.21	0.80	0.21	0.84	0.21	0.83	0.18	0.82	0.20	0.85	0.20
H	0.77	0.21	0.79	0.16	0.82	0.19	0.78	0.20	0.80	0.19	0.78	0.18	0.71	0.14	0.77	0.21	0.83	0.23
I	0.86	0.13	0.92	0.13	0.90	0.13	0.88	0.12	0.90	0.14	0.95	0.12	0.90	0.12	0.88	0.13	0.91	0.15
J	0.90	0.10	0.83	0.11	0.84	0.14	0.90	0.10	0.85	0.12	0.89	0.08	0.86	0.10	0.85	0.10	0.87	0.14
K	0.78	0.20	0.78	0.20	0.77	0.14	0.75	0.19	0.73	0.15	0.72	0.20	0.80	0.16	0.78	0.17	0.77	0.14
L	0.69	0.08	0.71	0.10	0.72	0.12	0.73	0.12	0.78	0.06	0.78	0.10	0.76	0.09	0.75	0.09	0.76	0.09
M	0.73	0.13	0.70	0.13	0.68	0.16	0.76	0.16	0.73	0.12	0.71	0.14	0.71	0.16	0.74	0.12	0.72	0.14
N	0.67	0.18	0.65	0.20	0.68	0.23	0.65	0.19	0.67	0.21	0.68	0.22	0.68	0.19	0.69	0.27	0.67	0.20
O	0.83	0.14	0.86	0.13	0.82	0.10	0.83	0.11	0.84	0.12	0.82	0.11	0.79	0.12	0.80	0.13	0.82	0.07

P	0.77	0.14	0.84	0.16	0.80	0.18	0.80	0.17	0.80	0.17	0.74	0.14	0.80	0.16	0.79	0.17	0.78	0.14
Q	0.85	0.07	0.80	0.11	0.85	0.11	0.84	0.10	0.80	0.09	0.85	0.09	0.80	0.09	0.80	0.09	0.78	0.11
R	0.87	0.16	0.85	0.12	0.84	0.12	0.87	0.13	0.87	0.13	0.87	0.15	0.87	0.13	0.88	0.13	0.88	0.12
S	0.81	0.28	0.81	0.20	0.82	0.26	0.80	0.19	0.79	0.22	0.76	0.21	0.79	0.18	0.78	0.21	0.78	0.18
T	0.80	0.10	0.84	0.08	0.83	0.07	0.84	0.11	0.85	0.07	0.88	0.11	0.86	0.10	0.88	0.10	0.83	0.08
U	0.75	0.14	0.68	0.14	0.67	0.11	0.68	0.18	0.72	0.14	0.71	0.10	0.72	0.15	0.71	0.12	0.69	0.15
V	0.77	0.13	0.81	0.16	0.78	0.16	0.75	0.12	0.81	0.17	0.76	0.17	0.80	0.12	0.74	0.16	0.83	0.16
W	0.81	0.14	0.75	0.14	0.82	0.19	0.78	0.15	0.77	0.18	0.76	0.13	0.76	0.17	0.78	0.16	0.76	0.12
X	0.73	0.17	0.80	0.21	0.76	0.19	0.77	0.22	0.78	0.17	0.78	0.21	0.73	0.18	0.78	0.18	0.74	0.21
Y	0.74	0.15	0.72	0.14	0.75	0.15	0.76	0.15	0.74	0.13	0.73	0.13	0.78	0.13	0.80	0.12	0.74	0.12
Z	0.86	0.20	0.87	0.18	0.88	0.16	0.86	0.17	0.82	0.15	0.82	0.17	0.83	0.15	0.87	0.16	0.86	0.16
0	0.84	0.13	0.88	0.15	0.88	0.14	0.85	0.15	0.87	0.16	0.84	0.09	0.84	0.14	0.83	0.12	0.88	0.14
1	0.93	0.09	0.92	0.10	0.93	0.09	0.91	0.09	0.95	0.10	0.92	0.07	0.93	0.06	0.92	0.08	0.95	0.08
2	0.80	0.22	0.82	0.21	0.82	0.28	0.84	0.24	0.80	0.21	0.83	0.23	0.80	0.25	0.78	0.25	0.83	0.20
3	0.81	0.21	0.84	0.19	0.86	0.18	0.85	0.22	0.86	0.18	0.84	0.23	0.79	0.20	0.83	0.18	0.85	0.24
4	0.78	0.13	0.81	0.16	0.85	0.11	0.77	0.18	0.80	0.16	0.80	0.19	0.81	0.20	0.83	0.12	0.79	0.20
5	0.84	0.25	0.85	0.23	0.83	0.28	0.85	0.29	0.82	0.26	0.85	0.27	0.85	0.29	0.85	0.29	0.85	0.27
6	0.91	0.14	0.86	0.16	0.85	0.15	0.83	0.18	0.88	0.16	0.86	0.19	0.83	0.17	0.86	0.16	0.87	0.12

7	0.94	0.19	0.88	0.17	0.84	0.15	0.88	0.18	0.89	0.18	0.87	0.20	0.88	0.18	0.84	0.18	0.86	0.19
8	0.80	0.22	0.82	0.21	0.83	0.24	0.81	0.23	0.80	0.27	0.83	0.25	0.79	0.24	0.79	0.24	0.79	0.24
9	0.87	0.16	0.83	0.15	0.86	0.18	0.85	0.18	0.85	0.18	0.86	0.19	0.89	0.17	0.89	0.12	0.86	0.19

Chart 4: Fh and Ffa table of noise at 30 percent cross-section

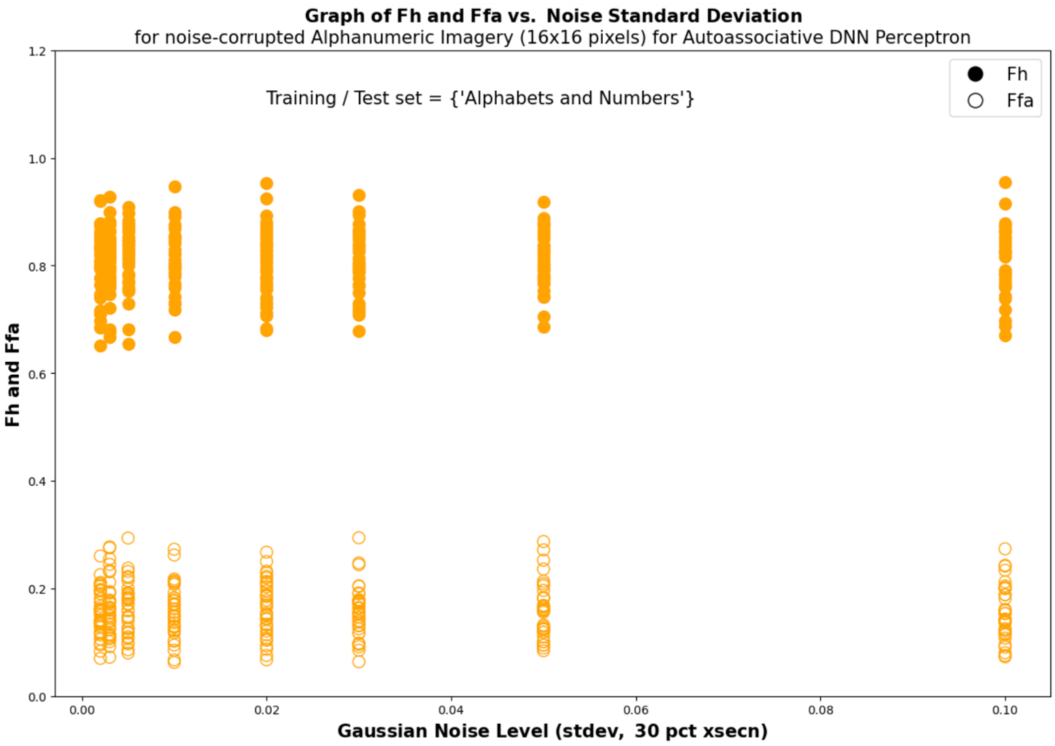

Figure 19: Fh and Ffa graph of noise at 30 percent cross-section

6.5 Noise at 35 percent cross-section

	stdev = 0.001		**stdev = 0.002**		**stdev = 0.003**		**stdev = 0.005**		**stdev = 0.01**		**stdev = 0.02**		**stdev = 0.03**		**stdev = 0.05**		**stdev = 0.1**	
	Fh	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**
A	0.79	0.12	0.80	0.13	0.83	0.15	0.84	0.15	0.83	0.12	0.81	0.14	0.79	0.13	0.83	0.16	0.84	0.13
B	0.78	0.21	0.80	0.24	0.77	0.25	0.80	0.25	0.81	0.24	0.80	0.26	0.83	0.27	0.82	0.19	0.80	0.19
C	0.81	0.12	0.83	0.17	0.82	0.15	0.89	0.11	0.85	0.18	0.87	0.16	0.85	0.14	0.82	0.16	0.83	0.14

D	0.80	0.16	0.84	0.10	0.76	0.12	0.75	0.14	0.80	0.15	0.74	0.17	0.84	0.13	0.78	0.12	0.85	0.18
E	0.75	0.08	0.72	0.08	0.70	0.07	0.71	0.09	0.76	0.08	0.75	0.07	0.75	0.08	0.74	0.12	0.72	0.11
F	0.81	0.15	0.79	0.13	0.82	0.14	0.87	0.14	0.85	0.15	0.85	0.16	0.89	0.17	0.83	0.11	0.88	0.13
G	0.81	0.18	0.83	0.17	0.82	0.23	0.85	0.20	0.82	0.23	0.77	0.16	0.81	0.22	0.81	0.20	0.78	0.20
H	0.79	0.19	0.74	0.17	0.77	0.19	0.78	0.19	0.80	0.16	0.75	0.23	0.79	0.20	0.74	0.20	0.76	0.17
I	0.91	0.09	0.90	0.14	0.89	0.12	0.91	0.13	0.93	0.16	0.93	0.12	0.91	0.09	0.88	0.11	0.93	0.12
J	0.86	0.09	0.87	0.10	0.84	0.13	0.90	0.09	0.86	0.11	0.84	0.11	0.85	0.13	0.88	0.11	0.90	0.11
K	0.77	0.17	0.77	0.19	0.73	0.22	0.78	0.14	0.73	0.22	0.74	0.22	0.72	0.18	0.72	0.21	0.72	0.22
L	0.73	0.13	0.70	0.11	0.75	0.12	0.77	0.09	0.82	0.11	0.73	0.14	0.76	0.10	0.79	0.09	0.76	0.10
M	0.71	0.16	0.71	0.16	0.70	0.14	0.66	0.14	0.68	0.15	0.73	0.14	0.68	0.16	0.71	0.19	0.73	0.17
N	0.68	0.17	0.66	0.17	0.62	0.20	0.68	0.20	0.74	0.20	0.65	0.20	0.68	0.22	0.64	0.17	0.70	0.21
O	0.85	0.10	0.84	0.15	0.77	0.10	0.81	0.09	0.85	0.10	0.84	0.10	0.81	0.09	0.80	0.09	0.78	0.10
P	0.78	0.18	0.76	0.13	0.77	0.18	0.80	0.19	0.77	0.17	0.78	0.14	0.80	0.17	0.78	0.13	0.78	0.13
Q	0.85	0.10	0.84	0.09	0.79	0.08	0.88	0.08	0.79	0.10	0.82	0.08	0.80	0.09	0.84	0.10	0.82	0.09
R	0.87	0.16	0.90	0.13	0.86	0.16	0.84	0.14	0.83	0.15	0.89	0.11	0.86	0.13	0.87	0.10	0.87	0.14
S	0.80	0.16	0.81	0.24	0.82	0.23	0.80	0.27	0.82	0.21	0.83	0.20	0.83	0.20	0.79	0.21	0.86	0.19
T	0.86	0.08	0.83	0.09	0.83	0.08	0.84	0.10	0.81	0.07	0.80	0.08	0.82	0.09	0.88	0.09	0.82	0.10
U	0.74	0.15	0.73	0.17	0.76	0.14	0.67	0.15	0.73	0.13	0.73	0.14	0.69	0.14	0.76	0.15	0.71	0.13

V	0.81	0.14	0.74	0.15	0.77	0.13	0.80	0.15	0.77	0.13	0.82	0.15	0.84	0.19	0.80	0.15	0.71	0.17
W	0.82	0.19	0.76	0.13	0.81	0.16	0.83	0.16	0.76	0.10	0.81	0.16	0.78	0.18	0.81	0.16	0.79	0.14
X	0.78	0.20	0.83	0.22	0.73	0.19	0.76	0.24	0.79	0.18	0.84	0.19	0.78	0.20	0.80	0.21	0.77	0.14
Y	0.76	0.13	0.83	0.12	0.80	0.13	0.70	0.15	0.78	0.10	0.75	0.10	0.82	0.12	0.72	0.12	0.67	0.11
Z	0.83	0.19	0.82	0.19	0.77	0.16	0.86	0.17	0.82	0.16	0.86	0.16	0.86	0.17	0.85	0.18	0.81	0.20
0	0.82	0.12	0.86	0.15	0.83	0.11	0.87	0.10	0.85	0.11	0.83	0.14	0.90	0.10	0.87	0.14	0.81	0.11
1	0.91	0.06	0.90	0.09	0.94	0.06	0.92	0.08	0.93	0.05	0.93	0.08	0.90	0.10	0.93	0.08	0.94	0.06
2	0.78	0.20	0.81	0.25	0.87	0.20	0.83	0.21	0.86	0.22	0.77	0.20	0.79	0.19	0.79	0.19	0.82	0.21
3	0.84	0.18	0.86	0.17	0.83	0.16	0.83	0.18	0.82	0.21	0.85	0.17	0.86	0.20	0.86	0.19	0.77	0.23
4	0.77	0.16	0.77	0.16	0.75	0.14	0.80	0.13	0.76	0.15	0.82	0.16	0.85	0.16	0.78	0.16	0.84	0.17
5	0.85	0.22	0.82	0.22	0.80	0.30	0.86	0.24	0.82	0.30	0.81	0.28	0.84	0.27	0.85	0.28	0.86	0.26
6	0.84	0.18	0.96	0.14	0.85	0.16	0.85	0.17	0.90	0.17	0.86	0.15	0.87	0.17	0.83	0.12	0.91	0.20
7	0.87	0.16	0.85	0.23	0.83	0.18	0.86	0.18	0.94	0.16	0.91	0.16	0.89	0.16	0.83	0.20	0.88	0.15
8	0.80	0.26	0.81	0.25	0.84	0.29	0.84	0.21	0.87	0.28	0.84	0.26	0.81	0.27	0.87	0.25	0.82	0.22
9	0.84	0.15	0.85	0.21	0.89	0.20	0.88	0.16	0.82	0.12	0.83	0.18	0.86	0.20	0.86	0.12	0.86	0.19

Chart 5: Fh and Ffa table of noise at 35 percent cross-section

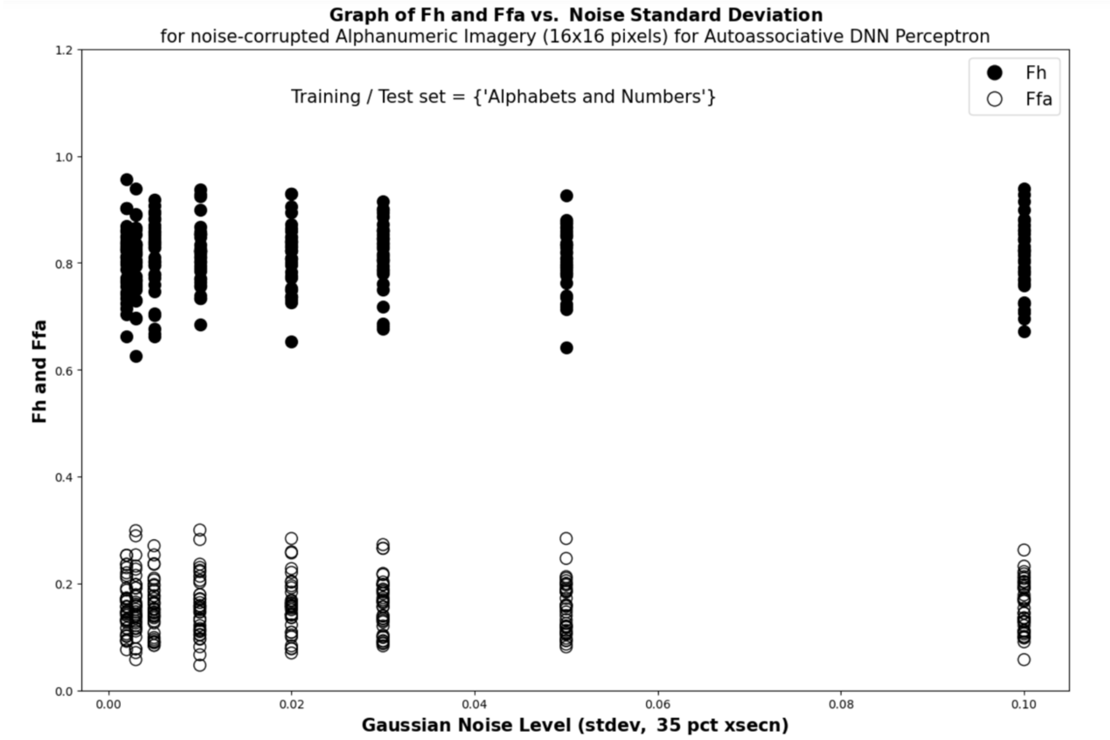

Figure 20: Fh and Ffa graph of noise at 35 percent cross-section

7 Dataset of American Sign Language Gestures

7.1 Network parameters

- Inputs: A vector with size 1024, containing 1024 input values.
- Hidden layers: 5 hidden layers in total. All layers are linear layer, with input size 1024 and output size also 1024.
- Weights: Each hidden layer contains 1M weights, in the form of a matrix with size [1024, 1024]. Output layer contains 256K weights, as a matrix with size [1024, 256].
- Bias: Bias of each hidden layer is a vector of size 1024. Bias for output layer is a vector of size 256.
- Activation function: Layer 1, 3 and 5 use ReLU as activation function, while layer 2, 4 and output use Sigmoid as activation function.
- Optimizer: Adam is used as our optimization method, where the learning rate is 0.001.
- Output: Output is a vector including 256 values.

7.2 Python code for heteroassociative DNN

In this part, we display Python code for our heteroassociative DNN in Figure 21. Same as before, a sequential container is used to build the model. This DNN has 5 input layers, and ReLU and Sigmoid are used as activation function in different layers.

```
# Construct a fully-connected network using torch.nn.Sequential.
# Sigmoid() used as a activation function in neural networks to map variables between 0 and 1.
training_model_dataset3 = torch.nn.Sequential(nn.Linear(1024, 1024), nn.ReLU(),
                                    nn.Linear(1024,1024),nn.Sigmoid(),
                                    nn.Linear(1024,1024),nn.ReLU(),
                                    nn.Linear(1024,1024),nn.Sigmoid(),
                                    nn.Linear(1024, 1024),nn.ReLU(),
                                    nn.Linear(1024,256),nn.Sigmoid())
# Use Adam as our optimization method
optimizer_dataset3 = optim.Adam(training_model_dataset3.parameters(), lr=1e-3)
# Mean-Square-Zero (MSE) Loss function
criterion_dataset3 = nn.MSELoss()
all_loss_dataset3 = []
executed in 50ms, finished 00:28:58 2022-02-13
```

Figure 21: Python code for heteroassociative DNN

We also run some preliminary tests to decide the number of training epochs. Figure 23, Figure 24 and Figure 24 are output figures with epoch equals to 10, 100 and 500 respectively. When the number of epoch increases, it is clear that the performance of DNN becomes better. In our formal training, we set training epoch as 1000 and think this would be a proper number. The code for training is shown in Figure 25.

Figure 22: Output figures with epoch = 10

Figure 23: Output figures with epoch = 100

Figure 24: Ouput figures with epoch = 500

```
# Begin training
epochs = 1000
for epoch in range(epochs):
#   Change numpy to tensor
    input_data = torch.from_numpy(dataset3_train_reshaped)
    output_data = torch.from_numpy(new_dataset1_reshaped)
#   Prediction
    predict_out = training_model_dataset3(input_data)
    loss = criterion_dataset3(predict_out, output_data)
#   Sampling
    if epoch % 100 == 0 :
        print("Epoch: " + str(epoch) + " --- "+ "Loss: " + str(loss.item()))
    all_loss_dataset3.append(loss)
    optimizer_dataset3.zero_grad()
#   Backward propagation
    loss.backward()
    optimizer_dataset3.step()
executed in 49.6s, finished 00:32:33 2022-02-13
```

Figure 25: Python code for training DNN

7.3 Training set configuration

Figure 26 is the training set of this DNN. There are 24 figures in total and the size of each figure is 16*16.

Figure 26: Training set #3

7.4 DNN output results for noiseless input

The computation of Fh and Ffa is the same as section 5. The results are shown in Figure 27.

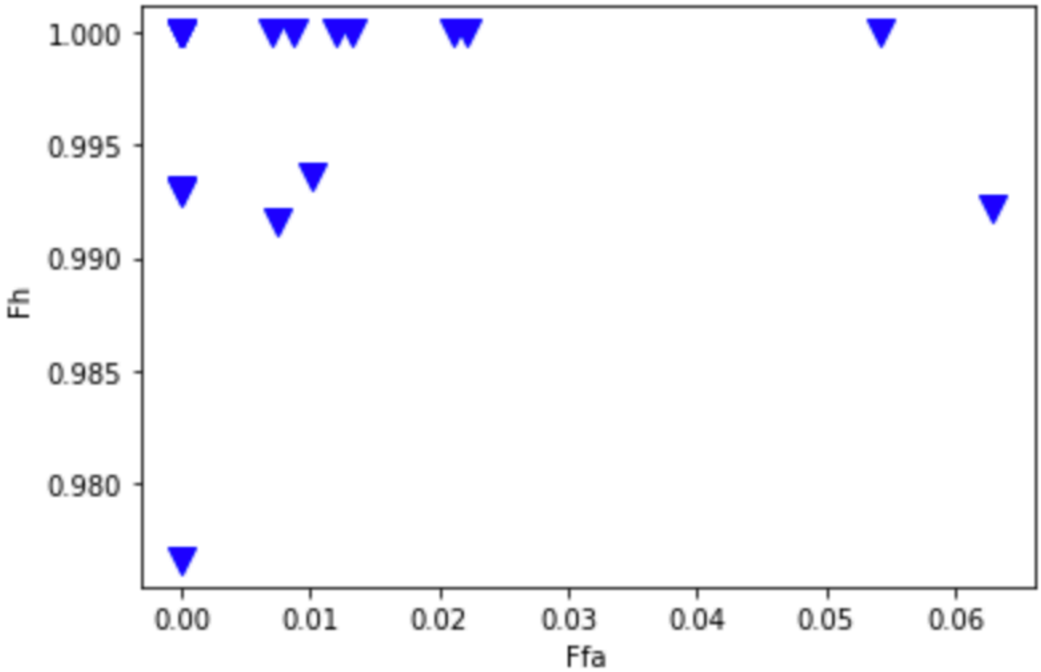

Figure 27: Output results of DNN

7.5 DNN output results for noise-corrupted input

In this section, we display output results after adding noise at 10, 20, 25, 30 and 35 percent cross-section to the dataset in the form of table as well as graph.

```
Table of Heteroassociative Deep Neural Network Response to Noisy Input
Number of Inputs  = 32x32   = 1024
Number of Weights in an Equivalent Single-Layer Perceptron = 1024x1024 = 1M
Number of Hidden Layers in This DNN = 5
Number of Weights in Hidden Layer 1 = 1024x1024 = 1M
Number of Weights in Hidden Layer 2 = 1024x1024 = 1M
Number of Weights in Hidden Layer 3 = 1024x1024 = 1M
Number of Weights in Hidden Layer 4 = 1024x1024 = 1M
Number of Weights in Hidden Layer 5 = 1024x1024 = 1M
Number of Outputs = 16x16   = 256
```

7.5.1 Noise at 10 percent cross-section

	stdev = 0.001		**stdev = 0.002**		**stdev = 0.003**		**stdev = 0.005**		**stdev = 0.01**		**stdev = 0.02**		**stdev = 0.03**		**stdev = 0.05**		**stdev = 0.1**	
	Fh	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**
A	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
B	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
C	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
D	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
E	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
F	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01
G	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
H	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
I	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00
K	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
L	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
M	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
N	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
O	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
P	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Q	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02

R	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
S	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08
T	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
U	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04
V	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
W	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
X	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Y	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

Chart 6: Fh and Ffa table of noise at 10 percent cross-section

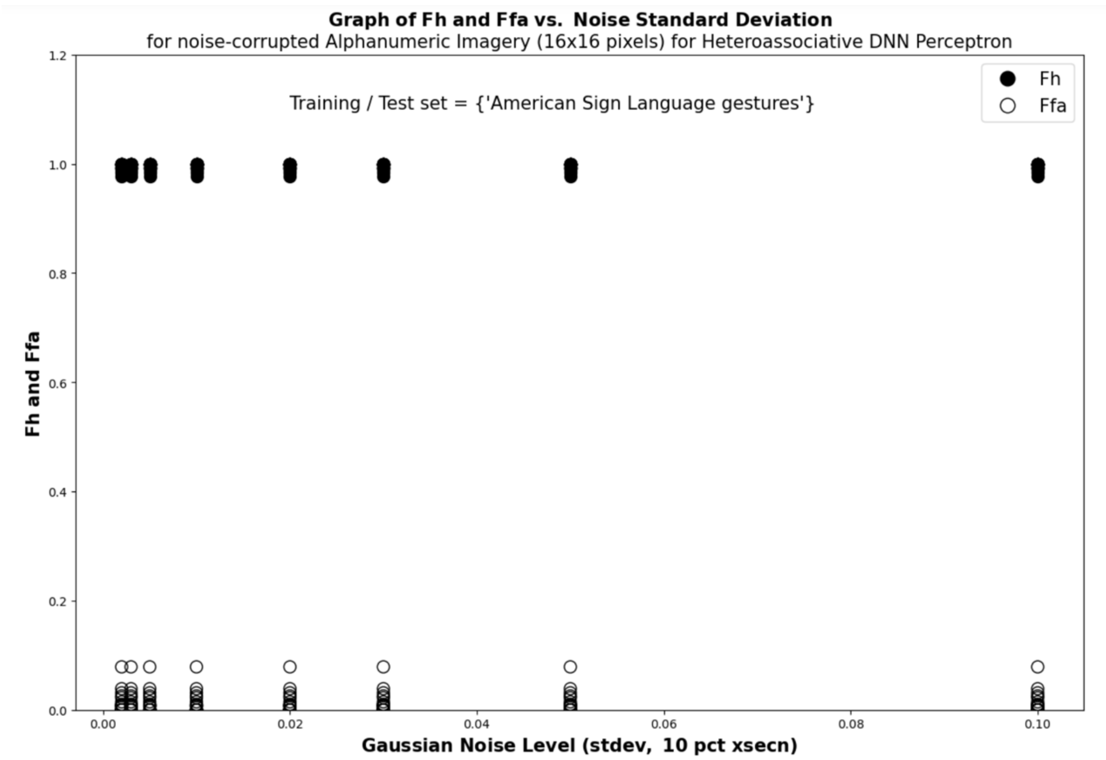

Figure 28: Fh and Ffa graph of noise at 10 percent cross-section

7.5.2 Noise at 20 percent cross-section

	stdev = 0.001		**stdev = 0.002**		**stdev = 0.003**		**stdev = 0.005**		**stdev = 0.01**		**stdev = 0.02**		**stdev = 0.03**		**stdev = 0.05**		**stdev = 0.1**	
	Fh	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**
A	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
B	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
C	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
D	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
E	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
F	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01
G	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
H	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
I	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00
K	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
L	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
M	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
N	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
O	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
P	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Q	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02

R	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
S	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08
T	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
U	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04
V	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
W	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
X	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Y	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

Chart 7: Fh and Ffa table of noise at 20 percent cross-section

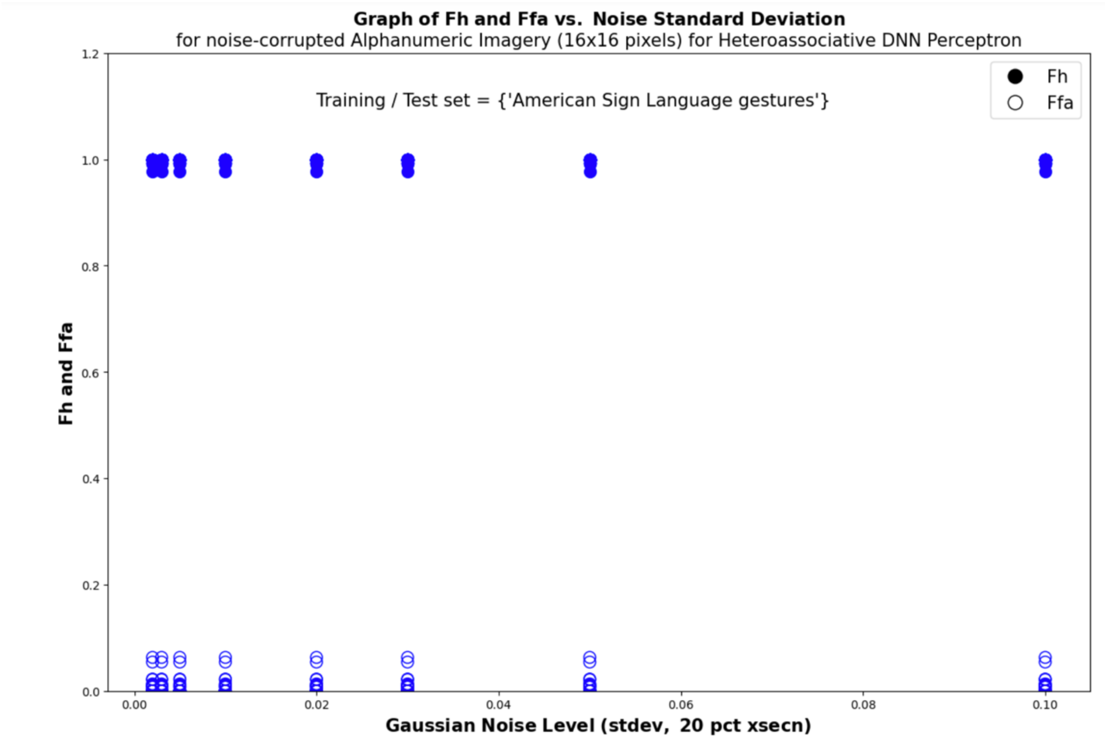

Figure 29: Fh and Ffa graph of noise at 20 percent cross-section

7.5.3 Noise at 25 percent cross-section

	stdev = 0.001	stdev = 0.002	stdev = 0.003	stdev = 0.005	stdev = 0.01	stdev = 0.02	stdev = 0.03	stdev = 0.05	stdev = 0.1

	Fh	Ffa	Fh	Ffa	Fh	Ffa	Fh	Ffa	Fh	Fh	Ffa	Fh	Ffa	Fh	Ffa	Fh	Ffa	Fh
A	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
B	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
C	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
D	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
E	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
F	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01
G	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
H	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
I	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00
K	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
L	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
M	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
N	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
O	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
P	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Q	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02
R	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

S	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08
T	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
U	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04
V	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
W	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
X	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Y	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

Chart 8: Fh and Ffa table of noise at 25 percent cross-section

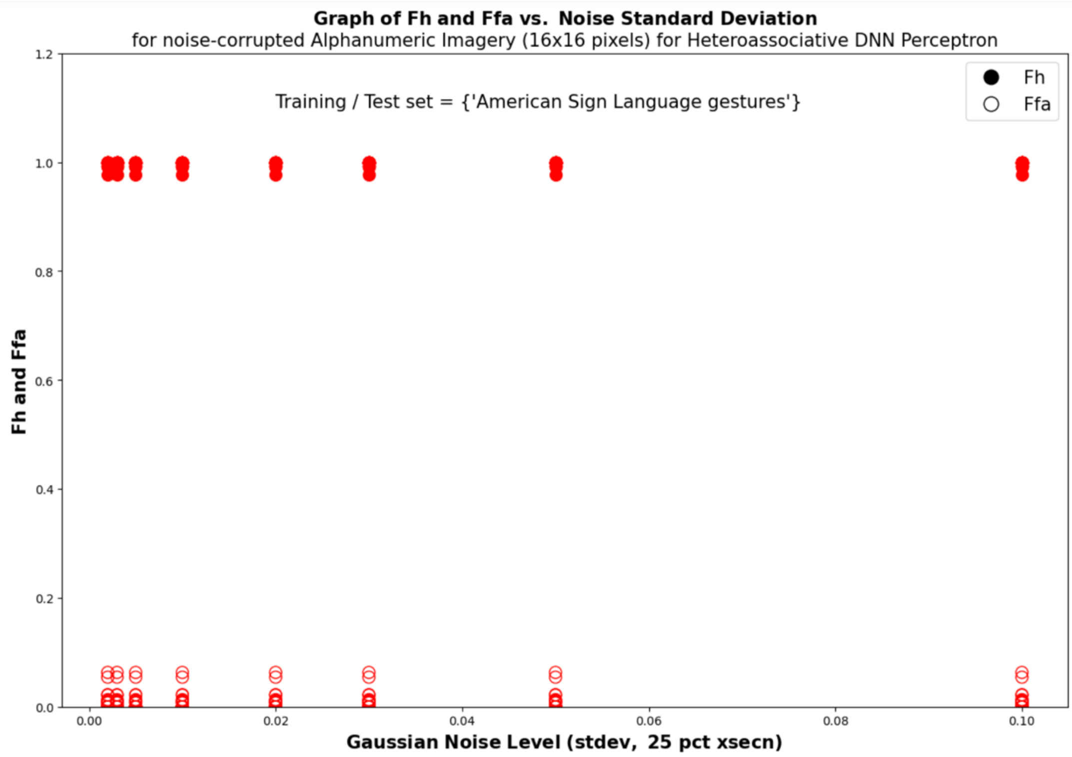

Figure 30: Fh and Ffa graph of noise at 25 percent cross-section

7.5.4 Noise at 30 percent cross-section

	stdev = 0.001	stdev = 0.002	stdev = 0.003	stdev = 0.005	stdev = 0.01	stdev = 0.02	stdev = 0.03	stdev = 0.05	stdev = 0.1

	Fh	Ffa	Fh	Ffa	Fh	Ffa	Fh	Ffa	Fh	Fh	Ffa	Fh	Ffa	Fh	Ffa	Fh	Ffa	Fh
A	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
B	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
C	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
D	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
E	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
F	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01
G	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
H	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
I	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00
K	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
L	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
M	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
N	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
O	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
P	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Q	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02
R	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

S	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.98	0.08
T	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
U	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	0.98	0.04
V	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
W	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
X	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Y	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

Chart 9: Fh and Ffa table of noise at 30 percent cross-section

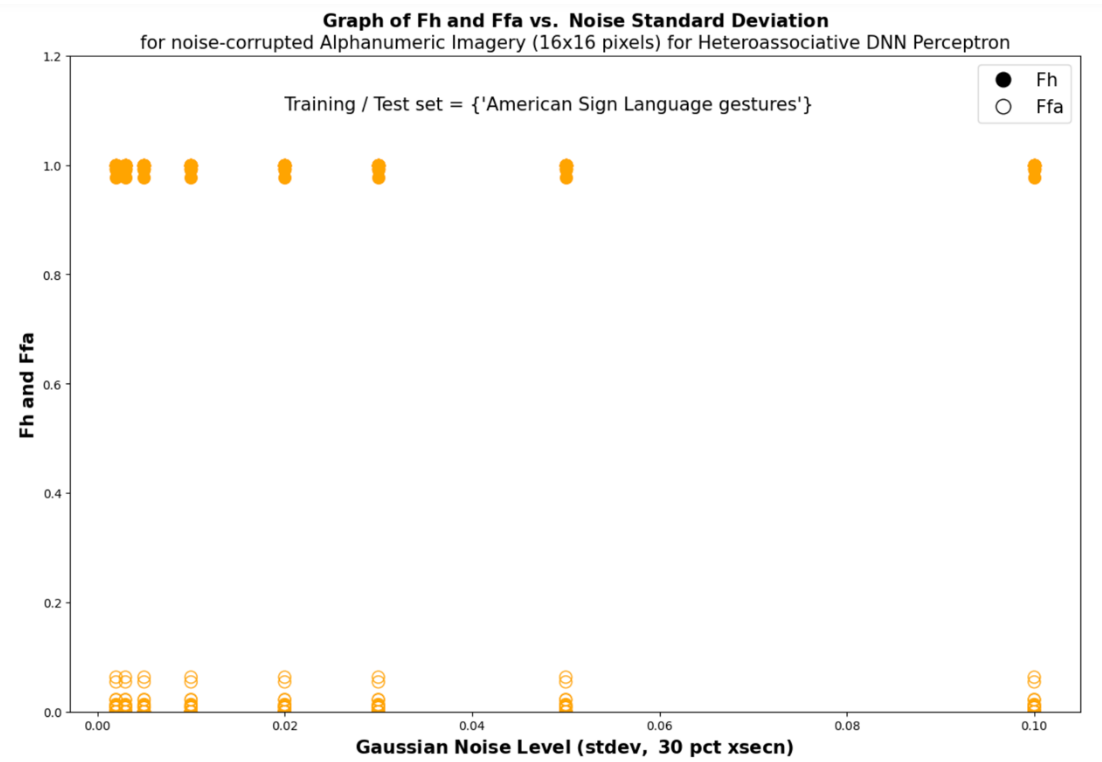

Figure 31: Fh and Ffa graph of noise at 30 percent cross-section

7.5.5 Noise at 35 percent cross-section

	stdev = 0.001	stdev = 0.002	stdev = 0.003	stdev = 0.005	stdev = 0.01	stdev = 0.02	stdev = 0.03	stdev = 0.05	stdev = 0.1

	Fh	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**	**Ffa**	**Fh**
A	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
B	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
C	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
D	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
E	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
F	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01	0.98	0.01
G	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
H	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
I	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00	0.98	0.00
K	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
L	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
M	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
N	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
O	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01
P	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Q	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02	0.99	0.02
R	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

S	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08	0.99	0.08
T	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
U	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04	1.00	0.04
V	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
W	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03	1.00	0.03
X	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Y	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

Chart 10: Fh and Ffa table of noise at 35 percent cross-section

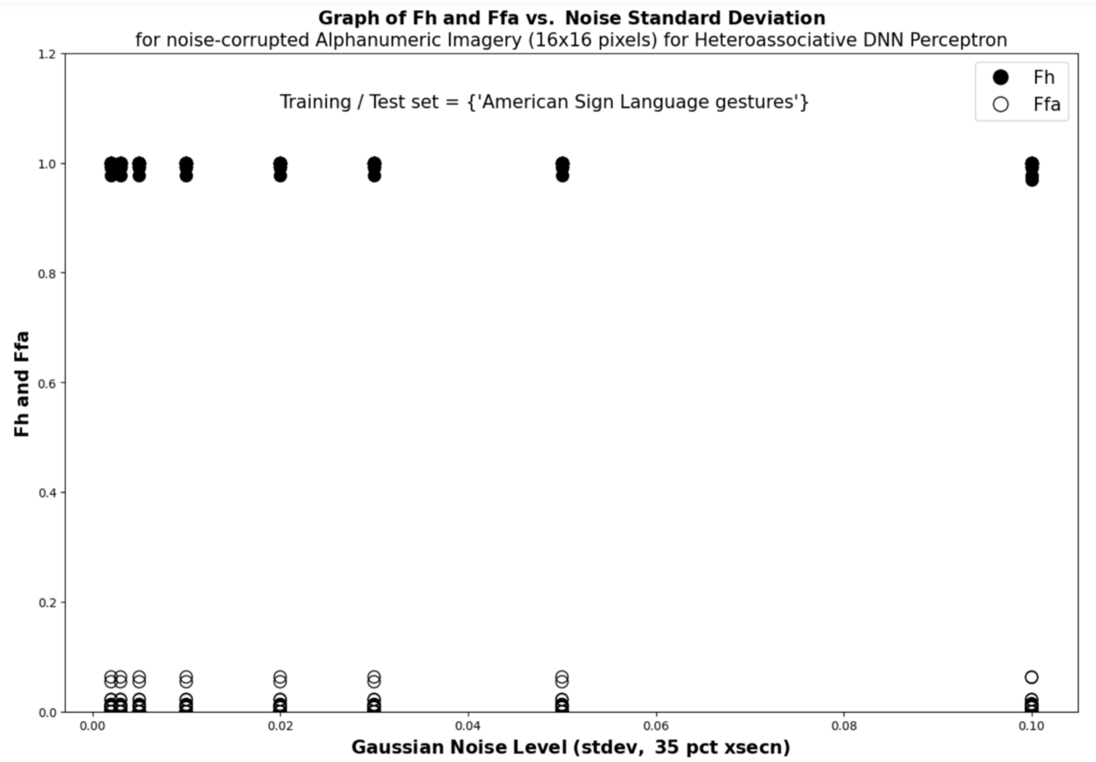

Figure 32: Fh and Ffa graph of noise at 35 percent cross-section

8 Discussion and Improvements

In this assignment, we have constructed some deep neural networks and run a few experiments. By comparing output results of Fh and Ffa on different inputs and outputs, we have some interesting observations.

One is that, when we use dataset #1 as input and output in both training and testing, smaller learning rate leads to better performance than large learning rate, meaning Fh is close to 1 and Ffa is close to 0. However, smaller learning rate also means a larger number of epoch is needed to train the model.

When we use dataset #1 to train the DNN and use #2 to test it, output figures of some specific characters are worse and more obscure than others, such as 'M', 'Q' and '9'. We suppose the reason might be the large difference between the figures of these characters in dataset #1 and dataset #2. What's more, when we add noise to dataset #2 and use noise-corrupted dataset #2 as input to test our DNN, the minimum value of Fh decreases from about 0.7 to 0.6. We think this happens might because our DNN is perturbed by the noise. To obtain better performance, we could try change the number of layers, the number of epoch, learning rate, etc.

Another interesting observation is that, when we use dataset #3 as input and t dataset #1 as output, the performance of DNN is actually great. It only trains 1000 epochs and has already achieved a quite satisfying result. Dataset #3 and dataset #1 seem nothing alike, but our DNN could be so smart and learn the important features successfully.