5.3.1.2 Group of Experiments for Selection of Hyper-parameters

Trained Network	Training Duration	Layers	dilation rate	Optimizer	Training Epoch	Min.Val MSE
A	Moderate	30	10	SGD based ADAM	162	0.00072596
C	Modeate	30	20	SGD based ADAM	205	0.00103128
D	Very Long	100	10	SGD based ADAM	174	0.00033686
E	Longer	30	10	MBGD based ADAM	162	0.00076923

Table 5.3: Overview on Group of Experiment for Selection of Hyper-parameters

I set up this set of experiments for hyper-parameter selection purpose. Even if trained network D which has 100 hidden layers has minimum validation mean square error, its training cost in terms of time is too long, I rejected it. Trained network C has larger dilation rate, it has larger receptive field, but it seems it does not have better results than the other trained network A in terms of minimum validation error. Trained Network E has similar minimum validation error as A, but it has longer training time when mini-batch is applied. Finally, I select hyper-parameters with trained network A for experiments set up for other purposes.

5.4 Simplistic Experiment as Benchmark for other Experiments

The simplistic experiment is divided into single density case and diverse densities case. The average values of error metrics are obtained by taking all testing data of 100 pictures into account for each experiment.

The reconstruction performance is related to the NMSE error evaluation. The best case has minimum NMSE value among all testing pictures, we treat it as the best reconstruction by neural network.

5.4.1 Single density

5.4.1.1 Testing Error of Simplistic Model of Single Density

Trained Network Applied	Index	Average NMSE	Average MSE	Average SSIM	Average PSNR
A	Phase	0.02671	0.001866	0.9110	79.4854
A	Attenuation	0.02671	8.6769e-10	0.9999	94.6807

Table 5.4: Testing Error of Simplistic Model of Single Density

The testing error for attenuation performs better than for the phase except for the average NMSE. The level of magnitude of phase projection is larger than attenuation projection for thousands of times, and the error of phase projection is larger than the error for attenuation projection. Since this is the single density case, phase is always proportional to attenuation with an unique ratio everywhere. At the output layer, each output channel is linear combination of last hidden layer channels, these two outputs are proportional everywhere. Therefore, attenuation and phase have identical NMSE value for the single density case.

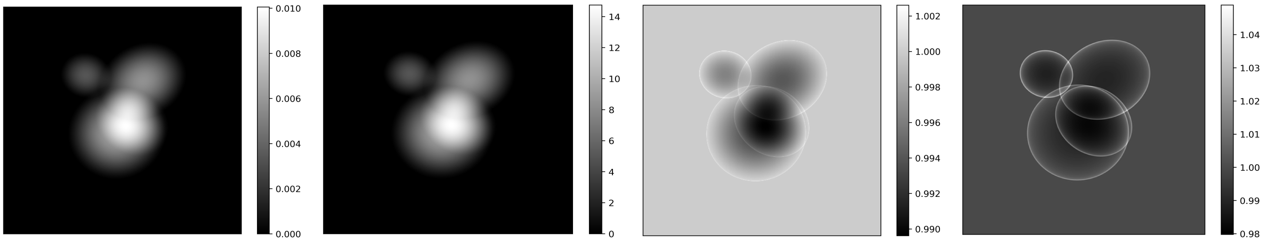
5.4.1.2 Corresponding Testing Error of Contrast Transfer Function Method

Index	Average NMSE	Average MSE	Average SSIM	Average PSNR
Phase	0.8879	5.6607	0.5693	46.0678
Attenuation	3.0561	3.5476e-05	0.9891	52.5542

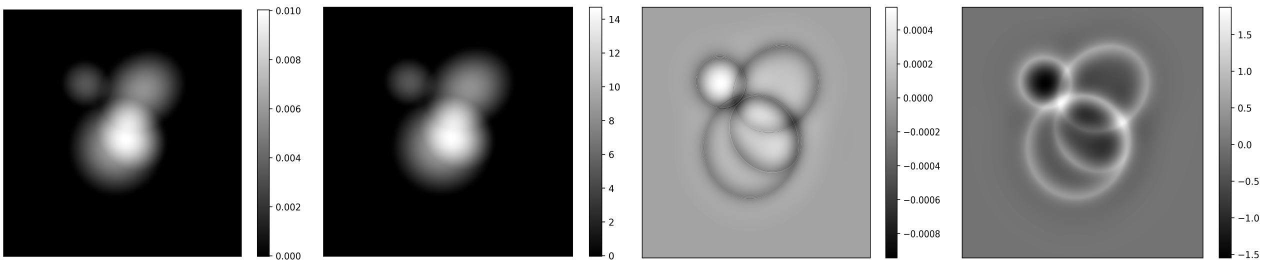
Table 5.5: Corresponding Testing Error of Contrast Transfer Function Method for Simplistic Model of Single Density

The attenuation and phase reconstruction by MSDNet performs better than contrast transfer function in terms of all error metrics. We will evaluate the best and worst reconstruction implied by NMSE visually next.

5.4.1.3 Best Case of Single Density Simplistic Model Phase Retrieval



(a) Attenuation Projection (b) Phase Projection (c) Phase Contrast Image for Shortest Distance (d) Phase Contrast Image for Longest Distance



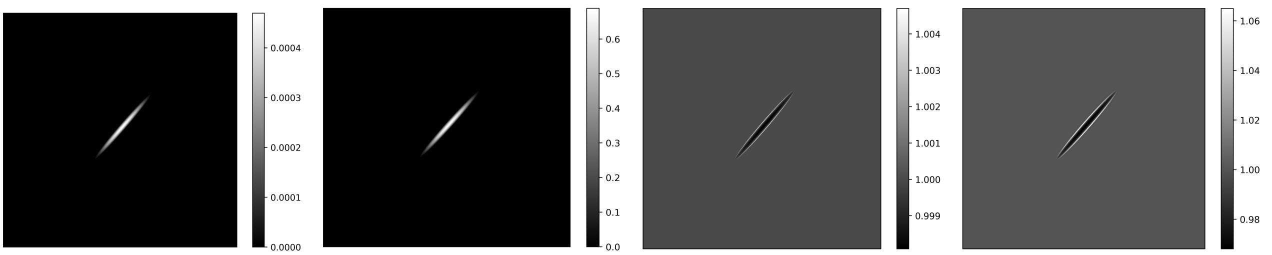
(e) MSD Attenuation Retrieval (f) MSD Phase Retrieval (g) CTF Attenuation Retrieval (h) CTF Phase Retrieval

Figure 5.1: Best Case of Single Density Simplistic Model Reconstruction Performance and Corresponding CTF Performance In Comparison

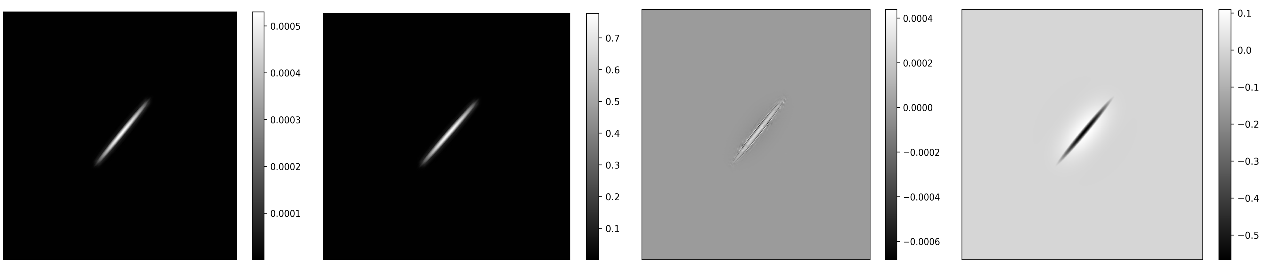
The best reconstructions by MSDNet are very similar to original projection images and have better results than contrast transfer function visually. The gray level range of reconstructions are compatible with the original projections, but there is a gap between gray level of reconstructions and original projections for contrast transfer function, especially for the phase.

However, the contrast transfer function can reconstruct and highlight the non-obvious shapes to some extent. In Fig.5.1 (h) CTF phase retrieval, there is a smaller non-obvious shape between two more obvious shapes, and it exists in phase projection but is not apparent. The MSDNet is unable to reconstruct it more clearly than CTF. This shape is paraboloid and has non-obvious contours in projection image.

5.4.1.4 Worst Case of Single Density Simplistic Model Phase Retrieval



(a) Attenuation Projection (b) Phase Projection (c) Phase Contrast Image for Shortest Distance (d) Phase Contrast Image for Longest Distance



(e) MSD Attenuation Retrieval (f) MSD Phase Retrieval (g) CTF Attenuation Retrieval (h) CTF Phase Retrieval

Figure 5.2: Worst Case of Single Density Simplistic Model Reconstruction Performance and Corresponding CTF Performance In Comparison

The worst reconstructions by MSDNet are quite similar to the original projection images and have better result than contrast transfer function visually. The gray level range of reconstructions has a tiny gap with original projections, but there is a larger gap for CTF result, especially for the phase.

5.4.2 Diverse densities

5.4.2.1 Testing Error of Simplistic Model of Diverse Densities

Trained Network Applied	Index	Average NMSE	Average MSE	Average SSIM	Average PSNR
B	Phase	0.3592	3.2686	0.7023	49.4558
B	Attenuation	0.0907	1.5574e-06	0.9995	67.1722

Table 5.6: Testing Error of Simplistic Model of Diverse Densities

The testing error of attenuation performs better than phase in terms of all error metrics, this is quite in line with the single density case. Because this is diverse densities case, the ratio between between attenuation and phase depends on the region in the projection image. For the single density case, this ratio is a constant over the whole image. For the diverse densities case, the ratio is different region by region. Therefore, attenuation and phase reconstruction have different NMSE values.

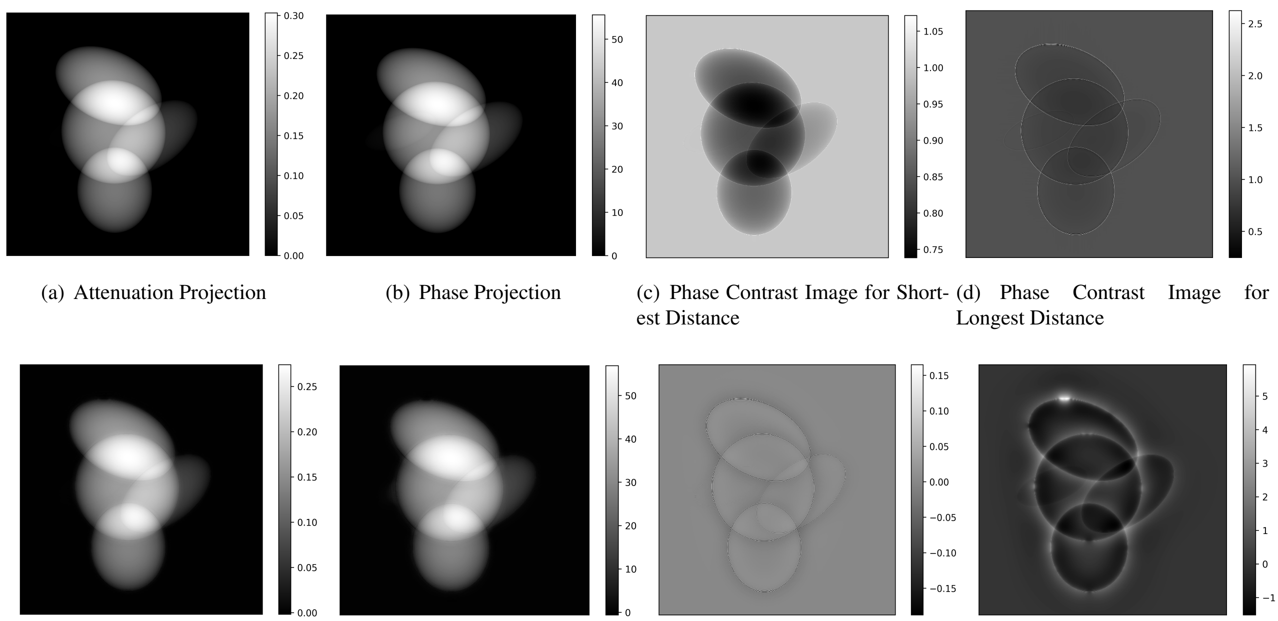
5.4.2.2 Corresponding Testing Error of Contrast Transfer Function Method

Index	Average NMSE	Average MSE	Average SSIM	Average PSNR
Phase	0.9647	32.2977	0.6637	39.9450
Attenuation	1.091	0.0005106	0.9422	43.0625

Table 5.7: Corresponding Testing Error of Contrast Transfer Function Method for Simplistic Model of Diverse Densities

The attenuation and phase reconstruction by MSDNet perform better than contrast transfer function in terms of all error metrics, this is in line with single density case. We will evaluate the best and worst reconstruction implied by NMSE visually.

5.4.2.3 Best Case of Diverse Density Simplistic Model Phase Retrieval



(a) Attenuation Projection (b) Phase Projection (c) Phase Contrast Image for Shortest Distance (d) Phase Contrast Image for Longest Distance

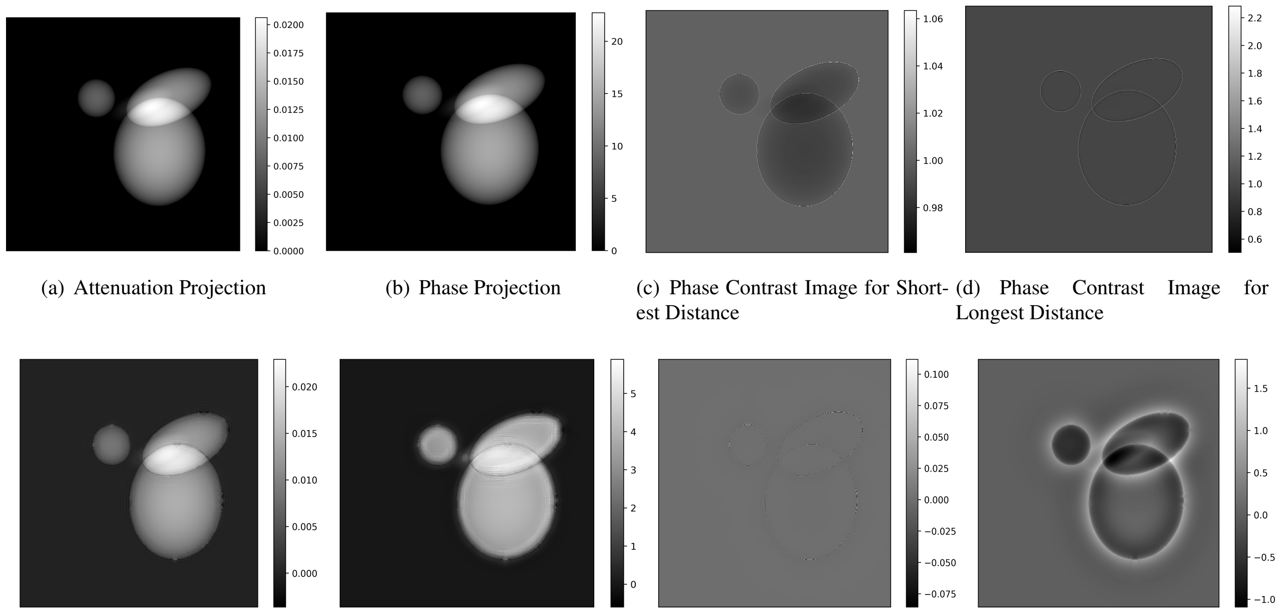
(e) MSD Attenuation Retrieval (f) MSD Phase Retrieval (g) CTF Attenuation Retrieval (h) CTF Phase Retrieval

Figure 5.3: Best Case of Diverse Density Simplistic Model Reconstruction Performance and Corresponding CTF Performance In Comparison

The best reconstructions by MSDNet are very similar to the original projection images and better results are obtained than with contrast transfer function visually. The gray level range of reconstructions are quite compatible with the original projections, but there is a gap between gray level of reconstructions and original projections for contrast transfer function, especially for the phase.This is in line with single density case.

However, the contrast transfer function can reconstruct and highlight the non-obvious shape. In Fig.5.3 (h) CTF phase retrieval, there is a smaller non-obvious shape covered by a big circle shape, and it exists in phase projection but it is not apparent. The MSDNet is unable to reconstruct it more clearly than CTF. This shape is paraboloid.

5.4.2.4 Worst Case of Diverse Density Simplistic Model Phase Retrieval



(a) Attenuation Projection (b) Phase Projection (c) Phase Contrast Image for Shortest Distance (d) Phase Contrast Image for Longest Distance

(e) MSD Attenuation Retrieval (f) MSD Phase Retrieval (g) CTF Attenuation Retrieval (h) CTF Phase Retrieval

Figure 5.4: Worst Case of Diverse Density Simplistic Model Reconstruction Performance and Corresponding CTF Performance In Comparison

The worst reconstructions by MSDNet are quite similar to the original projection images and better results are obtained than with contrast transfer function visually. The gray level range of phase reconstruction has a gap with the original projections, but there is a larger gap for CTF result, especially for phase.

However, the contrast transfer function can reconstruct and highlight the non-obvious shape. In Fig.5.4 (h) CTF phase retrieval, there is a smaller non-obvious shape between two more obvious shapes, and it exists in phase projection but it is not apparent. The MSDNet is unable to reconstruct it more clearly than CTF does. This shape is paraboloid that has non-obvious contour in projection image.

5.4.3 Conclusion

In terms of the evaluation metrics, attenuation and phase reconstructions performed by mixed-scale dense network is numerically better than what contrast transfer function does whatever single or diverse densities cases. And reconstruction for single density case is better than diverse densities case numerically as well. The mixed-scale dense network can learn the data distribution of projections and the data mapping relationship between phase contrast image and projection image from training data. However, it lacks of some image enhancement effect for some degree. The reconstruction by contrast transfer function can grasp the shape contour information from phase contrast images and highlight it in reconstructed projection images mainly for paraboloid shape.