The visual qualities of attenuation and phase reconstructions performed by both mixed-scale dense network and contrast transfer function become worse as noise level increases from 24dB (PPSNR) to 6dB. However, this effect related to the augmentation of the noise level is more obvious on mixed-scale dense network based phase projection reconstruction. The visual quality of contrast transfer function based phase reconstruction is quite robust towards gradually increased noise level because contrast transfer function has image enhancement effect especially for object contour, so that we can distinguish each shape from the overlapping objects. However, mixed-scale dense network has not the same property.

5.5.3.5 Conclusion

For diverse densities case, the robustness of attenuation and phase projection reconstructions towards noise also depends on the image we are dealing with. When shapes in original projection images have less overlaps, the reconstructions can overcome the disturbance made by noise for some degree, especially for the mixed-scale dense network. We can see there is more overlapping in the worst case than in the best case. This is in line with single density case,

5.5.4 Conclusion

Basically we have three factors to be considered for analysis, they are the number of densities involved, the noise level and the shapes overlapping degree.

Increase on each of them would triggers more difficulty for mixed-scale dense neural network to learn data distribution mapping between phase contrast images and projection images whatever attenuation or phase projection, the reconstruction would become more and more complicated and error would increase definitely. The neural network behaves worse as the inverse problem becomes more complicated as shown by experiments above.

The mixed-scale dense network based phase reconstruction has some kind of robustness towards gradually augmented noise in the more complicated diverse densities case, this is a good property as expected. Its efficiency to solve the shape overlapping issue is still quite limited, this is its drawback compared with contrast transfer function based phase reconstruction because contrast transfer function can extract the contour information from phase contrast images. Generally speaking, network reconstructions are closer to original projections numerically and visually compared to contrast transfer function method, but it depends on our visual requirements on phase reconstruction results if we have.

5.6 Experiment of Exploration on De-blurring Capacity of Neural Network in Phase Retrieval

5.6.1 Overview on Exploration on De-blurring Capacity of Neural Network in Phase Retrieval

Trained Network	Gaussian blurring	Noise Level(PPSNR)	Number of Density(s) involved	Shape(s) involved
L	Yes	No noise added	1	ellipsoid and paraboloid
M	Yes	12dB	1	ellipsoid and paraboloid

Table 5.13: Overview on Experiment of Exploration on De-blurring Capacity of Neural Network in Phase Retrieval

5.6.2 Testing Error of Trained Network for Gaussian Blurring Phase Contrast Images as Input

Appplied Network	Artifacts Added & Index	Average NMSE	Average MSE	Average SSIM	Average PSNR
L	Gaussian Blur Attenuation	0.02218	7.95199e-10	0.99999	95.60235
M	Gaussian Blur & 12dB Attenuation	0.0434	4.0303e-09	0.9999	88.7439
L	Gaussian Blur Phase	0.02218	0.00171	0.96073	80.40771
M	Gaussian Blur & 12dB Phase	0.0434	0.0087	0.9339	73.5493

Table 5.14: Testing Error of Trained Network for Gaussian Blurring Phase Contrast Images as Input

It is shown in Table 5.14 that the noise added causes some difficulties to mixed-scale dense network based reconstruction from phase contrast images blurred by a Gaussian kernel. Is is in line with the conclusion of the last part.

Comparing with Table 5.4, i.e. the simplistic single density case, the reconstruction from Gaussian blurred phase contrast images performs even a bit better than the simplistic case in terms of almost all evaluation metrics. It is due to more training epochs for some degree in Gaussian blurring case, and in section 5.5, all the experiments have 206 training epochs that is the largest among all the experiments done, their performance is worse than the simplistic case due to noise. Therefore, it can be justified that the mixed-scale dense network has capability to overcome the Gaussian blurring.

Comparing with Table 5.9, i.e. the single density noise case, the reconstructions from phase contrast images of 12dB noise level performs much worse than the reconstructions from Gaussian blurred phase contrast images of same noise level. This is because Gaussian blurring is acting as the noise filter.

5.6.3 Testing Error of Contrast Transfer Function Method on Same Testing Dataset

Artifacts Added & Index	Average NMSE	Average MSE	Average SSIM	Average PSNR
Gaussian Blur Attenuation	1.02057086	3.17861700e-06	0.99381400	60.02884714
Gaussian Blur & 12dB Attenuation	4.18664593	2.78134608e-05	0.98586642	50.03469930
Gaussian Blur Phase	1.15881785	7.39289470	0.56873564	43.72674059
Gaussian Blur & 12dB Phase	1.16203016	7.41016422	0.23526385	43.70663207

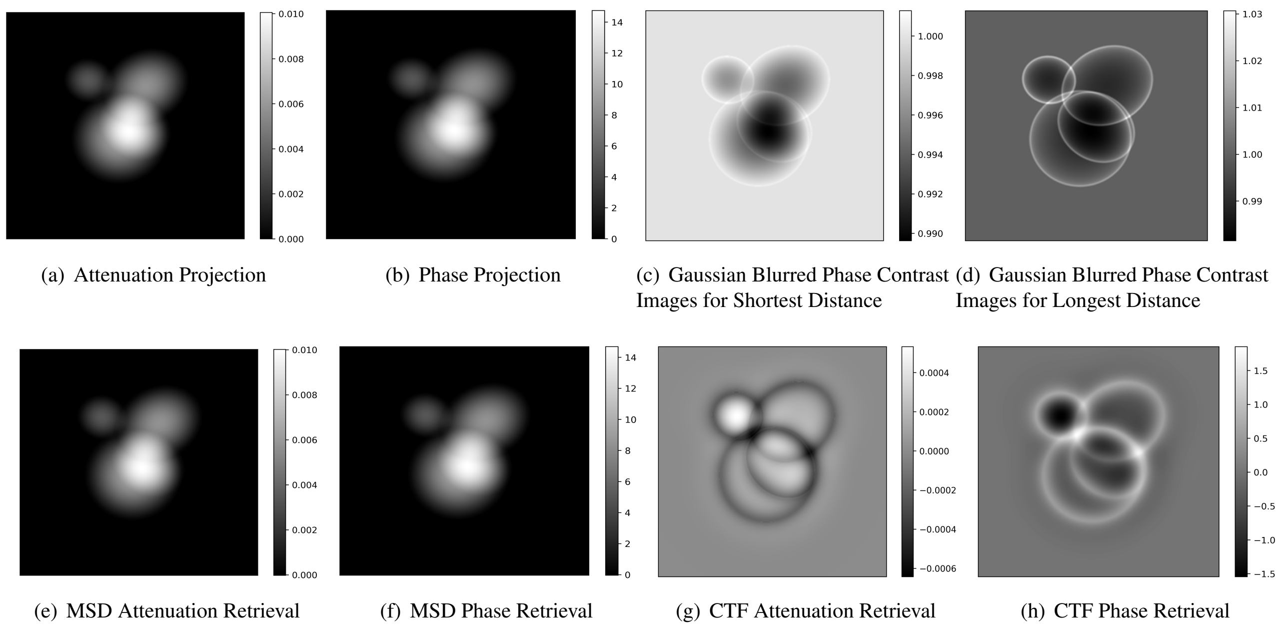
Table 5.15: Testing Error of Contrast Transfer Function Method on Same Testing Dataset

It is shown in Table 5.15 that noise added causes some difficulties to contrast transfer function based reconstruction from phase contrast images being Gaussian blurred. It is in line with the conclusion of the last part. However, the contrast transfer function behaves worse than mixed-scale dense network in terms of all evaluation metrics.

Comparing with Table 5.5, i.e. the simplistic single density case, phase reconstruction from non-noisy phase contrast images is a bit better than that from Gaussian blurred images, but attenuation reconstruction is a bit worse than that from Gaussian blurred images.

Comparing with Table 5.10, i.e. the single density noise case, the reconstructions from phase contrast images of 12dB noise level performs worse than the reconstructions from Gaussian blurred phase contrast images of the same noise level.This is because Gaussian blurring is acting as the noise filter.

5.6.4 Best Case of De-blurring Capacity of Neural Network for Non-noisy Gaussian Blurred images in Phase Retrieval



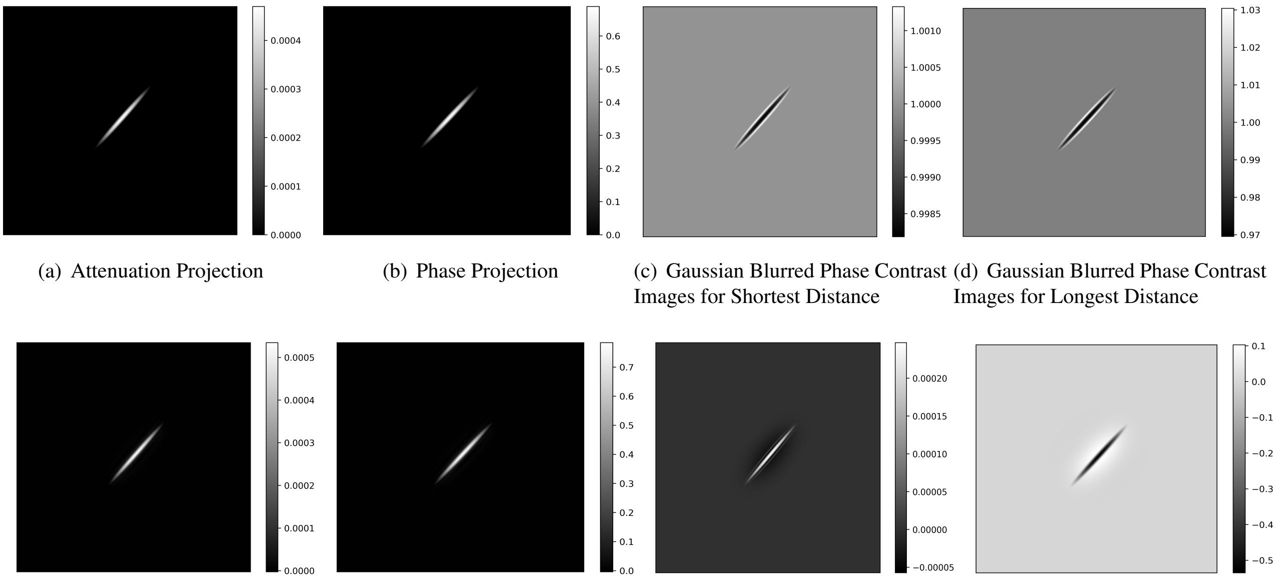
(a) Attenuation Projection (b) Phase Projection (c) Gaussian Blurred Phase Contrast Images for Shortest Distance (d) Gaussian Blurred Phase Contrast Images for Longest Distance

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

Figure 5.9: Best Case of De-blurring Capacity of Neural Network in Phase Retrieval

Comparing with Fig 5.1, both of mixed-scale dense network based and CTF based reconstructions perform as good as non-blurred case, it is in line with what the evaluation metrics reflects above.

5.6.5 Worst Case of De-blurring Capacity of Neural Network for Non-noisy Gaussian Blurred images in Phase Retrieval



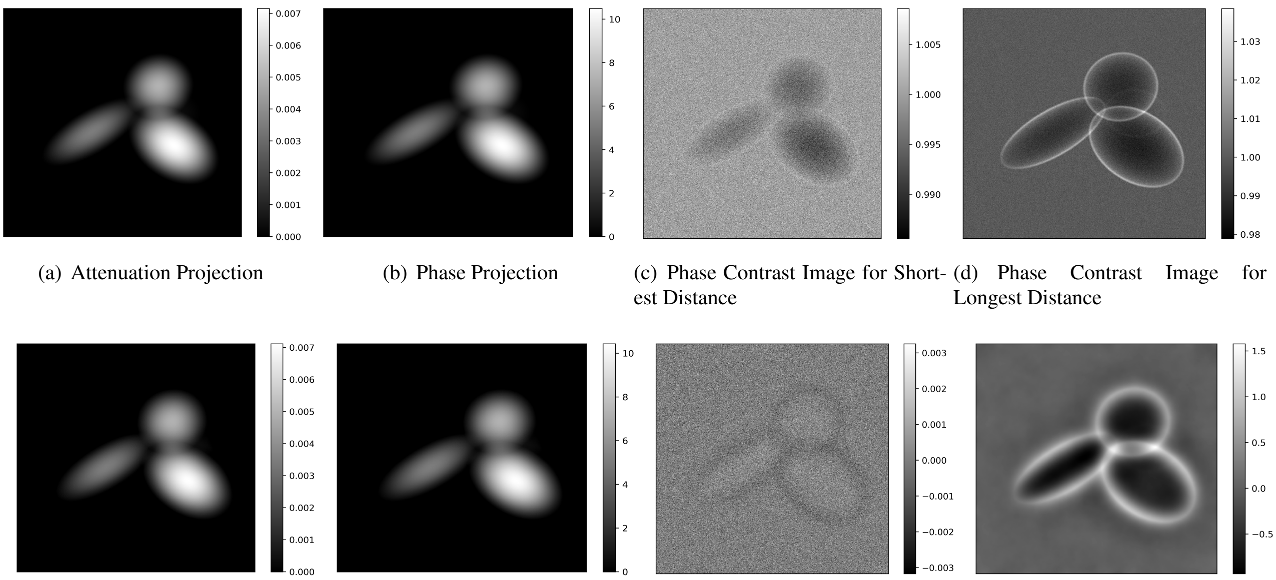
(a) Attenuation Projection (b) Phase Projection (c) Gaussian Blurred Phase Contrast Images for Shortest Distance (d) Gaussian Blurred Phase Contrast Images for Longest Distance

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

Figure 5.10: Worst Case of De-blurring Capacity of Neural Network in Phase Retrieval

Comparing with Fig 5.2, both of mixed-scale dense network based and CTF based reconstructions perform as good as non-blurred case,it is in line with what the evaluation metrics reflects above.

5.6.6 Best Case of De-blurring and De-noising Capacity of Neural Network for Noisy Gaussian blurred images in Phase Retrieval



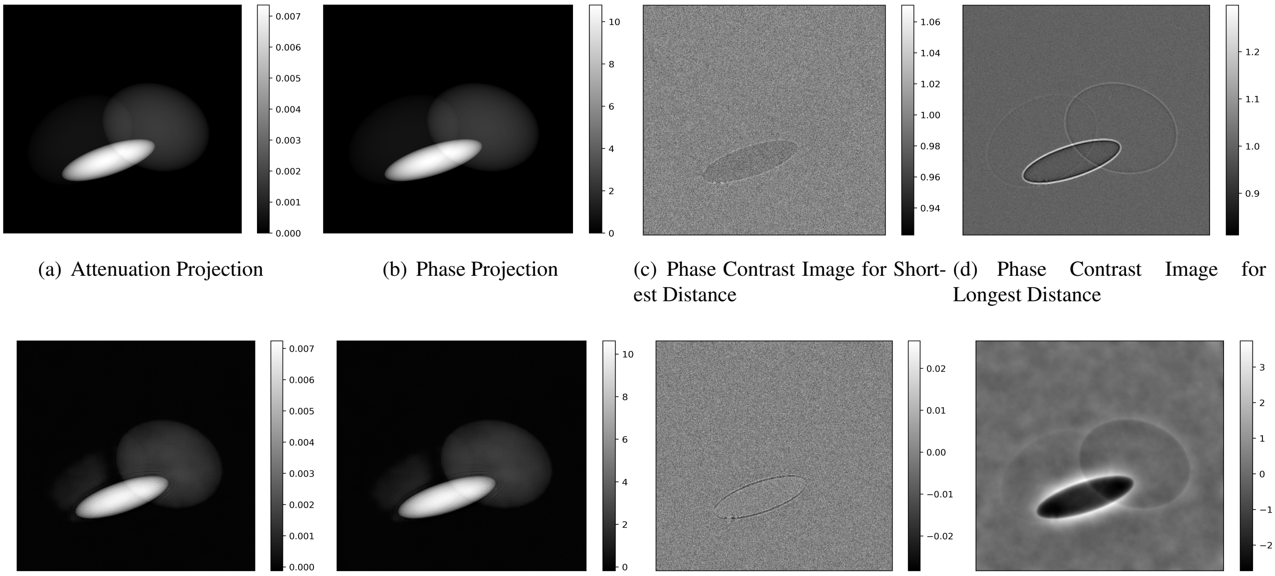
(a) Attenuation Projection (b) Phase Projection (c) Phase Contrast Image for Shortest Distance (d) Phase Contrast Image for Longest Distance

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

Figure 5.11: Best Case of De-blurring and De-noising Capacity of Neural Network for Noisy Gaussian blurred images in Phase Retrieval

Comparing with Fig 5.5, the mixed-scale dense network based reconstructions perform as good as the ones for the non-blurred case of the same noise level. And the contrast transfer function based phase reconstruction performs as good as the non-blurred of the same noise level case, but attenuation reconstruction performs quite worse, it is in line with deductions above based on evaluations metric as well.

5.6.7 Worst Case of De-blurring and De-noising Capacity of Neural Network for Noisy Gaussian blurred images in 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 5.12: Worst Case of De-blurring and De-noising Capacity of Neural Network for Noisy Gaussian blurred images in Phase Retrieval

Comparing with Fig 5.6, the mixed-scale dense network based reconstructions perform as good as the non-blurred the same noise level case. And the contrast transfer function based phase reconstruction performs as good as the non-blurred of same noise level. The attenuation reconstruction performs quite worse.

5.6.8 Conclusion

For both of noisy and non-noisy gaussian blurring cases, the mixed-scale dense network has capability to overcome the gaussian blurring. The contrast transfer function based phase reconstruction for noisy gaussian blurring case is also performing as good as non-noisy gaussian blurring case. The attenuation retrieval is not that good as for the non-noisy case.

5.7 Experiment of Exploration on Trained Neural Network Shape Generality in Phase Retrieval

5.7.1 Overview on Experiment of Exploration on Trained Neural Network Shape Generality in Phase Retrieval

Trained Network	Number of Density(s) involved in Training Data	Shape(s) involved in Training Data
N	1	ellipsoid
O	1	paraboloid

Table 5.16: Overview on Experiment of Exploration on Trained Neural Network Shape Generality in Phase Retrieval