Supplementary: Stochastic Blind Motion Deblurring

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I. PSNR COMPARISONS OF BENCHMARK DATASET [48]

In this section, we compare the PSNR results by our algorithm and the state-of-the-art methods on the benchmark dataset [48]. Please refer to the main paper for the reference number of compared papers.

TABLE I
PSNR COMPARISONS ON IMAGES BLURRED WITH KERNEL 01

Kernel 01 (35 x 35 pixels)					
	Image 1	Image 2	Image 3	Image 4	Average PSNR on all 4 images
Input	27.5770	21.6110	27.5300	22.8280	24.8865
Fergus [13]	20.9940	16.7300	29.2620	15.5230	20.6273
Shan [22]	31.3660	26.0020	31.9760	28.3460	29.4225
Cho [27]	33.9480	28.5160	35.7540	31.7530	32.4928
Xu & Jia [30]	33.2360	28.5220	35.5510	**32.4760**	32.4463
Krishnan [23]	33.8490	28.4480	33.4540	30.5400	31.5728
Whyte [34]	33.6940	27.6980	35.6780	31.2660	32.0840
Hirsch [37]	33.1610	**29.8300**	33.8040	31.3670	32.0405
[45]	32.7344	29.0660	34.4426	31.5099	31.9382
Ours	**34.2586**	28.4800	**36.4731**	31.3800	**32.6479**

TABLE II
PSNR COMPARISONS ON IMAGES BLURRED WITH KERNEL 02

Kernel 02 (35 x 35 pixels)					
	Image 1	Image 2	Image 3	Image 4	Average PSNR on all 4 images
Input	30.5290	24.6920	30.4350	25.7320	27.8470
Fergus [13]	33.4510	26.6720	32.3880	25.0110	29.3805
Shan [22]	32.2900	25.2290	29.2400	26.3530	28.2780
Cho [27]	32.9710	29.1550	33.5190	31.7960	31.8603
Xu & Jia [30]	34.2020	29.5420	34.5550	**32.0330**	32.5830
Krishnan [23]	33.7210	29.9210	32.5350	28.1970	31.0935
Whyte [34]	33.9460	27.5060	**35.3950**	31.9720	32.2048
Hirsch [37]	32.9750	30.0360	32.4980	24.8390	30.0870
[45]	33.4597	29.5346	32.2613	31.5776	31.7083
Ours	**33.9316**	**30.5831**	35.0956	31.0936	**32.6760**

TABLE III
PSNR comparisons on images blurred with Kernel 03

Kernel 03 (17 x 17 pixels)					
	Image 1	Image 2	Image 3	Image 4	Average PSNR on all 4 images
Input	35.0340	28.9960	35.4830	29.8340	32.3368
Fergus [13]	37.4360	24.9650	37.7190	25.9190	31.5098
Shan [22]	33.9210	27.4710	33.1390	28.5600	30.7728
Cho [27]	33.1640	27.8120	34.3690	30.4090	31.4385
Xu & Jia [30]	35.0030	29.0280	33.1960	31.6430	32.2175
Krishnan [23]	34.6090	28.5490	34.4870	29.0300	31.6688
Whyte [34]	37.9060	30.5740	36.0150	33.9600	34.6138
Hirsch [37]	35.7760	29.7310	36.8220	33.4490	33.9445
[45]	33.3367	28.2089	33.4608	30.6792	31.4214
Ours	**38.8244**	**30.6097**	**39.4545**	**32.5252**	**35.3535**

TABLE IV
PSNR comparisons on images blurred with Kernel 04

Kernel 04 (35 x 35 pixels)					
	Image 1	Image 2	Image 3	Image 4	Average PSNR on all 4 images
Input	30.2340	25.1480	30.9280	26.0610	28.0928
Fergus [13]	34.4660	25.7260	32.9720	24.7480	29.4780
Shan [22]	31.5320	24.2720	31.5590	27.0340	28.5993
Cho [27]	31.5210	27.2980	33.6540	31.0940	30.8918
Xu & Jia [30]	33.7200	28.2900	34.3830	31.6500	32.0108
Krishnan [23]	33.0950	27.9340	32.1890	29.8530	30.7678
Whyte [34]	33.8910	27.6720	34.6000	32.2180	32.0953
Hirsch [37]	33.5270	29.2480	33.8420	31.9050	32.1305
[45]	33.3153	28.3365	32.8216	30.7250	31.2996
Ours	**36.0225**	**29.6311**	**36.0230**	**33.2882**	**33.7412**

TABLE V
PSNR comparisons on images blurred with Kernel 05

Kernel 05 (35 x 35 pixels)					
	Image 1	Image 2	Image 3	Image 4	Average PSNR on all 4 images
Input	26.6430	20.8580	34.8070	34.5870	29.2238
Fergus [13]	19.4340	13.7690	34.9090	**34.9210**	25.7583
Shan [22]	28.4190	23.0910	34.5270	34.1250	30.0405
Cho [27]	33.0080	28.0960	34.4930	33.9370	32.3835
Xu & Jia [30]	**34.2590**	28.7040	35.0620	33.8790	**32.9760**
Krishnan [23]	30.0380	24.3820	34.2270	33.6880	30.5838
Whyte [34]	33.4980	27.5770	35.0380	34.0380	32.5378
Hirsch [37]	33.7230	28.9870	34.4900	34.0670	32.8168
[45]	34.2369	**28.7568**	34.4668	29.6495	31.7775
Ours	32.6129	28.3699	**35.2868**	33.9530	32.5557

TABLE VI
PSNR COMPARISONS ON IMAGES BLURRED WITH KERNEL 06

Kernel 06 (35 x 35 pixels)					
	Image 1	Image 2	Image 3	Image 4	Average PSNR on all 4 images
Input	27.6170	21.8890	28.2950	23.0830	25.2210
Fergus [13]	26.4800	20.8450	24.5550	17.4950	22.3438
Shan [22]	32.1290	21.2840	28.1710	25.8340	26.8545
Cho [27]	31.1710	26.6110	33.5510	28.7150	30.0120
Xu & Jia [30]	33.3100	26.9850	32.4450	28.9850	30.4313
Krishnan [23]	27.7020	22.2780	25.8430	22.5370	24.5900
Whyte [34]	33.2770	26.8810	33.7810	**29.6120**	30.8878
Hirsch [37]	33.3580	22.9440	33.1220	28.7150	29.5348
[45]	32.6774	27.4119	31.1692	28.9794	30.0595
Ours	**33.3672**	**28.5380**	**35.9813**	28.9353	**31.7449**

TABLE VII
PSNR COMPARISONS ON IMAGES BLURRED WITH KERNEL 07

Kernel 07 (35 x 35 pixels)					
	Image 1	Image 2	Image 3	Image 4	Average PSNR on all 4 images
Input	27.2220	21.9070	28.1990	22.4230	24.9378
Fergus [13]	21.2290	19.7110	27.2160	14.6340	20.6975
Shan [22]	30.5280	22.3360	28.8980	25.5470	26.8273
Cho [27]	33.4600	27.3050	33.5430	29.3490	30.9143
Xu & Jia [30]	**33.8990**	27.8380	33.8620	**29.9940**	**31.3983**
Krishnan [23]	28.1520	22.9090	29.2320	22.9190	25.8030
Whyte [34]	30.8130	25.9100	32.7660	26.7460	29.0588
Hirsch [37]	32.9020	27.6240	32.3250	24.4140	29.3163
[45]	33.4017	**28.1149**	32.8947	29.0570	30.8671
Ours	33.1947	27.0671	**34.3036**	29.2747	30.9600

TABLE VIII
PSNR COMPARISONS ON IMAGES BLURRED WITH KERNEL 12

Kernel 12 (49 x 49 pixels)					
	Image 1	Image 2	Image 3	Image 4	Average PSNR on all 4 images
Input	27.0590	20.2490	26.2820	21.8180	23.8520
Fergus [13]	26.7260	15.5230	18.2920	19.9120	20.1133
Shan [22]	25.0020	19.5720	25.4590	25.0010	23.7585
Cho [27]	31.1870	25.2950	32.9740	26.4610	28.9793
Xu & Jia [30]	31.9530	25.7370	32.5020	**27.8590**	29.5128
Krishnan [23]	26.7650	20.0370	24.6570	21.8220	23.3203
Whyte [34]	26.9360	**26.6010**	32.7350	26.5560	28.2070
Hirsch [37]	28.2560	24.5620	28.3870	26.0480	26.8133
[45]	31.4212	25.9144	31.5976	27.7728	29.1765
Ours	**33.3638**	26.0928	**33.4030**	27.6157	**30.1188**

II. Result images of benchmark dataset [48]

In this section, we show the recovered intrinsic images by our algorithm and the state-of-the-art software [45] on the benchmark dataset [48]. Please refer to [48]'s website (http://webdav.is.mpg.de/pixel/benchmark4camerashake/) for complete results by other methods. We recommend the readers to view the images on computer screen for better visual comparison.

Note that [45]'s results sometimes look sharper, but indeed their method may oversharpen the images and create halo artifacts at the edge pixels (thus results in lower PSNR). This might be caused by their use of explicit shock filter and bilateral filter in kernel estimation. We provide unblurred reference images at the beginning of each dataset for comparison.

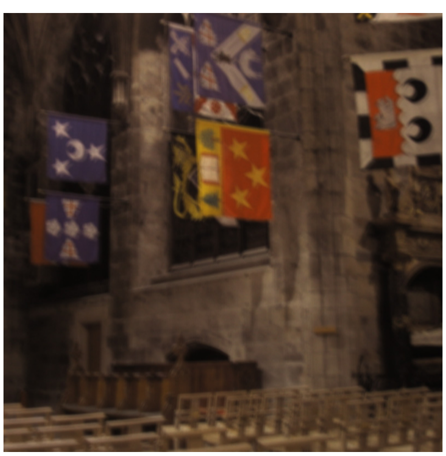
Fig. 1. Image 1, Reference

(a) Input, 27.58 dB

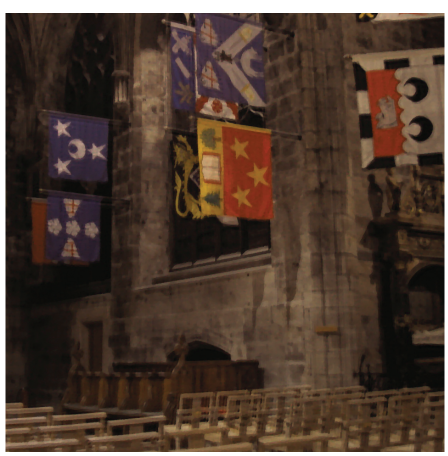
(b) Ours, 34.26 dB

(c) [45], 32.73 dB

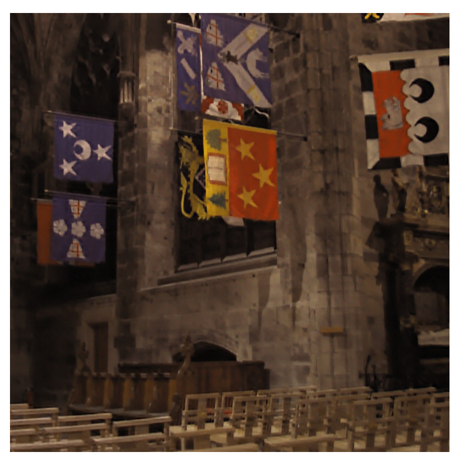
Fig. 2. Image 1, Kernel 1



(a) Input, 30.53 dB



(b) Ours, 33.93 dB



(c) [45], 33.46 dB

Fig. 3. Image 1, Kernel 2

(a) Input, 35.03 dB (b) Ours, 38.82 dB (c) [45], 33.34 dB

Fig. 4. Image 1, Kernel 3

(a) Input, 30.23 dB (b) Ours, 36.02 dB (c) [45], 33.32 dB

Fig. 5. Image 1, Kernel 4

(a) Input, 26.64 dB (b) Ours, 32.61 dB (c) [45], 34.24 dB

Fig. 6. Image 1, Kernel 5

(a) Input, 27.62 dB (b) Ours, 33.37 dB (c) [45], 32.68 dB

Fig. 7. Image 1, Kernel 6

(a) Input, 27.22 dB (b) Ours, 33.19 dB (c) [45], 33.40 dB

Fig. 8. Image 1, Kernel 7

(a) Input, 27.06 dB (b) Ours, 33.36 dB (c) [45], 31.42 dB

Fig. 9. Image 1, Kernel 12

Fig. 10. Image 2, Reference

(a) Input, 21.61 dB (b) Ours, 28.48 dB (c) [45], 29.07 dB

Fig. 11. Image 2, Kernel 1

(a) Input, 24.69 dB (b) Ours, 30.58 dB (c) [45], 29.53 dB

Fig. 12. Image 2, Kernel 2

(a) Input, 29.00 dB

(b) Ours, 30.61 dB

(c) [45], 28.21 dB

Fig. 13. Image 2, Kernel 3

(a) Input, 25.15 dB

(b) Ours, 29.63 dB

(c) [45], 28.34 dB

Fig. 14. Image 2, Kernel 4

(a) Input, 20.86 dB

(b) Ours, 28.37 dB

(c) [45], 28.76 dB

Fig. 15. Image 2, Kernel 5

(a) Input, 21.89 dB (b) Ours, 28.54 dB (c) [45], 27.41 dB

Fig. 16. Image 2, Kernel 6

(a) Input, 21.91 dB (b) Ours, 27.07 dB (c) [45], 28.11 dB

Fig. 17. Image 2, Kernel 7

(a) Input, 20.25 dB (b) Ours, 26.09 dB (c) [45], 25.91 dB

Fig. 18. Image 2, Kernel 12

Fig. 19. Image 3, Reference

(a) Input, 27.53 dB (b) Ours, 36.47 dB (c) [45], 34.44 dB

Fig. 20. Image 3, Kernel 1

(a) Input, 30.44 dB (b) Ours, 35.10 dB (c) [45], 32.26 dB

Fig. 21. Image 3, Kernel 2

(a) Input, 35.48 dB

(b) Ours, 39.45 dB

(c) [45], 33.46 dB

Fig. 22. Image 3, Kernel 3

(a) Input, 30.93 dB

(b) Ours, 36.02 dB

(c) [45], 32.82 dB

Fig. 23. Image 3, Kernel 4

(a) Input, 34.81 dB

(b) Ours, 35.29 dB

(c) [45], 34.47 dB

Fig. 24. Image 3, Kernel 5

(a) Input, 28.30 dB

(b) Ours, 35.98 dB

(c) [45], 31.17 dB

Fig. 25. Image 3, Kernel 6

(a) Input, 28.20 dB

(b) Ours, 34.30 dB

(c) [45], 32.90 dB

Fig. 26. Image 3, Kernel 7

(a) Input, 28.20 dB

(b) Ours, 34.29 dB

(c) [45], 32.89 dB

Fig. 27. Image 3, Kernel 12

Fig. 28. Image 4, Reference

(a) Input, 22.83 dB (b) Ours, 31.38 dB (c) [45], 31.51 dB

Fig. 29. Image 4, Kernel 1

(a) Input, 25.73 dB (b) Ours, 31.09 dB (c) [45], 31.58 dB

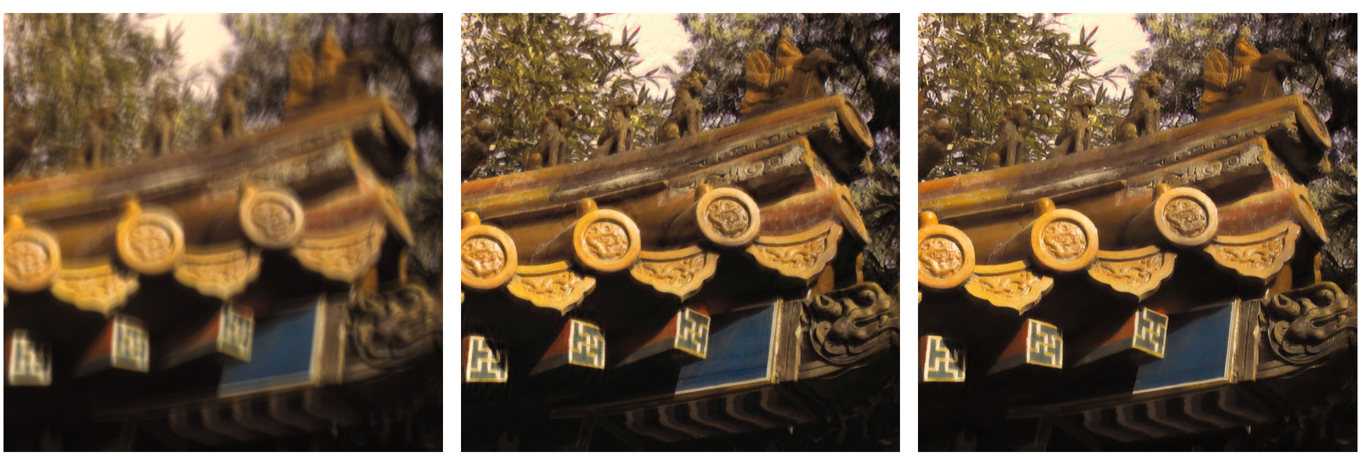
Fig. 30. Image 4, Kernel 2

(a) Input, 29.83 dB (b) Ours, 32.53 dB (c) [45], 30.68 dB

Fig. 31. Image 4, Kernel 3

(a) Input, 26.06 dB (b) Ours, 33.29 dB (c) [45], 30.72 dB

Fig. 32. Image 4, Kernel 4



(a) Input, 34.59 dB (b) Ours, 33.95 dB (c) [45], 33.99 dB

Fig. 33. Image 4, Kernel 5

(a) Input, 23.08 dB (b) Ours, 28.94 dB (c) [45], 28.98 dB

Fig. 34. Image 4, Kernel 6

(a) Input, 22.42 dB (b) Ours, 29.27 dB (c) [45], 29.06 dB

Fig. 35. Image 4, Kernel 7

(a) Input, 21.82 dB (b) Ours, 27.62 dB (c) [45], 27.77 dB

Fig. 36. Image 4, Kernel 12

III. Result images of running-time analysis

In this section, we show our result images and parameters for the running time analysis (Table II in the main paper). Fig. 37 shows the ground truth images and kernel. Fig. 38 - 46 show the results of gray-scale input images. Fig. 47 - 55 show the results of color input images.

The running time depends on the number of proposed samples, and the image and kernel size. The definitions of certain parameters are given below. We provide these parameters in the caption of each result image.

T: the number of alternates between intrinsic image update and kernel update (see Algo. 1, line 11).

N: the number of iterations for intrinsic image update and kernel update (see Algo. 2, line 2).

$M_{\mathbf{I}}$: the number of proposed samples in each iteration and each color channel for intrinsic image update (see M in Algo. 2, line 4).

$M_{\mathbf{K}}$: the number of proposed samples in each iteration for kernel update (see M in Algo. 2, line 4).

N_{final}: the number of iterations for final intrinsic image restoration (Algo. 1, line 18).

M_{final}: the number of proposed samples in each iteration and each color channel for final intrinsic image restoration (Algo. 1, line 18).

(a) True intrinsic (gray-scale) (b) True intrinsic (color) (c) True kernel

Fig. 37. Ground truth intrinsic images and kernel. The intrinsic images are resized to be 400×400, 800×800, 1200×1200, and the kernel is resized to be 15×15, 25×25, 35×35 for the test.

(a) Input (b) Our deblurred

Fig. 38. Image size 400×400, kernel size 15×15. $T = 5, N = 5, M_{\mathbf{I}} = 10000, M_{\mathbf{K}} = 100, N_{\text{final}} = 5, M_{\text{final}} = 200000$.

(a) Input (b) Our deblurred

Fig. 39. Image size 400×400, kernel size 25×25. $T = 5, N = 5, M_{\mathbf{I}} = 20000, M_{\mathbf{K}} = 200, N_{\text{final}} = 5, M_{\text{final}} = 200000$.

(a) Input (b) Our deblurred

Fig. 40. Image size 400×400, kernel size 35×35. $T = 5, N = 5, M_{\mathbf{I}} = 20000, M_{\mathbf{K}} = 200, N_{\text{final}} = 5, M_{\text{final}} = 400000$.

(a) Input (b) Our deblurred

Fig. 41. Image size 800×800, kernel size 15×15. $T = 5, N = 5, M_{\mathbf{I}} = 20000, M_{\mathbf{K}} = 200, N_{\text{final}} = 5, M_{\text{final}} = 400000$.

(a) Input (b) Our deblurred

Fig. 42. Image size 800×800, kernel size 25×25. $T = 5, N = 5, M_{\mathbf{I}} = 20000, M_{\mathbf{K}} = 200, N_{\text{final}} = 5, M_{\text{final}} = 400000$.

(a) Input (b) Our deblurred

Fig. 43. Image size 800×800, kernel size 35×35. $T = 5, N = 5, M_{\mathbf{I}} = 40000, M_{\mathbf{K}} = 200, N_{\text{final}} = 5, M_{\text{final}} = 800000$.

(a) Input (b) Our deblurred

Fig. 44. Image size 1200×1200, kernel size 15×15. $T = 5$, $N = 5$, $M_{\mathbf{I}} = 20000$, $M_{\mathbf{K}} = 200$, $N_{\text{final}} = 5$, $M_{\text{final}} = 600000$.

(a) Input (b) Our deblurred

Fig. 45. Image size 1200×1200, kernel size 25×25. $T = 5$, $N = 5$, $M_{\mathbf{I}} = 20000$, $M_{\mathbf{K}} = 200$, $N_{\text{final}} = 5$, $M_{\text{final}} = 600000$.

(a) Input (b) Our deblurred

Fig. 46. Image size 1200×1200, kernel size 35×35. $T = 5$, $N = 5$, $M_{\mathbf{I}} = 40000$, $M_{\mathbf{K}} = 200$, $N_{\text{final}} = 5$, $M_{\text{final}} = 800000$.

(a) Input (b) Our deblurred

Fig. 47. Image size 400×400, kernel size 15×15. $T = 5, N = 5, M_{\mathbf{I}} = 10000, M_{\mathbf{K}} = 100, N_{\text{final}} = 5, M_{\text{final}} = 200000$.

(a) Input (b) Our deblurred

Fig. 48. Image size 400×400, kernel size 25×25. $T = 5, N = 5, M_{\mathbf{I}} = 20000, M_{\mathbf{K}} = 200, N_{\text{final}} = 5, M_{\text{final}} = 200000$.

(a) Input (b) Our deblurred

Fig. 49. Image size 400×400, kernel size 35×35. $T = 5, N = 5, M_{\mathbf{I}} = 20000, M_{\mathbf{K}} = 200, N_{\text{final}} = 5, M_{\text{final}} = 400000$.

(a) Input (b) Our deblurred

Fig. 50. Image size 800×800, kernel size 15×15. $T = 5, N = 5, M_{\mathbf{I}} = 20000, M_{\mathbf{K}} = 200, N_{\text{final}} = 5, M_{\text{final}} = 400000$.

(a) Input (b) Our deblurred

Fig. 51. Image size 800×800, kernel size 25×25. $T = 5, N = 5, M_{\mathbf{I}} = 20000, M_{\mathbf{K}} = 200, N_{\text{final}} = 5, M_{\text{final}} = 600000$.

(a) Input (b) Our deblurred

Fig. 52. Image size 800×800, kernel size 35×35. $T = 5, N = 5, M_{\mathbf{I}} = 40000, M_{\mathbf{K}} = 400, N_{\text{final}} = 5, M_{\text{final}} = 800000$.

(a) Input (b) Our deblurred

Fig. 53. Image size 1200×1200, kernel size 15×15. $T = 5$, $N = 5$, $M_{\mathbf{I}} = 20000$, $M_{\mathbf{K}} = 200$, $N_{\text{final}} = 5$, $M_{\text{final}} = 600000$.

(a) Input (b) Our deblurred

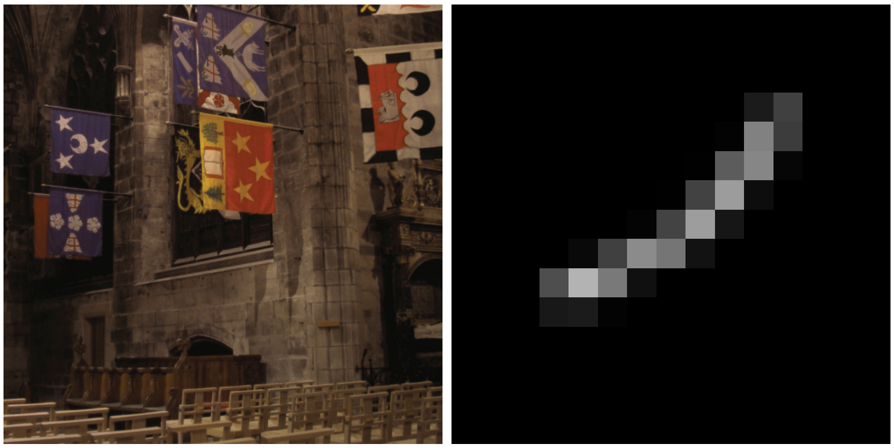
Fig. 54. Image size 1200×1200, kernel size 25×25. $T = 5$, $N = 5$, $M_{\mathbf{I}} = 20000$, $M_{\mathbf{K}} = 200$, $N_{\text{final}} = 5$, $M_{\text{final}} = 600000$.

(a) Input (b) Our deblurred

Fig. 55. Image size 1200×1200, kernel size 35×35. $T = 5$, $N = 5$, $M_{\mathbf{I}} = 40000$, $M_{\mathbf{K}} = 200$, $N_{\text{final}} = 5$, $M_{\text{final}} = 800000$.

IV. Result images of noise influence analysis

In this section, we show our results on synthetic data with different noise (white Gaussian noise) levels (also see Fig. 15 in the main paper). Fig. 56 shows the ground truth intrinsic image and kernel. Fig. 57- 62 shows the results at different noise levels. The standard deviation (σ) of the noise is set as 0, 0.01. 0.02, 0.03, 0.04 and 0.05 respectively.



(a) True intrinsic (b) True kernel

Fig. 56. Ground truth intrinsic images (800×800) and kernel (15×15).

(a) Input, 31.30 dB (b) Our deblurred, 34.46 dB

Fig. 57. The standard deviation $\sigma = 0$.

(a) Input, 30.86 dB (b) Our deblurred, 33.84 dB

Fig. 58. The standard deviation $\sigma = 0.01$.

(a) Input, 29.17 dB (b) Our deblurred, 32.57 dB

Fig. 59. The standard deviation $\sigma = 0.02$.

(a) Input, 26.79 dB (b) Our deblurred, 30.85 dB

Fig. 60. The standard deviation $\sigma = 0.03$.

(a) Input, 24.44 dB (b) Our deblurred, 30.17 dB

Fig. 61. The standard deviation $\sigma = 0.04$.

(a) Input, 22.35 dB (b) Our deblurred, 29.73 dB

Fig. 62. The standard deviation $\sigma = 0.05$.