DEEP GAUSSIAN DENOISER EPISTEMIC UNCERTAINTY AND DECOUPLED DUAL-ATTENTION FUSION - SUPPLEMENTARY MATERIAL -

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ABSTRACT

We present in this supplementary material extended visual denoising results from our test set. We show the qualitative results for different noise levels and for various backbone denoisers (DnCNN [1], MemNet [2], and RIDNet [3]), and the corresponding results with our proposed fusion method. As discussed in our main manuscript, the dual-attention fusion method that we present is directly applicable to other denoising setups. As an example, we also provide quantitative color denoising results in Table 1, and qualitative results in the subsequent Fig. 16, and 17. We report the baseline results of the backbone denoiser, of the averaging ensemble, and of our full fusion. In addition, we include the results with different image manipulation ablations. More specifically, the results over spatial manipulations, frequency-domain manipulations, and the joint application over their union. The best results are consistently obtained with our full fusion method, and using all of our different image manipulations.

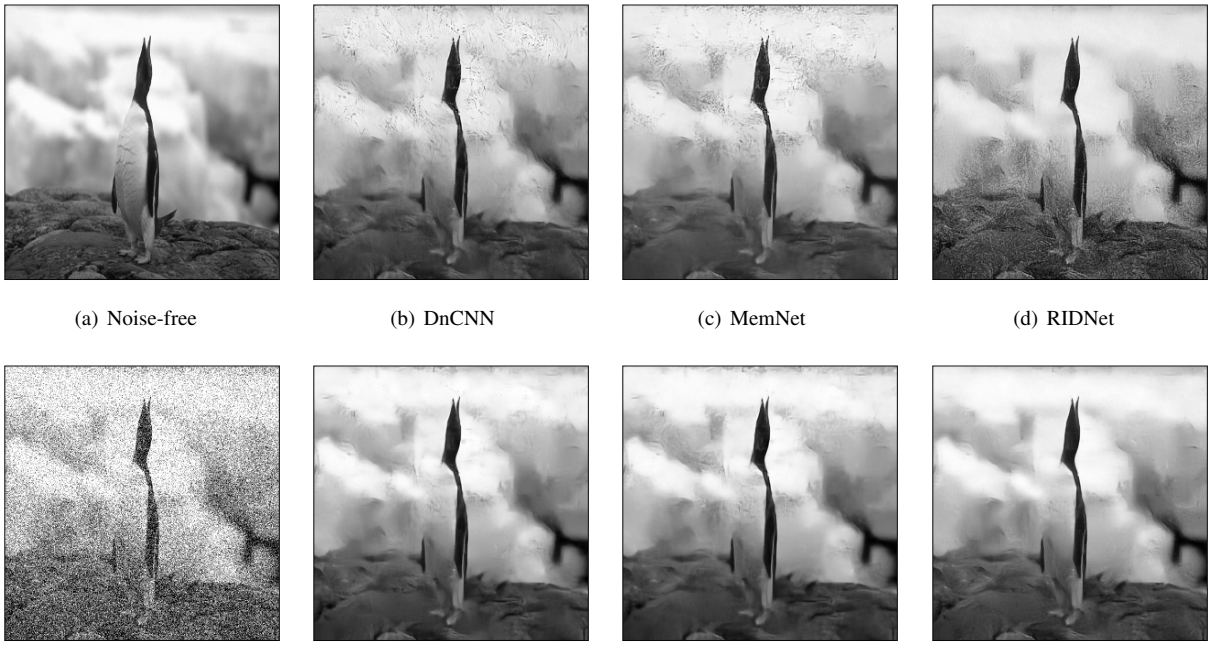
1. REFERENCES

[1] Kai Zhang, Wangmeng Zuo, Yunjin Chen, Deyu Meng, and Lei Zhang, "Beyond a Gaussian denoiser: Residual learning of deep CNN for image denoising," *IEEE Transactions on Image Processing*, vol. 26, no. 7, pp. 3142–3155, 2017.

[2] Ying Tai, Jian Yang, Xiaoming Liu, and Chunyan Xu, "MemNet: A persistent memory network for image restoration," in *International Conference on Computer Vision (ICCV)*, 2017.

[3] Saeed Anwar and Nick Barnes, "Real image denoising with feature attention," *International Conference on Computer Vision (ICCV)*, 2019.

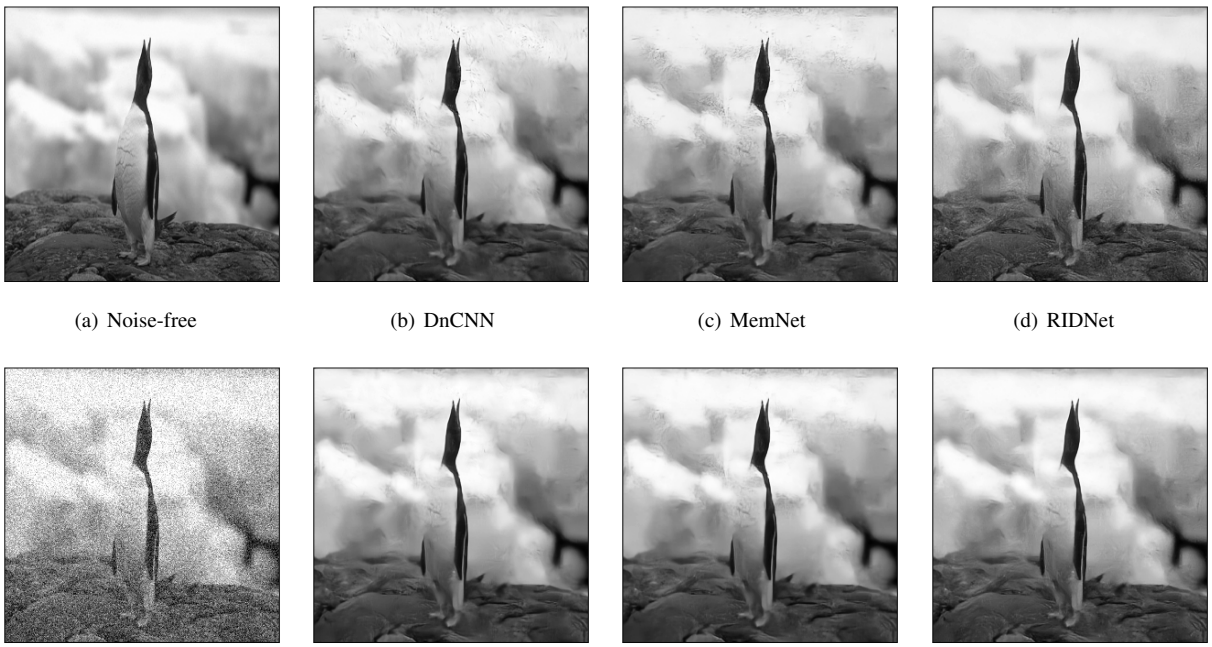
Our code and models are made publicly available at: https://github.com/IVRL/DEU



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 50$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

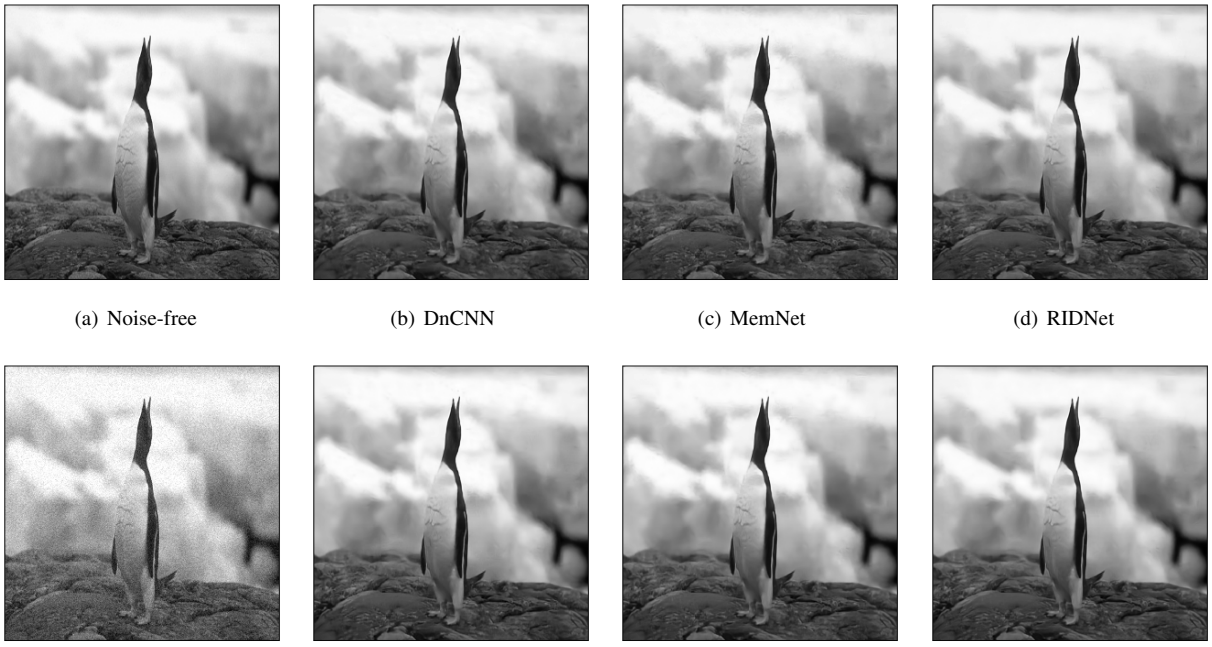
Fig. 1. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 50$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 30$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

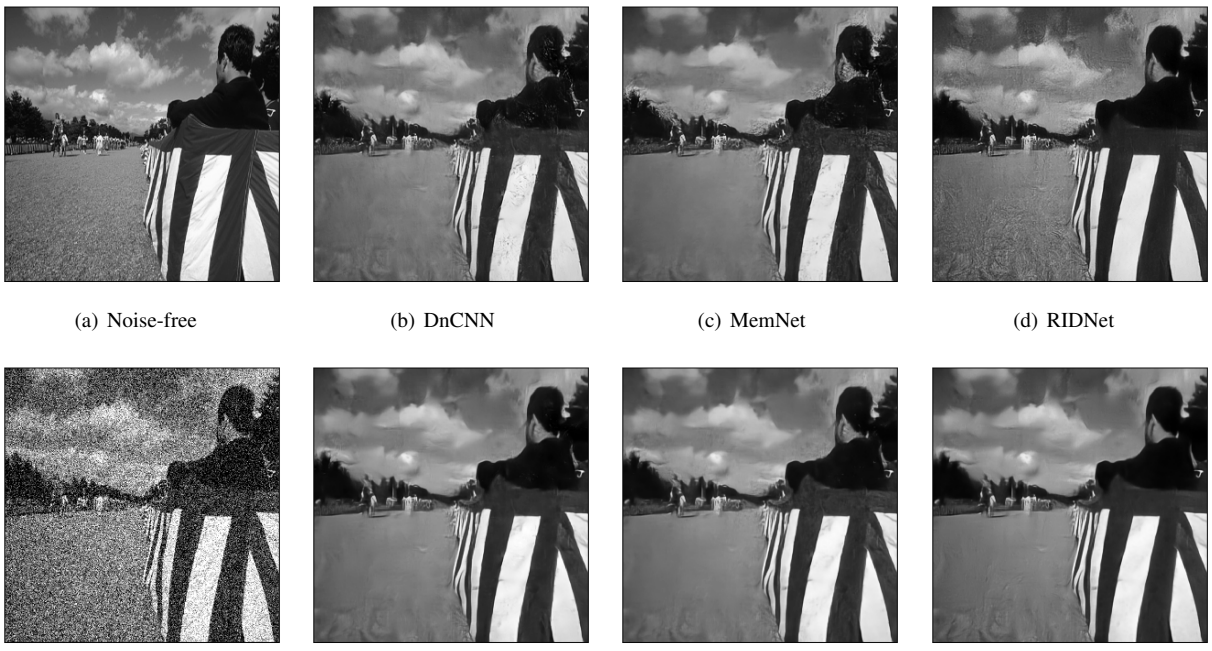
Fig. 2. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 30$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 10$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

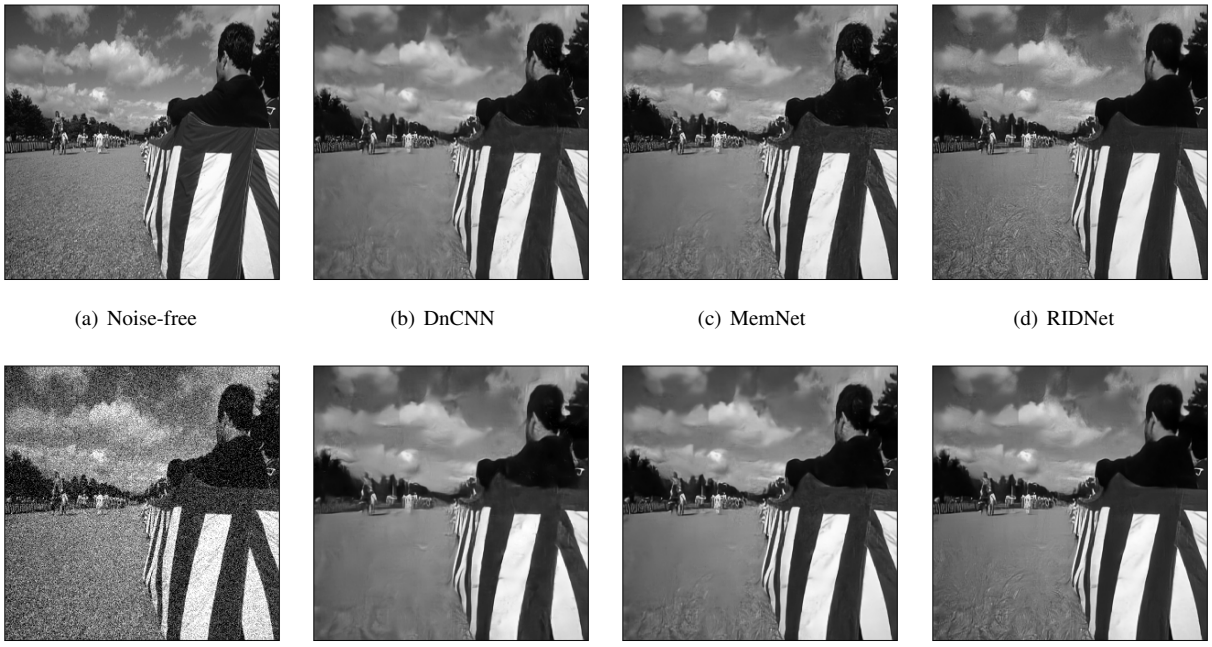
Fig. 3. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 10$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 50$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

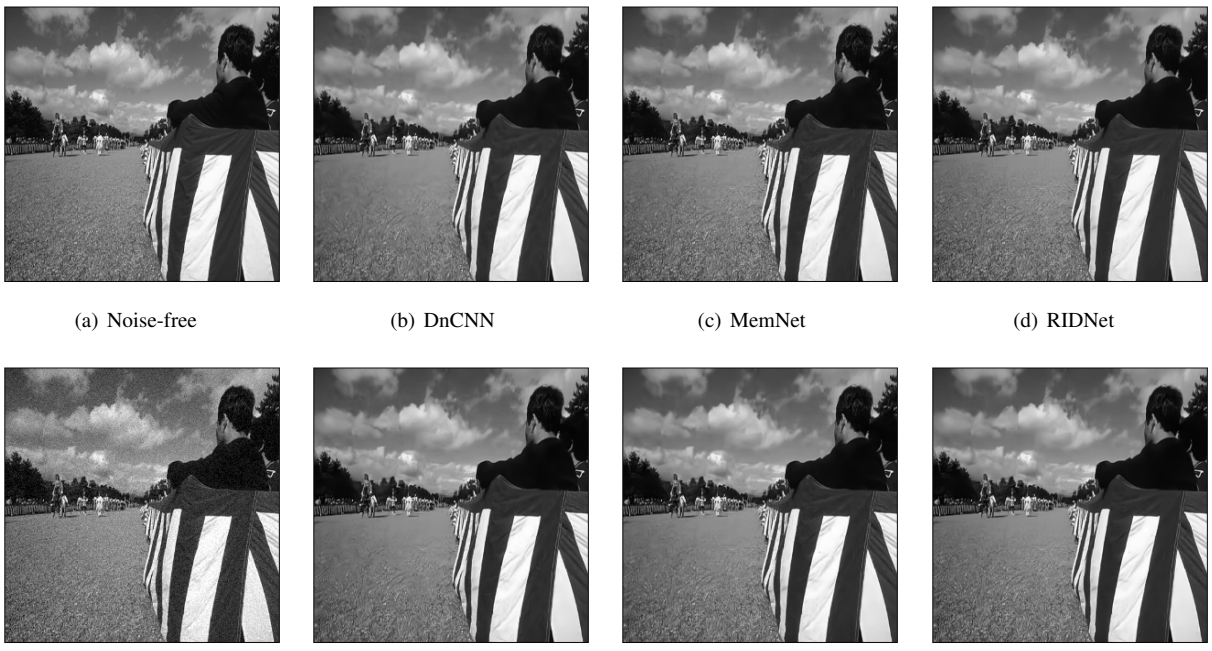
Fig. 4. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 50$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 30$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

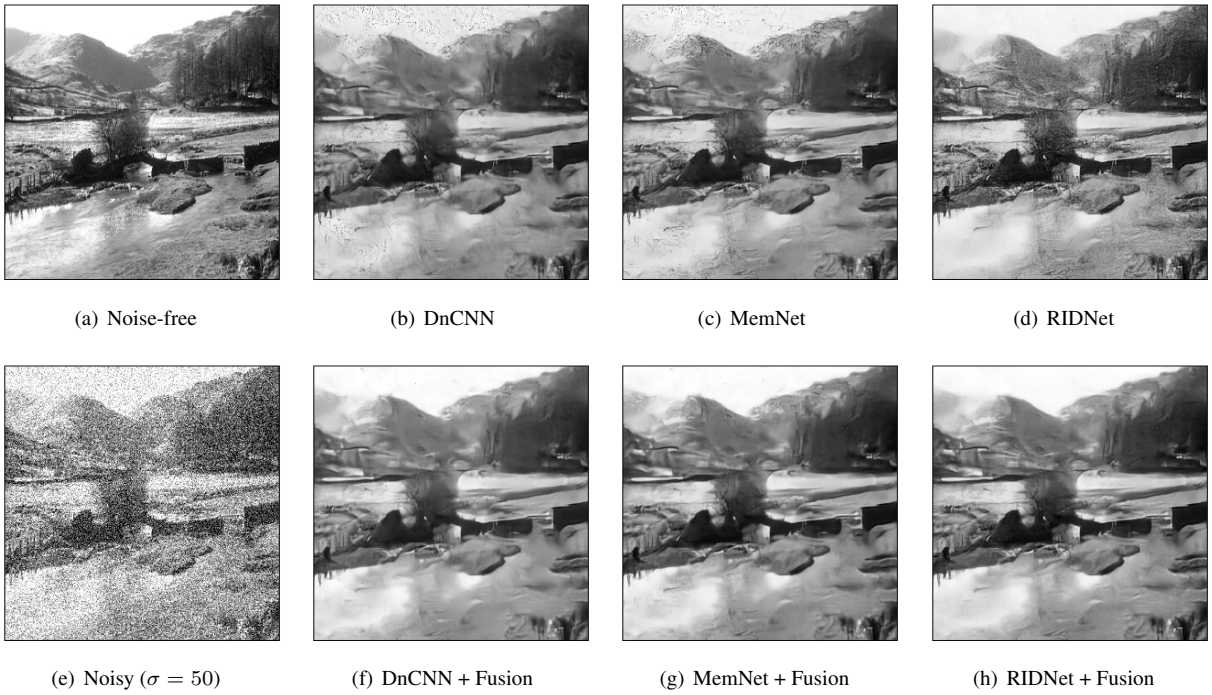
Fig. 5. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 30$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 10$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

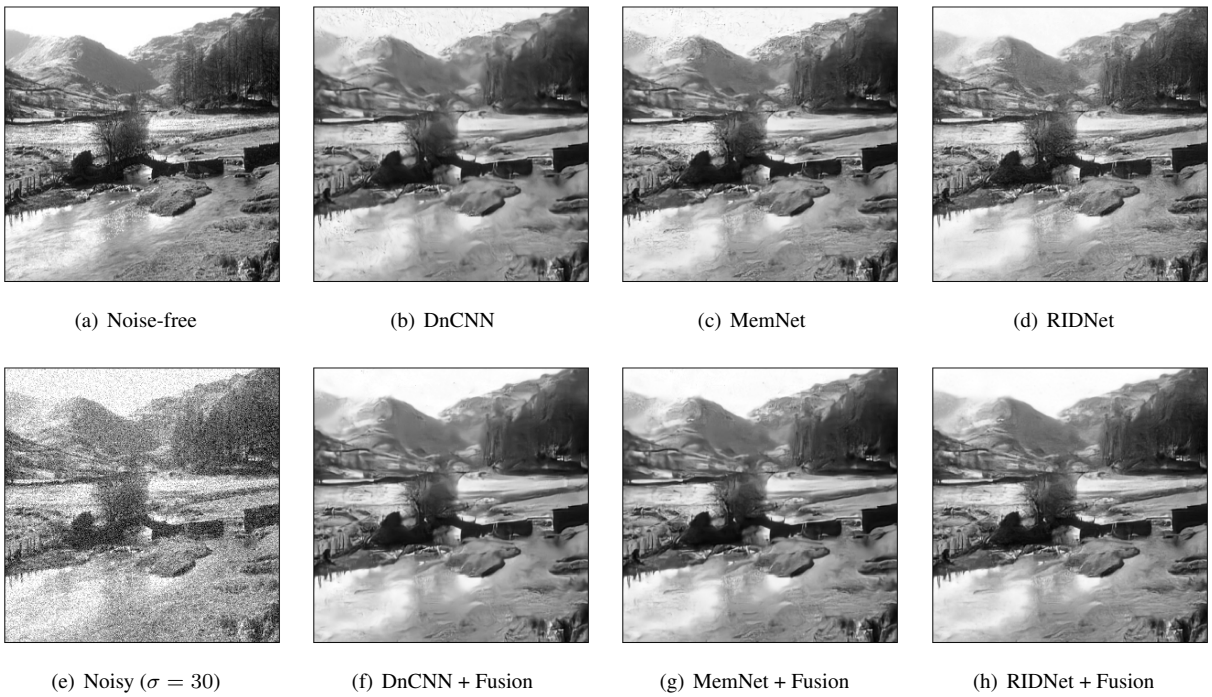
Fig. 6. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 10$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 50$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

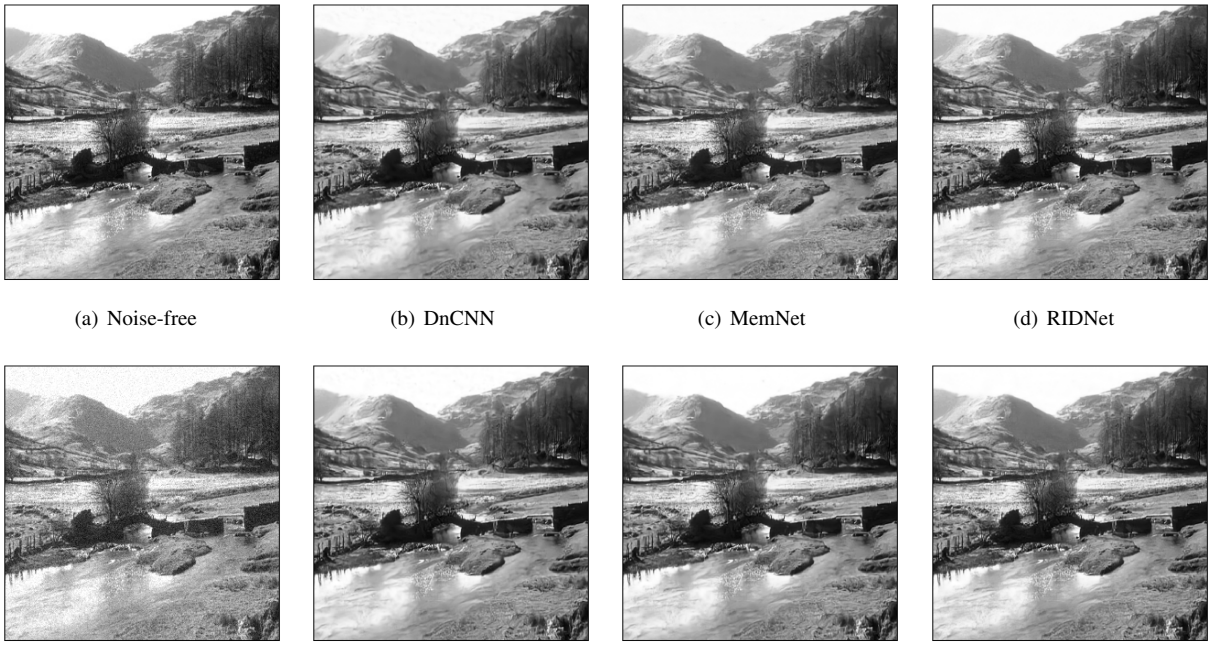
Fig. 7. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 50$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 30$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

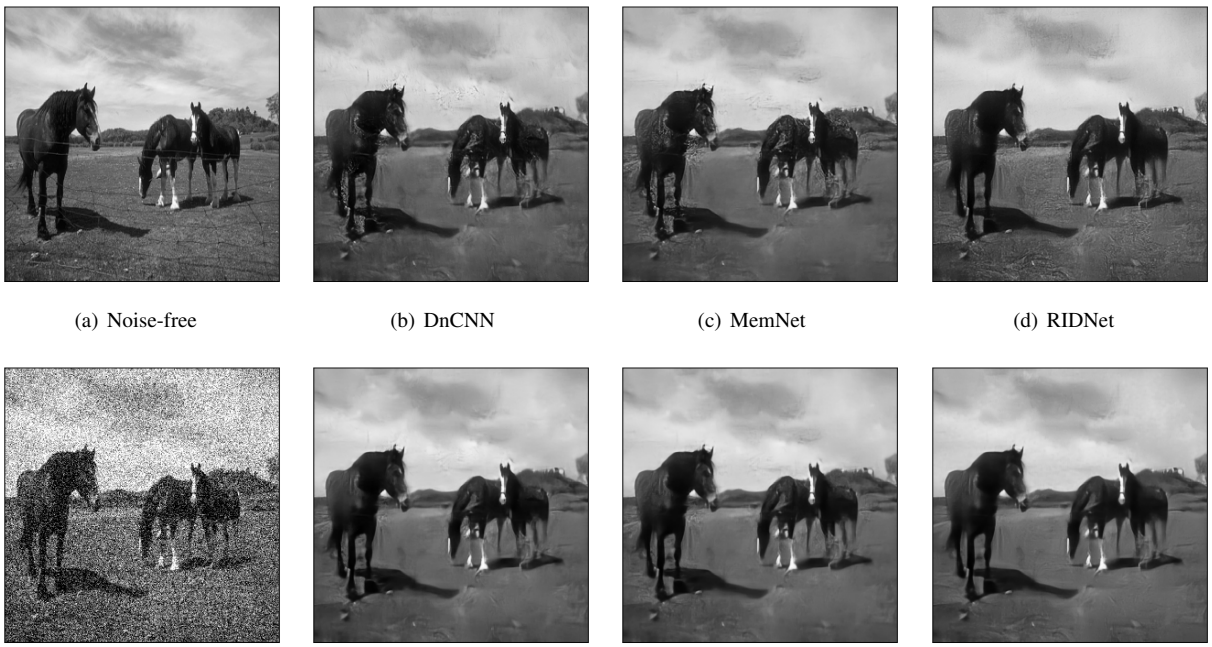
Fig. 8. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 30$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 10$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

Fig. 9. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 10$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

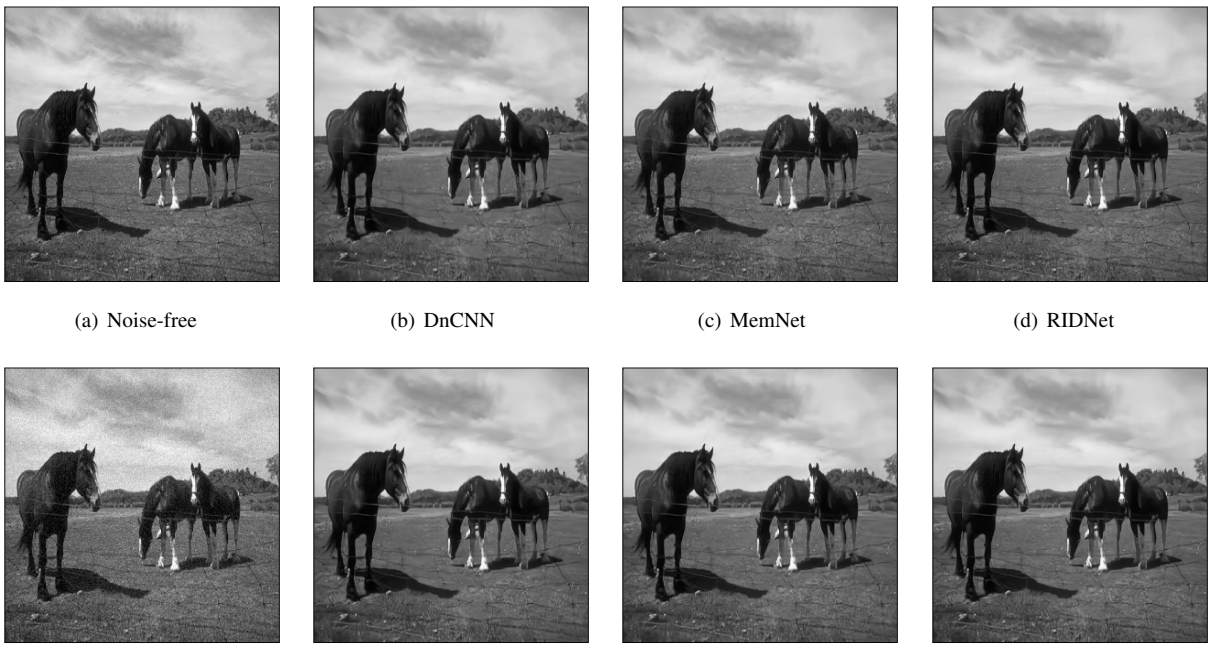
(e) Noisy ($\sigma = 50$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

Fig. 10. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 50$. Best viewed on screen.

(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 30$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

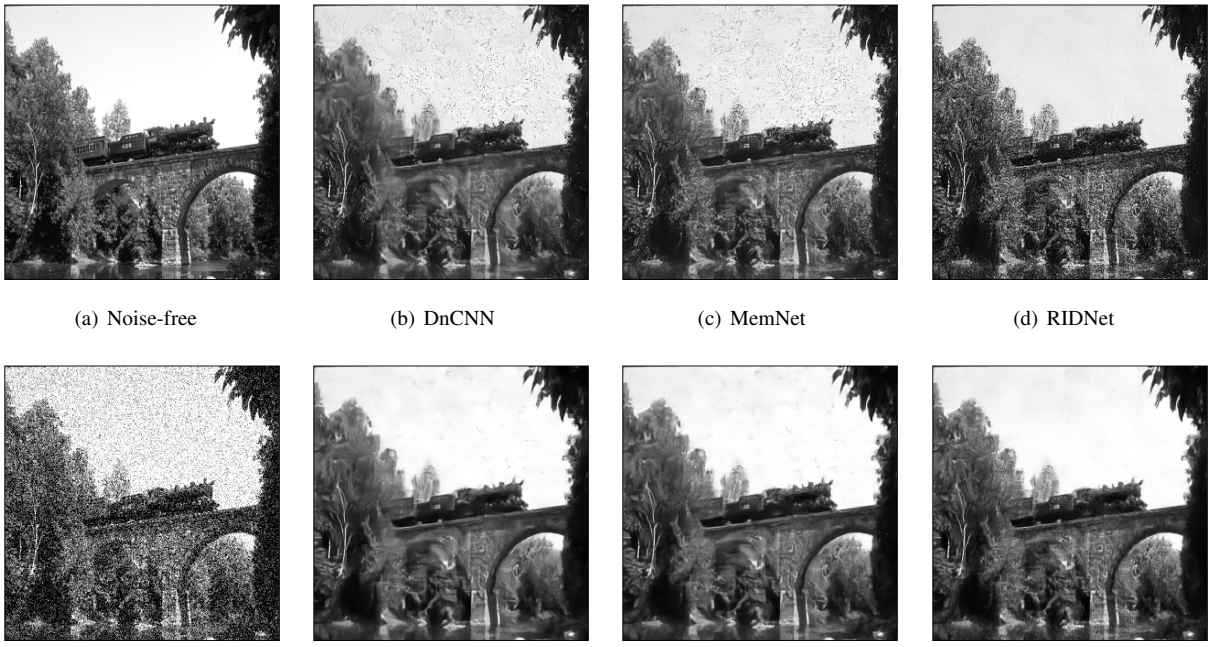
Fig. 11. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 30$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 10$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

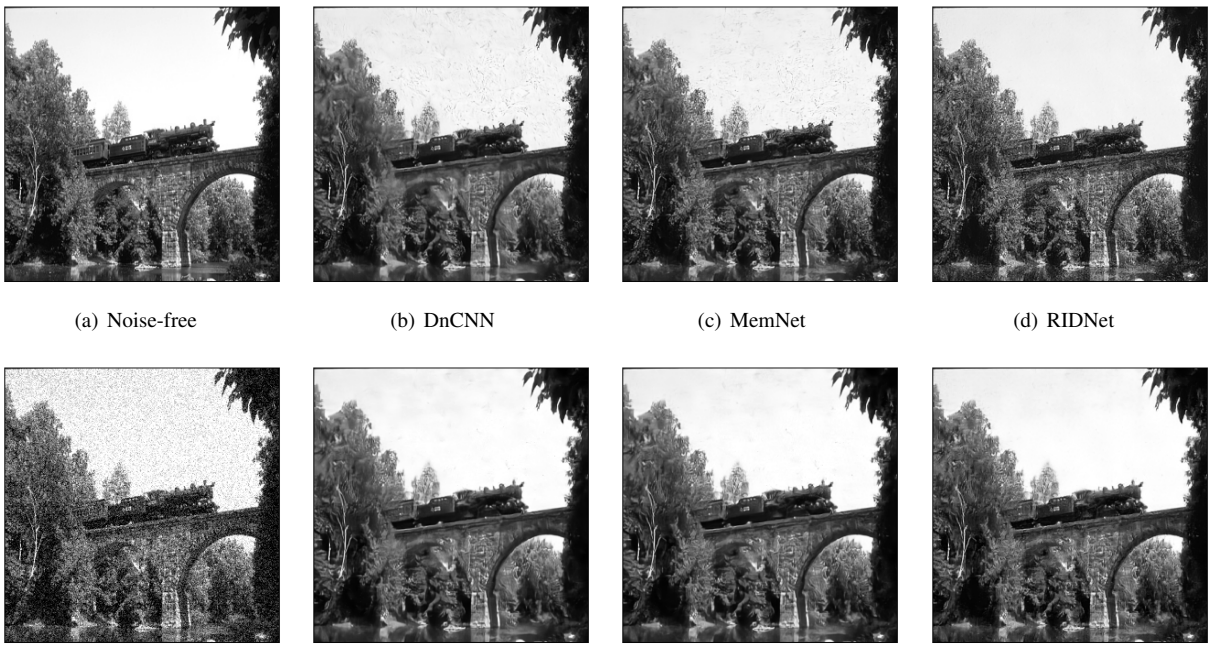
Fig. 12. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 10$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 50$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

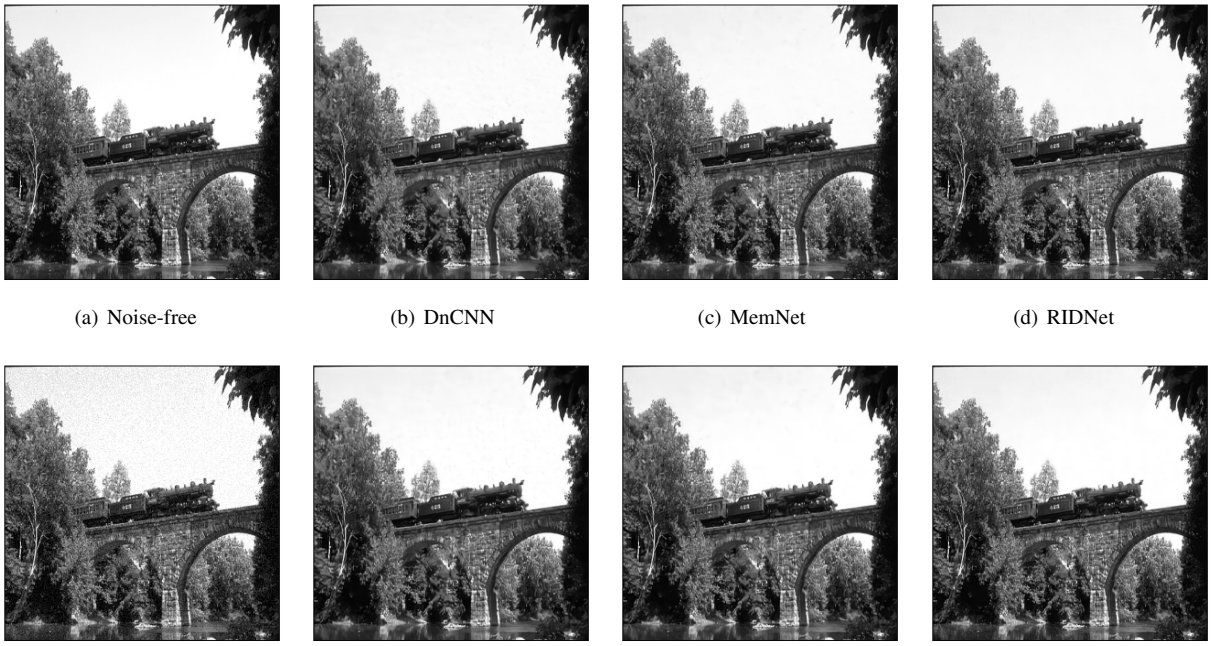
Fig. 13. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 50$. Best viewed on screen.



(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 30$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

Fig. 14. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 30$. Best viewed on screen.



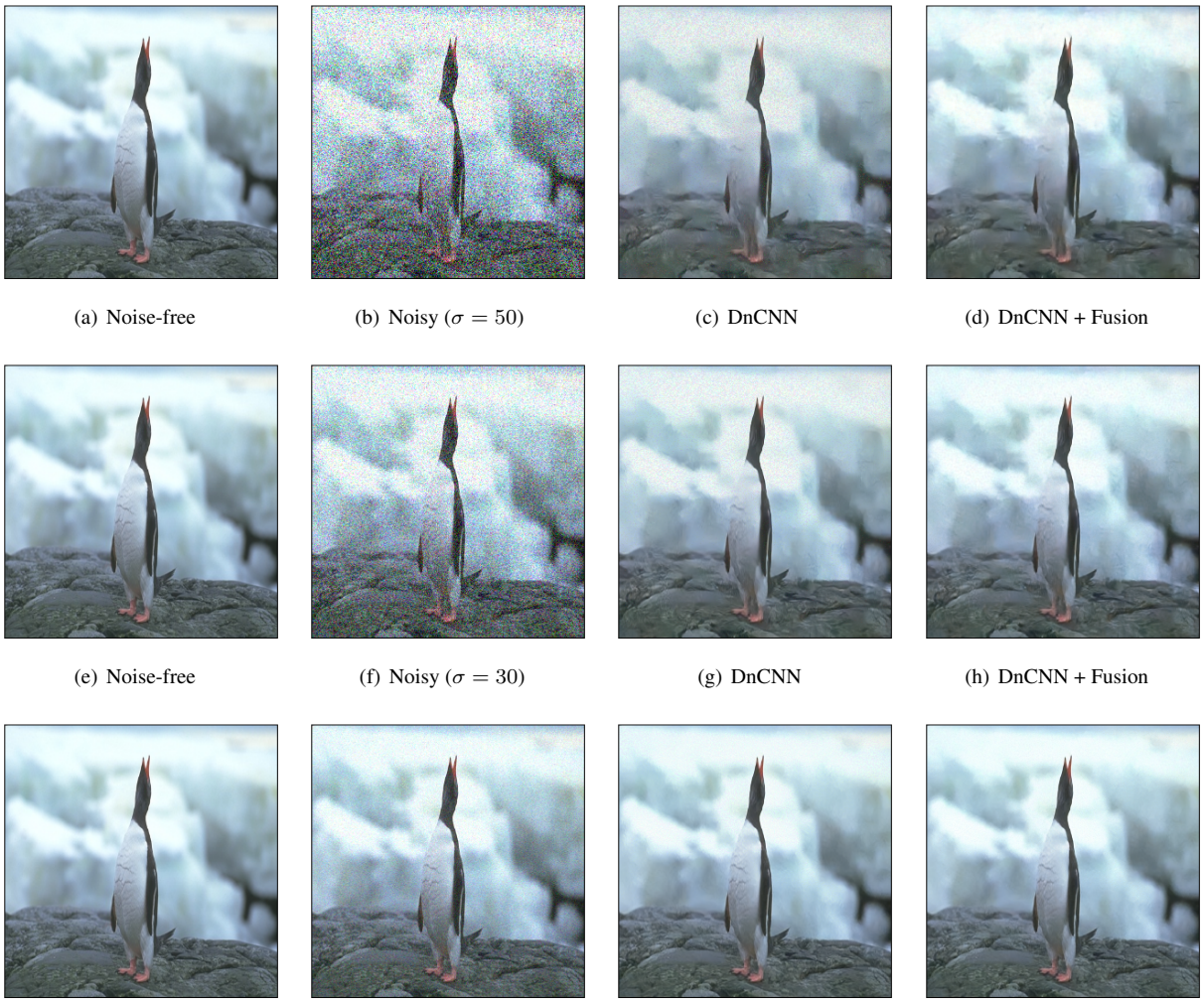
(a) Noise-free (b) DnCNN (c) MemNet (d) RIDNet

(e) Noisy ($\sigma = 10$) (f) DnCNN + Fusion (g) MemNet + Fusion (h) RIDNet + Fusion

Fig. 15. Sample visual denoising results of different baselines (top row), and the corresponding results with our proposed fusion method (bottom row), for a noise level $\sigma = 10$. Best viewed on screen.

Backbone denoiser	Noise level	Baseline result	Ensemble (SM - FM - Joint)	Ours full (SM - FM - Joint)
CDnCNN [1]	10	35.35	35.50 33.92 35.14	35.61 35.49 **35.68**
	20	31.27	31.38 30.91 31.35	31.79 31.83 **31.85**
	30	28.76	28.84 28.85 28.98	29.81 29.64 **29.87**
	40	26.80	26.87 27.23 27.15	28.49 28.50 **28.53**
	50	25.09	25.15 25.82 25.57	27.50 27.47 **27.56**

Table 1. Color Gaussian denoising PSNR (dB) results with the CDnCNN backbone, the averaging ensemble, and our full dual model. We include the ablations using only our spatially-manipulated (SM) or frequency-manipulated (FM) images, rather than all (Joint). The best results are highlighted in bold.

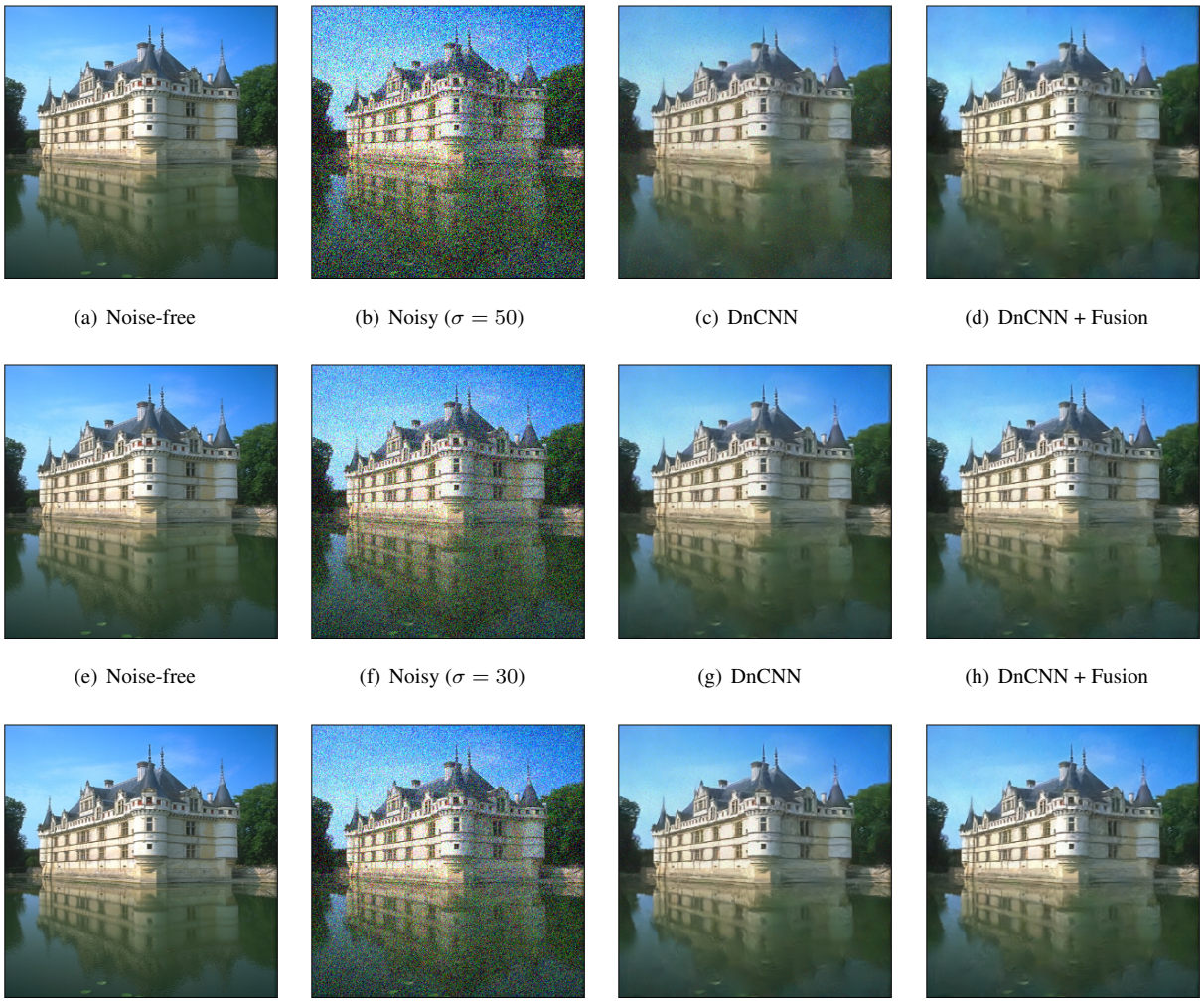


(a) Noise-free (b) Noisy ($\sigma = 50$) (c) DnCNN (d) DnCNN + Fusion

(e) Noise-free (f) Noisy ($\sigma = 30$) (g) DnCNN (h) DnCNN + Fusion

(i) Noise-free (j) Noisy ($\sigma = 10$) (k) DnCNN (l) DnCNN + Fusion

Fig. 16. Sample visual denoising results on color images with DnCNN (third column), and the corresponding results with our proposed fusion method (rightmost column), for noise levels $\sigma = 10, 30, 50$. Best viewed on screen.



(a) Noise-free (b) Noisy ($\sigma = 50$) (c) DnCNN (d) DnCNN + Fusion

(e) Noise-free (f) Noisy ($\sigma = 30$) (g) DnCNN (h) DnCNN + Fusion

(i) Noise-free (j) Noisy ($\sigma = 10$) (k) DnCNN (l) DnCNN + Fusion

Fig. 17. Sample visual denoising results on color images with DnCNN (third column), and the corresponding results with our proposed fusion method (rightmost column), for noise levels $\sigma = 10, 30, 50$. Best viewed on screen.