DA3D: Fast and Data Adaptive Dual Domain Denoising. Supplementary material

Abstract

This supplementary material includes: Detailed tables with SSIM and PSNR results for all the experiments in the paper, the experiment justifying the choice of the parameter τ, additional images, and the python code implementing DA3D.

Contents

1 SSIM summary table

These tables, for grayscale and color methods, show the SSIM average for different denoising methods. See Table 2 and Table 3 of the paper for the PSNR equivalents.

Method	$\sigma = 5$	$\sigma = 10$	$\sigma = 25$	$\sigma = 40$	$\sigma = 80$
BM3D	0.960	0.927	0.855	0.802	0.675
-	**0.960**	**0.927**	0.856	**0.805**	0.703
SAPCA	+0.000	+0.000	+0.001	+0.003	+0.028
	0.958	0.924	0.851	0.794	0.695
BM3D	0.958	0.924	0.853	0.801	0.703
	+0.000	+0.000	+0.002	+0.007	+0.008
	0.957	0.922	0.846	0.788	0.673
DDID	0.957	0.923	0.849	0.795	0.692
	+0.000	+0.001	+0.003	+0.007	+0.019
	0.957	0.921	0.844	0.785	0.675
EPLL	0.957	0.922	0.849	0.795	0.691
	+0.000	+0.001	+0.005	+0.010	+0.016
	0.939	0.909	0.819	0.751	0.621
G-NLM	0.944	0.916	0.832	0.773	0.662
	+0.005	+0.007	+0.013	+0.022	+0.041
	0.959	0.925	0.849	0.794	0.686
LSSC	0.959	0.926	0.855	0.801	0.698
	+0.000	+0.001	+0.006	+0.007	+0.012
MLP		0.924	0.856		
+		0.925	**0.857**		
BM3D		+0.001	+0.001		
	0.958	0.922	0.843	0.785	0.666
NLB	0.958	0.923	0.849	0.794	0.688
	+0.000	+0.001	+0.006	+0.009	+0.022
	0.958	0.922	0.847	0.792	0.690
NLDD	0.957	0.922	0.847	0.791	0.687
	-0.001	+0.000	+0.000	-0.001	-0.003
	0.952	0.905	0.804	0.705	0.496
NLM	0.955	0.916	0.832	0.774	0.659
	+0.003	+0.011	+0.028	+0.069	+0.163
	0.958	0.924	0.850	0.796	0.697
PID	0.957	0.923	0.847	0.792	0.688
	-0.001	-0.001	-0.003	-0.005	-0.009
	0.958	0.923	0.851	0.799	**0.704**
SAIST	0.958	0.924	0.850	0.797	0.703
	+0.000	+0.001	-0.001	-0.002	-0.001
Avg.	+0.001	+0.002	+0.005	+0.011	+0.027

Table 1: Average SSIM comparison between grayscale state-of-the-art methods. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

Method	$\sigma = 5$	$\sigma = 10$	$\sigma = 25$	$\sigma = 40$	$\sigma = 80$
BM3D	0.964 0.965 +0.001	0.932 0.934 +0.002	0.866 0.874 +0.008	0.798 0.820 +0.022	0.720 **0.728** +0.008
DDID	0.964 0.963 -0.001	0.933 0.934 +0.001	0.868 0.873 +0.005	0.812 0.823 +0.011	0.694 0.722 +0.028
NLB	0.965 **0.966** +0.001	0.933 **0.936** +0.003	0.862 **0.874** +0.012	0.801 **0.826** +0.025	0.726 0.722 -0.004
NLDD	0.964 0.964 +0.000	0.933 0.933 +0.000	0.872 0.873 +0.001	0.822 0.825 +0.003	0.717 0.715 -0.002
PID	0.963 0.963 +0.000	0.934 0.933 -0.001	0.874 0.874 +0.000	0.824 0.822 -0.002	0.724 0.717 -0.007
Avg.	+0.000	+0.001	+0.005	+0.012	+0.005

Table 2: Average SSIM comparison between color state-of-the-art methods. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

2 Detailed SSIM and PSNR tables

In this section we present denoising results for every evaluated image using all analyzed denoising methods. We add in each case, the denoising results of DA3D by using the corresponding method as the input guide. For every image and evaluated method, results were computed under five different levels of noise: $\sigma \in \{5, 10, 25, 40, 80\}$. For easier visualization, one table for each noise level is displayed. In tables 3,4,5,6 and 7 there are the results by using the SSIM performance metric for grayscale images, while for color they can be found on tables 8, 9, 10, 11 and 12.

For the PSNR metric, results can be seen on tables 13, 14, 15, 16 and 17 for grayscale images, while the same results but for color images are on tables 18, 19, 20, 21 and 22.

Detailed SSIM tables (grayscale)

$\sigma = 5$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	0.965	0.939	0.961	0.951	0.988	0.943	0.957	0.945	0.954	0.982	0.956
	0.964	0.939	0.961	0.951	0.988	0.944	0.958	0.944	0.955	**0.982**	0.956
	-0.000	-0.000	+0.000	+0.000	+0.000	+0.001	+0.000	-0.001	+0.000	+0.000	-0.000
BM3D-SAPCA	**0.966**	**0.944**	0.962	0.953	0.988	0.945	0.960	**0.946**	0.957	0.982	**0.957**
	0.966	0.944	0.963	**0.953**	0.988	**0.946**	**0.960**	0.946	**0.957**	**0.982**	0.957
	-0.000	-0.000	+0.000	+0.000	-0.000	+0.000	+0.000	-0.001	+0.000	+0.000	-0.000
EPLL	0.962	0.931	0.962	0.951	0.988	0.944	0.951	0.945	0.955	0.981	0.955
	0.962	0.931	0.961	0.951	0.987	0.944	0.952	0.944	0.955	0.981	0.955
	-0.000	-0.000	-0.000	+0.000	-0.000	-0.000	+0.001	-0.001	+0.000	+0.000	-0.000
Global	0.938	0.894	0.948	0.916	0.985	0.927	0.949	0.930	0.937	0.967	0.942
	0.947	0.901	0.950	0.927	0.986	0.932	0.953	0.933	0.942	0.972	0.946
	+0.009	+0.007	+0.002	+0.011	+0.001	+0.005	+0.004	+0.003	+0.004	+0.005	+0.003
NLM	0.959	0.933	0.958	0.944	0.983	0.936	0.944	0.941	0.949	0.972	0.952
	0.961	0.935	0.960	0.947	0.983	0.939	0.953	0.943	0.952	0.976	0.953
	+0.001	+0.002	+0.003	+0.003	+0.000	+0.004	+0.009	+0.002	+0.002	+0.004	+0.001
LSSC	0.966	0.941	0.962	0.951	0.988	0.944	0.959	0.945	0.955	0.981	0.956
	0.966	0.941	**0.963**	0.951	0.988	0.944	0.960	0.945	0.956	0.982	0.956
	+0.000	+0.000	+0.001	+0.000	+0.000	+0.001	+0.001	+0.000	+0.001	+0.000	+0.000
SAIST	0.964	0.937	0.961	0.949	**0.988**	0.942	0.958	0.944	0.954	0.982	0.955
	0.964	0.936	0.960	0.950	**0.988**	0.943	0.958	0.943	0.954	0.982	0.955
	-0.001	-0.001	-0.001	+0.000	+0.000	+0.001	+0.000	-0.001	+0.000	+0.000	-0.000
DDID	0.963	0.938	0.961	0.949	0.986	0.942	0.957	0.943	0.955	0.981	0.953
	0.963	0.937	0.961	0.949	0.986	0.942	0.957	0.942	0.955	0.981	0.953
	-0.000	-0.000	+0.000	+0.000	-0.000	-0.000	+0.000	-0.001	-0.000	+0.000	-0.000
PID	0.964	0.941	0.961	0.951	0.986	0.944	0.957	0.945	0.955	0.981	0.955
	0.963	0.940	0.961	0.950	0.985	0.943	0.957	0.944	0.955	0.981	0.955
	-0.001	-0.001	-0.001	-0.001	-0.000	-0.000	-0.000	-0.001	-0.000	-0.000	-0.001
NLDD	0.964	0.940	0.961	0.950	0.987	0.943	0.955	0.945	0.955	0.980	0.955
	0.964	0.939	0.960	0.950	0.987	0.943	0.955	0.944	0.955	0.980	0.954
	-0.001	-0.001	-0.001	-0.000	-0.000	-0.000	+0.000	-0.001	-0.000	+0.000	-0.000
NL-Bayes	0.965	0.941	0.961	0.951	0.988	0.943	0.955	0.946	0.955	0.979	0.955
	0.965	0.940	0.961	0.951	0.988	0.943	0.956	0.945	0.956	0.980	0.955
	-0.000	-0.000	-0.001	+0.000	-0.000	+0.000	+0.001	-0.001	+0.000	+0.001	+0.000

Table 3: SSIM comparison between state-of-the-art methods for grayscale images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

$\sigma = 10$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	0.942	0.888	0.930	0.908	0.969	0.883	0.921	0.916	0.908	0.968	0.928
	0.942	0.885	0.932	0.907	0.969	0.883	0.923	0.916	0.909	0.970	0.929
	-0.000	-0.003	+0.002	-0.001	+0.000	+0.000	+0.002	-0.000	+0.001	+0.002	+0.000
BM3D-SAPCA	**0.943**	**0.893**	0.934	**0.910**	0.970	0.890	0.929	**0.918**	0.913	0.969	0.929
	0.943	0.891	0.935	**0.910**	0.970	**0.890**	**0.930**	**0.918**	**0.913**	**0.970**	**0.930**
	-0.000	-0.002	+0.001	+0.000	+0.000	+0.000	+0.001	+0.000	+0.001	+0.001	+0.001
EPLL	0.932	0.884	0.934	0.906	0.968	0.885	0.901	0.913	0.910	0.965	0.928
	0.933	0.883	**0.935**	0.907	0.968	0.886	0.902	0.914	0.911	0.968	0.929
	+0.001	-0.001	+0.001	+0.001	+0.000	+0.001	+0.001	+0.001	+0.001	+0.003	+0.000
Global	0.923	0.875	0.923	0.886	0.966	0.870	0.899	0.900	0.894	0.944	0.916
	0.931	0.880	0.929	0.897	0.967	0.879	0.903	0.907	0.902	0.956	0.922
	+0.008	+0.005	+0.006	+0.011	+0.001	+0.009	+0.004	+0.007	+0.008	+0.012	+0.006
NLM	0.920	0.874	0.916	0.884	0.962	0.868	0.894	0.896	0.892	0.936	0.912
	0.930	0.882	0.929	0.896	0.963	0.880	0.909	0.909	0.902	0.954	0.920
	+0.010	+0.008	+0.014	+0.012	+0.001	+0.011	+0.016	+0.012	+0.010	+0.017	+0.009
LSSC	0.940	0.892	0.930	0.908	0.970	0.887	0.925	0.915	0.910	0.966	0.928
	0.942	0.890	0.934	0.909	0.970	0.888	0.927	0.917	0.911	0.969	0.929
	+0.002	-0.001	+0.004	+0.001	+0.001	+0.001	+0.002	+0.002	+0.001	+0.003	+0.001
MLP+BM3D	0.939	0.888	0.932	0.909	0.970	0.887	0.917	0.917	0.911	0.966	0.929
	0.940	0.886	0.934	0.909	0.970	0.888	0.923	0.917	0.912	0.969	0.930
	+0.000	-0.002	+0.002	+0.000	+0.000	+0.001	+0.005	+0.000	+0.001	+0.003	+0.001
SAIST	0.942	0.886	0.933	0.903	0.970	0.884	0.916	0.916	0.909	0.968	0.929
	0.942	0.884	0.933	0.904	**0.970**	0.884	0.918	0.916	0.909	**0.970**	0.929
	-0.001	-0.002	+0.001	+0.000	+0.000	+0.000	+0.002	-0.001	-0.000	+0.002	+0.000
DDID	0.940	0.886	0.929	0.904	0.966	0.883	0.923	0.915	0.909	0.967	0.925
	0.940	0.885	0.930	0.905	0.966	0.882	0.925	0.915	0.909	0.968	0.926
	-0.000	-0.001	+0.002	+0.000	-0.000	-0.000	+0.002	-0.000	+0.000	+0.002	+0.001
PID	0.940	0.888	0.933	0.906	0.966	0.886	0.925	0.917	0.911	0.968	0.928
	0.939	0.885	0.932	0.905	0.965	0.884	0.924	0.915	0.909	0.968	0.927
	-0.001	-0.003	-0.001	-0.001	-0.001	-0.001	-0.000	-0.001	-0.001	+0.000	-0.001
NLDD	0.940	0.886	0.933	0.905	0.969	0.885	0.906	0.915	0.911	0.966	0.928
	0.939	0.884	0.933	0.905	0.968	0.884	0.910	0.914	0.910	0.967	0.927
	-0.000	-0.002	-0.000	-0.000	-0.000	-0.001	+0.004	-0.000	-0.001	+0.002	-0.001
NL-Bayes	0.940	0.889	0.931	0.905	0.969	0.886	0.907	0.915	0.910	0.962	0.928
	0.941	0.888	0.933	0.907	0.969	0.886	0.912	0.916	0.911	0.967	0.928
	+0.001	-0.001	+0.002	+0.002	+0.000	+0.001	+0.005	+0.001	+0.001	+0.005	+0.001

Table 4: SSIM comparison between state-of-the-art methods for grayscale images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

$\sigma = 25$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	0.885	0.802	0.853	0.818	0.912	0.778	0.857	0.860	0.803	0.926	0.867
	0.891	0.800	0.853	0.818	0.912	0.773	0.856	0.867	0.800	0.938	0.873
	+0.006	-0.002	+0.000	-0.000	+0.000	-0.005	-0.001	+0.006	-0.003	+0.012	+0.006
BM3D-SAPCA	0.893	0.804	0.862	0.819	0.914	0.783	0.857	0.864	0.810	0.928	0.871
	0.897	0.803	0.862	0.820	0.913	0.779	0.857	0.868	0.807	0.939	0.876
	+0.004	-0.001	+0.000	+0.001	-0.001	-0.003	-0.000	+0.004	-0.003	+0.010	+0.005
EPLL	0.844	0.796	0.857	0.808	0.905	0.769	0.851	0.854	0.805	0.922	0.872
	0.861	0.798	0.860	0.814	0.908	0.768	0.854	0.862	0.805	0.935	0.876
	+0.017	+0.002	+0.004	+0.005	+0.003	-0.001	+0.003	+0.008	-0.000	+0.013	+0.005
Global	0.841	0.754	0.839	0.758	0.889	0.733	0.840	0.830	0.768	0.908	0.845
	0.868	0.760	0.843	0.781	0.898	0.745	0.848	0.852	0.776	0.924	0.862
	+0.027	+0.006	+0.003	+0.024	+0.009	+0.012	+0.007	+0.022	+0.008	+0.016	+0.016
NLM	0.831	0.747	0.817	0.747	0.877	0.721	0.822	0.814	0.757	0.879	0.829
	0.869	0.768	0.843	0.780	0.892	0.744	0.847	0.850	0.777	0.922	0.859
	+0.038	+0.021	+0.025	+0.033	+0.015	+0.022	+0.025	+0.036	+0.021	+0.043	+0.030
LSSC	0.879	0.797	0.856	0.815	0.910	0.779	0.858	0.853	0.804	0.921	0.865
	0.892	0.800	0.863	0.819	0.911	0.780	**0.860**	0.867	0.805	0.936	0.874
	+0.012	+0.003	+0.007	+0.004	+0.001	+0.000	+0.002	+0.013	+0.001	+0.015	+0.008
MLP+BM3D	0.880	**0.806**	0.866	**0.821**	**0.916**	**0.784**	0.859	0.868	**0.814**	0.931	0.875
	0.886	0.803	**0.867**	0.821	0.914	0.779	0.857	**0.869**	0.810	**0.940**	**0.878**
	+0.006	-0.002	+0.001	-0.001	-0.001	-0.005	-0.002	+0.001	-0.004	+0.008	+0.003
SAIST	0.894	0.795	0.848	0.808	0.914	0.772	0.858	0.864	0.799	0.933	0.873
	0.895	0.791	0.847	0.808	0.913	0.766	0.856	0.866	0.794	0.939	0.875
	+0.002	-0.004	-0.001	+0.000	-0.001	-0.006	-0.002	+0.002	-0.005	+0.007	+0.003
DDID	0.889	0.793	0.846	0.806	0.903	0.767	0.852	0.862	0.797	0.927	0.868
	0.894	0.794	0.852	0.809	0.903	0.765	0.856	0.866	0.795	0.937	0.873
	+0.004	+0.001	+0.005	+0.004	-0.000	-0.002	+0.003	+0.004	-0.001	+0.009	+0.005
PID	0.890	0.794	0.857	0.809	0.901	0.767	0.858	0.865	0.799	0.937	0.875
	0.890	0.788	0.852	0.808	0.901	0.761	0.853	0.863	0.792	0.938	0.873
	-0.000	-0.005	-0.005	-0.002	-0.001	-0.007	-0.005	-0.002	-0.007	+0.001	-0.002
NLDD	0.883	0.788	0.857	0.802	0.906	0.761	0.854	0.859	0.799	0.930	0.874
	0.886	0.786	0.854	0.805	0.905	0.759	0.852	0.861	0.794	0.935	0.874
	+0.003	-0.002	-0.003	+0.003	-0.000	-0.002	-0.002	+0.002	-0.005	+0.005	-0.000
NL-Bayes	0.878	0.787	0.855	0.799	0.907	0.764	0.850	0.856	0.798	0.914	0.865
	0.887	0.791	0.859	0.807	0.909	0.767	0.854	0.864	0.800	0.933	0.874
	+0.009	+0.004	+0.004	+0.008	+0.002	+0.003	+0.004	+0.007	+0.002	+0.019	+0.009

Table 5: SSIM comparison between state-of-the-art methods for grayscale images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

$\sigma = 40$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	0.819	0.737	0.801	0.745	0.859	0.705	0.823	0.816	0.736	0.878	0.816
	0.834	0.736	0.810	0.747	0.858	0.699	0.832	0.831	0.732	0.905	0.829
	+0.016	-0.001	+0.009	+0.002	-0.001	-0.006	+0.008	+0.015	-0.004	+0.027	+0.013
BM3D-SAPCA	0.840	**0.742**	0.809	0.749	**0.864**	**0.710**	0.828	0.826	**0.741**	0.889	0.827
	0.847	0.739	0.814	**0.749**	0.860	0.704	0.833	**0.834**	0.735	0.908	**0.833**
	+0.007	-0.003	+0.004	+0.000	-0.005	-0.006	+0.005	+0.009	-0.006	+0.019	+0.006
EPLL	0.759	0.732	0.803	0.736	0.843	0.697	0.820	0.811	0.735	0.879	0.824
	0.784	0.733	0.812	0.741	0.853	0.695	0.828	0.826	0.734	0.903	0.833
	+0.025	+0.001	+0.008	+0.005	+0.010	-0.002	+0.009	+0.015	-0.002	+0.024	+0.009
Global	0.756	0.686	0.778	0.658	0.820	0.648	0.796	0.779	0.697	0.858	0.786
	0.807	0.686	0.800	0.697	0.841	0.647	0.814	0.812	0.694	0.893	0.814
	+0.051	-0.001	+0.022	+0.038	+0.021	-0.002	+0.018	+0.033	-0.002	+0.036	+0.028
NLM	0.723	0.650	0.720	0.635	0.799	0.617	0.726	0.717	0.654	0.776	0.732
	0.803	0.700	0.799	0.697	0.834	0.667	0.810	0.808	0.708	0.882	0.804
	+0.079	+0.049	+0.079	+0.062	+0.035	+0.050	+0.084	+0.091	+0.054	+0.106	+0.072
LSSC	0.818	0.731	0.807	0.742	0.856	0.700	0.829	0.818	0.735	0.886	0.815
	0.835	0.731	**0.817**	0.745	0.857	0.694	0.833	0.830	0.732	0.905	0.827
	+0.016	+0.000	+0.009	+0.003	+0.002	-0.005	+0.004	+0.012	-0.003	+0.019	+0.012
SAIST	0.846	0.725	0.799	0.740	0.862	0.695	**0.838**	0.828	0.730	0.898	0.825
	0.846	0.717	0.803	0.736	0.857	0.684	0.835	0.831	0.722	**0.909**	0.829
	+0.001	-0.008	+0.004	-0.003	-0.005	-0.012	-0.003	+0.003	-0.009	+0.011	+0.005
DDID	0.835	0.722	0.794	0.728	0.843	0.687	0.820	0.818	0.723	0.880	0.819
	0.844	0.724	0.807	0.734	0.844	0.688	0.828	0.829	0.722	0.903	0.828
	+0.008	+0.002	+0.013	+0.006	+0.001	+0.001	+0.008	+0.011	-0.001	+0.023	+0.008
PID	0.838	0.724	0.812	0.733	0.841	0.687	0.833	0.829	0.728	0.905	0.831
	0.839	0.716	0.805	0.728	0.839	0.678	0.828	0.826	0.717	0.905	0.829
	+0.000	-0.009	-0.007	-0.005	-0.002	-0.010	-0.004	-0.002	-0.011	+0.000	-0.002
NLDD	0.826	0.712	0.806	0.727	0.851	0.683	0.831	0.824	0.726	0.898	0.830
	0.830	0.709	0.803	0.727	0.850	0.677	0.828	0.826	0.718	0.905	0.829
	+0.004	-0.003	-0.002	-0.000	-0.002	-0.006	-0.003	+0.002	-0.008	+0.007	-0.001
NL-Bayes	0.819	0.713	0.794	0.724	0.858	0.688	0.819	0.818	0.725	0.863	0.809
	0.833	0.715	0.803	0.732	0.859	0.686	0.828	0.829	0.724	0.900	0.827
	+0.014	+0.002	+0.009	+0.008	+0.001	-0.002	+0.009	+0.011	-0.001	+0.037	+0.018

Table 6: SSIM comparison between state-of-the-art methods for grayscale images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

$\sigma = 80$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	0.697	**0.626**	0.716	**0.610**	**0.758**	**0.596**	0.758	0.742	**0.638**	0.782	0.720
	0.712	0.621	0.726	0.603	0.747	0.593	0.771	0.765	0.633	0.824	0.739
	+0.015	-0.005	+0.010	-0.007	-0.010	-0.004	+0.013	+0.023	-0.005	+0.042	+0.019
BM3D-SAPCA	0.672	0.616	0.687	0.596	0.746	0.584	0.719	0.718	0.624	0.753	0.707
	0.708	0.625	0.726	0.602	0.751	0.593	0.766	0.764	0.634	0.824	0.743
	+0.035	+0.009	+0.040	+0.007	+0.005	+0.009	+0.047	+0.046	+0.010	+0.071	+0.036
EPLL	0.603	0.622	0.708	0.596	0.669	0.591	0.746	0.732	0.634	0.794	0.732
	0.621	0.622	0.724	0.593	0.725	0.588	0.765	0.759	0.630	0.827	0.743
	+0.018	-0.001	+0.016	-0.003	+0.055	-0.004	+0.018	+0.027	-0.005	+0.034	+0.011
Global	0.556	0.575	0.617	0.535	0.602	0.548	0.685	0.701	0.593	0.747	0.674
	0.641	0.580	0.715	0.533	0.681	0.541	0.730	0.739	0.592	0.814	0.720
	+0.085	+0.004	+0.098	-0.002	+0.078	-0.007	+0.044	+0.038	-0.001	+0.067	+0.045
NLM	0.493	0.463	0.509	0.434	0.549	0.432	0.503	0.521	0.463	0.562	0.534
	0.658	0.587	0.699	0.544	0.680	0.547	0.718	0.727	0.595	0.793	0.699
	+0.165	+0.124	+0.190	+0.110	+0.131	+0.116	+0.215	+0.206	+0.133	+0.230	+0.165
LSSC	0.684	0.616	0.704	0.599	0.741	0.583	0.749	0.743	0.631	0.783	0.710
	0.715	0.616	0.721	0.596	0.743	0.580	0.766	0.761	0.627	0.824	0.733
	+0.031	-0.000	+0.017	-0.003	+0.002	-0.002	+0.017	+0.018	-0.004	+0.041	+0.023
SAIST	**0.729**	0.624	0.726	0.605	0.754	0.594	**0.784**	0.756	0.638	0.808	0.731
	0.724	0.617	**0.733**	0.592	0.740	0.581	0.777	**0.766**	0.626	**0.830**	**0.743**
	-0.004	-0.007	+0.007	-0.013	-0.014	-0.014	-0.007	+0.009	-0.012	+0.022	+0.012
DDID	0.710	0.600	0.684	0.581	0.713	0.570	0.724	0.731	0.614	0.769	0.705
	0.724	0.610	0.715	0.585	0.724	0.576	0.754	0.757	0.618	0.815	0.728
	+0.014	+0.010	+0.032	+0.004	+0.011	+0.006	+0.030	+0.026	+0.004	+0.046	+0.023
PID	0.718	0.615	0.733	0.586	0.722	0.580	0.760	0.760	0.628	0.827	0.739
	0.709	0.603	0.724	0.569	0.716	0.565	0.757	0.755	0.610	0.828	0.733
	-0.009	-0.012	-0.008	-0.017	-0.006	-0.014	-0.003	-0.005	-0.017	+0.001	-0.006
NLDD	0.686	0.610	0.730	0.574	0.704	0.576	0.766	0.754	0.632	0.813	0.741
	0.689	0.601	0.726	0.565	0.713	0.567	0.760	0.755	0.616	0.827	0.736
	+0.003	-0.008	-0.004	-0.009	+0.010	-0.009	-0.006	+0.001	-0.016	+0.014	-0.005
NL-Bayes	0.665	0.606	0.691	0.570	0.720	0.570	0.732	0.733	0.624	0.730	0.686
	0.692	0.607	0.722	0.572	0.727	0.575	0.756	0.757	0.625	0.809	0.731
	+0.027	+0.002	+0.031	+0.002	+0.007	+0.004	+0.025	+0.025	+0.001	+0.079	+0.045

Table 7: SSIM comparison between state-of-the-art methods for grayscale images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

Detailed SSIM tables (color)

$\sigma = 5$	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
DDID	0.971	0.963	0.976	0.983	0.957	0.971	0.977	0.995	0.946	0.926	0.974	0.916	0.974	0.981	0.985
	0.971	0.963	0.976	0.984	0.956	0.973	0.977	0.997	0.944	0.924	0.974	0.913	0.974	0.981	0.985
	-0.000	-0.001	+0.000	+0.000	-0.001	+0.002	+0.000	+0.002	-0.002	-0.002	-0.000	-0.002	+0.000	-0.000	-0.000
PID	0.969	0.961	0.975	0.984	0.957	0.972	0.977	0.996	0.947	0.929	0.973	0.916	0.971	0.979	0.984
	0.969	0.961	0.975	0.984	0.955	0.973	0.977	**0.997**	0.945	0.928	0.973	0.915	0.972	0.980	0.984
	+0.001	-0.000	+0.000	-0.000	-0.001	+0.002	+0.000	+0.001	-0.001	-0.002	-0.000	-0.001	+0.001	+0.000	+0.000
NLDD	0.971	0.963	0.976	0.984	0.958	0.973	0.977	0.992	0.946	0.930	0.972	0.916	0.974	0.982	0.986
	0.971	0.963	0.976	0.984	0.956	0.974	0.977	0.996	0.944	0.928	0.972	0.913	0.974	0.982	0.986
	-0.000	-0.001	-0.000	+0.000	-0.001	+0.001	+0.000	+0.004	-0.002	-0.003	-0.000	-0.002	+0.000	-0.000	-0.000
NL-Bayes	0.972	**0.967**	0.977	0.984	**0.959**	0.974	0.977	0.989	0.948	**0.932**	0.972	**0.918**	0.975	0.983	0.987
	0.973	0.966	**0.977**	**0.985**	0.958	**0.977**	**0.978**	0.995	0.947	0.930	0.973	0.918	**0.976**	**0.983**	**0.987**
	+0.001	-0.001	+0.000	+0.001	-0.001	+0.002	+0.001	+0.006	-0.001	-0.001	+0.001	-0.000	+0.001	+0.000	+0.000
BM3D	0.972	0.964	0.976	0.984	0.959	0.972	0.976	0.996	**0.948**	0.927	**0.976**	0.914	0.971	0.981	0.986
	0.973	0.964	0.977	0.985	0.958	0.976	0.977	**0.997**	0.946	0.926	0.976	0.915	0.974	0.982	0.987
	+0.001	+0.001	+0.001	+0.001	-0.001	+0.004	+0.001	+0.002	-0.001	-0.001	-0.001	+0.001	+0.003	+0.001	+0.000

Table 8: SSIM comparison between state-of-the-art methods for color images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

$\sigma = 10$	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
DDID	0.933	0.916	0.956	0.976	0.934	0.952	0.966	0.991	0.908	0.884	0.951	0.843	0.950	0.952	0.966
	0.933	0.915	0.957	0.978	0.933	0.958	0.967	0.996	0.906	0.881	0.950	0.839	0.952	0.952	0.967
	+0.000	-0.001	+0.001	+0.002	-0.000	+0.007	+0.001	+0.005	-0.003	-0.003	-0.000	-0.004	+0.003	+0.000	+0.000
PID	0.932	0.914	0.956	0.979	0.934	0.955	0.967	0.995	0.910	0.885	0.950	**0.846**	0.947	0.949	0.964
	0.933	0.914	0.957	0.979	0.933	**0.959**	0.967	**0.997**	0.906	0.882	0.949	0.840	0.950	0.950	0.965
	+0.001	+0.000	+0.000	+0.000	-0.001	+0.004	+0.000	+0.002	-0.004	-0.003	-0.001	-0.006	+0.003	+0.001	+0.001
NLDD	0.932	0.917	0.956	0.977	0.933	0.953	0.965	0.985	0.903	0.884	0.948	0.843	0.950	0.953	0.967
	0.933	0.916	0.956	0.978	0.932	0.957	0.966	0.994	0.902	0.881	0.947	0.838	0.952	0.953	0.967
	+0.000	-0.001	-0.000	+0.001	-0.001	+0.005	+0.001	+0.009	-0.001	-0.003	-0.001	-0.005	+0.002	-0.000	+0.000
NL-Bayes	0.929	0.917	0.956	0.976	0.934	0.948	0.964	0.974	0.903	**0.886**	0.948	0.846	0.946	0.953	0.966
	0.934	**0.920**	0.958	0.979	0.935	0.959	0.966	0.993	0.905	0.885	0.949	0.844	**0.953**	**0.955**	**0.969**
	+0.005	+0.002	+0.003	+0.003	+0.001	+0.011	+0.003	+0.019	+0.002	-0.001	+0.001	-0.002	+0.007	+0.002	+0.002
BM3D	0.933	0.910	0.956	0.976	0.936	0.948	0.965	0.991	**0.911**	0.886	**0.954**	0.841	0.942	0.949	0.967
	0.935	0.914	**0.959**	**0.979**	**0.936**	**0.959**	**0.967**	0.996	0.907	0.883	0.953	0.835	0.951	0.953	0.968
	+0.003	+0.004	+0.002	+0.003	+0.000	+0.011	+0.003	+0.005	-0.004	-0.003	-0.001	-0.005	+0.009	+0.004	+0.002

Table 9: SSIM comparison between state-of-the-art methods for color images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

$\sigma = 25$	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
	0.829	0.798	0.903	0.954	0.892	0.891	0.938	0.979	0.848	0.837	0.910	0.776	0.868	0.851	0.898
DDID	0.829	0.795	0.912	0.966	0.896	0.910	0.946	0.993	**0.853**	0.839	0.915	0.778	0.878	0.852	0.901
	+0.000	-0.003	+0.008	+0.012	+0.004	+0.018	+0.008	+0.014	+0.005	+0.002	+0.005	+0.002	+0.010	+0.002	+0.003
	0.828	0.800	0.913	0.966	0.896	0.909	0.946	0.990	0.849	**0.839**	0.914	**0.781**	0.876	0.851	0.903
PID	0.825	0.797	**0.913**	**0.967**	0.895	**0.913**	0.946	**0.994**	0.847	0.837	0.913	0.778	0.880	0.853	0.904
	-0.003	-0.003	+0.001	+0.001	-0.001	+0.004	-0.000	+0.003	-0.002	-0.003	-0.001	-0.003	+0.004	+0.001	+0.002
	0.830	0.808	0.909	0.962	0.896	0.900	0.942	0.975	0.831	0.835	0.911	0.778	0.875	0.861	0.904
NLDD	0.829	0.804	0.912	0.966	0.896	0.911	0.945	0.992	0.829	0.835	0.912	0.778	**0.880**	0.860	**0.905**
	-0.001	-0.004	+0.003	+0.003	-0.000	+0.011	+0.002	+0.017	-0.002	+0.000	+0.001	+0.000	+0.005	-0.001	+0.000
	0.822	0.803	0.896	0.954	0.891	0.876	0.935	0.918	0.828	0.829	0.906	0.769	0.858	0.851	0.895
NL-Bayes	0.831	**0.809**	0.912	0.966	0.898	0.909	0.945	0.987	0.832	0.838	0.913	0.780	0.880	**0.861**	0.904
	+0.009	+0.006	+0.016	+0.012	+0.007	+0.033	+0.009	+0.069	+0.005	+0.009	+0.006	+0.011	+0.022	+0.011	+0.009
	0.833	0.790	0.904	0.955	0.895	0.888	0.938	0.971	0.850	0.837	0.914	0.779	0.859	0.840	0.895
BM3D	**0.834**	0.793	0.913	**0.967**	**0.900**	0.910	**0.947**	0.992	0.849	0.839	**0.917**	0.780	0.876	0.850	0.902
	+0.000	+0.004	+0.009	+0.012	+0.005	+0.022	+0.009	+0.021	-0.001	+0.002	+0.003	+0.002	+0.018	+0.010	+0.007

Table 10: SSIM comparison between state-of-the-art methods for color images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

$\sigma = 40$	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
DDID	0.752	0.707	0.850	0.927	0.860	0.836	0.907	0.960	0.808	0.803	0.881	0.744	0.791	0.742	0.826
	0.753	0.705	0.866	0.953	0.871	0.863	0.927	0.988	0.814	**0.810**	**0.895**	0.752	0.806	0.743	0.832
	+0.001	-0.002	+0.016	+0.026	+0.011	+0.027	+0.020	+0.028	+0.007	+0.007	+0.014	+0.008	+0.014	+0.002	+0.006
PID	0.751	0.710	0.866	0.955	0.870	0.867	**0.928**	0.986	**0.815**	0.809	0.894	**0.755**	0.805	0.749	0.835
	0.746	0.704	**0.866**	**0.956**	0.869	**0.868**	0.927	**0.991**	0.811	0.808	0.893	0.753	0.805	0.747	0.834
	-0.005	-0.006	+0.000	+0.001	-0.001	+0.001	-0.001	+0.005	-0.004	-0.001	-0.001	-0.003	-0.000	-0.002	-0.001
NLDD	0.753	0.722	0.858	0.946	0.870	0.853	0.920	0.964	0.808	0.803	0.889	0.748	0.806	**0.763**	**0.840**
	0.751	0.716	0.864	0.954	0.870	0.866	0.925	0.988	0.808	0.806	0.892	0.752	**0.812**	0.759	0.840
	-0.002	-0.006	+0.005	+0.009	+0.000	+0.013	+0.005	+0.024	-0.001	+0.003	+0.003	+0.003	+0.006	-0.004	-0.001
NL-Bayes	0.741	0.712	0.829	0.924	0.855	0.809	0.904	0.869	0.788	0.786	0.877	0.723	0.776	0.747	0.824
	0.756	**0.723**	0.862	0.953	**0.873**	0.864	0.924	0.980	0.810	0.808	0.892	0.753	**0.812**	0.762	0.840
	+0.016	+0.010	+0.033	+0.029	+0.018	+0.055	+0.021	+0.111	+0.022	+0.022	+0.016	+0.030	+0.035	+0.015	+0.016
BM3D	0.751	0.689	0.827	0.910	0.855	0.807	0.894	0.929	0.802	0.793	0.875	0.733	0.772	0.728	0.816
	0.754	0.697	0.858	0.952	0.873	0.860	0.926	0.984	0.811	0.808	0.895	0.752	0.802	0.738	0.829
	+0.003	+0.008	+0.030	+0.042	+0.018	+0.052	+0.031	+0.054	+0.009	+0.015	+0.020	+0.019	+0.030	+0.011	+0.013

Table 11: SSIM comparison between state-of-the-art methods for color images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

σ = 80	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
DDID	0.630	0.517	0.719	0.850	0.779	0.714	0.837	0.905	0.733	0.726	0.816	0.677	0.645	0.523	0.673
	0.638	0.510	0.752	0.913	0.816	0.768	0.893	0.973	0.766	0.753	0.862	0.704	0.667	0.517	0.683
	+0.009	-0.007	+0.033	+0.064	+0.036	+0.053	+0.056	+0.068	+0.034	+0.027	+0.047	+0.027	+0.023	-0.007	+0.010
PID	0.634	0.500	0.754	0.925	0.816	0.780	0.900	0.972	0.772	0.752	0.863	**0.708**	0.670	0.517	0.683
	0.626	0.483	0.747	0.922	0.814	0.773	0.897	**0.979**	0.768	0.750	0.862	0.705	0.660	0.500	0.673
	-0.008	-0.017	-0.007	-0.003	-0.002	-0.006	-0.003	+0.007	-0.004	-0.003	-0.001	-0.003	-0.010	-0.017	-0.010
NLDD	0.621	0.502	0.728	0.909	0.816	0.766	0.888	0.962	0.768	0.746	0.850	0.705	0.661	0.526	0.682
	0.618	0.485	0.730	0.920	0.814	0.775	0.896	0.978	0.764	0.748	0.856	0.705	0.655	0.508	0.673
	-0.003	-0.017	+0.002	+0.011	-0.002	+0.009	+0.009	+0.016	-0.003	+0.001	+0.006	-0.000	-0.006	-0.018	-0.009
NL-Bayes	0.624	**0.525**	0.735	**0.931**	0.814	**0.810**	**0.906**	0.895	0.755	0.742	0.855	0.694	0.669	**0.543**	0.687
	0.622	0.504	0.736	0.925	0.819	0.786	0.900	0.973	0.764	0.750	0.858	0.706	0.665	0.524	0.682
	-0.002	-0.021	+0.001	-0.006	+0.005	-0.024	-0.006	+0.077	+0.009	+0.009	+0.003	+0.012	-0.004	-0.019	-0.005
BM3D	**0.658**	0.523	0.746	0.893	0.807	0.750	0.875	0.912	0.767	0.746	0.849	0.691	0.672	0.540	**0.693**
	0.647	0.503	**0.759**	0.923	**0.823**	0.778	0.902	0.974	**0.774**	**0.757**	**0.867**	0.708	**0.679**	0.517	0.689
	-0.012	-0.020	+0.013	+0.031	+0.016	+0.028	+0.027	+0.061	+0.007	+0.012	+0.018	+0.017	+0.007	-0.023	-0.005

Table 12: SSIM comparison between state-of-the-art methods for color images. The first line of each row shows the SSIM obtained by denoising the test image. The second line shows the SSIM of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.005 are shown in gray.

Detailed PSNR tables (grayscale)

$\sigma = 5$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	38.29	37.29	38.18	37.52	36.52	37.13	39.86	38.76	37.82	41.16	38.09
	38.23	37.26	38.21	37.52	36.46	37.13	39.89	38.71	37.84	41.29	38.11
	-0.06	-0.03	+0.02	-0.01	-0.05	+0.00	+0.03	-0.05	+0.02	+0.14	+0.02
BM3D-SAPCA	38.36	**37.51**	**38.46**	**37.63**	36.66	**37.30**	**40.07**	**38.89**	**38.02**	41.48	**38.32**
	38.29	37.46	38.42	37.60	36.57	37.27	40.05	38.84	38.01	**41.49**	38.29
	-0.07	-0.05	-0.04	-0.03	-0.08	-0.03	-0.02	-0.05	-0.01	+0.01	-0.03
EPLL	37.56	36.80	38.05	37.38	36.45	37.03	39.01	38.58	37.74	40.45	37.92
	37.53	36.75	38.08	37.34	36.40	36.98	39.04	38.55	37.74	40.75	37.93
	-0.03	-0.05	+0.04	-0.04	-0.05	-0.05	+0.03	-0.03	+0.00	+0.30	+0.01
Global	34.24	34.32	32.69	34.52	35.89	35.97	37.81	37.07	35.81	33.01	34.44
	35.13	34.83	33.32	35.18	36.08	36.26	38.27	37.46	36.25	34.44	35.21
	+0.89	+0.51	+0.63	+0.66	+0.19	+0.29	+0.45	+0.39	+0.44	+1.43	+0.76
NLM	37.10	36.51	37.64	36.68	35.03	36.48	38.58	38.02	37.14	39.79	37.41
	37.20	36.62	37.80	36.85	35.04	36.62	39.02	38.20	37.28	40.18	37.56
	+0.10	+0.11	+0.16	+0.16	+0.01	+0.14	+0.44	+0.18	+0.14	+0.39	+0.15
LSSC	38.47	37.36	38.23	37.46	36.73	37.17	39.95	38.74	37.91	41.02	38.16
	38.48	37.36	38.31	37.48	36.77	37.18	40.06	38.77	37.95	41.22	38.19
	+0.01	-0.00	+0.08	+0.02	+0.04	+0.01	+0.11	+0.03	+0.04	+0.19	+0.03
SAIST	**38.55**	37.27	38.26	37.44	**36.85**	37.14	39.92	38.71	37.91	41.25	38.12
	38.49	37.23	38.24	37.45	36.81	37.13	39.94	38.67	37.91	41.36	38.14
	-0.05	-0.05	-0.02	+0.01	-0.04	-0.01	+0.01	-0.05	-0.00	+0.10	+0.01
DDID	37.77	36.98	38.10	37.26	35.69	36.99	39.51	38.49	37.76	40.98	37.88
	37.69	36.94	38.07	37.23	35.63	36.96	39.47	38.44	37.72	40.95	37.81
	-0.08	-0.05	-0.03	-0.03	-0.06	-0.02	-0.04	-0.06	-0.04	-0.03	-0.06
PID	37.79	37.05	38.11	37.31	35.73	36.98	39.50	38.59	37.73	40.96	37.94
	37.70	36.98	38.07	37.25	35.68	36.93	39.41	38.49	37.66	40.91	37.86
	-0.09	-0.08	-0.04	-0.06	-0.06	-0.05	-0.09	-0.10	-0.06	-0.05	-0.08
NLDD	38.23	37.17	38.22	37.35	36.44	36.99	39.53	38.65	37.86	40.87	38.03
	38.15	37.12	38.18	37.32	36.38	36.97	39.49	38.58	37.82	40.97	37.97
	-0.08	-0.06	-0.04	-0.04	-0.06	-0.03	-0.03	-0.07	-0.04	+0.10	-0.06
NL-Bayes	38.36	37.28	38.27	37.41	36.56	37.06	39.61	38.76	37.90	40.74	38.09
	38.32	37.24	38.26	37.41	36.53	37.05	39.66	38.73	37.91	41.02	38.10
	-0.04	-0.03	-0.00	-0.00	-0.03	-0.01	+0.05	-0.03	+0.01	+0.28	+0.02

Table 13: PSNR comparison between state-of-the-art methods for grayscale images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in gray.

$\sigma = 10$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	34.94	33.91	34.06	34.01	32.46	33.60	36.81	35.92	33.96	37.37	34.71
	34.92	33.89	34.20	34.04	32.46	33.64	36.92	35.95	34.04	37.71	34.81
	-0.02	-0.02	+0.13	+0.03	-0.00	+0.05	+0.11	+0.03	+0.08	+0.34	+0.11
BM3D-SAPCA	35.06	**34.09**	**34.48**	34.14	32.65	33.81	37.07	36.07	34.22	37.83	34.94
	35.01	34.05	34.45	**34.16**	32.58	**33.83**	**37.13**	**36.07**	**34.23**	**37.97**	**34.96**
	-0.05	-0.04	-0.03	+0.02	-0.07	+0.02	+0.06	+0.00	+0.02	+0.14	+0.03
EPLL	33.62	33.64	33.98	33.82	32.15	33.49	35.79	35.60	33.96	36.57	34.59
	33.63	33.65	34.06	33.87	32.13	33.53	35.92	35.69	33.99	37.14	34.66
	+0.02	+0.01	+0.08	+0.05	-0.02	+0.04	+0.13	+0.09	+0.03	+0.57	+0.07
Global	33.40	33.06	32.94	32.88	32.12	32.88	35.41	34.75	33.16	34.72	33.66
	33.81	33.36	33.26	33.33	32.22	33.26	35.80	35.26	33.51	35.75	34.14
	+0.41	+0.30	+0.32	+0.45	+0.09	+0.38	+0.38	+0.51	+0.35	+1.03	+0.48
NLM	33.36	32.96	33.47	32.80	31.47	32.88	35.26	34.64	33.21	35.65	33.67
	33.70	33.27	33.80	33.22	31.50	33.27	35.77	35.18	33.55	36.45	34.06
	+0.34	+0.31	+0.33	+0.42	+0.04	+0.38	+0.51	+0.54	+0.35	+0.80	+0.39
LSSC	34.96	34.00	34.10	33.98	32.56	33.67	36.95	35.87	34.08	37.24	34.80
	35.05	34.04	34.27	34.07	32.65	33.75	37.10	36.02	34.16	37.63	34.90
	+0.09	+0.04	+0.17	+0.09	+0.09	+0.07	+0.14	+0.15	+0.07	+0.40	+0.10
MLP+BM3D	34.46	33.92	34.17	34.05	32.64	33.71	36.60	35.98	34.13	36.48	34.77
	34.45	33.92	34.25	34.10	32.60	33.76	36.84	36.01	34.19	37.56	34.88
	-0.01	-0.01	+0.08	+0.05	-0.04	+0.05	+0.23	+0.03	+0.06	+1.08	+0.11
SAIST	**35.23**	33.90	34.22	33.92	**32.71**	33.66	36.60	35.90	34.10	37.51	34.82
	35.19	33.88	34.26	33.96	32.68	33.68	36.70	35.92	34.11	37.79	34.87
	-0.04	-0.03	+0.03	+0.05	-0.03	+0.02	+0.10	+0.02	+0.01	+0.28	+0.06
DDID	34.64	33.73	33.92	33.84	31.85	33.56	36.54	35.82	34.00	37.53	34.62
	34.55	33.69	33.92	33.84	31.78	33.55	36.54	35.78	33.97	37.57	34.57
	-0.09	-0.04	-0.01	+0.00	-0.07	-0.01	-0.00	-0.05	-0.02	+0.04	-0.05
PID	34.54	33.75	34.03	33.87	31.79	33.61	36.62	35.83	34.00	37.44	34.66
	34.41	33.66	33.98	33.82	31.70	33.55	36.52	35.73	33.92	37.43	34.56
	-0.13	-0.09	-0.05	-0.05	-0.09	-0.06	-0.10	-0.10	-0.08	-0.01	-0.09
NLDD	34.83	33.85	34.16	33.89	32.35	33.61	36.22	35.85	34.11	37.23	34.76
	34.74	33.78	34.15	33.88	32.27	33.59	36.24	35.80	34.05	37.45	34.69
	-0.09	-0.07	-0.02	-0.01	-0.08	-0.02	+0.03	-0.04	-0.06	+0.22	-0.07
NL-Bayes	34.93	33.91	34.17	33.88	32.48	33.63	36.23	35.88	34.11	36.85	34.74
	34.94	33.91	34.23	33.96	32.44	33.68	36.46	35.94	34.14	37.39	34.81
	+0.01	+0.00	+0.06	+0.08	-0.03	+0.05	+0.23	+0.07	+0.04	+0.54	+0.07

Table 14: PSNR comparison between state-of-the-art methods for grayscale images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in gray.

$\sigma = 25$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	30.61	29.89	29.42	29.69	27.70	29.87	32.85	32.07	29.57	32.26	30.18
	30.74	29.94	29.57	29.78	27.75	29.91	32.88	32.30	29.61	33.00	30.42
	+0.13	+0.05	+0.16	+0.09	+0.04	+0.04	+0.02	+0.23	+0.04	+0.74	+0.24
BM3D-SAPCA	30.89	30.01	29.78	29.78	27.82	29.98	32.87	32.22	29.76	32.76	30.45
	30.96	30.05	29.86	29.87	27.77	**30.05**	32.88	32.37	29.78	**33.22**	30.58
	+0.07	+0.04	+0.07	+0.09	-0.05	+0.07	+0.02	+0.15	+0.02	+0.46	+0.14
EPLL	28.52	29.70	29.27	29.48	27.17	29.64	32.20	31.72	29.60	31.38	30.21
	28.90	29.83	29.59	29.68	27.32	29.78	32.45	32.04	29.70	32.52	30.46
	+0.38	+0.13	+0.32	+0.20	+0.15	+0.14	+0.24	+0.32	+0.10	+1.14	+0.25
Global	28.93	28.50	28.86	28.11	26.92	28.73	31.40	30.78	28.64	30.96	29.26
	29.72	28.90	29.14	28.84	27.19	29.28	31.96	31.57	29.04	32.01	29.86
	+0.79	+0.40	+0.29	+0.73	+0.27	+0.54	+0.56	+0.80	+0.40	+1.04	+0.60
NLM	28.86	28.47	28.52	27.95	26.38	28.64	31.25	30.58	28.56	30.52	28.96
	29.68	29.00	28.91	28.75	26.79	29.24	31.90	31.47	29.04	31.80	29.64
	+0.82	+0.53	+0.39	+0.80	+0.41	+0.61	+0.65	+0.89	+0.48	+1.28	+0.68
LSSC	30.41	29.86	29.51	29.59	27.62	29.86	33.03	31.84	29.64	32.23	30.23
	30.73	30.00	29.86	29.80	27.74	30.00	**33.06**	32.30	29.75	32.99	30.53
	+0.32	+0.14	+0.35	+0.20	+0.12	+0.14	+0.03	+0.46	+0.11	+0.76	+0.29
MLP+BM3D	30.05	30.05	29.75	29.82	27.82	30.00	32.81	32.34	**29.88**	31.79	30.50
	30.26	**30.06**	**29.89**	**29.89**	27.77	30.03	32.81	**32.39**	29.88	33.05	**30.67**
	+0.20	+0.01	+0.14	+0.07	-0.05	+0.02	+0.01	+0.05	-0.01	+1.25	+0.16
SAIST	31.00	29.81	29.21	29.56	**27.88**	29.84	32.92	32.13	29.59	32.08	30.23
	31.04	29.84	29.43	29.68	27.83	29.87	32.87	32.32	29.61	32.84	30.48
	+0.04	+0.03	+0.23	+0.12	-0.06	+0.02	-0.05	+0.19	+0.02	+0.76	+0.25
DDID	30.71	29.79	29.43	29.51	27.34	29.75	32.58	32.16	29.54	32.63	30.32
	30.71	29.80	29.49	29.59	27.29	29.77	32.57	32.22	29.52	32.98	30.36
	-0.00	+0.01	+0.07	+0.08	-0.06	+0.02	-0.01	+0.05	-0.02	+0.34	+0.04
PID	30.47	29.79	29.65	29.62	27.17	29.81	32.76	32.16	29.61	32.72	30.41
	30.38	29.66	29.52	29.58	27.06	29.72	32.48	32.06	29.47	32.80	30.32
	-0.09	-0.13	-0.13	-0.04	-0.10	-0.09	-0.28	-0.10	-0.13	+0.08	-0.10
NLDD	30.37	29.75	29.63	29.54	27.33	29.72	32.60	32.01	29.64	32.31	30.38
	30.37	29.68	29.59	29.57	27.26	29.72	32.42	32.02	29.54	32.66	30.33
	-0.01	-0.07	-0.04	+0.03	-0.07	-0.00	-0.17	+0.01	-0.10	+0.35	-0.05
NL-Bayes	30.31	29.67	29.44	29.39	27.44	29.65	32.40	31.92	29.57	31.54	30.10
	30.52	29.82	29.68	29.60	27.47	29.82	32.59	32.17	29.68	32.48	30.39
	+0.21	+0.15	+0.25	+0.21	+0.03	+0.17	+0.18	+0.24	+0.11	+0.95	+0.29

Table 15: PSNR comparison between state-of-the-art methods for grayscale images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in gray.

$\sigma = 40$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	27.92	27.69	26.97	27.46	25.30	27.91	30.38	29.80	27.60	29.14	27.70
	28.24	27.79	27.23	27.57	25.39	27.99	30.58	30.13	27.63	30.01	27.93
	+0.32	+0.10	+0.26	+0.12	+0.09	+0.08	+0.20	+0.32	+0.03	+0.87	+0.22
BM3D-SAPCA	28.56	27.88	27.40	27.58	25.53	28.04	30.48	30.06	27.73	29.68	28.06
	28.70	**27.95**	27.52	**27.67**	25.45	**28.11**	30.68	**30.30**	**27.74**	**30.24**	**28.14**
	+0.14	+0.06	+0.12	+0.09	-0.08	+0.07	+0.21	+0.24	+0.00	+0.57	+0.08
EPLL	26.05	27.68	27.01	27.35	24.81	27.80	29.94	29.59	27.62	28.43	27.80
	26.79	27.82	27.36	27.55	25.18	27.95	30.31	30.01	27.70	29.75	28.07
	+0.74	+0.14	+0.34	+0.20	+0.37	+0.15	+0.37	+0.42	+0.09	+1.33	+0.27
Global	26.42	26.51	26.50	25.80	24.51	26.67	28.80	28.56	26.60	28.41	26.78
	27.48	26.81	26.87	26.59	25.11	27.08	29.45	29.40	26.86	29.41	27.36
	+1.07	+0.30	+0.38	+0.79	+0.59	+0.41	+0.65	+0.84	+0.27	+1.00	+0.59
NLM	26.18	26.30	26.16	25.62	23.96	26.49	28.25	28.16	26.44	27.64	26.27
	27.38	26.98	26.74	26.56	24.78	27.33	29.40	29.41	27.13	29.08	27.15
	+1.21	+0.68	+0.58	+0.94	+0.82	+0.84	+1.15	+1.25	+0.69	+1.44	+0.88
LSSC	28.11	27.77	27.17	27.44	25.29	27.94	30.80	29.85	27.60	29.10	27.70
	28.43	27.84	**27.55**	27.59	25.45	28.00	30.77	30.16	27.68	30.07	27.99
	+0.31	+0.08	+0.38	+0.14	+0.16	+0.05	-0.03	+0.31	+0.07	+0.98	+0.28
SAIST	28.74	27.60	26.95	27.46	**25.62**	27.89	**31.06**	30.03	27.56	29.06	27.74
	28.76	27.62	27.27	27.52	25.51	27.86	30.80	30.25	27.55	29.86	27.96
	+0.02	+0.02	+0.32	+0.06	-0.11	-0.03	-0.26	+0.22	-0.02	+0.80	+0.22
DDID	28.43	27.62	27.17	27.30	25.04	27.77	30.31	29.99	27.52	29.51	27.84
	28.55	27.65	27.29	27.40	25.07	27.82	30.40	30.13	27.50	29.98	27.92
	+0.12	+0.04	+0.12	+0.10	+0.03	+0.06	+0.09	+0.14	-0.02	+0.47	+0.08
PID	28.34	27.68	27.40	27.42	24.98	27.85	30.65	30.09	27.63	29.95	28.05
	28.32	27.53	27.22	27.34	24.91	27.73	30.42	30.00	27.45	29.99	27.96
	-0.02	-0.15	-0.18	-0.08	-0.07	-0.12	-0.23	-0.09	-0.18	+0.05	-0.09
NLDD	28.21	27.55	27.35	27.38	25.24	27.82	30.51	30.04	27.64	29.65	27.86
	28.28	27.47	27.28	27.37	25.19	27.75	30.34	30.04	27.50	29.98	27.83
	+0.06	-0.07	-0.07	-0.01	-0.06	-0.07	-0.18	+0.01	-0.14	+0.33	-0.03
NL-Bayes	28.09	27.47	27.00	27.22	25.36	27.75	30.13	29.86	27.53	28.59	27.48
	28.38	27.59	27.30	27.42	25.42	27.86	30.34	30.15	27.59	29.71	27.80
	+0.29	+0.12	+0.29	+0.20	+0.06	+0.11	+0.21	+0.29	+0.05	+1.12	+0.33

Table 16: PSNR comparison between state-of-the-art methods for grayscale images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in gray.

$\sigma = 80$	Barba.	Boat	Camer.	Couple	Finge.	Hill	House	Lena	Man	Monta.	Peppe.
BM3D	24.88	24.84	23.94	**24.38**	22.57	25.37	27.17	26.88	**25.10**	24.86	24.39
	25.07	24.77	23.84	24.34	22.57	**25.45**	27.14	27.15	25.05	25.50	24.48
	+0.20	-0.07	-0.09	-0.05	-0.00	+0.08	-0.04	+0.28	-0.05	+0.64	+0.09
BM3D-SAPCA	24.36	24.64	23.83	24.16	22.28	25.09	26.55	26.45	24.90	24.98	24.37
	24.97	**24.85**	23.98	24.36	22.62	**25.45**	27.10	27.14	25.08	25.74	**24.65**
	+0.61	+0.22	+0.15	+0.19	+0.34	+0.36	+0.56	+0.68	+0.18	+0.77	+0.28
EPLL	22.82	24.75	23.79	24.27	21.13	25.32	26.68	26.47	25.00	24.60	24.27
	23.13	24.82	23.89	24.29	22.24	25.41	26.99	26.98	25.01	25.53	24.51
	+0.31	+0.07	+0.10	+0.02	+1.11	+0.10	+0.31	+0.50	+0.01	+0.93	+0.24
Global	22.74	23.59	22.54	23.11	19.98	24.39	24.65	25.65	24.12	24.24	22.94
	23.77	23.84	23.24	23.27	21.79	24.54	25.48	26.30	24.25	25.01	23.57
	+1.02	+0.25	+0.69	+0.16	+1.81	+0.15	+0.82	+0.66	+0.14	+0.77	+0.62
NLM	22.35	22.92	22.23	22.50	19.49	23.48	23.73	24.45	23.28	23.29	22.22
	24.01	24.04	23.20	23.46	21.58	24.65	25.64	26.33	24.40	24.91	23.61
	+1.66	+1.11	+0.97	+0.96	+2.09	+1.17	+1.91	+1.87	+1.12	+1.62	+1.38
LSSC	24.76	24.73	23.84	24.21	22.28	25.16	27.00	26.82	24.90	24.62	24.19
	25.06	24.72	23.90	24.25	22.45	25.26	27.04	27.05	24.93	25.55	24.43
	+0.30	-0.01	+0.06	+0.03	+0.17	+0.10	+0.03	+0.23	+0.03	+0.93	+0.24
SAIST	25.34	24.72	23.96	24.25	**22.65**	25.30	**27.67**	26.89	24.97	24.86	24.40
	25.36	24.77	**24.16**	24.25	22.52	25.29	27.25	**27.21**	24.98	25.44	24.54
	+0.02	+0.05	+0.20	-0.01	-0.13	-0.01	-0.42	+0.32	+0.00	+0.58	+0.14
DDID	25.00	24.59	23.69	24.14	21.95	25.16	26.53	26.74	24.84	24.86	23.99
	25.20	24.63	23.80	24.13	22.20	25.23	26.80	27.00	24.81	25.34	24.15
	+0.20	+0.04	+0.11	-0.02	+0.25	+0.07	+0.27	+0.26	-0.03	+0.48	+0.16
PID	25.07	24.73	24.11	24.14	22.18	25.28	26.99	27.08	24.98	**25.79**	24.54
	24.98	24.50	23.91	23.90	22.08	25.05	26.74	26.90	24.70	25.74	24.36
	-0.08	-0.22	-0.20	-0.25	-0.10	-0.22	-0.25	-0.17	-0.29	-0.06	-0.18
NLDD	24.55	24.62	24.12	24.00	22.07	25.19	26.88	26.91	25.05	25.61	24.15
	24.68	24.46	23.99	23.86	22.21	25.08	26.73	26.89	24.80	25.74	24.07
	+0.13	-0.16	-0.13	-0.14	+0.15	-0.11	-0.15	-0.01	-0.25	+0.13	-0.07
NL-Bayes	24.25	24.46	23.72	23.82	22.09	25.01	26.28	26.54	24.86	24.40	23.56
	24.72	24.53	23.94	23.94	22.39	25.18	26.67	26.95	24.92	25.34	24.00
	+0.46	+0.07	+0.22	+0.12	+0.30	+0.18	+0.39	+0.42	+0.07	+0.95	+0.44

Table 17: PSNR comparison between state-of-the-art methods for grayscale images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in gray.

Detailed PSNR tables (color)

$\sigma = 5$	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
DDID	38.57	34.89	39.74	45.59	39.20	42.43	44.14	50.06	38.34	37.54	42.93	36.65	38.92	35.94	37.70
	38.46	34.80	39.65	45.61	39.05	42.39	44.16	52.53	38.16	37.40	42.83	36.49	38.87	35.87	37.58
	-0.11	-0.09	-0.09	+0.02	-0.15	-0.04	+0.02	+2.47	-0.19	-0.15	-0.10	-0.16	-0.05	-0.07	-0.12
PID	38.08	34.79	39.38	45.80	39.03	42.57	44.12	51.76	38.27	37.54	42.70	36.50	38.41	35.65	37.23
	38.10	34.73	39.38	45.71	38.92	42.53	44.13	**53.46**	38.13	37.43	42.66	36.40	38.49	35.68	37.21
	+0.02	-0.05	+0.00	-0.10	-0.11	-0.04	+0.01	+1.70	-0.14	-0.12	-0.04	-0.09	+0.09	+0.03	-0.02
NLDD	38.64	34.88	39.89	45.68	39.30	42.65	44.14	48.34	38.33	37.70	42.79	36.58	38.89	35.92	37.80
	38.55	34.80	39.80	45.67	39.14	42.58	44.15	51.01	38.13	37.52	42.71	36.41	38.88	35.90	37.69
	-0.10	-0.08	-0.09	-0.01	-0.16	-0.07	+0.00	+2.67	-0.20	-0.18	-0.08	-0.16	-0.02	-0.02	-0.12
NL-Bayes	**39.12**	**35.48**	**40.53**	46.01	**39.84**	43.30	44.20	47.50	38.90	**38.09**	42.91	**37.03**	39.38	**36.54**	**38.63**
	39.07	35.17	40.46	46.13	39.67	43.28	**44.35**	50.75	38.67	37.94	42.95	36.88	**39.40**	36.28	38.40
	-0.05	-0.31	-0.07	+0.12	-0.17	-0.02	+0.16	+3.26	-0.23	-0.15	+0.04	-0.15	+0.02	-0.26	-0.23
BM3D	39.02	35.24	40.09	45.98	39.68	43.17	44.12	51.01	**38.94**	37.83	**43.53**	36.82	38.75	36.11	38.38
	39.05	35.07	40.26	**46.15**	39.65	**43.36**	44.32	53.34	38.74	37.75	43.34	36.78	39.14	36.13	38.33
	+0.03	-0.17	+0.16	+0.17	-0.03	+0.19	+0.20	+2.33	-0.20	-0.08	-0.19	-0.04	+0.39	+0.02	-0.05

Table 18: PSNR comparison between state-of-the-art methods for color images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in **gray**.

$\sigma = 10$	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
	34.73	30.59	36.26	43.15	36.45	39.58	41.73	46.59	35.70	35.05	39.72	33.75	35.11	31.23	33.49
DDID	34.66	30.45	36.20	43.35	36.37	39.62	41.88	49.78	35.54	34.93	39.70	33.61	35.15	31.13	33.42
	-0.07	-0.14	-0.06	+0.20	-0.08	+0.05	+0.14	+3.19	-0.16	-0.12	-0.02	-0.13	+0.04	-0.10	-0.08
	34.47	30.30	36.06	43.65	36.36	39.73	41.91	48.69	35.81	35.08	39.66	33.79	34.68	30.82	32.93
PID	34.53	30.26	36.10	43.56	36.31	39.76	41.90	**50.88**	35.61	34.98	39.62	33.65	34.85	30.86	32.98
	+0.06	-0.05	+0.05	-0.09	-0.05	+0.02	-0.00	+2.19	-0.20	-0.11	-0.04	-0.15	+0.17	+0.04	+0.05
	34.73	30.55	36.40	43.21	36.50	39.45	41.58	44.75	35.58	35.07	39.53	33.73	35.12	31.23	33.59
NLDD	34.68	30.41	36.33	43.34	36.41	39.49	41.68	48.34	35.46	34.97	39.52	33.60	35.19	31.17	33.52
	-0.04	-0.13	-0.07	+0.13	-0.09	+0.05	+0.10	+3.58	-0.12	-0.10	-0.01	-0.13	+0.07	-0.06	-0.06
	34.82	**31.00**	36.66	43.18	36.71	39.57	41.43	42.94	35.86	35.26	39.50	**33.92**	35.16	**31.70**	33.96
NL-Bayes	34.99	30.89	**36.82**	43.73	36.81	39.98	41.83	47.48	35.92	**35.28**	39.68	33.91	**35.50**	31.68	**34.00**
	+0.18	-0.11	+0.16	+0.55	+0.09	+0.41	+0.40	+4.54	+0.06	+0.01	+0.19	-0.01	+0.34	-0.01	+0.04
	34.88	30.63	36.42	43.34	36.69	39.67	41.61	46.56	**36.23**	35.23	**40.10**	33.77	34.63	31.24	33.82
BM3D	**35.01**	30.69	36.70	**43.85**	**36.89**	**40.22**	**41.98**	50.09	36.10	35.20	40.02	33.75	35.26	31.50	33.89
	+0.12	+0.06	+0.27	+0.51	+0.20	+0.55	+0.37	+3.53	-0.13	-0.03	-0.07	-0.02	+0.63	+0.26	+0.08

Table 19: PSNR comparison between state-of-the-art methods for color images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in **gray**.

$\sigma = 25$	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
DDID	30.15	26.14	31.90	39.38	32.87	35.35	38.11	41.10	32.67	32.35	36.13	31.25	30.14	25.86	28.26
	30.16	26.06	31.99	40.00	32.94	35.55	38.62	44.78	32.70	32.35	36.38	31.23	30.25	25.85	28.21
	+0.01	-0.08	+0.09	+0.62	+0.07	+0.20	+0.52	+3.68	+0.03	+0.00	+0.26	-0.02	+0.11	-0.01	-0.05
PID	30.21	26.10	32.08	**40.30**	32.97	35.58	38.65	43.62	32.88	32.45	36.37	**31.38**	30.24	25.68	28.18
	30.19	26.12	32.10	40.09	32.95	35.57	38.65	**45.80**	32.72	32.35	36.34	31.28	30.33	25.77	28.27
	-0.02	+0.01	+0.03	-0.21	-0.02	-0.01	+0.00	+2.19	-0.16	-0.10	-0.02	-0.10	+0.09	+0.10	+0.09
NLDD	30.23	26.35	32.05	39.64	33.01	35.40	38.13	40.30	32.49	32.30	36.07	31.26	30.34	26.05	28.44
	30.22	26.23	32.04	39.83	32.98	35.48	38.47	44.20	32.41	32.27	36.26	31.23	30.40	26.01	28.36
	-0.02	-0.11	-0.01	+0.19	-0.02	+0.08	+0.33	+3.90	-0.08	-0.03	+0.18	-0.04	+0.05	-0.04	-0.08
NL-Bayes	30.02	26.38	31.73	39.00	32.76	34.88	37.56	36.81	32.33	32.12	35.70	31.04	29.99	26.04	28.38
	30.34	**26.42**	**32.24**	40.17	33.21	**35.72**	38.51	42.45	32.67	32.46	36.31	31.37	**30.51**	**26.21**	**28.54**
	+0.32	+0.04	+0.52	+1.17	+0.45	+0.84	+0.95	+5.64	+0.34	+0.34	+0.61	+0.33	+0.52	+0.18	+0.16
BM3D	30.16	25.93	31.75	39.45	32.77	34.95	38.14	39.87	33.03	32.30	36.33	31.17	29.73	25.57	28.28
	30.31	26.07	32.17	**40.30**	**33.23**	35.61	**38.73**	44.22	**33.05**	**32.48**	**36.54**	31.37	30.29	25.89	28.41
	+0.15	+0.14	+0.43	+0.85	+0.45	+0.66	+0.59	+4.35	+0.03	+0.17	+0.21	+0.20	+0.56	+0.33	+0.13

Table 20: PSNR comparison between state-of-the-art methods for color images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in gray.

$\sigma = 40$	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
DDID	28.09	24.17	29.55	36.85	30.82	32.83	35.96	37.82	31.04	30.67	34.24	29.86	27.79	23.31	25.80
	28.15	24.12	29.71	37.91	31.04	33.14	36.83	41.47	31.13	30.79	**34.75**	29.90	27.90	23.32	25.81
	+0.06	-0.05	+0.16	+1.06	+0.22	+0.31	+0.87	+3.65	+0.09	+0.12	+0.52	+0.05	+0.12	+0.00	+0.01
PID	28.20	24.28	**29.79**	**38.20**	31.11	33.20	**36.88**	40.55	**31.37**	**30.85**	34.74	**30.05**	28.00	23.47	25.97
	28.12	24.21	29.76	37.99	31.04	33.15	36.82	**42.42**	31.12	30.76	34.71	29.90	27.95	23.48	25.95
	-0.08	-0.06	-0.03	-0.21	-0.07	-0.05	-0.06	+1.88	-0.25	-0.09	-0.03	-0.14	-0.05	+0.02	-0.01
NLDD	28.14	24.37	29.63	37.34	30.93	33.06	36.12	37.59	30.98	30.62	34.26	29.82	28.02	23.64	26.04
	28.16	24.25	29.67	37.78	30.96	33.16	36.62	41.15	30.92	30.68	34.62	29.82	28.05	23.57	25.98
	+0.01	-0.11	+0.04	+0.44	+0.03	+0.10	+0.51	+3.56	-0.06	+0.06	+0.36	-0.00	+0.03	-0.07	-0.05
NL-Bayes	27.75	24.27	29.05	36.19	30.40	32.16	35.18	33.69	30.33	30.14	33.54	29.27	27.52	23.50	25.82
	28.25	**24.41**	29.78	37.93	31.18	**33.30**	36.58	39.26	31.11	30.80	34.58	29.93	**28.12**	**23.71**	**26.10**
	+0.49	+0.14	+0.73	+1.74	+0.78	+1.15	+1.40	+5.57	+0.79	+0.66	+1.04	+0.66	+0.60	+0.21	+0.28
BM3D	27.80	23.86	28.72	35.96	30.29	32.08	35.32	35.31	30.62	30.15	33.83	29.24	27.28	23.04	25.65
	28.13	24.06	29.47	37.85	**31.18**	33.09	36.66	39.93	31.19	30.72	34.69	29.87	27.85	23.34	25.89
	+0.33	+0.20	+0.74	+1.89	+0.90	+1.01	+1.34	+4.62	+0.57	+0.57	+0.86	+0.63	+0.58	+0.30	+0.24

Table 21: PSNR comparison between state-of-the-art methods for color images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in gray.

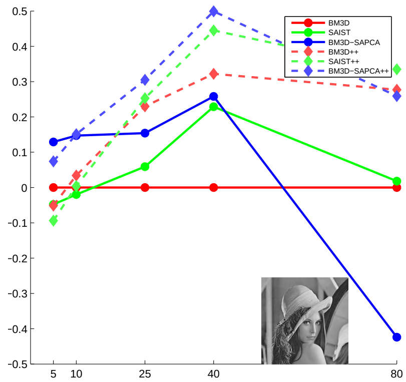
$\sigma = 80$	Alley	Baboon	Compu.	Dice	F16	Flowe.	Girl	Gradi.	House	Lena	Maggie	Peppe.	Traff.	Trees	Valld.
DDID	25.26	21.50	25.98	32.38	27.34	28.86	32.20	32.75	27.43	27.77	31.11	27.08	24.64	20.26	22.67
	25.41	21.52	26.23	33.78	27.82	29.29	33.72	35.77	27.94	28.12	32.24	27.41	24.78	20.24	22.72
	+0.16	+0.01	+0.25	+1.41	+0.48	+0.42	+1.52	+3.02	+0.50	+0.36	+1.13	+0.34	+0.14	-0.02	+0.05
PID	25.42	21.49	26.24	**34.40**	27.92	29.40	34.04	35.70	**28.34**	28.17	32.31	**27.61**	24.82	20.34	22.80
	25.29	21.34	26.10	34.03	27.83	29.20	33.87	**36.51**	28.10	28.04	32.23	27.47	24.66	20.19	22.67
	-0.13	-0.15	-0.15	-0.37	-0.09	-0.20	-0.17	+0.81	-0.24	-0.14	-0.08	-0.14	-0.17	-0.14	-0.13
NLDD	25.18	21.47	25.87	33.62	27.44	29.50	33.03	34.23	26.51	27.96	31.32	27.23	24.72	20.45	22.77
	25.17	21.34	25.84	34.00	27.48	29.36	33.74	36.20	26.47	27.99	31.87	27.20	24.61	20.28	22.66
	-0.01	-0.13	-0.03	+0.39	+0.04	-0.14	+0.71	+1.97	-0.04	+0.03	+0.54	-0.03	-0.11	-0.17	-0.11
NL-Bayes	25.12	**21.60**	25.74	34.19	27.44	29.42	33.67	31.76	26.45	27.85	31.78	26.82	24.71	**20.55**	22.73
	25.21	21.51	25.89	34.20	27.67	**29.52**	33.85	35.51	26.67	28.05	31.96	27.20	24.74	20.43	22.72
	+0.09	-0.09	+0.15	+0.01	+0.23	+0.11	+0.18	+3.75	+0.22	+0.20	+0.19	+0.38	+0.03	-0.12	-0.00
BM3D	**25.55**	21.53	26.13	33.84	27.77	29.14	33.55	32.56	28.15	28.11	32.00	27.11	24.82	20.32	**22.82**
	25.52	21.46	**26.28**	34.22	**28.07**	29.39	**34.09**	35.67	28.26	**28.26**	**32.43**	27.46	**24.89**	20.25	22.80
	-0.03	-0.07	+0.15	+0.37	+0.30	+0.25	+0.54	+3.11	+0.11	+0.15	+0.43	+0.35	+0.07	-0.07	-0.02

Table 22: PSNR comparison between state-of-the-art methods for color images. The first line of each row shows the PSNR obtained by denoising the test image. The second line shows the PSNR of DA3D using the corresponding denoising algorithm to generate the guide. The third line shows the improvement due to DA3D. The best result for each image is shown in **bold**, and the ones within a range of 0.2 dB are shown in **gray**.

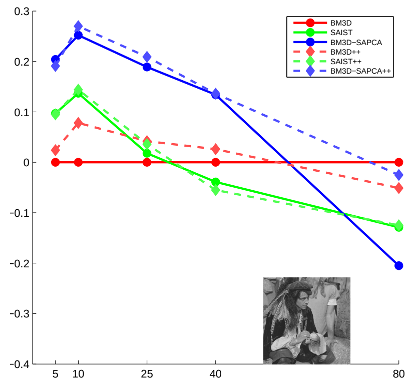
3 PSNR comparison on images for different noises

In figures 1 and 2 the PSNR gain over the BM3D algorithm is compared for the best methods and their post-processed results using DA3D for both color and grayscale images.

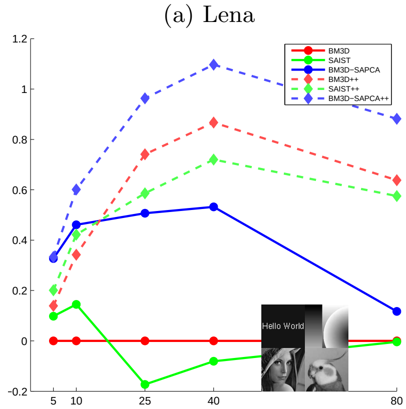
In figures 3 and 4 we compare the results of some of the best performing methods for a couple of grayscale and color images.



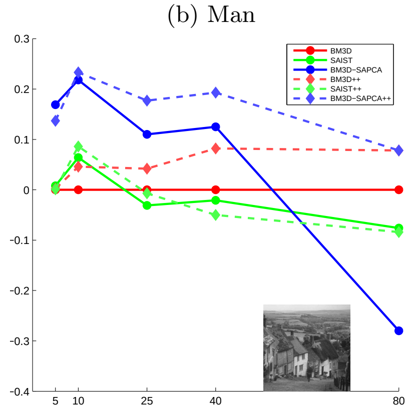
(a) Lena



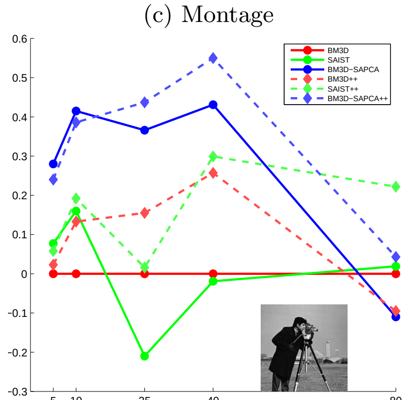
(b) Man



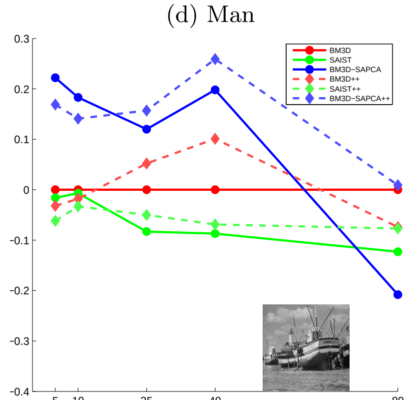
(c) Montage



(d) Man

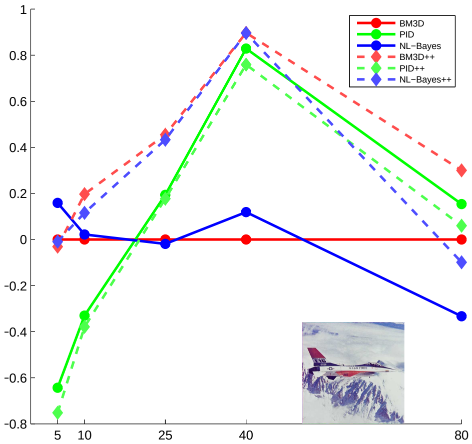


(e) Cameraman

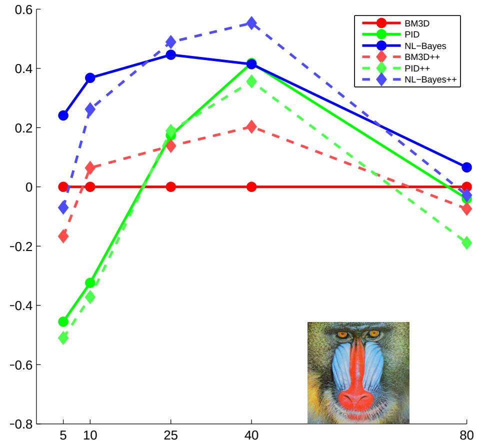


(f) Boat

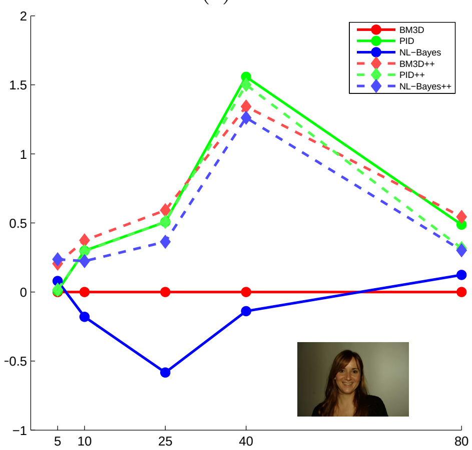
Figure 1: PSNR gain between the evaluated grayscale methods (and their respective post-processed results with DA3D, noted as '++' in the tables) over the results of BM3D for all noise levels.



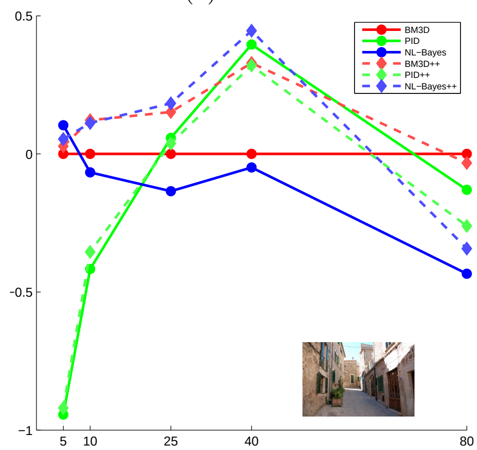
(a) F16



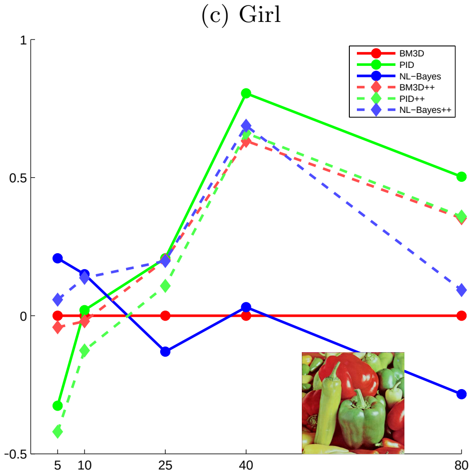
(b) Baboon



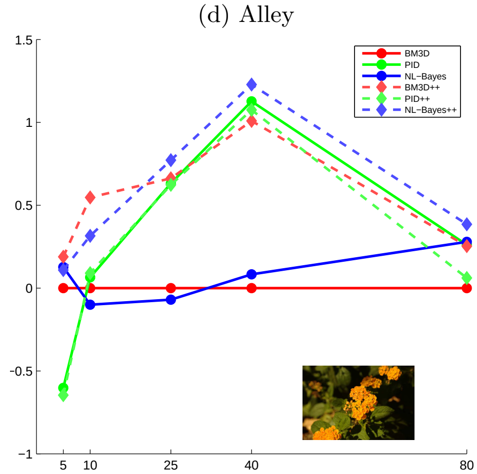
(c) Girl



(d) Alley



(e) Peppers



(f) Flowers

Figure 2: PSNR gain between the evaluated color methods (and their respective post-processed results with DA3D, noted as '++' in the tables) over the results of BM3D for all noise levels.

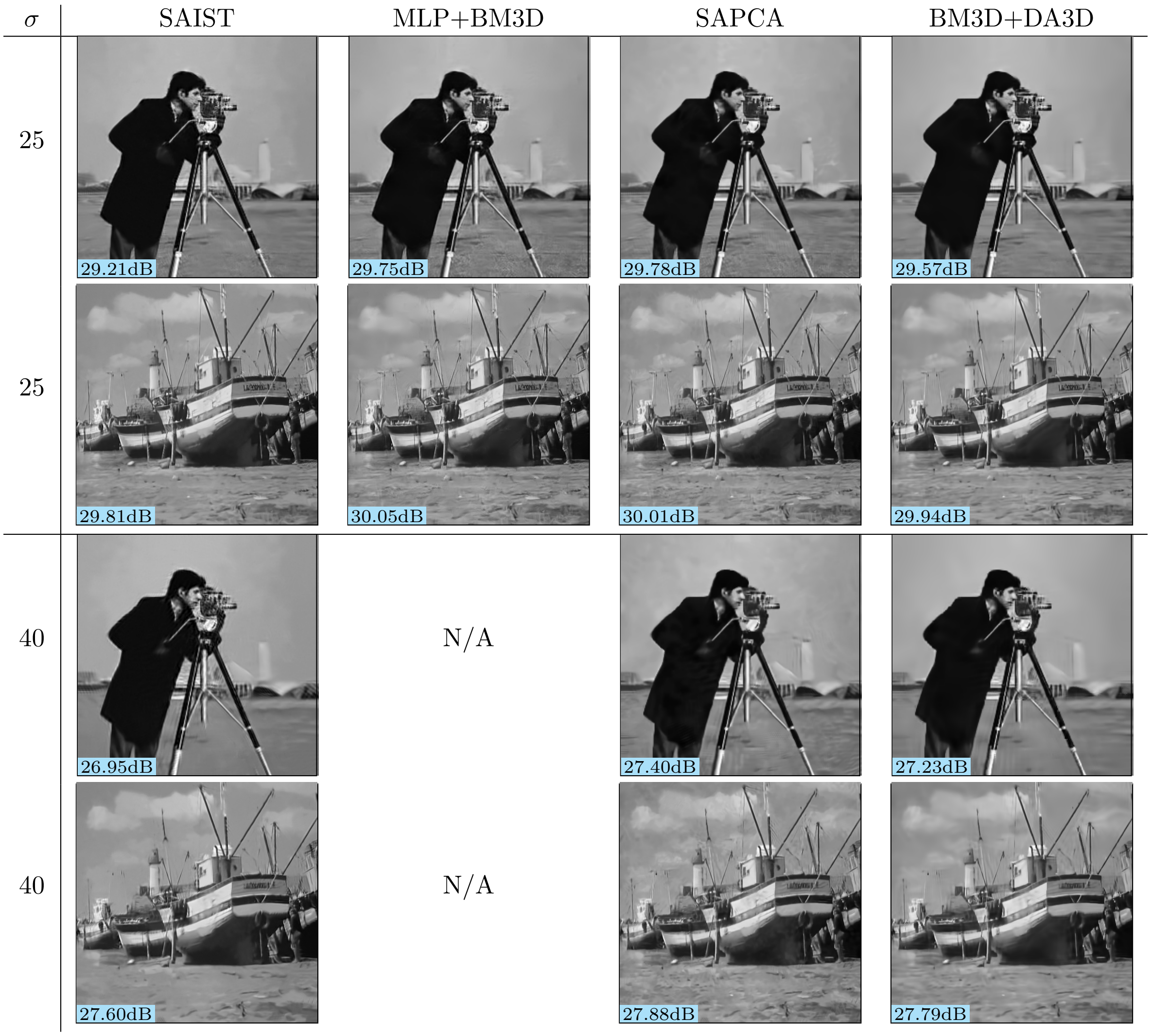


Figure 3: **Some results with grayscale images.** Comparison of three of the best performing algorithms with BM3D+DA3D. Note that sometimes the results of BM3D+DA3D have less artifacts.

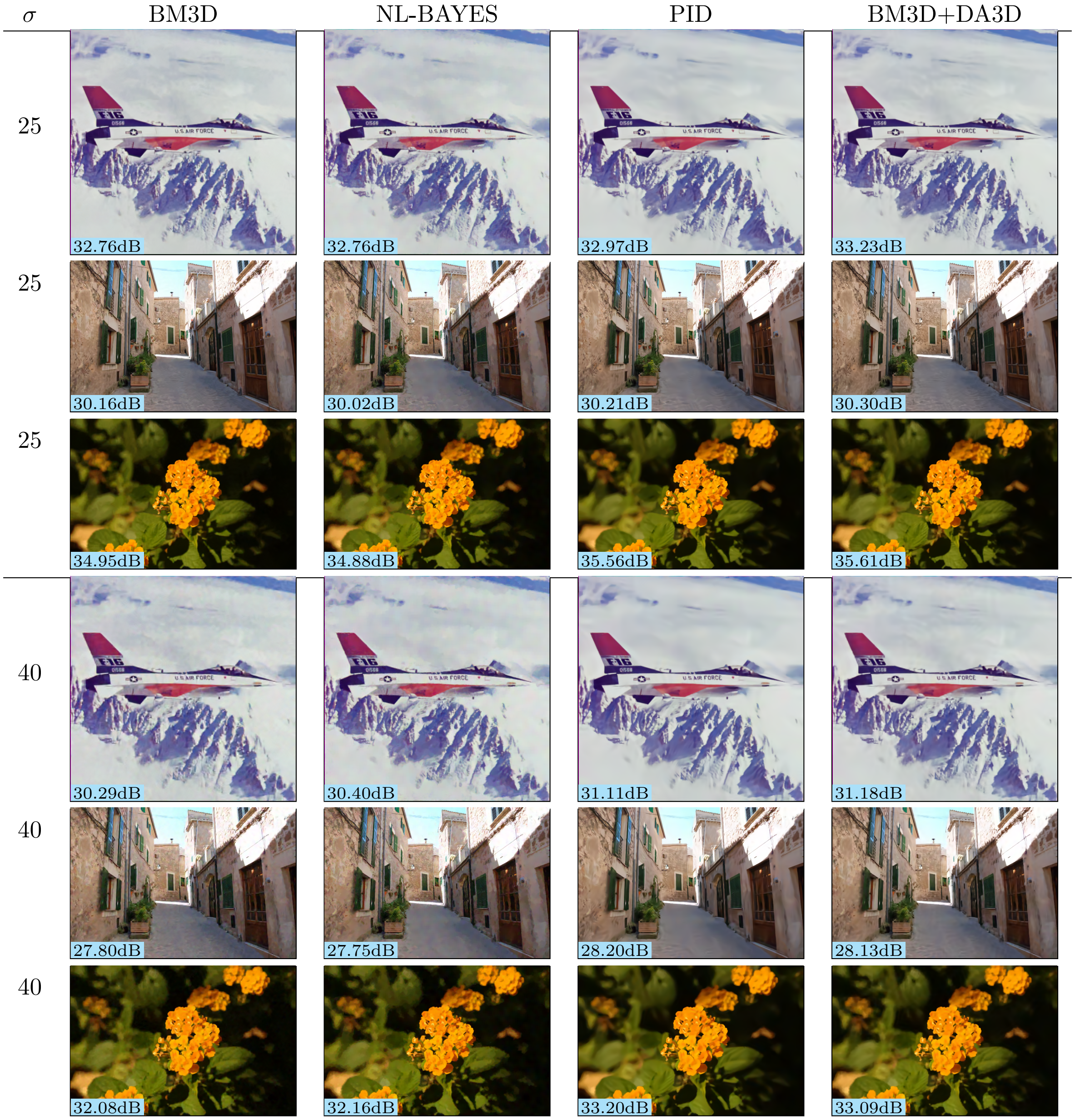


Figure 4: **Some results with color images.** Comparison of three of the best performing algorithms with BM3D+DA3D on color images.

4 Running time and choice of τ

We explain here how the threshold $\tau = 2$ was chosen. Taking BM3D as guide we analyze the PSNR gain of DA3D as function of the threshold τ. A higher τ implies more time, however we observe that the gain reaches a plateau around $\tau = 2$ (Figure 5, left). But the relation between τ and the computing time is image dependent.

Looking at the processing time, which is proportional to the number of processed samples (Figure 5, right) we observe that by processing 3% of the image samples we can guarantee a PSNR gain for every image. Moreover, for several images the algorithm stops before 3% as the threshold $\tau = 2$ is attained earlier.

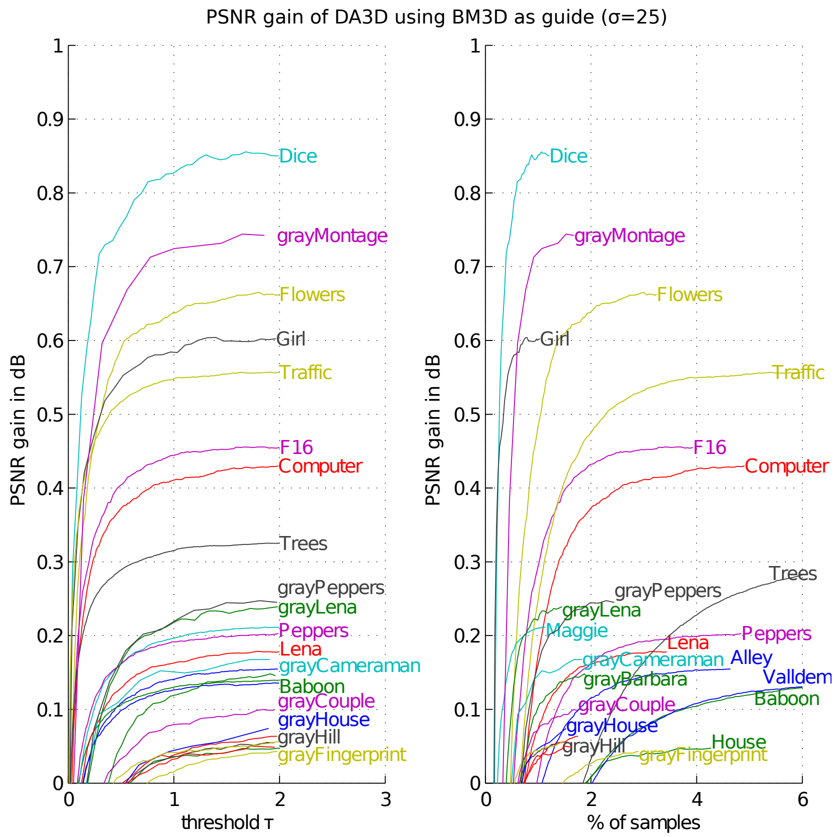


Figure 5: **Quality of DA3D vs. time.** This experiment uses BM3D as guide. The graphs on the left show the improvement of DA3D (with respect the PSNR of the guide) as function of the threshold τ for all the images. We note that setting $\tau > 1$ guarantees an improvement for all the images, the graphs reach a plateau at $\tau = 2$. The graphs on the right show the improvement as function of number of samples (expressed as percentage of the image size). Stopping the algorithm as soon as it gets to 3% of the samples guarantees an improvement for all the images.

5 DA3D python implementation

The python implementation of DA3D is reported below in the file **da3d_lib.py**. For simplicity this code uses *scipy.fftpack* to compute the Fourier transforms. However, as a result it is also 2.5 times slower than using the FFTW (which was used in the experiments). The code uses `numpy 1.8.0`, `numexpr 2.3.1`, and `scipy-0.13`.

The following lines show how to call DA3D to denoise `y.png` using the guide `g.png`:

```
import numpy as np
from scipy.misc import imread, imsave
from da3d_lib import DA3D
y = imread('y.png').astype(np.float32).transpose((2, 0, 1))
g = imread('g.png').astype(np.float32).transpose((2, 0, 1))
x = DA3D(g, y, 25)
imsave('denoised.png',x.clip(0,255).transpose((1,2,0)))
```

da3d_lib.py

```
import numpy as np
import numexpr as ne
from scipy.fftpack import dct,idct,fft2,ifft2

def colorTransform(image):
    return dct(image, norm = 'ortho', axis = 0)

def colorTransformInverse(image):
    return idct(image, norm = 'ortho', axis = 0)


def DA3D(guide, noisy, sigma, r=31, sigma_s=14.0, gamma_r=.7, gamma_f=.8, threshold = 2):
    """
    Data Adaptive Dual Domain Denoising
    Input: guide: image as np.float32 array with shape <nch, nrows, ncols>
           noisy: same as guide
           sigma: noise std deviation
           [r=31]: half patch size
           [threshold=2]: the threshold \\tau
    Output: image as np.float32 array

    NOTE: For simplicity this code uses scipy.fftpack, but as a result this
          version is 2.5 times slower than the one using the wrapped FFTW.
    """
    c = noisy.shape[0]
    s = 2 * r + 1
    s = int(2**(np.ceil(np.log2(s))))  # we round to a power of 2
    sigma2=sigma**2

    guide = colorTransform(guide)
    noisy = colorTransform(noisy)

    # allocating internal variables
    guide = np.pad(guide, ((0, 0), (r, s - r - 1), (r, s - r - 1)), 'symmetric')
    noisy = np.pad(noisy, ((0, 0), (r, s - r - 1), (r, s - r - 1)), 'symmetric')
    result = np.zeros(noisy.shape, dtype = np.float32)
```

```
    agg_weights = np.zeros(noisy.shape[1:], dtype = np.float32)

    gm_to_G = np.zeros((c,s,s), dtype = np.float32)
    ym_to_Y = np.zeros((c,s,s), dtype = np.float32)

    K = np.empty((c, s, s), dtype = np.float32)
    gamma_r_sigma2 = np.float32(gamma_r * sigma2)

    h = np.exp(- (np.arange(-r, s - r, dtype = np.float32))**2 / (2 * sigma_s**2))
    h = h * h[:, np.newaxis]

    # PARAMETERS FOR THE ESTIMATION OF THE REGRESSION PLANE
    gamma_r_regression = gamma_r *10 # DEFAULT 10 times the denoising range
    gamma_r_regression_sigma2 = np.float32(gamma_r_regression * sigma2)
    sigma_s_regression = sigma_s * np.sqrt(2)

    # spatial support for the regression
    hh = np.exp(- (np.arange(-r, s - r, dtype = np.float32))**2 / (2*sigma_s_regression**2))
    hh = hh * hh[:, np.newaxis]

    # precompute linear fitting parameters
    A = np.array(np.meshgrid( np.arange(-r, s - r, dtype = np.float32),
                              np.arange(-r, s - r, dtype = np.float32) ))

    # Define the utility functions
    calcDist = ne.NumExpr('sum((g - ctr)**2, axis = 0)',
                          [('g', float), ('ctr', float)])
    if c==1:                                      # HACK for monochrome images
       calcDist1 = ne.NumExpr('(g - ctr)**2', [('g', float), ('ctr', float)])
       calcDist = lambda g, ctr: np.squeeze(calcDist1 (g,ctr),axis=0)

    calcBilateral = ne.NumExpr('exp(-d / (gamma_r_sigma2)) * h',
                     [('d', float), ('gamma_r_sigma2', float), ('h', float)])

    # computes tht shrinkage factor for a certain FFT G (complex)
    computeK = ne.NumExpr('where(G.real*G.real + G.imag*G.imag > 1e-5,'+
                'exp( - gamma_f * V / (G.real*G.real + G.imag*G.imag)  )  , 0)',
                [('G', complex),  ('V', float), ('gamma_f', float)])

    aw = agg_weights[r:r+1-s, r:r+1-s]
    q  = 0
    while True:                                                    # MAIN LOOP

        ### STEP 1. Choice of the patch to process
        i, j = np.unravel_index(np.argmin(aw), aw.shape)
        if aw[i, j] > threshold:
            break
        current_threshold= aw[i, j]
        q += 1
#        if 100.0*q/np.prod(aw.shape) > 3.0: # STOP baed on % of points
#            break

        # extract the patches g and y
        g = guide[:, i:i+s, j:j+s].copy()
        y = noisy[:, i:i+s, j:j+s].copy()

```

```
        ### STEP 2. Estimation and removal of regression surface (color gradient)
        central = g[:, r, r, np.newaxis, np.newaxis]
        d = calcDist(g, central)

        ### regression surface over a large support and a much larger range
        kreg = calcBilateral(d, gamma_r_regression_sigma2, hh)          # eq. 8.
        regparm = np.linalg.lstsq((A * kreg).reshape(2, s * s).T,
                     ((y - central) * kreg).reshape(c, s * s).T)[0]
        P = np.dot(regparm.T, A.reshape(2, s * s)).reshape(c, s, s)     # eq. 7.

        g -= P
        y -= P

        ### THE ACTUAL DENOISING STARTS HERE
        ### STEP 3. Select pixels to process by defining a weights k within the patch
        # use a smaller support and range for the actual denoising
        d = calcDist(g, central)
        k = calcBilateral(d, gamma_r_sigma2, h)

        ### STEP 4. Remove useless pixels (according to k) replacing them with the average
        sum_k = np.sum(k)
        gt = np.dot(g.reshape((c, s * s)), k.reshape((s * s))) / sum_k
        yt = np.dot(y.reshape((c, s * s)), k.reshape((s * s))) / sum_k

        kcomp = 1 - k
        np.add(k * g, kcomp * gt[:, np.newaxis, np.newaxis], gm_to_G)
        np.add(k * y, kcomp * yt[:, np.newaxis, np.newaxis], ym_to_Y)

        V = sigma2 * np.vdot(k, k)

        ### STEP 5. Fourier shrinking
        K = computeK(fft2(gm_to_G), V, gamma_f)   # shrinkage factors   # eq. 6.
        K[:,0,0] = 1
        Y=fft2(ym_to_Y)
        Y[:] *= K                                 # apply the shrinkage
        ym_to_Y=ifft2(Y)

        ### STEP 6. Aggregation
        result[:, i:i+s, j:j+s] += ((np.real(ym_to_Y) + k * P -
                                     kcomp * yt[:, np.newaxis, np.newaxis])) * k
        agg_weights[i:i+s, j:j+s] += k * k

    print "Info:: percentage of sampled points: %.2f  last threshold:%.2f"%(
                     100.0*q/np.prod(aw.shape), current_threshold)
    result = result[:, r:r+1-s, r:r+1-s]
    return colorTransformInverse(result) / agg_weights[r:r+1-s, r:r+1-s]
```