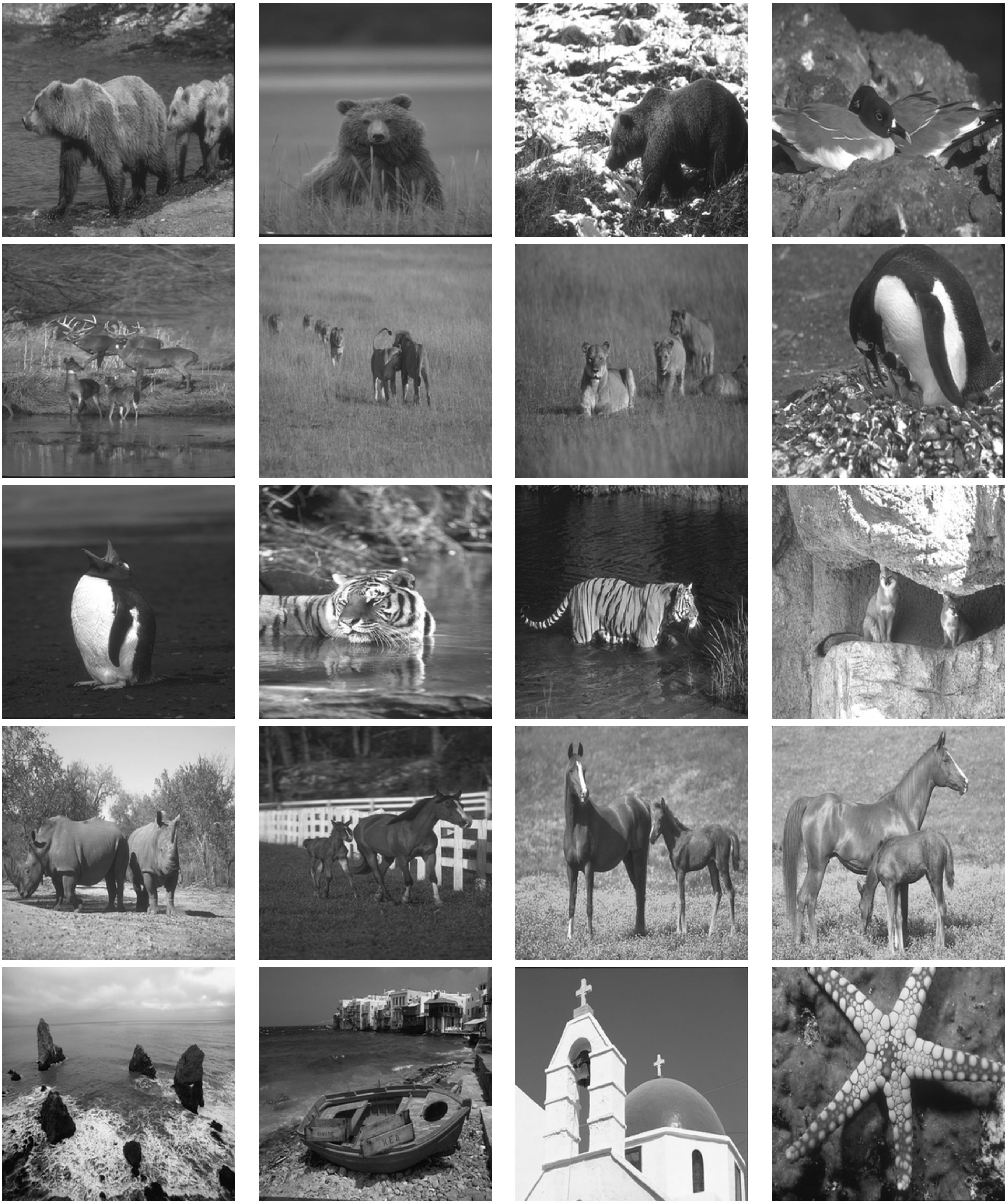
Supplementary material for the paper: "Improving Denoising Algorithms via a Multi-Scale Meta-Procedure" Paper ID: 100

March 28, 2011

1 Training images

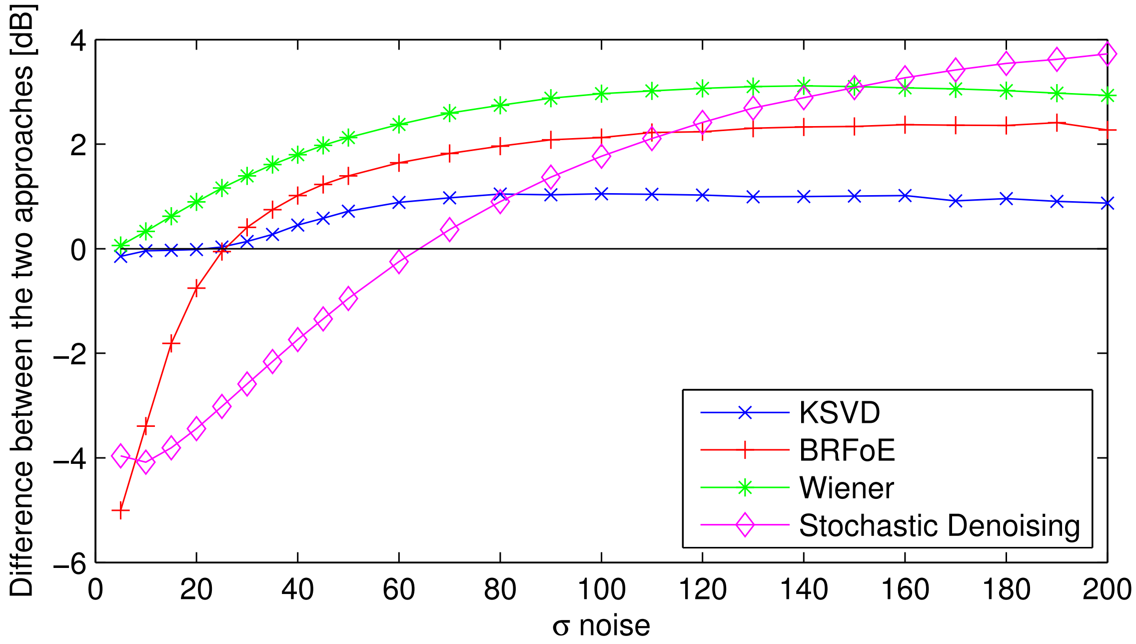


The hyper-parameters of our method were tuned on 20 training images for the Berkeley segmentation. The images are color images, but we worked on black and white versions by averaging the color channels. The image are all either of size 481×321 or of size 321×481. We removed one pixel row at the bottom of the images and one pixel column at the right of the images in order to create images of size either 480×320 or 320×480. The reason for this was to create images that are multiples of 8 in height and width.

2 Test images

The 13 test images are usually named “Barbara”, “Boat”, “Cameraman”, “Couple” (or “Living Room”), “Fingerprint”, “Flintstones”, “Hill” (or “Goldhill”), “House”, “Baboon” (or “Mandrill”), “F16” (or “Fighter Jet”), “Lena”, “Man” (or “Pirate”) and “Peppers”. The images “Cameraman”, “House” and “Peppers” are of size 256×256 and all others are of size 512×512. The images “Baboon” and “F16” were color images which we converted to black and white by averaging the color channels, as we did in the training set. All other images are black and white.

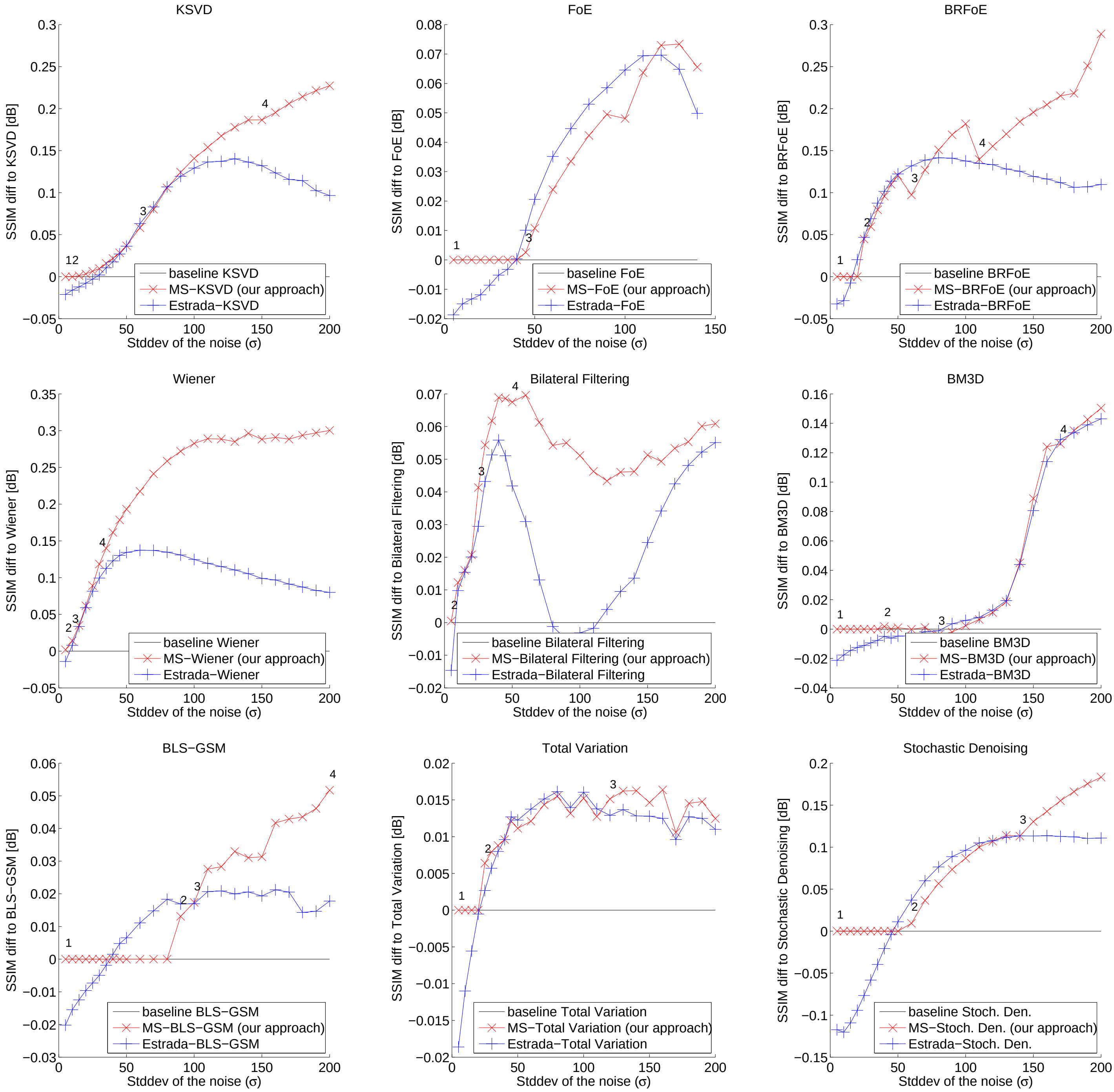
3 Notes on how to denoise lower frequencies



In Sec. 3 ("How to denoise lower frequencies") of the paper, we explained that first down-scaling, then denoising is preferable to first denoising, then down-scaling. However, we provided results on only one image, for one noise setting and using only one denoising algorithm (KSVD).

To gather statistics, we compared the two approaches on the 20 training images for different noise levels. We chose the algorithms KSVD, BRFoE, Wiener and Stochastic denoising. The figure above reports the average difference between the two methods, where a value larger than 0 indicates that it is better to first down-scale, then denoise than vice-versa. So we see that first down-scaling, then denoising is better than the other way around when the noise is strong.

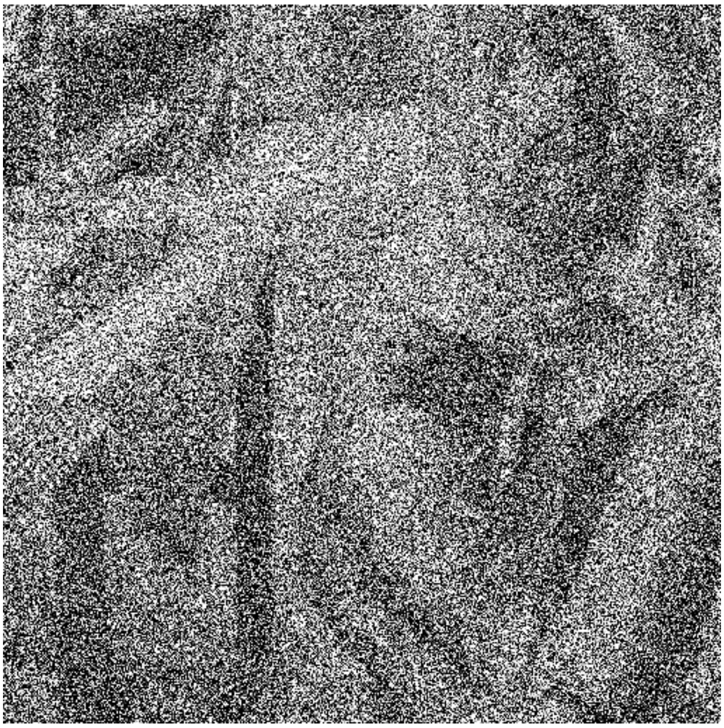
4 Improvements in terms of SSIM



The most commonly used measure for image quality is the peak signal to noise ratio (PSNR), which is related to the mean squared error. A shortcoming of the PSNR is that it does not take into account the visual appearance of an image. A measure that attempts to address this issue is the structural similarity index (SSIM) [2]. The SSIM is a value ranging between 0 and 1, where higher values indicate higher similarities.

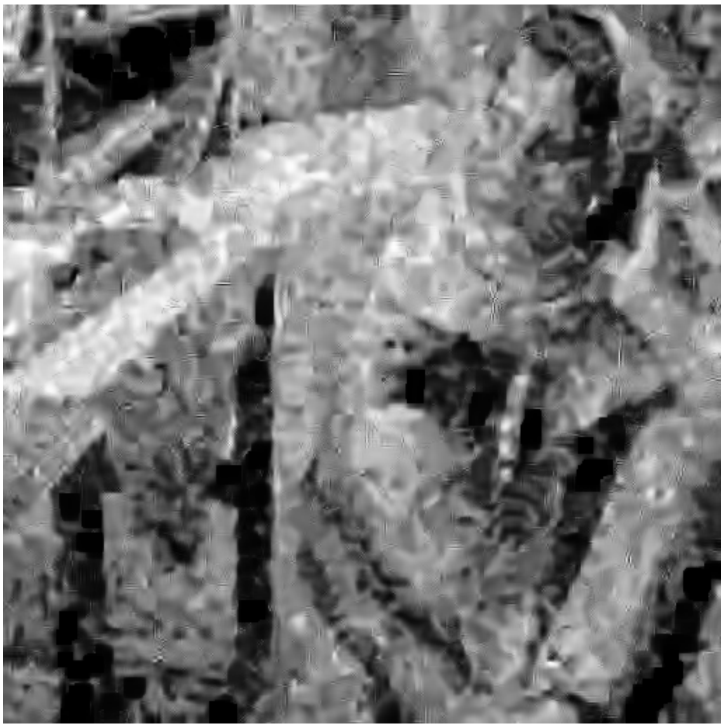
In the paper, we presented improvements achieved by our approach in terms of PSNR. In the figure above we present the same results in terms of SSIM. We see similar trends as for the PSNR: Our approach outperforms the method proposed by Estrada et al. [1] in most cases. The greatest gains are achieved for the methods KSVD, BRFoE and Wiener.

5 Visual comparison for the “Barbara” image



noisy $\sigma = 200$
PSNR: 7.59dB, SSIM: 0.074

ground truth



denoised with BM3D
PSNR: 18.88dB, SSIM: 0.429

denoised with MS-BM3D
PSNR: 20.96dB, SSIM: 0.591

The images above show the results obtained with BM3D and MS-BM3D (our approach) when noise with $\sigma = 200$ is added to the “Barbara” image. In the noisy image, one can barely recognize the original image content. BM3D is able to partially recover the image, but also introduces many artifacts. Surfaces that should be smooth look very grainy. Some patches are completely black, which further degrades the image quality. Combining BM3D with our multi-scale approach (MS-BM3D) produces an image with fewer artifacts. Surfaces appear smooth again and it is easier to recognize the original image content. Even some details are recovered: For instance part of the texture of the table cloth is discernible.

noisy $\sigma = 50$
PSNR: 14.77dB, SSIM: 0.44

ground truth

denoised with Wiener
PSNR: 20.77dB, SSIM: 0.579

denoised with MS-Wiener
PSNR: 22.99dB, SSIM: 0.731

The image "Barbara" has been corrupted with AWGN ($\sigma = 50$) and denoised with Wiener and MS-Wiener. The image produced by MS-Wiener looks much smoother than the one produced by Wiener (without multi-scale extension).

noisy $\sigma = 50$
PSNR: 14.77dB, SSIM: 0.44

ground truth

denoised with KSVD
PSNR: 25.35dB, SSIM: 0.791

denoised with MS-KSVD
PSNR: 26.08dB, SSIM: 0.842

The image "Barbara" has been corrupted with AWGN ($\sigma = 50$) and denoised with KSVD and MS-KSVD. With KSVD, regions of the image that should be smooth appear "wavy". These low-frequency artifacts are due to the fact that KSVD denoises images patch by patch: Adding Gaussian noise with mean 0 will result in noise vectors with a non-zero average value on small patches. The smaller the patch size, the more dramatic this effect. Applying our multi-scale approach (MS-KSVD) reduces this effect: Few artifacts are visible in the smooth regions of the image, yet fine details have not been deteriorated.

6 Visual comparison on all images

We now display the images produced by the nine denoising algorithms in the plain and multi-scale settings (i.e. plain vs. our approach) for all images in the test set. We will use three different noise levels: $\sigma = 50$, $\sigma = 90$ and $\sigma = 130$. We report the PSNR and SSIM of each image.

Image "Barbara" with $\sigma = 50$

noisy
PSNR:14.77dB, SSIM:0.444

ground truth

KSVD
PSNR:25.35dB, SSIM:0.791

MS-KSVD
PSNR:26.08dB, SSIM:0.842

FoE
PSNR:23.63dB, SSIM:0.785

MS-FoE
PSNR:23.34dB, SSIM:0.764

BRFoE
PSNR:21.34dB, SSIM:0.606

MS-BRFoE
PSNR:22.71dB, SSIM:0.707

Wiener
PSNR:20.77dB, SSIM:0.579

MS-Wiener
PSNR:22.99dB, SSIM:0.731

BilateralFiltering
PSNR:23.10dB, SSIM:0.733

MS-BilateralFiltering
PSNR:23.19dB, SSIM:0.734

BM3D
PSNR:27.30dB, SSIM:0.875

MS-BM3D
PSNR:27.19dB, SSIM:0.871

BLS-GSM
PSNR:24.42dB, SSIM:0.797

MS-BLS-GSM
PSNR:24.42dB, SSIM:0.797

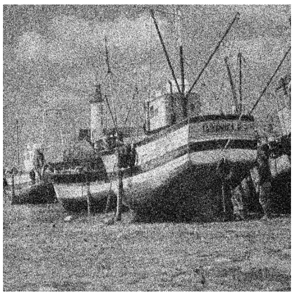
TV
PSNR:23.17dB, SSIM:0.747

MS-TV
PSNR:23.09dB, SSIM:0.739

Stochastic
PSNR:22.66dB, SSIM:0.669

MS-Stochastic
PSNR:22.66dB, SSIM:0.669

Image “Boat” with $\sigma = 50$



noisy
PSNR:14.59dB, SSIM:0.406

ground truth

KSVD
PSNR:25.79dB, SSIM:0.760

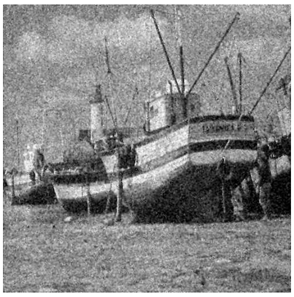
MS-KSVD
PSNR:26.32dB, SSIM:0.797

FoE
PSNR:25.38dB, SSIM:0.769

MS-FoE
PSNR:25.71dB, SSIM:0.792

BRFoE
PSNR:21.97dB, SSIM:0.596

MS-BRFoE
PSNR:24.64dB, SSIM:0.732



Wiener
PSNR:21.41dB, SSIM:0.565

MS-Wiener
PSNR:24.98dB, SSIM:0.743

BilateralFiltering
PSNR:24.06dB, SSIM:0.712

MS-BilateralFiltering
PSNR:25.12dB, SSIM:0.743

BM3D
PSNR:26.65dB, SSIM:0.811

MS-BM3D
PSNR:26.70dB, SSIM:0.819

BLS-GSM
PSNR:26.13dB, SSIM:0.785

MS-BLS-GSM
PSNR:26.13dB, SSIM:0.785

TV
PSNR:25.03dB, SSIM:0.734

MS-TV
PSNR:25.15dB, SSIM:0.748

Stochastic
PSNR:24.38dB, SSIM:0.685

MS-Stochastic
PSNR:24.38dB, SSIM:0.685

Image "Cameraman" with $\sigma = 50$

noisy
PSNR:14.93dB, SSIM:0.179

ground truth

KSVD
PSNR:25.44dB, SSIM:0.704

MS-KSVD
PSNR:25.44dB, SSIM:0.716

FoE
PSNR:24.63dB, SSIM:0.756

MS-FoE
PSNR:24.07dB, SSIM:0.715

BRFoE
PSNR:20.92dB, SSIM:0.449

MS-BRFoE
PSNR:22.68dB, SSIM:0.602

Wiener
PSNR:21.17dB, SSIM:0.374

MS-Wiener
PSNR:23.73dB, SSIM:0.689

BilateralFiltering
PSNR:22.51dB, SSIM:0.576

MS-BilateralFiltering
PSNR:24.30dB, SSIM:0.703

BM3D
PSNR:26.03dB, SSIM:0.777

MS-BM3D
PSNR:25.90dB, SSIM:0.770

BLS-GSM
PSNR:25.45dB, SSIM:0.725

MS-BLS-GSM
PSNR:25.45dB, SSIM:0.725

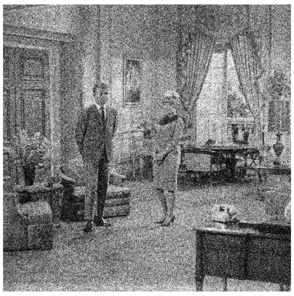
TV
PSNR:24.44dB, SSIM:0.749

MS-TV
PSNR:24.21dB, SSIM:0.743

Stochastic
PSNR:22.45dB, SSIM:0.517

MS-Stochastic
PSNR:22.45dB, SSIM:0.517

Image "Couple" with $\sigma = 50$



noisy
PSNR:14.58dB, SSIM:0.433

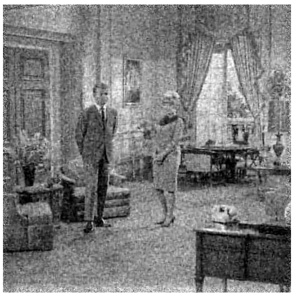
ground truth

KSVD
PSNR:25.43dB, SSIM:0.760

MS-KSVD
PSNR:25.90dB, SSIM:0.792

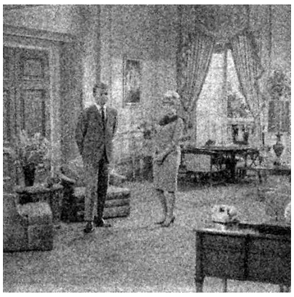
FoE
PSNR:25.00dB, SSIM:0.749

MS-FoE
PSNR:25.59dB, SSIM:0.796



BRFoE
PSNR:22.01dB, SSIM:0.627

MS-BRFoE
PSNR:24.51dB, SSIM:0.743



Wiener
PSNR:21.42dB, SSIM:0.593

MS-Wiener
PSNR:24.67dB, SSIM:0.731

BilateralFiltering
PSNR:23.97dB, SSIM:0.701

MS-BilateralFiltering
PSNR:24.73dB, SSIM:0.726

BM3D
PSNR:26.43dB, SSIM:0.812

MS-BM3D
PSNR:26.55dB, SSIM:0.825

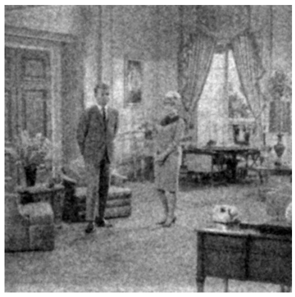
BLS-GSM
PSNR:25.84dB, SSIM:0.779

MS-BLS-GSM
PSNR:25.84dB, SSIM:0.779

TV
PSNR:24.62dB, SSIM:0.708

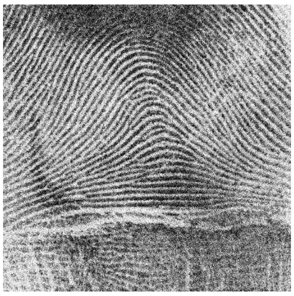
MS-TV
PSNR:24.81dB, SSIM:0.726

Stochastic
PSNR:24.35dB, SSIM:0.698

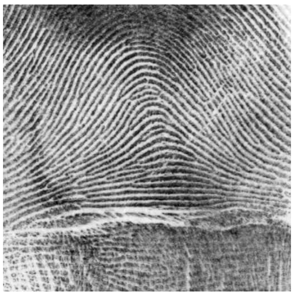


MS-Stochastic
PSNR:24.35dB, SSIM:0.698

Image "Fingerprint" with $\sigma = 50$



noisy
PSNR:14.71dB, SSIM:0.776



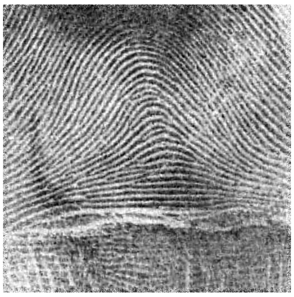
ground truth

KSVD
PSNR:23.19dB, SSIM:0.857

MS-KSVD
PSNR:24.08dB, SSIM:0.896

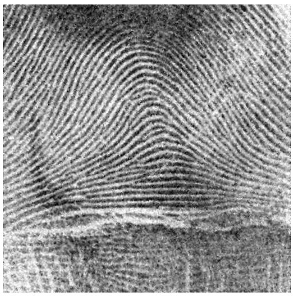
FoE
PSNR:22.57dB, SSIM:0.821

MS-FoE
PSNR:23.37dB, SSIM:0.895

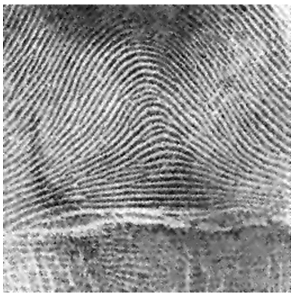


BRFoE
PSNR:21.87dB, SSIM:0.888

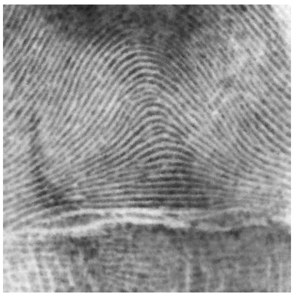
MS-BRFoE
PSNR:22.93dB, SSIM:0.861



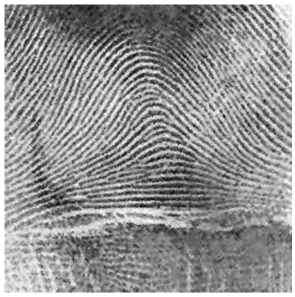
Wiener
PSNR:21.02dB, SSIM:0.872



MS-Wiener
PSNR:23.03dB, SSIM:0.872



BilateralFiltering
PSNR:19.33dB, SSIM:0.635



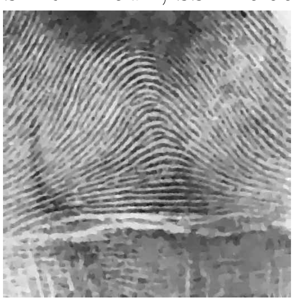
MS-BilateralFiltering
PSNR:23.18dB, SSIM:0.874

BM3D
PSNR:24.49dB, SSIM:0.904

MS-BM3D
PSNR:24.45dB, SSIM:0.908

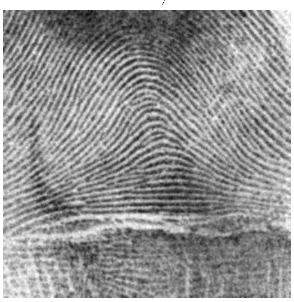
BLS-GSM
PSNR:23.22dB, SSIM:0.861

MS-BLS-GSM
PSNR:23.22dB, SSIM:0.861

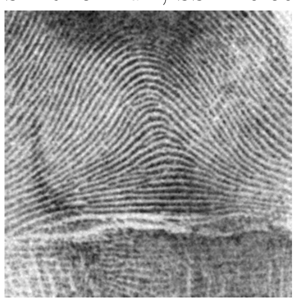


TV
PSNR:20.91dB, SSIM:0.722

MS-TV
PSNR:21.78dB, SSIM:0.795



Stochastic
PSNR:22.42dB, SSIM:0.851



MS-Stochastic
PSNR:22.42dB, SSIM:0.851

Image “Flintstones” with $\sigma = 50$

noisy
PSNR:15.20dB, SSIM:0.647

ground truth

KSVD
PSNR:24.24dB, SSIM:0.884

MS-KSVD
PSNR:24.05dB, SSIM:0.884

FoE
PSNR:23.35dB, SSIM:0.869

MS-FoE
PSNR:23.19dB, SSIM:0.855

BRFoE
PSNR:21.84dB, SSIM:0.791

MS-BRFoE
PSNR:22.40dB, SSIM:0.839

Wiener
PSNR:20.88dB, SSIM:0.768

MS-Wiener
PSNR:22.90dB, SSIM:0.849

BilateralFiltering
PSNR:19.72dB, SSIM:0.732

MS-BilateralFiltering
PSNR:23.02dB, SSIM:0.846

BM3D
PSNR:25.04dB, SSIM:0.911

MS-BM3D
PSNR:24.60dB, SSIM:0.899

BLS-GSM
PSNR:23.93dB, SSIM:0.880

MS-BLS-GSM
PSNR:23.93dB, SSIM:0.880

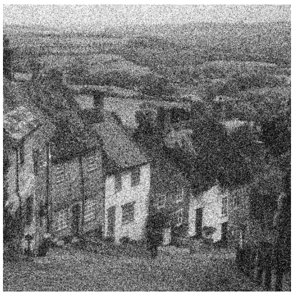
TV
PSNR:22.10dB, SSIM:0.833

MS-TV
PSNR:22.40dB, SSIM:0.851

Stochastic
PSNR:20.97dB, SSIM:0.784

MS-Stochastic
PSNR:20.97dB, SSIM:0.784

Image "Hill" with $\sigma = 50$



noisy
PSNR:14.67dB, SSIM:0.388

ground truth

KSVD
PSNR:26.22dB, SSIM:0.740

MS-KSVD
PSNR:26.76dB, SSIM:0.769

FoE
PSNR:26.07dB, SSIM:0.745

MS-FoE
PSNR:26.54dB, SSIM:0.772

BRFoE
PSNR:22.36dB, SSIM:0.601

MS-BRFoE
PSNR:25.42dB, SSIM:0.728

Wiener
PSNR:21.61dB, SSIM:0.564

MS-Wiener
PSNR:25.77dB, SSIM:0.729

BilateralFiltering
PSNR:25.46dB, SSIM:0.723

MS-BilateralFiltering
PSNR:25.80dB, SSIM:0.722

BM3D
PSNR:27.05dB, SSIM:0.787

MS-BM3D
PSNR:27.18dB, SSIM:0.795

BLS-GSM
PSNR:26.65dB, SSIM:0.762

MS-BLS-GSM
PSNR:26.65dB, SSIM:0.762

TV
PSNR:25.83dB, SSIM:0.703

MS-TV
PSNR:25.86dB, SSIM:0.709

Stochastic
PSNR:25.38dB, SSIM:0.699

MS-Stochastic
PSNR:25.38dB, SSIM:0.699

Image “House” with $\sigma = 50$

noisy
PSNR:14.56dB, SSIM:0.125

ground truth

KSVD
PSNR:27.52dB, SSIM:0.733

MS-KSVD
PSNR:28.78dB, SSIM:0.781

FoE
PSNR:27.29dB, SSIM:0.774

MS-FoE
PSNR:27.72dB, SSIM:0.763

BRFoE
PSNR:21.43dB, SSIM:0.418

MS-BRFoE
PSNR:25.23dB, SSIM:0.632

Wiener
PSNR:21.47dB, SSIM:0.332

MS-Wiener
PSNR:26.55dB, SSIM:0.722

BilateralFiltering
PSNR:25.05dB, SSIM:0.599

MS-BilateralFiltering
PSNR:26.95dB, SSIM:0.720

BM3D
PSNR:29.61dB, SSIM:0.806

MS-BM3D
PSNR:29.61dB, SSIM:0.804

BLS-GSM
PSNR:28.35dB, SSIM:0.759

MS-BLS-GSM
PSNR:28.35dB, SSIM:0.759

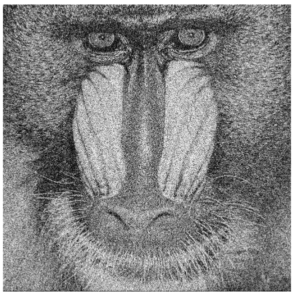
TV
PSNR:27.46dB, SSIM:0.784

MS-TV
PSNR:27.39dB, SSIM:0.783

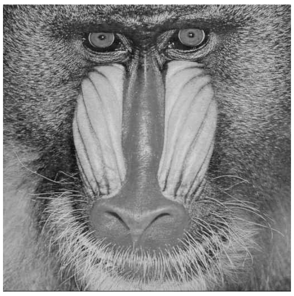
Stochastic
PSNR:25.45dB, SSIM:0.557

MS-Stochastic
PSNR:25.45dB, SSIM:0.557

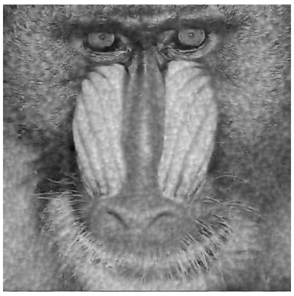
Image "Baboon" with $\sigma = 50$



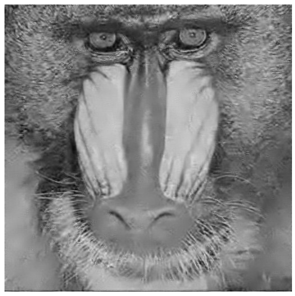
noisy
PSNR:14.55dB, SSIM:0.513



ground truth

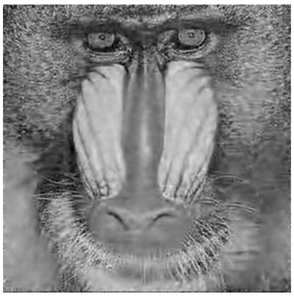


KSVD
PSNR:22.10dB, SSIM:0.669

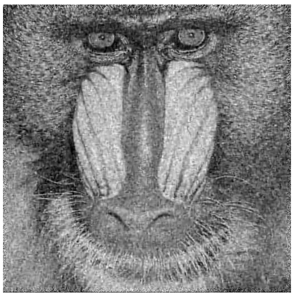


MS-KSVD
PSNR:22.39dB, SSIM:0.701

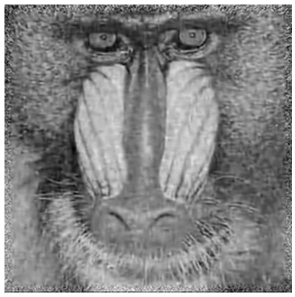
FoE
PSNR:21.76dB, SSIM:0.655



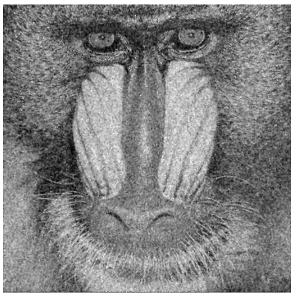
MS-FoE
PSNR:21.77dB, SSIM:0.705



BRFoE
PSNR:20.72dB, SSIM:0.663

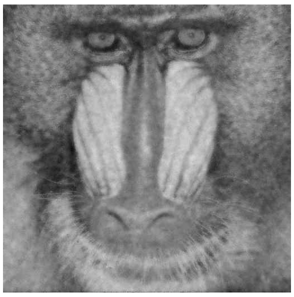


MS-BRFoE
PSNR:21.23dB, SSIM:0.657



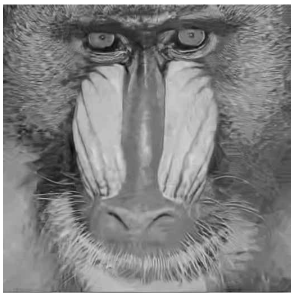
Wiener
PSNR:20.18dB, SSIM:0.640

MS-Wiener
PSNR:21.42dB, SSIM:0.660

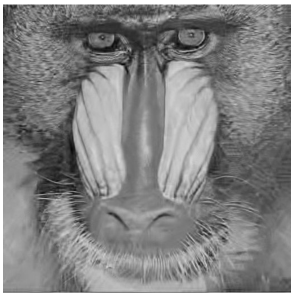


BilateralFiltering
PSNR:21.39dB, SSIM:0.613

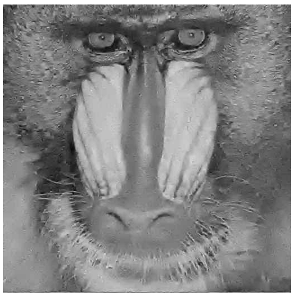
MS-BilateralFiltering
PSNR:21.55dB, SSIM:0.657



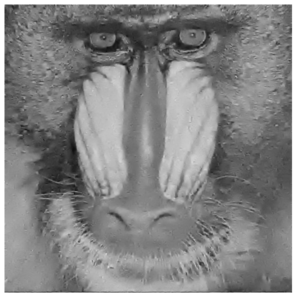
BM3D
PSNR:22.56dB, SSIM:0.713



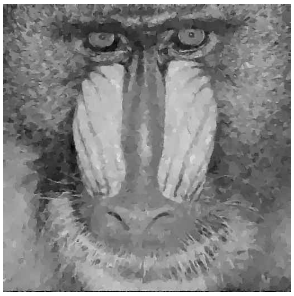
MS-BM3D
PSNR:22.57dB, SSIM:0.723



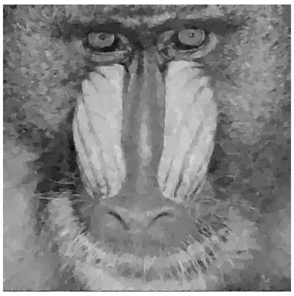
BLS-GSM
PSNR:22.21dB, SSIM:0.680



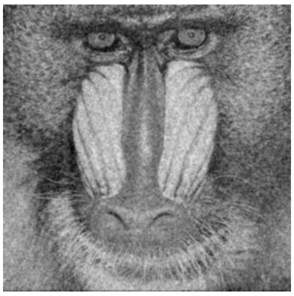
MS-BLS-GSM
PSNR:22.21dB, SSIM:0.680



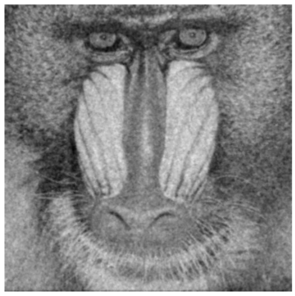
TV
PSNR:21.60dB, SSIM:0.638



MS-TV
PSNR:21.60dB, SSIM:0.628



Stochastic
PSNR:21.31dB, SSIM:0.658



MS-Stochastic
PSNR:21.31dB, SSIM:0.658

Image “F16” with $\sigma = 50$

noisy
PSNR:15.09dB, SSIM:0.335

ground truth

KSVD
PSNR:27.04dB, SSIM:0.791

MS-KSVD
PSNR:27.91dB, SSIM:0.870

FoE
PSNR:27.17dB, SSIM:0.858

MS-FoE
PSNR:27.20dB, SSIM:0.856

BRFoE
PSNR:22.43dB, SSIM:0.519

MS-BRFoE
PSNR:25.58dB, SSIM:0.719

Wiener
PSNR:21.75dB, SSIM:0.489

MS-Wiener
PSNR:26.36dB, SSIM:0.807

BilateralFiltering
PSNR:24.98dB, SSIM:0.753

MS-BilateralFiltering
PSNR:26.64dB, SSIM:0.828

BM3D
PSNR:28.49dB, SSIM:0.876

MS-BM3D
PSNR:28.40dB, SSIM:0.871

BLS-GSM
PSNR:27.76dB, SSIM:0.845

MS-BLS-GSM
PSNR:27.76dB, SSIM:0.845

TV
PSNR:26.42dB, SSIM:0.836

MS-TV
PSNR:26.71dB, SSIM:0.847

Stochastic
PSNR:25.21dB, SSIM:0.654

MS-Stochastic
PSNR:25.21dB, SSIM:0.654

Image "Lena" with $\sigma = 50$

noisy
PSNR:14.61dB, SSIM:0.354

ground truth

KSVD
PSNR:27.39dB, SSIM:0.784

MS-KSVD
PSNR:28.58dB, SSIM:0.864

FoE
PSNR:27.29dB, SSIM:0.832

MS-FoE
PSNR:27.96dB, SSIM:0.841

BRFoE
PSNR:22.32dB, SSIM:0.548

MS-BRFoE
PSNR:26.09dB, SSIM:0.737

Wiener
PSNR:21.76dB, SSIM:0.518

MS-Wiener
PSNR:27.13dB, SSIM:0.802

BilateralFiltering
PSNR:25.88dB, SSIM:0.766

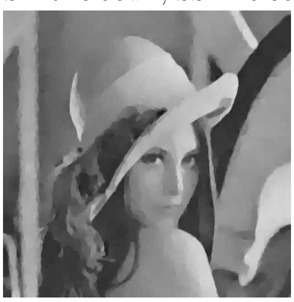
MS-BilateralFiltering
PSNR:27.08dB, SSIM:0.796

BM3D
PSNR:28.98dB, SSIM:0.865

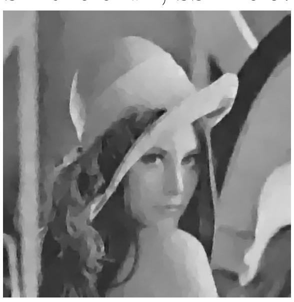
MS-BM3D
PSNR:29.04dB, SSIM:0.870

BLS-GSM
PSNR:28.17dB, SSIM:0.842

MS-BLS-GSM
PSNR:28.17dB, SSIM:0.842



TV
PSNR:26.81dB, SSIM:0.807



MS-TV
PSNR:27.05dB, SSIM:0.816

Stochastic
PSNR:25.89dB, SSIM:0.681

MS-Stochastic
PSNR:25.89dB, SSIM:0.681

Image “Man” with $\sigma = 50$


noisy
PSNR:14.66dB, SSIM:0.404


ground truth


KSVD
PSNR:25.85dB, SSIM:0.747


MS-KSVD
PSNR:26.36dB, SSIM:0.786


FoE
PSNR:25.54dB, SSIM:0.753


MS-FoE
PSNR:26.03dB, SSIM:0.778


BRFoE
PSNR:22.07dB, SSIM:0.604


MS-BRFoE
PSNR:25.00dB, SSIM:0.734


Wiener
PSNR:21.55dB, SSIM:0.572


MS-Wiener
PSNR:25.49dB, SSIM:0.747


BilateralFiltering
PSNR:24.83dB, SSIM:0.728


MS-BilateralFiltering
PSNR:25.59dB, SSIM:0.744


BM3D
PSNR:26.76dB, SSIM:0.800


MS-BM3D
PSNR:26.73dB, SSIM:0.802


BLS-GSM
PSNR:26.34dB, SSIM:0.777


MS-BLS-GSM
PSNR:26.34dB, SSIM:0.777

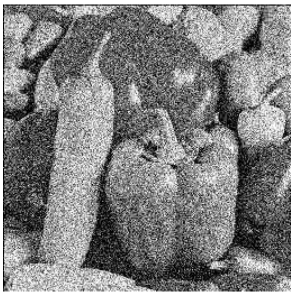

TV
PSNR:25.54dB, SSIM:0.730


MS-TV
PSNR:25.76dB, SSIM:0.745


Stochastic
PSNR:25.01dB, SSIM:0.700


MS-Stochastic
PSNR:25.01dB, SSIM:0.700

Image "Peppers" with $\sigma = 50$


noisy
PSNR:14.67dB, SSIM:0.167

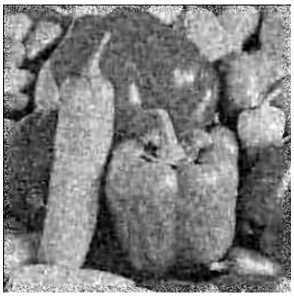

ground truth


KSVD
PSNR:25.98dB, SSIM:0.762


MS-KSVD
PSNR:26.12dB, SSIM:0.766


FoE
PSNR:25.41dB, SSIM:0.769


MS-FoE
PSNR:24.27dB, SSIM:0.743


BRFoE
PSNR:21.41dB, SSIM:0.506


MS-BRFoE
PSNR:23.42dB, SSIM:0.689


Wiener
PSNR:21.35dB, SSIM:0.420


MS-Wiener
PSNR:23.82dB, SSIM:0.716


BilateralFiltering
PSNR:22.95dB, SSIM:0.637


MS-BilateralFiltering
PSNR:24.12dB, SSIM:0.692


BM3D
PSNR:26.72dB, SSIM:0.794


MS-BM3D
PSNR:26.57dB, SSIM:0.786


BLS-GSM
PSNR:26.08dB, SSIM:0.760


MS-BLS-GSM
PSNR:26.08dB, SSIM:0.760


TV
PSNR:24.52dB, SSIM:0.747


MS-TV
PSNR:24.71dB, SSIM:0.753


Stochastic
PSNR:23.16dB, SSIM:0.625


MS-Stochastic
PSNR:23.16dB, SSIM:0.625

Image "Barbara" with $\sigma = 90$

noisy
PSNR:10.83dB, SSIM:0.242

ground truth

KSVD
PSNR:21.73dB, SSIM:0.609

MS-KSVD
PSNR:22.61dB, SSIM:0.701

FoE
PSNR:21.54dB, SSIM:0.668

MS-FoE
PSNR:22.07dB, SSIM:0.682

BRFoE
PSNR:17.42dB, SSIM:0.395

MS-BRFoE
PSNR:21.70dB, SSIM:0.639

Wiener
PSNR:16.81dB, SSIM:0.373

MS-Wiener
PSNR:21.90dB, SSIM:0.649

BilateralFiltering
PSNR:21.93dB, SSIM:0.632

MS-BilateralFiltering
PSNR:21.89dB, SSIM:0.635

BM3D
PSNR:24.17dB, SSIM:0.759

MS-BM3D
PSNR:24.24dB, SSIM:0.765

BLS-GSM
PSNR:22.42dB, SSIM:0.685

MS-BLS-GSM
PSNR:22.47dB, SSIM:0.687

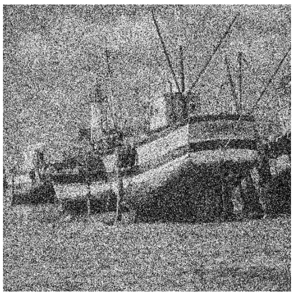
TV
PSNR:21.94dB, SSIM:0.664

MS-TV
PSNR:21.87dB, SSIM:0.658

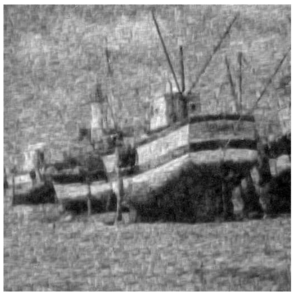
Stochastic
PSNR:20.46dB, SSIM:0.498

MS-Stochastic
PSNR:21.72dB, SSIM:0.611

Image "Boat" with $\sigma = 90$


noisy
PSNR:10.68dB, SSIM:0.226


ground truth


KSVD
PSNR:22.55dB, SSIM:0.571

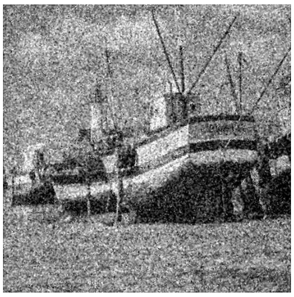

MS-KSVD
PSNR:24.18dB, SSIM:0.703


FoE
PSNR:22.67dB, SSIM:0.641


MS-FoE
PSNR:23.55dB, SSIM:0.691


BRFoE
PSNR:17.62dB, SSIM:0.393


MS-BRFoE
PSNR:22.53dB, SSIM:0.610


Wiener
PSNR:17.06dB, SSIM:0.366


MS-Wiener
PSNR:23.01dB, SSIM:0.638


BilateralFiltering
PSNR:22.82dB, SSIM:0.608


MS-BilateralFiltering
PSNR:23.20dB, SSIM:0.636


BM3D
PSNR:24.35dB, SSIM:0.710


MS-BM3D
PSNR:24.39dB, SSIM:0.718


BLS-GSM
PSNR:23.90dB, SSIM:0.670


MS-BLS-GSM
PSNR:23.97dB, SSIM:0.683


TV
PSNR:23.17dB, SSIM:0.640


MS-TV
PSNR:23.25dB, SSIM:0.645


Stochastic
PSNR:21.44dB, SSIM:0.502


MS-Stochastic
PSNR:22.67dB, SSIM:0.590

Image “Cameraman” with $\sigma = 90$

noisy
PSNR:10.88dB, SSIM:0.086

ground truth

KSVD
PSNR:21.95dB, SSIM:0.467

MS-KSVD
PSNR:22.65dB, SSIM:0.640

FoE
PSNR:21.62dB, SSIM:0.669

MS-FoE
PSNR:22.06dB, SSIM:0.637

BRFoE
PSNR:17.00dB, SSIM:0.285

MS-BRFoE
PSNR:20.31dB, SSIM:0.507

Wiener
PSNR:17.01dB, SSIM:0.225

MS-Wiener
PSNR:21.34dB, SSIM:0.599

BilateralFiltering
PSNR:20.82dB, SSIM:0.515

MS-BilateralFiltering
PSNR:22.07dB, SSIM:0.618

BM3D
PSNR:23.56dB, SSIM:0.700

MS-BM3D
PSNR:23.19dB, SSIM:0.691

BLS-GSM
PSNR:22.72dB, SSIM:0.603

MS-BLS-GSM
PSNR:22.71dB, SSIM:0.615

TV
PSNR:22.33dB, SSIM:0.687

MS-TV
PSNR:22.22dB, SSIM:0.683

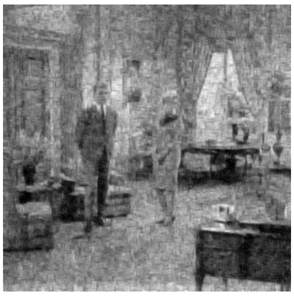
Stochastic
PSNR:20.41dB, SSIM:0.351

MS-Stochastic
PSNR:20.47dB, SSIM:0.519

Image “Couple” with $\sigma = 90$

noisy
PSNR:10.64dB, SSIM:0.233

ground truth



KSVD
PSNR:22.49dB, SSIM:0.590

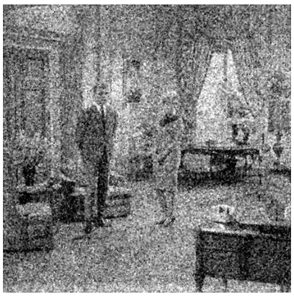
MS-KSVD
PSNR:23.74dB, SSIM:0.678

FoE
PSNR:22.45dB, SSIM:0.594

MS-FoE
PSNR:23.36dB, SSIM:0.675

BRFoE
PSNR:17.67dB, SSIM:0.412

MS-BRFoE
PSNR:22.43dB, SSIM:0.593



Wiener
PSNR:17.01dB, SSIM:0.379

MS-Wiener
PSNR:22.75dB, SSIM:0.603

BilateralFiltering
PSNR:22.77dB, SSIM:0.601

MS-BilateralFiltering
PSNR:22.92dB, SSIM:0.607

BM3D
PSNR:23.95dB, SSIM:0.688

MS-BM3D
PSNR:24.08dB, SSIM:0.706

BLS-GSM
PSNR:23.56dB, SSIM:0.646

MS-BLS-GSM
PSNR:23.66dB, SSIM:0.663

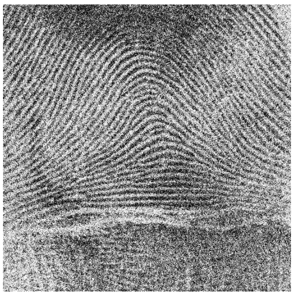
TV
PSNR:22.93dB, SSIM:0.602

MS-TV
PSNR:23.04dB, SSIM:0.613

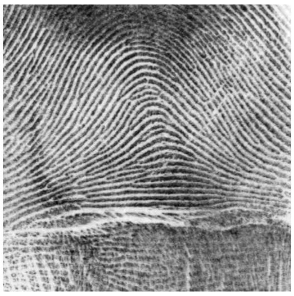
Stochastic
PSNR:21.43dB, SSIM:0.517

MS-Stochastic
PSNR:22.61dB, SSIM:0.579

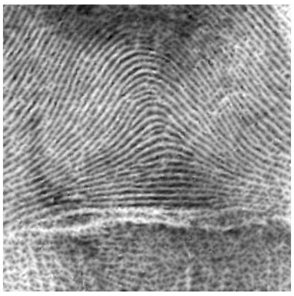
Image “Fingerprint” with $\sigma = 90$



noisy
PSNR:10.80dB, SSIM:0.546



ground truth



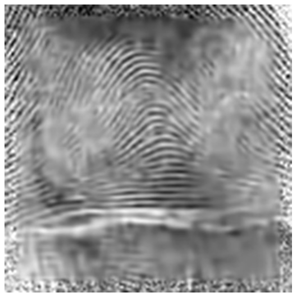
KSVD
PSNR:20.34dB, SSIM:0.742

MS-KSVD
PSNR:21.97dB, SSIM:0.812

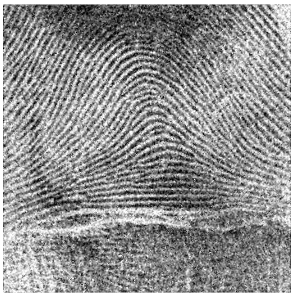
FoE
PSNR:18.36dB, SSIM:0.489

MS-FoE
PSNR:20.24dB, SSIM:0.791

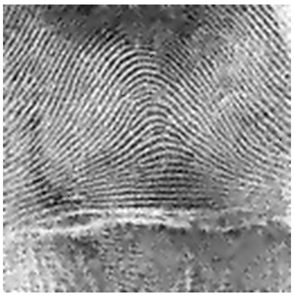
BRFoE
PSNR:17.68dB, SSIM:0.752



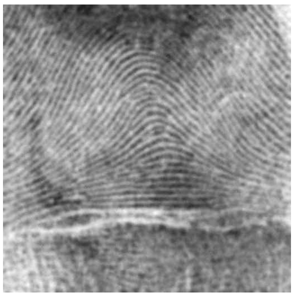
MS-BRFoE
PSNR:17.70dB, SSIM:0.401



Wiener
PSNR:16.96dB, SSIM:0.725



MS-Wiener
PSNR:20.62dB, SSIM:0.724



BilateralFiltering
PSNR:18.23dB, SSIM:0.510

MS-BilateralFiltering
PSNR:20.40dB, SSIM:0.710

BM3D
PSNR:22.08dB, SSIM:0.818

MS-BM3D
PSNR:22.09dB, SSIM:0.821

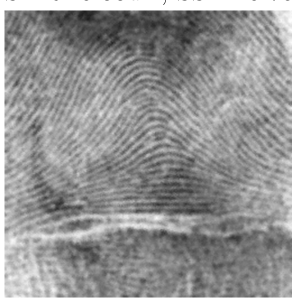
BLS-GSM
PSNR:20.34dB, SSIM:0.705

MS-BLS-GSM
PSNR:20.88dB, SSIM:0.758

TV
PSNR:18.55dB, SSIM:0.525

MS-TV
PSNR:19.25dB, SSIM:0.618

Stochastic
PSNR:20.38dB, SSIM:0.776



MS-Stochastic
PSNR:18.10dB, SSIM:0.491

Image “Flintstones” with $\sigma = 90$

noisy
PSNR:11.08dB, SSIM:0.456

ground truth

KSVD
PSNR:20.64dB, SSIM:0.745

MS-KSVD
PSNR:20.59dB, SSIM:0.743

FoE
PSNR:19.57dB, SSIM:0.703

MS-FoE
PSNR:20.31dB, SSIM:0.733

BRFoE
PSNR:17.82dB, SSIM:0.638

MS-BRFoE
PSNR:17.75dB, SSIM:0.572

Wiener
PSNR:17.05dB, SSIM:0.611

MS-Wiener
PSNR:19.08dB, SSIM:0.685

BilateralFiltering
PSNR:17.94dB, SSIM:0.598

MS-BilateralFiltering
PSNR:19.98dB, SSIM:0.712

BM3D
PSNR:21.78dB, SSIM:0.811

MS-BM3D
PSNR:21.00dB, SSIM:0.767

BLS-GSM
PSNR:20.71dB, SSIM:0.758

MS-BLS-GSM
PSNR:20.90dB, SSIM:0.775

TV
PSNR:19.50dB, SSIM:0.704

MS-TV
PSNR:19.82dB, SSIM:0.729

Stochastic
PSNR:19.41dB, SSIM:0.675

MS-Stochastic
PSNR:17.62dB, SSIM:0.571

Image “Hill” with $\sigma = 90$

noisy
PSNR:10.77dB, SSIM:0.191

ground truth

KSVD
PSNR:23.11dB, SSIM:0.589

MS-KSVD
PSNR:25.03dB, SSIM:0.673

FoE
PSNR:23.85dB, SSIM:0.616

MS-FoE
PSNR:24.64dB, SSIM:0.670

BRFoE
PSNR:18.04dB, SSIM:0.378

MS-BRFoE
PSNR:23.82dB, SSIM:0.611

Wiener
PSNR:17.22dB, SSIM:0.342

MS-Wiener
PSNR:24.12dB, SSIM:0.615

BilateralFiltering
PSNR:24.26dB, SSIM:0.628

MS-BilateralFiltering
PSNR:24.25dB, SSIM:0.617

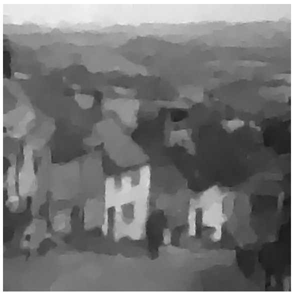
BM3D
PSNR:25.01dB, SSIM:0.674

MS-BM3D
PSNR:25.27dB, SSIM:0.695

BLS-GSM
PSNR:24.89dB, SSIM:0.655

MS-BLS-GSM
PSNR:24.89dB, SSIM:0.663

TV
PSNR:23.95dB, SSIM:0.589



MS-TV
PSNR:24.11dB, SSIM:0.600

Stochastic
PSNR:21.96dB, SSIM:0.505

MS-Stochastic
PSNR:24.18dB, SSIM:0.611

Image "House" with $\sigma = 90$

noisy
PSNR:10.74dB, SSIM:0.054

ground truth

KSVD
PSNR:23.20dB, SSIM:0.444

MS-KSVD
PSNR:25.99dB, SSIM:0.727

FoE
PSNR:23.40dB, SSIM:0.695

MS-FoE
PSNR:24.98dB, SSIM:0.707

BRFoE
PSNR:17.24dB, SSIM:0.253

MS-BRFoE
PSNR:23.16dB, SSIM:0.565

Wiener
PSNR:17.19dB, SSIM:0.192

MS-Wiener
PSNR:24.32dB, SSIM:0.679

BilateralFiltering
PSNR:23.63dB, SSIM:0.582

MS-BilateralFiltering
PSNR:24.75dB, SSIM:0.683

BM3D
PSNR:26.42dB, SSIM:0.746

MS-BM3D
PSNR:26.33dB, SSIM:0.742

BLS-GSM
PSNR:25.62dB, SSIM:0.715

MS-BLS-GSM
PSNR:25.76dB, SSIM:0.713

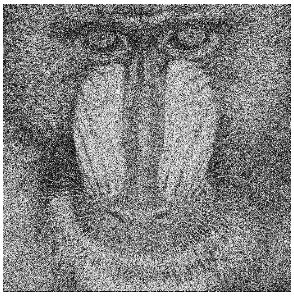
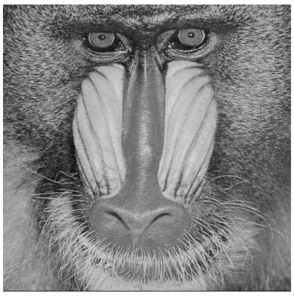
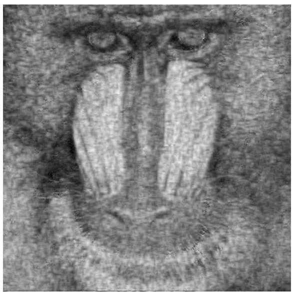
TV
PSNR:23.74dB, SSIM:0.712

MS-TV
PSNR:24.27dB, SSIM:0.724

Stochastic
PSNR:22.05dB, SSIM:0.376

MS-Stochastic
PSNR:23.52dB, SSIM:0.598

Image “Baboon” with $\sigma = 90$


noisy
PSNR:10.62dB, SSIM:0.274

ground truth

KSVD
PSNR:20.33dB, SSIM:0.521

MS-KSVD
PSNR:20.57dB, SSIM:0.520

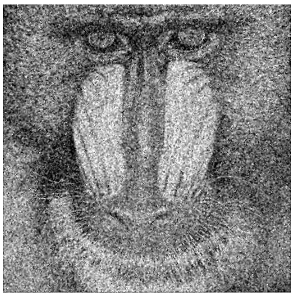



FoE
PSNR:19.97dB, SSIM:0.436

MS-FoE
PSNR:20.34dB, SSIM:0.517

BRFoE
PSNR:17.06dB, SSIM:0.437

MS-BRFoE
PSNR:19.85dB, SSIM:0.448

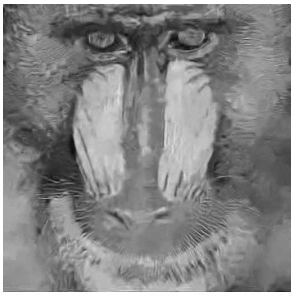



Wiener
PSNR:16.41dB, SSIM:0.413

MS-Wiener
PSNR:20.05dB, SSIM:0.462

BilateralFiltering
PSNR:20.34dB, SSIM:0.499

MS-BilateralFiltering
PSNR:20.19dB, SSIM:0.482




BM3D
PSNR:20.86dB, SSIM:0.542

MS-BM3D
PSNR:20.82dB, SSIM:0.525

BLS-GSM
PSNR:20.61dB, SSIM:0.513

MS-BLS-GSM
PSNR:20.60dB, SSIM:0.524




TV
PSNR:20.22dB, SSIM:0.472

MS-TV
PSNR:20.28dB, SSIM:0.465

Stochastic
PSNR:19.57dB, SSIM:0.502

MS-Stochastic
PSNR:20.06dB, SSIM:0.469

Image “F16” with $\sigma = 90$

noisy
PSNR:11.19dB, SSIM:0.187

ground truth

KSVD
PSNR:23.46dB, SSIM:0.559

MS-KSVD
PSNR:25.07dB, SSIM:0.791

FoE
PSNR:24.05dB, SSIM:0.769

MS-FoE
PSNR:24.75dB, SSIM:0.786

BRFoE
PSNR:17.96dB, SSIM:0.330

MS-BRFoE
PSNR:23.30dB, SSIM:0.667

Wiener
PSNR:17.41dB, SSIM:0.312

MS-Wiener
PSNR:24.01dB, SSIM:0.740

BilateralFiltering
PSNR:23.50dB, SSIM:0.635

MS-BilateralFiltering
PSNR:24.30dB, SSIM:0.735

BM3D
PSNR:25.76dB, SSIM:0.802

MS-BM3D
PSNR:25.64dB, SSIM:0.802

BLS-GSM
PSNR:25.00dB, SSIM:0.736

MS-BLS-GSM
PSNR:25.09dB, SSIM:0.754

TV
PSNR:24.07dB, SSIM:0.766

MS-TV
PSNR:24.32dB, SSIM:0.777

Stochastic
PSNR:21.77dB, SSIM:0.450

MS-Stochastic
PSNR:23.31dB, SSIM:0.623

Image "Lena" with $\sigma = 90$

noisy
PSNR:10.72dB, SSIM:0.190

ground truth

KSVD
PSNR:23.51dB, SSIM:0.597

MS-KSVD
PSNR:26.31dB, SSIM:0.789

FoE
PSNR:24.37dB, SSIM:0.749

MS-FoE
PSNR:25.40dB, SSIM:0.765

BRFoE
PSNR:17.94dB, SSIM:0.353

MS-BRFoE
PSNR:24.20dB, SSIM:0.682

Wiener
PSNR:17.21dB, SSIM:0.323

MS-Wiener
PSNR:24.96dB, SSIM:0.727

BilateralFiltering
PSNR:24.47dB, SSIM:0.665

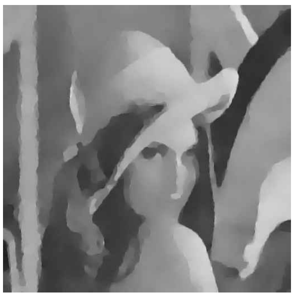
MS-BilateralFiltering
PSNR:25.02dB, SSIM:0.709

BM3D
PSNR:26.42dB, SSIM:0.786

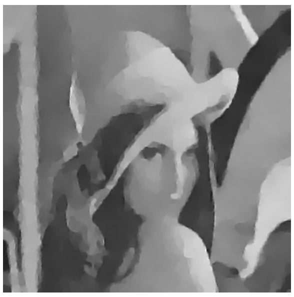
MS-BM3D
PSNR:26.51dB, SSIM:0.801

BLS-GSM
PSNR:25.88dB, SSIM:0.761

MS-BLS-GSM
PSNR:25.84dB, SSIM:0.754



TV
PSNR:24.58dB, SSIM:0.735



MS-TV
PSNR:24.98dB, SSIM:0.748

Stochastic
PSNR:22.18dB, SSIM:0.482

MS-Stochastic
PSNR:24.41dB, SSIM:0.653

Image "Man" with $\sigma = 90$

noisy
PSNR:10.74dB, SSIM:0.212

ground truth

KSVD
PSNR:22.70dB, SSIM:0.593

MS-KSVD
PSNR:24.31dB, SSIM:0.680

FoE
PSNR:22.99dB, SSIM:0.629

MS-FoE
PSNR:23.86dB, SSIM:0.673

BRFoE
PSNR:17.77dB, SSIM:0.391

MS-BRFoE
PSNR:23.08dB, SSIM:0.620

Wiener
PSNR:17.13dB, SSIM:0.361

MS-Wiener
PSNR:23.61dB, SSIM:0.639

BilateralFiltering
PSNR:23.52dB, SSIM:0.630

MS-BilateralFiltering
PSNR:23.74dB, SSIM:0.639

BM3D
PSNR:24.57dB, SSIM:0.693

MS-BM3D
PSNR:24.46dB, SSIM:0.692

BLS-GSM
PSNR:24.16dB, SSIM:0.661

MS-BLS-GSM
PSNR:24.26dB, SSIM:0.675

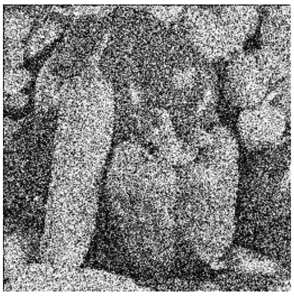
TV
PSNR:23.64dB, SSIM:0.632

MS-TV
PSNR:23.83dB, SSIM:0.645

Stochastic
PSNR:21.71dB, SSIM:0.512

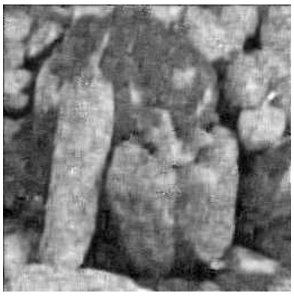
MS-Stochastic
PSNR:23.40dB, SSIM:0.613

Image “Peppers” with $\sigma = 90$



noisy
PSNR:10.75dB, SSIM:0.073

ground truth

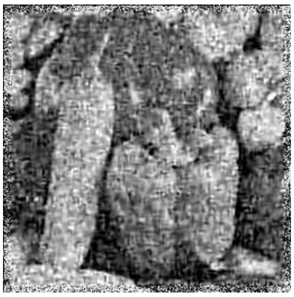


KSVD
PSNR:22.05dB, SSIM:0.497

MS-KSVD
PSNR:22.69dB, SSIM:0.683

FoE
PSNR:22.08dB, SSIM:0.677

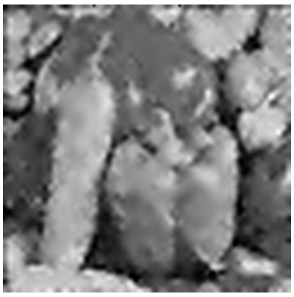
MS-FoE
PSNR:22.10dB, SSIM:0.654



BRFoE
PSNR:17.23dB, SSIM:0.323

MS-BRFoE
PSNR:21.28dB, SSIM:0.619

Wiener
PSNR:16.99dB, SSIM:0.250



MS-Wiener
PSNR:21.70dB, SSIM:0.648

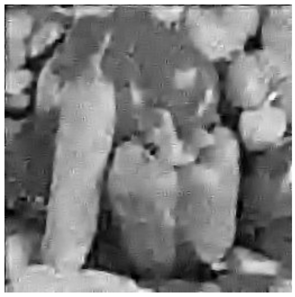
BilateralFiltering
PSNR:21.44dB, SSIM:0.604

MS-BilateralFiltering
PSNR:21.90dB, SSIM:0.639

BM3D
PSNR:23.94dB, SSIM:0.707

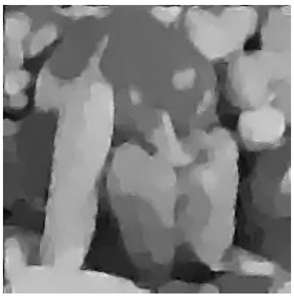
MS-BM3D
PSNR:23.48dB, SSIM:0.686

BLS-GSM
PSNR:23.12dB, SSIM:0.637



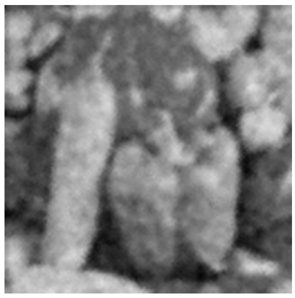
MS-BLS-GSM
PSNR:23.14dB, SSIM:0.652

TV
PSNR:21.89dB, SSIM:0.676



MS-TV
PSNR:21.78dB, SSIM:0.671

Stochastic
PSNR:20.84dB, SSIM:0.448



MS-Stochastic
PSNR:21.03dB, SSIM:0.618

Image “Barbara” with $\sigma = 130$

noisy
PSNR:9.02dB, SSIM:0.146

ground truth

KSVD
PSNR:19.66dB, SSIM:0.498

MS-KSVD
PSNR:21.65dB, SSIM:0.643

FoE
PSNR:20.21dB, SSIM:0.593

MS-FoE
PSNR:21.27dB, SSIM:0.631

BRFoE
PSNR:15.00dB, SSIM:0.278

MS-BRFoE
PSNR:20.67dB, SSIM:0.549

Wiener
PSNR:14.32dB, SSIM:0.261

MS-Wiener
PSNR:21.00dB, SSIM:0.591

BilateralFiltering
PSNR:20.99dB, SSIM:0.556

MS-BilateralFiltering
PSNR:21.03dB, SSIM:0.580

BM3D
PSNR:21.95dB, SSIM:0.653

MS-BM3D
PSNR:21.92dB, SSIM:0.664

BLS-GSM
PSNR:21.44dB, SSIM:0.612

MS-BLS-GSM
PSNR:21.52dB, SSIM:0.628

TV
PSNR:20.86dB, SSIM:0.592

MS-TV
PSNR:20.96dB, SSIM:0.596

Stochastic
PSNR:18.36dB, SSIM:0.380

MS-Stochastic
PSNR:20.81dB, SSIM:0.532

Image "Boat" with $\sigma = 130$

noisy
PSNR:8.96dB, SSIM:0.138

ground truth

KSVD
PSNR:20.31dB, SSIM:0.460

MS-KSVD
PSNR:22.71dB, SSIM:0.618

FoE
PSNR:20.94dB, SSIM:0.560

MS-FoE
PSNR:22.28dB, SSIM:0.610

BRFoE
PSNR:15.12dB, SSIM:0.278

MS-BRFoE
PSNR:21.26dB, SSIM:0.513

Wiener
PSNR:14.39dB, SSIM:0.254

MS-Wiener
PSNR:21.74dB, SSIM:0.557

BilateralFiltering
PSNR:21.80dB, SSIM:0.524

MS-BilateralFiltering
PSNR:22.02dB, SSIM:0.565

BM3D
PSNR:22.72dB, SSIM:0.620

MS-BM3D
PSNR:23.01dB, SSIM:0.645

BLS-GSM
PSNR:22.56dB, SSIM:0.587

MS-BLS-GSM
PSNR:22.67dB, SSIM:0.608

TV
PSNR:21.94dB, SSIM:0.572

MS-TV
PSNR:22.15dB, SSIM:0.586

Stochastic
PSNR:18.96dB, SSIM:0.376

MS-Stochastic
PSNR:21.63dB, SSIM:0.502

Image “Cameraman” with $\sigma = 130$


noisy
PSNR:9.02dB, SSIM:0.050


ground truth


KSVD
PSNR:19.49dB, SSIM:0.300


MS-KSVD
PSNR:21.31dB, SSIM:0.591


FoE
PSNR:19.11dB, SSIM:0.593


MS-FoE
PSNR:20.54dB, SSIM:0.584


BRFoE
PSNR:14.58dB, SSIM:0.201


MS-BRFoE
PSNR:18.67dB, SSIM:0.476


Wiener
PSNR:14.38dB, SSIM:0.158


MS-Wiener
PSNR:20.04dB, SSIM:0.552


BilateralFiltering
PSNR:19.95dB, SSIM:0.483


MS-BilateralFiltering
PSNR:20.78dB, SSIM:0.577


BM3D
PSNR:21.72dB, SSIM:0.630


MS-BM3D
PSNR:21.60dB, SSIM:0.646


BLS-GSM
PSNR:21.04dB, SSIM:0.508


MS-BLS-GSM
PSNR:21.16dB, SSIM:0.594


TV
PSNR:21.11dB, SSIM:0.647


MS-TV
PSNR:20.76dB, SSIM:0.623


Stochastic
PSNR:18.41dB, SSIM:0.259


MS-Stochastic
PSNR:19.83dB, SSIM:0.441

Image “Couple” with $\sigma = 130$

noisy
PSNR:8.94dB, SSIM:0.141

ground truth

KSVD
PSNR:20.05dB, SSIM:0.470

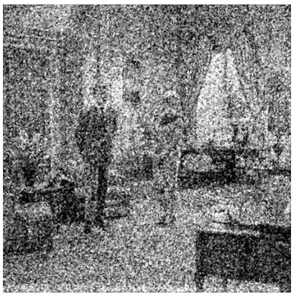
MS-KSVD
PSNR:22.48dB, SSIM:0.589

FoE
PSNR:20.66dB, SSIM:0.509

MS-FoE
PSNR:22.20dB, SSIM:0.578

BRFoE
PSNR:15.12dB, SSIM:0.293

MS-BRFoE
PSNR:21.07dB, SSIM:0.457



Wiener
PSNR:14.30dB, SSIM:0.265

MS-Wiener
PSNR:21.62dB, SSIM:0.516

BilateralFiltering
PSNR:21.79dB, SSIM:0.523

MS-BilateralFiltering
PSNR:21.86dB, SSIM:0.529

BM3D
PSNR:22.44dB, SSIM:0.598

MS-BM3D
PSNR:22.90dB, SSIM:0.636

BLS-GSM
PSNR:22.30dB, SSIM:0.560

MS-BLS-GSM
PSNR:22.47dB, SSIM:0.582

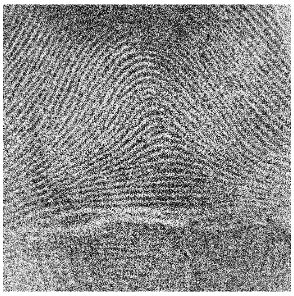
TV
PSNR:21.91dB, SSIM:0.543

MS-TV
PSNR:21.97dB, SSIM:0.548

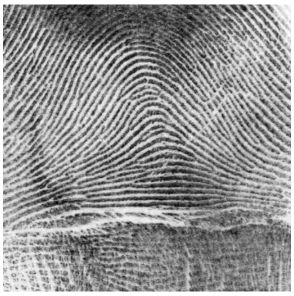
Stochastic
PSNR:18.91dB, SSIM:0.392

MS-Stochastic
PSNR:21.61dB, SSIM:0.502

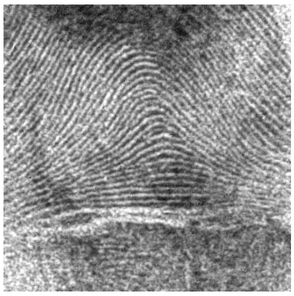
Image “Fingerprint” with $\sigma = 130$



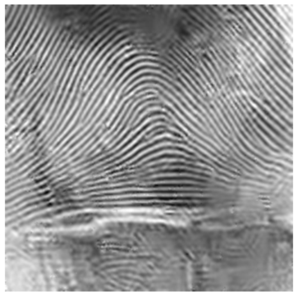
noisy
PSNR:9.02dB, SSIM:0.379



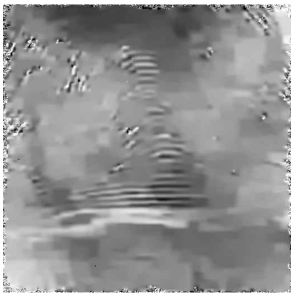
ground truth



KSVD
PSNR:18.61dB, SSIM:0.667



MS-KSVD
PSNR:20.48dB, SSIM:0.713



FoE
PSNR:16.33dB, SSIM:0.227

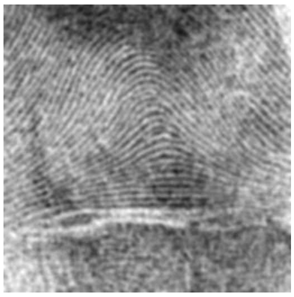
MS-FoE
PSNR:19.35dB, SSIM:0.699

BRFoE
PSNR:15.17dB, SSIM:0.624

MS-BRFoE
PSNR:15.95dB, SSIM:0.146

Wiener
PSNR:14.38dB, SSIM:0.591

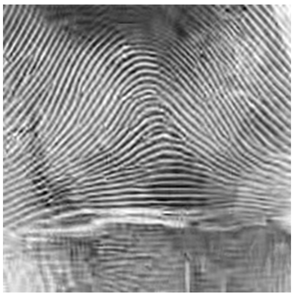
MS-Wiener
PSNR:17.51dB, SSIM:0.416



BilateralFiltering
PSNR:17.58dB, SSIM:0.443

MS-BilateralFiltering
PSNR:18.36dB, SSIM:0.511

BM3D
PSNR:20.20dB, SSIM:0.718



MS-BM3D
PSNR:20.85dB, SSIM:0.755

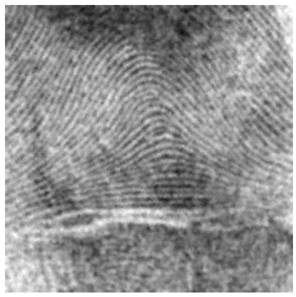
BLS-GSM
PSNR:18.65dB, SSIM:0.562

MS-BLS-GSM
PSNR:19.37dB, SSIM:0.636

TV
PSNR:17.19dB, SSIM:0.374

MS-TV
PSNR:18.11dB, SSIM:0.533

Stochastic
PSNR:18.29dB, SSIM:0.686



MS-Stochastic
PSNR:17.70dB, SSIM:0.469

Image “Flintstones” with $\sigma = 130$


noisy
PSNR:9.11dB, SSIM:0.333


ground truth


KSVD
PSNR:18.59dB, SSIM:0.627


MS-KSVD
PSNR:18.76dB, SSIM:0.639


FoE
PSNR:17.16dB, SSIM:0.537


MS-FoE
PSNR:18.11dB, SSIM:0.617


BRFoE
PSNR:15.40dB, SSIM:0.532


MS-BRFoE
PSNR:15.67dB, SSIM:0.347


Wiener
PSNR:14.64dB, SSIM:0.504


MS-Wiener
PSNR:17.44dB, SSIM:0.545


BilateralFiltering
PSNR:17.31dB, SSIM:0.536


MS-BilateralFiltering
PSNR:18.28dB, SSIM:0.602


BM3D
PSNR:19.69dB, SSIM:0.715


MS-BM3D
PSNR:19.24dB, SSIM:0.682


BLS-GSM
PSNR:18.95dB, SSIM:0.652


MS-BLS-GSM
PSNR:19.08dB, SSIM:0.674


TV
PSNR:18.02dB, SSIM:0.595


MS-TV
PSNR:18.31dB, SSIM:0.624


Stochastic
PSNR:17.89dB, SSIM:0.592


MS-Stochastic
PSNR:17.34dB, SSIM:0.535

Image "Hill" with $\sigma = 130$

noisy
PSNR:9.01dB, SSIM:0.109

ground truth

KSVD
PSNR:20.51dB, SSIM:0.465

MS-KSVD
PSNR:23.73dB, SSIM:0.588

FoE
PSNR:22.06dB, SSIM:0.534

MS-FoE
PSNR:23.63dB, SSIM:0.589

BRFoE
PSNR:15.28dB, SSIM:0.250

MS-BRFoE
PSNR:22.62dB, SSIM:0.490

Wiener
PSNR:14.48dB, SSIM:0.224

MS-Wiener
PSNR:23.12dB, SSIM:0.543

BilateralFiltering
PSNR:23.03dB, SSIM:0.546

MS-BilateralFiltering
PSNR:23.13dB, SSIM:0.544

BM3D
PSNR:23.49dB, SSIM:0.589

MS-BM3D
PSNR:24.12dB, SSIM:0.630

BLS-GSM
PSNR:23.62dB, SSIM:0.572

MS-BLS-GSM
PSNR:23.76dB, SSIM:0.586

TV
PSNR:23.02dB, SSIM:0.536

MS-TV
PSNR:23.11dB, SSIM:0.547

Stochastic
PSNR:19.21dB, SSIM:0.364

MS-Stochastic
PSNR:22.77dB, SSIM:0.521

Image "House" with $\sigma = 130$

noisy
PSNR:8.97dB, SSIM:0.028

ground truth

KSVD
PSNR:20.36dB, SSIM:0.270

MS-KSVD
PSNR:24.26dB, SSIM:0.684

FoE
PSNR:21.10dB, SSIM:0.648

MS-FoE
PSNR:23.45dB, SSIM:0.665

BRFoE
PSNR:14.70dB, SSIM:0.174

MS-BRFoE
PSNR:21.29dB, SSIM:0.554

Wiener
PSNR:14.43dB, SSIM:0.127

MS-Wiener
PSNR:22.40dB, SSIM:0.627

BilateralFiltering
PSNR:22.43dB, SSIM:0.571

MS-BilateralFiltering
PSNR:23.02dB, SSIM:0.646

BM3D
PSNR:24.42dB, SSIM:0.686

MS-BM3D
PSNR:24.94dB, SSIM:0.711

BLS-GSM
PSNR:23.94dB, SSIM:0.645

MS-BLS-GSM
PSNR:24.08dB, SSIM:0.677

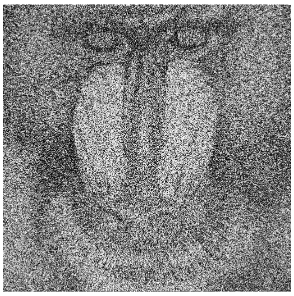
TV
PSNR:22.73dB, SSIM:0.692

MS-TV
PSNR:23.28dB, SSIM:0.696

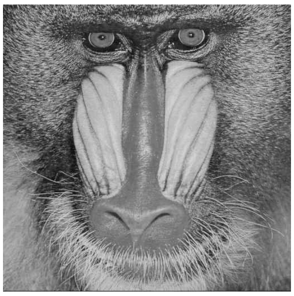
Stochastic
PSNR:19.24dB, SSIM:0.265

MS-Stochastic
PSNR:22.26dB, SSIM:0.522

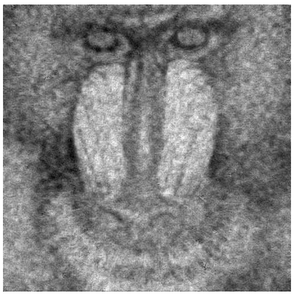
Image "Baboon" with $\sigma = 130$



noisy
PSNR:8.96dB, SSIM:0.164



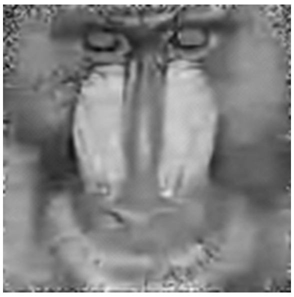
ground truth



KSVD
PSNR:18.73dB, SSIM:0.425

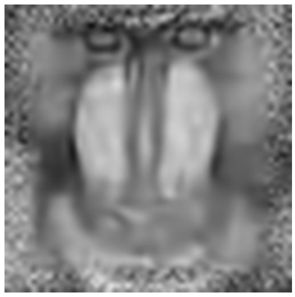
MS-KSVD
PSNR:19.90dB, SSIM:0.424

FoE
PSNR:18.98dB, SSIM:0.359

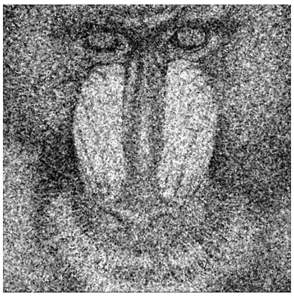


MS-FoE
PSNR:19.69dB, SSIM:0.403

BRFoE
PSNR:14.69dB, SSIM:0.302



MS-BRFoE
PSNR:19.30dB, SSIM:0.345



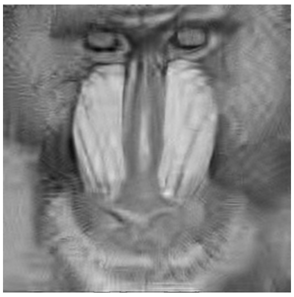
Wiener
PSNR:14.00dB, SSIM:0.284

MS-Wiener
PSNR:19.55dB, SSIM:0.384

BilateralFiltering
PSNR:19.62dB, SSIM:0.425

MS-BilateralFiltering
PSNR:19.65dB, SSIM:0.399

BM3D
PSNR:20.00dB, SSIM:0.453



MS-BM3D
PSNR:20.12dB, SSIM:0.453

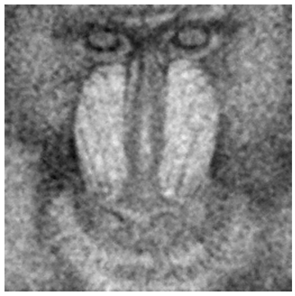
BLS-GSM
PSNR:19.92dB, SSIM:0.437

MS-BLS-GSM
PSNR:19.90dB, SSIM:0.429

TV
PSNR:19.64dB, SSIM:0.399

MS-TV
PSNR:19.71dB, SSIM:0.389

Stochastic
PSNR:17.76dB, SSIM:0.380



MS-Stochastic
PSNR:19.48dB, SSIM:0.413

Image “F16” with $\sigma = 130$

noisy
PSNR:9.32dB, SSIM:0.120

ground truth

KSVD
PSNR:21.14dB, SSIM:0.440

MS-KSVD
PSNR:23.79dB, SSIM:0.758

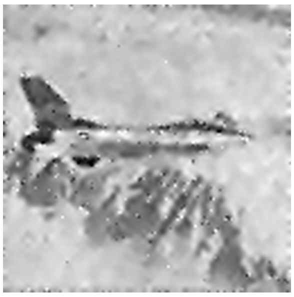
FoE
PSNR:22.11dB, SSIM:0.708

MS-FoE
PSNR:23.49dB, SSIM:0.752

BRFoE
PSNR:15.54dB, SSIM:0.245

MS-BRFoE
PSNR:21.83dB, SSIM:0.597

Wiener
PSNR:14.90dB, SSIM:0.229



MS-Wiener
PSNR:22.62dB, SSIM:0.686

BilateralFiltering
PSNR:22.59dB, SSIM:0.554

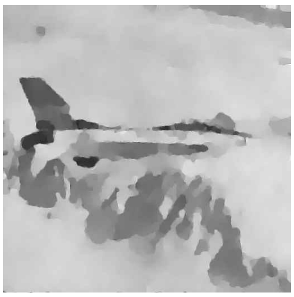
MS-BilateralFiltering
PSNR:23.13dB, SSIM:0.701

BM3D
PSNR:24.02dB, SSIM:0.741

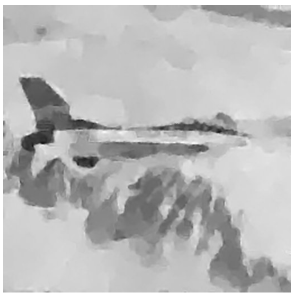
MS-BM3D
PSNR:24.25dB, SSIM:0.760

BLS-GSM
PSNR:23.69dB, SSIM:0.682

MS-BLS-GSM
PSNR:23.73dB, SSIM:0.723



TV
PSNR:22.95dB, SSIM:0.727



MS-TV
PSNR:23.12dB, SSIM:0.732

Stochastic
PSNR:19.31dB, SSIM:0.341

MS-Stochastic
PSNR:22.33dB, SSIM:0.522

Image “Lena” with $\sigma = 130$

noisy
PSNR:8.97dB, SSIM:0.117

ground truth

KSVD
PSNR:20.67dB, SSIM:0.478

MS-KSVD
PSNR:24.66dB, SSIM:0.738

FoE
PSNR:22.21dB, SSIM:0.686

MS-FoE
PSNR:23.96dB, SSIM:0.716

BRFoE
PSNR:15.30dB, SSIM:0.251

MS-BRFoE
PSNR:22.58dB, SSIM:0.599

Wiener
PSNR:14.49dB, SSIM:0.228

MS-Wiener
PSNR:23.43dB, SSIM:0.671

BilateralFiltering
PSNR:23.15dB, SSIM:0.580

MS-BilateralFiltering
PSNR:23.63dB, SSIM:0.656

BM3D
PSNR:24.36dB, SSIM:0.705

MS-BM3D
PSNR:25.07dB, SSIM:0.745

BLS-GSM
PSNR:24.26dB, SSIM:0.688

MS-BLS-GSM
PSNR:24.35dB, SSIM:0.708

TV
PSNR:23.48dB, SSIM:0.700

MS-TV
PSNR:23.76dB, SSIM:0.707

Stochastic
PSNR:19.33dB, SSIM:0.358

MS-Stochastic
PSNR:22.90dB, SSIM:0.549

Image “Man” with $\sigma = 130$

noisy
PSNR:9.00dB, SSIM:0.130

ground truth

KSVD
PSNR:20.31dB, SSIM:0.481

MS-KSVD
PSNR:23.15dB, SSIM:0.614

FoE
PSNR:21.27dB, SSIM:0.556

MS-FoE
PSNR:22.78dB, SSIM:0.602

BRFoE
PSNR:15.21dB, SSIM:0.275

MS-BRFoE
PSNR:21.77dB, SSIM:0.510

Wiener
PSNR:14.45dB, SSIM:0.251

MS-Wiener
PSNR:22.47dB, SSIM:0.569

BilateralFiltering
PSNR:22.51dB, SSIM:0.554

MS-BilateralFiltering
PSNR:22.61dB, SSIM:0.575

BM3D
PSNR:23.16dB, SSIM:0.620

MS-BM3D
PSNR:23.39dB, SSIM:0.630

BLS-GSM
PSNR:22.89dB, SSIM:0.585

MS-BLS-GSM
PSNR:23.13dB, SSIM:0.610

TV
PSNR:22.71dB, SSIM:0.585

MS-TV
PSNR:22.66dB, SSIM:0.587

Stochastic
PSNR:19.12dB, SSIM:0.385

MS-Stochastic
PSNR:22.29dB, SSIM:0.532

Image "Peppers" with $\sigma = 130$

noisy
PSNR:9.01dB, SSIM:0.039

ground truth

KSVD
PSNR:19.67dB, SSIM:0.332

MS-KSVD
PSNR:21.10dB, SSIM:0.627

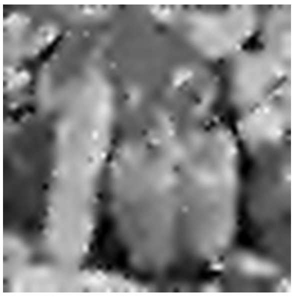
FoE
PSNR:19.54dB, SSIM:0.597

MS-FoE
PSNR:20.72dB, SSIM:0.612

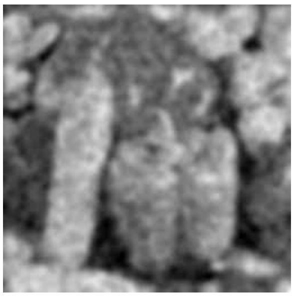
BRFoE
PSNR:14.82dB, SSIM:0.224

MS-BRFoE
PSNR:19.59dB, SSIM:0.550

Wiener
PSNR:14.53dB, SSIM:0.170



MS-Wiener
PSNR:20.34dB, SSIM:0.592



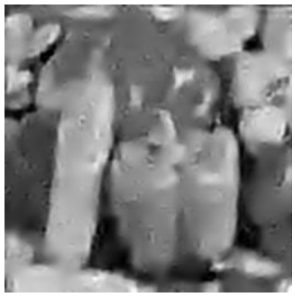
BilateralFiltering
PSNR:20.62dB, SSIM:0.587

MS-BilateralFiltering
PSNR:20.63dB, SSIM:0.595

BM3D
PSNR:21.84dB, SSIM:0.628

MS-BM3D
PSNR:21.41dB, SSIM:0.642

BLS-GSM
PSNR:21.39dB, SSIM:0.568

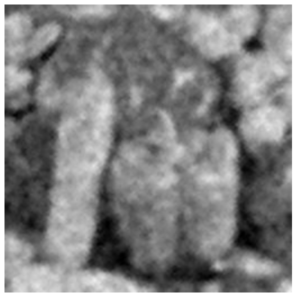


MS-BLS-GSM
PSNR:21.23dB, SSIM:0.633

TV
PSNR:19.85dB, SSIM:0.615

MS-TV
PSNR:20.22dB, SSIM:0.619

Stochastic
PSNR:18.70dB, SSIM:0.328



MS-Stochastic
PSNR:20.37dB, SSIM:0.547

References

[1] Estrada, F., Fleet, D., Jepson, A.: Stochastic image denoising. In: Proceedings of the British Machine Vision Conference (BMVC) (2009)

[2] Wang, Z., Bovik, A., Sheikh, H., Simoncelli, E.: Image quality assessment: From error visibility to structural similarity. IEEE Transactions on Image Processing 13(4), 600–612 (2004)