MULTIRESOLUTION BILATERAL FILTERING FOR IMAGE DENOISING

CONTENT

- Brief summarization of the paper key-findings.
- An introduction to the multiresolution bilateral filtering and its various methods that it consists of.
- Our implementation and comparison against different filters.
- Conclusion

PAPER STUDIED

- The paper studied was called: *Multiresolution Bilateral Filtering for Image Denoising*, by Ming Zhang and Bahadir K. Gunturk.
- The paper presented a non-linear signal filtering algorithm that is effective against removing low-resolution noise. It does this by using bilateral filtering in combination with wavelet-thresholding.
- The paper compared this method against white gaussian noise in comparison to other filtering methods. This filter was shown to be very effective according to this paper. [1]

PAPER PSNR COMPARISON

- The paper compared different filtering methods against white gaussian noise with different mean square error values.
- This was attempted with multiple images.
- Different filters gave the following PSNR-values: [1]

Results

TABLE I

PSNR COMPARISON OF THE BAYESSHRINK METHOD [3], THE BILATERAL FILTER [16], SEQUENTIAL APPLICATION OF THE BAYESSHRINK [3] AND THE BILATERAL FILTER [16] METHODS, NEW SURE THRESHOLDING [8], 3-D CF [14], AND THE PROPOSED METHOD FOR SIMULATED ADDITIVE WHITE GAUSSIAN NOISE OF VARIOUS STANDARD DEVIATIONS (THE NUMBERS WERE OBTAINED BY AVERAGING THE RESULTS OF SIX RUNS)

Input Image	σ_n	BayesShrink [3]	Bilateral Filter [16]	[3] Followed by [16]	New SURE [8]	3DCF [14]	Proposed Method
Barbara 512×512	10	31.25	31.37	30.92	32.18	34.98	31.79
	20	27.32	27.02	27.16	27.98	31.78	27.74
	30	25.34	24.69	25.23	25.83	29.81	25.61
Boats 512×512	10	31.98	32.02	31.81	32.90	33.92	32.58
	20	28.55	28.40	28.43	29.47	30.88	29.25
	30	26.71	26.57	26.66	27.63	29.12	27.24
Goldhill 512×512	10	31.94	32.08	31.93	32.69	33.62	32.48
	20	28.69	28.90	28.80	29.52	30.72	29.50
	30	27.13	27.50	27.34	27.89	29.16	27.77
Peppers 256×256	10	31.49	32.98	31.89	33.18	34.68	33.45
	20	27.85	29.07	28.01	29.33	31.29	30.20
	30	25.73	27.02	26.07	27.13	29.28	28.18
House 256×256	10	33.07	33.77	33.09	34.29	36.71	34.62
	20	29.83	29.63	29.79	30.93	33.77	31.37
	30	27.12	28.11	28.10	28.98	32.09	29.24
Lena 512×512	10	33.38	33.65	33.39	34.45	35.93	34.48
	20	30.27	30.33	30.29	31.33	33.05	31.28
	30	28.60	28.54	28.62	29.55	31.26	29.33
Average		29.24	29.54	29.31	30.29	32.34	30.34

BILATERAL FILTER 1

- A non-linear (algorithmic) filter that does spatial averaging without smoothing out the edges.
- Works in images by taking weighted sum of the pixels in a local neighborhood that depend both on the spatial and intensity distance. This method allows the filter to preserve edges of the image, while filtering out the noise.
- Is used in tone-mapping, volumetric denoising, image-enhancement, etc. [1]

BILATERAL FILTER 2

- **Bilateral filter output**: $\tilde{I}(x) = \frac{1}{C}\sum_{y \epsilon \mathcal{N}(x)} e^{\frac{-\|y-x\|^2}{2\sigma_d^2}} e^{\frac{-|I(y)-I(x)|^2}{2\sigma_r^2}} I(y)$
- $\mathcal{N}(x)$ = Spatial neighborhoods of x.
- $\boldsymbol{\sigma_d}$ and $\boldsymbol{\sigma_r}$ = Fall-off weights in spatial and intensity domains. Typically selected with trial-and-error, because there is no studied method for optimizing them. The paper, however observes that the optimal σ_r is linearly proportional to the standard deviation of the noise.
- **C** = Normalization constant = $\sum_{y \epsilon \mathcal{N}(x)} e^{\frac{-\|y-x\|^2}{2\sigma_d^2}} e^{\frac{-|I(y)-I(x)|^2}{2\sigma_r^2}}$ [1]

WAVELET-THRESHOLDING

- **Wavelet-thresholding**: A denoising method. Consists decomposing the signal into *approximation* (low-frequency) and *detail* (high-frequency) sub-bands. These sub-bands are a sparse representations for signals and images. In them, noise can be made more visible and can be more easily *shrunk* out.
- Thresholding strategies include *BayesShrink, VisuShrink,* and *SureShrink*. [1],[2]

MULTIRESOLUTION BILATERAL FILTER

- The filter uses wavelet transform on the image. The detail sub-bands are decomposed at two levels.
- Bilateral filter is applied to approximation sub-band.
- Wavelet thresholding is applied to detail sub-bands.
- The image is reconstructed with inverse wavelet transform. [1]

Scheme Picture

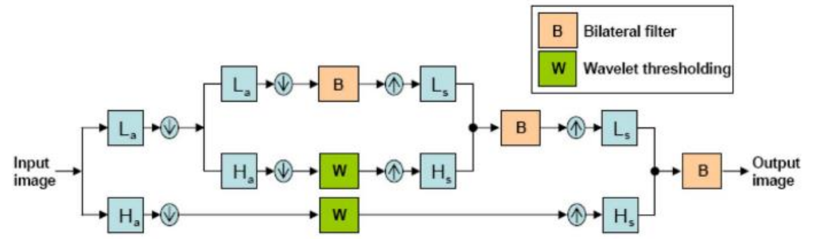

Fig. 5. Illustration of the proposed method. An input image is decomposed into its approximation and detail subbands through wavelet decomposition. As the image is reconstructed back, bilateral filtering is applied to the approximation subbands, and wavelet thresholding is applied to the detail subbands. The analysis and synthesis filters (L_a, H_a, L_s, and H_s) form a perfect reconstruction filter bank. The illustration shows one approximation subband and one detail subband at each decomposition level; this would be the case when the data is 1-D. For a 2-D data, there are, in fact, one approximation and three (horizontal, vertical, and diagonal) detail subbands at each decomposition level. Also, in the illustration, there are two levels of decomposition; the approximation subbands could be decomposed further in an application.

OUR IMPLEMENTATION

- We have our own implementation on this filter.
- Our implementation is made with Python using *OpenCV*, *Skimage*, and *Pywavelets* packages.
- We will be demoing this implementation against both white gaussian noise (like in the paper) and uniform noise using multiple images.
- Because we do not have the images, nor do we have the exact parameters used by the paper's study. This why, we will not be making the same comparisons as the paper.
- The paper's method used *BayesShrink method, our method uses VisuShrink* because it gives better results.

TAKE-AWAYS

- Multiresolution Bilateral Filter is a non-linear filter that is works well against low-resolution noise while preserving the image edges.
- It works by combining bilateral filtering and wavelet thresholding.

REFERENCES

- [1] M. Zhang, B. Z. Gunturk, Multiresolution Bilateral Filtering for Image Denoising, IEEE Transactions On Image Processing, 11.6 (2002): 670-684
- [2] MathWorks, Wavelet Denoising, 2023, Available at (Referenced in 12.04.2023)

Thank you! Questions?