Image Denoising: Review and Recent Breakthrough

C.-C. Jay Kuo
University of Southern California

Outline

- Image denoising overview
- Nonlocal Means Algorithm
- Experimental Results
- Conclusions and Future Works

Image Denoising

Noisy image

ANL Denoised image

Image Denoising Overview

Brief History of Image Denoising

1950s

- Television engineering
- Rely on autocovariance function for optimal signal representation and transmission

1960s

- First Digital Image

Have you ever see the first digital image?

First Digital Image

The first film photo registered by a computer and recreated in pixels—30,976 to be exact. (1957) (176 x 176)

“image of three-month-old baby”

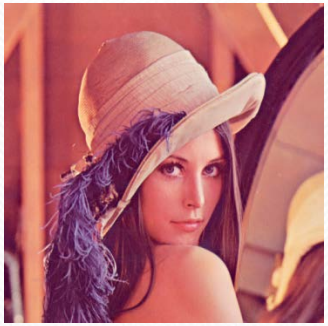
Brief History of Image Denoising

1970s

- USC
- Frequency domain techniques, direct inversion, or recursive Kalman filtering, etc

Lena Image

- Lena = Lena Söderberg
- Swedish model who posed nude for the November 1972 issue
- Signal and Image Processing Institute (SIPI)
- Reason:
  - Tired of usual test images
  - Good output dynamic range
  - Human face
- "Somebody happened have a recent issue of *Playboy*"



Brief History of Image Denoising

1980s

•J-S. LEE, "*Digital image enhancement and noise filtering by use of local statistics*," IEEE Transactions on Pattern Analysis and Machine Intelligence. Vol. PAMI-2, pp. 165-168. Mar. 1980 (Cited by 759)

1990s

- Wavelet transforms
- Wiener filter
- Total variation minimization

Brief History of Image Denoising

2003

- Gaussian scalar mixture (GSM) algorithm

2005

- Nonlocal mean (NLM) algorithm

Image Denoising Overview

- Summary
  - Classical problem in image/video processing
  - X = S+N
    - X = noisy signal
    - S = original signal
    - N = Noise
  - Nonlocal means (NL-means) algorithm
    - A. Buades, B. Coll., and J. Morel, "*A non local algorithm for image denoising*," in Proc. Int. Conf. Computer Vision and Pattern Recognition (CVPR), vol. 2, 2005, pp. 60–65.
    - Sep 2009 ➔ cited by 153

Basic Concept: Image Denoising

- $X_1 = S+N_1$
- $X_2 = S+N_2$
- .
- .
- $X_n = S+N_n$

- $(X_1+X_2+\ldots+X_n)/N = (S+S+\ldots+S)/N + (N_1+N_2+\ldots+N_n)/N$

$= S+(N_1+N_2+\ldots+N_n)/N$

N is AWGN ➔ $(N_1+N_2+\ldots+N_n)/N \sim 0$


1 Sample


10 Samples


100 Samples

Concept Evolution – Repeated Pattern

Repeated Pattern
"High correlation"

Concept Evolution – Self Similarity

Self-similarity
"High correlation"

Nonlocal Means Algorithm

- For given noisy image $f = \{ f(i) \mid i \in \Omega \}$, the NL-means denoised value $\hat{f}(i)$ at pixel i is obtained by a weighted average of all pixels in its neighborhood

$$\hat{f}(i) = \frac{1}{C(i)} \sum_{j \in \Omega_S} w(i, j) f(j)$$

$C(i) = \sum_{j \in \Omega_S} w(i, j)$ is a normalization constant

$w(i, j)$ is determined by the similarity of the Gaussian neighborhood between pixels i and j

$$w(i, j) = \exp\left(-\frac{\left\| N_i - N_j \right\|_{2,a}^2}{h^2}\right)$$

Denoising Benchmark

- Denoising algorithm
  - Mean filter (MF)
  - Gaussian filter (GF)
  - Partial differential equation (PDE)
  - Total variation minimization (TV)
  - Nonlocal-means (NL)
- Proposed technique
  - Adaptive nonlocal-means (ANL)

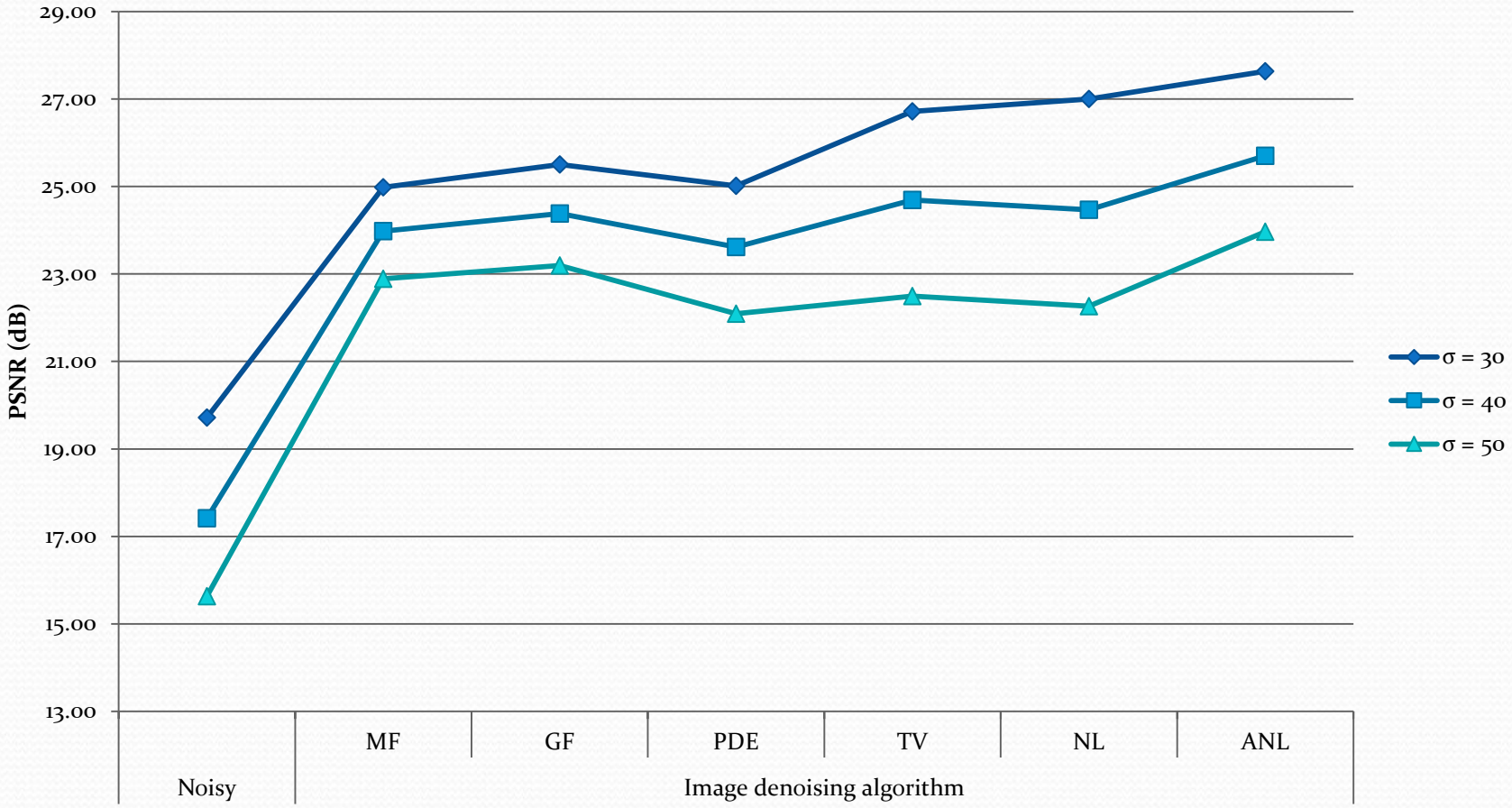
Experiment Setting

- Parameters
  - 7 representative test images
  - Additive white Gaussian noise (AWGN) with zero mean and standard deviation σ = 20, 30 and 40

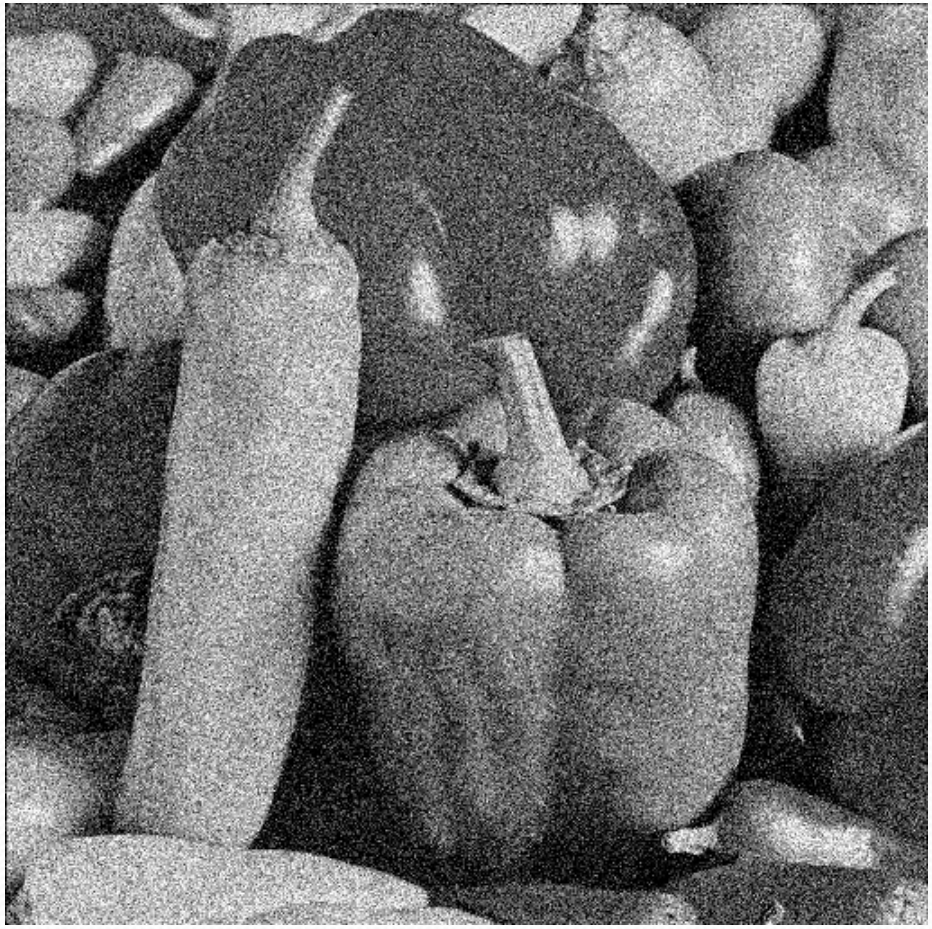
Experiment Results (NL vs. ANL)

Image	Average PSNR (dB)								
	Sigma = 20			Sigma = 30			Sigma = 40		
	NL	ANL	Δ	NL	ANL	Δ	NL	ANL	Δ
Lena	31.02	31.98	0.96	27.50	30.04	2.54	24.37	28.27	3.90
Zelda	31.85	32.83	0.98	28.18	30.72	2.55	25.06	28.76	3.70
Peppers	30.93	31.59	0.65	27.50	29.79	2.29	24.40	28.00	3.60
airplain	30.52	30.93	0.41	27.20	29.05	1.85	24.34	27.41	3.07
Barbara	29.85	30.30	0.45	26.65	28.41	1.76	23.89	26.74	2.85
Elaine	30.40	30.82	0.42	27.30	29.58	2.28	24.32	28.10	3.78
Girlface	31.75	32.29	0.54	28.12	29.98	1.86	25.06	27.92	2.86
Average	30.90	31.53	**0.63**	27.49	29.65	**2.16**	24.49	27.89	**3.39**

Experiment Results – Performance Comparison



Noisy Image – σ=40

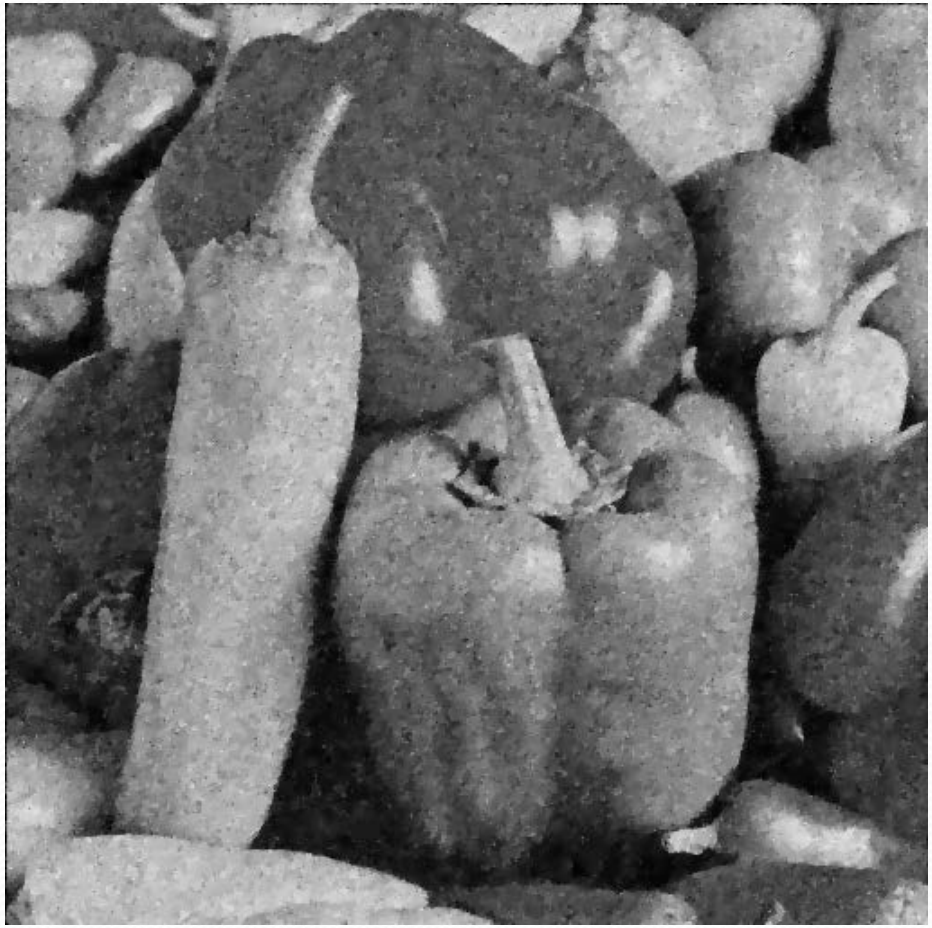


Mean Filter

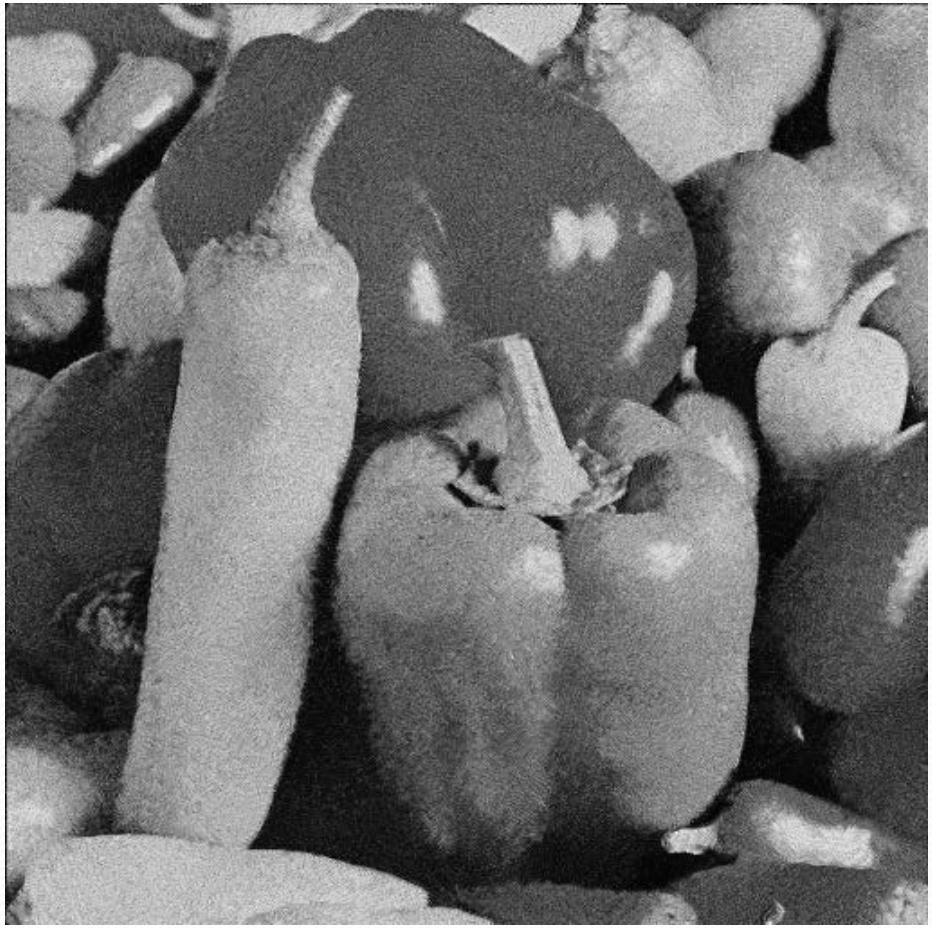
Gaussian Filter

Partial Differential Equation

Total Variation Minimization



Nonlocal Means



Adaptive Nonlocal Means

Other Example: Girlface

Noisy image (σ=40)

NL denoised image

ANL denoised image

Other Example: Zelda

Noisy image (σ=40)

NL denoised image

ANL denoised image

Thank you