Extension of Non-Local Means Algorithm with Gaussian Filtering for highly noisy images

Sachin Chachada[1], Byung Tae Oh[1], Namgook Cho[1], San A. Phong[2], Daniel Manchala[2] & C.-C. Jay Kuo[1]
[1]Signal and Image Processing Institute, USC
[2]Xerox Corporation

Motivation & Introduction

• **NLM estimate of pixel *i* from AWGN corrupted noisy image *X* is given by (Fig 1.)**

$$I_{NLM}(i) = \sum_{j\in\Omega_X} w(i,j)X(j) \quad \text{where} \quad w(i,k) = \exp\left(-\frac{\|X(n_i) - X(n_k)\|^2_{2,a}}{h^2}\right)$$

• **Consider weight estimation between two homogenous regions, it can be shown that**

$$\mathrm{Var}\left(\|X(n_i) - X(n_k)\|^2_{2,a}\right) = \mathrm{Var}\left(\|N(n_i) - N(n_k)\|^2_{2,a}\right) = 8\sigma^4$$

• **Ideally, for homogenous region, this Sum of Weighted Squared Difference (SWSD) should be zero. However for highly noisy images, weight estimation is not robust and is of the order of σ^4, where σ is the standard deviation of noise.**

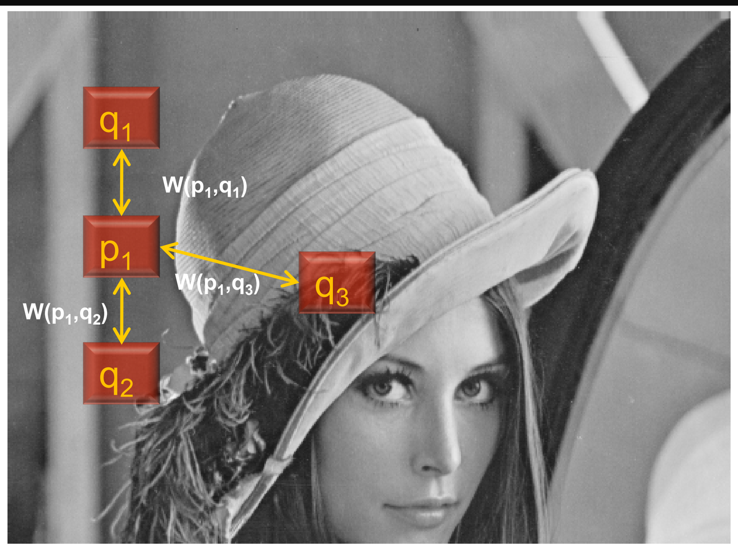

Fig 1. Since p_1 has a more similar neighborhood to q_1 and q_2 as compared to q_3, $W(p_1,q_1)$ and $W(p_2,q_2)$ will be (and should be) greater than $W(p_1,q_3)$

Proposed Algorithm

• **Pre-filter image with Gaussian filter G_b with filter parameter b** $X_g = X * G_b$

• **Weight estimation from Gaussian filtered image**

$$w_g(i,k) = \exp\left(-\frac{\|X_g(n_i) - X_g(n_k)\|^2_{2,a}}{h^2}\right)$$

• **Estimate denoised image using these weights**

$$I_{EWNLM}(i) = \sum_{j\in\Omega_X} w_g(i,j)X(j)$$

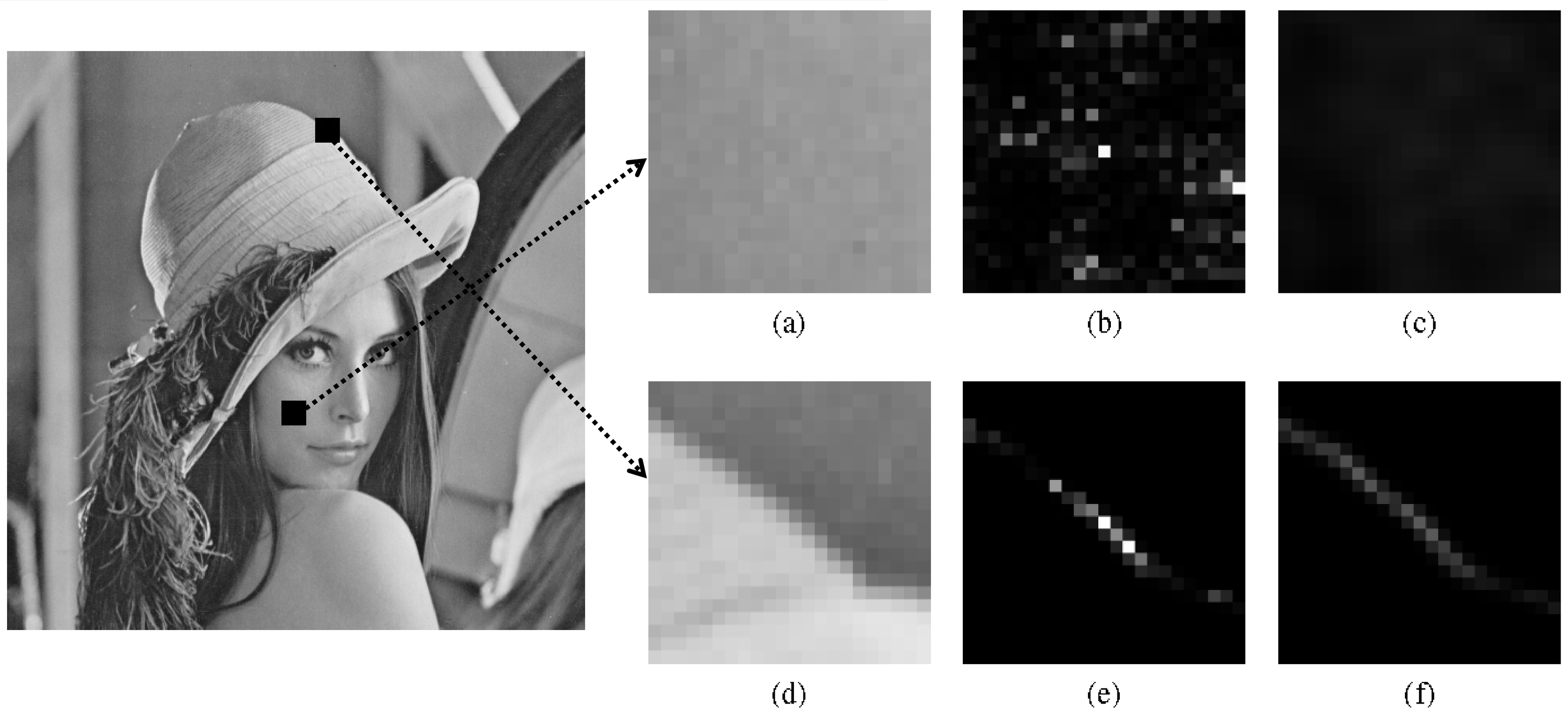

Fig 2. The original patches in the smooth and edged regions are shown in (a) and (d), the weight distributions for the central pixel denoising using the standard NLM are shown in (b) and (e), and the weight distributions for the central pixel denoising using the proposed EWNLM are shown in (c) and (f), respectively. It can be seen that (c) and (f) give more robust weight estimation. All images have been normalized on a common scale for comparative visualization.

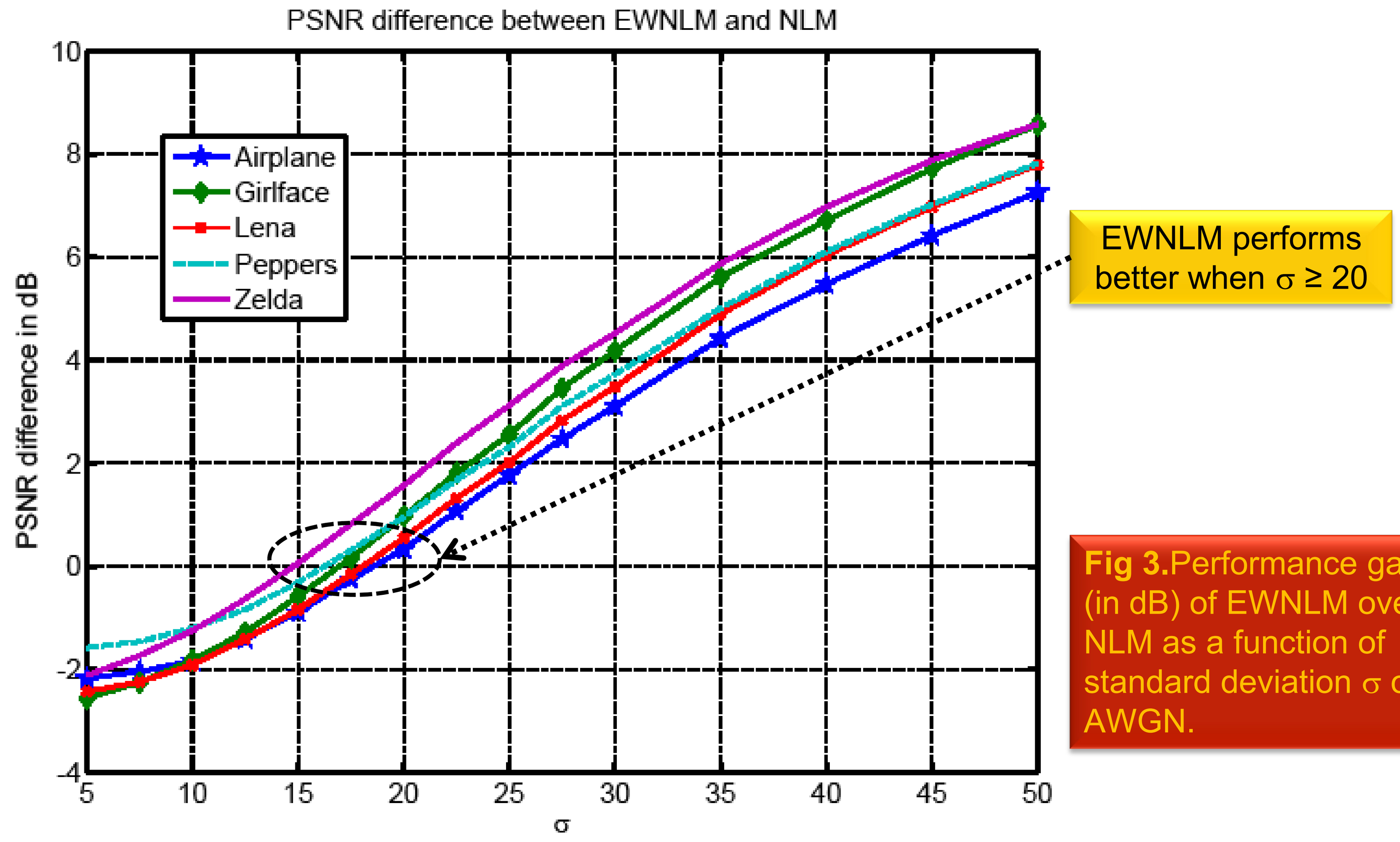

Fig 3. Performance gain (in dB) of EWNLM over NLM as a function of standard deviation σ of AWGN.

Discussion & Future Work

• Performance of NLM degrades for highly noisy images.
• Gaussian filter reduces the noise variance and thus the variance of SWSD term, thereby giving more robust weight estimation (Fig. 2).
• Performance of EWNLM is better when the standard deviation of noise is greater or equal to 20 (Fig. 3).
• EWNLM performs well on both edged and flat regions (Fig. 4).

Future Work:
• Understand why EWNLM fails for standard deviation less than 20.
• Adaptive EWNLM to improve results for smaller standard deviations.

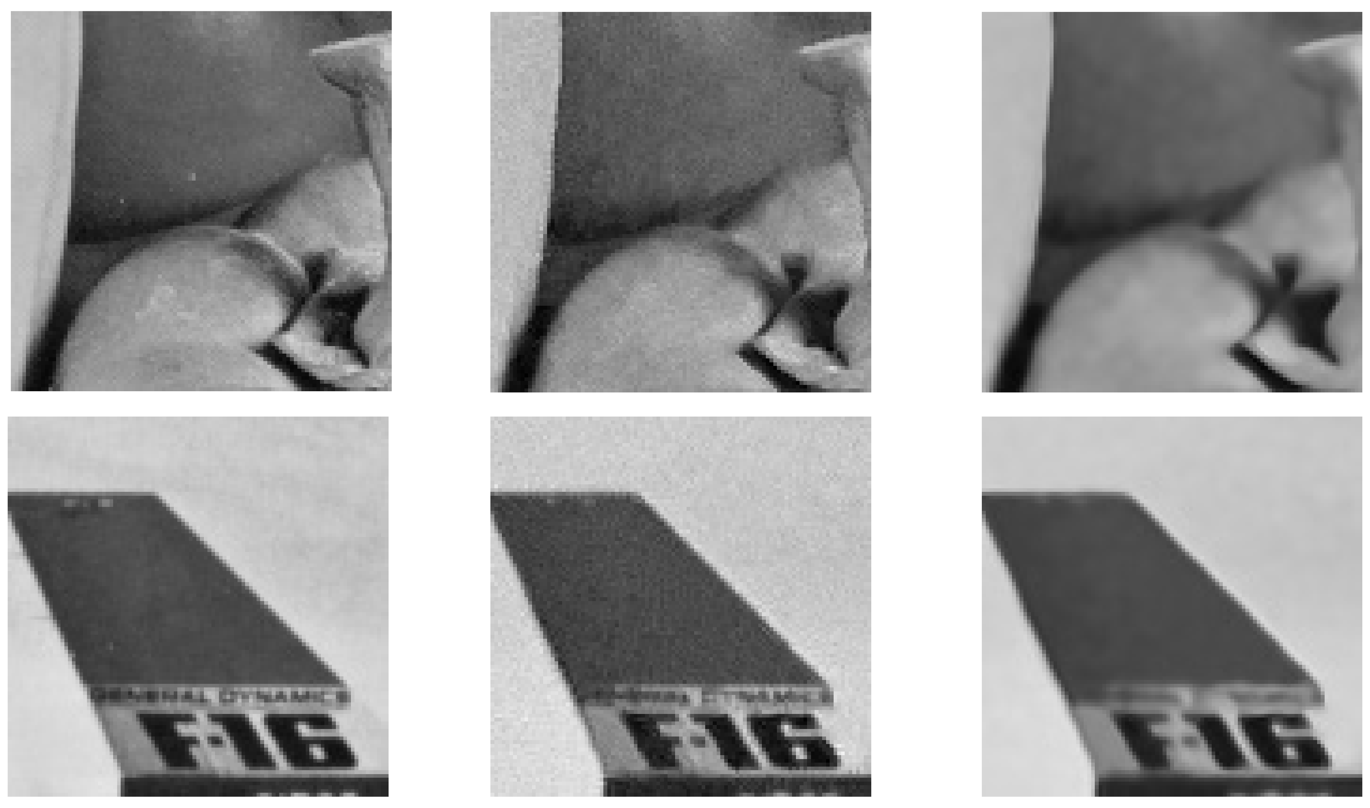

Fig 4. (Left) Original image, (Center) NLM filtered image, (Right) EWNLM filtered image Standard deviation of noise = 20.

Email: chachada@usc.edu

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Ming Hsieh Institute
Ming Hsieh Department of Electrical Engineering