Image Denoising for Signal-Dependent Noise

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Overview

- → Sensor noise characterization
- → Total least squares image model
- → Solutions to the TLS problem
- → Experimental results

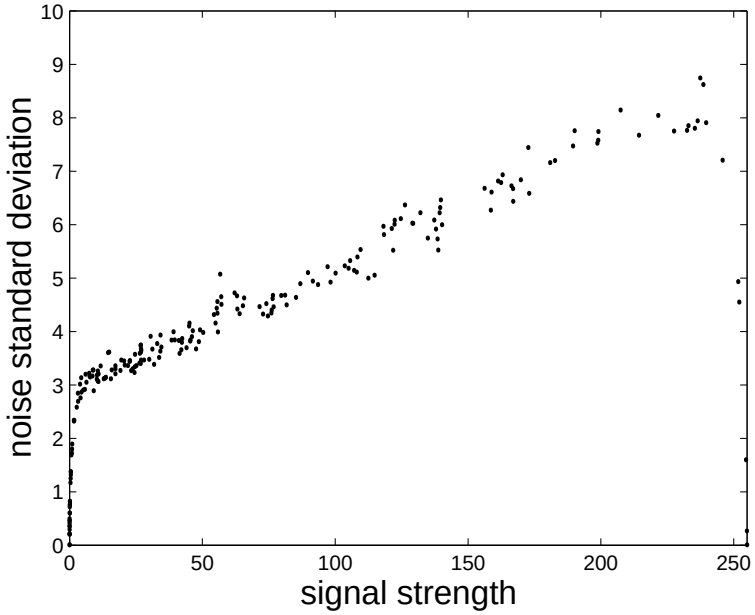
Sensor Noise in Digital Cameras

→ Images corrupted by device-specific noise in digital imaging devices.

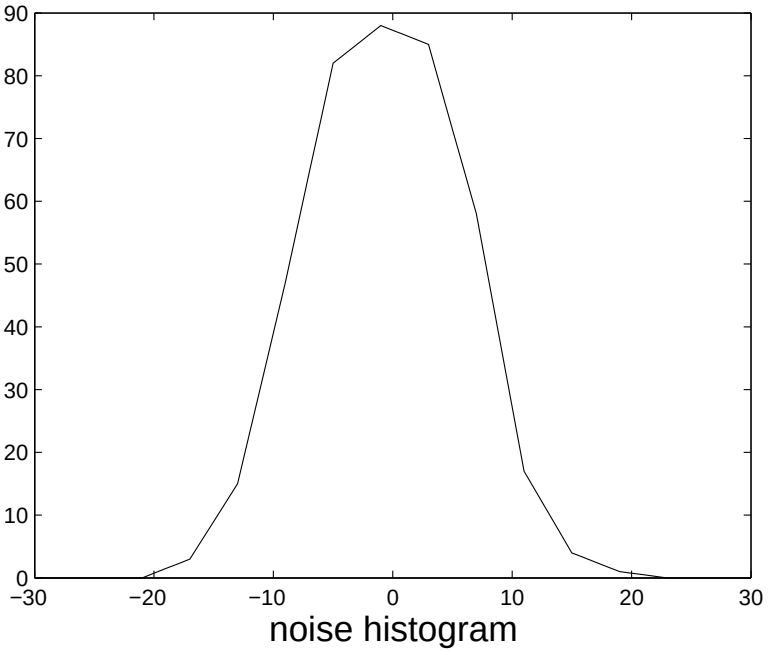
→ Noise is the biggest problem in digital camera today.



Camera Calibration Experiment: Agilent CMOS APS Image Sensor



Camera Calibration Experiment: Agilent CMOS APS Image Sensor

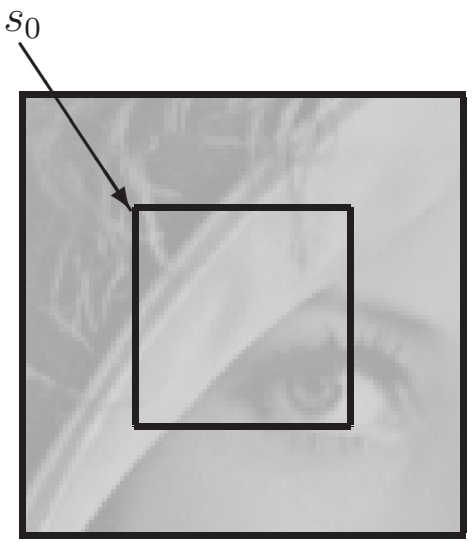


CMOS Image Sensor Noise Models

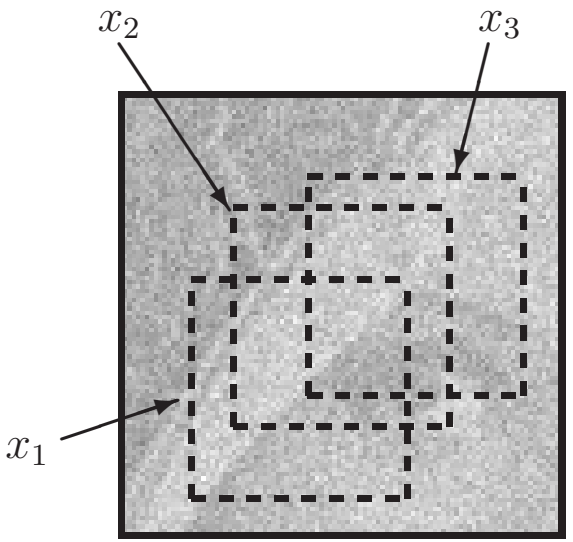
$$x = s + (k_0 + k_1 s)\delta$$

where $\delta \sim \mathcal{N}(0, 1)$.

Image model using patches



ideal image s



noisy image x

We would like: $\vec{s}_0 = [\vec{x}_1, \ldots, \vec{x}_n]\vec{\alpha} = X\vec{\alpha}$

But: $\vec{s}_0 \notin \mathtt{span}\{\vec{x}_i\}$

Allowing perturbation

→ Least Squares:

$$\vec{s}_0 + \vec{e}_0 = X\vec{\alpha}$$

→ Total Least Squares:

$$\vec{s}_0 + \vec{e}_0 = (X + E)\vec{\alpha}$$

Solution to TLS image model

→ Minimization problem

$$\min_{\vec{s}_0+\vec{e}_0=(X+E)\vec{\alpha}} \|[E, \vec{e}_0]\|_F^2$$

→ Solution to TLS $\left([X, \vec{s}_0] = U\Sigma V^T\right)$

$$\begin{bmatrix} \vec{\alpha}_{\text{TLS}} \\ 1 \end{bmatrix} = c \cdot \vec{v}_{n+1}$$

→ But we don't know $\vec{s}_0$...

Working around $\vec{s}_0$

→ We need $\vec{v}_{n+1}$!!!

→ Singular value decomposition

$$P = [X, \vec{s}_0]^T [X, \vec{s}_0] = (U\Sigma V^T)^T (U\Sigma V^T) = V\Sigma^2 V^T$$

Our Strategy...

estimate	eigen vector	compute	estimate $\vec{s}_0$
P	$P = V\Sigma^2 V^T$	$\vec{\alpha}$ from $\vec{v}_{n+1}$	$\hat{s}_0 = X\vec{\alpha}$

Estimating P matrix

$\rightarrow P \approx \mathcal{E}\{P\}$

$\rightarrow$ See paper for more details...

proposed algorithm

noisy $(k_0, k_1) = (25, 0)$



proposed algorithm

Portilla (method in [1])



[1] J. Portilla, V. Strela, M. J. Wainwright, E. P. Simoncelli, “Image Denoising Using Scale Mixture of Gaussians in the Wavelet Domain,” *IEEE Trans. Image Processing*, vol. 12, 2003.

proposed algorithm

Pizurica (method in [2])



[2] A. Pizurica, W. Philips, I. Lemahieu, M. Acheroy, “A joint inter- and intrascale statistical model for Bayesian wavelet based image denoising,” *IEEE Trans. Image Processing*, 2002.

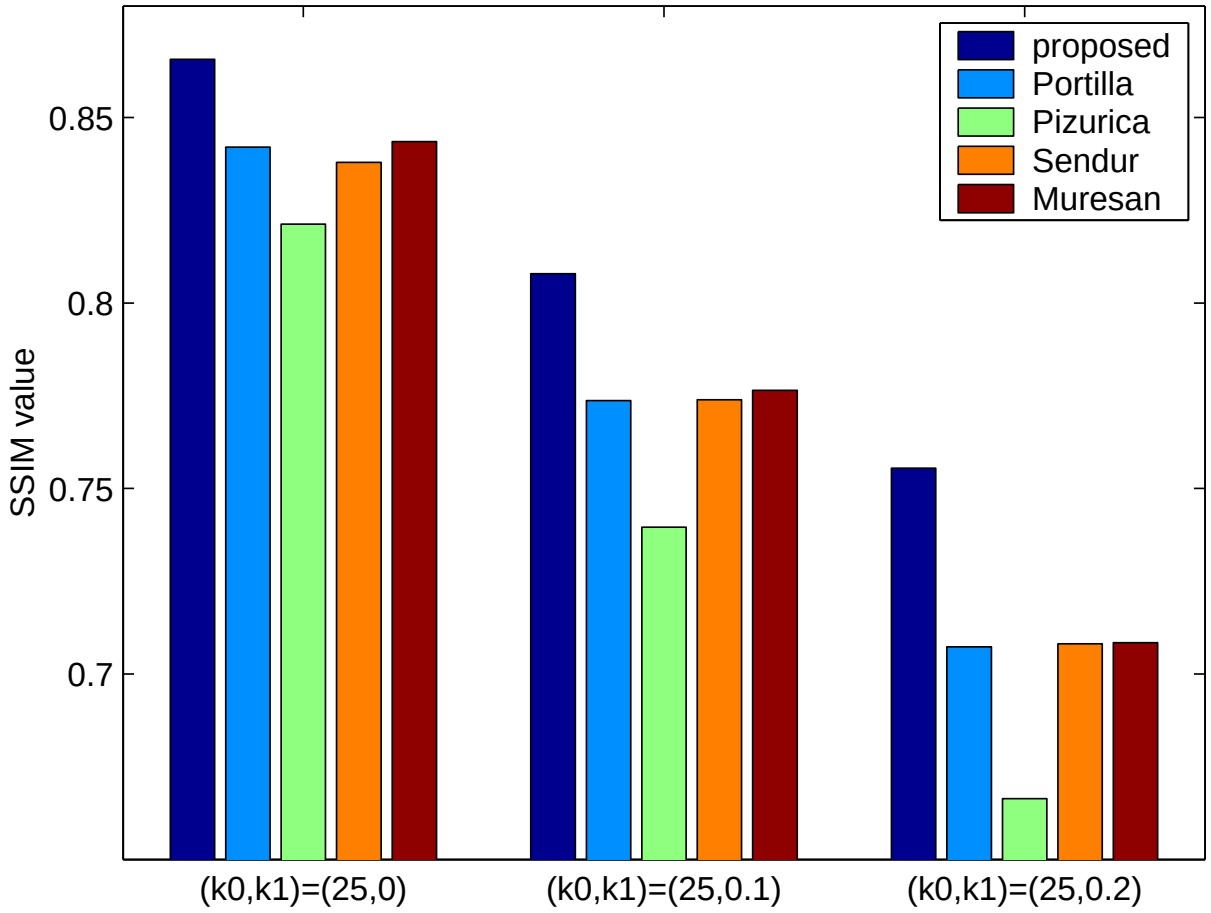
proposed algorithm

Sendur (method in [3])



[3] L. Sendur, I. W. Selesnick, “Bivariate shrinkage functions for wavelet-based denoising exploiting interscale dependency,” *IEEE Trans. Signal Processing*, vol. 50, 2002.

Performance for *Barbara* image evaluated using SSIM

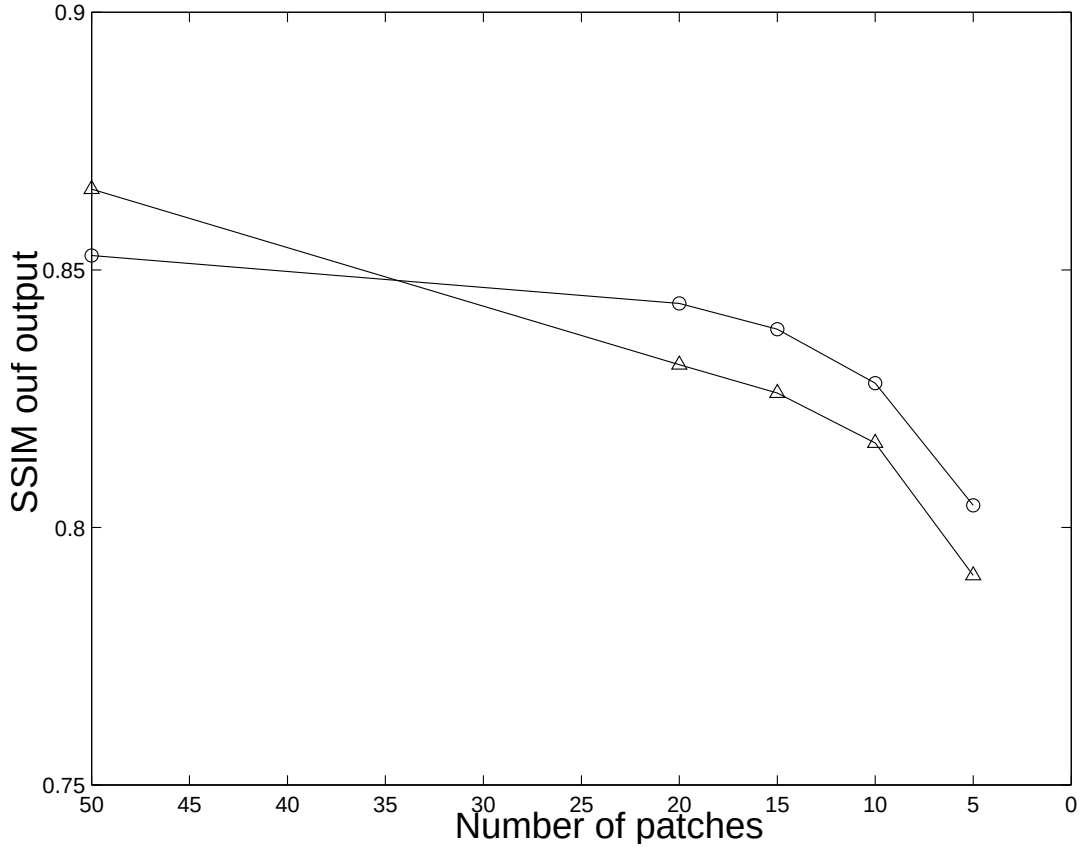


$$x = s + (k_0 + k_1 s)\delta$$

Computational Cost

→ Eigen decomposition of $P \in \mathbb{R}^{n \times n}$ requires $O(n^2)$ operations

→ Tradeoffs for n and image quality



Conclusion

- → Image patch modeled as a linear combination of noisy image patches.
- → A new technique to solve the TLS problem.
- → Improved image quality when compared to recently published works.

For more information...

- K. Hirakawa, T. W. Parks, “Image Denoising for Signal-Dependent Noise,” ICASSP 2005.
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