Joint Demosaicing and Denoising

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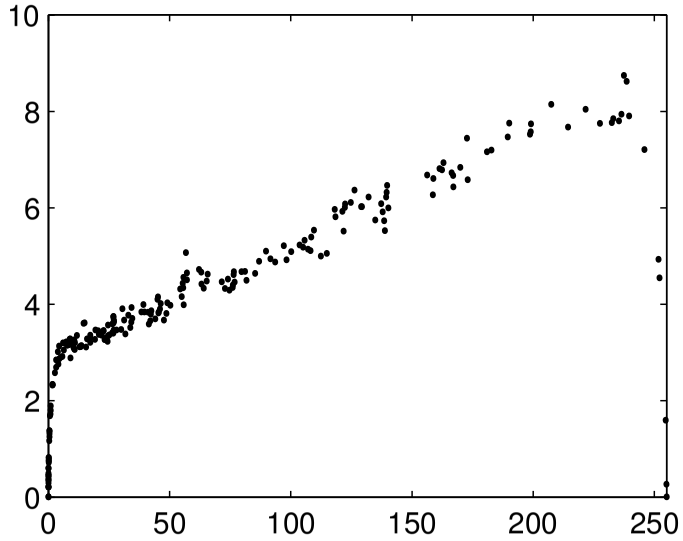
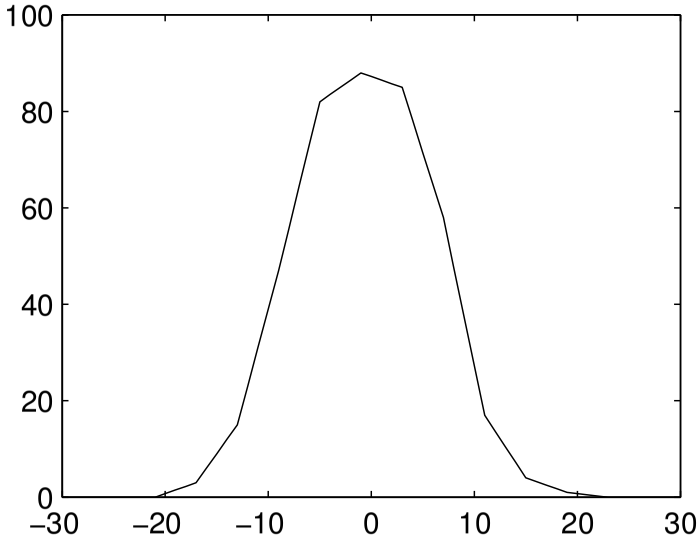
Problem Overview

- Digital cameras perform poorly in low-light environment. Sensor data corrupted by signal-dependent noise. Perhaps the biggest problem digital cameras face today.
- Impractical to interpolate *then* denoise.
- Impractical to denoise *then* interpolate.
- Combining demosaicing and denoising!



Measuring CMOS/CCD image sensor noise



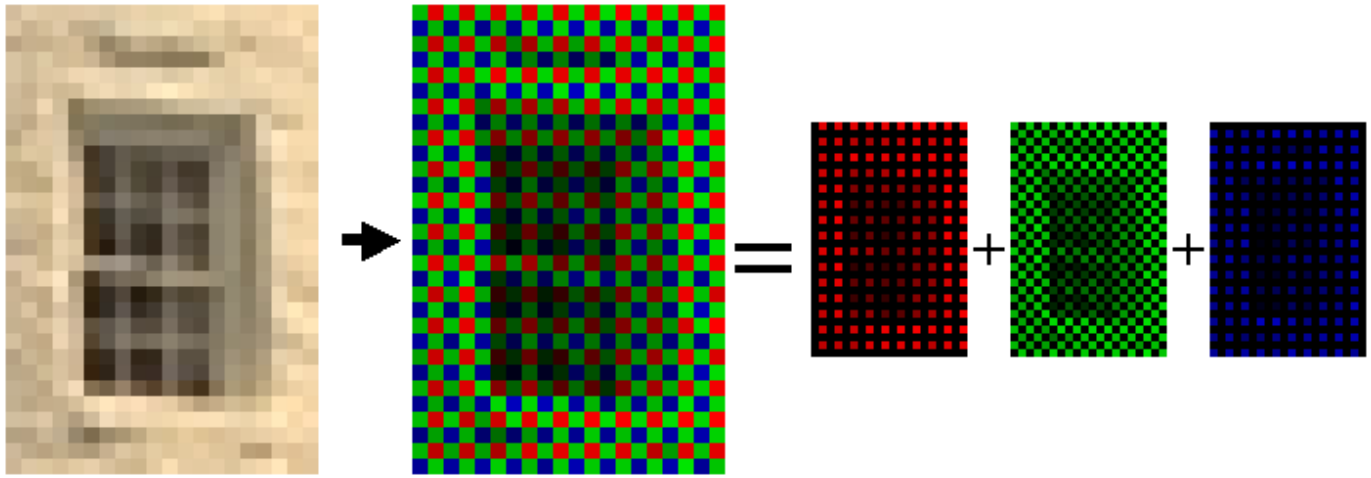


Noise standard deviation and histogram of Agilent CMOS APS image sensor.

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

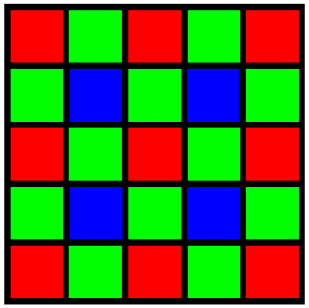
where $\delta \sim \mathcal{N}(0, 1)$

Demosaicing and Sensor Noise



- Attempt to preserve sharpness in image also amplifies noise.
- Noise patterns form false edge structures.
- Interpolation adds structure to noise.
- Denoising before demosaicing results in blurry output images.

Motivation: Demosaicing + Denoising

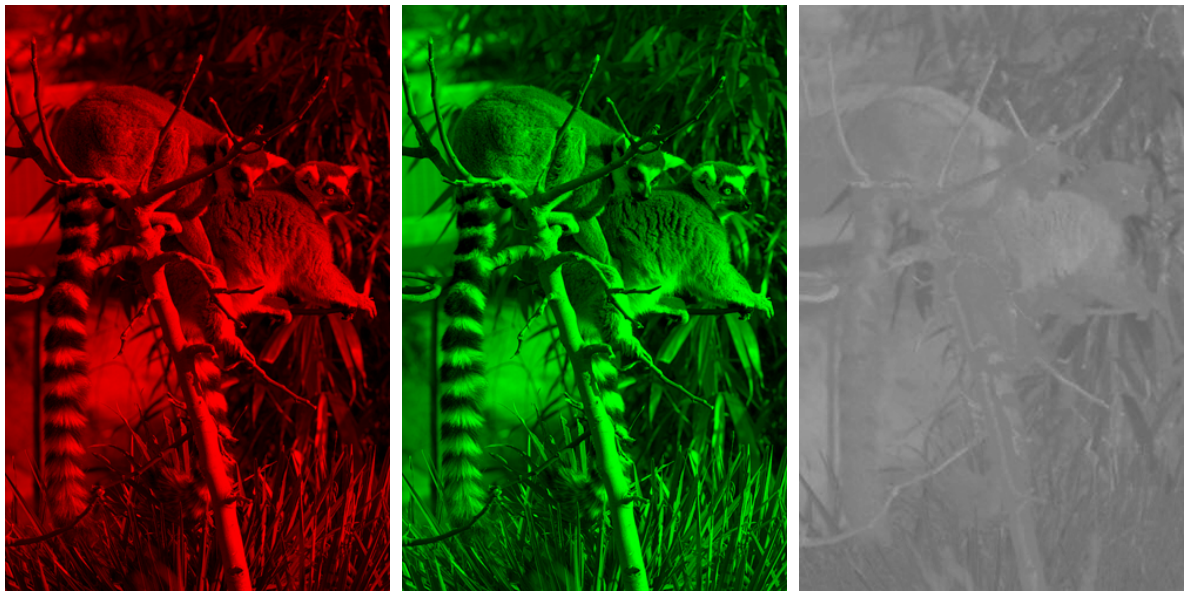


$$\begin{aligned} Y(i) =& X(i) + \Big(k_0 + k_1 X(i)\Big)\delta(i) \\ =& X(i) + N(i) \end{aligned}$$

Pixel Value Estimation

$$\begin{aligned}\hat{G}(0) &= \sum_{i} \alpha(i)\big(X(i)+N(i)\big) \\ &= \sum_{i\in\{\texttt{green}\}} \alpha(i)\big(G(i)+N(i)\big) \\ &\quad + \sum_{i\in\{\texttt{red}\}} \alpha(i)\big(R(i)+N(i)\big) + \sum_{i\in\{\texttt{blue}\}} \alpha(i)\big(B(i)+N(i)\big)\end{aligned}$$

Difference Image and Highpass Filtering



$$\sum_i h(i)\big(R(i) - G(i)\big) = 0$$

$$\sum_i h(i)R(i) = \sum_i h(i)G(i)$$

Restriction on Filtering

We impose a restriction:

$$\sum_{i \in \{\texttt{red}\}} \alpha(i) = 0$$

$$\sum_{i \in \{\texttt{blue}\}} \alpha(i) = 0$$

$$\sum_{i \in \{\texttt{red}\}} \alpha(i) R(i) = \sum_{i \in \{\texttt{red}\}} \alpha(i) G(i)$$

Single-Color Image Denoising

$$\hat{G}(0) = \sum_{i \in \{\texttt{green}\}} \alpha(i)\big(G(i) + N(i)\big) + \sum_{i \in \{\texttt{red}\}} \alpha(i)\big(G(i) + N(i)\big) + \sum_{i \in \{\texttt{blue}\}} \alpha(i)\big(G(i) + N(i)\big)$$

$$= \sum_{i} \alpha(i)\big(G(i) + N(i)\big)$$

Quick Summary

- Optimize denoising filter coefficients $\alpha(i)$ for single-color image, $G(i) + N(i)$.
- Impose a restriction:

$$\sum_{i \in \texttt{red}} \alpha(i) = \sum_{i \in \texttt{blue}} \alpha(i) = 0$$

- Estimate:

$$\hat{G}(0) = \sum_{i} \alpha(i) Y(i)$$

Estimation of Red and Blue

- For $\hat{R}(0)$:

$$\sum_{i \in \texttt{green}} \alpha(i) = \sum_{i \in \texttt{blue}} \alpha(i) = 0$$

- For $\hat{B}(0)$:

$$\sum_{i \in \texttt{green}} \alpha(i) = \sum_{i \in \texttt{red}} \alpha(i) = 0$$

Example Algorithm Using TLS Denoising

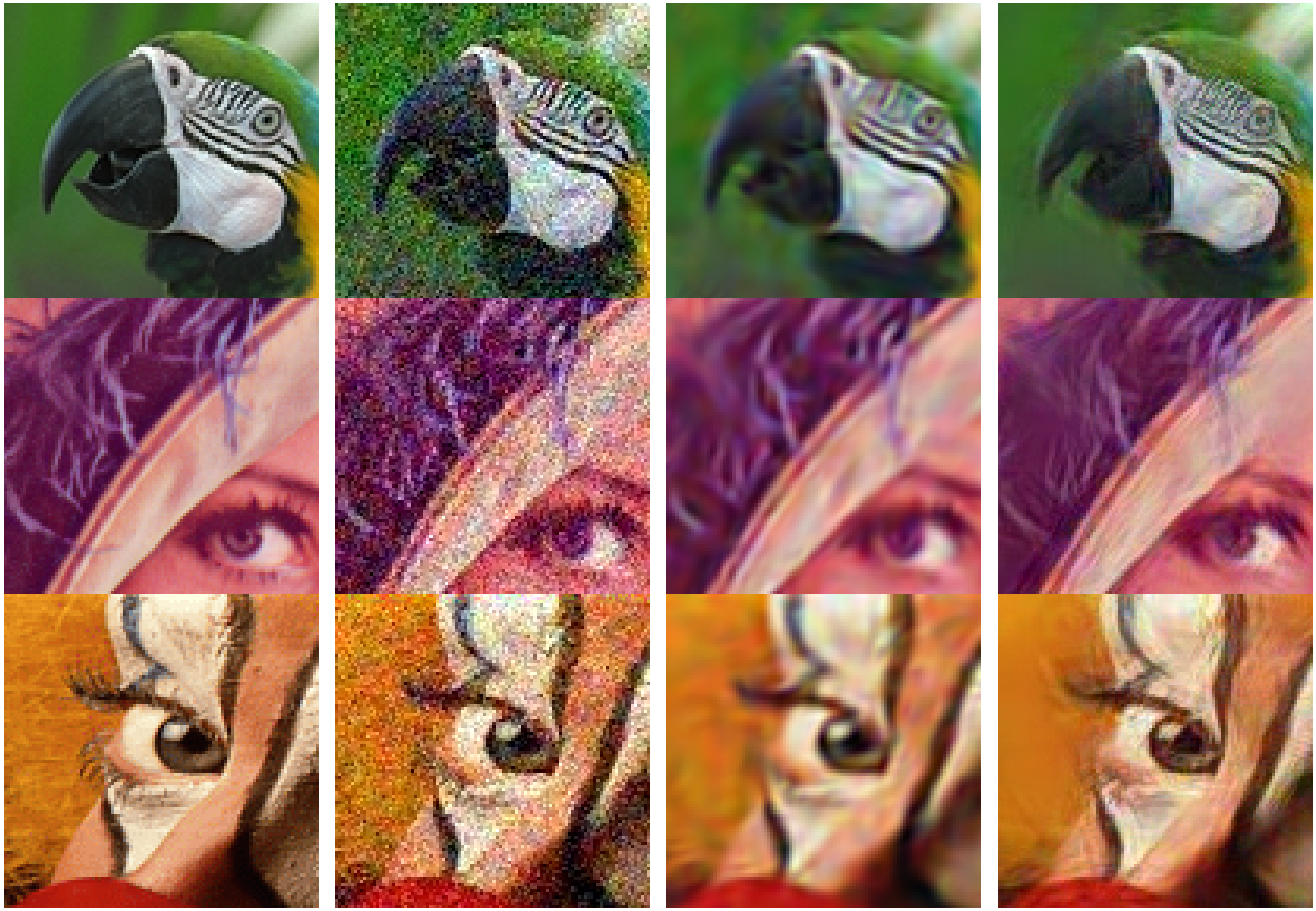
- TLS Denoising handles CMOS/CCD sensor noise model.
- Decimate X to get R_s, G_s, B_s.
- Assume that if

$$G(0) \simeq \sum_i \alpha(i)\big(G_s(i) + N(i)\big)$$

then

$$G(0) \simeq \sum_i \alpha(i)\big(G(i) + N(i)\big)$$

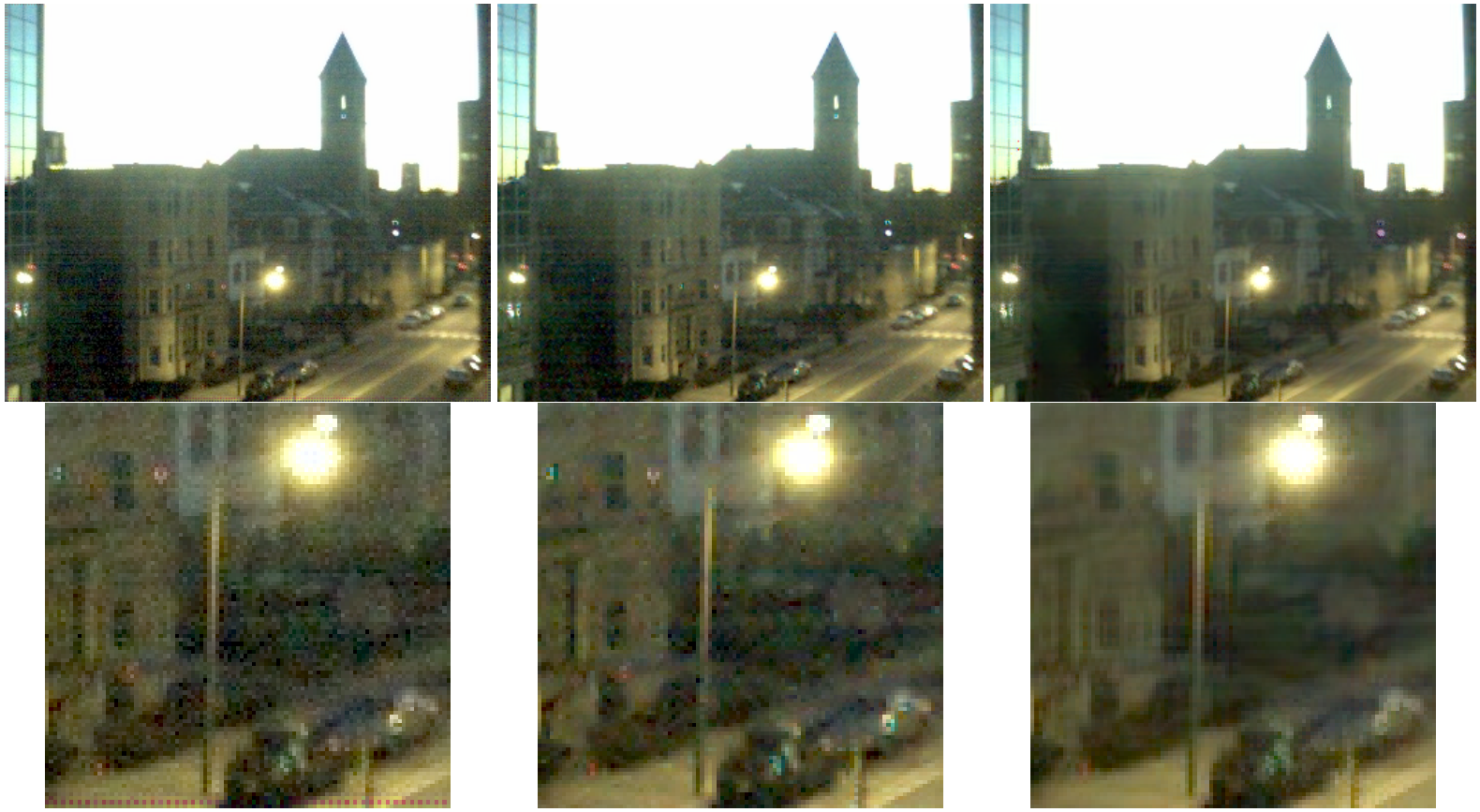
[1] K. Hirakawa, T.W. Parks, “Image Denoising for Signal-Dependent Noise,” IEEE ICASSP, 2005.



original method in [2] method in [2]+[3] proposed method

[2] B.K. Gunturk *et al.* “Color Plane Interpolation Using Alternating Projections,” IEEE Trans. Im. Proc., v.11, 2002.

[3] J. Portilla *et al.*, “Image Denoising Using Scale Mixture of Gaussians in the Wavelet Domain,” IEEE Trans. Im. Proc., v.12, 2003.



method in [2] method in [4] proposed method

[2] B.K. Gunturk *et al.* “Color Plane Interpolation Using Alternating Projections,” IEEE Trans. Im. Proc., v.11, 2002.

[4] K. Hirakawa *et al.* “Adaptive Homogeneity-Directed Demosaicing Algorithm,” IEEE Trans. Im. Proc., v.14, 2005.

Average error measured in SCIELAB

			"parrots"			"lena"			"clown"		
noise level (k_0, k_1)			demosaicing method [2]	[4]	proposed	demosaicing method [2]	[4]	proposed	demosaicing method [2]	[4]	proposed
(0,0)			1.66	1.01	3.44	1.45	1.47	2.87	14.52	16.29	31.14
(25,0)	denoising method	none	58.10	69.18	22.27	46.02	53.88	19.75	242.97	266.28	156.82
		[3]	26.11	29.28	N/A	20.26	22.12	N/A	218.19	221.16	N/A
		[5]	26.73	30.00	N/A	21.18	22.97	N/A	218.42	221.78	N/A
		[1]	22.65	24.38	N/A	19.44	21.97	N/A	210.55	221.56	N/A
(25,0.1)	denoising method	none	86.68	104.67	29.17	76.49	88.49	26.99	283.61	306.08	176.41
		[3]	35.77	40.24	N/A	30.44	33.15	N/A	243.33	239.11	N/A
		[5]	36.76	41.51	N/A	32.33	35.13	N/A	246.50	240.67	N/A
		[1]	31.86	36.68	N/A	28.93	32.11	N/A	233.04	235.52	N/A
(25,0.2)	denoising method	none	122.49	149.82	36.33	114.87	134.10	36.01	331.96	355.38	195.77
		[3]	47.48	53.27	N/A	44.60	50.16	N/A	273.37	261.21	N/A
		[5]	49.77	55.11	N/A	47.86	53.38	N/A	276.92	263.41	N/A
		[1]	42.23	48.55	N/A	41.40	47.18	N/A	266.07	279.74	N/A

[1] K. Hirakawa, T.W. Parks, "Image Denoising for Signal-Dependent Noise," IEEE ICASSP, 2005.
[2] B.K. Gunturk *et al.* "Color Plane Interpolation Using Alternating Projections," IEEE Trans. Im. Proc., v.11, 2002.
[3] J. Portilla *et al.*, "Image Denoising Using Scale Mixture of Gaussians in the Wavelet Domain," IEEE Trans. Im. Proc., v.12, 2003.
[4] K. Hirakawa *et al.* "Adaptive Homogeneity-Directed Demosaicing Algorithm," IEEE Trans. Im. Proc., v.14, 2005.
[5] A. Pizurica *et al.* "A joint inter- and intrascale statistical model for Bayesian wavelet based image denoising," IEEE Trans. Im. Proc., 2002.

Conclusion

- Characterized sensor noise in digital cameras.
- Designed a general method to combine demosacing and denoising.
  - Estimated pixel values as a linear combination of Bayer pattern pixels.
  - Imposed a restriction on filter coefficients.
  - Designed a demosaicing algorithm using TLS denoising method.

Announcement...

- Please come visit our other poster, “Chromatic Adaptation and White-Balance Problem” at WedPmPO3.
- Hirakawa is looking for a tenure-track university position in the US. Any suggestions would be appreciated.