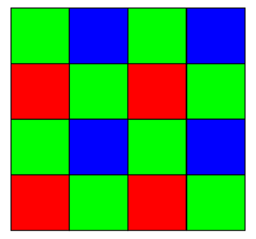
FILTER DESIGN FOR ADAPTIVE FREQUENCY-DOMAIN BAYER DEMOSAICKING

Eric Dubois, School of IT and Engineering (SITE), University of Ottawa, Canada

1

The problem: Most digital color cameras capture only one color component at each spatial location using a color filter array (CFA), such as the Bayer CFA. The remaining components must be reconstructed by interpolation from the captured samples.



Bayer color filter array

The raw CFA output is a spatial-domain multiplexing of the R,G,B components of the color image.

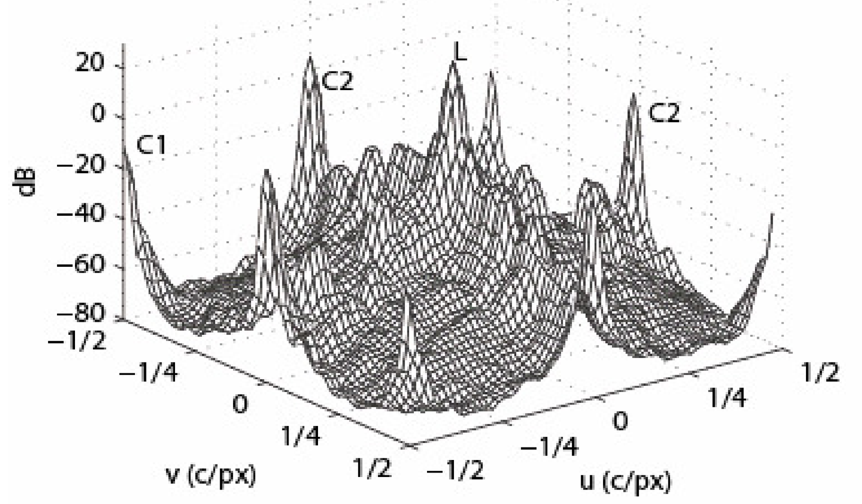
$$f_{\mathrm{CFA}}[n_1,n_2]=\tfrac{1}{2}f_G[n_1,n_2](1+(-1)^{n_1+n_2})+\tfrac{1}{4}f_R[n_1,n_2](1-(-1)^{n_1})(1+(-1)^{n_2})$$
$$+\tfrac{1}{4}f_B[n_1,n_2](1+(-1)^{n_1})(1-(-1)^{n_2})$$

2

Frequency Domain Model [1]: The spatial-domain multiplexing model can be converted to a frequency-domain multiplexing model by a simple manipulation of the above equation:

$$f_{\mathrm{CFA}}[n_1,n_2]=\left(\frac{1}{4}f_R[n_1,n_2]+\frac{1}{2}f_G[n_1,n_2]+\frac{1}{4}f_B[n_1,n_2]\right)$$
$$+\left(-\frac{1}{4}f_R[n_1,n_2]+\frac{1}{2}f_G[n_1,n_2]-\frac{1}{4}f_B[n_1,n_2]\right)(-1)^{n_1+n_2}$$
$$+\left(-\frac{1}{4}f_R[n_1,n_2]+\frac{1}{4}f_B[n_1,n_2]\right)\left((-1)^{n_1}-(-1)^{n_2}\right)$$
$$=f_L[n_1,n_2]+f_{C1}[n_1,n_2](-1)^{n_1+n_2}+f_{C2}[n_1,n_2]\left((-1)^{n_1}-(-1)^{n_2}\right)$$

$$F_{\mathrm{CFA}}(u,v)=F_L(u,v)+F_{C1}(u-0.5,v-0.5)+F_{C2}(u-0.5,v)-F_{C2}(u,v-0.5)$$



$$\begin{bmatrix} f_L \\ f_{C1} \\ f_{C2} \end{bmatrix}=\begin{bmatrix} \frac{1}{4} & \frac{1}{2} & \frac{1}{4} \\ -\frac{1}{4} & \frac{1}{2} & -\frac{1}{4} \\ -\frac{1}{4} & 0 & \frac{1}{4} \end{bmatrix}\begin{bmatrix} f_R \\ f_G \\ f_B \end{bmatrix} \qquad \begin{bmatrix} f_R \\ f_G \\ f_B \end{bmatrix}=\begin{bmatrix} 1 & -1 & -2 \\ 1 & 1 & 0 \\ 1 & -1 & 2 \end{bmatrix}\begin{bmatrix} f_L \\ f_{C1} \\ f_{C2} \end{bmatrix}$$

Frequency domain approach: Estimate the three components f_L, f_{C1} and f_{C2} from the CFA signal using filters and convert them to f_R, f_G, and f_B as above.

Main problem: L-C2 crosstalk

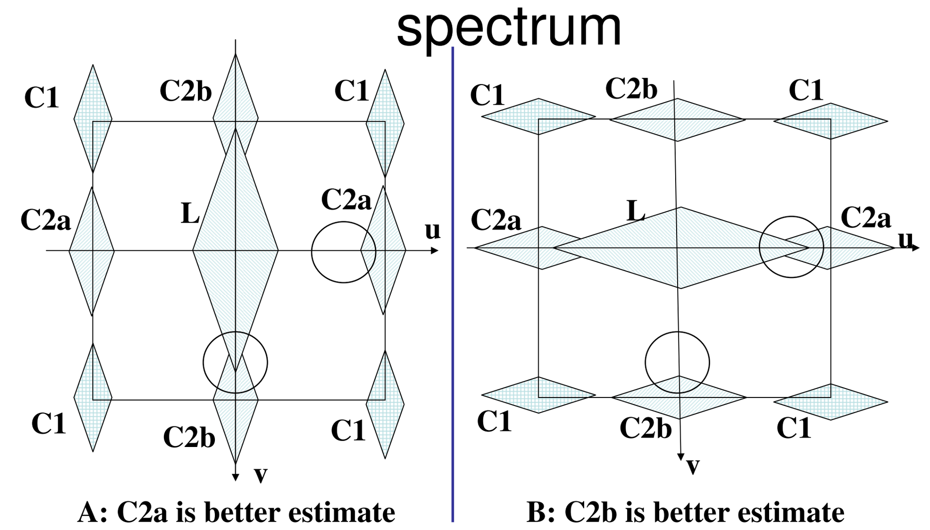
3

Adaptive frequency-domain demosaicking

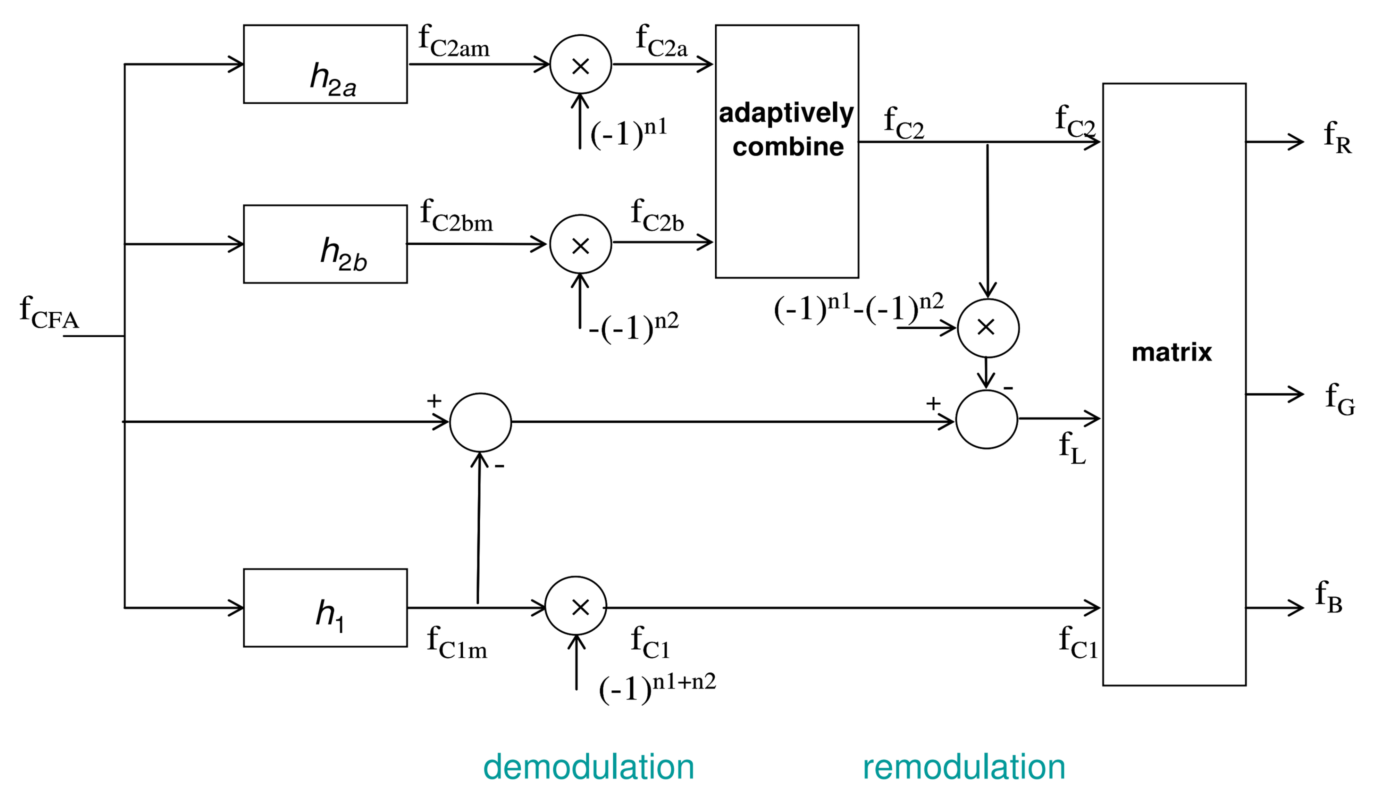
KEY OBSERVATION: There are TWO separate copies of C2, and usually only ONE of them is **locally** affected by crosstalk.

Original | Bilinear | Using C2a only | Using C2b only

Typical scenarios for **local** spectrum



4



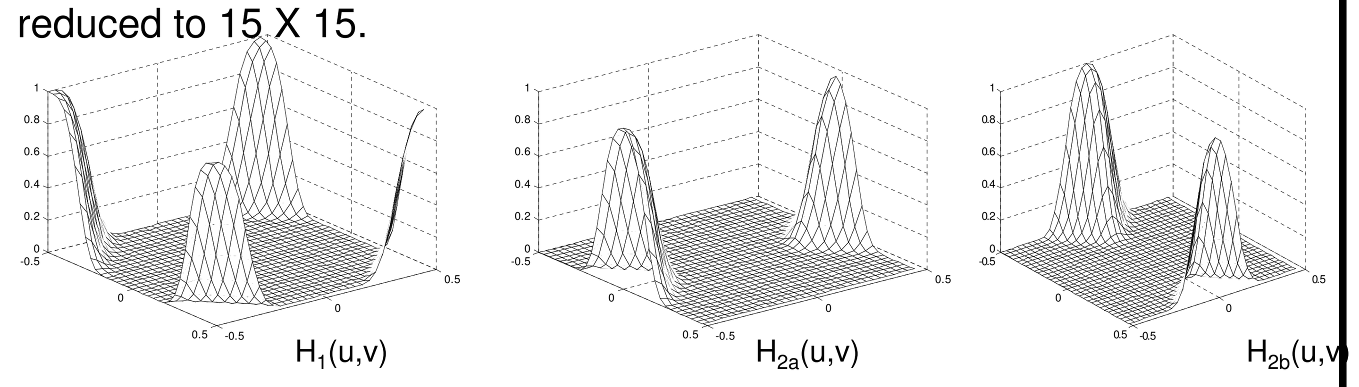
Block diagram of adaptive frequency-domain demosaicking system

Main issue of this paper: how to choose the filters h_1, h_{2a}, h_{2b}

5

Filter design methods:

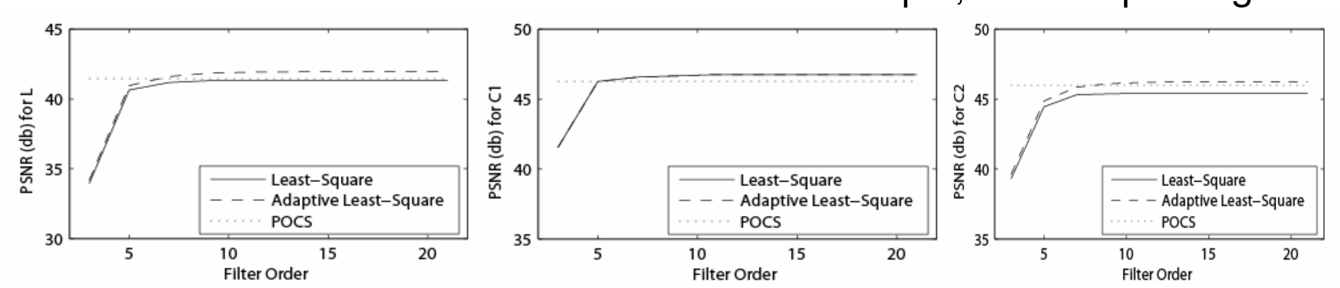
Frequency domain design: The original algorithm [2] used 21 X 21 filters designed using the window method. Attempts were made to improve over these results using minimax design techniques, and to reduce the filter order. No improvements were achieved, and the filter order could only be reduced to 15 X 15.



Frequency response of 21 X 21 window-designed filters [2]

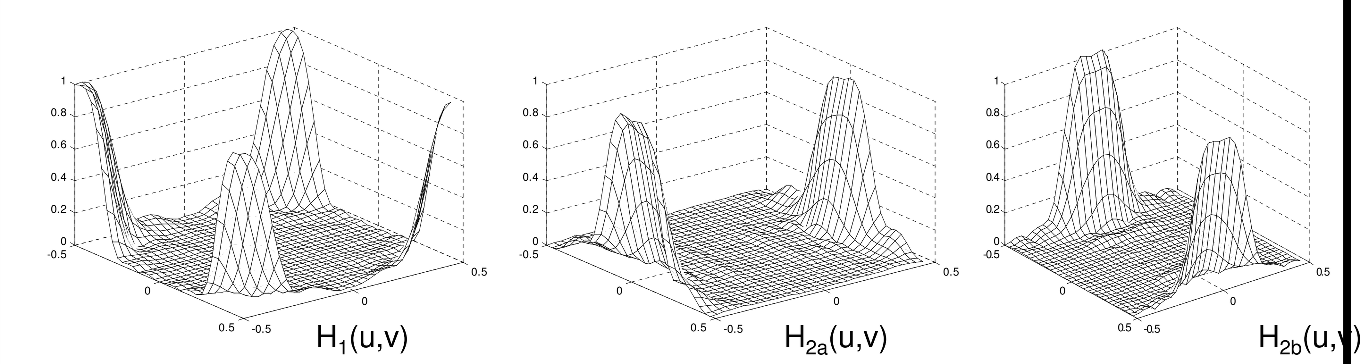
6

Least-squares design: The filters h_1, h_{2a} and h_{2b} have been designed to minimize the total squared error between the original C1 and C2 components and those estimated from the CFA signal using the system shown in box 4, over a training set of typical images. The details are presented in the paper. With this approach, filters of size 11 X 11 are sufficient to achieve the full benefit of the technique, while improving



PSNR as a function of filter order

Note: POCS refers to method of [3]



Frequency response of 11 X 11 least squares filters

7

Conclusions

- The adaptive frequency-domain Bayer demosaicking algorithm has shown the lowest mean-square reconstruction error among published techniques for the Kodak dataset.
- The filter order can be reduced to 11 X 11 with no loss of performance, and very good results can be achieved with 7 X 7 filters
- Further work is evaluating the trade-off between demosaicking performance and computational complexity with this scheme.
- Thanks to Brian Leung for carrying out many of the experiments.

References:

[1] D. Alleysson, S. Süsstrunk and J. Hérault, "Linear demosaicing inspired by the human visual system," *IEEE Trans. Image Processing*, vol. 14, pp. 439-449, Apr. 2005.
[2] E. Dubois, "Frequency-domain methods for demosaicking of Bayer-sampled color images," *IEEE Signal Processing Letters*, vol. 12, pp. 847-850, Dec. 2005.
[3] B.K. Gunturk, Y. Altunbasak and R.M. Mersereau, "Color plane interpolation using alternating projections," *IEEE. Trans. Image Processing*, vol. 11, pp. 997-1013, Sept. 2002.