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EXPLOITATION OF INTER-COLOR CORRELATION FOR COLOR IMAGE DEMOSAICKING

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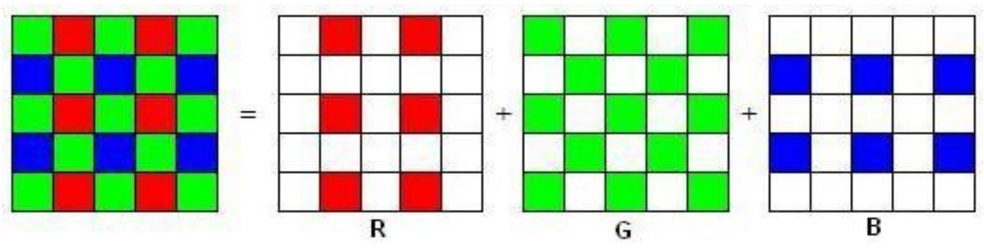
Introduction

- Color filter array (CFA) allows only one color to be captured at each pixel.
- Most popular design used to achieve this is the Bayer pattern.
- Image demosaicking or CFA interpolation is a process of interpolating missing color samples to reconstruct a full color image.



General Assumption

Most of the demosaicking methods make an assumption that the high frequencies between R, G and B are largely identical and thus color difference are low pass signal.

$$R-G=(R_l+R_h)-(G_l+G_h)=(R_l-G_l)$$

If interpolated $\hat{G}$ is fully available by some interpolation process, then interpolated red component can be recovered by Color Difference interpolation (CDI) method

$$\hat{R}_{CDI}=\zeta\{K_R\}+\hat{G}=\zeta\{R_a-\hat{G}_a\}+\hat{G}$$

where $\zeta\{.\}$ denotes low pass filtering on the color difference image.

$$\hat{R}_{CDI}=\zeta\{R_a-\hat{G}_a\}+\hat{G}=R_l-\hat{G}_l+\hat{G}$$

In a similar manner, blue component can be recovered.

Proposed Algorithm

Distortion Analysis of Low pass filter (LPF):

The simplest way to demosaicking is to apply low pass filter (LPF) to each channel independently.

$$\hat{R}_{LPF}=\zeta\{R_a\}=R_l$$

Distortion can be given by :

$$D_{LPF}=R-\hat{R}_{LPF}=R-R_l=R_h$$

Assuming D_{LPF} and R_h follows Laplace Distribution with zero mean, i.e. $E[D_{LPF}]=0$ and $E[R_h]=0$ then variance of final distortion can be given by:

$$\sigma^2_{D_{LPF}}=E[(R-R_l)^2]=E[R_h^2]=\sigma^2_{R_h}$$

Distortion Analysis of CDI method :

The interpolated red component by CDI method can be given by:

$$\hat{R}_{CDI}=R_l-\hat{G}_l+\hat{G}=R_l+\hat{G}_h$$

where $\hat{G}_h\ (\hat{G}-\hat{G}_l)$ is the high pass filtered output of G component.
Distortion can be given by :

$$D_{CDI}=R-\hat{R}_{CDI}=R-R_l-\hat{G}_h$$

$$D_{CDI}=(R_h-\hat{G}_h),D^2_{CDI}=R_h^2+\hat{G}_h^2-2\times R_h\times\hat{G}_h$$

Then variance of final distortion can be given by :

$$E[D^2_{CDI}]=E[R_h^2]+E[\hat{G}_h^2]-2\times E[R_h\times\hat{G}_h]$$

Assuming $\hat{G}_h$ and D_{CDI} follows Laplace Distribution with zero mean, variance can be given by

$\sigma^2_{\hat{G}_h}$ = E$[\hat{G}_h^2]$ and $\sigma^2_{D_{CDI}}$ = E$[\hat{D}^2_{CDI}]$

Correlation coefficient estimated between $\hat{G}_h$ and R_h is given by,

$$\rho_{R_h\hat{G}_h}=E[R_h\times\hat{G}_h]/(\sigma_{R_h}\times\sigma_{\hat{G}_h})$$

We get,

$$\sigma^2_{D_{CDI}}=\sigma^2_{D_{LPF}}+\sigma^2_{\hat{G}_h}-2\times\sigma_{\hat{G}_h}\times\sigma_{R_h}\times\rho_{R_h\hat{G}_h}$$

Here, $\rho_{R_h\hat{G}_h}\in(-1,+1)$ and it tells about the similarity between high frequency component of two channel. Higher value means edge structure in R and $\hat{G}_h$ component are quite similar. Now,

$$\sigma^2_{D_{CDI}}-\sigma^2_{D_{LPF}}=\sigma_{\hat{G}_h}\times(\sigma_{\hat{G}_h}-2\times\sigma_{R_h}\times\rho_{R_h\hat{G}_h})$$

For $\sigma^2_{D_{CDI}}<\sigma^2_{D_{LPF}}$, $\sigma_{\hat{G}_h}-2\times\sigma_{R_h}\times\rho_{R_h\hat{G}_h}<0$, which reduces to

$$\rho_{R_h\hat{G}_h}>0.5\times\sigma_{\hat{G}_h}/\sigma_{R_h}$$

For, $\sigma^2_{D_{CDI}}>\sigma^2_{D_{LPF}}$, $\sigma_{\hat{G}_h}-2\times\sigma_{R_h}\times\rho_{R_h\hat{G}_h}>0$, which reduces to

$$\rho_{R_h\hat{G}_h}<0.5\times\sigma_{\hat{G}_h}/\sigma_{R_h}$$

Proposed Demosaicking Scheme:

- From above analysis, we observe that CDI method does not work in some cases and thus simple LPF should be used and vice-versa
- We propose a linear combination of LPF method and CDI method on a block by block basis to generate a more accurate prediction for demosaicking
- Optimal weights are estimated in LMMSE sense for each block.

$$\hat{r}=w_1\hat{r}_{LPF}+w_2\hat{r}_{CDI}$$

Here $\hat{r}\in\hat{R}$ is to be interpolated block of size M X N. w1 and w2 are the weighted coefficient for the combinations. Thus the distortion (d) between original block (r) and interpolated block :

$$d=r-\hat{r}=r-(w_1\hat{r}_{LPF}+w_2\hat{r}_{CDI})=w_1d_{LPF}+w_2d_{CDI}$$

To get the optimal weights in LMMSE sense, the problem can be formulated as below

$$\min_{w_1,w_2}\quad E[d^2]$$
$$\text{s.t}\quad \sum_{i=1,2}w_i=1$$

$$\begin{cases}w_1=E[d_{CDI}(d_{CDI}-d_{LPF})]/E[(d_{CDI}-d_{LPF})^2],\\ w_2=E[d_{LPF}(d_{LPF}-d_{CDI})]/E[(d_{CDI}-d_{LPF})^2]\end{cases}$$

In a similar manner, blue component can be reconstructed.

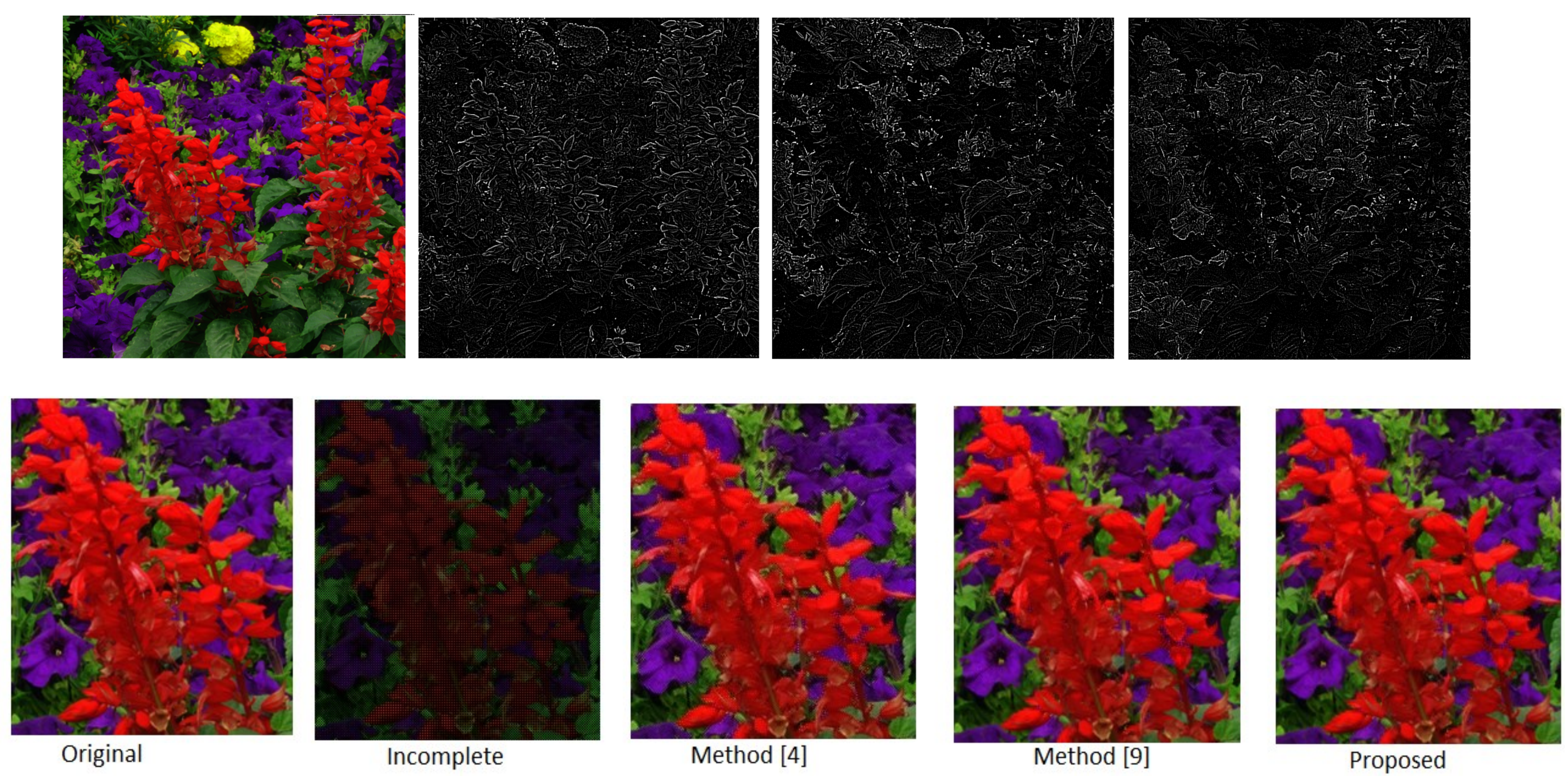
Simulation Results

Table 1. PSNR (dB) Comparison for red component. Pro refers to proposed algorithm and Avg refers to average.

Img	[4]	[5]	[7]	[8]	[9]	Pro
(1)	26.94	27.44	27.28	29.29	29.16	**29.30**
(2)	32.60	32.18	32.81	33.05	34.04	**34.15**
(3)	30.38	32.43	31.10	35.05	36.80	**37.02**
(4)	37.20	35.22	36.61	36.09	37.09	**37.42**
(5)	35.45	35.64	35.31	36.31	34.28	**37.40**
(6)	32.39	33.50	33.72	35.49	33.24	**35.67**
(7)	34.70	35.16	36.33	**38.26**	36.72	37.73
(8)	36.91	37.12	38.16	**39.84**	37.87	39.02
(9)	35.32	35.85	36.23	36.95	35.78	**37.24**
(10)	28.32	30.10	29.24	32.14	30.54	**32.20**
(Avg)	33.02	33.45	33.67	35.24	34.55	**35.72**

Table 2. PSNR (dB) Comparison for blue component. Pro refers to proposed algorithm and Avg refers to average.

IMG	[4]	[5]	[7]	[8]	[9]	Pro
(1)	25.12	25.29	25.12	26.71	26.98	**27.23**
(2)	31.73	29.99	30.93	30.31	**31.73**	31.16
(3)	30.72	30.62	29.48	31.16	30.72	**31.40**
(4)	37.29	34.10	36.38	34.49	35.62	**35.66**
(5)	36.99	35.45	36.76	36.67	38.06	**38.20**
(6)	34.66	33.36	35.38	36.30	**36.48**	36.36
(7)	35.55	35.49	36.13	36.83	37.34	**37.50**
(8)	35.75	33.79	36.81	37.66	39.37	**39.52**
(9)	37.30	36.71	37.90	38.99	**39.18**	39.00
(10)	27.77	28.88	28.38	30.91	31.77	**32.10**
(Avg)	33.28	32.26	33.32	34.01	34.72	**34.82**



Original Incomplete Method [4] Method [9] Proposed

Conclusion

- Made a detailed analysis of inter-color correlation among the channels and compared the distortion obtained by LPF and CDI method
- Proposed an approach that exploits the correlation between different color components effectively than the existing algorithms
- Experimental results demonstrate that proposed algorithm outperforms the existing algorithm.

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