Color filter array with sparse color sampling crosses for mobile phone image sensors

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Abstract

In order to solve the conflict between the size constraints of mobile phone cameras and image quality, it is an effective approach to improve the light sensitivity of imaging sensors. A color filter array comprising sparsely distributed crosses of color sampling blocks is proposed, in which nearly 69% of elements are transparent ones that detect luminance directly with a higher sensitivity than the remaining color-filtered ones. Monochromatic images resulted from the majority white pixels are of high spatial resolution and of low noise. They are used along with the sparse color samplings to generate color images. An advantage of the color sampling crosses is that monochromatic images can be estimated with less error, which is critical for the successive calculation of color images. Experiments have been conducted using a Canon 30D camera under normal and low light levels. Results showed that the color filter array could greatly reduce image noise that usually occurs with the conventional Bayer pattern under low light levels, and did not cause noticeable color artifacts that would normally occur with under-sampling of chrominance.

Introduction

Phone cameras are much more readily to use than standalone digital cameras. As mobile phones are becoming smaller and thinner, the size constraints of mobile phones put forward a request of small image sensors. At the same time, consumers are continuously pursuing higher image quality. It is a well-known fact that the reduction in sensor size causes a reduction in light sensitivity, and therefore may cause a reduction in image quality if compensating illumination is not provided, for example, by flashlights. However, when phone cameras are used as video cameras, using flashlight usually is not a possible option. In addition, market surveys show that mobile phone cameras are frequently needed under low light levels. In order to solve the conflict between sensor size and image quality, to improve the light sensitivity of sensors is an effective approach.

Comparing with a black-and-white camera, a color camera using the same image sensor and a RGB color filter array (CFA) has only 1/10 of the ISO speed of the black-and-white one [1]. Some Cyan-Magenta-Yellow CFAs and RGB CFAs with white pixels have been proposed in an attempt to increase light energy reaching image sensors [2, 3]. However, the CMY CFAs usually have color artifact problems, and those CFAs with white pixels usually provide limited improvements because of low rates of white pixels (<50%). A fundamental problem in these CFAs is that luminance and chrominance is not really separated. Hence, improvements in one generally cause losses in another. A novel imaging paradigm with majority pixels being white ones and the remaining pixels being sparsely distributed color filtered ones has been proposed by the author [4], in which white pixels generate luminance information and RGB color pixels provide pure chrominance information. Luminance and chrominance are integrated in Lab color space. Because luminance and chrominance can be separated well in sampling and processing stages, the rate of white pixels can be designed to be over 50%.

In the novel paradigm, luminance is very important because it determines the resolution of output color images. Luminance can also provide useful information for chrominance calculation as there is a strong correlation between luminance and chrominance for natural images. Therefore, it is critical to make a good estimation of luminance. A CFA comprising sparse color sampling crosses is proposed in this paper, with which good estimation of luminance can be likely.

Sparse color sampling crosses and image formation

Figure 1 shows the CFA comprising cross-shaped color sampling blocks. Each 3x3 sampling cross consists of a blue element at the center, two green elements at top and bottom respectively, and two red elements at left and right respectively. Such crosses repeat every four pixels horizontally and vertically, and the remaining elements are transparent (white elements) for direct luminance detection. The overall color sampling rate is about 31%, and luminance sampling rate is nearly 69%.

	G				G		
R	B	R		R	B	R	
	G				G		
	G				G		
R	B	R		R	B	R	
	G				G		

Figure 1. A color filter array comprising sparse color sampling crosses. Blank cells represent for transparent elements

Monochromatic images are first calculated from white pixels by means of directional interpolation based on edge information. For the center pixel of each cross block, edge is evaluated in four directions – horizontal, vertical and 2 oblique directions (Figure 2):

Horizontal: $E_h=1/[1+\mathrm{mean}(|w2-w3|, |w4-w5|, |w6-w7|)]$
Vertical: $E_v=1/[1+\mathrm{mean}(|w2-w6|, |w1-w8|, |w3-w7|)]$
NE oblique: $E_e=1/[1+|w3-w6|]$
NW oblique: $E_w=1/[1+|w2-w7|]$ (1)

		W1		
	W2		W3	
W4		W_c		W5
	W6		W7	
		W8		

Figure 2. Interpolation of luminance values at color sampling pixels. The center pixel W_c is first estimated, and then four tips of the sampling cross.

For the center pixel of a sampling cross, the luminance value can be interpolated possibly along four directions:

Horizontal: $I_h=(w4+w5)/2$
Vertical: $I_v=(w1+w8)/2$
NE oblique: $I_e=(w3+w6)/2$
NW oblique: $I_w=(w2+w7)/2$ (2)

The edge-weighted average of interpolation of the center pixel is:

$$W_c=(I_h*E_h+I_v*E_v+I_e*E_e+I_w*E_w)/(E_h+E_v+E_e+E_w) \tag{3}$$

Once the luminance value of the center pixel is estimated, pixel values of the four tips of a cross can then be estimated based on W1…W8 and Wc using a similar interpolation approach.

It is a reasonable and effective assumption that for natural images gray scale version and RGB versions have very similar profile. This assumption has been used in some demosaic algorithms [5, 6]. In this paper, it is assumed:

$$I(x)-kH(x)\approx c \tag{4}$$

where *I(x)* represents luminance image, *H(x)* represents either of RGB components, and *k* and *c* are constants (see Figure 3). Parameters *k* and *c* can be resolved from two pixels whose *I(x)* and *H(x)* are known. Pixels of sampling crosses can be those pixels after full frames of luminance images are calculated. RGB images can be calculated using following equation:

$$H(x) \approx \frac{I(x) - c}{k} \tag{5}$$

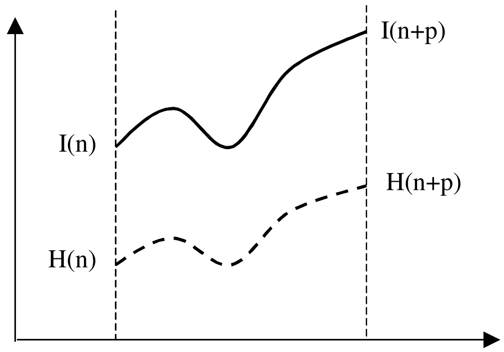

Figure 3. Estimation of color components *H(x)* based on luminance component *I(x)*. It is assumed gray scale images have similar profiles as RGB components.

To form output color images, color images estimated using equation (5) are low-pass filtered, transformed into Lab color space, and the luminance component (L) is replaced with the monochromatic images [4].

Experimental results

A simulation experiment using the proposed CFA was conducted. Tested images were captured using a Canon 30D camera equipped with a Sigma lens (18-50mm f/2.8 EX DC). The results are shown in Figure 4 and Figure 5. They are cropped to show details clearly.

Figure 4a is an underexposed picture using 6% of correct exposure level (F10, 1/1600 sec, ISO100). Bayer pattern and an adaptive homogeneity-directed demosaic algorithm [5] were used to generated the image from raw image data. As can be seen, there is severe image noise due to under-exposure in the picture. A sampled image as specified as in Figure 1 was constructed from the underexposed image as shown in Figure 4a and a correctly exposed image (F10, 1/100 sec, ISO100) – the underexposed image contributed the color filtered pixels and the correctly exposed image contributed the white pixels. Figure 4b shows the demosaiced image from the sampled image. As can be seen, image noise has been greatly reduced.

(a) (b)

Figure 4. A simulation experimental result under a low light level. Size: 280x201 pixels. (a) A picture captured using 6% of correct exposure. Bayer CFA was used. (b) The proposed CFA was used. Chrominance is from (a) and luminance is from a correct exposure. Chrominance and luminance were combined in Lab space.

Figure 5. An experimental result under sufficient light level. The proposed CFA was used. Size: 651x371 pixels.

Figure 5 shows another picture captured under a correct exposure level. The proposed CFA was used. It can be seen that the image quality is satisfactory, and color artifacts are barely noticeable even for the fine check pattern of the shirt and the busy pattern of hay.

Conclusion

The proposed novel CFA has promising values in making small image sensors. The majority white pixels will enable mobile phone cameras to capture quality images under low light levels and sufficient light levels.

References

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