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Image Quality Performance of CMOS image sensor equipped with CMY color filter

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Abstract

Recently, smartphones are equipped with high resolution mobile camera modules of 100 million pixels or more. After that, it is expected that much higher resolution mobile camera modules will be mounted. However, in order to mount more pixels in a limited space, the pixel size must be reduced. If 1.0 um pixel sensor was the mainstream in the past, now 0.64um pixel sensor has been developed now, and a sensor with smaller pixel will be developed in the future. However, there are technical limitations. In terms of image quality of sensor, if the size of pixel becomes smaller, the amount of light received decreases, and the image quality in terms of noise becomes poor .In order to solve this limitation, an attempt is made to develop a high-sensitivity sensor in various ways. One of them is the image sensor using CMY color filter technology. CMY color filter has higher sensitivity than RGB, so it is advantageous for developing high sensitivity sensors.

In this paper, we introduce the image quality performance of the CMOS image sensor equipped with CMY color filter in mobile devices.

Introduction

The point of view of image quality, the larger pixel size of sensor, the greater the amount of light received, and the better the SNR (Signal to Noise Ratio) of the image quality. However, in the case of a mobile sensor used in a smartphone, the size of the pixel needs to be small in order to realize a high resolution mobile image sensor with a limited space. Although high resolution sensors equipped with micro pixels of RGB (Red, Green and Blue) color filters are being developed, the amount of light that is received per pixel decreases, which limits the performance of the sensor. Various attempts are being made to overcome these limitations one of them is the CMY (Cyan, Magenta and Yellow) sensor.

The CMY sensor can use a CMY color filter to increase the sensitivity of the sensor. Accordingly, it is possible to develop a high resolution sensor in the same area. The Bayer type of image sensor is shown in Figure 1

Figure 1. Bayer Type (a) RGB Sensor, (b) CMY Sensor

The sensor equipped with the CMY color filter transmits light in a wider wavelength band than an RGB sensor. The Figure 2 shows the spectral characteristics of RGB and CMY color filters. Therefore, the CMY sensor can obtain a sensor output superior to SNR compared to RGB by taking advantage of the wide spectrum characteristics. This is advantageous for the development of high sensitivity sensor.

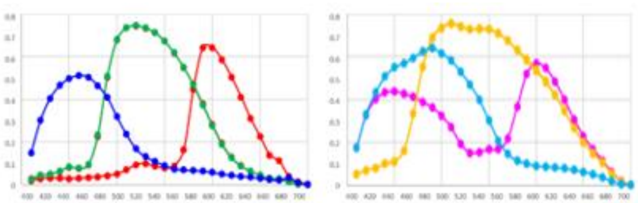

Figure 2. Example of the Quantum Efficiency: (a) RGB Sensor, (b) CMY Sensor

Proposed approach

Currently, RGB sensors are widely used in smartphones. The reason is that the output raw data of the RGB sensor is directly processed by the ISP (Image Signal Processor) mounted on the AP (Application Processor) and converted into a JPEG image immediately as shown in Figure 3. But in order to use a CMY sensor mounted on a smartphone, image processing must be performed and convert to RGB Bayer pattern as shown in Figure 4. This is because the ISP installed in the AP doesn't receive output raw of CMY sensor.

From the viewpoint of image quality, in this environment, there is no image conversion loss for RGB sensor that do not require conversion, and the color conversion performance of CMY sensor affects image quality.

Figure 3. Image Processing for RGB Sensor

Figure 4. Image Processing for CMY Sensor

The CMY color filter transmits more light than RGB, which is advantageous for developing high sensitivity sensor. However, CMY sensor needs to be converted to RGB domain. These advantages and disadvantages collectively affect the image quality of sensor. To evaluate the image quality of CMY sensor, we consider two cases. The first is to color conversion performance. The second is to quantify general image quality.

Color Conversion Performance

Since the ISP of the AP that processes the image only receives RGB signals as input, in order to check the image quality, the CMY sensor's output raw data must be processed and converted into RGB Bayer pattern. The sensitivity of each pixel

(Cyan, Magenta and Yellow) is different in the Bayer pattern of the sensor. Therefore, there is a situation in which only pixels with relatively high sensitivity can be saturated when taking a picture. It is a reasonable situation for pixels with different sensitivities to partially saturate when the sensor receives strong light. However, the CMY sensor has to consider color conversion. When the first saturation situation of the pixel with high sensitivity of the sensor occurs, the color conversion converts the image including saturated pixel signal information. However, the lost pixel signal cannot be restored, and in the case of CMY, the image is color converted including the loss signal, and as a result, false colors occur as a side effect as shown in Figure 5, which is different from RGB. We define this as early saturation.

Figure 5. Example of the Image Quality: (a) RGB Sensor, (b) CMY Sensor

When processing color conversion by referring to the wrong signal, you can see false color. Also, when the signal is lost during color conversion, detail loss occurs. Therefore, color conversion performance is very important for the image quality of the CMY image sensor.

General image quality

Ensuring general image quality performance is very important. Because the CMY sensor has superior sensitivity compared to the RGB sensor, it can take advantage of SNR in terms of image quality. However, since AP cannot receive output raw of the CMY sensor as input, it must be converted to RGB with the color conversion algorithm to obtain the final image. As a result, image quality loss may occur depending on the conversion performance. This means that a set equipped with a CMY sensor cannot guarantee image quality that is always superior to RGB.

Therefore, we define Resolution, YSNR, Chroma Noise and Color Accuracy in order to quantitatively confirm the superiority and inferiority of image quality. And then, the objective image quality is verified and compared with the obtained image. [1]

How to Evaluation Method

To evaluate the image quality of the CMY sensor, the 0.7um pixel, 40 Mega CMOS image sensor module equipped with a CMY color filter is prepared. And then prepare a sensor module equipped with RGB color filters under the same conditions. Prepare a test zig board that can be combined with the module to get raw data. The Figure 6 shows test zig board for raw data of image sensor.

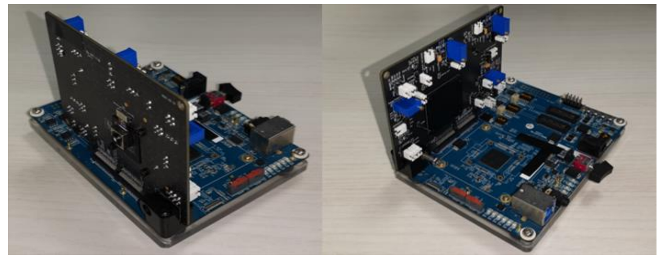

Figure 6. Test Zig Board for getting raw data of image sensor

Define capture conditions, including light source and target charts. In order to measure the resolution, the TE268 Chart is captured with CMY and RGB modules under the light source of 1000 lux or higher. To measure SNR, Chroma Noise and Color Accuracy, the Macbeth chart is captured with CMY and RGB modules under the light source of D50, 700lux and 5 lux. Additional images can be obtained if necessary. Figure 7 shows the TE268 [2] and Macbeth Charts.

Figure 7. (a) TE268 Chart, (b) Macbeth Chart

Finally, we compare and analyze the final images obtained through image processing. First of all convert CMY to RGB raw through color conversion. We define this as CMY Processed Raw. To compare the sensor IQ performance, set the same AP parameter setting and process the AP simulation. The white balance gain and color correction matrix must be properly entered as inputs. With the secured JPG image, we can compare the images and verify the quality performance. Figure 8 shows the AP simulation process for JPG.

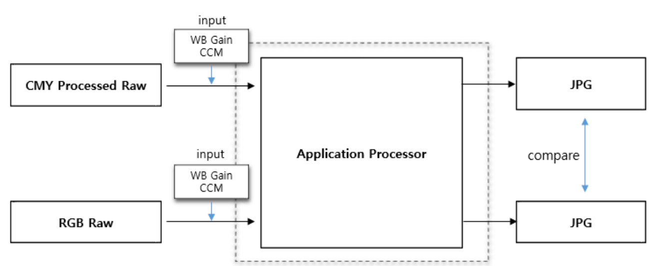

Figure 8. Application Processor Simulation Process for JPG

Result

In CMY images, false colors are found in the high frequency region during color conversion as shown in Figure 9. In the case of false color, it is caused by incorrectly referencing other areas during color conversion.

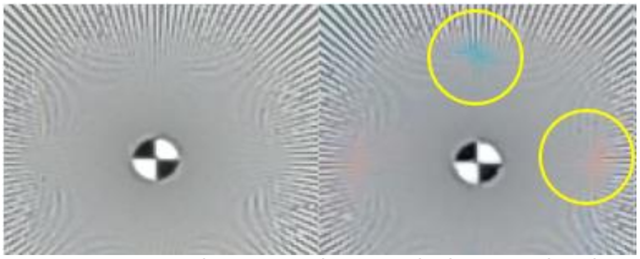

Figure 9. Image Quality, False Color: (a) RGB Sensor, (b) CMY Sensor

Figure 10 shows the detail loss. Detail loss in CMY means that the original signal is lost during color conversion. Due to the CMY color filter characteristics, the signal may be lost from raw data.

Figure 10. Image Quality, Detail Loss: (a) RGB Sensor, (b) CMY Sensor

Figure 11 shows the early saturation. Early saturation in CMY. Due to the difference in sensitivity for each channel, some channels can become saturated. If color conversion is performed, the signal lost during saturation cannot be restored, resulting in false color. RGB also occurs, but CMY has a very strong false color.

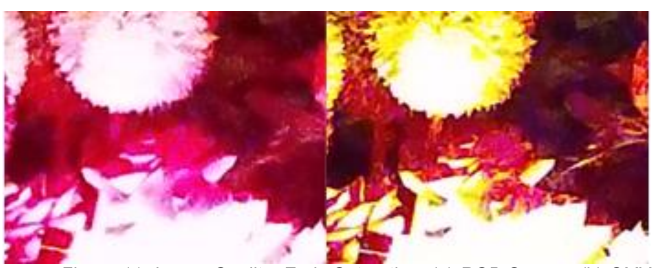

Figure 11. Image Quality, Early Saturation: (a) RGB Sensor, (b) CMY Sensor

Table 1 shows that the high sensitivity CMY sensor equipped with the CMY filter is 106.8% better than the RGB sensor in YSNR. Especially in low light, it is more than 10% superior to RGB as shown Figure 12. However, the chroma noise and color accuracy in low light are inferior as shown Figure 13. The chroma noise can be obtained according to the following equation (1). The resolution and color accuracy in indoor are equivalent as shown Figure 14 and Figure 15.

Overall it has quantitative performance of 94.4% compared to the RGB sensor. The overall quantitative IQ performance can be obtained according to the following equation (2).

Table 1. Experimental results

Evaluation Items		② Normalization Value	Absolute Value	
		CMY	RGB	CMY
Resolution	MTF 10 (LP/PH)	105.8%	0.492	0.520
	MTF 30 (LP/PH)	103.2%	0.437	0.451
	MTF 50 (LP/PH)	102.6%	0.397	0.407
Sub Score		**103.9%**		
Y SNR	Low Lux (dB)	110.2%	26.84	29.57
	indoor (dB)	103.5%	37.19	38.49
Sub Score		**106.8%**		
① Chroma Noise	Low Lux	72.6%	1.57	2
	indoor	76.7%	0.73	0.9
Sub Score		**74.7%**		
Color Accuracy	Low Lux (△Eab)	84.5%	9.3	10.74
	indoor (△Eab)	100.0%	12.76	12.76
Sub Score		**92.3%**		
Total Score		**94.4%**		

$$Chroma\ Noise = \sqrt{\mathrm{Avg}\{(a - a_{\mathrm{avg}})^2\} + \mathrm{Avg}\{(b - b_{\mathrm{avg}})^2\}} \quad (1)$$

$$\begin{aligned} &Normalization\ Value \\ &Y\ SNR\ (\%) = \left(\frac{CMY_{(absolute)}}{RGB_{(absolute)}}\right) \times 100 \\ &Chroma\ Noise\ (\%) = \left(\frac{CMY_{(absolute)}}{RGB_{(absolute)}}\right) \times 100 \\ &Color\ Accuracy\ (\%) = \{2 - \left(\frac{CMY_{(absolute)}}{RGB_{(absolute)}}\right)\} \times 100 \end{aligned} \quad (2)$$

Figure 12. IQ, Y SNR of Low Lux: (a) RGB Sensor 26.84dB, (b) CMY Sensor 29.57dB, indoor (a) 37.19dB (b) 38.49dB

Figure 13. IQ, Color Accuracy of Low Lux: (a) RGB Sensor △Eab 9.3, (b) CMY Sensor △Eab 10.74, Chroma Noise (a) 1.57, (b) 2

Figure 14. IQ, Color Accuracy of indoor: (a) RGB Sensor △Eab 12.76 (b) CMY Sensor △Eab 12.76, Chroma Noise (a) 0.73, (b) 0.9

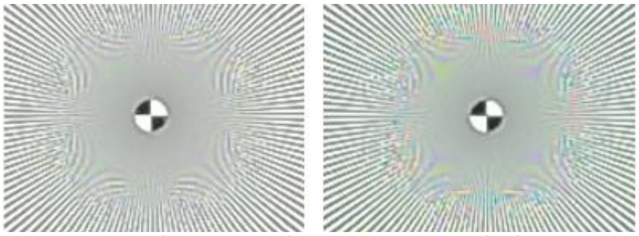

Figure 15. IQ, Resolution of MTF 10(LP/PH): (a) RGB Sensor 0.492, (b) CMY Sensor 0.520

Conclusion

The quantitative results of this paper are not superior to RGB characteristics because it is difficult to convert CMY colors at the current level, and there are problems such as side effects, weaknesses, and deterioration of image quality.

This means that from an image quality point of view we have to consider the image processing pipeline. Even if the sensor characteristics are excellent, since the mobile AP only RGB channel input, CMY must process color conversion to RGB. Therefore, in terms of image quality at the setting level, it is important to ensure that the excellent SNR performance obtained from the CMY sensor is not lost during color conversion processing. We hope to solve these technical problems and we expect the smartphone with CMY sensor to become main stream in the future.

References

[1] Artmann, U. Image quality assessment using the dead leaves target: experience with the latest approach and further investigations. *Proc. SPIE*, **9404**, 94040J (2015)

[2] https://www.image-engineering.de/products/charts/all/584-te268x

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