TND6114/D

Image Sensor Color Correction

ON Semiconductor®

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TECHNICAL NOTE

Introduction

This reference document will describe the basic process to obtain colors from a digital image sensor.

Basic Process to Obtain Color Images from Digital Image Sensnors

CCD and CMOS solid-state image sensors contain an array of photosensitive elements called pixels. The pixels collect light from a scene and convert it into electrical signal. The signal is then digitized and processed. Digital cameras use CCD or CMOS image sensors to capture images.

Silicon−based image sensors are sensitive to light with wavelengths from up to 1050 nm, as shown in Figure 1.

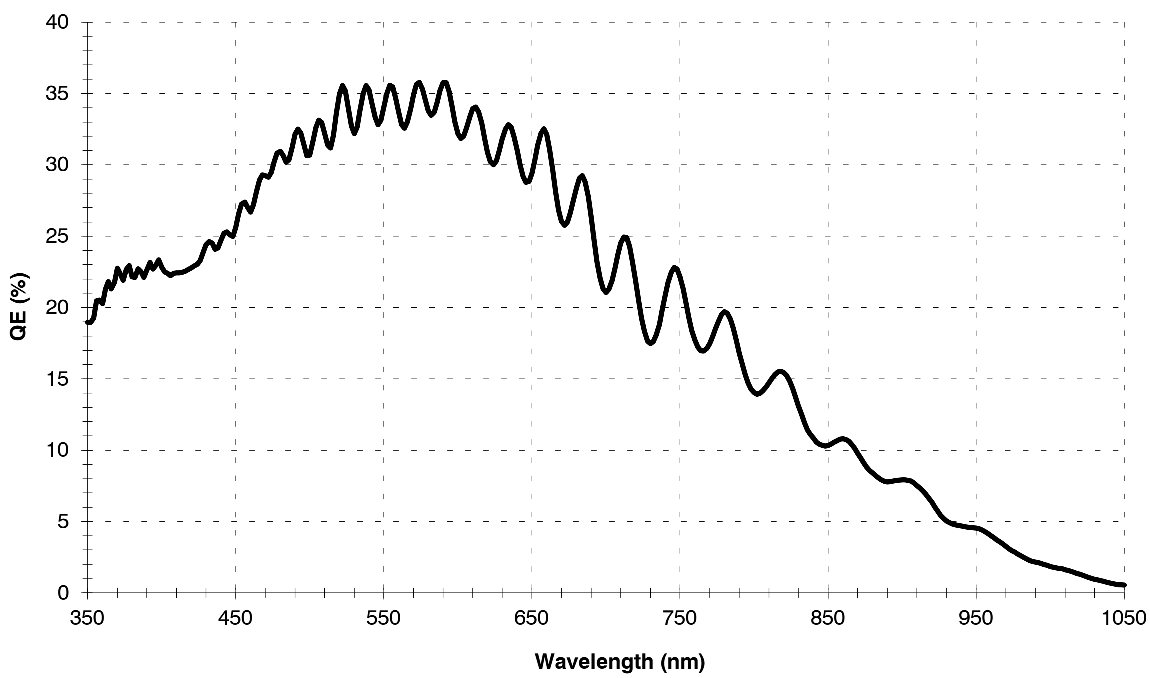

Figure 1. Spectral Response of a CMOS Image Sensor

Images captured by a solid state image sensor are, therefore, monochrome in nature. To generate a color image, three primary colors (Red, Green, Blue) are required for each pixel. Before the invention of color image sensors, the color image was created by superimposing three identical images with three different primary colors. These images were captured by placing a color filter in front of the sensor, allowing a certain bandwidth of the visible light to pass through.

Bayer Color Filter Array and Color Interpolation

In early 1970s, Bryce Bayer realized that an image sensor with a color filter array (CFA) pattern like that shown in Figure 2 would allow the reconstruction of all the colors of a scene from a single image capture. This specific CFA pattern is now known as a “Bayer pattern” and is used in most of the world’s color digital camera systems.

G1	R	G1	R
B	G2	B	G2
G1	R	G1	R
B	G2	B	G2

Figure 2. Bayer CFA Patterns

After capture, the signal of each pixel is read out sequentially; digitized and stored in memory. The original data for each pixel only contains information about one color, depending on which filter is positioned over that pixel. However, information for all three primary colors is needed to construct a color image. The missing information is extracted based on the information gathered by the neighboring pixels. This is called “color interpolation”. There are a variety of interpolation methods, such as “Nearest Neighbor Interpolation”, “Bilinear Interpolation”, and “Bi-cubic Interpolation”, etc. These simple methods are described in the literature. The quality of the final image depends in large part on which algorithm is used. For this reason many camera manufacturers consider their best color interpolation algorithms to be trade secrets and do not publish them.

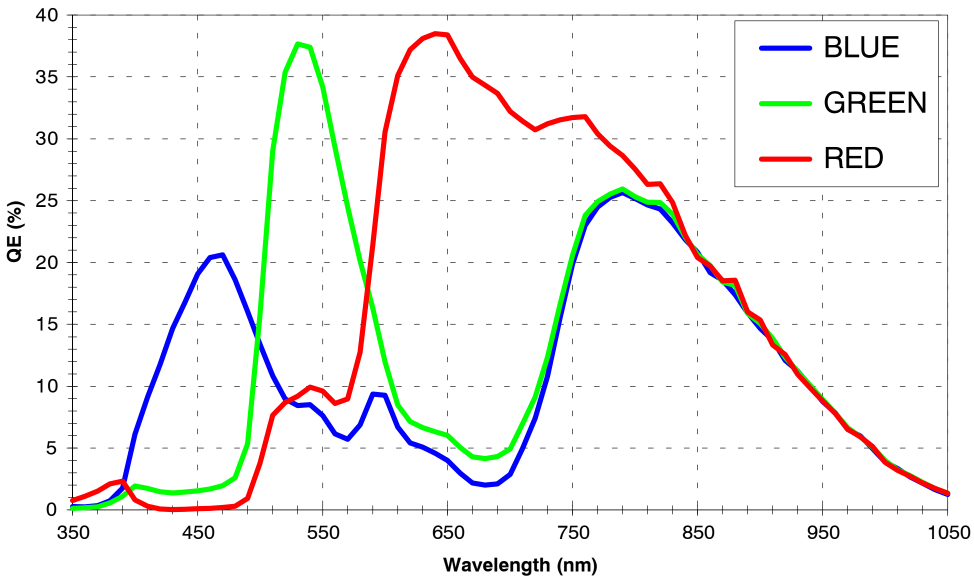

Figure 3. Spectral Response of a CMOS Sensor with RGB CFA

The colors values obtained through the color interpolation process are called native colors. Due to the spectral characteristics of the optics (lens, filters) used in the system, the lighting conditions (such as daylight, fluorescent, or tungsten) of the scene, and the characteristics of the color filters of the sensor, the native RGB data may not provide a faithful color rendition.

Color Correction Matrix (CCM)

For this reason an additional step called color correction is required. In most cases, the native spectral RGB is first converted into a standard R’G’B’ (sRGB, for example) color space by a 3x3 color correction matrix, shown in Figure 4. sRGB is the standard color format for most digital imaging input and output devices.

$$\begin{matrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{matrix} \bullet \begin{matrix} R \\ G \\ B \end{matrix} = \begin{matrix} R' \\ G' \\ B' \end{matrix}$$

Figure 4. Color Correction Matrix for RGB → R’G’B’

Generating the correct values for the 3x3 color matrix requires a great deal of knowledge in image science. The spectral response of the CCD is different from the spectral response of an output device. In turn, the spectral response of the output device is different from the spectral response of the human eye. Therefore, “perfect” color reproduction is not possible, because we do not have the spectral information for the scene. ON Semiconductor will provide analytical matrix coefficients (a_{ij}, b_{ij}) to its customers given the characteristic of the optics and a certain lighting condition for a specific sensor. This matrix minimizes the color error for the range of hues of which the eye is most critical. The native primaries can then be converted to the color space to match the output device for optimal color reproduction.

Many imaging systems function more efficiently by using a luminance/color−difference color space, such as YUV or YC_rC_b. This allows the system to process the brightness and color signals separately. Figure 5 shows the color conversion matrix from the standard sRGB color space and the YC_rC_b color space for JPEG compression.

$$\begin{matrix} +0.289 & +0.587 & +0.114 \\ -0.169 & -0.441 & +0.500 \\ +0.500 & -0.418 & -0.081 \end{matrix} \bullet \begin{matrix} R' \\ G' \\ B' \end{matrix} = \begin{matrix} Y \\ C_b \\ C_r \end{matrix}$$

Figure 5. Color Conversion Matrix for R’G’B’ → YC_rC_b

Today, the conversion matrix operation is generally performed in a digital signal processor. After the processing, the data can be converted back to a color space suitable for any output device.

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