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APPLICATION NOTE

ImageMOS™

White Balance and Color Correction in Digital Cameras

1.0 Introduction

White Balance and Color Correction are processing operations performed to ensure proper color fidelity in a captured digital camera image. In digital cameras an array of light detectors with color filters over them is used to detect and capture the image. This sensor does not detect light exactly as the human eye does, and so some processing or correction of the detected image is necessary to ensure that the final image realistically represents the colors of the original scene.

Before White Balance and Color Correction

After White Balance and Color Correction

Revision 1 – 10/11/00

2.0 White Balance

2.1 Definition

The white balance operation (also called color balance, illuminant correction) uses the color white as the standard for adding the correct overall color 'bias" to a captured image. The aim of this is to basically want all white objects in the scene to be white in the image.

White balance is necessary for two reasons:

1. the sensor itself is not equally sensitive across the visible spectrum, consequently the color of white scene objects will be shifted to have a different hue, and
2. The human eye adjusts to the different hues in illuminants, making white objects appear the same color white even under different colored lights. It is necessary to have the camera do this same adjustment or pictures will look like they have a color cast.

2.2 White Balance Operation

The white balance operation is implemented by making sure white elements in a scene appear white in the image. Output devices such as printers and displays create the color white when the individual color element signals are equal. In other words, white is created on a computer monitor when the RGB signals to the monitor are equal, R = G = B. The same is true for printers. When C = Y = M, the color white is created. So for a captured image, white balance is obtained when the color data signal for white scene elements are equal. When looking at the captured data for a white element in the scene, if R = G = B (or equivalence in other color spaces), the image is "white balanced". If we look at the data for a white scene element and the color data is not equal, we need to perform white balance correction operation so that the color signals are equal and the image is white balanced. The white balance operation takes the form of:

$$\mathbf{R_{wb} = A_1 * R_o}$$
$$\mathbf{G_{wb} = A_2 * G_o}$$
$$\mathbf{B_{wb} = A_3 * B_o,}$$

Where $\mathbf{R_{wb}}$, $\mathbf{G_{wb}}$, and $\mathbf{B_{wb}}$ is the white balanced output signal, $\mathbf{R_o}$, $\mathbf{G_o}$, and $\mathbf{B_o}$ is the **R, G,** and **B** output signals from the camera, before white balancing, and $\mathbf{A_{1\text{-}3}}$ are the coefficients needed to equalize the signals for the color white. Depending on whether you are performing white balance before or after color interpolation, there may be two separate green signals, one for each of the green pixels in the Bayer pattern, and a corresponding white balance coefficient for each.

2.3 White Balance Implementation

White balance can be implemented as a post-processing step. The white balance coefficients needed to equalize the color signals in response to a white scene are computed. The color signals are multiplied by these coefficients and the resulting image is white balanced. This will need to be done for each image captured.

In the Motorola ImageMOS™ arrays, white balancing can be done by individually adjusting the color channel gains for each color signal. This eliminates the need for post-processing of the image. The white balance coefficients are turned into equivalent color channel gains, which adjust the color signals before exiting the sensor array chip.

The challenge of white balance is in determining what the color channel coefficients or gains should be. A typical way of accomplishing this is to capture an image of a white (or grey, grey is just a “shade” of white) card or other white element, and examining the camera output. The proper coefficients or channel gains are computed which make the color signals equal when capturing the white card.

There are several problems with this. White balancing needs to be done for each different illuminant used. A camera which is white balanced outdoors will not be white balanced under indoor illumination, and vice versa. Also most camera users do not want to have to bother to capture white card images and go through the white balance procedure at all, even if infrequently needed. So cameras need to have a way of automatically white balancing themselves. To accomplish this many cameras have white balance algorithms used to determine the white balance coefficients, or settings for different standard illuminants, which can be programmed into the camera.

Motorola’s ImageMOS™ sensors support any of these white balance implementations. White balancing can be done as a post-processing step, or color channel gains can be programmed. White balance coefficients or color channel gains can be controlled by an automatic white balance algorithm and updated constantly if desired. Motorola has companion chips and algorithms developed for this purpose if needed.

2.4 White Balance Coefficients for Standard Illuminants

The following tables gives white balance coefficients and color channel gain values for some typical illuminants. One or the other of these can be used in your system to perform basic white balancing. These settings are for use with Motorola RGGB ImageMOS™ sensor arrays. **These settings, however, are only approximate and are for specific lamps used in Motorola’s laboratories. These values change when different IR filters are used, and when the illuminant spectrums differ from those in the table. No guarantees are provided that these settings will white balance your output images in your specific application.**

Illuminant	White Balance Coefficients			
	Red	Green (of Red)	Green (of Blue)	Blue
Daylight 65	1.32	1.02	1.0	1.2
Horizon	1.0	1.3	1.42	2.74
Cool White Fluor.	1.3	1.0	1.0	1.6
U30 Fluorescent	1.0	1.0	1.1	2.1
Incandescent 'A'	1.0	1.18	1.26	2.2

Table 1. RGGB ImageMOS™ Example White Balance Coefficients

When writing to the ImageMOS™ VGA sensor (MCM20014) in particular, the values that have to be written to the sensors color gain registers are as follows:

Illuminant	Color Channel Gain Settings (hex)			
	Red	Green (of Red)	Green (of Blue)	Blue
Daylight 65	04	00	00	02
Horizon	00	04	06	A0
Cool White Fluor.	04	00	00	09
U30 Fluorescent	02	02	02	0F
Incandescent 'A'	00	03	04	17

Table 2. RGGB ImageMOS Example Color Channel Gain Values for White Balance

3.0 Color Correction

3.1 Definition

Color Correction (also called saturation correction or color saturation) is an additional processing step which "tunes" image colors so they replicate scene colors. Color correction is necessary because the basic filter sets used on digital cameras do not match the color "filters" in the human eye. The colors in captured images usually need to be made more "saturated", which gives a more brilliant look to colors.

3.2 Color Correction Operation

Color correction is another mathematical operation performed on the output signals. In its most common form, color correction takes the form of a 3 X 3 matrix operation:

$$R_{cc} = A_{11}*R_o + A_{12}*G_o + A_{13}*B_o$$
$$G_{cc} = A_{21}*R_o + A_{22}*G_o + A_{23}*B_o$$
$$B_{cc} = A_{31}*R_o + A_{32}*G_o + A_{33}*B_o$$

Where R_{cc}, G_{cc}, and B_{cc} is the color corrected output signals, A_{11} – A_{33} are the matrix coefficients for the color correction matrix, and R_o, G_o, and B_o are the camera output signals (which may of already undergone other processing steps such as white balance).

The challenge of color correction is, of course, to determine the color correction matrix coefficients. The matrix coefficients are computed by a mathematical mapping of the sensor response function onto the color matching function of the output device. The matrix coefficients change for different lenses and IR filters used, for different output devices such as monitors and printer, and for different types of sensors and color filter options. The matrix coefficients are therefore variable under different applications and hardware usage.

Motorola has determined that the following color correction matrix may work with Motorola's ImageMOS™ sensors under many applications. This matrix is provided as an example only and does not ensure it will work for your particular case.

A_{11} = 1.1809	A_{12} = -0.0951	A_{13} = -0.1355
A_{21} = -0.2441	A_{22} = 1.2961	A_{23} = -0.0519
A_{33} = 1.7144	A_{31} = -0.1807	A_{32} = -0.4453

Table 3. ImageMOS™ Example Color Correction Matrix Coefficients

3.3 Color Correction Implementation

There are many other implementations of color correction. In many cases it is not necessary to use a 3 X 3 matrix implementation. Simpler forms of color correction may be used. In other cases more complex, non-linear color correction methods may be warranted.

In digital cameras programmable or variable color correction means are sometimes implemented. Motorola has companion chips and algorithms, which work with the ImageMOS™ sensor arrays for this purpose if needed.