Auto-White Balance for Digital Still Camera

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***Abstract*-Due to the continuing decline in the cost of the digital cameras are becoming increasingly popular. Besides affordability the quality of digital camera is also important for the consumer. There are many factors that have grate effect upon the quality of digital cameras. White balance is one of the keys to the quality of digital cameras. In this paper the white balance methods based on gray world assumption, perfect reflector assumption, and some creative ideas about balancing colors in digital image recorded by digital camera are presented.**

Index Terms-**white balance.**

I. INTRODUCTION

When an image or video sequence is captured, a white object such as a piece of paper, will not show white color in different light sources due to its different color temperatures. To eliminate its effect, a white balance mechanism is needed. Thus color temperature is the one of the factors that causes the variation in colors of the recorded image. What is color temperature? The absolute temperature that we heat a standard black body (metal) to make it radiate the same light as a certain light source is called the color temperature of the light source (See Fig. 1).

At low color temperature the black body radiates the red color and radiant wavelength is relatively longer hence the objects recorded under such light source have reddish color. Similarly, at high color temperature it radiates blue color and radiant wavelength is relatively short hence the objects recorded under such light source have bluish color. But human vision do not cause the variations in colors due to the presence of different light sources because of the "color constancy" of human eye.

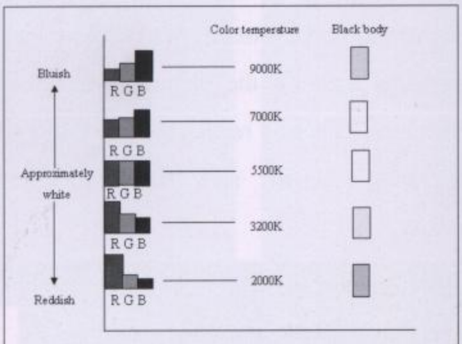

Fig. 1: The process of heating a black body.

To do the simulation with the color constancy, many algorithms are developed such as white balance based on Gray World Assumption, Perfect Reflector Assumption, Fuzzy Rules. We will discuss each method one by one in detail.

II. WHITE BALANCE BASED ON GRAY WORLD ASSUMPTION

The Gray World assumption states that given an image with sufficient amount of color variations, the average values of the red, green, and blue components of the image should meet on a common gray value. In our real world scenes the pictures that we take often have very different color variations. Since those variations in color are random and independent, each of the red, green, and blue components of per pixel in the image has an equal probability of being above or below a fixed value in its respective component. If we take a large enough amount of samples, we would expect each average value of the red, green, and blue components of these samples to converge to a fixed value. Therefore, if we take all pixels in an image with similar dynamic ranges for each of its color components into account, the average values of the red, green, and blue components of the image would tend to converge to a gray color.

How should we implement white balance methods under the Gray World Assumption? There is an idea of making use of an approximate simulation of the chromatic adaptation process of the human visual mechanism. Chromatic adaptation [1] refers to adjustments of the visual mechanism in response to the average chromaticity of the stimulus to which the eyes are exposed, so a white object generally will be recognized as white, regardless of the illuminant under which it is viewed. White balance methods can take advantage of the above visual characteristic by forcing the average values of the red, green, and blue components of the image to converge toward a gray value. For example, if a camera under a tungsten light takes an image, the camera output image will have a red-yellow cast over the entire image. The effect of this red-yellow cast disturbs the Gray World Assumption of the original image. By carrying out the Gray World Assumption on the camera output image, we would be able to remove the red-yellow cast and reconstruct the colors of our original scene.

To find out a reference gray value, just pick the average of the three component averages as the reference gray value for white balance adjustment. But the colors of objects can be described by their brightness, hue, and saturation [2] and human visual systems are more sensitive to brightness signals than chromaticity signals (hue and saturation). Green color signals are good substitutes for brightness signals because approximately sixty percent of the brightness signals come from green color signals and red and blue color signals regarded as the chromaticity signals. Picking up the average of three components as the reference gray value for white balance adjustment increases the probability of changing the brightness signals from the original ones increases, because of this brightness signals are slightly changed, we would easily feel that the color is strange. Hence taking the average of three components as a common gray value is not suitable. Thus making the use of average value of green components as the reference gray value for white balance adjustment is suitable as it not only avoids changing in brightness signals but also reduces the amount of calculation of scaling the color channels toward the reference gray value.

First, the average values of red, green, and blue components of an image (R_{avg}, G_{avg}, and B_{avg}) are calculated as shown in Fig. 2. Some people consider that taking all pixels in an image into account is not an accurate sampling. There is a substitute for only picking up these pixels whose brightness is higher than a certain threshold. Both the sampling methods are basically similar. Second, the ratios of the green average value to the red average value (G_{ave} / R_{ave}) and the green average value to the blue average value (G_{ave} / B_{ave}) are computed. Finally, if the individual ratio falls into the previously designed scope (R_{th} and B_{th}), we believe that the image is at white balance; otherwise, in case that the ratio goes beyond the scope, we need to adjust the red and blue signals according to the ratios (G_{ave} / R_{ave} and G_{ave} / B_{ave}) to accomplish the desired white balance.

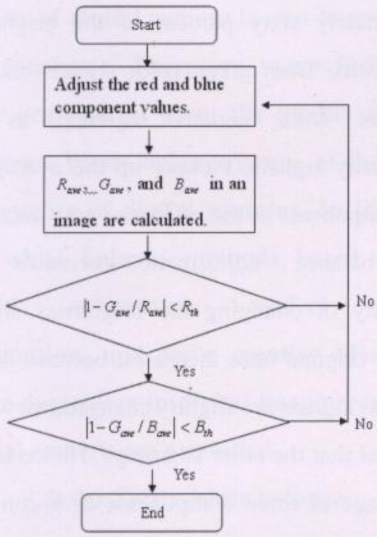

Fig. 2: A white balance flow chart based on the Gray World Assumption.

Generally, white balance methods based on the Gray World Assumption can be used to good effect. However, white balance methods based on the Gray World Assumption forces the color in an image from one extreme to another when a major portion of an image are occupied by an object having a high chromatic color. If we consider the elimination of a large object with high chromatic color and adjust the scale factors accordingly, we would have a better result.

III. White Balance Based on Perfect Refector Assumption

The Perfect Reflector Assumption states that the specularities or glossy surfaces in an image convey a good amount of information about the illuminant. Therefore, the red, green, and blue values of the brightest or most reflective pixel can be used to stand for a relative variation under different illuminants. To make the specularities white, scale the image's individual color component in order to reconstruct the color appearance of an object.

Reason for using the specularities or glossy surfaces in an image as the reference white point is given from the process of trichromatic image capture [3]. The structure of trichromatic image capture is shown as follows:

$$R_{exp} = K_{cr} \sum_{\lambda} S(\lambda) R(\lambda) r_c(\lambda)$$

$$G_{exp} = K_{cg} \sum_{\lambda} S(\lambda) R(\lambda) g_c(\lambda)$$

$$B_{exp} = K_{cb} \sum_{\lambda} S(\lambda) R(\lambda) b_c(\lambda)$$

where R_{exp}, G_{exp}, and B_{exp} are red, green, and blue relative responses; $S(\lambda)$ is the spectral power distribution of the light source; $R(\lambda)$ is the spectral reflectance of the object; $r_c(\lambda)$, $g_c(\lambda)$, and $B_c(\lambda)$ are the red, green, and blue spectral responses of the image-capturing device; and K_{cr}, K_{cg}, and K_{cb} are normalizing factors. The combined product of $S(\lambda)$ and $R(\lambda)$ gives the actual spectral power distribution that hits the eyes or is adsorbed by camera's sensors. The actual spectral power distribution that hits the eyes or is adsorbed by camera's sensors is directly proportional to the spectral power distribution of light source when it comes to specularities or glossy surfaces in an image. Therefore, these specularities or glossy surfaces in an image grasp the actual color of the light source. Thus taking the advantage of these specularities or glossy surfaces in an image as the reference white point for white balance adjustment is suitable.

Generally, pixel with the greatest $(R+G+B)$ value in an image represents the specularities or glossy surfaces which convey a great deal of information about the illuminant. But taking the pixel with the greatest $(R+G+B)$ value in an image as the reference white point is wrong in many situations. Other choice to find out the reference white point exactly is to convert the pixel from the RGB color space to the YC_rC_b color space according to CCIR 601 standard; where Y is the luminance, and C_r, C_b are the color components. The pixel with the highest luminance value in an image could be regarded as the reference white point. The common drawback of both choosing concepts lies in only thinking one pixel over. But still it is more reliable that taking the pixel with the highest luminance value in an image than taking the pixel with the greatest $(R+G+B)$ value in an image as the reference white point.

First, find out the reference white point in an image by converting the pixel from the RGB color space to Y according to CCIR 601 standard for white balance adjustment as shown in Fig. 3. Pick up the pixel with the greatest luminance value as the reference white point. Second, compute the scale factors according to the reference white point. Finally, the red, green, and blue values of each pixel in an image are multiplied by corresponding scale factors respectively. After white balance adjustment, the white regions in the image turn to true white and the regions with other colors are adjusted proportionately.

However, the white balance method based on Perfect Reflector assumption

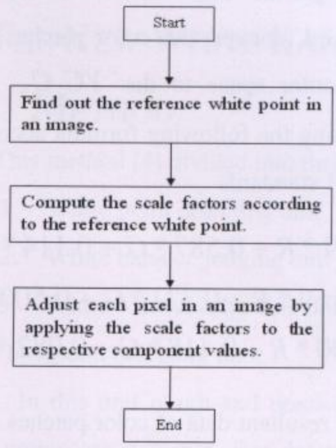

Fig. 3: The white balance methodology flow chart based on the Perfect Reflector Assumption.

do not work well when the image is under relatively bright light conditions or overexposed because of the camera often renders the bright parts of an image as a result of its limited contrast range. If we think over the adaptive exposure settings of an image, we would have a better result after applying this method.

IV. WHITE BALANCE BASED ON FUZZY RULES

This method uses the color characteristics in YC_rC_b color space. To seize the color characteristics in YC_rC_b color space some experiments are perform in order to get related statistic results. According to the statistic results, fuzzy rules are developed and the white balance algorithm is developed according to those fuzzy rules. Next paragraph describes the experiments.

First, place the Macbeth Color Checkers under different light sources indicating distinct color temperatures.

Color Temperature (Kelvin)	6575	4289	2884	2264
Light Source	Daylight	Cool White	INCa	Horizon

Second, use a small window inside each color patch in the Macbeth Color Checkers and calculate the average of those pixels within the windows to get the RGB values of the color patches. Third, convert the color patches from the RGB color space to the YC_rC_b color space by using the following formula according to CCIR 601 standard.

$$Y = 0.299 * R + 0.587 * G + 0.114 * B$$
$$C_b = -0.169 * R - 0.331 * G + 0.500 * B$$
$$C_r = 0.500 * R - 0.418 * G - 0.082 * B$$

Finally, the resultant data of color patches in the Macbeth Color Checkers are plotted on the C_r - C_b coordinate. A monochromatic patch illuminated with a standard light source will be on a nominal position on the C_r - C_b coordinate. However, with different light sources, the position will deviate toward C_r (low color temperature) axis or C_b (high color temperature). Some of the experimental results are summarized in Figure 4.

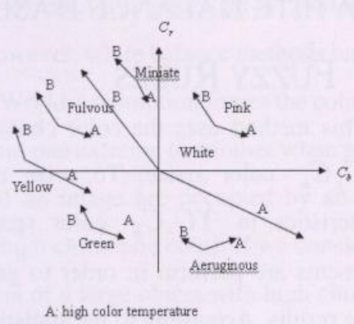

Fig. 4: The experimental data of color patches under different light sources.

The experimental results describe that:

1. A dark color has less deviation from nominal position under different light sources, as opposed to the bright color, where the deviation is significant on C_r and C_b components.
2. When a white color is illuminated with different light sources, the ratio of C_r to C_b will be approximately between –1.5 and –0.5.
3. At high luminance, the color components are easy to be saturated; while at low luminance, the color components become colorless.

The fuzzy rules based on these experimental results are developed for white balance adjustment:

1. The averages of C_r and C_b for each segment will be weighted with small values under the conditions of high-end and low-end luminance in order to avoid being saturated and colorless.
2. The averages of C_r and C_b for each segment are weighted less for dark colors than bright colors.
3. When a large object or background occupies more than one segment, its color will dominate that segment. The ratio of C_r to C_b will be similar among adjacent segments. The given weighting for that segment having a uniform chromatic color is small in order to avoid over compensation on the color of the picture.
4. If the ratio of C_r to C_b of the segment is approximately between –1.5 to –0.5, the probability of being a white region increases, the given weighting is the largest.

After defining the fuzzy rules, the white balance method is developed, for this purpose divide the image into eight segments. The averages of C_r and C_b components of all pixels within each segment are calculated. The weighting factors for each segment are determined under fuzzy rules. Then calculate C_r' and C_b' values of the whole image based on the averages of C_r, C_b components and the weighting factor within each segment; where C_r' and C_b' values indicate the deviation of the image from the white balance point and are used to obtain gains for C_r and C_b values of each pixel. If C_r' and C_b' values are not close to the original point, we consider that it is not at white balance, the iteration will be performed. Fig. 5 is a flow chart of the white balance method under the fuzzy control means.

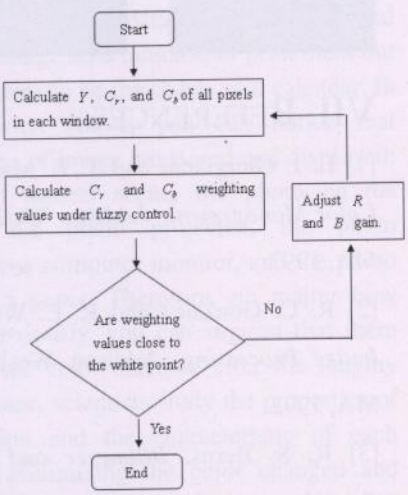

Fig. 5: A flow chart of white balance method under fuzzy control means.

This white balance method under fuzzy control means remove not only the extreme conditions of being saturated and colorless but also the influence of a large object or background having a uniform chromatic color within fuzzy rules. However, the performance of the above method is barely satisfactory because of the two major causes, one is that we do not have enough segments to get a relative grasp for an image, and the other is that it is not suitable to use the same C_r' and C_b' values for C_r and gain adjustments for all pixels.

V. THE NEW WHITE BALANCE METHOD

This method [4] divided into three units:

1. White point detecting unit
2. White balance judging unit
3. White balance adjusting unit

1. White point detecting unit:

In this unit rough and precise reference white points are detected. For detecting rough reference white point first, we put the GretagMacbeth ColorChecker under extremely high color temperature (Daylight) and extremely low color temperatures (Horizon). Second, calculate the average of those pixels present at the bottom of the GretagMacbeth ColorChecker, then calculate those chromaticity values ($\sqrt{C_r^2+C_b^2}$) of the achromatic color patches and picked up the largest value as the prescribed threshold (CH_{th}, 60 in our experiments). Finally using the Equation 1.1 highly chromatic colors are detected and removed from overall image pixels values which are converted into YC_rC_b color space. To get rough reference point, we took the average of all pixels from

$$\sqrt{C_r^2+C_b^2} \le CH_{th} \qquad (1.1)$$

which we removed the highly chromatic pixels. For detecting precise reference point advance global point detecting method is used.

2. White balance adjusting unit:

This unit calculates the ratio of the rough reference white pixels to all pixels of an image

(R_{rough}) and the ratio of the precise reference white pixels to all pixels of an image ($R_{precise}$) and a P_{rough} value, defined as prescribed proportion (0.2 in our experiments). Finally mode M_a is set to 0 or 1 or 2 as shown in Fig. 6.

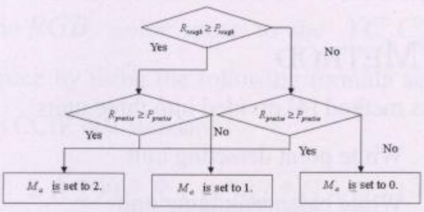

Fig. 6: The flow chart of Mode setting.

3. White Balance Adjusting unit:

This unit corresponds to compute the scale factors according the M_a and use it to scale the components. The rough reference white point defined as (R_r, G_r, B_r) and Y_r is the luminance value of the rough reference white point calculated by using Equation 3.1,

$$Y_r = 0.299 * R_r + 0.587 * G_r + 0.114 * B_r \qquad (1.5)$$

Thus the scale factors of each color component according to the rough reference white point are,

$$R_{rgain} = Y_r / R_r$$
$$G_{rgain} = Y_r / G_r$$
$$B_{rgain} = Y_r / B_r$$

Similarly, scale factors of each color component according to the rough reference white point are,

$$R_{pgain} = Y_p / R_p$$
$$G_{pgain} = Y_p / G_p$$
$$B_{pgain} = Y_p / B_p$$

When M_a is equal to 0, the white balance adjustment is stopped. When M_a is equal to 1, we select the minor between ($R_{rgain}, G_{rgain}, B_{rgain}$) and ($R_{pgain}, G_{pgain}, B_{pgain}$) as the actual scale factors. When M_a is equal to 2, we select ($R_{pgain}, G_{pgain}, B_{pgain}$) as the actual scale factors. Third, scale each color component according to its respective scale factor.

VI. Visual Results

Image taken under

Cool White Light

Resulting images after applying:

Gray World Assumption	Perfect Reflector Assumption
	
Fuzzy Rules	The New white Balance method
	

VII. References

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