A Method to Improve Robustness of the Gray World Algorithm

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Abstract. The gray world algorithm is a popular white balance algorithm used for digital camera, but its effect is influenced by the wrong color temperature estimation result due to the incorrect assumption. To resolve this problem, an improved method of gray world algorithm is presented in this paper. Every patch in the picture is detected by edge detection, and weight value is set for each one according to the size of the patches. Then this weighted image is processed by the gray world algorithm to reduce the influence of big color patches in the image and promote the accuracy of color temperature estimate. The simulation results show that this algorithm can achieve more accurate white balance correction than other gray world algorithm.

Introduction

Color constancy of human eyes can make us recognize the true color of objects under complex illumination conditions. However, image sensor records the real color of objects, so a picture captured by image sensor depends not only on the color of the object, but also the color temperature of external light source. Such as, a white object under the low color temperature appears reddish. On the contrary, it is bluish in high color temperature environment. To correct this color deviation due to different color temperature of light source, white balance algorithm is necessary to adjust the image recorded by sensor. The aim of this adjustment is not only the appearance of the image, but also significant for the next use, such as object analysis, pattern recognition, medical imaging, etc.

In the past years, several automatic white balance algorithms have been proposed [1]. Generally, these algorithms can be divided into two classes, algorithms based on direct pixel calculation and algorithms using information obtained by learning. The first class includes gray world algorithm [2], perfect reflect method [3] and so on. Because of its low computational complexity, it is suitable for situations with high real-time requirements such as digital camera and cell phone. But the large color patches in the scene seriously affect the algorithm's color temperature estimation accuracy, which has impaction on color adjustment result. Some methods have been proposed to resolve this problem, for example, the image regions based algorithm [4], the method searching color patches by machine learning [5], the method based on image feature [6] etc. The second class includes the algorithm based on Neural Network [7], the algorithm based on gamut mapping [8,9,10], the algorithm based on statistical analysis [11] etc. Although those algorithms can achieve good results, they are difficult to meet the requirements of real-time due to the large amount of calculation.

An improved method of the gray world algorithm is presented in this paper, which improves the accuracy of gray world algorithm in the scene existing big uniform color objects. This algorithm reduces their interference by finding those out. In the algorithm, edge detection is applied to determine the edge line of objects, and image region segmentation is performed to find those color patches out. A weight value is set for every found color patch according to their sizes, which decreases these influence on color temperature estimation and improves color adjustment effect.

Gray World Algorithm

Von Kries Theory. Von Kries theory indicates that the transformation relationship between the two different light sources is actually an independent gain adjustment of the three color channels. Three gain coefficients to adjust three kinds of pyramidal signals (M, L, S) are different. In this model, the RGB channel is usually considered as an approximation of the M, L, and S retinal bands.

That is, those three gain coefficients are used to adjust an image under one light source to another one.

An image I under light condition $e = (e_R, e_G, e_B)^T$ can be converted to I' under light $e' = (e'_R, e'_G, e'_B)^T$ by the following Eq. 1.

$$I' = DI = \begin{bmatrix} \frac{e'_R}{e_R} & 0 & 0 \\ 0 & \frac{e'_G}{e_G} & 0 \\ 0 & 0 & \frac{e'_B}{e_B} \end{bmatrix} I \quad (1)$$

The matrix D in the formula (1) is determined by the ratio of the three channels of the two light sources. Formula (1) shows that if the gain coefficient between the light source and the standard light source is known, the image can be adjusted to the standard light source, so the white balance algorithm is realized. In fact the theory is a very important theoretical basis for color constancy. Many white balance algorithms use different methods to get the gain coefficient. Then the image is adjusted by white balance according to the theory.

Gray World Hypothesis. The gray world algorithm is proposed by G.Buchusbaum in 1980, which is a classic auto white balance algorithm. It is simple, effective and widely used. The gray world algorithm is based on an assumption that the average reflectance in the scene with rich color changes is achromatic. That is, the average of three color channels R_{avg}, G_{avg}, B_{avg} should be equal.

In the physical sense, the gray world algorithm assumes that the mean value of the average reflection of the natural scene in standard light is a constant value, which is approximately "gray". In the given image, the gray world assumes that the reflection surface is rich enough, so it can be used as a microcosm of nature. But the average value of three channels is not equal in non-standard light source. That is, the means of three channels are greater or less than the grey value. And the deviation is used to estimate color temperature. The average value of RGB is chosen as grey value under standard light source, as Eq. 2.

$$\text{Gray} = \left(R_{avg} + G_{avg} + B_{avg}\right) \quad (2)$$

The ratio between actual light source *e* and standard light source *e'* is calculated by Eq. 3–Eq. 5.

$$\frac{e'_R}{e_R} = \frac{\text{Gray}}{R_{avg}} \quad (3)$$

$$\frac{e'_G}{e_G} = \frac{\text{Gray}}{G_{avg}} \quad (4)$$

$$\frac{e'_B}{e_B} = \frac{Gray}{B_{avg}} \quad (5)$$

Color Adjustment. According the Von Kries theory, partial color image is adjusted by the gain coefficient from temperature estimate result, as the following formula:

$$R' = \frac{\text{Gray}}{R_{avg}} R \quad (6)$$

$$G' = \frac{\text{Gray}}{G_{avg}} G \quad (7)$$

$$B' = \frac{\text{Gray}}{B_{avg}} B \quad (8)$$

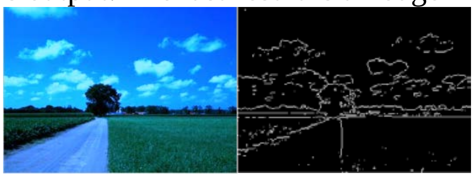
So the white balance adjustment is realized. But the coefficient is obtained by the gray world assumption. When the assumption doesn't hold because of deficient color variations, the coefficient doesn't represent the real relation between environment temperature and standard light source. So the adjustment with this coefficient can't achieve the desired results. For this situation, image edge is used to decrease the weight of those regions and reduce the influence to gray world hypothesis. Then the more correct temperature estimate result and accuracy color adjustment is got.

Edge Based Algorithm

The algorithm based on image edge in this paper contains three steps. First, edge information of the image is detected by edge detection operator. Then the color patches in image are extracted by the edge information. Finally each pixel in image is weighted according to the pixel location, and the gain correction used for color adjustment is got by this weighted image.

Edge Detection. The edge of the image is very important information, and the major basis for image segmentation, recognition and extraction. Edge is the image region with gray level discontinuity, and the edge contains a wealth of information (direction, step properties, shape, etc.). In essence, the image edge is the representative of the discontinuity of image local characteristics, which marks the end of a region and the beginning of another area (gray level mutation, color mutation, texture structure mutation, etc.). Because of the rich color information in the image edge, those areas are very suitable for color temperature estimation.

The Sobel operator filters the noise by weighting influence of the pixels position, so it is chosen to detect image edge. The Sobel operator contains two matrixes which are used to detect the vertical and horizontal edges respectively. Each pixel in the image is operated with the two matrixes, and the maximum value is the pixel's output. The last result is an edge image, as fig. 1 shows.



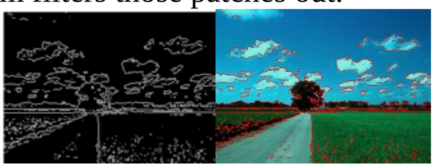
(a) **(b)**

Fig. 1. Edge detection result by Sobel operator: (a) Original image, (b) Sobel's result

Image Segmentation. Image segmentation algorithm based on image edge is used to locate color patches. The boundary search algorithm is used to divide image into color patches. After edge detection, edge connection algorithm is performed to ensure the extracted edge closed. Then based on detected image edge, the region filling and segmentation is completed by the four direction filling algorithm. This algorithm scans edge image from four directions respectively, from top to bottom, from left to right, from top to bottom, from right to left. Then the closed region surrounded by the closed edge is filtered out, and the color patches of the image are separated.

The purpose of edge connections is to make the edge closed, and link the small gap in the middle of the two sides of the edge. It refers the idea of regional growth, and if a large gradient threshold is used, the important edge points are got. Let these edge lines grow along the ends until they meet the image edge or other edge points. Thus the important edge points are retained without many chaos trivial thin edges, and let them form closed contours and facilitate segmentation.

After edge detection and edge connection, the edge image with closed edge is obtained with the maximum degree, and the color patches in original image are surrounded by these closed edges. At last, image segmentation algorithm filters those patches out.



(a) **(b)**

Fig. 2. (a) Image after edge connection, (b) Image segmentation result

White Balance Adjustment. After image is divided into many regions, a weight value $\delta(\mathrm{x,y})$ is set for every pixel according its location.

$$\delta(\mathrm{x,y}) = \begin{cases} 1 & , \ E(x,y) = 1 \\ \left(1 - \frac{s(\mathrm{x,y})}{S}\right) & , \ E(x,y) = 0 \end{cases} \tag{9}$$

$E(x,y)$ is edge image, S is the image size, $s(\mathrm{x,y})$ is the size of the region which the pixel $(\mathrm{x,y})$ locates. By Eq. 9, the basic idea of weight setting is: the weight of pixels in the image edge is set to maximum value 1, for other pixels, those weights depend on those regions' size, the larger the size, the smaller the weight. Using got weight value, the white balance process is completed as following steps. First, the weighted mean of the three channels are calculated by Eq. 10–Eq. 12.

$$R_{avg-w} = \frac{\sum(\delta(x,y)*R(x,y))}{\sum\delta(x,y)} \tag{10}$$

$$G_{avg-w} = \frac{\sum(\delta(x,y)*G(x,y))}{\sum\delta(x,y)} \quad (11)$$

$$B_{avg-w} = \frac{\sum(\delta(x,y)*B(x,y))}{\sum\delta(x,y)} \quad (12)$$

Then, the weighted average gray value of the image is calculated by following formula:

$$Gray_w = \frac{R_{avg-w} + G_{avg-w} + B_{avg-w}}{3} \quad (13)$$

Finally, the more accurate channel gain values are calculated by the Eq. 14 – Eq. 16. According to Von Kries theory, the gain is used to adjust the image with better results. Fig. 3 is the final result.

$$g_{R-w} = \frac{Gray_w}{R_{avg-w}} \quad (14)$$

$$g_{G-w} = \frac{Gray_w}{G_{avg-w}} \quad (15)$$

$$g_{B-w} = \frac{Gray_w}{B_{avg-w}} \quad (16)$$

(a) **(b)**

Fig. 3. White balance results: (a) original image (b) image after white balance

Experimental Results

Subjective Evaluation. In order to make subjective evaluation of the image white balance results, the ColorChecker image library from Simon Fraser University (SFU) Computer Vision Laboratory is used. Every image in this library has a ColorChecker (color testing standard card). Four different sets of images from the picture library are chosen to test algorithm's effect. They are sky scene, grass scene, bright scene and common scene respectively. Fig. 5 is the results of four group images processed by gray world algorithm, regions based algorithm and this paper's improved algorithm.

(a) **(b)** **(c)** **(d)**

Fig. 4. Results of four group image: (a) original image, (b) gray word algorithm, (c) region based algorithm, (d) Improved method

The original image in Fig. 5 (a) has obvious bias because the white balance is improper. The gray world algorithm processed images are shown in Fig. 5 (b). Because the first three scenes don't satisfy gray world assumption, the partial color doesn't get a good correction. In sky scene and grass scene, the bluish original images are over-adjusted, so the results are reddish. The results of the paper [4] in Fig.5 (c) is better than gray word algorithm, but they are still not accurate enough. While the improved algorithm makes more accurate adjustment, processed images have natural color. In bright scenes, the gray world algorithm obviously doesn't adjust the serious reddish image accurately, so the results in Fig.5 (b) are obviously still reddish. The proposed algorithm has more accuracy adjustment results, so the test card shows its true color. For common scene, because it meets the gray world assumption, so the gray world algorithm achieves the desired results, but it is not as accurate as the paper [4] and the improved algorithm. The simulation results show that the improved algorithm get more accurate white balance results. Especially for the scene in which the color is not rich, it effectively avoids the adjusting deviation of the traditional gray world algorithm and achieves better white balance effect under different color temperature.

Objective Evaluation. CIE defined color space CIELUV in 1976, and the value ΔE based on this space color is convenient and accurate to describe the deviation of test color to standard color.

$$\Delta E = \sqrt{C_{ar}^2 + C_{ab}^2} \quad (17)$$

C_{ar} and C_{ab} are the average of C_r and C_b in YC_rC_b color space respectively. The smaller the ΔE value is, the better the effect of the white balance algorithm is.

Table 1: ΔE value of four group image

	Original	Gray World	Paper[4]	Improved algorithm
sky scene	11.63	11.15	7.62	2.49
grass scene	25.10	1.43	2.60	0.62
bright scene	57.39	17.26	11.40	8.80
common scene	31.97	3.012	0.59	1.59

ΔE is calculated on the four group result images of gray world algorithm, image regions based algorithm [4] and the improved algorithm. The results are shown in Table 1. In the three scenes with large color patch, the adjustment for image by gray world is not obvious. Compared with the other two algorithms, the improved algorithm significantly enhances the effect and reduces the ΔE value. This is consistent with the subjective evaluation results of the last section.

Summary

In this paper, the improved algorithm extracts color patches in the scene using edge information. Then weight value is set for every pixel according its location relation with the detected color patch. This method reduces the big color patches' impaction on the results of gray world hypothesis, which makes the algorithm achieve better result. Compared with the gray world algorithm and image regions based algorithm, this algorithm significantly improves adjustment accuracy in different scenes. The simulation results show that the improved algorithm is effective. It can be implemented with FPGA and ASIC to use in ISP, which has good application and economic prospect.

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