Implementation of automatic white-balance based on adaptive-luminance*

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A novel automatic white-balance algorithm based on adaptive-luminance is proposed in this paper. This algorithm redefines the gray pixels region, which can filter the gray pixels accurately. Furthermore, with the relations between gray pixels' luminance with standard light source and their chroma *Cb*, *Cr* shifts with other color temperatures, the algorithm establishes the equations between the captured pixels and the original ones, which can estimate the gains of RGB channels exactly. To evaluate the proposed algorithm, the objective comparison method and the subjective observation method are both used, and the test results prove that the effects of image emendated by the proposed algorithm are excelled to that by traditional algorithms. Finally, the algorithm is implemented with VLSI design, and the result of synthesis proves that it can satisfy real-time application.

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The colors of images recorded by image sensors depend on the illumination. Unlike human vision, image sensors cannot adapt their spectral responses to cope with different lighting conditions. As a result, a captured white object will appear reddish under incandescent light and bluish under fluorescent light. So the captured images need to be corrected by white balance (WB). The white balance adjustment can be performed either manually or automatically. For most consumers, the automatic white balance(AWB) is convenient and expeditious. Therefore, it makes a sense to development the AWB methods. In past years, many AWB methods were proposed, for example the gray world assumption (GW) algorithm, the max white algorithm, the fuzzy rules method, etc[1-5]. But, these algorithms mostly attempt to make corrected images equal to original ones approximately by adjusting the RGB gains of corresponding channel amplifiers. This paper describes a novel AWB algorithm, which can make images return to original images by using the relations between gray pixels' luminance values at standard light source and their chroma *Cb*, *Cr* shifts at other color temperatures. With the objective comparison, the efficiency of image emendated by the proposed algorithm is proved to be excelled to that by the traditional algorithms. Finally, this algorithm is implemented with VLSI design, and the result of synthesis proves that it can satisfy real-time application.

Most of the traditional AWB algorithms make use of the pre-captured image to adjust the gains of the RGB channel amplifiers to achieve white balance. These algorithms have their own merits, and defaults as well.

The gray world approach(GW) is one of the most archaic and commonly known white balance algorithms[1,2]. It assumes that the average intensities of the red, green and blue channels should be equal when plenty of colors abound in an image. The gray world method has the benefits of simple calculation and common practicability. However, when a large object or background with an uniform color, the color compensation may cause the loss of integrity of the color.

In order to overcome the problem existed in gray world, a modified gray world algorithm (MGW) has been proposed [3]. The MGW algorithm predefines an appropriate region in the color differential domain. For color compensation, the values of *R* and *B* gains are converted into values within the predefined region.

The predefined region improves the robust of the MGW algorithm effectively, but the integrated color difference value will be abruptly changed when the object has a monotone color.

Fuzzy rules method employs the fuzzy theory for the color gain determination in order to reduce the effect of a large object with uniform color. Therefore, experiments are implemented to get statistic results. At high luminance, the color components are easy to be saturated; while at low luminance, the color components become colorless.

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By analyzing the above traditional algorithms, this paper proposes a novel algorithm that implements automatic white balance based on adaptive-luminance(LAWB). This algorithm divides into two parts that are the definition of gray pixel region and the calculation of gains.The LAWB redefines the gray pixel region in basis of the following observations: 1) Those pixels with high brightness will be excluded from the region because its color components are easy to be saturated, the same to the pixels of low brightness because its color components are easy to become colorless; 2) The chroma *Cb* and *Cr* of gray pixels are near to the region in *Cb*, *Cr* coordinates; 3) Under different light sources, the ratio of *Cb* to *Cr* of a white object is about between -1.5 and -0.5. The redefined region can be expressed by (1).

$$\begin{aligned} &\chi < Y < \mu \\ &-\alpha < Cb < \alpha \\ &-\beta < Cr < \beta \\ &-1.5 < Cr/Cb < -0.5 \end{aligned} \quad , \tag{1}$$

where χ , μ , α and β are predefined parameters. With the redefined region, the LAWB algorithm can sieve the gray pixels from the captured image accurately.

The image recorded by image sensor is usual RGB format. The analysis of LAWB algorithm needs to use *YCbCr* format image, and the conversion matrix between RGB color space and YCbCr color space is shown as the following formula:

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.1687 & -0.3312 & 0.5000 \\ 0.5000 & -0.4187 & -0.0813 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} . \tag{2}$$

For the gray pixel under the standard light source, its color values of the RGB color space and YCbCr color space have the following relations:

$$Y = R = G = B \ , \ Cb = Cr = 0 \ . \tag{3}$$

When the light source has been changed, the values of R, G and B of gray pixel will shift accordingly. Supposed that ΔR , ΔG and ΔB are the shifts of the values of *R*, *G* and *B* and Y' , Cb' and Cr' are the values of the pre-captured image, the correlation of them can be described as (4).

$$\begin{bmatrix} Y' \\ Cb' \\ Cr' \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.1687 & -0.3312 & 0.5000 \\ 0.5000 & 0.4187 & -0.0813 \end{bmatrix} \begin{bmatrix} R+\Delta R \\ G+\Delta G \\ B+\Delta B \end{bmatrix} . \tag{4}$$

If we can find out the correlation between ΔR and *R*, we will compute the gain R_g of the *R* channel by (5). G_g and B_g of the *G* and *B* channels are adjusted similarly.

$$R_g = R/(R+\Delta R) \ . \tag{5}$$

Supposed that the average values of the pre-captured image in YCbCr space are $\overline{Y}$, $\overline{Cb}$ and $\overline{Cr}$, we can acquire equations (6), (7) with (2), (3) and (4).

$$\overline{Cb} = -0.1687\Delta R - 0.3312\Delta G + 0.5000\Delta B \ , \tag{6}$$

$$\overline{Cr} = 0.5000\Delta R + 0.4187\Delta G - 0.0813\Delta B \ . \tag{7}$$

To find out the correlations between ΔR , ΔG , ΔB and $\overline{Y}$, $\overline{Cb}$, $\overline{Cr}$, we must search for the third equation.

Wang[6] testified in his study that gray pixels' luminance *Y* with standard light source and their chroma CbCr under other color temperatures have the correlation. Through capturing GretagMacbeth ColorChecker under different standard light source in light box, they find that the value *Y* of the neutral blocks (from white to black) is linearly proportional to the sum of absolute values of *Cb* and *Cr* at any light source approximately. Furthermore, when the value *Y* is below a given value, the line proportions at different light sources are equal nearly, as shown in Fig.1.

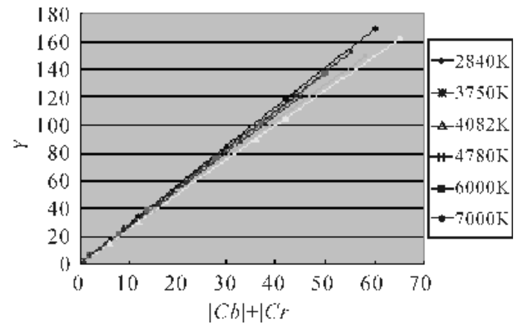

Fig.1 The relationship between illumination value and the sum of absolute values of *Cb* and *Cr*

Therefore, we might suppose that those proportions under different light sources can be replaced by a fixed value *k* when *Y* is less than a given value. Then we can obtain the formula (8).

$$Y = k(|\overline{Cb}| + |\overline{Cr}|) . \tag{8}$$

The following formulas can be obtained from the Eqs. (3) and (4).

$$Y = 0.299(\overline{R} - \Delta R) + 0.587(\overline{G} - \Delta G) + 0.114(\overline{B} - \Delta B) \ . \tag{9}$$

Combining the formulas (8) with (9), we can acquire (10).

$$\overline{Y}-k(|\overline{Cb}|+|\overline{Cr}|)=0.299\Delta R+0.587\Delta G+0.114\Delta B \cdot \quad (10)$$

With the (6), (7) and (10), we can achieve the following formulas.

$$\Delta R=-1.92\left[\overline{Y}-k(|\overline{Cb}|+|\overline{Cr}|)\right]+1.405\overline{Cb}+3.487\overline{Cr} \quad , \quad (11)$$

$$\Delta G=2.488\left[\overline{Y}-k(|\overline{Cb}+\overline{Cr}|)\right]-0.856\overline{Cb}-1.776\overline{Cr} \, , \quad (12)$$

$$\Delta B=\left[\overline{Y}-k(|\overline{Cb}|+|\overline{Cr}|)\right]+4.232\overline{Cb} \quad . \quad (13)$$

After the value ΔR has been acquired, we can obtain the value of R_g with the formula (5). It is the same with G_g and B_g. Noticeably, the formula (8) will have a large error when the sum of absolute values of *Cb* and *Cr* is too big. So the thresholds of α and β in formula (1) should not get too much.

To evaluate the algorithm, the objective comparison method and the subjective observation method are both used.

The performance of the LAWB algorithm is evaluated by the light source model proposed by LAM[8]. Firstly, a natural image is changed to an image under incandescent or fluorescent light by the light source model. Then, the output image is corrected by AWB algorithm. Finally, by comparing the white-balanced image and the input natural image, the performance of the given AWB algorithm can be evaluated. Suppose we want to convert a given natural image with color temperature 6500 K into incandescent illumination around 3000 K, the given image is first transformed to CIE-XYZ domain and then multiplied by the following conversion matrix.

$$\begin{bmatrix} \frac{X_{3000K\_white}}{X_{6500K\_white}} & 0 & 0 \\ 0 & \frac{Y_{3000K\_white}}{Y_{6500K\_white}} & 0 \\ 0 & 0 & \frac{Z_{3000K\_white}}{Z_{6500K\_white}} \end{bmatrix} , \quad (14)$$

where $X_{6500\,K\_white}$, $Y_{6500\,K\_white}$ and $Z_{6500\,K\_white}$ are the gray point values of the color temperature of the input image in CIE-*XYZ* domain. In order to evaluate the LAWB algorithm and other algorithms, the Euclidean distance (ΔE_{ab}) in CIELAB between the input image of the light source model and the white-balanced image is calculated for each algorithm:

$$\begin{aligned} &\Delta E_{ab}=\left[(\Delta L)^2+(\Delta a)^2+(\Delta b)^2\right]^{1/2} \, , \\ &\Delta L=L_{output}-L_{input} \, , \\ &\Delta a=a_{output}-a_{input} \, , \quad \Delta b=b_{output}-b_{input} \, , \end{aligned} \quad (15)$$

where L_{output}, a_{output} and b_{output} are the *L*, *a* and *b* coordinates of the output image in CIELAB domain.

Three groups of images with two different color temperature light sources, 2840 K and 7000 K, are used for the simulation. The results are shown in Tab.1 and Tab.2. The first image group represents the images with one dominated color. The second image group represents the images with two dominated colors. The third image group represents the images with abundant colors. The χ, μ, α, β and k values of the LAWB algorithm are set to be 60, 200, 30, 30 , 2.75 respectively.

Tab.1 The average ΔE_{ab} of three groups of images (2840K)

Image group	Before white balancing	GW	SDWGD	LAWB
1	29.57	14.35	13.86	11.43
2	35.16	6.31	6.14	5.82
3	26.46	9.45	8.57	8.21

Tab.2 The average ΔE_{ab} of three groups of images (7000K)

Image group	Before white balancing	GW	SDWGD	LAWB
1	22.16	10.78	10.25	8.87
2	18.56	5.41	5.12	4.96
3	14.22	9.97	9.24	8.54

As indicated in the Tab.1 and Tab.2, the average ΔE_{ab} of LAWB is smaller than that of GW and SDWGD in both 2840 K and 7000 K color temperature light sources. Thus, the LAWB algorithm is a highly effective algorithm.

We apply our algorithm on the image shown in Fig.2(a). Apparently, the color of the image tends to be too reddish.

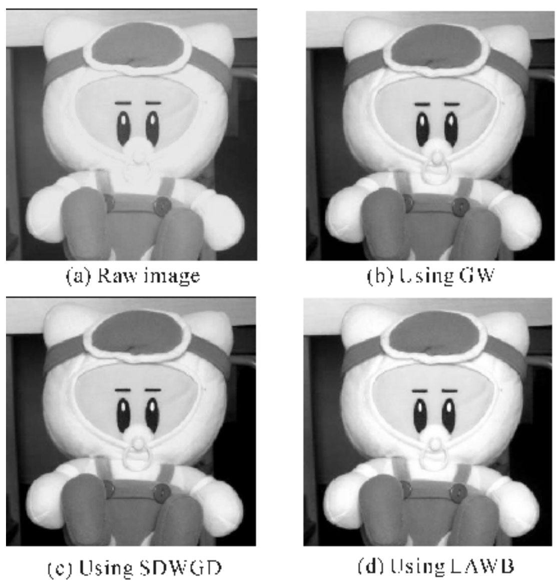

Fig.2 The views of several AWB algorithms

We use three automatic white balance methods respectively, which are GW, SDWGS and the LAWB. The pictures after emendation are shown below. From the pictures, we can see that the result in (b) by GW is too grayish and the result in (c) by SDWGD is still slightly reddish. The result in (d) by our proposed method LAWB is satisfied.

LAWB algorithm has been implemented with VLSI design. The system can be divided into four modules, which are the data processing module, the color space conversion module, the data statistics module and the gain calculation module. The structure sketch of the module division is shown as Fig.3.

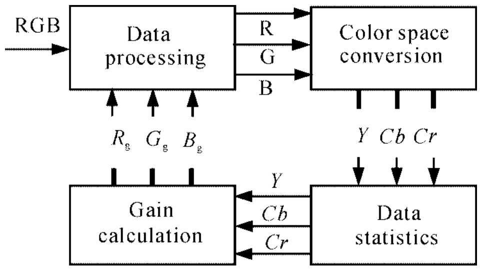

Fig.3 The structure sketch of the LAWB module division

Fig.4 shows the results of simulation about LAWB. The clock period is selected as 30 ns. The rst is the reset signal, and when it is on the high level the system will work normally.

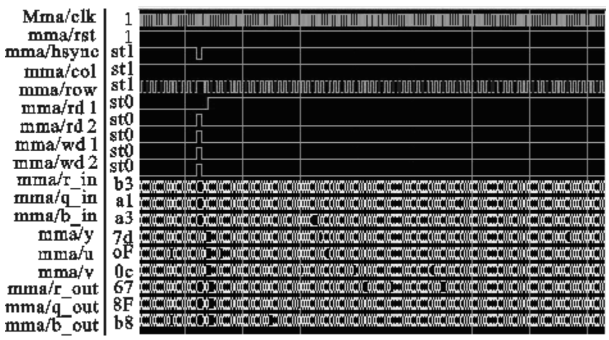

Fig.4 The simulation results of LAWB

The hsync and vsync are the row synchronization and the frame synchronization respectively, and the space between adjacent rows is 2 clks. There is time-delay between input and output of pixels, because the pipelined architecture has been used in the design of multiplier.

The target chip of integration is EP1C12Q240C8N of Cyclone series. The result of synthesis shows that maximum frequency is 76.324 MHz. This result proves that the LAWB algorithm we proposed can satisfy the requirement of real-time processing completely.

In conclusion, a novel AWB algorithm has been presented based on luminance measurement. This algorithm uses the relations between gray pixels' luminance *Y* under standard light source and their chroma *Cb*, *Cr* under other color temperatures and compensates for the color shifts exactly. With simulation test, the algorithm is proved to be highly effective. Finally, this algorithm is implemented with VLSI design, and the result of synthesis proves that it can satisfy the requirement of real-time processing.

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