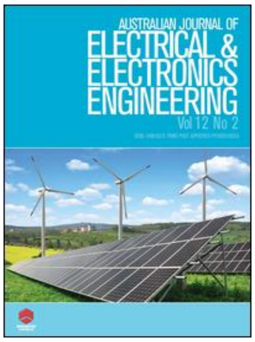

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ARTICLE

A low complexity automatic white balance algorithm for AMOLED hardware driving using histogram shifting with compensation

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ABSTRACT

Automatic white balance (AWB) is one of the most important functions for display devices. As to active-matrix organic light-emitting diode (AMOLED) driving, it not only needs reasonable colour cast correcting results, but also require high power efficiency. In the existing techniques, the power constraint is achieved resource-costly, and has not been applied in AWB algorithms. This article proposes an AWB algorithm combined with simple power constraint method and excellent colour cast correcting ability. Without the part of computing coefficients in conventional AWB algorithms, and replacing most of multiplications with additions, the computational complexity of the proposed algorithm is reduced. The experimental results show that the proposed algorithm is competitive with that of state-of-the-art AWB algorithms and the value of power dissipation for the images processed by the proposed algorithm is 33.76%, 19.95% and 41.26% smaller than grey-world (GW), white-patch (WP) and colour histogram stretching (CHS) algorithm, respectively. The proposed algorithm can also be implemented in AMOLED driving owing to its low computational complexity.

Abbreviation

Power Constraint(PD)

ARTICLE HISTORY

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KEYWORDS

AMOLED; automatic white balance algorithm; power constraint

1. Introduction

In recent years, with the development of science and technology, the display technique has advanced at a significant pace. Active-matrix organic light-emitting diode (AMOLED), as a new generation of display, is regarded to be the indispensable part for future mobile display because of its outstanding properties, such as great image quality, high contrast, wide-viewing angle, short response time and long lifetime according to Chaji, Servati and Nathan (2005, 499–500), Ashtiani, Chaji and Nathan (2007, 36–39) and Michael et al. (2001, 191–195), comparing with LCD or OLED. However, AMOLED's excellent performance should be supported by many driving modules, in which automatic white balance (AWB) plays an important role.

AWB is one of the most essential processing functions for and mobile devices to reduce the colour cast of the image taken under different illuminations. Among all components, the display panels always consume a substantial portion of power in devices as mentioned by Shin et al. (2013, 1017–1030), and traditional AWB algorithms never takes power consumption into consideration while low power is important to nowadays mobile devices, especially to AMOLED screen to increase its lifetime. To improve the efficiency of power dissipation (PD) on AMOLED screens, various work based on software has been done. Lee et al. (2012) proposed a PCCE algorithm based on convex theory. Chang et al. (2016, 623-625) proposed an adjustable pixel dimming to reduce the pixel values, which is further improved by Chondro and Ruan (2016, 791-800) by using overexposure corrector. Although these methods have excellent performance, the high complexity makes them unsuitable for hardware optimisation.

The problem of AWB has been studied for many years. Existing AWB algorithms, in literature, can be divided into two categories: one is low-level-feature-based methods, such as grey world (GW), mentioned by Chengqiang et al. (2015, 791–800) and Buchsbaum (1980, 1–26), white patch (WP), done by Lam (2005) and Wang et al. (2011, 979–983) proposed colour histogram stretching (CHS), based on which lot of work has been done: Ryo et al. (2015, 1562–1570) proposed a white-balancing technique to correct the colour balance of a complex scene under multiple light sources, using intrinsic image decomposition; Im et al. (2014, 127–128) proposed a dark channel prior-based AWB algorithm to estimate white point; the other is high-level-feature-based methods, such as neural network-based Gijsenij and Gevers' (2011, 687–698) work, the Support Vector Machine (SVM) based, the work of Viad et al (2002, 2374–2386), and the scenario semantic information-based methods by Ning, De and Bing (2009, 2279–2282).

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Although high-level-feature-based methods usually achieve better performance, they have lot of predicted models and pretty high computational complexity, and they are more time-consuming and resources exhausting. From a practical point of view, low-level-feature-based algorithms can produce reasonable results with small computational cost, which makes them more preferable in AMOLED driving. In general, low-level-feature-based methods are less complex and more friendly to hardware. However, most of these traditional methods have low robustness. For instance, the GW algorithm works well in images with a sufficient amount of colour variations while it will become invalid in images with a dominant colour; the WP algorithm requires a white area in image; the CHS algorithm only alleviates the colour cast and brighten the image as well, which is not wanted in this word. In addition, the computation of gain coefficients in these algorithms will increase the complexity and there is no method to control the PD, which is essential in the AWB algorithm for AMOLED driving.

In this article, our contributions can be summarised as: 1) an effective *Power Constraint* method, which is not so complex as mentioned in Lee et al. (2012), Chang et al (2016) and Chondro and Ruan's (2016) work, is proposed and applied to the proposed algorithm to reduce the PD; 2) a low computational complexity AWB algorithm is proposed based on histogram shifting with compensation (HSC). In the main part of proposed algorithm, the histograms of red and blue channels are adjusted to match the green channel, which is invariable. In order to make up for the vacancy after the histogram shift of the channel with higher mean grayscale, the compensation part has been proposed to enhance the performance; 3) a hardware display system based on FPGA, SDRAM and AMOLED panel has been built to exhibit the visual results.

This article is organised as follows: In Section 2, we review some traditional AWB algorithms. Then, in Section 3, the proposed algorithm is introduced. Experimental results are presented subsequently in Section 4. Finally, a brief conclusion is given in Section 5.

2. Traditional AWB algorithms

In this section, two low-level-feature AWB algorithms are introduced: one is the classic GW, and the other is CHS.

2.1. Gray world algorithm

One of the most common and widely used traditional AWB algorithm is the GW algorithm.

If an input image with size of M × N, using I(x, y) to present the grey level of the pixel, where x and y depict its position. The first step of the GW algorithm is to calculate the average of R, G, B channel, which is computed as:

$$\begin{cases} R_{avg} = \frac{1}{M\times N}\sum_{x=1}^{M}\sum_{y=1}^{N} I_r(x,y) \\ G_{avg} = \frac{1}{M\times N}\sum_{x=1}^{M}\sum_{y=1}^{N} I_g(x,y) \\ B_{avg} = \frac{1}{M\times N}\sum_{x=1}^{M}\sum_{y=1}^{N} I_b(x,y) \end{cases} \tag{1}$$

where, $I_r(x, y)$, $I_g(x, y)$, $I_b(x, y)$ are the values of red, green and blue channel of the pixel, respectively.

Then, the original pixel values are modified by the Equation (2) to get the new pixel values.

$$\begin{cases} I_r'(x,y) = I_r(x,y) \times \frac{G_{avg}}{R_{avg}} \\ I_g'(x,y) = I_g(x,y) \times \frac{G_{avg}}{G_{avg}} \\ I_b'(x,y) = I_b(x,y) \times \frac{G_{avg}}{B_{avg}} \end{cases} \tag{2}$$

where, $I_r(x, y)$, $I_g(x, y)$, $I_b(x, y)$ are the original pixel values, and $I_r'(x, y)$, $I_g'(x, y)$, $I_b'(x, y)$ are the new pixel values adjusted by the GW algorithm.

The advantages of the GW algorithm is its simplicity and low computation. It works well if the input image has high colour variation. However, for the input image with large part of the same colour or with heavy colour cast, the GW algorithm performs badly, which can be indicated from the gain coefficient in Equation (2).

2.2. Color histogram stretching algorithm

In the theory of CHS algorithm, two tonal thresholds should be found. Then stretching the tonal values between the two thresholds for each channel. The equation is as follow:

$$\begin{cases} I_r' = \frac{I_r - Low_r}{High_r - Low_r} \times range + \min_r \\ I_g' = \frac{I_g - Low_g}{High_g - Low_g} \times range + \min_g \\ I_b' = \frac{I_b - Low_b}{High_b - Low_b} \times range + \min_b \end{cases} \tag{3}$$

where *I* is the input tonal value of a pixel, and *I'* is the output tonal value of a pixel. High and Low are the high threshold and low threshold, respectively. The *range* is the output tonal range and the *min* is the lowest tonal value of pixels, which are default as 255 and 0, according to Su's (2011) work.

2.3. Visual results

Figure 1 shows three images: the original blueish image (left), the one processed by GW algorithm (middle) and the one processed by CHS algorithm

(a)

(b)

(c)

Figure 1. The original blueish image, the one processed by GW algorithm and the one processed by CHS algorithm.

(right). It can be concluded that both the GW and CHS algorithms have poor performance in processing the image with heavy colour cast. Meanwhile, these two algorithms do not have the process to reduce the power consumption is another reason why it cannot be the colour reduction algorithm for AMOLED driving.

3. Proposed algorithm

The GW algorithm and the CHS algorithm both have advantages. However, the low robustness and the lack of method to reduce PD are critical problems of the two algorithms.

After studying and verifying the two algorithms, we are inspired to propose our colour reduction algorithm, namely HSC. The core ideas of the algorithm include the introduction of power constraint and compensation, and the replacement of multiplications by additions.

Figure 2 is the flowchart of HSC algorithm. Firstly, the grey levels of the three channels are processed by power constraint. The next step is HSC.

3.1. Power constraint

In order to meet the requirement of the low power consumption and prolong the lifetime of AMOLED display, it is obliged to reduce the display power while the image quality is good enough for consumers. One effective method is to add a pretreatment, power constraint, before adjusting grey levels. The method needs to multiply the original grey levels by a power constraint coefficient k, where $0 < k < 1$. The advantage of this method is that the grey levels can be decreased without changing the shape of the histogram. The key point in this step is to compute k, and the method proposed by this article is described as follow.

- **Step 1**: Calculate the sum of R, G and B channel by all pixels and representing as SR, SG and SB, respectively
- **Step 2**: Three coefficients used to deter-mine the power constraint coefficient are calculated by SR, SG and SB.
- **Step 3**: The power constraint coefficient is determined based on the three coefficients from step 2.

The computational process is described as:

$$\begin{cases} k_1 = \min\left\{\frac{SR}{SG}, \frac{SG}{SR}\right\} \\ k_2 = \min\left\{\frac{SR}{SB}, \frac{SB}{SR}\right\} \\ k_3 = \min\left\{\frac{SG}{SB}, \frac{SB}{SG}\right\} \\ k = \min(\max(k_1, k_2, k_3, 0.8), 0.9) \end{cases} \tag{4}$$

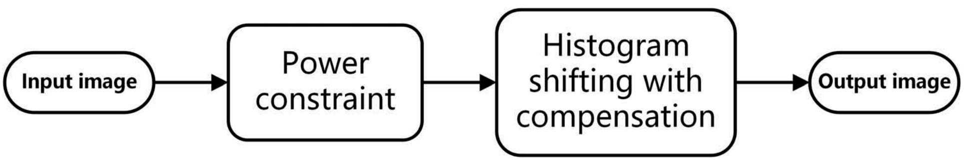


Figure 2. Flow chart of the whole process.

We empirically evaluate the equation above and the advantage is that power constraint achieves expected effect while the coefficient k is ensured not to be too small (or too large) to darken the image badly (or make power constraint in invalid). The grey levels of each channel are updated by:

$$H'[i] = H[i] \times k, 0 \le i \le N - 1 \tag{5}$$

where $H[i]$ is the original grey level of the i-th pixel, and $H'[i]$ is the updated grey level, and N is the total number of the pixels.

While the step of power constraint is done, it comes to the process of histogram shifting.

3.2. Histogram shifting

Histogram shifting is the method to change the position of the histograms of the input image to enlarge the overlap area. Only the red and blue channels are moved while the green channel is invariable.

Firstly, the average of R, G and B channel should be calculated, which is the same as the first step in the GW algorithm. The values can be obtained from Equation (1).

Secondly, two difference, of which one is between red and green channel and the other is between blue and green channel, are computed by the three average values.

$$\begin{cases} diff_1 = R_{avg} - G_{avg} \\ diff_2 = B_{avg} - G_{avg} \end{cases} \tag{6}$$

Then, it needs to keep the grey levels of green channel invariable and subtract the two corresponding differences from the grey levels of red and blue channel, respectively. The new grey levels are obtained by:

$$\begin{cases} I_r'(x,y) = I_r(x,y) - diff_1 \\ I_g'(x,y) = I_g(x,y) \\ I_b'(x,y) = Ib(x,y) - diff_2 \end{cases} \tag{7}$$

After shifting, there is no pixel of blue channel with high grey level, while the high grey levels show the important characteristics of the image. To make up for the vacancy, the compensation is proposed.

3.3. Compensation

There are two main steps in this part.

- **Step 1**: Determine the region of compensation.

$$dx = [X_{\max}(x,y) - (X_{avg} - G_{avg}), X_{\max}(x,y)] \tag{8}$$

where, X represents one of the red or blue channel, X_{max} represents the biggest value of this channel.

- **Step 2**: Sample the pixel $I(x,y)$, whose value is in the region dx, according to its coordinate number $n = x + y$. The sampling interval is set to be $T = 3$, which is determined by experimental results. The specimen's value keeps in-variable and the others are adjusted by histogram shifting.

3.4. Visual results

Figure 3 shows the image processed without compensation and that processed with compensation. They show better performance compared with those in Figure 1. From the right image in Figure 3, the highlight part (the sky) is more brilliant than that in the left due to the compensation.

In summary, the first step of HSC algorithm is to multiply the grey levels with power constraint coefficient k, which can decrease the PD of the algorithm. Then, the grey levels of the red and blue channel are renewed by histogram shifting while keeping the green channel invariable. Finally, the bigger one of the red and blue channel is processed by the compensation.

By this method, the PD is reduced, and the colour cast is reduced a lot because the main part of each channel is almost coincided with the other two channels by histogram shifting. In addition, lots of multiplications used in traditional algorithms are replaced by additions in our HSC algorithm, which is more friendly to hardware. As a result, the proposed HSC algorithm is suitable for AMOLED driving.

(a)

(b)

Figure 3. The image processed without compensation and that processed with compensation.

4. Experimental results and analysis

In this section, we present a number of experimental results to demonstrate the performance of the processed algorithm, in comparison with other state-of-the-art low-level-feature-based ABW algorithms.

4.1. Experiment setup

4.1.1. Software environment

We implemented a custom displaying Matlab simulation platform, which was initially used for algorithm exploration, and which later served as the analysation for the processed data.

4.1.2. CAD tools

For physical display, we built a Verilog-based display system, which we both designed and synthesised the initialisation (for SDRAM), read (from SDRAM) and display of the system using Altera Quartus II.

4.1.3. Hardware display system

The complete hardware display system consists of PC (used to input an original image), FPGA (in which is the AMOLED driving logic), SDRAM (used to store the hex-format image data from PC) and Samsung AMOLED panel (used as display panel). The detail of all the components above is illustrated in Table. 1.

The images processed by algorithms have been displayed on FPGA with SDRAM to drive the AMOLED screen. The system diagram and hardware system for the AMOLED display is showed in Figure 4.

4.2. Evaluation methodology

4.2.1 Overlap Area (OA)

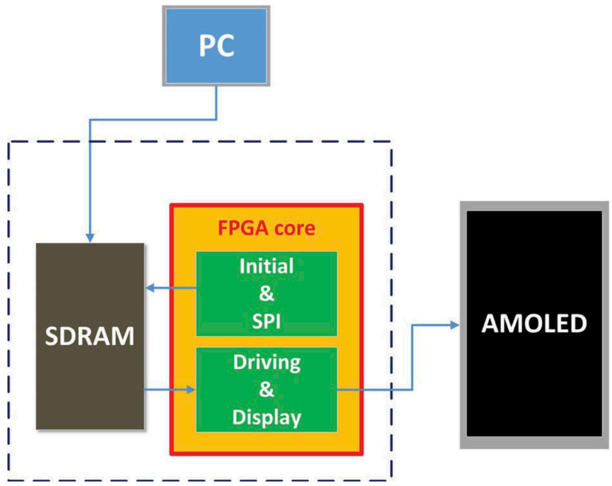
Overlap area is an important parameter to evaluate the effect of algorithms, which is computed by:

$$\begin{cases} OA = \sum_{i=0}^{255} \min(hist\_r[i], hist\_g[i], hist\_b[i]) \\ hist\_x[i] = Hist\_x[i]/(M \times N) \end{cases} \quad (9)$$

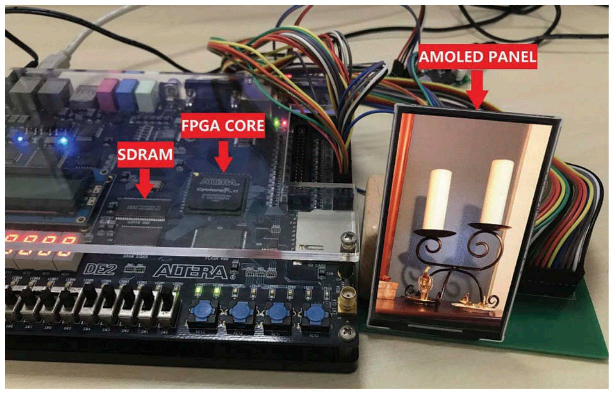
where OA represents the overlap area of histogram of an image, *Hist_c[i]* represents the number of pixels with the grey level *i*, *hist_c[i]* represents the ratio of *Hist_c[i]* to *N*, and *c* can be *r*, *g* or *b*. *N* is the total number of pixels of image, *W* and *H* is the horizontal and vertical resolution, respectively.

Table 1. Hardware display system.

Device	Version	Function
PC	/	Load original image
FPGA	Cyclone II EP2C35F672C6N	Driving & display logic
SDRAM	ISSI IS42S16400D-7TL	Storage
AMOLED	Samsung AMS369FG06	Display panel



(a)



(b)

Figure 4. System diagram for AMOLED display and hardware display system (PC is excluded).

4.2.2. Euclidean Distance (ED)

Euclidean distance (ED) is another parameter to evaluate the effect of algorithms, proposed by Jang et al. (2008, 1462–1465). The first step to calculate ED is to convert the image to CIE L*a*b* space, in which the reference white point is defined as $L_1^* = 96$, $a_1^* = -0.062$, $b_1^* = -0.067$. The value of ED is computed by:

$$\begin{cases} ED = \sum_{(i,j)\in\sigma_p} ED(i,j)/N_p \\ ED\,(i,j) = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \\ \sigma_p = \{(i,j)|L_2^* > 50, a_2^* < 15, b_2^* < 15\} \end{cases} \quad (10)$$

where $\Delta L^* = L_2^*\text{-}L_1^*$, $\Delta a^* = a_2^*\text{-}a_1^*$, $\Delta b^* = b_2^*\text{-}b_1^*$, L_1^*, a_1^* and b_1^* is the value of reference white, and L_2^*, a_2^* and b_2^* is the one of the processed image, σ_p is the area of the pixels with the condition of $L_2^* > 50$, $a_2^* < 15$, $b_2^* < 15$. *ED(i, j)* is the value of *ED* of the pixel with the coordinate of *(i, j)*, N_p is the total number of pixels in the area σ_p. *ED* is the distance between those pixels in σ_p with the reference white, which is the smaller the better.

4.2.3. Power Dissipation

PD is the key parameter to evaluate the power consumption of an AMOLED screen. According to the

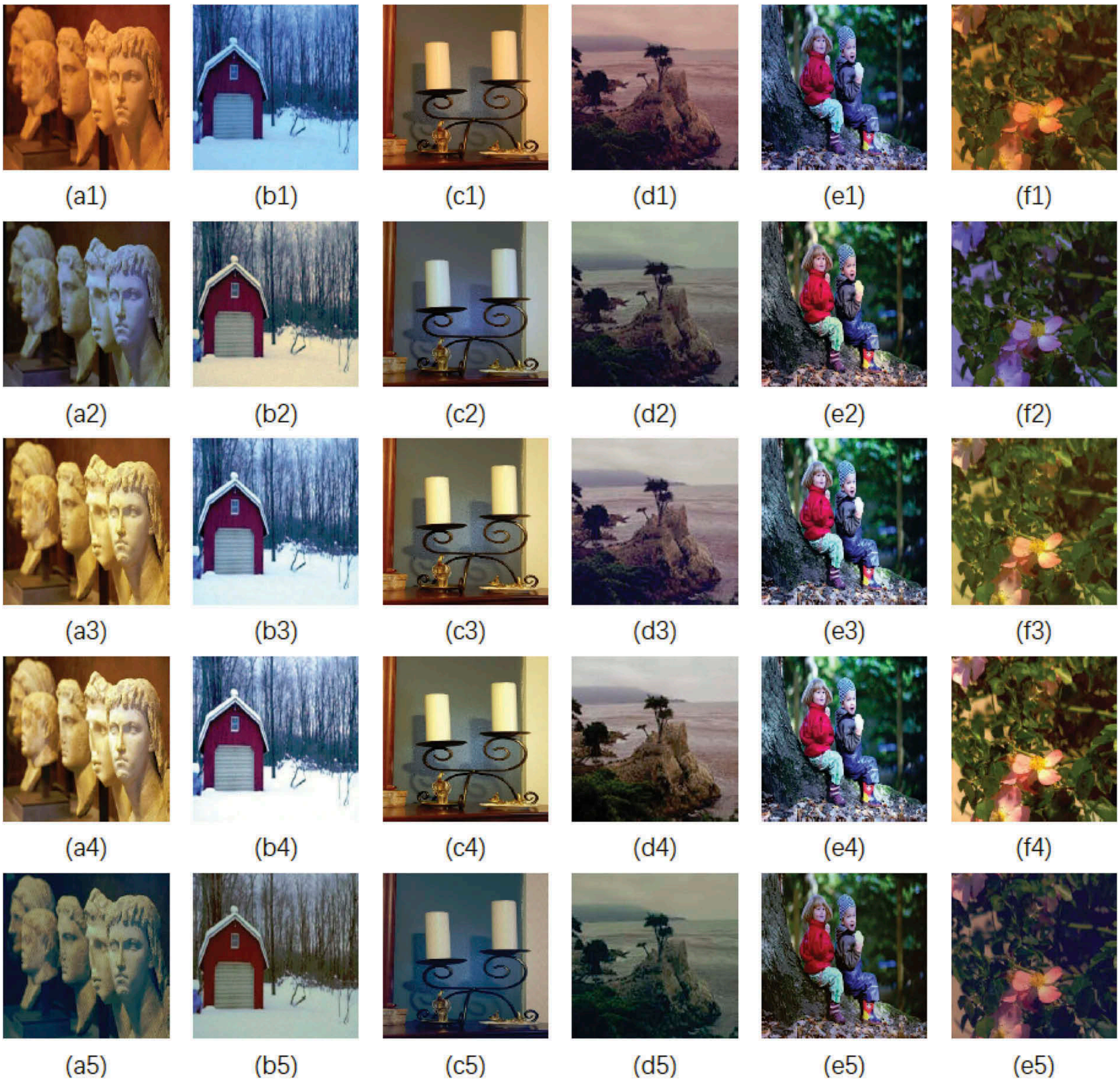


Figure 5. Images processed by different algorithms, where the first row represents the original images, the second row represents the results of GW, the third row represents the results of CHS, the fourth row represents the results of HSC.

work of Dong, Choi, and Zhong (2009), PD can be approximately calculated by:

$$PD = \frac{1}{S}\sum_{i=0}^{M}\sum_{j=0}^{N}[\omega rR^2(i,j) + \omega gG^2(i,j) + \omega bB^2(i,j)] \quad (11)$$

where ω_r, ω_g and ω_b are the corresponding coefficients.

Table 2. Statistics of indexes by different algorithms.

Algorithm	OA	ED	PD
GW [8][9]	0.3303	73.37	552.33
WP [8][10]	0.2723	74.55	457.03
CHS [11]	0.261	81.3	622.87
HSC [proposed]	0.3723	58.21	365.85

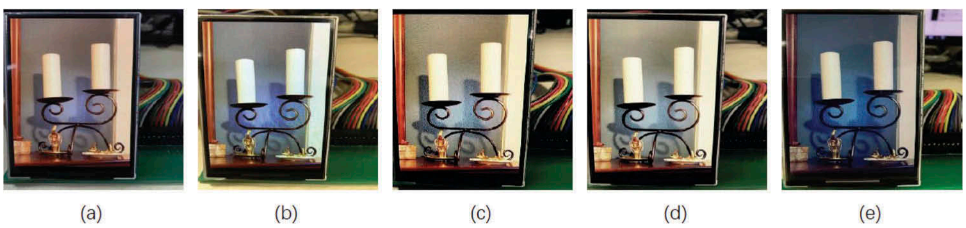


Figure 6. (a) Original image with colour cast, (b) image processed by GW algorithm, (c) image processed by WP algorithm, (d) image processed by CHS algorithm, (e) image processed by the proposed algorithm displayed on AMOLED.

4.3. Experimental results

4.3.1. Subjective evaluations

In order to compare the visual effect of images processed by algorithms above, six images with different colour cast are taken for the examples to illustrate the results, shown in Figure 5, where the images in the first row are the original images, the ones in the second, third, fourth and fifth row are processed by GW, WP, CHS and HSC, respectively. From Figure 5, we can see that the GW algorithm will be invalid when images with one dominant colour; the WP algorithm performs not good when there is no white pixel in the image; the CHS algorithm can only alleviate the colour cast and brighten the whole image, which is a disadvantage when applied for AMOLED driving.

4.3.2. Objective evaluations

More than 20 images with different colour cast are processed by GW, WP, CHS (other complex algorithms are excluded in this part because of their particular experimental environment and most of them are also based on these classic AWB algorithms) and the proposed algorithm, and the mean value of OA, ED and PD for each algorithm are shown in Table 2, from which we can see that the mean value of OA for images processed by HSC algorithm is 12.72%, 36.72% and 42.64% larger than that processed by GW, WP and CHS algorithm, respectively; the mean value of ED for images processed by HSC algorithm is 20.66%, 21.92% and 28.40% smaller than that processed by GW, WP and CHS algorithm, respectively; and the mean value of PD for images processed by HSC algorithm is 33.76%, 19.95% and 41.26% smaller than that processed by GW, WP and CHS algorithm, respectively.

From the statistics above, we can conclude that the proposed algorithm is better than the traditional algorithms in all these three indexes (only not as good as WP in ED). The most important aspect is that the significant improvement of PD benefits from power constraint makes the proposed algorithm suitable for AMOLED driving.

4.3.3. Hardware display

The proposed algorithm has been verified on FPGA with SDRAM to drive the display on AMOLED screen, and it has good performance as expected. The system diagram and hardware system have been shown in Figure 4.

According to the hardware display system, based on Altera Cyclone II FPGA, the original image with red colour cast, the one processed by GW, WP, CHS and the proposed HSC algorithm are displayed on AMOLED panel (they are influenced by illumination a little), shown in Figure 6.

The image processed by proposed algorithm shows good performance, which demonstrates the success of the proposed algorithm and the accomplishment of hardware display system.

5. Conclusion

An AWB algorithm using HSC is proposed for both high quality and low cost in this article. To decrease the PD and improve the display effect, the proposed algorithm combines the method of power constraint and histogram shifting. The experimental results show that the mean value of overlap area (OA) for images processed by our HSC algorithm is 12.72%, 36.72% and 42.64% larger than that processed by classic GW, WP and CHS algorithm, respectively. More importantly, the mean value of PD for images processed by our HSC algorithm is decreased by 33.76%, 19.95% and 41.26% comparing with that processed by GW, WP and CHS algorithm, respectively. The proposed HSC algorithm with high processing quality and low cost is believed to be more suitable for AMOLED driving.

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