# Novel Content Adaptive Algorithm with Low-Power Consumption for Dual-Cell LCDs

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## Abstract

***Dual-cell LCD technology realizes a contrast ratio of up to 200,000:1 by stacking two LCD panels. However, due to the addition of the optical control layer, the power consumption increases. We propose an algorithm to reduce the backlight according to the image content, use a double-layer optical control remapping algorithm to ensure the brightness of Dual-cell LCDs. The average power consumption is reduced by approximately 20%.***

## Author Keywords

Dual-cell LCDs; low power consumption; content adaptive

## 1. Introduction and Background

Local Dimming technology divides the backlight into a number of zones, dynamically adjusting the brightness of each zone to achieve the goals of reducing power consumption and enhancing contrast. The display quality of Local Dimming technology is influenced by the size of its zones. Due to the relatively large size of these zones, halo effects often occur at the boundaries between bright and dark areas. Furthermore, because of the characteristic of backlight diffusion and overlap among different zones, the brightness of high-light content in high-contrast images tends to decrease.

The Dual-cell LCD technology facilitates the division of the backlight into millions of individual zones by adopting a double-layer cell design of black/white panel and color panel.This fine granularity enables pixel-level precision in light control, thereby effectively mitigating the halo effects and brightness decrement of high-light content that are inherent challenges in Local Dimming technology.

However, the incorporation of the light control layer in Dual-cell displays results in a decrease in transmittance, consequently leading to an increase in overall power consumption. This is manifested as relatively high surface temperatures on the display screen. To tackle this issue while preserving the unique advantages of Dual-cell LCD, we proposed an algorithm that dynamically adjusts the global backlight based on the image content to minimize system power consumption. The self-developed mapping curve is used to compensate the data of sub layer and main layer to ensure the the retention of image fidelity and brightness.

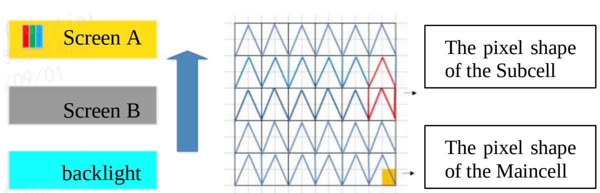


**Figure 1.** Dual Cell screen backlight module schematic diagram and pixel shape

Our Dual-cell LCD technology achieves a contrast ratio as high as 200,000:1, approaching the performance of OLED by stacking two LCD screens. The schematic diagram of its module is shown in Figure 1.

Screen A, referred to as the Main Screen, displays RGB color signals, while Screen B, termed the Dimming Screen, displays grayscale images. Screens A and B are tightly bonded together, with each pixel on Screen B corresponding to four pixels on Screen A. Screen A adjusts details and colors, while Screen B modulates brightness. Through two-dimensional independent light control on Screen B, it achieves million-level zoning for ultra-high-precision dynamic backlight control. The pixels on Screen A (Main cell) are square-shaped. To avoid the generation of rainbow patterns due to the overlay of the two screens, the pixels on Screen B (Subcell) are shaped like a 'V', and the area of one pixel on Screen B is four times that of one pixel on Screen A.

Light from brighter surrounding pixels is blocked by the sub-cell layer, effectively serving as a filter for individual pixels. Consequently, Dual-cell displays can achieve more precise brightness control compared to local dimming backlight techniques. However, due to the unique dual-cell structure, the light emitted from the backlight source needs to pass through two LCD screens, significantly reducing optical efficiency. To ensure that Dual-cell displays achieve the same brightness perceived by the human eye as conventional MLED displays, the backlight of Dual-cell displays requires a higher luminance, leading to increased power consumption and higher surface temperatures.

The algorithmic flow of our proposed content-adaptive dynamic backlight adjustment system is shown in Figure 2, primarily divided into three major modules: backlight brightness calculation, sub-cell backlight compensation, and main-cell data compensation. Different from the conventional dual-cell display, our approach reduces backlight by analyzing the brightness characteristics of each frame, thereby achieving lower power consumption. Based on our proprietary mapping curves, we adjust the brightness of both the sub-cell and main-ell on a pixel-by-pixel basis, ensuring a high contrast ratio while also reducing power consumption.

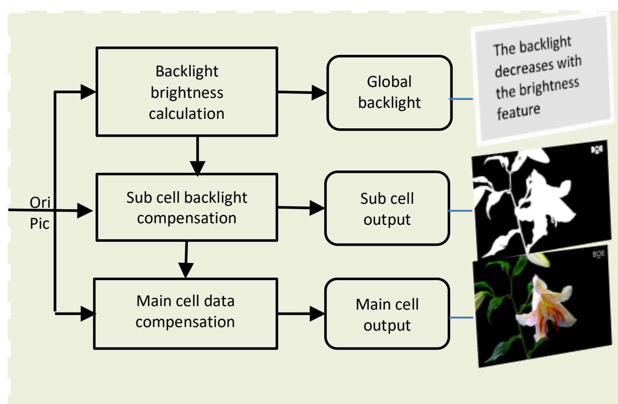


**Figure 2.** The flowchart of proposed algorithm

## 2. Method

### *2.1. Backlight brightness calculation*

Firstly, we classify images into three types based on their brightness characteristics of each frame: high-contrast images,


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high-brightness images, and natural images. If an image simultaneously contains high-brightness and low-brightness regions, and the proportion of the low-brightness region to the total image area exceeds the low-brightness classification threshold, while the proportion of the high-brightness region exceeds the high-brightness classification threshold but is less than the highlight image judgment threshold, then the image is deemed a high-contrast image. If the proportion of the low-brightness region exceeds the low-brightness classification threshold and the proportion of the high-brightness region exceeds the highlight image judgment threshold, then the image is classified as a high-brightness image. If neither of these conditions is met, the image is classified as a natural image.

Secondly, the initial backlight value is calculated according to the image type. In high-brightness images, the proportion of high-brightness regions is significant. Therefore, under this condition, the backlight value is not reduced and the initial backlight value is set to the maximum backlight value. When the image is a natural image, to ensure that when the backlight is reduced, even if the overall brightness of the image decreases, the human eye is not sensitive to the degree of brightness reduction. A minimum backlight brightness threshold for this condition is set based on the maximum brightness value of the original image. A natural-image backlight value can be calculated based on the maximum brightness value, minimum brightness value, and average brightness value of the original image. In this mode, the initial backlight value is set to the maximum of the minimum backlight brightness threshold and the natural-image backlight value. If the image is classified as a high-contrast image, the initial backlight value for this mode is calculated based on the average brightness of the total image and the proportion of the high-brightness regions occupying the whole image area.

Thirdly, the initial backlight value undergoes an adjustment process to ensure a smoother transition in backlight intensity. A significant difference in brightness between consecutive frames can result in abrupt changes in backlight brightness and subsequent screen flicker. To mitigate this, a threshold for the maximum permissible brightness difference without causing a sharp change in backlight, along with a step size for backlight adjustment is established. If the absolute difference in brightness between two successive frames exceeds this maximum brightness difference threshold, the actual backlight output for the subsequent frame is calculated as the previous frame's backlight output plus the backlight adjustment step size.

### 2.2. Sub cell backlight compensation

If the global backlight is reduced while the data of sub cell and main cell remain unchanged, it ensures that no detail in the image is lost, but it leads to a significant decrease in the overall brightness of the image. To address this, compensating both the sub-cell and main-cell data can help maintain the original image information while minimizing the decrease in overall brightness as much as possible (a decrease in brightness is inevitable, especially when the original data of the sub-cell and main-cell for a certain pixel have already reached their maximum values, leaving no room for compensation when the global backlight is reduced).

Firstly, assuming the global backlight remains unchanged, the sub-cell data *sub_old* can be calculated based on the original image.

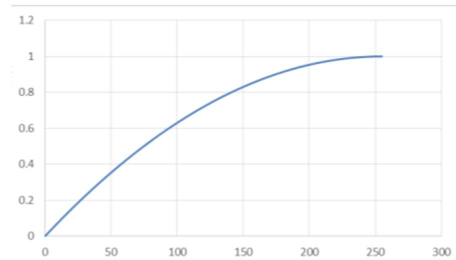
Secondly, the sub-cell data is calculated according to the *sub_old* data and the current frame of global backlight value, as shown in Equation 1:

$$\left(\frac{sub\_new}{255}\right)^{\gamma_1} \times \left(\frac{global\_BL}{255}\right)^{\gamma_0} = \left(\frac{sub\_old}{255}\right)^{\gamma_1} \qquad (1)$$

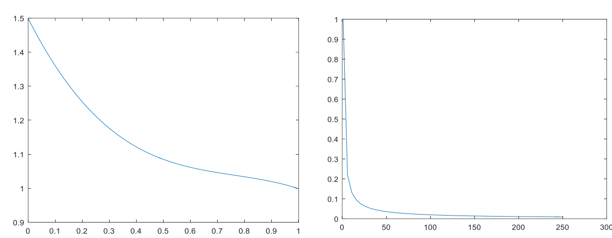
If the *sub_new* data overflow during the compensation process, the maximum value will be taken, and the incomplete data compensation will be completed through the data compensation of the main cell.

Thirdly, filtering processing is applied to the data of the sub-cells. Due to manufacturing deviations, there is a certain distance between the sub-cell and the main cell, and it cannot be guaranteed that each pixel of the two-layer LCD panel corresponds to each other one by one. At the boundary between bright and dark areas, dark content may exhibit halo effects due to overly bright backlight, while the insufficient backlight of bright content leads to a deficiency in details or the occurrence of ghosting phenomena at the interface between bright and dark regions, and these phenomena are more pronounced at large viewing angles.

Based on the brightness distribution characteristics surrounding each pixel, a filter kernel is designed on a pixel-by-pixel basis to perform smooth filtering on sub-cell backlight. The filtering outcome is influenced by four factors: the grayscale value at that position, the ratio of the grayscale value at that position to the maximum value within the filtering range, the ratio of the grayscale value at that position to the grayscale value at the center of the filter kernel, and the distance from that position to the center of the filter.




(a)



(b) (c)

**Figure 3.** Influence of gray value, maximum gray value and center pixel gray value on filtering weight

- (a) The influence coefficient of the grayscale value on the filtering weight is denoted as *K_pixel*. As illustrated in Figure 3(a), the greater the grayscale value, the more significant its impact on the filtering weight.
- (b) The degree of brightness enhancement at the bright-dark boundary of sub-cells is related to the grayscale value of the bright content, necessitating consideration of the relationship between the filtering center and neighboring pixels. The contrast at the filtering center *contrastC* is defined as the grayscale value at the center

to the ratio of the grayscale values within the filter template's coverage. The influence coefficient of contrastC on the filtering weight is denoted as *K_contrast1*. As illustrated in Figure 3(b), the higher the *contrastC*, the smaller the corresponding *K_contrast1*, causing the grayscale value of the central pixel to approach more closely that of the brighter content.

- (c) Pixels with grayscale values lower than the central pixel still possess a certain weight, which may result in insufficient brightness enhancement of the sub-cell grayscale value at the bright-dark boundary. The maximum contrast contrastM is defined as the ratio of the maximum grayscale value within the filtering range to the grayscale value of each pixel within the filtering area. The influence coefficient of contrastM on the filtering weight is denoted as K_contrast2. As shown in Figure 3(c), a higher contrastM indicates that the grayscale value at the corresponding position is smaller compared to the maximum grayscale value, leading to a smaller K_contrast2.
- (d) A distance parameter K_distance is set for the pixels covered by the filtering template relative to the central pixel, where a greater distance results in a smaller filtering weight. This parameter constitutes a fixed template and is unaffected by the sub-cell data.

### 2.3 Main cell data compensation

The purpose of the main cell data compensation module is to calculate the grayscale compensation values for the three channels of each pixel based on the sub-cell data and brightness values of that pixel, and the compensation result is used to drive the LCD. Before and after the backlight reduction, the simulated brightness of the superposition of the main cell data, the sub cell data and the global backlight data should be equal.

When the global backlight is less than the maximum value, there will be liquid crystal compensation overflow, resulting in the loss of display details and brightness reduction. The lower the global backlight value, the smaller the overflow threshold becomes, and the more severe the detail loss in the high-brightness areas. Therefore, we adopt a new curve mapping for the input brightness that exceeds the overflow threshold. For those that do not exceed the threshold, adjustments are made according to the new curve. The specific calculation process is as follows:

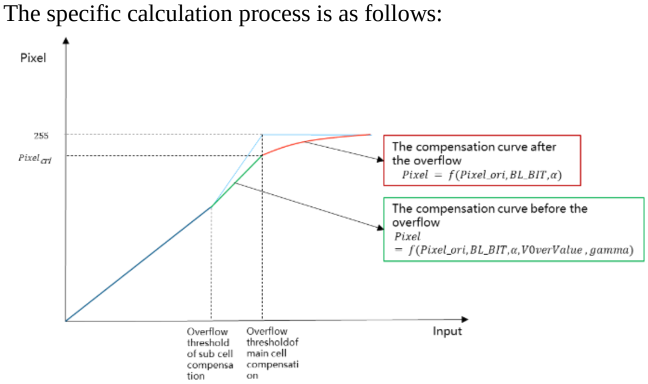



**Figure4.** The main-cell data compensation mapping relationship

Firstly, the backlight value for the current frame image is calculated to determine the corresponding overflow threshold. If the brightness value of a pixel in the input image exceeds this overflow threshold, it will result in compensation overflow and loss of detail in bright areas.

Next, count the maximum brightness of the entire image. If the maximum brightness value of the entire image is less than or equal to the overflow threshold, the compensation values for the three channels of each pixel can be calculated on a pixel-by-pixel basis. However, if the maximum brightness value of the entire image is greater than the overflow threshold, a proprietary mapping curve developed by us is used to determine the compensation values for the three channels of each pixel.

The mapping curve is illustrated in Figure 4. When the pixel compensation in the sub-cell for a given pixel does not exceed the overflow threshold, the main-cell data utilizes the original data. When the brightness value of the pixel is greater than or equal to the overflow threshold, there is a channel overflow situation, and the compensation after overflow is calculated using the compensation curve as described in Equation 2:

$$Pixel = f_{\alpha,BL\_BIT}(Pixel\_ori) \quad (2)$$

$\alpha$ represents the coefficient for the overflow liquid crystal compensation curve.

When the brightness value of the pixel is greater than the overflow threshold of the sub cell, and less than the overflow threshold of the main cell, there is no channel overflow situation in the main-cell data, and the compensation value should satisfy Equation 3:

$$Pixel = f_{gamma,\alpha,V0verValue,BL\_BIT}(Pixel\_ori) \quad (3)$$

After calculating the RGB three-channel compensation values, the dither module can be added to improve the picture quality by selecting the appropriate template.

## 3. Experiment and result

We have validated the content-adaptive algorithm with low power consumption on a 10.25-inch Dual-cell display, using test images with a resolution of 1920x720. The test platform is illustrated in Figure 5:

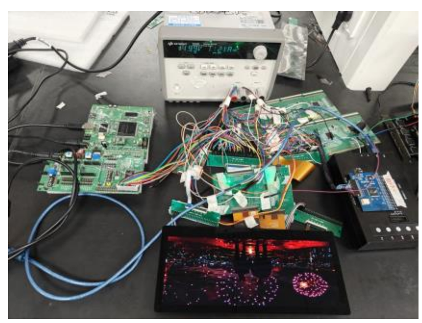


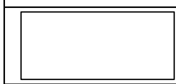
**Figure5.** 10.25-inch Dual-cell Display Testing Platform

We test the effectiveness of our proposed algorithm from three aspects: brightness, picture quality and power consumption.

### 3.1 Brightness test

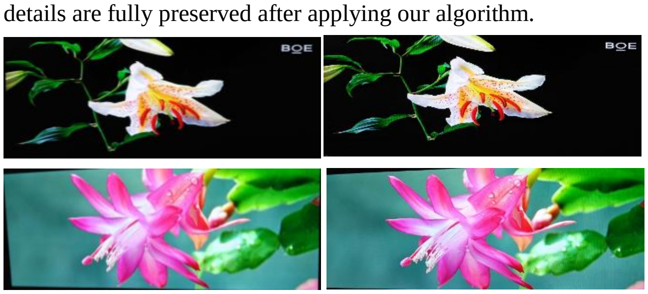
We conducted a comparative analysis of the relative brightness among Dual-cell products with BLU (Backlight Unit), Dual-cell products with BLU and our proposed algorithm, and MLED products with 1440 local dimming zones. Since the maximum brightness of the MLED product and the Dual-cell product are different, it is more reasonable to test the relative brightness. During the test, the brightness of all products was set to their maximum values, which were considered as 100%, when displaying a fully white screen. We then measured the brightness values of high-brightness areas under the three conditions, and the results are presented in Table 1. The results indicated that Dual-cell products with BLU exhibited higher relative brightness for high-brightness content compared to MLED products. Even when the backlight intensity was reduced, the relative brightness of high-brightness content in Dual-cell products remained higher than that of MLED products, demonstrating that our proposed algorithm preserved the advantage of high brightness.

**Table 1.** A comparison of the relative brightness between Dual-cell products and MLED

| Test picture | Relative brightness | | |
|---|---|---|---|
| | Dual-cell + BLU | Dual-cell + BLU + algorithm | MLED 1440 zones |
|  | 100%<br>512.2 | 100%<br>512.2 | 100%<br>676.8 |
|  | 64.7%<br>331.3 | 57.3%<br>293.8 | 56.5%<br>382.2 |
|  | 85.7%<br>439.3 | 77.2%<br>395.4 | 66%<br>446.8 |

### 3.2 Picture quality test

In Figure 6, (a) shows the image quality of the Dual-cell display after applying our algorithm, while (b) shows the image quality of the Dual-cell display with the backlight at its original level. The experimental results reveal that, in comparison to the image of the Dual-cell display with the backlight unchanged, the image details are fully preserved after applying our algorithm.



(a) (b)

**Figure 6.** Display results after and before algorithm

### 3.3 Power consumption test

We tested the actual power consumption of the Dual-cell display after applying our algorithm when displaying different pictures. When displaying a fully white image, the power consumption of the global backlight, sub-cell, and the system power consumption value at this time is denoted as 100%. The system power consumption was primarily influenced by variations in BLU power consumption, while changes in sub-cell and main-cell power consumption were essentially negligible. Figure 7 presents the relative system power consumption of the partial test images compared to the fully white image. The results indicate that our proposed algorithm achieved a reduction in system power consumption by approximately 20%.

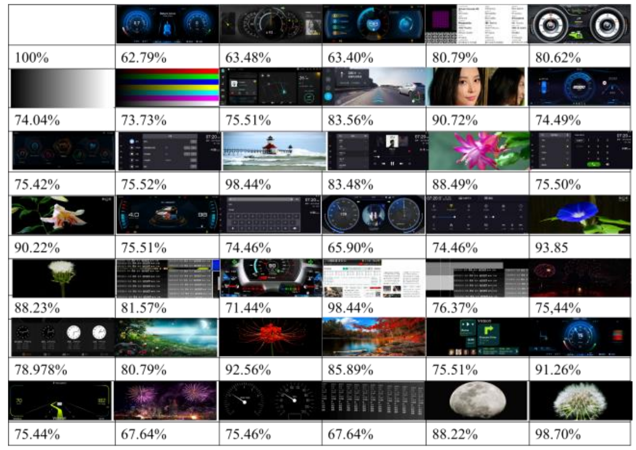



**Figure 7.** The relative system power consumption of the partial test images

## 4. Conclusion

The new content adaptive algorithm is used to reduce the backlight according to the display content of the screen, while ensuring image detail and brightness through dual compensation by the sub-cell and main-cell. Compared to MLED displays, Dual-cell technology produces darker dark areas, higher contrast, clearer image quality, richer details in small high-brightness areas, and an overall power consumption reduction of approximately 20%.

## 5. References

1. Yanhui Xi et al. P‑152: A High Precision and High Contrast Algorithm based on Dual‑cell LCDs[J]. SID Symposium Digest of Technical Papers, 2020, 51(1) : 1960- 1962.