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Research Article

Local Dimming Algorithm of Automotive LCD Instrument Based on Otsu and Maximum Entropy

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In order to reasonably reduce the energy consumption of automotive LCD instrument and improve the display quality, a new local dimming algorithm is proposed in this paper. Firstly, the gray image of the input image is obtained by using the maximum principle, and then, the LED backlight brightness value is obtained by using Otsu method and maximum entropy method. The BMA backlight smoothing algorithm is improved by combining bilinear interpolation algorithm, and the dimming image is obtained by using pixel compensation algorithm based on logarithm. Then, for low brightness images, high brightness images, low contrast images, and high contrast images, typical algorithms are used to simulate and compare, and the image processing effects of various local dimming algorithms are analyzed. Finally, the entropy weight method is used to objectively evaluate the local dimming algorithm. The results show that the new local dimming algorithm reduces the energy consumption and improves the display quality, which verifies the effectiveness of the proposed algorithm.

1. Introduction

LCD in automobile liquid crystal instrument is different from OLED. It is a nonautonomous light-emitting display device, which needs to rely on backlight module to provide backlight [1]. Because LED has the characteristics of energy saving, environmental protection, and long service life, the straight down LED backlight module is widely used as its backlight in automotive LCD instruments. However, the output brightness of the traditional backlight is constant, resulting in high energy consumption, poor contrast, and light leakage of the display. In order to solve this series of problems, researchers proposed a local dimming algorithm. The local dimming algorithm divides the image into several partitions, and the backlight source changes accordingly according to the pixel content of the corresponding partition. More basic local dimming algorithms include max method, average method, sqrt method, and standard deviation method [2]. Max method takes the maximum gray value of the corresponding partition as the backlight brightness value, which will not cause obvious loss of details, but the energy-saving effect is poor. The average method takes the average gray value of the corresponding partition as the backlight brightness value. Compared with the max method, the average method has better energy-saving effect, but it is prone to gray truncation. Sqrt method and standard deviation method obtain the backlight brightness value of the corresponding partition on the basis of average method. Compared with average method, sqrt method retains more image details and reduces energy consumption to a certain extent compared with max method, but it is also prone to gray truncation. At the same time, there are typical local dimming algorithms such as error correction method, CDF threshold method, and IMF method [3, 4]. In the error correction method, the weighting coefficient before the correction value is fixed, resulting in some images cannot get the ideal LED backlight brightness value, and the scope of application is limited. Both CDF threshold method and IMF method are suitable for high brightness images and can enhance the contrast of images, but for images with a large proportion of dark scenes, the LED backlight brightness obtained by the two algorithms is low, which is easy to cause excessive pixel compensation and is easy to lose details. In recent years, some scholars have proposed better local dimming algorithms. Wu [5] proposed a new local dimming algorithm that uses the improved hybrid leapfrog algorithm to extract the backlight brightness, which improves the image contrast. Song et al. [6] proposed a local dimming algorithm based on deep learning that directly generates a compensation image from the input image without any backlight dimming level information. Zhang et al. [7] proposed a new adaptive local dimming method to change the backlight brightness value in combination with human visual characteristics. Zhao [8] proposed a local dimming algorithm based on image local brightness. Although some scholars at home and abroad have proposed some local dimming algorithms, there is still much room for improvement in energy saving and improving display quality. This paper presents a local dimming algorithm for automotive LCD instrument, which improves the display quality and reduces the energy consumption.

2. A New Local Dimming Algorithm

Otsu method has good processing effect for bimodal image and image edge region in gray histogram. It has the characteristics of simple calculation, high real-time performance, and relatively good processing effect. It is often used to obtain the initial threshold in the field of threshold segmentation. However, because Otsu method only considers the maximization of target and background segmentation when doing threshold segmentation, it is often difficult for Otsu method to obtain a better segmentation threshold for some images whose gray value of target and background is close. Otsu method has a good processing effect for the image with obvious distinction between the background layer and the target layer, that is, the image with double peaks in the gray histogram, and also in the edge area of the gray value of the image. The maximum entropy method and Otsu method have a good complementary effect. They have a good recognition and segmentation effect in the region with low discrimination between the background and the target boundary, while the processing effect in the edge region of gray image is poor [9]. By comprehensively analyzing the advantages and disadvantages of existing local dimming algorithms, this paper proposes a local dimming algorithm based on OTSU and maximum entropy, including local dynamic backlight extraction algorithm, backlight smoothing algorithm, and pixel compensation algorithm.

2.1. Backlight Extraction. The specific steps of the new backlight region extraction algorithm are as follows:

(1) Convert the input image into a gray image by using the maximum principle

Firstly, this paper uses the maximum principle to gray the input image to obtain the gray image; that is, the maximum value of the red, green, and blue primary colors of each pixel is taken as the gray value of the pixel. By using the maximum principle to obtain the gray value, it can ensure that the brightness value of LED backlight calculated in the subsequent backlight extraction algorithm will not be too

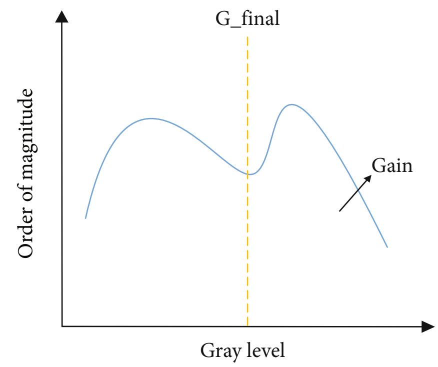


FIGURE 1: Schematic diagram of gain region.

FIGURE 2: Block effect simulation diagram.

low, so as to avoid the impact on the image display effect due to excessive pixel compensation to a great extent. At this time, the three primary colors of red, green, and blue are represented by eight channels, which is 256 levels; the quantization range of the gray value is 0-255, as shown in

$$\text{gray}(x, y) = \max\left(R(x, y), G(x, y), B(x, y)\right). \tag{1}$$

In the formula, $R(x, y)$, $G(x, y)$, and $B(x, y)$ are the three primary color components of red, green, and blue at the pixel.

(2) Obtain the first level target value by using Otsu method

After obtaining the gray image of the input image, the Otsu method (maximum inter class variance method) is used to adaptively select the first level target value according to the gray image of each image partition. The specific steps are as follows:

For an image with a resolution of $A \times B$, it contains M gray levels $\{0, 1, 2, \cdots, M-1\}$, and N_i is the number of pixels with gray level i, as shown in

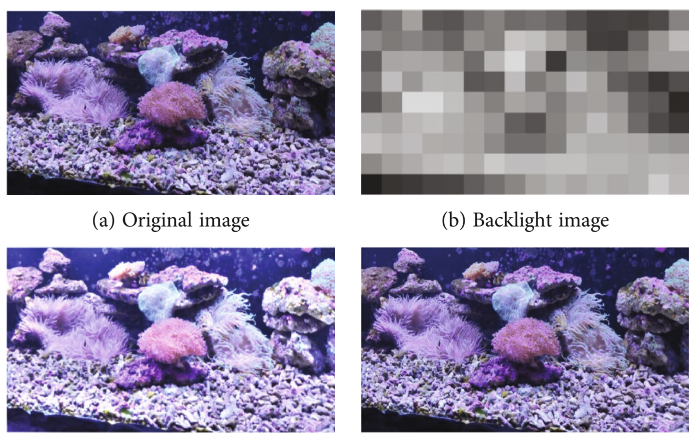
$$P_{Oi} = \frac{N_i}{AB}. \tag{2}$$

In the formula, P_{Oi} is the gray probability corresponding to the gray level i, where $\sum_0^{M-1} P_{Oi} = 1$ and $P_{Oi} \geq 0$.

If the segmentation threshold is f, the gray image pixels are divided into $[0, f]$ and $[f+1, M-1]$, that is, corresponding to background Back1 and target Back2. $P_1(f)$ and $P_2(f)$ are the total pixel probabilities of background Back1 and

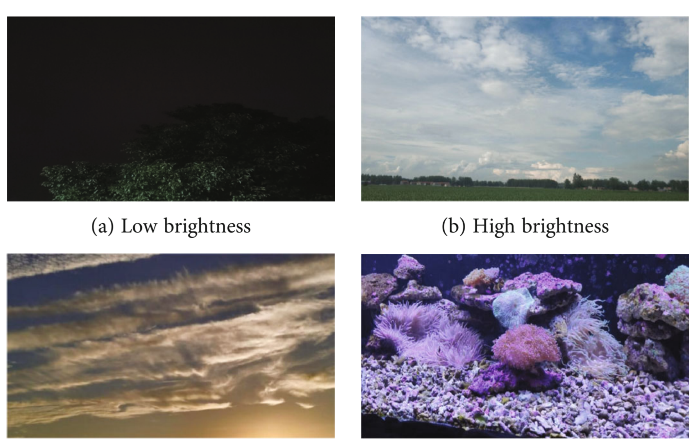
(a) Original image
(b) Backlight image
(c) Traditional BMA
(d) Improved BMA

FIGURE 3: Effect comparison of backlight smoothing algorithm.



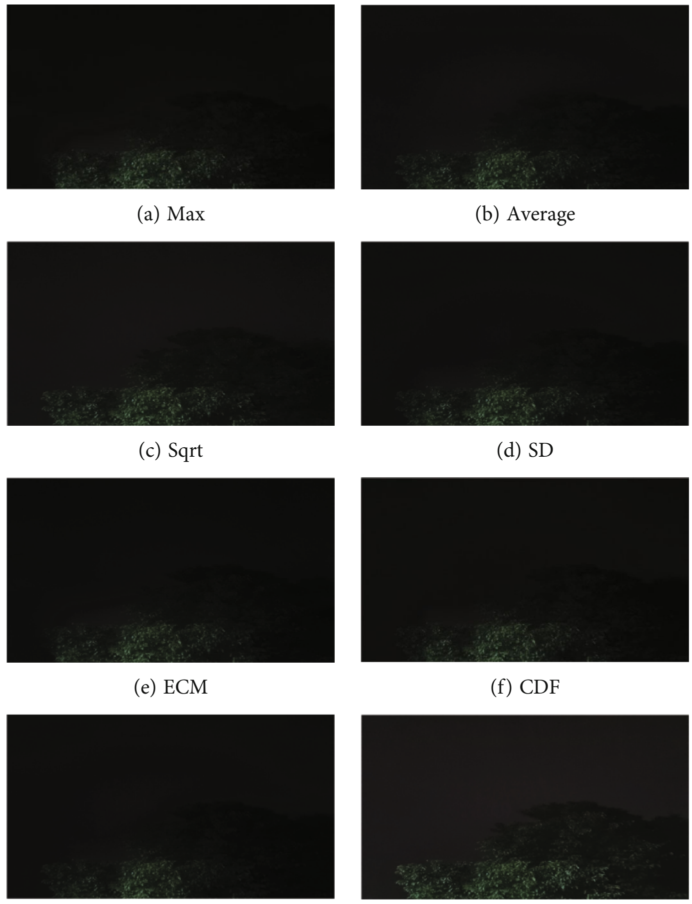
(a) Original image
(b) Backlight image
(c) Traditional pixel compensation
(d) Improved pixel compensation

FIGURE 4: Effect comparison of pixel compensation algorithm.



(a) Low brightness
(b) High brightness
(c) Low contrast
(d) High contrast

FIGURE 5: Sample image.



(a) Max (b) Average (c) Sqrt (d) SD (e) ECM (f) CDF (g) IMF (h) New

Figure 6: Low brightness image simulation diagram.

target Back2, respectively, and $\mu_1(f)$ and $\mu_2(f)$ are the average gray values of background Back1 and target Back2, respectively, as shown in

$$\mu_1(f)=\sum_{i=0}^{f} i\frac{P_{Oi}}{P_1(f)},\qquad \mu_2(f)=\sum_{i=f+1}^{M-1} i\frac{P_{Oi}}{P_2(f)}, \tag{3}$$

where μ_0 is the average gray value of the input image and C is the inter class variance, as shown in

$$\begin{aligned} C(f) &= P_1(f)(\mu_1(f)-\mu_0)^2 + \mathrm{P}_2(f)(\mu_2(f)\text{-}\mu_0)^2 \\ &= P_1(f)P_2(f)(\mu_1(f)-\mu_2(f))^2, \\ C(G1) &= \max_{1\le f\le M-1} C(f). \end{aligned} \tag{4}$$

In the formula, $C(G1)$ is the maximum interclass variance and $G1$ is the target threshold.

(3) Obtain the secondary target value by using the maximum entropy method On the basis of Otsu method

Within the range of [90%, 110%] of the primary target value obtained by Otsu method, the secondary target value is obtained by maximum entropy method. The specific steps are as follows:

Taking the segmentation threshold f_2 as the boundary, it is divided into two parts: Back3 and Back4, which correspond to gray areas $[0, f_2]$ and $[f_2+1, M-1]$, respectively. $P_{e1}(f_2)$ and $P_{e2}(f_2)$ are the probability sum of gray levels in two gray areas, respectively.

The sum of information entropy $\mathrm{th}_{\mathrm{total}}$ of Back3 and Back4 is

$$\begin{aligned} \mathrm{th}_{\mathrm{total}}(f_2) &= \mathrm{th}(\mathrm{Back3}) + \mathrm{th}(\mathrm{Back4}) \\ &= -\sum_{i=0}^{f_2} \frac{P_{Oi}}{P_{e1}} \ln \frac{P_{Oi}}{P_{e1}} - \sum_{i=f_2+1}^{M-1} \frac{P_{Oi}}{P_{e2}} \ln \frac{P_{Oi}}{P_{e2}}. \end{aligned} \tag{5}$$

For the flat part of the curve in the gray histogram of the input image, the information entropy is large; the steep region with less gray level information is the region with low complexity and low information entropy. By traversing f_2 in the gray range of $[0.9G1, 1.1G1]$, the gray level $G2$ corresponding to the maximum value of $\mathrm{th}_{\mathrm{total}}(f_2)$ is the secondary target value.

Figure 7: High brightness image simulation diagram.

(4) Calculate the target segmentation threshold

The target segmentation threshold G_final is obtained by comprehensively considering the primary target value and secondary target value in steps (2) and (3).

$$G\_\text{final} = \frac{G1 + G2}{2}. \quad (6)$$

(5) Calculate the backlight brightness value

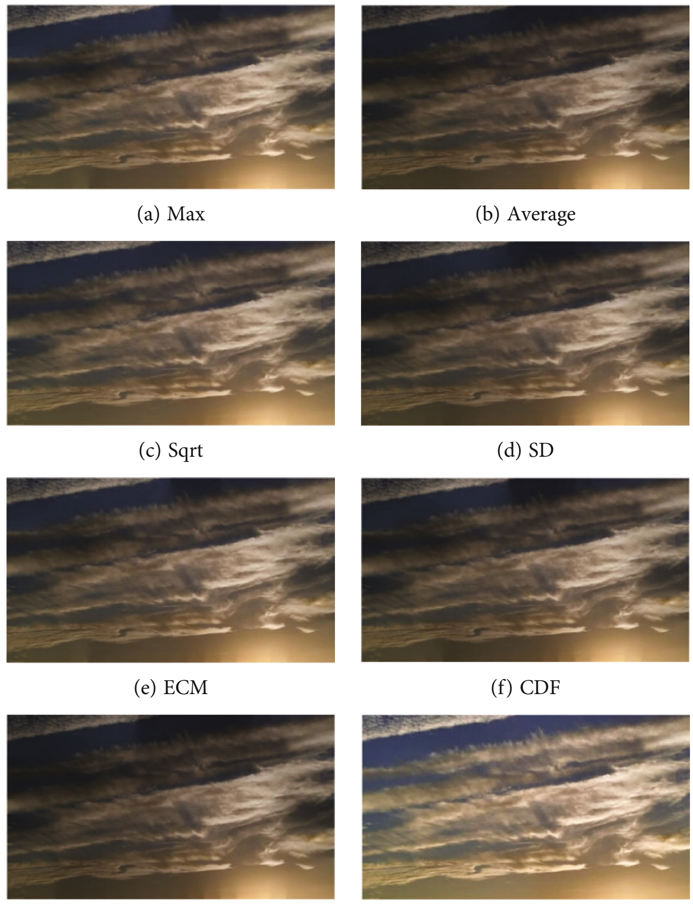
The area where the gray value is greater than G_final is regarded as the gain area gain, as shown in Figure 1.

After obtaining the gain region, the relevant idea of error correction method is used, as shown in

$$\begin{aligned} \text{BL}_{\text{gain}} &= \text{mean}(\text{gain}), \\ K &= \frac{\text{BL}_{\text{gain}} - G\_\text{final}}{\text{BL}_{\text{max}}}, \\ \text{BL}_{\text{new}} &= \text{BL}_{\text{avg}} + K \times \frac{(\text{BL}_{\text{max}} - \text{BL}_{\text{avg}})^2}{255}. \end{aligned} \quad (7)$$

In the formula, BL_{gain} is the average gray value of the gray image gain area; K is the gain coefficient. *Cor* is the correction amount obtained by introducing the error correction method, and BL_{new} is the backlight brightness value of LED lamp obtained by applying the new local dynamic backlight extraction algorithm.

2.2. Backlight Smoothing. Due to the light diffusion of LED lights in adjacent zones, it will affect adjacent zones. If the pixel is compensated directly, there will be obvious "block effect" in the image. Therefore, before pixel compensation, backlight smoothing is needed to eliminate the "block effect." The simulation effect of block effect is shown in Figure 2. At present, LSF algorithm and BMA algorithm are widely used for backlight smoothing. Compared with LSF algorithm, BMA algorithm has the advantages of simple operation, less hardware resources, and better backlight smoothing effect. However, because the traditional BMA algorithm uses a simple surrounding image processing when expanding the matrix for smoothing filtering, it will cause some loss to the final backlight smoothing effect. The algorithm adopts bilinear interpolation expansion method when expanding the matrix. This method effectively considers the image information of the original matrix, and the performance of the algorithm is improved.



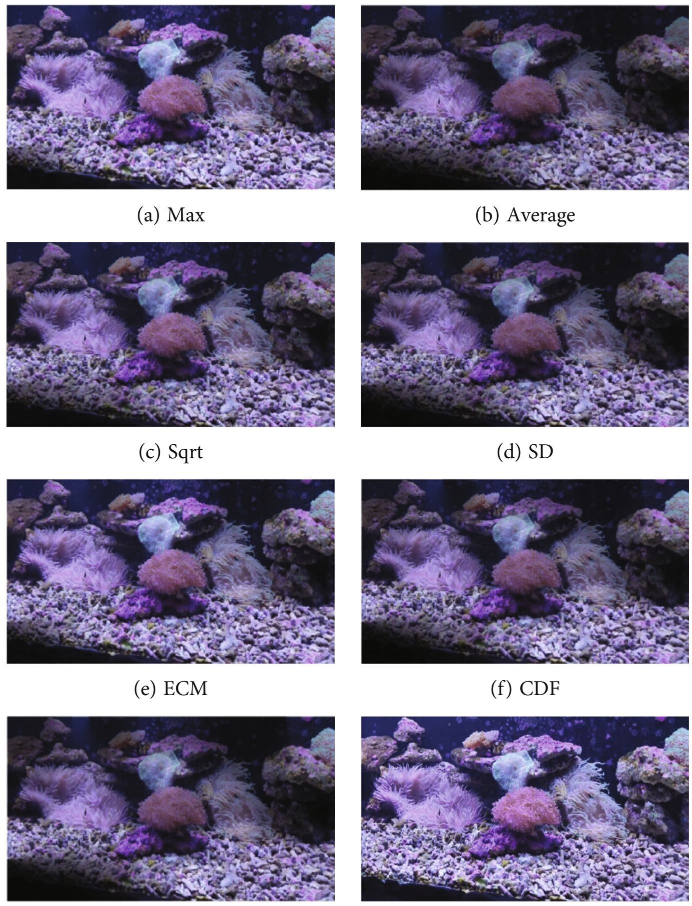
(a) Max (b) Average (c) Sqrt (d) SD (e) ECM (f) CDF (g) IMF (h) New

FIGURE 8: Low contrast image simulation diagram.

The core idea of the improved BMA algorithm is as follows:

(1) The surrounding mirror image is only a simple copy of the boundary, resulting in a large error. The bilinear interpolation algorithm is used to expand the matrix, which fully considers the nearest four vertices around the pixel to be calculated. In the initial matrix expansion, the bilinear interpolation algorithm is used to replace the traditional method of surrounding mirror image to expand the matrix to obtain the expansion matrix BL_{exp}, as shown

$$BL_{exp} = \begin{bmatrix} BL_{bil_{1,1}} & BL_{bil_{1,2}} & BL_{bil_{1,3}} & L & BL_{bil_{1,c}} & BL_{bil_{1,c+1}} & BL_{bil_{1,c+2}} \\ BL_{bil_{2,1}} & BL_{bil_{2,2}} & BL_{bil_{2,3}} & L & BL_{bil_{2,c}} & BL_{bil_{2,c+1}} & BL_{bil_{2,c+2}} \\ BL_{bil_{3,1}} & BL_{bil_{3,2}} & BL_{bil_{3,3}} & L & BL_{bil_{3,c}} & BL_{bil_{3,c+1}} & BL_{bil_{3,c+2}} \\ M & M & M & M & M & M & M \\ BL_{bil_{r,1}} & BL_{bil_{r,2}} & BL_{bil_{r,3}} & L & BL_{bil_{r,c}} & BL_{bil_{r,c+1}} & BL_{bil_{r,c+2}} \\ BL_{bil_{r+1,1}} & BL_{bil_{r+1,2}} & BL_{bil_{r+1,3}} & L & BL_{bil_{r+1,c}} & BL_{bil_{r+1,c+1}} & BL_{bil_{r+1,c+2}} \\ BL_{bil_{r+2,1}} & BL_{bil_{r+2,2}} & BL_{bil_{r+2,3}} & L & BL_{bil_{r+2,c}} & BL_{bil_{r+2,c+1}} & BL_{bil_{r+2,c+2}} \end{bmatrix}. \quad (8)$$



(a) Max (b) Average (c) Sqrt (d) SD (e) ECM (f) CDF (g) IMF (h) New

Figure 9: High contrast image simulation diagram.

(2) The backlight smoothing initial expansion matrix $BL_{\exp}$ is smoothed by equation (9) to obtain the initial smoothing filter matrix BL_{filt}

$$\begin{aligned}\mathrm{BL}_{\mathrm{filt}_{i,j}} = {} & 0.32 \times \mathrm{BL}_{\mathrm{bil}_{i,j}} + 0.1 \times \left(\mathrm{BL}_{\mathrm{bil}_{i,j-1}} + \mathrm{BL}_{\mathrm{bil}_{i,j+1}}\right) \\ & + 0.1 \times \left(\mathrm{BL}_{\mathrm{bil}_{i-1,j}} + \mathrm{BL}_{\mathrm{bil}_{i+1,j}}\right) + 0.07 \\ & \times \left(\mathrm{BL}_{\mathrm{bil}_{i-1,j-1}} + \mathrm{BL}_{\mathrm{bil}_{i-1,j+1}} + \mathrm{BL}_{\mathrm{bil}_{i+1,j-1}} + \mathrm{BL}_{\mathrm{bil}_{i+1,j+1}}\right).\end{aligned} \quad (9)$$

(3) After smoothing the matrix, the nearest neighbor interpolation algorithm is replaced by bilinear interpolation algorithm to double the size of the matrix

(4) Repeat steps (1)~(3) twice. Finally, the bilinear interpolation algorithm is used to expand the smoothing filter matrix to the size of the original image. The comparison of algorithms is shown in Figure 3

2.3. Pixel Compensation. If the brightness value of LED backlight obtained by the local dynamic backlight extraction algorithm is too small, the traditional pixel compensation algorithm will lead to overcompensation of image pixels, which will lead to gray truncation and poor reliability of the algorithm. This paper proposes a pixel compensation algorithm based on logarithm, which can stretch the low brightness region and enhance the high brightness region, which reduces the distortion of the image to a great extent, as shown in

$$V(x,y) = \ln\left(\left(\frac{\mathrm{gray}_{\max}}{g(x,y)}\right)^{0.2} \times e\right), \quad \begin{cases} R'(x,y) = V(x,y) * R(x,y), \\ G'(x,y) = V(x,y) * G(x,y), \\ B'(x,y) = V(x,y) * B(x,y). \end{cases} \quad (10)$$

In the formula, $\mathrm{gray}_{\max}$ is the maximum gray value of each image partition gray image; $g(x,y)$ is the backlight smoothing value at pixel (x,y) obtained by backlight smoothing of LED backlight brightness matrix; $V(x,y)$ is the pixel adjustment coefficient.

The comparison between traditional pixel compensation algorithm and logarithm-based pixel compensation algorithm is shown in Figure 4.

Table 1: Subjective evaluation effect.

	Max	Average	Sqrt	SD	ECM	CDF	IMF	New
Low brightness	Substandard	Substandard	Substandard	Substandard	Substandard	Substandard	Substandard	Good
High brightness	Substandard	Good	General	General	General	General	General	Good
Low contrast	Good	Substandard	General	General	General	General	Substandard	Good
High contrast	Good	Good	Good	Good	Good	Good	Good	Good

Table 2: Objective evaluation index of local dimming algorithm.

Index	Calculation formula	Evaluation significance
SER	SER = (1-(BL_AVG/255)) × 100%	Energy-saving effect
OFR	OFR = $OF_{sum}/A \times B$	Image retention effect
CR	CR = MAX(BL)/MIN(BL)	Image display enhancement effect

Table 3: Objective evaluation results.

Algorithm	Low brightness				High brightness				Low contrast				High contrast			
	SER	OFR	CR	SUM	SER	OFR	CR	SUM	SER	OFR	CR	SUM	SER	OFR	CR	SUM
Max	65	80	60	70.71	70	80	68	68.73	70	80	80	77.20	75	80	80	78.33
Average	85	50	70	63.38	80	80	85	83.16	80	62	80	69.17	80	80	85	81.92
Sqrt	65	65	50	60.34	70	80	72	71.26	70	74	70	72.40	75	85	80	79.74
SD	80	60	60	64.09	70	80	80	76.33	70	70	80	71.19	75	85	85	81.66
ECM	70	70	60	66.89	70	80	75	73.16	70	74	80	73.60	75	85	80	79.74
CDF	80	70	60	68.94	70	80	80	76.33	70	71	80	71.80	75	85	80	79.74
IMF	85	55	80	68.91	70	80	85	79.50	80	62	80	69.17	75	85	85	81.66
New	85	85	70	80.34	80	80	85	83.16	80	82	80	81.20	80	85	85	83.33

3. Effect Verification of Local Dimming Algorithm

On the MATLAB platform, different local dimming algorithms are used to simulate low brightness image, high brightness image, low contrast image, and high contrast image. The resolution of the test image is 1920 × 1080, and image partition is 16 × 9. The sample image is shown in Figure 5, and the simulation results are shown in Figures 6–9.

According to the simulation results, six testers are invited to subjectively evaluate the simulation images according to the five grades of excellent, good, general, substandard, and inferior in the closed dark light environment. The results are shown in Table 1.

4. Algorithm Evaluation

4.1. Evaluation Index. Based on the comprehensive analysis of the classical objective evaluation methods, this paper proposes to take the energy-saving rate (SER), overflow rate (OFR), and contrast (CR) as the objective evaluation indexes for the regional dimming algorithm, as shown in Table 2.

In the formula, BL_AVG is the average brightness of all LED backlights corresponding to an input image, and the value range is $[0 - 255]$; OF_{sum} is the total number of pixel overflow after pixel compensation; MAX(BL) and MIN(BL) are the maximum and minimum brightness of LED backlight obtained by using the regional dynamic backlight extraction algorithm.

4.2. Result Analysis. Three objective evaluation indexes of energy saving rate, overflow rate, and contrast are extracted from the backlight brightness value and backlight compensation pixel value. In this paper, the entropy weight method based on objective indexes is used to evaluate and score the algorithm, eliminate the interference of subjective factors, give weights to each objective evaluation index, and then convert it into the quantification of the quality evaluation of regional dimming algorithm.

The evaluation results obtained by entropy weight method are shown in Table 3.

Table 1 evaluates the image from the subjective visual perception of the tester, and Table 3 analyzes the processing effect of the algorithm from the objective indicators. The consistency between Tables 1 and 3 is good, which verifies the excellent processing effect of the algorithm proposed in this paper on reducing energy consumption and improving display quality.

5. Discussion

(1) A new local dimming algorithm for automotive LCD instrument is proposed, which can reduce energy consumption and improve display quality. It mainly

includes the comprehensive use of Otsu method and maximum entropy method to determine the brightness value of LED backlight, the improvement of BMA backlight smoothing algorithm by bilinear interpolation, and the pixel compensation algorithm based on logarithm

(2) The new local dimming algorithm and other local dimming algorithms proposed in this paper are simulated and analyzed on four typical images. It is found that the local dimming algorithm proposed in this paper can effectively improve the display quality, which shows that this algorithm has wide applicability

(3) The entropy weight method is used to objectively evaluate the quality of the algorithm, which proves that the local dimming algorithm proposed in this paper can effectively reduce energy consumption and improve the display quality

Data Availability

No data were used to support this study.

Conflicts of Interest

There is no potential conflict of interest in this study.

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