On-line Detection Methods for Printing Image Chromatic Aberration Based on Super-pixel

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Abstract

Aiming at the problem of low accuracy and speed for the on-line chromatic aberration detection in color printing industry presented a new detection method. The adjacent pixels with similar characteristics are gathered together by the algorithm of simple linear iterative clustering which based on the idea of super-pixel, each image is segmented into super-pixels that are some compact structure and approximate uniform pixel block. The multiple similar pixels in pixel block are replaced by super-pixel, and extracted the color feature of two images. Finally, the chromatic aberration is calculated by CIEDE2000 color difference formula. The experimental results show that method mentioned above could effectively reduce calculated amount and improve the detection efficiency on the premise of the certain detection accuracy.

Keywords

Color Printing, Simple Linear Iterative Clustering, Super-Pixel, Chromatic Aberration.

1. Introduction

The color of printing image was easily affected by external factors in the process of production, which result in color deviation. The precision and accuracy of the traditional manual detection methods cannot meet the needs of industrial production, or unable to perceive tiny color difference [1]. To overcome this defect, researchers and technicians have been trying to use machine vision to instead of human vision in online chromatic aberration detection system.

In recent years, more and more scholars were interested in the research of online quality detection system for printing image chromatic aberration. Aiming at the chromatic aberration detection for color printing images, Ishimaru I, Hata S, Hirokari M proposed the method of to convert the image from RGB color space to CMYK space, and then computing chromatic aberration in CMYK space [2]. This method is faster. Luo J, Zhang Z presented that extract the feature of image by color histogram and adopt the method of artificial neural network to classify images under the condition of standard light source [3]. This method improved the detection accuracy. This method improved the detection accuracy effectively.

Actually, most of the printing images were collected by linear CCD camera and transforms the image from RGB color space into uniform color space [4, 5] by using color space conversion model. If calculate the chromatic aberration of printing image and standard image by per-pixel comparing, following the two problems:

(1) For per-pixel comparing, the requirement for image registration is high accurate. However, high precision of image registration algorithm will lead to increasing the amount of calculation obviously, and reduce detection efficiency.

(2) The formula of chromatic aberration has higher complexity, if compare each pixel for whole image, the amount of calculation will increase sharply and cannot meet the industrial real-time requirements.

In this paper, the whole printing image was segmented into K piece based on the idea of super-pixel. Using super-pixel instead of the multiple similar pixels in the pixel piece, and extract the color characteristics of standard image and printing image respectively, calculating the chromatic aberration by using CIEDE2000 formula. Experimental verification, under the premise that guarantee the accuracy, detection time had been shortened obviously and efficiency had been enhanced greatly, basically meet the real-time requirements of industrial production.

2. Chromatic aberration detection method based on super- pixel

2.1 Section Headings

At present, on-line detection often use linear CCD camera to obtain images which are RGB mode. But RGB color space is non-uniform [6], cannot suitable for comparing the difference between the two colors due to each component had a higher correlation, which is not conformity with the visual perception characteristics of human. In order to solve this problem, we need to transfer images to an uniform color space that is not associated with equipment.

At present, CIEL * a * b * color space is regarded as uniform and widely used for calculating the chromatic aberration. CIE color space is established on the basis of the human eye vision and color measurement, without being affected by equipment changes. Beyond that CIE system has the largest color gamut space, including any color.

The relationship between RGB color space and CIEL*a*b* color space is as follows:

$RGB \rightarrow XYZ \rightarrow CIEL*a*b*$

Among them, the concrete manifestation is as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3575 & 0.1804 \\ 0.2128 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9502 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

$$L^* = 116 \times (Y/Y_n)^{1/3} - 16 \tag{2}$$

$$a^* = 500 \times [f(X/X_n) - f(Y/Y_n)] \tag{3}$$

$$b^* = 200 \times [f(Y/Y_n) - f(Z/Z_n)] \tag{4}$$

$$f(t) = \begin{cases} t^{1/3} & t > 0.008856 \\ 7.787 * t + 16/116 & other \end{cases} \tag{5}$$

X_n, Y_n and Z_n shows tristimulus values, under the standard illuminant D65, [X_n Y_n Z_n]=[95.047 100 108.883].

2.2 Super- pixel division

In 2003, the concept of super pixel was presented by Ren [7], it is a pixel block which is compact structure, approximate uniform, irregular and consists of many adjacent pixels with similar features, such as color, texture and brightness. It divides pixels into different pixel groups based on the similarity among the pixels, and expresses image characteristics by super-pixels, which can largely reduce the complexity of the subsequent image processing.

This paper uses the simple linear iterative clustering (SLIC) algorithm, which is a kind of super-pixel segmentation algorithm, and it has fast processing speed, conserve memory, higher edge alignment [8]. The SLIC steps are divided into the following steps:

(1) Initializing seed points: according to the set of super pixel number, the seed point has uniform distributed in the whole image. Suppose images have M pixels, and the pixels are divided into K same size of super-pixels, each pixel size for M/K, then the adjacent seeds point distance approximation for:

$$D = \sqrt{M/K} \tag{6}$$

(2) Calculating the gradient value of all pixels which in the 3*3 neighborhood of the seed point, and then move the seed point to the smallest position of the gradient value, record it as a new seed point. This is to avoid the seed points falling near the contour boundary, affecting the clustering effect.

(3) Searching similar pixels in the region of 2S*2S with seed point as center, clustering and assigning class labels.

(4) Measuring the distance from each search pixel to the seed point, including the color distance and spatial distance. formulas as follows:

$$d_{lab} = \sqrt{(l_n - l_i)^2 + (a_n - a_i)^2 + (b_n - b_i)^2} \tag{7}$$

$$d_s = \sqrt{(x_n - x_i)^2 + (y_n - y_i)^2} \tag{8}$$

$$S' = \sqrt{(\frac{d_{lab}}{m})^2 + (\frac{d_s}{D})^2} \tag{9}$$

Among them, d_{lab} represents color distance, d_s represents spatial distance, S' represents the distance measurement of two pixels, D is the distance between two seed points, m is the equilibrium parameter.

Set color characteristic value of each super-pixel is $V_i(L,A,B)$, i=1,2…K, and each pixel is $v_j(l,a,b)$, $j=1,2...M/K$, then:

$$V_i(L,A,B) = \frac{\sum_{j=1}^{M/K} v_j(l,a,b)}{M/K} \tag{10}$$

2.3 Chromatic aberration calculation

In order to achieve the better purpose of chromatic aberration detection, the industry applicable chromatic aberration formulas are essential. International Commission on Illumination(referred to as CIE) introduced CIE1976L*a*b* formula in 1976, which widely used in printing industry, textile industry, form as follows:

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \tag{11}$$

ΔE is the distance between any two points in L * A * b * color space. L is lightness in L * a * b * color space, if $L1- L2 > 0$, samples with high lightness, which is shallower than the standard color, deep conversely. A is red and green axis of the L * a * b * color space, if $a1- a2 > 0$, samples more red than the standard sample, conversely more green. b is the yellow and blue of L * a * b * color space, if $b1 - b2 > 0$, showing that samples more yellow than the standard color, otherwise more blue.

The CIE set up the committee TC1-47 to solve the problem which CIE1976L*a*b* formula cannot accurately predict the chromatic aberration under the condition of different lightness was large. They put forward a new formula CIEDE2000 [9,10] for chromatic aberration in 2001. The formula further improves the accuracy of the chromatic aberration evaluation for the industry. The form of CIEDE2000 formula as follows:

$$\Delta E_{00} = \sqrt{(\frac{\Delta L'}{K_L S'_L})^2 + (\frac{\Delta C_{ab}'}{K_C S'_C})^2 + (\frac{\Delta H_{ab}'}{K_H S'_H})^2 + R_T(\frac{\Delta C_{ab}'}{K_C S'_C})(\frac{\Delta H_{ab}'}{K_H S'_H})} \tag{12}$$

The formula calculation steps as follows:

(1) Calculating the lightness L, chroma a and b, and psychological saturation C_{ab} in L*a*b* color space.

$$C_{ab} = \sqrt{a^2 + b^2} \tag{13}$$

(2) Calculating L', a', b', hue h'_{ab}, adjustment factor G of an axis in CIEL*a*b* color space.

$$\begin{cases} G = 0.5 \times \left(1 - \sqrt{\dfrac{\overline{C_{ab}}^7}{\overline{C_{ab}}^7 + 25^7}}\right) \\ L' = L \\ a' = (1+G) \times a \\ b' = b \\ h'_{ab} = \tan^{-1}(b/a) \end{cases} \tag{14}$$

$\overline{C_{ab}}$ is the arithmetic average of printing image C_{ab1} and C_{ab2}.

(1) Calculating the difference of lightness ΔL, chromaΔC_{ab} hue Delta $\Delta H'_{ab}$.

$$\begin{cases} \Delta L' = L_1 - L_2 \\ \Delta C' = C_{ab1} - C_{ab2} \\ \Delta H'_{ab} = 2 \times \sqrt{C_{ab1} C_{ab2}} \times \sin(\dfrac{\Delta h_{ab}}{2}) \\ \Delta h'_{ab} = h_{ab1} - h_{ab2} \end{cases} \tag{15}$$

(2) Calculating weight function S_L、S_C、S_H and rotation function R_T、R_C.

$$\begin{cases} S_L = 1 + \dfrac{0.015 \times (\overline{L'} - 50)^2}{\sqrt{20 + (\overline{L'} - 50)^2}} \\ S_C = 1 + 0.045 \times \overline{C'_{ab}} \\ S_H = 1 + 0.015 \times \overline{C'_{ab}} \times T \end{cases} \tag{16}$$

$$T = 1 - 0.17 \times \cos(\overline{h'_{ab}} - 30^\circ) + 0.24 \times \cos(2\overline{h'_{ab}}) + 0.32 \times \cos(3\overline{h'_{ab}} + 6^\circ) - 0.20 \times \cos(4\overline{h'_{ab}} + 63^\circ) \tag{17}$$

$$\begin{cases} R_T = -\sin(2\Delta\theta) \times R_C \\ \Delta\theta = 30 \times \exp\left[-(\dfrac{\overline{h'_{ab}} - 275^\circ}{2})^2 \right] \\ R_C = 2 \times \sqrt{\dfrac{\overline{C_{ab}}^7}{\overline{C_{ab}}^7 + 25^7}} \end{cases} \tag{18}$$

(3) The chromatic aberration was calculated by the formula (12). K_L, K_C, K_H is correction coefficient of is the actual using conditions. Under the condition of CIE standard observation, K_L=K_C=K_H=1.

In this paper, when we using CIEDE2000 formula to calculate chromatic aberration. The L, a, b values are the color characteristic value $V_i(L,A,B)$, i=1,2...K of super-pixels in L * a * b * color space

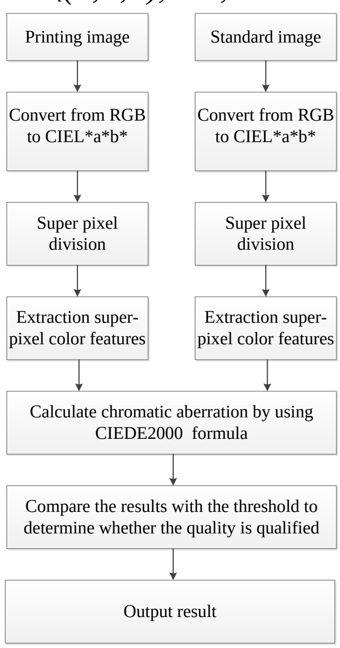


Fig.1 Flow chart of chromatic aberration detection algorithm based on super-pixel

2.4 Threshold setting and evaluation principles

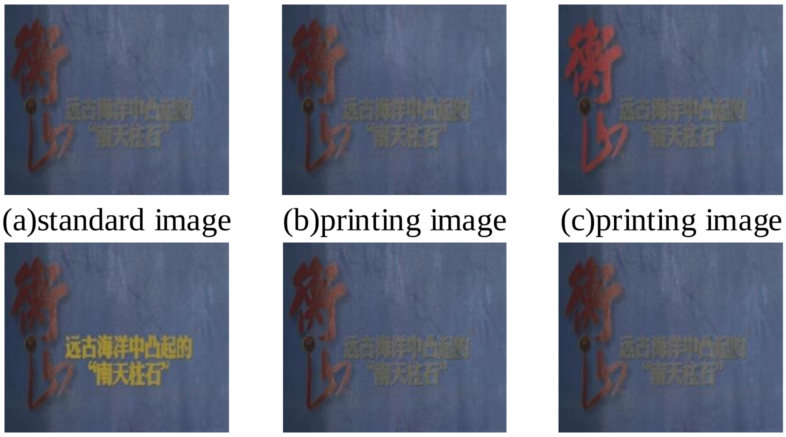
In order to judge the color printing quality, the 6NBS is taken as threshold of chromatic aberration detection in printing industry [11]. The principle of this method is: (1) If the chromatic aberration values of each super-pixel for whole printing image less than 6 NBS, the printing image is qualified. (2) If individual super-pixel values greater than or equal to 6NBS, then determine the printing image is not qualified.

2.5 Algorithm process

The specific flow of algorithm is shown in Fig. 1.

3. Experimental results and discussion

This experiment completes the image acquisition by using linear CCD camera under standard light source. Image size is 419*496, among them 1 standard image and 5 printing images, as shown in Fig. 2.

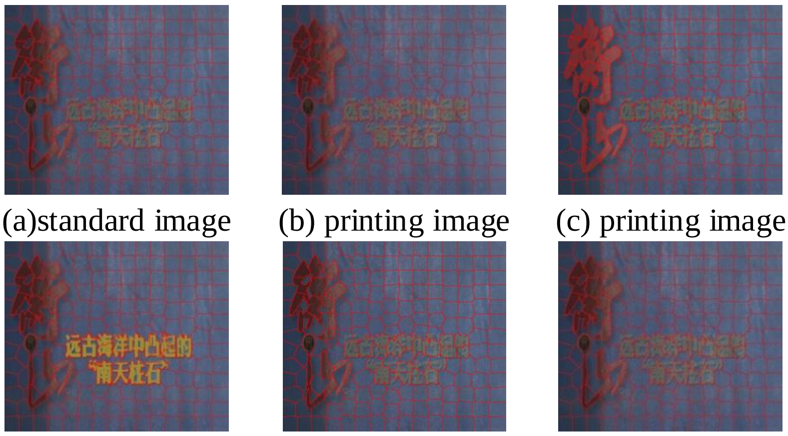


(a)standard image (b)printing image (c)printing image

(d)printing image (e)printing image (f)printing image

Fig.2 Experimental images for chromatic aberration detection

The algorithm preset K=200 before the super pixel segmentation, each image will be divided into about 200 pixels. But the program will automatically split according to the feature of image in the actual experimental process. For this experiment, images are divided into 196 super-pixels, as shown in Fig. 3

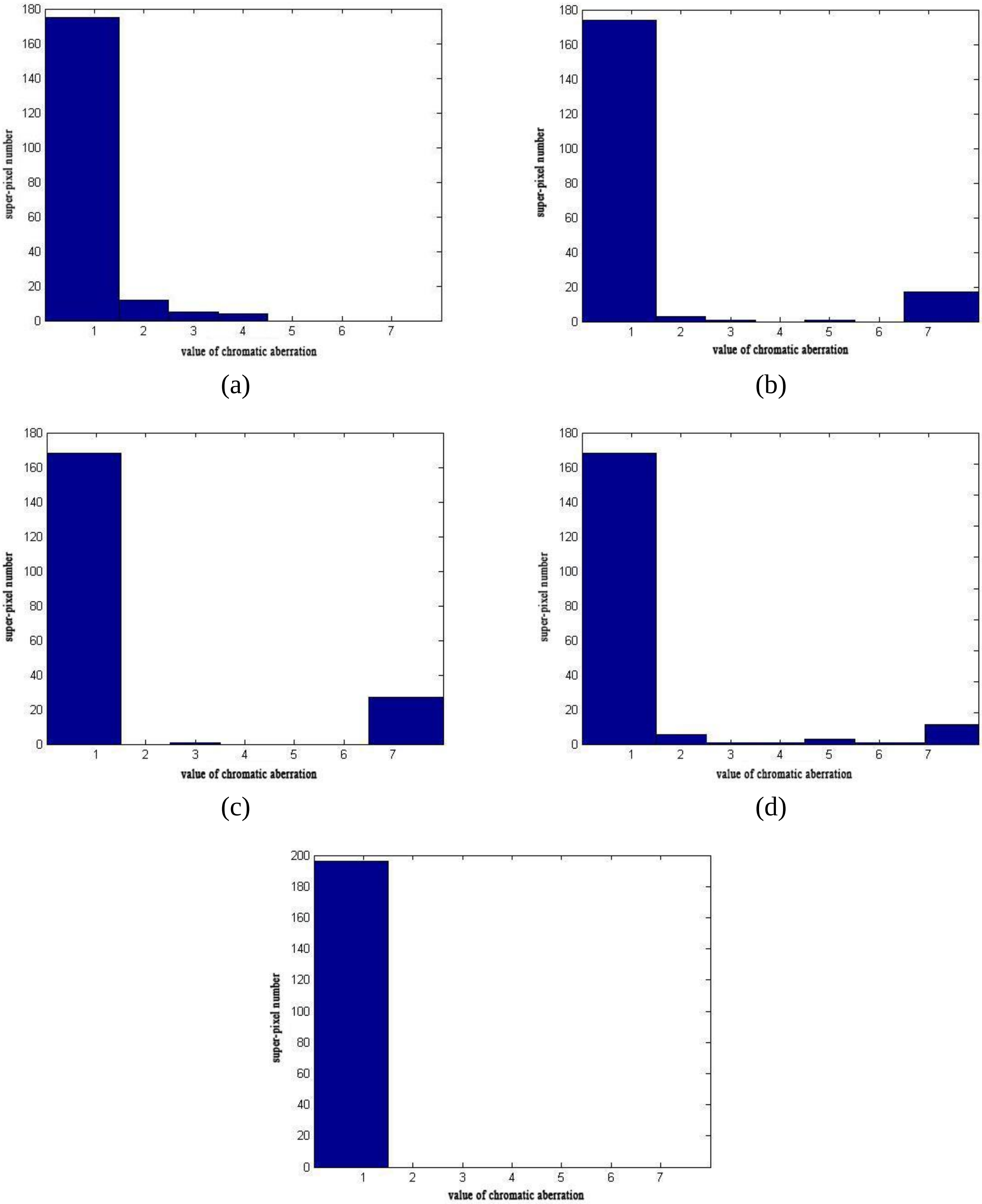


(a)standard image (b) printing image (c) printing image

(d) printing image (e) printing image (f) printing image

Fig. 3 The result of super-pixel segmentation

As we can see form figure 3, the original image has 207824 pixels. Each image is segmented into 196 super-pixels based on the ideal of super pixel, which is equivalent to 196 pixels for each image. Then we can calculate the value of chromatic aberration between standard image and printing image by using CIEDE2000 formula. In order to observe difference of quality for standard image and printing images conveniently, we use histogram distribution to show the chromatic aberration of two images. Among them, the chromatic aberration values larger than 6 are denoted by 7, see Fig. 4.



(a) (b) (c) (d) (e)

Fig.4 The distribution diagram of chromatic aberration value

The horizontal axis shows color difference, and the longitudinal axis shows super-pixel number. According to the chromatic aberration value distribution in Figure 4 and the judgment principle in part one, the quality evaluation results for printing images are shown in Table 1.

Table 1. Quality evaluation results for printing images

Printing image	ΔE(NBS)	Judgement result
Fig.2(b)	All less than 6	Qualified
Fig.2(c)	Partial greater than 6	Unqualified

Fig.2(d)	Partial greater than 6	Unqualified
Fig.2(e)	Partial greater than 6	Unqualified
Fig.2(f)	All less than 6	Qualified

The detection time and detection accuracy are important factors to evaluate the performance of algorithm. In order to demonstrate the capabilities of the proposed method, this paper presents detection result of the traditional per-pixel comparing method, the average value of color image method, and the method of literature which proposed the principle of image segmentation based on the printing machine ink position [12]. The comparison results for the four methods are shown in Table 2.

Table 2 The comparison results for the four methods

		$\Delta E_{max}(NBS)$	$\Delta E_{avg}(NBS)$	$\Delta E_{min}(NBS)$	T(s)
Fig.2(b)	The proposed method	0.8974	0.3663	0	4.020
	Per-pixel comparing	5.0761	0.3723	0	960.754
	Average value of color	0.3723	0.3723	0.3723	1.169
	Literature [12]	2.1136	0.6673	0	5.361
Fig.2(c)	The proposed method	25.9031	1.8479	0	4.191
	Per-pixel comparing	12.9826	0.9696	0	958.233
	Average value of color	0.9696	0.9696	0.9696	1.261
	Literature [12]	5.5954	2.3363	0	5.553
Fig.2(d)	The proposed method	44.2212	4.2479	0	3.999
	Per-pixel comparing	23.3936	1.6138	0	961.491
	Average value of color	1.6138	1.6138	1.6138	1.236
	Literature [12]	5.4101	3.016	0	5.448
Fig.2(e)	The proposed method	8.0693	0.6593	0	3.975
	Per-pixel comparing	12.9826	0.8568	0	960.681
	Average value of color	0.8568	0.8568	0.8568	1.490
	Literature [12]	1.5223	0.2236	0	4.830
Fig.2(f)	The proposed method	1.0025	0.0037	0	4.017
	Per-pixel comparing	0.8858	0.0023	0	961.156
	Average value of color	0.0023	0.0023	0.0023	1.239
	Literature [12]	0.4435	0.0733	0	4.976

The comparison results of four methods are expressed by four parameters: maximum chromatic aberration value as ΔE_{max}, average chromatic aberration value as $\Delta E_{avg}(NBS)$, minimum chromatic aberration value as $\Delta E_{min}(NBS)$ and detection time as T(s).

As observed from the Table 2 and Table 1, the judgement result of the proposed method and per-pixel comparing method is consistent. For Fig.2(b) and Fig.2(f), the maximum chromatic aberration values are not more than 6, so these two images are qualified. On the contrary, the maximum chromatic aberration values of Fig.2(c), Fig.2(d) and Fig.2(e) are greater than 6, which reflected that these three images are unqualified.

For taking the average value of color image to calculate chromatic aberration, the image color details are fuzzy. In Table 2, it is clear that each image's maximum chromatic aberration value all less than threshold. So each image is qualified. It is different from the judgement result of pre-pixel comparing method.

The method proposed in literature [12] also used image segmentation to improve detection efficiency. The principle of image segmentation is to divide the image according to the position of the machine ink. This segmentation method does not take into account the characteristics of the image itself, it is easy to distribute the chromatic aberration in different sub regions, and ignore the small area of chromatic aberration while weakening the existence of chromatic aberration. The calculation results are shown in Table 2. Its decisive result also has defects.

The results in Table 2 and analysis mentioned above showed that the proposed method performs better of judgement result and detection time than other three methods. For accuracy, the performance of per-pixel comparing method is best in theory, but the result of proposed method is consistent with it and the detection efficiency is much greater than it. For efficiency, the best performance is taking the average value of color image, however, its accuracy is far less than the proposed method. The method which proposed in literature [12], owing to the segmentation is not reasonable, it is highly easy to cause the error rate, and cannot guarantee the accuracy of detection. In this paper, the method can be considered to set the number of super-pixels, according to the characteristics of different color images, reasonable segmentation can reduce the error rate of image detection, and improve detection accuracy.

4. Conclusion

In this paper, we introduce the method of super-pixel segmentation for image preprocess, use the super-pixels instead of the large number of pixels to solve the problem which is lowly speed and precision in the on-line detection of chromatic aberration. This method can reduce the complexity of the algorithm effectively, reduce the amount of computation. The experimental results show that the proposed method can solve the problem of speed. We choose the CIEDE2000 formula for calculating chromatic aberration value by comparing the characteristics of various chromatic aberration formulas. What the reason is that CIEDE2000 should be able to reflect small chromatic aberration effectively. The experimental results show that the proposed method can improve the detection efficiency greatly under the premise of ensuring the detection accuracy.

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