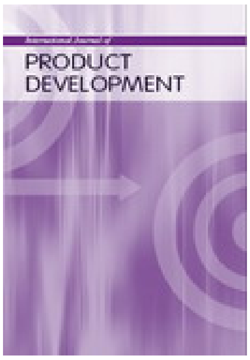

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Colour offset compensation method of product packaging image based on colour difference interpolation

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Colour offset compensation method of product packaging image based on colour difference interpolation

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Abstract: In order to effectively improve the accuracy of image colour offset compensation and reduce the compensation time, a colour offset compensation method based on colour difference interpolation is proposed in this paper. Based on bilinear chromatic aberration interpolation algorithm, the full resolution chromatic aberration signal of image is estimated preliminarily. After image filtering, the basic colour data and grey balance data of the image are compared to obtain the colour offset. Taking colour block as the minimum unit of deviation compensation, the average value of extended colour level interpolation was added to the single colour level of the calibrated image to complete colour offset compensation. Experimental results show that the maximum compensation time of the proposed method is only 29.6 s, and the maximum MSE value of the compensation result is only 0.179, indicating that the proposed method has higher compensation accuracy.

Keywords: chromatic interpolation algorithm; linear filtering; product packaging image; colour offset compensation.

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1 Introduction

With the development of image making technology, colour image is widely used in product packaging (Gao et al., 2021; Li et al., 2020). There are some colour perception differences between product packaging image acquisition device and human visual system. Therefore, in the actual packaging production process, it is necessary to carry out colour processing on the product packaging picture, so as to make the image full of colour and reasonable colour matching (Li et al., 2021).

However, in the process of image information collection, due to the influence of environmental light source, acquisition object itself, reflection characteristics and other factors, the colour of the collected image is greatly different from the actual image (Lu and Pan, 2019). Colour offset can reflect the important law of colour change (Zhou et al., 2021). Therefore, it is necessary to compensate the colour offset of product packaging image, which can effectively improve the colour quality of the image.

At present, researchers in related fields have carried out research on image colour offset compensation methods. Fu et al. (2020) proposed image denoising and absorption compensation methods in underwater polarisation imaging. The background region selection strategy based on automatic attenuation difference graph can estimate the background light without considering the existence of target region. In the absorption compensation step, a new absorption compensation constraint strategy is introduced into the colour recovery algorithm of detection signal light. The strategy relies on well preserved colour components and absorption priority constraints. The image restoration or enhancement method of this method is more effective. Yu et al. (2021) proposed a micro image illumination compensation method based on illumination difference estimation. Firstly, the image containing cells is obtained, and then the cells are located on the slide through image segmentation to remove the cells. The removed cell region is filled by thin plate spline interpolation to obtain the background image. Then two methods of estimating illumination difference from background image are given. Finally, illumination compensation is performed by adding an input image and an illumination difference image. This method can eliminate uneven illumination without using white reference image. However, the above methods still have the problems of poor image colour offset compensation effect, low precision and long time.

In order to solve the above problems, this paper introduces a method to compensate the colour deviation of product packaging image by using colour difference interpolation technology. The design idea of this method is as follows:

1. In bell template, the position of image pixel is determined, and the position of each pixel is estimated by using its adjacent RGB pixel value. Then, the brightness of each position was estimated by a 3-dof filter matrix, and the chromatic aberration of the image was obtained by comparing with the Bell template.

2. The colour components of the point are obtained by calculating the average value of the colour components of adjacent pixels, and then the R, G and B single channels are interpolated respectively to restore all the colour components, so as to preliminarily estimate the full resolution colour difference signal of the image.

3. The linear filtering algorithm is used to de-noise the external packaging image to reduce the impact of noise on the subsequent compensation process. The grey-scale data of the image were collected, and the basic colour data and grey balance data of the product outer packaging image were compared according to the grey balance principle, so as to obtain the colour offset of the product outer packaging image.

4. Use image reflection algorithm to calculate the colour reflectance of the product packaging image, then convert the colour of the brightness histogram of the image area and determine the colour offset compensation function according to the processing results of the error module.

5 The colour block is taken as the minimum deviation compensation unit of the product packaging image. Under the constraint of the above compensation function, the average value of the extended colour level interpolation is added to the single colour level of the calibration image to obtain the final colour offset complement, so as to complete the colour offset compensation.

2 Bilinear chromatic interpolation algorithm design

In this study, the location of image pixels is determined in The Bell template, and the location of each pixel is estimated by using its adjacent RGB pixel values. Then, the brightness of each position is estimated by a 3-dof filter matrix and compared with the Bell template to obtain the image chromatic aberration. Based on this, the colour components of the point are obtained by calculating the average value of the colour components of adjacent pixels, and then the R, G and B single channels are interpolated respectively to restore all the colour components, so as to obtain the estimation value of the full resolution colour difference signal of the image, which lays a foundation for the subsequent colour offset compensation.

2.1 Image chromatic aberration representation

In the Bell template, the position of each pixel in the image is determined, and the position of each pixel is estimated by using its adjacent RGB pixel value (Li and Wang, 2020). In this process, the weight coefficient m_i used should also remain unchanged. As the first constraint condition, the second constraint is to use 3×3 standard space symmetric convolution. Under these two constraints, a filtering matrix with 3 degrees-of-freedom is designed to estimate the brightness of each position, namely:

$$\Phi = \begin{pmatrix} R & G & R \\ G & B & G \\ R & G & R \end{pmatrix} \begin{pmatrix} a & b & a \\ b & c & b \\ a & b & a \end{pmatrix} \tag{1}$$

In formula (1), Φ is the estimated luminance at the position of each pixel. The chromatic aberration of each pixel position can also be expressed in the following ways:

$$\Psi_{CFA}(z,x)m_i(z,x) = m_i(j,i)\sum_j K_j(z,x) \tag{2}$$

Therefore, the Bell template chromatic aberration image is expressed as:

$$\Psi_{CFA}(z,x) = \sum_i \Psi_{CFA}(z,x)m_i(z,x) \tag{3}$$

Formula (3) shows that the Bell template chromatic aberration image is composed of three down sampled modulated chromatic aberration images. In order to estimate the full resolution chromatic aberration signal, a simple bilinear interpolation filter can be used.

2.2 Analysis of bilinear interpolation algorithm

Bilinear interpolation algorithm is to interpolate the three single channels of RGB respectively, which is a classical and common algorithm in interpolation algorithm (Xin et al., 2020; Yan et al., 2021; Pan et al., 2020). Therefore, in this section, the bilinear interpolation algorithm is analysed in this study, and the colour components of the point are obtained by calculating the average value of the colour components of adjacent pixels. Then, *R*, *G* and *B* single channels are interpolated respectively to recover all the colour components, so as to preliminarily estimate the full-resolution chromatic aberration signal of the image.

The basic principle of bilinear is to calculate the average value of the colour components of the neighbouring pixels to obtain the colour components of the pixel. The calculation formula is:

$$F(j,i) = \frac{\sum_{1}^{D} F(q,p)}{M} \tag{4}$$

In formula (4), D is the number of pixels of the channel in the filter window, $F(j,i)$ represents the colour component of the pixel to be sought, $F(q,p)$ represents the colour component of the adjacent pixels around the pixel in the same channel and M represents the adjacent pixels of the same channel number.

In order to obtain the other two colour components at the position of a single pixel of the image, in the 3 × 3 neighbourhood around the pixel, the pixels of the colour components to be obtained are summed and the average value is taken as the value of the colour of the pixel, as shown in Figure 1.

Figure 1 Bayer type template for bilinear interpolation

G11	R12	G13	R14	G15	R16
B21	G22	B23	G24	B25	G26
G31	R32	G33	R34	G35	R36
B41	G42	B43	G44	B45	G46
G51	R52	G53	R54	G55	R56
B61	G62	B63	G64	B65	G66

As shown in Figure 1, assuming that $B_{j,i}$ is a point of the *B* component in the image, the *G* component and *R* component are missing at this point and the *G* component $G_{j,i}$ of this point is first restored as:

$$G_{j,i} = \frac{G_{j-1,i} + G_{j+1,i} + G_{j,i-1} + G_{j,i+1}}{4} \tag{5}$$

The red components on green pixels are divided into two categories according to their positions.

1 If the green point is on an even line, then the red component $R_{j,i}$ of this point is:

$$R_{j,i} = \frac{R_{j-1,i} + R_{j+1,i}}{2} \tag{6}$$

2 If the green point is in an odd column, then the red component $R_{j,i}$ of this point is:

$$R_{j,i} = \frac{R_{j,i-1} + R_{j,i+1}}{2} \tag{7}$$

Interpolate the red component on the blue pixel, if it is $B_{j,i}$, then $R_{j,i}$ is:

$$R_{j,i} = \frac{R_{j-1,i-1} + R_{j-1,i+1} + R_{j+1,i-1} + R_{j+1,i+1}}{4} \tag{8}$$

The bilinear interpolation processing is completed by using the above process, and the estimation value of the full resolution colour difference signal is obtained, which lays a foundation for the subsequent colour offset compensation.

3 Product packaging image colour offset compensation method

Based on the above preliminary estimation of the full-resolution colour difference signal of the image, this study completes the colour offset compensation processing through the following process: basic noise reduction → obtain the colour offset by comparing the basic colour data and grey balance data → determine the colour offset compensation function → add the average value of extended colour scale interpolation to the monochrome colour scale of the calibrated image to complete the colour offset compensation.

3.1 Analyse the colour offset of product packaging image

Before the colour deviation compensation of external packaging image, the colour offset of external packaging image is analysed. There are some problems such as image noise in colour offset analysis of product packaging image (Hu et al., 2020a; Akroush and Wicks, 2020). To this end, the linear filtering algorithm is used to de-noise the external packaging image, and it is expressed as follows:

$$Q = \alpha \sum_{i=1}^{n} W_i + E \tag{9}$$

In formula (9), W_i represents the noise obtained on the outer packaging of the product, α represents the noise processing coefficient and E represents the linear filtering method coefficient. The method can effectively deal with the noise in product packaging images, thus providing a reliable basis for the analysis of colour cast on packaging.

Then, analyse the reason of colour deviation of product packaging image. The human eye is sensitive to the neutral grey area in the colour product packaging image (Hu et al., 2020b). Therefore, grey balance algorithm is used to analyse the deviation of product packaging image. When using the grey balance algorithm, the grey-scale data of the outer package of the product must be collected and expressed as follows:

$$R(e) = Q \times \frac{J_C + H_H}{\beta} \tag{10}$$

In formula (10), J_C represents the basic colour data of the product outer packaging image, H_H represents the grey balance data of the product outer packaging image and β represents the calculation factor of the grey balance. Through the above formula, the collection of grey-scale data of product outer packaging is completed. Then, the colour cast of the product outer packaging image is analysed and expressed as follows:

$$S(P) = \frac{R(e)}{\gamma} \sum_{j=1}^{Q} T_j \times H_H \tag{11}$$

In formula (11), T_j represents the colour cast of the product packaging image, and γ represents the colour cast analysis factor.

3.2 Determine the colour offset compensation function of product packaging image

Through the analysis of the colour deviation of the above product outer packaging image, the colour deviation compensation function of the outer packaging image is further determined. Through the image reflection algorithm, the colour reflectivity of the product outer packaging image is calculated, and the calculated results are collected by the image acquisition method. The calculation formula is as follows:

$$Y = \sum_{i=1}^{Q} U_i \times \theta \times \frac{\delta}{\varepsilon} \tag{12}$$

In formula (12), θ is the chromaticity of the product's outer packaging image, U_i is the fixed light in the product packaging, δ is the illuminance coefficient of the product's outer packaging image, and ε is the average brightness of the original image. After calculating the colour reflectance of the image of the product packaging, the gloss curve of the product packaging can be obtained. Then, the luminance histogram of the region corresponding to the obtained product packaging image is introduced and converted into luminance and colour (Chen et al., 2020). Based on the colour difference interpolation algorithm, the colour deviation compensation function of the product packaging image is determined on the premise of guaranteeing the quality of the original image by processing the error module.

$$P = \sum_{i=1}^{\theta} O_i \times \sqrt{\mu \times \rho} \tag{13}$$

In formula (13), μ represents the compensation algorithm coefficient, ρ represents the compensation function operation coefficient and O_i represents the chromatic aberration parameter of the basic image.

According to the above calculation results, the interpolation average value after compensation is used to add colour levels to each component of the compensated outer packaging image, so as to determine the colour deviation compensation function of the outer packaging image, thus laying a foundation for the colour deviation compensation of the product outer packaging image.

3.3 *Product packaging image colour offset compensation*

Taking the colour block as the minimum deviation compensation unit of product outer packaging image and the product outer packaging image processed by the above method as the reference image, the mean value of the colour block of each image to be corrected is calculated and the difference value of *R*, *G* and *B* is calculated by using the mean value of the corresponding area of the standard image. The formula is as follows:

$$\begin{cases} A_R = \sum \omega \sqrt{z^2 + x^2 + c^2} \\ A_G = \sum \varphi tan\left(\frac{x}{z}\right) \\ A_B = \sum \tau tan\left(\frac{c}{\sqrt{z^2 + x^2}}\right) \end{cases} \tag{14}$$

In formula (14), A_R, A_G and A_B, respectively represent the interpolated average values of red, green and blue colour components, ω, φ and τ, respectively represent the weight coefficients of each component and z, x and c, respectively represent the three colour components.

In order to ensure the accuracy of colour deviation compensation of product packaging image, the colour scale of calibrated image is almost the same as that of reference image. Then, the offset compensated product packaging image is obtained by adding the extended colour scale interpolation average value to the monochrome colour scale of the calibrated image. The formula is as follows:

$$A = \sigma \times \left(s - \frac{1}{d}\right) \tag{15}$$

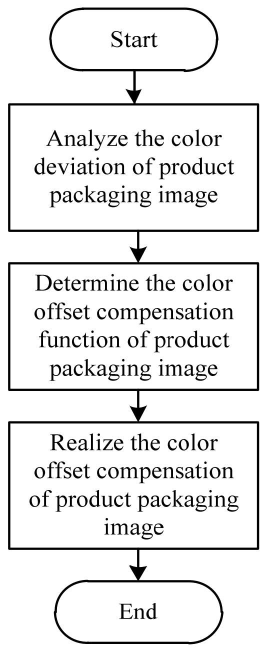
In formula (15), σ is the interpolation compensation coefficient of the outer package image, s is the average colour level of the outer package image and d is the monochrome colour level of the outer package image.

Because the above calculation is the interpolation compensation after the colour scale extension, the calibrated product packaging image is corrected. However, the chromatic aberration average is not equal to the monochromatic average of the reference image, making the product's outer packaging image brightness somewhat different from the reference image. To this end, according to the accuracy requirements of the product outer packaging image, the weighting coefficient is modified and the inverse operation method is adopted, and the formula is as follows:

$$A_Q = \sum_{i=1}^{s} A_i \times \frac{j_z}{\phi} \tag{16}$$

In formula (16), A_i is the weighting factor of the product packaging image, j_z is the parameter of the reference image, and ϕ is the offset compensation. Using the above formula, repeat the cyclic operation on the weight factor until the required accuracy of product packaging image is obtained, so as to compensate the colour deviation of product packaging. The algorithm flow is shown in Figure 2.

Figure 2 Algorithm flow chart



In the above process, after denoising the outer packaging image, the basic colour data and grey balance data of the image are compared according to the grey balance principle, so as to obtain the colour offset of the image. Then, based on the colour offset compensation function, the colour block was used as the minimum deviation compensation unit of the product packaging image and the average value of the extended colour level interpolation was added to the single colour level of the calibration image, and the colour offset compensation was completed according to the colour offset supplement amount.

4 Experimental simulation and analysis

In order to verify the effectiveness of colour offset compensation method for product packaging image based on colour difference interpolation, the following experiments are designed.

4.1 Setting the experimental environment

The experiment was carried out in MATLAB environment. The experimental data came from The Bayer image set, from which 500 product packaging images were selected. Before the experiment, the data of two adjacent pixels were used to restore the images. Because in the Bayer image interpolated in this paper, the number of green points is 1/4 of all pixels, while blue and red are 1/4 of all pixels. When interpolation restores, the number of calculations is the same.

Comparative methods were method of Fu et al. (2020), method of Yu et al. (2021).

4.2 Experiment indicators

In the experimental group, the performance of different methods were compared according to the compensation accuracy, compensation effect (PSNR value) and compensation time of product packaging image colour offset.

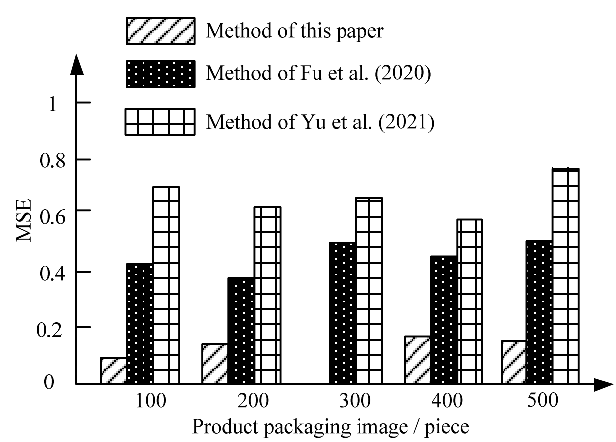
4.3 Comparison results of colour offset compensation accuracy of product outer packaging image

In order to verify the colour offset compensation accuracy of product outer packaging image of method of this paper, MSE value was taken as evaluation index. The smaller the MSE value is, the higher the colour offset compensation accuracy is. Its calculation formula is as follows:

$$MSN = \frac{\sum_{i=0}^{s}\sum_{i=0}^{d}\left(j_z - A_i\right)^2}{\sum_{i=0}^{s}\sum_{i=0}^{d}\left(j_z\right)^2} \tag{17}$$

Method of Fu et al. (2020), method of Yu et al. (2021) and method of this paper were respectively used for comparison, and the comparison results of colour offset compensation accuracy of product outer packaging images with different methods were obtained, as shown in Figure 3.

Figure 3 Comparison results of colour offset compensation accuracy of different methods



According to Figure 3, when the product packaging image is 500, the MSE value of the average product packaging image colour offset compensation of method of Fu et al. (2020) is 0.453. According to method of Yu et al. (2021), the average MSE value of colour offset compensation of product outer packaging image is 0.658. However, the average MSE value of colour offset compensation for product packaging images of method of this paper is only 0.179. Therefore, it can be seen that the MSE value of colour offset compensation for product outer packaging image of method of this paper is small, indicating that method of this paper can effectively improve the accuracy of colour offset compensation for product outer packaging image. The reason for this result is that Method of this paper calculates the colour reflectance of the outer packaging image of the product by using the image reflection algorithm, then converts the colour of the brightness histogram of the image area, and determines the colour offset compensation function according to the processing results of the error module. Under the constraint of compensation function, the average value of extended colour level interpolation is added to the single colour level of the calibrated image, so the compensation accuracy is improved.

4.4 Product packaging image colour offset compensation effect comparison

To further verify the colour offset compensation effect of product outer packaging image of method of this paper, PSNR value was taken as evaluation index. The larger the PSNR value is, the less distortion of product packaging image after colour difference interpolation is achieved, and the better colour offset compensation effect of product packaging image is achieved. Its calculation formula is as follows:

$$PSNR = \frac{\sum_{i=0}^{s}\sum_{i=0}^{d}\left(j_z - A_i\right)^2}{MSN} \tag{18}$$

Method of Fu et al. (2020), method of Yu et al. (2021) and method of this paper were respectively used for comparison, and the comparison results of colour offset compensation effect of product outer packaging images obtained by different methods are shown in Table 1.

Table 1 Comparison results of colour offset compensation by different methods

Product packaging image	*Method of this paper/dB*	*Method of Fu et al. (2020)/dB*	*Method of Yu et al. (2021)/dB*
R	31.898	31.197	27.365
G	32.364	30.962	24.169
B	31.526	28.269	24.968
PSNR value	31.429	30.828	25.364

According to the data in Table 1, PSNR values of product outer packaging images interpolated by different methods are different. Among them, the PSNR value of the product outer packaging image of method of Fu et al. (2020) after interpolation is 30.828 dB, and that of the product outer packaging image of method of Yu et al. (2021) after interpolation is 25.364 dB. PSNR value of the product packaging image of method of this paper after colour difference interpolation is as high as 31.429 dB. Therefore, the PSNR value of the product packaging image of method of this paper after colour difference interpolation is larger, indicating that the product packaging image of method of this paper after colour difference interpolation has less distortion and the product packaging image colour offset compensation effect is better. The reason for this result is that method of This Paper uses the linear filtering algorithm to de-noise the external packaging image before compensation, reducing the impact of noise on the subsequent compensation process and determines the colour offset compensation function according to the error module processing results to improve the constraint of the function and improve the compensation effect.

4.5 Product packaging image colour offset compensation time comparison

Further verify the colour offset compensation time of product outer packaging image of method of this paper. Method of Fu et al. (2020), method of Yu et al. (2021) and method of this paper were respectively used for comparison, and the comparison results of colour offset compensation time of product outer packaging images with different methods were obtained, as shown in Table 2.

Table 2 Time comparison of colour offset compensation by different methods

Product packaging image / piece	*Method of this paper/s*	*Method of Fu et al. (2020)/s*	*Method of Yu et al. (2021)/s*
100	10.2	16.3	19.8
200	15.4	22.9	25.3
300	19.8	29.5	32.5
400	24.9	35.8	38.6
500	29.6	39.6	42.3

According to the data in Table 2, colour offset compensation time of different methods increases with the increase of image data of product outer packaging. When the outer package image of the product is 500, the time of colour offset compensation of Method of Fu et al. (2020) is 39.6 s, and that of Method of Yu et al. (2021) is 42.3 s. However, the time of colour offset compensation for Method of this paper is only 29.6 s. Therefore, it can be seen that method of this paper takes less time to compensate the colour offset of product packaging image.

5 Conclusions

In order to effectively improve the accuracy of colour offset compensation and reduce the compensation time, a colour offset compensation method based on colour difference interpolation is proposed. The bilinear colour difference interpolation algorithm is used to estimate the full resolution colour difference signal of the image, and the noise component of the image is linear filtered, and the colour offset of the image is calculated. Then, the colour deviation compensation function was determined according to the corresponding relationship and the optimal value of the image colour, and the colour block was taken as the minimum unit of the deviation compensation, and the average value of the extended colour level interpolation was added to the single colour level of the calibrated image to compensate the colour deviation.

According to the experimental results, this method has a good effect on colour offset compensation of product outer packaging image. The maximum compensation time is only 29.6 s, and the maximum MSE value of compensation result is only 0.179. The above results show that the proposed method can effectively improve the compensation accuracy and reduce the compensation time. However, due to the limitation of research time, this method does not take into account the interframe noise reduction of multiple product packaging images. Therefore, in the following study, the temporal correlation of images can be utilised to further optimise the performance of the method.

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