Image correction method for the colour contrast effect using inverse processes of the brain

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Abstract

In the colour contrast effect, the impression of a colour changes according to the situation; cases occur in which the colour appearance is misunderstood. We propose an image signal processing method for preventing such misperception of colour. Many conventional image improving methods emphasize the contrast of images as same as the brain does. However, by their processes, the colour contrast effect is not canceled; we misunderstand the colour. The objective of this study is to perceive original colour. Therefore, we propose an image correction method using inverse processes of the brain in order to cancel the processes of the brain, the colour contrast effect. We verified whether the proposed method corrected the colour contrast effect by conducting a psychological experiment. The results show that the method succeeds in canceling the colour contrast effect.

Keywords:
Colour contrast; Lateral inhibition; Weber-Fechner law; Inverse process

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1. Introduction

The objective of this study is to perceive original colour by image correction using inverse processes of the brain. In the colour contrast effect, the impression of a colour changes with situations (Kirschmann, 1892; Jameson and Hurvich, 1959; Hurvich and Jameson, 1960); there is a case in which

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the colour appearance perceived incorrectly. We propose an image signal processing method for preventing such misperception of colour.

It is believed that one of the factors of the colour contrast effect is lateral inhibition of the neurons in the brain (Oehler and Spillmann, 1981). The lateral inhibition phenomenon is caused by the structure of cortical networks, where neurons inhibit their neighbours (Kuffler, 1953; Blakemore et al., 1970; Kelly, 1973). Another phenomenon in human sensory perception is known as the Weber-Fechner law (Fechner, 1987), a psychological law, which states that the relationship between stimulus and perception is logarithmic.

These two phenomena were used for the image processing method developed by Kobayashi et al. (Kobayashi et al., 2007; Kato and Kobayashi, 1999). They proposed the contrast enhancement method by global conversion derived from the Weber-Fechner law and local conversion by lateral inhibition. Similar to these methods, the primary process of various methods for improving image is to enhance contrast (Chen et al., 2010; Beghdadi and Negrate, 1989; Starck et al., 2003; Meylan et al., 2007; Panetta et al., 2008; Ramponi, 1999; Smolka and Wojciechowski, 2001; Oakley and Bu, 2007; Xiao and Ohya, 2007). Note that the contrast enhancement processes used in such methods are similar to the processes of the brain. However, by their brain like processes, the colour contrast effect would be enhanced, and the impression of a colour would change to a large extent; the colour appearance would be misunderstood. Most of such methods does not change color components; they mainly change luminance components (Chen et al., 2010; Beghdadi and Negrate, 1989; Panetta et al., 2008; Ramponi, 1999; Smolka and Wojciechowski, 2001; Oakley and Bu, 2007; Xiao and Ohya, 2007). This means that the colour contrast effect still remains. Meylan et al. (2007) have proposed a method changing color components. The method, however, would be enhance the colour contrast effect because it uses the algorithm derived from a model of retinal processing in human visual system.

On the contrary to such contrast enhancement methods based on brain like processes, we propose an image correction method using each inverse process of the Weber-Fechner law as global conversion and lateral inhibition as local conversion in order to perceive original colour without being influenced by the surroundings. We verified whether our proposed method can correct the colour contrast effect by conducting a psychological experiment.

2. Conventional contrast enhancement method

We briefly introduce the contrast enhancement method proposed by Kobayashi et al. (2007), because our proposed method is the opposite of the contrast enhancement method. The contrast enhancement method includes global conversion derived from the Weber-Fechner law and local conversion by lateral inhibition.

2.1. Weber-Fechner law as global conversion

The Weber-Fechner law describes the relationship between the magnitude of physical stimuli and the magnitude of psychological sense. The relationship is expressed as follows.

$$E = k \ln R + c, \tag{1}$$

where R is the magnitude of physical stimulus, E is the magnitude of psychological sense, and k and c are constants.

Kobayashi et al. (2007) used the Weber-Fechner law for enhancing contrast. Let v be a response to light stimuli, and v_L and v_U be the minimum and maximum of the dynamic range, respectively. According to the Weber's law, the differences in the intensity dv in the positive and negative channels are normalized by the power of the background as follows:

$$dV_{posi} \propto \frac{dv}{v - v_L}, \tag{2}$$

$$dV_{nega} \propto \frac{dv}{v_U - v}. \tag{3}$$

According to the Fechner's law, the response to the intensity is proportional to the integrated forms as follows:

$$V_{posi} \propto \ln(v - v_L), \tag{4}$$

$$V_{nega} \propto -\ln(v_U - v). \tag{5}$$

Finally, the total response is represented by a linear summation of both channels as follows:

$$V(v) = \ln \frac{v - v_L + \delta_{posi}}{v_U - v + \delta_{nega}}, \tag{6}$$

where $V(v)$ is the converted output, and δ_{posi} and δ_{nega} are the constants of integration. The setting method of δ_{posi} and δ_{nega} is described in Sec. 2.2. Figure 1 shows an example of Eq. (6), in which both the input and output are normalized from 0 to 1. This conversion shows a reverse-S-shape response.

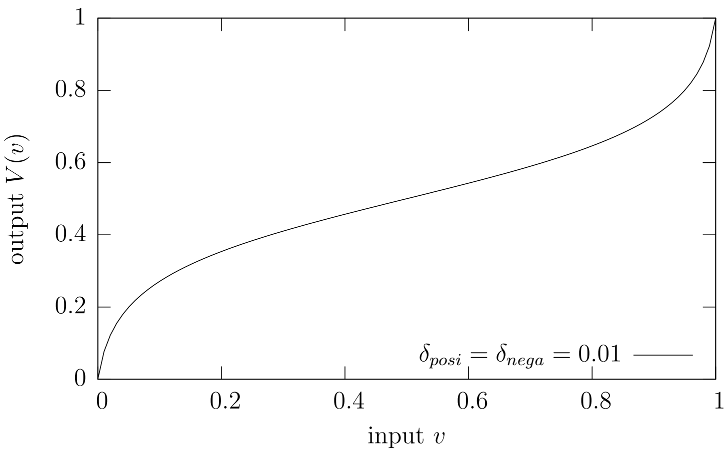

Figure 1: Example of reverse-S-shape conversion.

2.2. Lateral inhibition as local conversion

The lateral inhibition phenomenon in retinal cells has the effect of detecting and enhancing contrast (Kuffler, 1953). This is caused by the concentric receptive fields that are classified into ON-centre OFF-surround and OFF-centre ON-surround types. The former leads to the positive channel described in Sec. 2.1, while the later leads to the negative channel described in Sec. 2.1.

In this model of brain processes, the global conversion expressed in Eq. (6) is calculated after this local lateral inhibitory conversion is calculated. δ_{posi} and δ_{nega} in Eq. (6) are determined according to the contrast in each local area as follows.

$$\delta_{posi} = \begin{cases} v - v_{ave} + \beta_{posi} & (v \geq v_{ave}) \\ \beta_{posi} & (v < v_{ave}), \end{cases} \tag{7}$$

$$\delta_{nega} = \begin{cases} \beta_{nega} & (v \geq v_{ave}) \\ v_{ave} - v + \beta_{nega} & (v < v_{ave}), \end{cases} \tag{8}$$

where v_{ave} is the mean luminance of the surrounding area. The radius of the surrounding area was set as 3. β_{posi} and β_{nega} are constants whose values determine the boundary degree of the reverse-S-curve. They are defined as $\beta_{posi} = \beta_{nega} > 0$. The degree of curvature of the reverse-S-shape depends on the values of δ_{posi} and δ_{nega}, as shown in Fig. 1. When δ is greater, the degree of curvature is smaller, and when δ is smaller, the degree of curvature is greater.

3. Proposed method

The objective of this study is to perceive original colour by image correction. In the colour contrast effect, adjacent colours enhance each other. Based on the enhancement processes in the human brain, Kobayashi et al. (Kobayashi et al., 2007; Kato and Kobayashi, 1999) proposed the contrast enhancement method using global conversion derived from the Weber-Fechner law and local conversion by lateral inhibition. On the contrary, we propose an image correction method using each inverse process of the Weber-Fechner law as global conversion and lateral inhibition as local conversion in order to prevent misperception of colour.

Here, it is examined whether both the global and local conversion can be applied to colour stimuli. The Weber-Fechner law, which is used as global conversion, is established in many senses. Therefore, in our opinion, the Weber-Fechner law can be applied to colour stimuli. On the other hand, in lateral inhibition as local conversion, there is no problem because double colour-opponent receptive fields have been found in primary visual area (Livingstone and Hubel, 1984; Johnson et al., 2001).

In our proposed method, we selected the CIE 1976 ($L^*a^*b^*$) colour space because it is a colour-opponent space with a luminance dimension, and it is also necessary to calculate colour differences accurately. As the colour space is perceptually uniform, it is suitable for accurate calculations.

The brief procedure is as follows. First, a subject image is converted using decoding gamma, because most displays performs gamma-decoded. Second, the global and local conversions are applied to L^*, a^*, and b^* of the image. Finally, the image by the global and local conversions is converted using encoding gamma. The global and local conversions are explained in detail as follows.

3.1. Global conversion

The inverse function of Eq. (6) is calculated as follows:

$$V(v) = \frac{\exp(v) \times (v_U + \delta_{nega}) + v_L - \delta_{posi}}{1.0 + \exp(v)}, \tag{9}$$

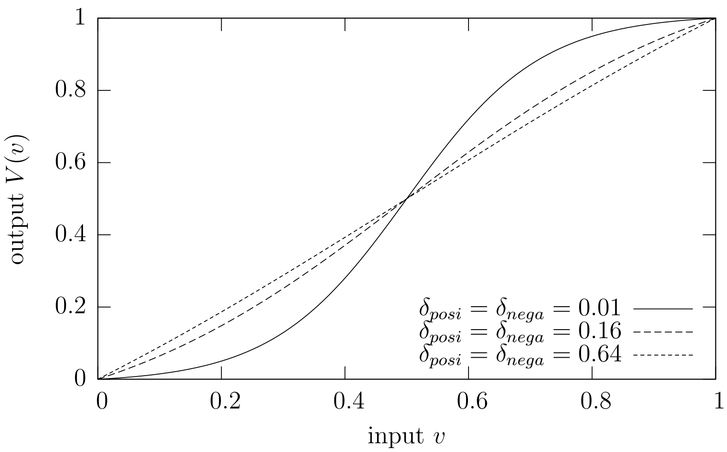

Figure 2: Example of S-shape conversion.

here $V(v)$ is the converted output, v is the input, and δ_{posi} and δ_{nega} are the parameters that determine the degree of curvature of the S-shape.

In order to normalize from 0.0 to 1.0, the output of Eq. (9) is normalized as follows:

$$V(v) = \frac{\exp(S \times (v+T))(v_U + \delta_{nega}) + v_L - \delta_{posi}}{1.0 + \exp(S \times (v+T))}, \tag{10}$$

$$S = \ln\frac{(1.0+\delta_{posi})(1.0+\delta_{nega})}{\delta_{posi}\delta_{nega}}, \tag{11}$$

$$T = \frac{1}{S}\ln\frac{\delta_{posi}}{1.0+\delta_{nega}}. \tag{12}$$

Figure 2 shows an example of S-shape conversion using Eq. (9). The setting method of δ_{posi} and δ_{nega} is described in Sec. 2.2.

3.2. Local conversion

The setting equations of β_{posi} and β_{nega} shown in Eqs. (7) and (8) are mutually replaced, and the coefficient α is added as follows:

$$\delta_{posi} = \begin{cases} \beta_{nega} & (v \geq v_{ave}) \\ \alpha(v_{ave} - v) + \beta_{nega} & (v < v_{ave}) \end{cases} \tag{13}$$

$$\delta_{nega} = \begin{cases} \alpha(v - v_{ave}) + \beta_{posi} & (v \geq v_{ave}) \\ \beta_{posi} & (v < v_{ave}) \end{cases}, \tag{14}$$

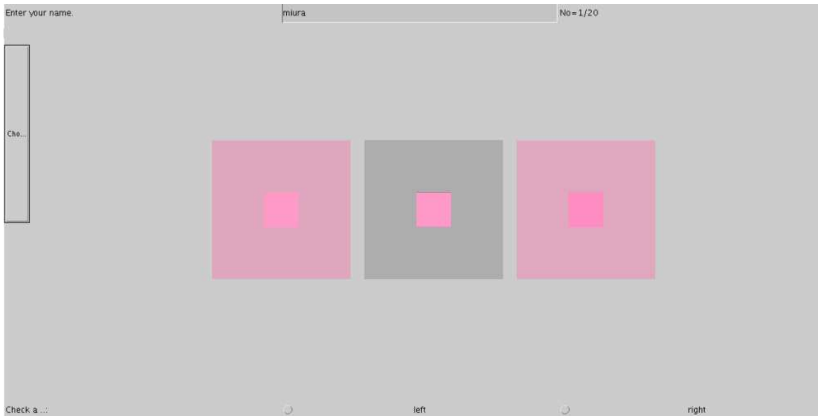

Figure 3: Example of display.

where α controls the intensity of the canceling contrast. Since the reverse process of Eqs. (7) and (8) cannot be calculated mathematically, we propose the mutually replaced form instead of the exact reverse process. The values of these δ_{posi} and δ_{nega} are substituted into Eqs. (10)–(12) as global conversion.

According to preliminary psychological experiments, the parameters are set as follows: β_{posi} ($=\beta_{nega}$) for L^*, a^*, and b^* are 0.8, 0.2, and 0.2, respectively, and the value of α for L^*, a^*, and b^* is all 2.0. The radius of the surrounding area is 3. The decoding gamma factor is 2.2, and the encoding gamma factor is 1/2.2.

4. Psychological experiments

Psychological experiments were conducted to verify whether the proposed method corrects the colour contrast effect. The psychological experiments were conducted according to the method described below.

The subjects were 10 naive university students with normal colour vision. An example of the computer screen is shown in Fig. 3. Three images were displayed in the center of the screen, and the middle image was for comparison with the original colour. Of the left and right images, one was the original image and the one on the other side was the image converted by our proposed method. Two choices were displayed under the images, left and right. The decision button was on the left side.

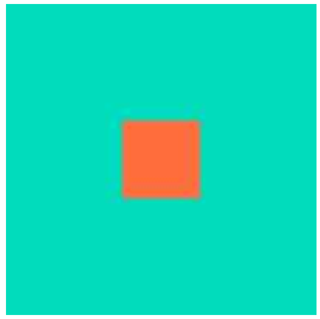

Figure 4: Example of an image used in psychological experiments.

Each image used in the psychological experiments was composed as follows. The central test area was about 1.15° square, which was surrounded by an area of about 5.0° square. This was called the inducing area. The distance from the display to the subjects was about 1 metre. Figure 4 shows an example of the image.

The inducing area of the central image was gray, whose luminance was the same as that of the inducing area of each original image. This was so that the subjects could compare the test area of the central image with the original colour under the same surrounding luminance condition. The original and converted images were randomly placed. The subjects alternatively chose the left or right images, without knowing which was the original image and which was the converted image.

There were 10 combinations each of hue contrast and saturation contrast for the test colour and inducing colour to avoid any bias in the experiment. For the saturation contrast, five test colours were chosen: a positive (red) and a negative (green) on the a^* axis, a positive (yellow) and a negative (blue) on the b^* axis, and a positive a^* and positive b^* (orange). The higher and lower saturations for each of the five test colours were chosen as the inducing colours. For the hue contrast, two test colours were chosen, a positive a^* and positive b (orange) and a negative a^* and positive b^* (yellow-green). For every two test colours, five inducing colours were chosen: a positive (red) and a negative (green) on the a^* axis, a positive (yellow) and a negative (blue) on the b^* axis, and the opposite colour of the test colour. The 20 combinations of images were displayed in random order.

The procedure of the psychological experiments was as follows.

Table 1: Total psychological result.

	Total	Saturation contrast	Hue contrast
Choice probability of image Converted by proposed method (%)	83.0	90.0	76.0

Table 2: Results for saturation contrast.

Inducing colour	Red	Green	Yellow	Blue	Orange
Inducing colour $<$ test colour Choice probability (%)	100.0	80.0	90.0	90.0	90.0
Inducing colour $>$ test colour Choice probability (%)	90.0	90.0	90.0	80.0	100.0

1. The subjects sat on a chair so facing the computer screen.
2. They pushed the start button.
3. The three images were displayed in the centre (Fig. 3).
4. They alternatively selected the left or right image that she or he thought was close to the test colour of the middle image. No time limit was imposed.
5. They confirmed the choice.
6. After a sufficient interval, next three images were displayed.
7. The subjects repeated the procedure from step (4) until 20 image combinations were completed.

4.1. Results

The choice probabilities of the image converted by our proposed method are shown in Table 4.1. The results show that our proposed method could reproduce colours very close to the appearance of the original colours.

The choice probabilities for the saturation and hue contrast of each image are shown in Tables 4.1 and 4.1. Both high and low probabilities were seen. This situation can be explained as follows. The original images included images with both a strong and weak colour contrast effect. In the strong colour contrast effect, the appearance of the test colour was converted close to the original colour, and the choice probability of image converted by our

Table 3: Results for hue contrast.

Inducing colour	Red	Green	Yellow	Blue	Opponent colour
Test colour is orange Choice probability (%)	60.0	90.0	90.0	50.0	80.0
Test colour is yellow-green Choice probability (%)	90.0	100.0	70.0	50.0	80.0

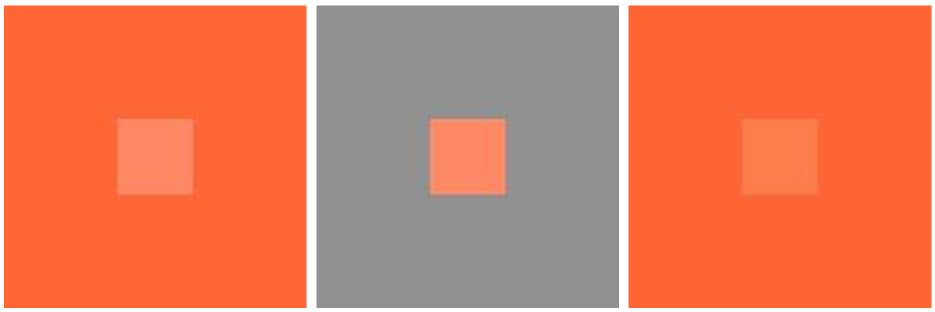

Figure 5: Example of high choice probability. Left: original image, centre: image for comparison, right: converted image.

proposed method was high. Figure 5 shows an example of a strong colour contrast effect. In this situation, all the subjects chose the image converted by our method. This shows that our method can correct the colour appearance in a strong colour contrast effect. Note that the test colour in the image for comparison is physically same as that of the original image, whereas it is not the same as in the converted image. Nevertheless, it was judged that the converted test colour was similar to the original test colour.

On the other hand, in the weak colour contrast effect, colour illusion hardly occurred. It would therefore be desirable if the original image were hardly converted. Figure 6 shows an example of a weak colour contrast effect. In the case of yellow-green as the inducing colour and blue as the test colour, the choice probability was 50 percent, which was the same as chance. In such a case, because the colour contrast effect is very weak, the choice probability at the level of chance gives a successful result.

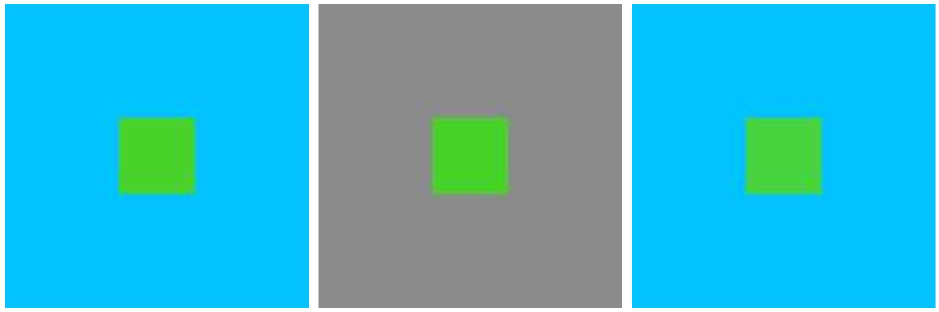

Figure 6: Example of low choice probability. Left: original image, centre: image for comparison, right: converted image.

5. Natural image

Our proposed method was applied to a natural image, although quantitative evaluation was impossible. The natural image was Peppers from the Waterloo Repertoire ColorSet (Kominek, 2008).

For the Peppers image, Figure 7 shows the original image, and Figure 8 shows the image converted by our proposed method. Natural images seem to be converted without any difficulties. The difference between the colour impressions of the original and converted images is subtle. In order to reveal the difference, we show the contrast-enhanced image of Peppers using the conventional enhancing method in Fig. 9. The enhancement conversion was executed for each axis in CIE 1976 ($L^*a^*b^*$), as described in Sec. 2, that is, the enhancement conversion was quite the opposite to that of the proposed method. Regarding the colour impression, the converted image obtained by our method is fine.

However, the converted image obtained by the proposed method was slightly blurred. This problem is unavoidable because the objectives of contrast enhancement and perception of the original colour are contrary to each other. Either the image has to be selected depending on the purpose, namely colour correction or contrast enhancement. Or, we could combine our proposed method and the methods changing mainly luminance components (Chen et al., 2010; Beghdadi and Negrate, 1989; Panetta et al., 2008; Ramponi, 1999; Smolka and Wojciechowski, 2001; Oakley and Bu, 2007; Xiao and Ohya, 2007), if our method was applied to only colour components.

Figure 7: Original image of Peppers.

6. Conclusions

The objective of this study was to perceive original colour by image correction. We propose an image correction method using inverse processes of the Weber-Fechner law as global conversion and lateral inhibition as local conversion in order to perceive the original colour without being influenced by the surroundings. We also verified whether the proposed method corrects the colour contrast effect by conducting a psychological experiment. The result of the tests showed that the method successfully cancel the colour contrast effect.

Future studies should be aimed at achieving high-accuracy image correction. To accomplish this, the six coefficients that decide the degree of curvature of the S-shape conversion in each axis in CIE 1976 ($L^*a^*b^*$) would need to be adjusted more.

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Figure 8: Converted image of Peppers by proposed method.

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Figure 9: Contrast enhanced image of Peppers by the conventional enhancing method.

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