Illumination Manipulation and Specular Reflection Analysis of Still Image with Single Object

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Abstract

A lighting manipulation scheme for still images is proposed in this paper. By using the dichromatic-based model, the reflection component can be resolved through a single-image specular reflection removal method with the characteristics of color constancy. Finally virtual illumination can be generated through the recombination of the reflection component. The scenes illumination can be estimated using the proposed automatic method without knowing the illumination spectra, three-dimensional object modeling, or texture databases. Experimental results show that the method is useful for handling the single or multicolor objects in scenes.

Keywords: Chromaticity, Dichromatic-based model, specular removal, color consistence, virtual illumination.

1. Introduction

Establishing the relighting in the computer graphics needs the provision of the light sources from different directions. Using only one single input image is not enough to complete the relighting of the objects in the image. In this paper, we propose a method which can modify the illumination conditions in images. By separating the specular reflection and automatically evaluating the illumination in the image, the reconstruction of 3-D scene can be discarded and we can perform realistic control on illumination colors in images.

In recent research about specular highlight removal [1], most methods on separating the specular reflection components in a single image are based on the reflection model established by Shafer [2]. The reflection model assumes the complex light paths as a simple reflection component and analyzes the highlight information based on polarized photography. Thereafter, more related methods have been proposed. For example, the T-shape image color space proposed by Shafer and Klinker can be used to analyze the neighboring pixels of an object [3]. In this method, the reflected specular and diffused colors are viewed as orthogonal color vectors. However, in the bright image textures, the linear distribution model is hardly used to estimate the vectors in the color space.

The specular-free image (SFI) method determines the diffused components by estimating either the intensity or chromaticity of the image. Tan's method [4] generates the SFI by analyzing the maximum chromaticity space at first. In this method, the specular reflection is considered as the chromaticity deviation and the maximum chromaticity is set as the pixel common chromaticity. When the maximum chromaticity is extracted and discarded, the specular component can be removed. However, in a non-single color image, different maximum chromaticity in the chromaticity space for different textures could be observed. Therefore, the controversy exists on selecting the chromaticity. Yoon's specular-free two-band image (SFTBI) method [5], which uses the specular-invariant to determine the diffused reflection component, is thus proposed. A diffused reflection image with low chromaticity can be obtained. In addition, Shen proposed the modified specular-free image (MSFI) [6] method to improve Yoon's method.

The SFI method is usually used together with the neighboring region analysis. Although the SFI method usually cannot get precise component analysis during the separation process, SFI can easily obtain the result without specular components. The specular reflection pixels can be found by analyzing the difference between the SFI and the intrinsic image in the neighboring region. In Tan's method [4], the iteration process is used at low chromaticity range for both the SFI and normalized image. The high-quality or bright-color texture images can be successfully processed by setting regional chromaticity. Yoon and Shen proposed different mechanisms to improve the iteration efficiency. Other types of methods are based on the dichromatic reflection model. For example, Ping's inpainting method [7], which repairs the highlight points (also considered as region of interest, ROI). Rouf proposed the star filter to filter the highlight points based on the structural characteristics [8].

In this paper, the proposed method mainly deals with the color constancy based on the chromaticity and integrated the methods of high-light removal proposed by Tan and Shan [4], [6] to achieve the reflection removal purpose.

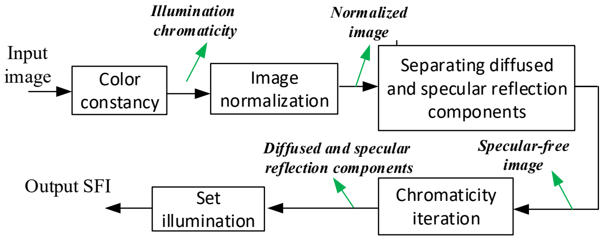


Fig. 1: The system diagram of the proposed method.

2. Proposed Method

Figure 1 shows the system diagram of the proposed method. The proposed illumination estimation method is based on the Ikeuchi's inverse-intensity chromaticity space [9]. In this space, the specular component will be labeled and then be transferred to the Hough space to statistically determine the corresponding chromaticity direction. Illumination estimation mainly aims to provide the correct intensity information during the separation of reflection components. The intensities of non-white light illuminations are inhomogeneous while changing the intensity. Therefore, we assume that the illumination transformation is correctly estimated using the same compensation mechanism.

The dichromatic-based model is used to determine the diffused reflection components. The SFI can be obtained using Tan's method [9]. Then the improved SFI, called the simplified mechanism of SFI can achieved. First, Tan's method mentioned that the image intensity can be divided into two parts according to the dichromatic-based model. That is,

$$\mathbf{I}(\underline{\mathbf{x}}) = w_d \int_\Omega S(\lambda)E(\lambda)\mathbf{q}(\lambda)d\lambda + w_S \int_\Omega E(\lambda)\mathbf{q}(\lambda)d\lambda, \quad (1)$$

where $\mathbf{I}(\underline{\mathbf{x}}) = \{I_r, I_g, I_b\}$ denotes the color vector of image intensity recorded by a camera. $\underline{\mathbf{x}}=\{x,y\}$ denotes the 2D coordinates, $\mathbf{q} = \{q_r, q_g, q_b\}$ denotes the 3D vector of sensor sensitivity. $S(\lambda)$ and $E(\lambda)$ denote the diffused and the illumination spectral distributions, respectively. w_d and w_S denote for the weighting factors of specular and diffuse reflection, respectively. The values depend on the geometric structure in the regional coordinate $\underline{\mathbf{x}}$. Image intensity is within the visible spectrum (Ω). As shown in Eq. (1), the dichromatic-based model describes the image pixel intensity by separating them into two reflection components: $w_d \int_\Omega S(\lambda)E(\lambda)\mathbf{q}(\lambda)d\lambda$, which denotes the diffused reflection components, and $w_S \int_\Omega E(\lambda)\mathbf{q}(\lambda)d\lambda$, which denotes the specular reflection components in an image. Diffused component includes the reflection spectrum of the object, while the specular one just depends on the illumination. The specular and diffused reflection components are two independent color vectors, which can be expressed as two bold-face characters, **B** and **G**, respectively. We also assume that the specular components are uniformly distributed in the scene so that the illumination colors are independent to the regional coordinates. The intensity equation of the original image can be replaced a simplified combination:

$$\mathbf{I}(\underline{\mathbf{x}}) = w_d\mathbf{B}(\underline{\mathbf{x}}) + w_S\mathbf{G}, \quad (2)$$

where

$$\mathbf{B}(\underline{\mathbf{x}}) = \int_\Omega S(\lambda)E(\lambda)\mathbf{q}(\lambda)d\lambda, \quad (3)$$

$$\mathbf{G} = \int_\Omega E(\lambda)\mathbf{q}(\lambda)d\lambda. \quad (4)$$

In order to analysis the relationship between the reflection components and scaling factor. The image chromaticity is defined by using the normalized RGB components. Here, the chromaticity (σ), diffuse chromaticity (Λ), and specular chromaticity (Γ) are defined as

$$\boldsymbol{\sigma}(\underline{\mathbf{x}}) = \frac{\mathbf{I}(\underline{\mathbf{x}})}{I_r(\underline{\mathbf{x}})+I_g(\underline{\mathbf{x}})+I_b(\underline{\mathbf{x}})}, \quad (5)$$

$$\boldsymbol{\Lambda}(\underline{\mathbf{x}}) = \frac{\mathbf{B}(\underline{\mathbf{x}})}{B_r(\underline{\mathbf{x}})+B_g(\underline{\mathbf{x}})+B_b(\underline{\mathbf{x}})}, \quad (6)$$

$$\boldsymbol{\Gamma} = \frac{\mathbf{G}}{(G_r+G_g+G_b)}, \quad (7)$$

Substituting Eqs. (5) and (6) into Eq. (2), the chromaticity equation becomes

$$\mathbf{I}(\underline{\mathbf{x}}) = m_d(\underline{\mathbf{x}})\boldsymbol{\Lambda}(\underline{\mathbf{x}}) + m_s(\underline{\mathbf{x}})\boldsymbol{\Gamma}, \quad (8)$$

where

$$m_d(\underline{\mathbf{x}}) = w_d\{B_r, B_g, B_b\}, \quad (9)$$

$$m_s(\underline{\mathbf{x}}) = w_s\{G_r, G_g, G_b\}. \quad (10)$$

In the reflection model shown in Eq. (1), in which only the specular reflection component exists (w_d=0), $\mathbf{\Gamma}$ will be independent of the specular geometrical parameter w_S. In the definition on chromaticity, the range of image chromaticity, diffuse chromaticity, and specular chromaticity are all within the range {0, 1}. That is, $\{\sigma_r+\sigma_g+\sigma_b\} = \{\Lambda_r+\Lambda_g+\Lambda_b\} = \{\Gamma_r+\Gamma_g+\Gamma_b\} = 1$. The illuminant chromaticity is estimated based on the color constancy method in Ref. [2] to evaluate the chromaticity $\mathbf{\Gamma}^{est} = \{\Gamma_r^{est}, \Gamma_g^{est}, \Gamma_b^{est}\}$. Assume that the evaluated chromaticity is correct. The image with corrected illumination is defined as a normalized image:

$$\mathbf{I}'(\underline{\mathbf{x}}) = m_d'(\underline{\mathbf{x}})\boldsymbol{\Lambda}'(x) + m_s'(\underline{\mathbf{x}})\frac{1}{3}, \tag{11}$$

where
$$m_d(\underline{\mathbf{x}})\boldsymbol{\Lambda}(\underline{\mathbf{x}}) = [m_d'(\underline{\mathbf{x}})\boldsymbol{\Lambda}'(\underline{\mathbf{x}})]\boldsymbol{\Gamma}^{\text{est}}, \tag{12}$$

$$m_s(\underline{\mathbf{x}})\boldsymbol{\Gamma} = \left[m_s'(\underline{\mathbf{x}})\frac{1}{3}\right]\boldsymbol{\Gamma}^{\text{est}}. \tag{13}$$

The normalized image can be denoted as $\mathbf{I}'(\underline{\mathbf{x}}) = \frac{\mathbf{I}(\mathbf{x})}{\boldsymbol{\Gamma}^{\text{est}}}$. The normalized illumination color is $\frac{\boldsymbol{\Gamma}}{\boldsymbol{\Gamma}^{\text{est}}} = \{1,1,1\}$. In $\mathbf{I}'(\underline{\mathbf{x}})$, $\boldsymbol{\Gamma}' = \{\frac{1}{3},\frac{1}{3},\frac{1}{3}\}$ and $3m_s = m_s'$. Normalized image will be considered as a diffused reflection image illuminated by a standard white light.

Since Tan's specular-to-diffuse mechanism does not generate a real diffuse image, the image can be seemed as a fake diffused reflection image. In this mechanism, the maximum chromaticity is used. The definition of maximum chromaticity of image pixels is as follow

$$\tilde{\sigma}'(\underline{\mathbf{x}}) = \frac{\max(I'_r(\underline{\mathbf{x}}), I'_g(\underline{\mathbf{x}}), I'_b(\underline{\mathbf{x}}))}{I'_r(\underline{\mathbf{x}})+I'_g(\underline{\mathbf{x}})+I'_b(\underline{\mathbf{x}})}, \tag{14}$$

where $(I'_r(\underline{\mathbf{x}}), I'_g(\underline{\mathbf{x}}), I'_b(\underline{\mathbf{x}}))$ is obtained in the normalized image, σ' denotes the chromaticity of the normalized image. Note that $\tilde{\sigma}'$ is different from σ' and the range of $\tilde{\sigma}'$ is not between 0 and 1. With Eqs. (11) to (13), the maximum chromaticity of image pixels in Eq. (14) can be rewritten as:

$$\tilde{\sigma}'(\underline{\mathbf{x}}) = \frac{m_d'(\underline{\mathbf{x}})\tilde{\Lambda}'(\underline{\mathbf{x}}) + m_s'(\underline{\mathbf{x}})\frac{1}{3}}{m_d'(\underline{\mathbf{x}})[\Lambda_r'(\underline{\mathbf{x}}), \Lambda_g'(\underline{\mathbf{x}}), \Lambda_b'(\underline{\mathbf{x}})] + m_s'(\underline{\mathbf{x}})}.$$

By setting $\tilde{\Lambda}' = \max(\Lambda'_r, \Lambda'_g, \Lambda'_b)$, both m_d' and m_s' can also be determined. Since the maximum chromaticity of diffused reflection is usually higher than that of specular reflection and, in generally, $\tilde{\Lambda}' > \frac{1}{3}$, and

$$\tilde{\sigma}'_{\text{diff}} > \tilde{\sigma}'_{\text{spec}}, \tag{15}$$

$$\frac{\tilde{\Lambda}'}{[\Lambda_r', \Lambda_g', \Lambda_b']} > \frac{m_d'\tilde{\Lambda}'(\underline{\mathbf{x}}) + m_s'\frac{1}{3}}{m_d'[\Lambda_r', \Lambda_g', \Lambda_b'] + m_s'}. \tag{16}$$

In the normalized image, $(\Lambda_r' + \Lambda_g' + \Lambda_b') = 1$. Removing the pixel $(\underline{\mathbf{x}})$ and substituting m_s' ($m_s' = m_d'(\frac{\tilde{\Lambda}' - \tilde{\sigma}'}{\tilde{\sigma}' - \frac{1}{3}})$) into Eq. (16), we can finally obtain the equation that can represent the relationship between the image chromaticity and illumination chromaticity:

$$\tilde{I}'(\underline{\mathbf{x}}) = m_d'\left(\tilde{\Lambda}' - \frac{1}{3}\right)\left(\frac{\tilde{\sigma}'}{\tilde{\sigma}' - \frac{1}{3}}\right). \tag{17}$$

In the above equation, m_d' is computed by assuming the same chromaticity. In the specular pixel $(\underline{\mathbf{x}}_1)$ and diffused pixel $(\underline{\mathbf{x}}_2)$, the same chromaticity is used such that $\tilde{\Lambda}'(\underline{\mathbf{x}}_1) = \tilde{\Lambda}'(\underline{\mathbf{x}}_2) = \tilde{\sigma}'(\underline{\mathbf{x}}_2)$ ($m_s' = m_d'$ here). We can determine m_d' by using:

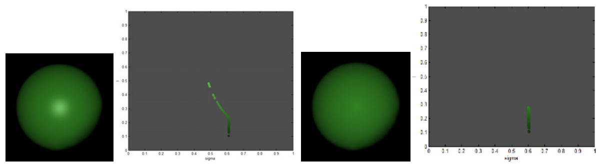
$$m_d'(\underline{\mathbf{x}}_1) = \frac{\tilde{I}'(\underline{\mathbf{x}}_1)[3\tilde{\sigma}'(\underline{\mathbf{x}}_1) - 1]}{\tilde{\sigma}'(\underline{\mathbf{x}}_1)[3\tilde{\Lambda}'(\underline{\mathbf{x}}_1) - 1]}. \tag{18}$$

The finally result is

$$m_s'(\underline{\mathbf{x}}_1) = [I'_r(\underline{\mathbf{x}}_1) + I'_g(\underline{\mathbf{x}}_1) + I'_b(\underline{\mathbf{x}}_1)]m_d'(\underline{\mathbf{x}}_1),$$

where the diffused reflection component is

$$m_d'(\underline{\mathbf{x}}_1)\tilde{\Lambda}'(\underline{\mathbf{x}}_1) = \tilde{I}'(\underline{\mathbf{x}}_1) - \frac{m_s'(\underline{\mathbf{x}}_1)}{3}. \tag{19}$$



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

Fig. 2: (a) The original image; (b) Projection of pixel intensity in (a) into the chromatic space ($\tilde{\sigma}'$, $\tilde{I}'$); (c) The SFI with the maximum chromaticity; (d) The projection of pixel intensity in (c) into the chromatic space ($\tilde{\sigma}'$, $\tilde{I}'$).

Figures 2(a) and 2(b) show an input image and its 2D projection of the maximum chromatic intensity $\tilde{\sigma}'$ and intensity $\tilde{I}'$, respectively. In Fig. 2(b), the x axis denotes the maximum chromaticity intensity $\tilde{\sigma}'$, while the y axis denotes the intensity $\tilde{I}'$. Fig. 2(c) shows the SFI obtained by suing Tan's method with setting the $\tilde{\Lambda}' = \max(\Lambda'_r, \Lambda'_g, \Lambda'_b)$ in the maximum chromaticity for all image pixels. In Fig. 2(d), the SFI specular component has the same chromaticity with the diffused one.

Yoon proposed a simplified SFI method based on the property of invariant specular reflection, whose mechanism is shown as follows:

$$\mathbf{I}_{sf}(\underline{\mathbf{x}}) = \mathbf{I}'(\underline{\mathbf{x}}) - \mathbf{I}_{min}(\underline{\mathbf{x}}), \tag{20}$$

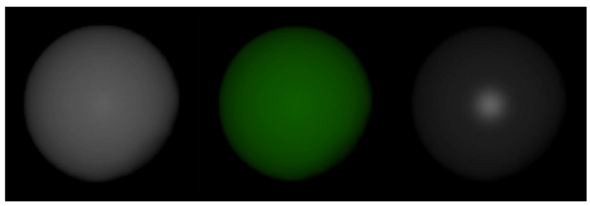
$$\mathbf{I}_{min}(\underline{\mathbf{x}}) = m_d\,\lambda_{min}(\underline{\mathbf{x}}) + \frac{1}{3}m_s'(\underline{\mathbf{x}}), \tag{21}$$

where $\mathbf{I}_{sf}$ presents SFI, $\mathbf{I}_{min}$ presents the minimum pixel value of the normalized image in RGB channels. Similarly, we assume that the specular reflection is also invariant in the HSV space:

$$\mathbf{I}_{min}(\underline{\mathbf{x}}) = \begin{cases} S = 0 \\ V = \min(I_r, I_g, I_b) \end{cases}. \tag{22}$$

Different from the Tan's method, we use the HSV color space to determine the SFI, which is shown in Fig. 3(b). The S and V components present the saturation and scalar intensity values, respectively. And the specular and diffused components of chromaticity are the same with that in the input image. By subtracting the change of specular component, the intensity of SFI shown in Fig. 3(a) will be a uniform intensity. Fig. 3(c) shows the invariant specular reflection part of the original image. The SFI component is determined as follows:

$$\mathbf{I}_{sf}(\underline{\mathbf{x}}) = m_d\left(\lambda(\underline{\mathbf{x}}) - \lambda_{min}(\underline{\mathbf{x}})\right). \tag{23}$$

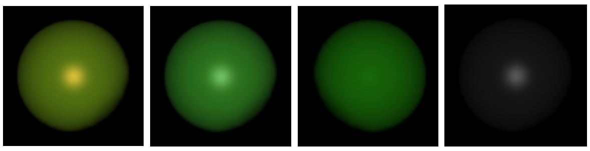


(a) (b) (c)

Figure 3: (a) intensity of SFI; (b) SFI; (c) invariant specular

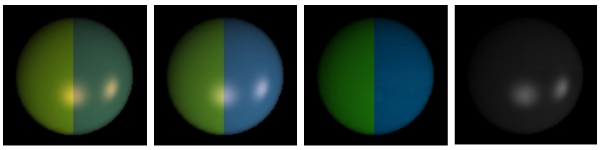
part $\mathbf{I}_{min}$.

The illumination setting for the final output SFI image is the last step. The user can define a new reflectivity by setting $\sum_{u\in\{r,g,b\}} \mathbf{\Gamma}^{\text{set}}$. That is, the separating specular and diffused reflections parts can be edited for the final combination. Finally, by replacing the original chromaticity with the new one $\mathbf{\Gamma}^{\text{set}} = \{\Gamma_r^{\text{set}}, \Gamma_g^{\text{set}}, \Gamma_b^{\text{set}}\}$, the final SFI image can be obtained.



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

Fig. 5: (a) Image of a spherical object illuminated by a halogen lamp; (b) Normalized image with chromaticity RGB = (0.5324, 0.3077, 0.1594); (c) Separated diffused component; (d) Separated specular component.



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

Fig. 6: (a) Dichromatic image of a spherical object illuminated by a halogen lamp; (b) Normalized image with chromaticity RGB =(0.2187, 0.2695, 0.7812); (c) Separated diffused component; (d) Separated specular component.

3. Experiment Results

Suppose that the reflection light is generated from a fixed illumination in a scene. The proposed system can automatically detect the light source and then perform image normalization so that the image can be separated into the normalized image, diffused image, and specular image. By setting the chromaticity, the user can obtain the image with a modified illumination color. Figures 5 and 6 provide two demonstrations of the proposed method on resetting the chromaticity. Figure 5(a) shows an input image, in which the single-color spherical object is illuminated by a halogen lamp with the color temperature 4700 °K. Figure 5(b) shows the normalized image using the designated illumination chromaticity RGB = (0.5324, 0.3077, 0.1594). Figures 5(c) and 5(d) show the extracted diffused and specular components, respectively. There are two colors in the spherical object shown in Fig. 6(a). The illumination is the same as that in Fig. 5(a). However, the designated illumination chromaticity RGB= (0.2187, 0.2695, 0.7812) in Fig. 6(b) is different from that in Fig. 5(b). By using the proposed method, Figs. 6(c) and 6(d) show the separated diffused and specular components, respectively.

4. Conclusion

We propose a method to simulate the object images under various illumination colors without constructing the 3-D model of the scene or requiring multiple input images. In addition, the reflectivity can also be assigned and be combined with the separated diffused components to obtain the designated image. The improved mechanism of SFI is used to accelerate the iteration process. Given an input image, the system will separate the specular and reflection components at first. Thus the high-light removal can be achieved. A graphical user interface has been implemented so that the users can easily manipulate the system to obtain the images with various illumination conditions such as the chromaticity and reflectivity.

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