# EFFICIENT IMPROVEMENT METHOD FOR SEPARATION OF REFLECTION COMPONENTS BASED ON AN ENERGY FUNCTION

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**ABSTRACT**

In this paper, we propose a novel and effective method for improving the accuracy of separating reflection components in a single image based on the dichromatic reflection model after calculating the diffuse reflection component by any existing method. Separating reflection components accurately is very important and useful in computer vision to detect highlight areas, which are often regarded as outliers, and to enhance image quality, especially texture, because we can control the intensity and apply a filter independently to each reflection component. Our proposed method is based on unsharp masking and an energy function. The method does not require any information in advance, and is applicable to many products, such as TVs. Experimental results show that our method can improve the separation of reflection components by a maximum of 13.06 dB in the peak signal-to-noise ratio (PSNR).

***Index Terms—*** Reflection components, dichromatic, diffuse, specular, energy function

## 1. INTRODUCTION

In recent years, high-resolution displays such as 4K and 8K televisions are becoming more common. We can feel a deep sensation by watching high-resolution images, but it is still difficult to depict textures in detail, by high resolution alone. Human perception depends on texture elements such as gloss, plasticity, surface contours, and transparency[1]. Some studies have been conducted to improve gloss in images [1, 2], but if the gloss of an image is improved by enhancing the contrast to all pixels, some objects end up with unnatural textures because all pixels in the image would be processed without detecting and separating the gloss areas. That is why it is very important to separate reflection components and to detect the gloss areas in an image to improve its gloss.

Separation of reflection components is also an important preprocessing step in image content editing [3, 4, 5, 6]. As reported in [5, 6], dichromatic editing separates and processes two reflection components independently and recombines them to achieve various visual effects.

A number of studies have been conducted to create a novel method for separating reflection components accurately [7]. The studies are roughly divided into two types: those using multiple images [8, 9, 10, 11, 12] and those using a single image [13, 14, 15, 16, 17]. Because our goal is to improve image quality in display systems such as TVs, we have to separate reflection components by using only a single image.

As a method of separating reflection components in a single image, Tan et al. [13] proposed making a specular-free image by setting the maximum chromaticity of each pixel to an arbitrary scalar value. A specular-free image is an image free from specular components but it is not the same as diffuse components in color. A specular-free image can also be created by a simple operation proposed by Shen et al. [14]. The method of Tan et al. [13] iteratively separates reflection components by using the specular-free image and the relations between two neighboring pixels. Their method requires no information other than a single input image, but often fails on the boundary of objects and the color, which has the same hue but different saturation. Additionally, their method needs a significant amount of iterations to deal with a large image.

Yang et al. [15] extended the method of Tan et al. [13]. Their extended method is different in that it estimates the maximum diffuse chromaticity. They calculated the diffuse chromaticity by the use of a bilateral filter with coefficients determined by the approximated maximum diffuse chromaticity. Their method also does not require any information in advance and is faster than [13] even for large images. Their method has better accuracy and robustness than [13] in some cases, but still has the same defects.

Akashi et al. [16] proposed a method based on sparse non-negative matrix factorization (NMF) to separate reflection components. NMF is one of the general matrix analysis methods for multivariate data, which are composed of only non-negative values such as image pixels, sound signals, and purchase data. NMF can produce frequent patterns and can be applied in many areas. The method of Akashi et al. [16] can calculate single-color areas and separate reflection components at the same time. That method also yields more accurate separation results than the method of Tan et al. [13] and Yang et al. [15] in experimental images, but it uses three parameters that

[1] http://global.canon/en/news/2015/sep08e.html

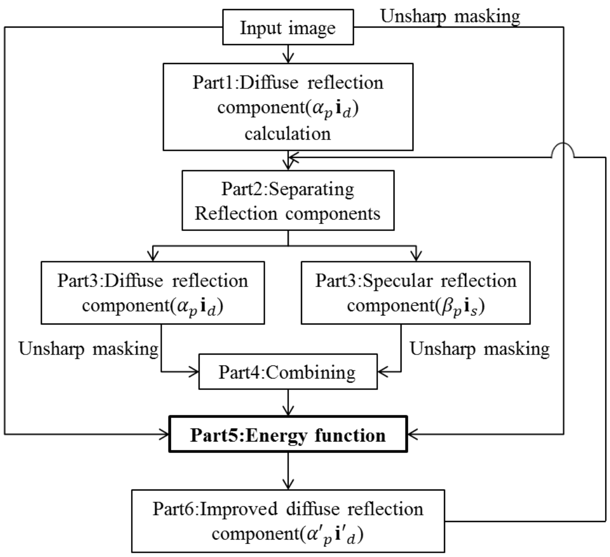



**Fig. 1.** Block diagram of our proposed method.

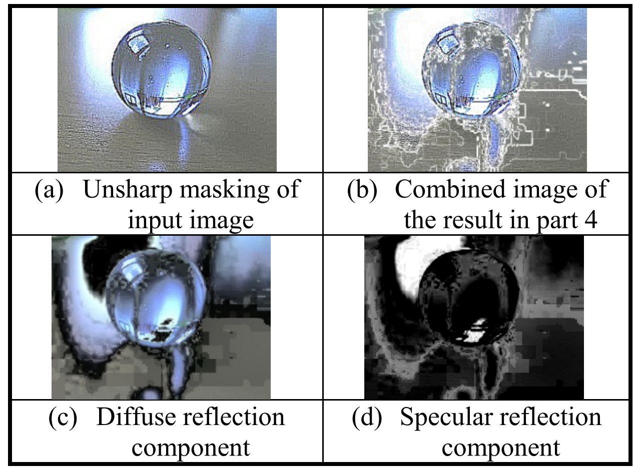



**Fig. 2.** Example images with poor reflection separation.

depend on the number of body colors, sparse regularization, and convergence. The three inadequate parameters may result in inaccurate separation components.

Shen et al. [14] used a modified specular-free (MSF) image and Nguyen et al. [17] used tensor voting for separation of reflection components. The former method proved to be robust to noise by using MSF, and the latter method can get the diffuse reflection distribution and dominant color of a diffuse region, regardless of noise. However, the method of Shen et al. [14] has difficulties dealing with bright images. The method of Nguyen et al. [17] is faster without iterative loops than the method of Tan et al. [13], but has difficulty in deciding the parameter adequately to obtain good results.

In this paper, we show that our method can improve the accuracy to separate reflection components by using unsharp masking and an energy function after calculating the diffuse reflection component by any existing method.

## 2. PROPOSED METHOD

The five abovementioned separation methods [13, 14, 15, 16, 17] are based on the dichromatic reflection model [18], which is the linear combination of a diffuse component and a specular component. Specifically, the RGB values of the 3-vector $\mathbf{i}_p$ of a pixel p are given by

$$\mathbf{i}_p = \alpha_p \mathbf{i}_d + \beta_p \mathbf{i}_s, \tag{1}$$

where $\alpha_p$ and $\beta_p$ are the coefficients of the diffuse and specular reflection for each pixel, respectively, and $\mathbf{i}_d$ and $\mathbf{i}_s$ are the diffuse reflection color of the object surface and the specular reflection color of the illumination existing in the scene for each pixel, respectively.

Our proposed method aims to improve the separation accuracy of calculated reflection components by the use of unsharp masking and the energy function. Our method flow is shown in Figure 1.

In part 1, we obtain the diffuse reflection component from a single image using any of the aforementioned methods.

In part 2, we separate reflection components using the dichromatic reflection model [18], which is indicated by equation (1). To solve the equation for each pixel, we assume that specular reflection color $\mathbf{i}_s$ is known and is set to white for all pixels. RGB values are thus described by the 3-vector $\mathbf{i}_p$, and the diffuse reflection component $\alpha_p \mathbf{i}_d$ is already calculated in part 1. Therefore, $\beta_p$ can be calculated by solving equation (1). Because we have one unknown number in three equations, we use singular value decomposition (SVD) to solve these equations numerically.

In part 4, each reflection component is combined as in equation (1) after processed by the unsharp masking filter with 3x3 box filter and k=10. The unsharp masking input image (Figure 2 (a)) and the combined image (Figure 2(b)) would be the same if the separation is perfect. The low separation accuracy makes these images largely different in pixel values. In Figure 2, as example images with poor reflection separation, we used an image [19] and process it by the method of Yang et al. [15]. To find the reason for the low separation accuracy of the reflection components when we get a large difference in the unsharp masking, we presume that the pixel value of reflection components with low accuracy has a greater difference value than the surrounding pixels; this means the pixel value has a high-frequency component and is enhanced by unsharp masking.

In part 5, we find the plausible diffuse reflection pixel coordinate to minimize the energy function using the combined images of part 4, the input image, and the processed input image by unsharp masking. We define the energy function as equation (2).

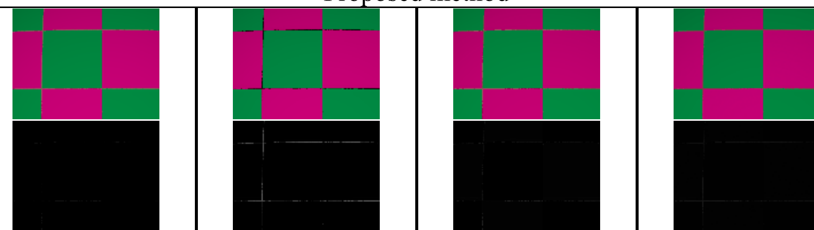
| Input image | Ground truth | Tan et al. [13] | Shen et al. [14] | Yang et al. [15] | Akashi et al. [16] |
|---|---|---|---|---|---|
|  | | | | | |
| PSNR (dB) of conventional methods | | Diffuse : 34.80<br>Specular: 35.44 | Diffuse : 29.08<br>Specular: 29.72 | Diffuse : 31.75<br>Specular: 32.60 | Diffuse : 31.57<br>Specular: 32.11 |
| | | Proposed method | | | |
| Improvement PSNR (dB)<br>Average diffuse : 4.43<br>Average specular : 8.09<br>Maximum diffuse : 5.73<br>Maximum specular: 13.06 | |  | | | |
| PSNR (dB) of proposed method | | Diffuse : 40.13 (5.33)<br>Specular: 48.50 (13.06) | Diffuse : 30.36 (1.28)<br>Specular: 31.62 (1.90) | Diffuse : 37.16 (5.41)<br>Specular: 42.31 (9.71) | Diffuse : 37.30 (5.73)<br>Specular: 39.82 (7.71) |

**Fig. 3.** Experimental results of synthetic image by using methods of Tan et al., Shen et al., Yang et al., Akashi et al., and the proposed method. All images except the input image and ground truth are enlarged images.

$$E_{p,p'} = E_{input} + E_{um} = \omega \left\| \mathbf{i}_{input}(p) - \mathbf{i}_{input}(p') \right\|_2^2 + (1-\omega) \left\| \mathbf{i}_{input\_um}(p') - \mathbf{i}_{combined\_um}(p') \right\|_2^2. \quad (2)$$

Here, $E_{input}$ and $E_{um}$ are the RGB pixel value differences of the input image between the coordinates and the RGB pixel value differences of unsharp masking, respectively, and ω is the weight coefficient. If the difference of unsharp masking exceeds a certain threshold value, we regard it (coordinate $p$) as the wrong diffuse reflection pixel and calculate the plausible diffuse reflection pixel (coordinate $p'$) from the minimum energy function in a search area. The search area is decided from the specular reflection component because it would be enough to search for the plausible diffuse reflection pixel over the specular reflection area. In other words, we calculate the pixel coordinate $p'$ of the plausible diffuse reflection based on the idea that the pixel coordinate having the closest RGB value of the input image and the smallest difference of unsharp masking would have better diffuse reflection.

In part 6, we replace the wrong diffuse reflection component with the plausible diffuse reflection component by using the energy function in part 5. As a result, we can improve the diffuse reflection component to obtain good separation reflection components. We can also use the improved diffuse reflection component ($\alpha'_p \mathbf{i}'_d$) as the input of part 2 repeatedly to obtain more accurate reflection components. The convergence is judged by equation (3) or a certain repeat count.

$$\mathrm{RMSE}_{n,n-1} < \varepsilon, \quad (3)$$

where RMSE is the root mean square error between the previous diffuse reflection component and the current diffuse reflection component, and ε is a certain threshold value.

## 3. EXPERIMENTAL RESULTS

We conducted several experiments using synthetic images and real images to examine the effectiveness of our proposed method. We set the parameters as follows: weight coefficient ω = 0.146 in the energy function, convergence parameter ε = 0.2, and maximum repeat count 10 for all of our experiments.

As the method of calculating the diffuse reflection component, we used the methods of [13, 14, 15, 16]. The source codes of [13, 14, 15] are freely available on the author's website[2]. The source code of [16] is not available; therefore, we implemented the code according to their paper. The method of [16] has three parameters, and we set body color parameter to 5, sparse regularization parameter to 3,

[2] Tan et al.[13] http://tanrobby.github.io/code.html#
Shen et al. [14] http://www.ivlab.org/publications.html
Yang et al. [15] http://www.cs.cityu.edu.hk/profile/qiyang.html

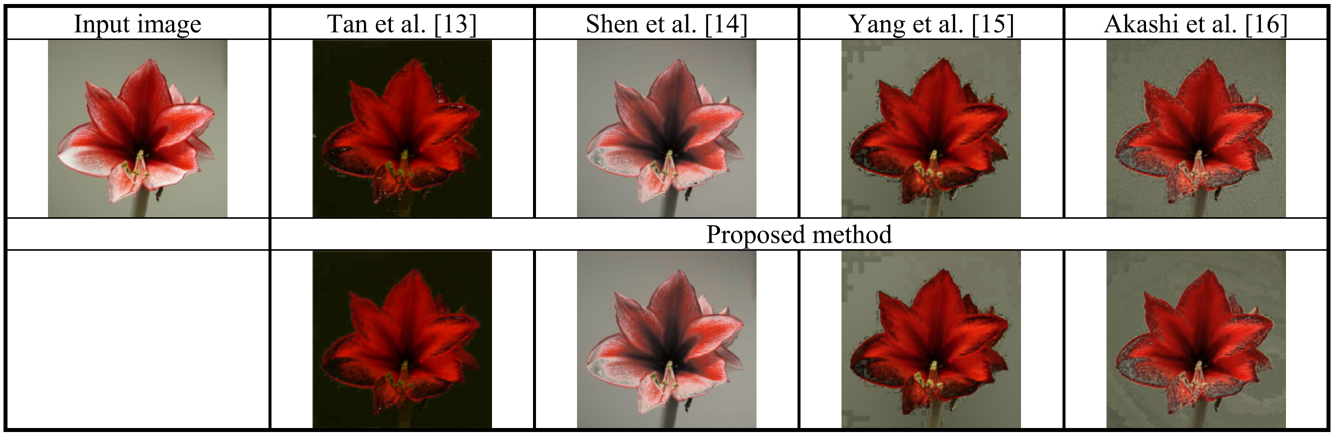



**Fig. 4.** Experimental results of real image by using existing methods and the proposed method.

and the convergence parameter to exp(-15) for all of our experiments. The separation accuracy of the method [16] depends on the initial values of the two factorized matrices, which are usually decided at random. In the synthetic image experiment, we chose the best diffuse reflection accuracy from three experimental results.

### 3.1. Synthetic image

We first applied our method to the synthetic image shown in Figure 3. The results are also shown as enlarged images to clarify the improvements. The enlarged areas are indicated by the red rectangles in ground truth images. The numbers in parentheses show the improvement dB of the peak signal-to-noise ratio (PSNR) in each method. The experimental results show that our proposed method improves the separation accuracy in each method according to the PSNR values. Compared with other method results, our method reduces the artifacts, which are black pixels in the diffuse image and white pixels in the specular image, around the color boundaries. The separation accuracy improvement around the color boundaries is one of the advantages of our method, because all of the other methods fail to separate reflection components around the boundaries. The improvement dB is low in the Shen et al. method [14] compared with that in the other methods. Our method uses the calculated diffuse reflection component and improves the separation accuracy by using the energy function. Therefore, the improvement dB seems to depend on the separation accuracy of the calculated diffuse reflection component.

### 3.2. Real image

Next, we applied our method to the real image shown in Figure 4. Here, we use the dataset in [20] and show only the results of diffuse images. We cannot show the effectiveness of our method in numerical terms such as the PSNR and it is difficult to describe the improvement of separation accuracy due to the lack of ground truth for the real image. However, our method gives more separation accuracy of reflection components. Compared with the result of the Tan et al. method [13], our method reduces the white line artifacts, which are caused by low separation accuracy pixels. Compared with the result of the Yang et al. method [15] and the Akashi et al. method [16], our method reduces the artifacts caused by mosquito noise around the boundary of the flower. In contrast to the accuracy attained in the Shen et al. method [14], our method does not create major artifacts.

## 4. CONCLUSION

This paper demonstrates the effectiveness of our proposed method for improving the separation of reflection components by the use of unsharp masking and an energy function. Our proposed method can use any existing method to calculate the diffuse reflection component and improve it with the energy function, especially around the color boundaries. Consequently, it can be easily extended with any state-of-the-art separation methods proposed in the future.

We show the effectiveness of our method in numerical terms by using a synthetic image and the PSNR, which was a maximum 13.06 dB better in the specular reflection component and a maximum 5.73 dB better in the diffuse reflection component. We also show the effectiveness by using a real image, which was clearly better around the boundary.

In all our experiments, we used the same parameters without any input image analysis. Therefore, we would obtain better results if we set the parameters according to the input image analysis results. We are considering the application of the proposed separation reflection method to improve the image quality but we do not yet have a good model to control the intensity and apply a filter independently. This will be investigated in a future study.

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