Voting-based separation of diffuse and specular pixels

K.-J. Yoon and I.-S. Kweon

A fast and efficient algorithm to separate diffuse and specular pixels in a single image without explicit colour segmentation or any prior information is proposed. It is applicable to highly textured objects/scenes under arbitrary illumination conditions. Experimental results show accurate separation results for natural images.

Introduction: Most algorithms in computer vision assume that the surfaces in a scene are perfect Lambertian. However, the presence of specular reflection is inevitable in most images. Although many methods have been proposed to separate specular pixels from an image, they have some critical limitations. Some can only deal with uniform coloured objects [1] and some need prior information about the scene illumination and assume a single illumination source [2, 3]. We propose a fast and efficient algorithm to separate diffuse and specular pixels using a single image, which is taken under a general situation, without any prior knowledge or explicit colour segmentation.

Reflection models: There are two forms of reflections; diffuse and specular reflection. These two kinds of reflection can be described by the dichromatic reflection model, which is proposed by Shafer [4]. It suggests that the spectral factor can be expressed as the weighted sum of two reflectance functions. If we take an image using a digital camera that has three sensors (r, g and b), the colour of a pixel x can be written as

$$I_c(x) = m_d(x)\Lambda_c(x) + m_s(x)\Gamma_c(x) \quad c \in \{r, g, b\} \tag{1}$$

where $\Lambda_c(x)$ and $\Gamma_c(x)$ represent surface and illumination chromaticity, respectively. $m_d(x)$ and $m_s(x)$ are geometric scaling factors of diffuse and specular reflection which depend on the scene geometry of a pixel x. Therefore, the first and second part of the right side of (1) represent the diffuse and specular reflection component, respectively.

Separation method: Diffuse pixels have small scaling factors of specular reflection and, therefore, the diffuse reflection component is dominant. In addition, adjacent diffuse pixels have similar scaling factors of specular reflection as well as diffuse chromaticity.

Assume that three adjacent pixels $(x-1, x, x+1)$ are diffuse pixels and lie in the surface patch with uniform diffuse chromaticity, so that Λ_c becomes independent of image co-ordinates. We can then remove the specular reflection component in (1) using the colour difference of two pixels $(x-1, x)$ as

$$I_c(x) - I_c(x-1) \cong m_d(x)\Lambda_c - m_d(x-1)\Lambda_c = [m_d(x) - m_d(x-1)]\Lambda_c \tag{2}$$

because $m_s \ll m_d$ and $m_s(x) \simeq m_s(x-1)$. Without loss of generality, we can simply set $\Lambda_r + \Lambda_g + \Lambda_b = 1$. Then, the following equation can be easily derived:

$$\begin{aligned}\sum_c [I_c(x) - I_c(x-1)] &= \sum_c I_c(x) - \sum_c I_c(x-1) \\ &= \sum_c [m_d(x) - m_d(x-1)]\Lambda_c = [m_d(x) - m_d(x-1)]\sum_c \Lambda_c(x) \\ &= [m_d(x) - m_d(x-1)]\end{aligned} \tag{3}$$

Equation (3) means that the difference of diffuse geometric scaling factors of diffuse pixels equals the difference of their total intensity values. Using (2) and (3), the diffuse chromaticity of the surface containing pixels $(x-1, x)$ is obtained as

$$\Lambda(x-1, x) = \frac{\{I(x-1) - I(x)\}}{\{\sum_c I_c(x-1) - \sum_c I_c(x)\}} \tag{4}$$

In the same manner, we can find another diffuse chromaticity, $\Lambda(x, x+1)$, using two diffuse pixels $(x, x+1)$. If all of three adjacent pixels are diffuse pixels and lie in the surface patch with uniform diffuse chromaticity, two diffuse chromaticities, $\Lambda(x-1, x)$ and $\Lambda(x, x+1)$, will be the same. If we denote the L_1-norm of $(\Lambda(x-1, x)$-$\Lambda(x, x+1))$ as ε, we can label pixels as diffuse using the following test:

$$l(x-1) = l(x) = l(x+1) = \mathit{diffuse} \quad \mathit{if}\ \varepsilon < \Delta \tag{5}$$

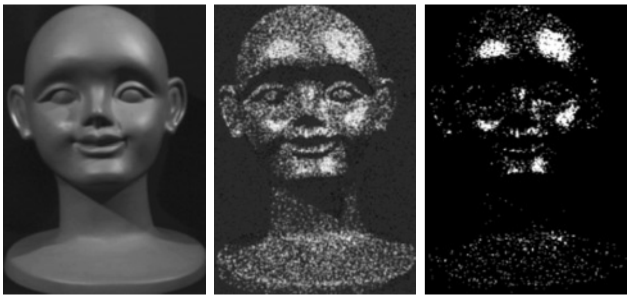
Here, Δ is the predefined threshold. At this point, if ε is larger than Δ, we cannot label these pixels. Fortunately, this problem can be resolved using a voting scheme. If ε is larger than the threshold, we vote all three pixels into specular pixels. After all tests at each pixel, we can find specular pixels by checking the votes V^s of all pixels:

$$l(x) = \begin{cases} \mathit{diffuse} & \mathit{if}\ V^s(x) < \lambda \\ \mathit{specular} & \text{otherwise} \end{cases} \tag{6}$$

In this algorithm, each pixel is tested six times. If a pixel x is a specular pixel, the final value of the specularity vote $V^s(x)$ will be six. We use 5 as the λ value for all experiments.

Colour boundary: The assumption that adjacent pixels lie in the same surface patch with uniform diffuse chromaticity is not valid at the colour boundaries. Therefore, we should exclude colour edge pixels. Previous work required the colour segmentation step to deal with this problem. Unlike these studies, we extract colour edge pixels by comparing chromaticity and intensity values of pixels because we do not require any regional information.

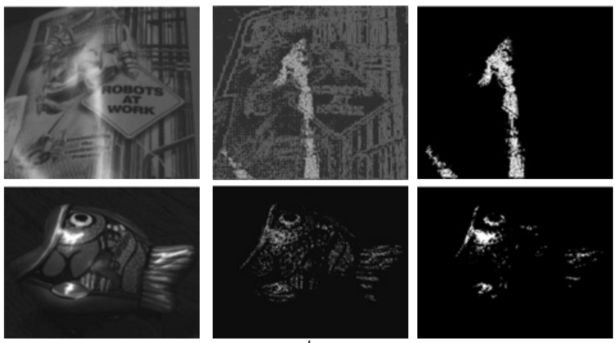
Experimental results and conclusion: We experimented with images taken under different situations. The images in Figs. 1 and 2 are from the work of Tan and Ikeuchi [3] (http://www.cvl.iis.u-tokyo.ac.jp/~robby/). Fig. 1 shows a result for the image of a uniform chromaticity object under a single illumination source. The proposed method successfully separates specular and diffuse pixels based on the number of specularity votes shown in Fig. 1*b*. When applied to the multi-coloured (textured) object image taken under a single illumination source, the proposed method also accurately separates specular and diffuse pixels as in Fig. 2.



a b c

Fig. 1 *Specular reflection analysis result—uniform chromaticity object under single illumination source*

a Input images
b Specularity votes
c Specular pixels



a b c

Fig. 2 *Specular reflection analysis result—multi-coloured object under single illumination source*

a Input images
b Specularity votes
c Specular pixels

Fig. 3 is the result for the multi-coloured object image taken under multiple illumination sources. As we expected, the proposed method separates specular pixels very well regardless of the illumination condition.

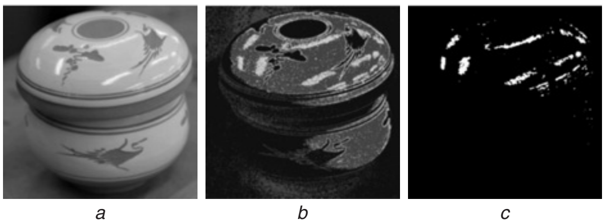


Fig. 3 *Specular reflection analysis result—multi-coloured object under multiple illumination sources*

a Input images
b Specularity votes
c Specular pixels

The proposed algorithm has some advantages. It does not require any prior information about the illumination conditions and texture of objects. Therefore, it is applicable to highly textured objects/scenes. In addition, it is simple and fast (0.03 s/frame) since the processes are performed with only two or three pixels and are non-iterative.

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