Reduced Illumination Patterns for Acquisition of Specular and Diffuse Normal Maps

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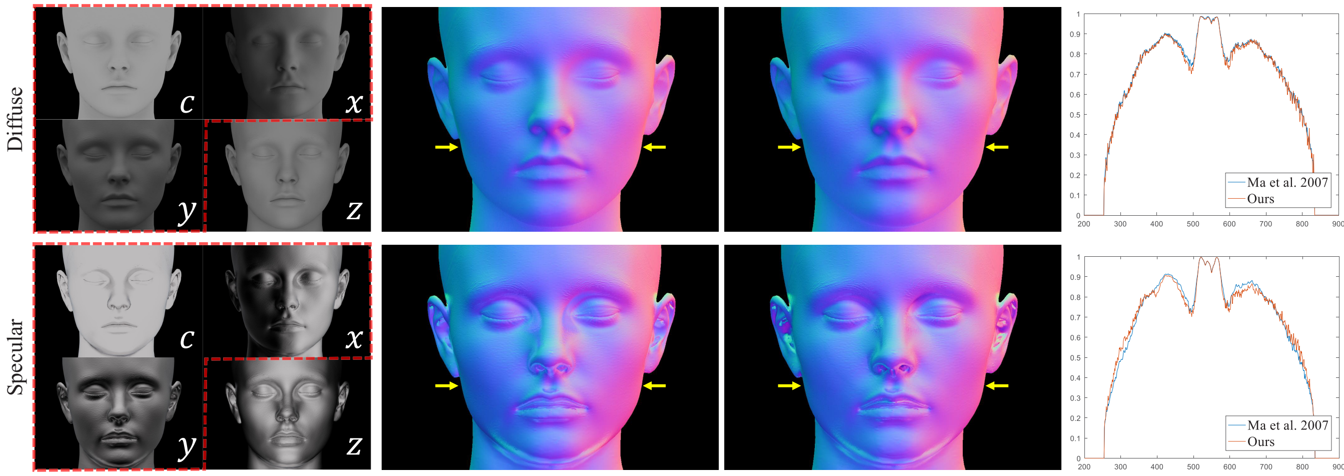

Reflectances under Illumination Patterns | [Ma et al. 2007] (using *Four* Patterns) | Ours (using *Three* Patterns) | Z-component of Normal (yellow arrows)

Figure 1: *Comparison of diffuse and specular normal maps from [Ma et al. 2007] using four patterns (XYZ-gradient and constant patterns) and our method using three patterns (without Z-gradient pattern). The yellow arrows indicate the locations of the scan line for the plots.*

Abstract

We propose an efficient computational method to acquire diffuse and specular normal map with three types of illumination patterns by removing the redundancy of the conventional method. By analyzing the relationship between four reflectances under XYZ-gradient and constant patterns, the number of patterns needed is reduced to three patterns.

Keywords: polarization, surface normals, facial capture

Concepts: •**Computing methodologies** → *Computational photography; Shape analysis;*

1 Introduction

Ma et al. [2007] proposed a method to acquire diffuse and specular surface normal maps of an object using four spherical gradient illumination patterns. The method is derived from the insight that the centroid orientation of diffuse or specular reflectance distribution correspond to the surface normal or reflected direction, respectively. They showed that the method is suitable for real-time normal capture using time-multiplexed illumination due to the low number of patterns needed.

However, there is a redundancy in these four illumination patterns for computing surface normal. They needed only three spherical gradient patterns defined in a [-1, +1] range to estimate the first moment of the reflectance function, but it was impossible to emit illumination with negative intensity. Thus, they additionally used a constant pattern as a fourth illumination pattern, which led to the redundancy of the method.

In this work, we propose an efficient computational method to acquire diffuse and specular normal map with *three* types of illumination patterns by removing the redundancy of [Ma et al. 2007]. By analyzing the relationship between four reflectances under XYZ-gradient and constant patterns for both diffuse and specular reflection, our method obtains a fourth reflectance from the other three reflectances and acquires surface normal using only three illumination patterns. Experimental results on synthetic images show our method gives comparable result to [Ma et al. 2007] qualitatively and quantitatively.

2 Our Approach

Here we explain how surface normals are computed from three patterns P_x, P_y and P_c for both diffuse and specular cases.

2.1 Lambertian Surface Reflection

For Lambertian surface reflection, the observed reflectances under gradient and constant patterns can be expressed as follows [Ma et al. 2007]:

$$L_i = \frac{2\pi\rho_d}{3} n_i, \quad L_c = \pi\rho_d, \tag{1}$$

where L_i and L_c are reflectances under gradient patterns P_i and P_c respectively, $i \in \{x, y, z\}$, ρ_d is the diffuse albedo, and n_i is the i-axis component of surface normal. From Eq. 1 and the equation $n_x^2 + n_y^2 + n_z^2 = 1$, the relationship between four reflectances are derived as follows:

$$L_x^2 + L_y^2 + L_z^2 = \frac{4}{9} L_c^2. \tag{2}$$

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Using this relationship, one reflectance can be estimated from three other reflectances, instead of being observed under a pattern. This allows us to obtain a normal map from only three patterns. We observe three reflectances $L_x.L_y$ and L_c and estimate the L_z as follows:

$$L_z = \sqrt{\frac{4}{9}L_c^2 - L_x^2 - L_y^2}. \quad (3)$$

Although there are two values that satisfy the relationship (*i.e.* plus and minus), we removed the negative values by utilizing $n_z > 0$ which is derived from the fact that captured objects are facing the camera. Then, from the four reflectances (three observed reflectances and an estimated reflectance), a normal map can be obtained in the same way as [Ma et al. 2007]. In the experiments, we use the shifted pattern $P'_i = \frac{1}{2}(P_i + P_c)$ instead of P_i to avoid the problem of negative intensity.

2.2 Specular Surface Reflection

For the specular surface reflection, the observed reflectance L_i under translated gradient pattern P_i can be expressed as follows:

$$L_i = r_i c_F \int_\Omega \omega'_r S(\vec{\mathbf{z}}, \vec{\omega}')d\vec{\omega}', \quad (4)$$

where $\vec{r}$ is the specular reflected direction, S is a specular reflectance lobe symmetrical around $\vec{r}$, and c_F is a constant corresponding to the foreshortening. Since the specular lobe S is assumed to be non-zero for small solid angle [Ma et al. 2007], ω'_r is also approximately constant in this solid angle. Moreover, ω'_r ($\vec{\omega}' \cdot \vec{r}$) varies slower than the foreshortening ($\vec{\omega}' \cdot \vec{n}$) around a small solid angle around $\vec{r}$, which makes our approximation considering ω'_r as a constant more reasonable. The value of ω'_r near this angle is 1 because the centroid of the specular lobe lies on the orientation of $\vec{r}$. Then, Eq. (4) is expressed as follows:

$$\begin{aligned} L_i &\approx r_i c_F \int_\Omega S(\vec{\mathbf{z}}, \vec{\omega}')d\vec{\omega}' \\ &= r_i L_c, \end{aligned} \quad (5)$$

where $L_c = c_F \int_\Omega S(\vec{\mathbf{z}}, \vec{\omega}')d\vec{\omega}'$. From Eq. 4 and the equation $r_x^2 + r_y^2 + r_z^2 = 1$, the relationship between four reflectances are derived as follows:

$$L_x^2 + L_y^2 + L_z^2 = L_c^2. \quad (6)$$

Similarly to Lambertian case, L_z can be estimated from three other reflectances. However, the solution cannot be determined as a plus value or a minus value because r_z does not have constraint such as $n_z > 0$. To solve this problem, we utilize the diffuse normal n^d obtained from Lambertian surface reflection. We compute diffuse reflected direction $\vec{r}^d$ from $\vec{n}^d$ as $\vec{r}^d = 2(\vec{n}^d \cdot \vec{v})\vec{n}^d - \vec{v}$ where $\vec{v}$ is a view direction, then the estimated L_z computed as:

$$L_z = \begin{cases} +\sqrt{L_c^2 - L_x^2 - L_y^2} & \text{if } r_z^d > 0 \\ -\sqrt{L_c^2 - L_x^2 - L_y^2} & \text{otherwise.} \end{cases} \quad (7)$$

Strictly the criterion should be r_z instead of r_z^d. However, since these two values are same in low frequency, we determine L_z with assistance from r_z^d. Then, the surface normal is obtained in the same way as [Ma et al. 2007] using L_x, L_y, L_z and L_c. Additionally, when we compute r_z, we used r_z^d on the pixel where $|r_z|$ or $|r_z^d|$ is smaller than threshold (0.25) to reduce the ambiguity near the criterion.

3 Results and Discussion

We compared the surface normal from [Ma et al. 2007] and our method using the synthetic images generate by physics-based renderer [Jakob 2010] for diffuse and specular reflection. Figure 1 shows that the normal map of our method is qualitatively very similar to that of [Ma et al. 2007]. We also measured PSNRs of the results for quantitative comparison, and obtained 31.18dB for a diffuse normal and 22.43dB for a specular normal.

Since our method is based on [Ma et al. 2007], it fails similarly when there is inter-reflections, self-shadowing, rotationally asymmetric reflectance lobe, or wide specular lobe. Figure 1 shows both of the methods fails in the self-shadowed region such as the corner of nose.

The reduced number of illumination patterns allows more efficient real-time normal capture using time-multiplexed illumination. Also, it helps better registration between images when we acquire high-quality diffuse and specular normals for dynamic facial expressions. Our method can also be applied to other methods based on [Ma et al. 2007].

References

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