二つの点光源を用いた物体反射特性の取得

Acquiring Surface Reflectance Using Two Point Light Sources

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1. Introduction

Reflectance of 3D surface is very important for applications in the fields of computer graphics and computer vision. An algorithm for estimating reflectance of 3D surface is presented in this paper. Our algorithm computes albedo of surface from the parameters of intensity variation curve and separated diffuse component. The separation of diffuse and specular components from surface reflection from 3D object with complex texture illuminated by one point light source has been reported in [1]. However, with only one light source, some region on object surface will lose its real texture information due to shading, which may hinder some computer vision task. Surface illuminated with multiple light sources help for providing more information for acquiring texture and albedo, but the reflection separation will remain a problem. In this paper, we will propose a method for estimating surface reflectance and separating diffuse and specular components from reflection of a 3D object illuminated with two point light sources, by applying an iterative method to fit the simplified Torrance-Sparrow model to the reflection variation data. The tentative experimental results demonstrate the effectiveness of proposed approach.

2. Intensity Variation

In our experiment, the object is set on a rotary table, with two point light sources located on both sides of camera. The geometry configuration is illustrated in Fig. 1.

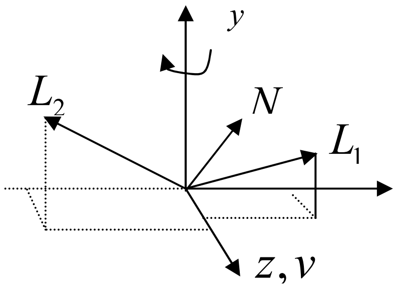

Fig.1. Geometry configuration

View direction v is coincident with z axis; L_1, L_2 are fixed two light source directions; N is the normal vector of a 3D point, which is visible from the camera. All vectors are unit vectors. We also suppose that the distances from object to light sources are very large compared with the radius of object. We take image sequence with 4 degrees interval, while rotating object about y axis. The camera and rotary table are carefully calibrated [2]. Using a modeling approach [3], for each 3D point on object surface, the intensity variation curve is sampled which contains 31 samples within 120 degrees. During sampling, the two peaks are included in the curve as could as possible, which is useful for computing normal vector. The intensity variation curve of a 3D point is sampled within a 3x3 pixels area in an image of surface for alleviating noise. The two peaks correspond to the two light sources.

3. Reflection Model

The intensity of a pixel on an image is proportional to the reflection of a 3D point on the surface. We use a simplified Torrance-Sparrow [4] model to describe the reflection behavior of a 3D point. In the case of two point light sources, the reflection may be represented by Eq. (1).

$$I = I_d + I_s = K_d \sum_{i=1}^{2}\left(L_i \cdot N\right) + K_s \sum_{i=1}^{2} \exp\left(-\alpha_i^2 / \sigma^2\right) \qquad (1)$$

Here L_i are light source directions that are assumed known and measured manually. And N is normal vector of a 3D point on object surface. Parameters K_d and K_s are diffuse and specular reflectance, α_i is the angle between normal vector and the bisector of view direction and each light direction, and σ represent the roughness of surface in a small area. For simplicity, we use polar coordinates to express each vector. With some simple mathematical arrangement, using polar coordinate of light source direction vectors, view direction and normal vector, Eq. (1) can be rewritten in the form of Eq. (2) and (3):

$$I_d = A\sin\theta + B\cos\theta + C \qquad (2)$$

$$I_s = D_1 \exp\left(-\left(\frac{E_1-\theta}{F}\right)^2\right) + D_2 \exp\left(-\left(\frac{E_2-\theta}{F}\right)^2\right) \qquad (3)$$

where θ is the rotation angle of turntable, other parameters are deduced from Eq. (1) using several mathematical operations.

4. Separation of reflection

Before separating reflection components for each 3D point, we need to estimate numerically the parameters in Eq. (2) and (3). Since the model is a nonlinear model, Levenberg-Marquardt method is employed to minimize following fitting error:

$$E = \sum_k W_k \left(I(\theta_k; A,B,C,D_1,E_1,D_2,E_2,F) - I_k \right)^2 \qquad (3)$$

As we known that for reflection from 3D surface, specular reflection is more difficult to be modeled compared to diffuse reflection. Due to the limited camera's dynamic range, the highlight region may contain more noise than diffuse region. Therefore, we employ a weighting function to put more dependence on the diffuse reflection. To this end, we set the weighting function to be the inverse of specular reflection as Eq. (4):

$$W_{\theta k} = \left(a + \exp\left(-\left(\frac{E_1-\theta_k}{F}\right)^2\right) + \exp\left(-\left(\frac{E_2-\theta_k}{F}\right)^2\right) \right)^{-1/2} \qquad (4)$$

Constant a is empirically from 10^{-9} to 10^{-3}, which is only to guarantee the weighting be meaningful numerically. In order to estimate the parameters in Eq. (2) and (3) to fit the intensity variation, the initial guess is needed. The initial values of first 3 parameters in diffuse component are the values at a position located far enough from the two specular peak positions. Since there are some noises in the raw data, some cautions should be paid for finding the peak values and peak locations. A common used low pass filter is a good tool for solving this problem. Roughness F is given with an empirical value 0.08. Initial values of D_1 and D_2 are the peak values located at E_1 and E_2. With 4 or 5 iterations, all parameters can be computed. After all parameters of reflection model are estimated, diffuse and specular components can be separated from the original raw reflection data using these parameters.

5. Albedo map

The separated diffuse component can be used for computing albedo map consisted by diffuse reflectance represented by Eq. (5):

$$K_d = \frac{I_d}{L_1 \cdot N + L_2 \cdot N} \qquad (5)$$

Since we know the light and view directions, the surface normal is computed from the estimated curve parameters. Then the albedo map can be computed from the light, normal vectors and the diffuse component.

6. Experimental Results

The validity of the proposed algorithm has been demonstrated by applying it to the simulated data and data acquired from the real images of object illuminated with two light sources with known direction by a camera with fixed view direction. Fig. 3(a) shows one of original images; (b) is the separated specular and (c) diffuse component; (d) is the computed albedo map which is independent of light directions. The algorithm computes the specular component and subtracts it from original reflection to get the diffuse component. Since the albedo map is computed from diffuse reflection, we can maintain the resolution of albedo map to be the same level as that of original image.

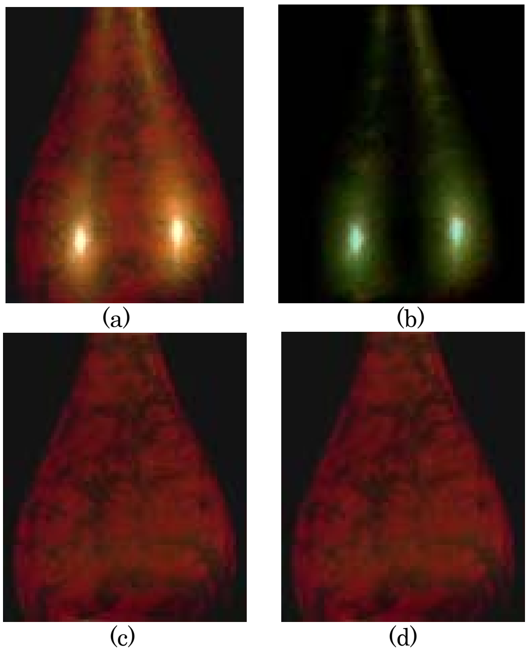

Fig. 3. (a) Original image; (b) separated specular and (c) separated diffuse component; (d) albedo map

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