Measuring the Shape and Reflectance of Real Objects for Reproducing the Material Appearance

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Abstract In this paper, we propose a method for measuring the shape and reflectance of real objects for reproducing the material appearance. The measurement is performed with a simple apparatus consisting of an RGB-D camera, a turning table, and a single point light source. The shape is reconstructed from depth images and the reflectance is estimated from changing intensities based on the Ward reflectance model. It was confirmed that our system can reproduce the realistic appearance of objects which can support users to perceive the material.

Keywords: shape reconstruction, reflectance estimation, Ward reflectance model

1. Introduction

When users are shopping online, they cannot touch or hold products, and they sometimes make mistaken decisions. Therefore, the system that can provide the material perception of the products is required.

There are many existing systems which reconstruct the shape and estimate the reflectance of real objects. Some systems measure the reflectance by setting different light sources and cameras around the object [1][2]. Some other systems use a gonioreflectometer to measure the reflectance on the surface [3][4]. Detailed reflectance is acquired in their systems, but accurate camera calibration and expensive measurement setup are necessary, and besides, it takes a long time to measure the reflectance.

On the other hand, some systems use a monocular camera to estimate the shape and reflectance [5][6]. These systems do not require a large-scaled measurement setup and long measurement time, but only the limited amount of information is obtained from a monocular camera, which can lead to unstable estimation and incorrect results.

Based on these studies, we propose a system that can measure the shape and reflectance of real objects for reproducing the material appearance. A simple measurement setup is used, and parameters to find are reduced by assuming that the incoming and outgoing directions of reflectance are the same for measuring the reflectance.

2. Measuring the Shape and Reflectance of Real Objects

We use an RGB-D camera to acquire the depth and color images of an object. The shape is firstly reconstructed, and the then the reflectance is estimated based on the Ward reflectance model [7].

2.1 Measurement Setup

The measurement setup is shown in Fig. 1. The system consists of a PC, a Microsoft Kinect v2 RGB-D camera, a turning table and a small LED light that was fixed to the camera. When capturing the object, we set the room dark except that the object was lighted by the LED light. In this way, different views of the object can be captured by the camera.

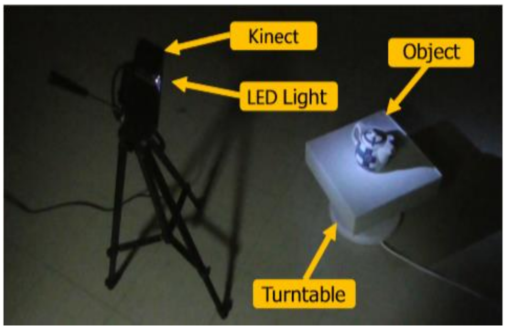


Fig. 1. Measurement Setup

The depth and color images were captured by the RGB-D camera at the frame rate of 30 frames per second. The resolutions of depth and color images were 640×480 and 1920×1024 pixels respectively. The specifications of the PC were Intel Core i7-7700 CPU, 16GB memory and NVIDIA GeForce GTX 1070 6GB PC for GPU.

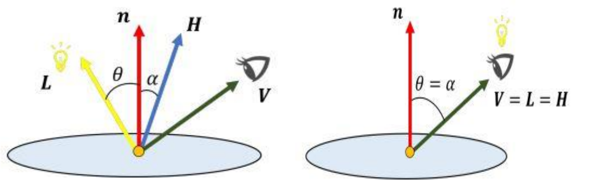
2.2 Reconstructing the 3D Shape

We use KinectFusion [8] to combine the depth images and reconstruct the 3D shape as polygonal meshes, constituting surfaces and normals. The normal of the vertex is smoothed by averaging the adjacent normals on the surface.

2.3 Estimating the Reflectance based on the Ward Reflectance Model

The system firstly determines which pixel of each color image corresponds to each vertex at the viewpoint. As the object is rotating, the luminance values on the surface are changing frame by frame. We can find the correspondence between the object vertex and the color pixel by reprojecting the reconstructed shape with respect to the camera viewpoint at each frame.

The system then estimates the reflectance of every vertex on the reconstructed 3D shape by using the Ward reflectance model, which is one of the Bidirectionally Reflectance Distribution Function (BRDF) models and variables used in the model can be seen in Fig.2 (a), where L and V represents the incident and reflected light directions on a surface point, H is the halfway vector between L and V, n is the normal, θ is the angle between



(a) (b)

Fig 2. Variables used in the BRDF model and our assumption: (a) Variables used in the BRDF model (b) Assumption of the same vectors: light, view and halfway vectors, and the same angles: θ and α

the normal and the incident light, and α is the angle between the normal and the halfway vector.

We assume the objects with a homogeneous surface, and use the isotropic Ward model. The Ward model has only a few parameters, and it determines how much light is reflected from the incoming direction L to the outgoing direction V at a surface point as follows:

$$f_r(\theta_i, \theta_o) = \frac{k_d}{\pi} + k_s \frac{1}{\sqrt{\cos\theta_i \cos\theta_o}} \frac{e^{-\left[\frac{\tan^2\theta_h}{m^2}\right]}}{4\pi m^2} \quad (1)$$

where, θ_i *and* θ_o are the incoming and outgoing angles, θ_h is the halfway angle between the normal and the halfway vector, k_d and k_s are diffuse and specular reflection albedos, and m is the roughness of the surface.

In our measurement setup, since an LED light is attached to the camera, we can assume that the light and view vectors coincide, and the halfway vector is consequently the same as these two vectors as shown in Fig. 2 (b). Therefore, θ and α are the same in the formula, and we can reduce the parameters to find.

3. Experimental Result

In our experiment, the target object is a teapot with the homogeneous surface. Fig. 3 (a) shows the original object and Fig. 3 (b) shows the reconstructed 3D model. The highlight can be seen on the surface of the reconstructed model, and additionally, fine gloss and brightness changes can be observed when it rotates.

(a) (b)

Fig. 3. The target object: a teapot: (a) Original object (b) Reconstructed 3D model

The fitting result between the observed brightness of R component and the estimated reflectance based on the Ward model is shown in Fig. 4, where the diffuse reflection components are dominant in the region with large θ values and the highlight of specular reflection are observed in the region with small θ values.

4. Conclusion

We proposed a system that can measure the shape and reflectance of real objects to reproduce the material appearance. Future work includes measuring more detailed geometry of objects and reproducing the appearance of rough surface materials.

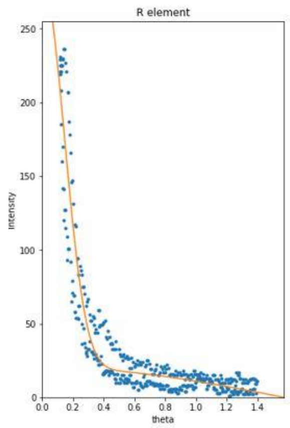


Fig. 4. Fitting result between the observed brightness of R component and estimated reflectance based on the Ward model

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