Extracting Realistic Textures from Reference Spheres

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Abstract. This paper proposes a method for extracting realistic textures from real-world reference spheres. The BRDF parameters of fundamental materials, as well as a material weight map for the sphere are obtained through a non-linear optimization process. The material weight map can be used as a conventional texture for relighting. With the BRDF models recovered, the real and natural appearances of 3D objects can be reproduced under novel lighting and viewing directions.

Keywords: BRDF; Material Weight; Texture Mapping; Realistic Rendering

1 Introduction and Related works

Realistic rendering is one of the research areas developing rapidly in computer graphics literature in recent years, and the representation of true materials in the scene plays an important role, which can be described using BRDF (Bi-directional Reflectance Distribution Function). To express complex spatially-varying appearances of real world objects, H. Lensch, J. Kautz et. al [1] developed a image-based method for recovering material properties, using a Splitting-Reclustering-Fitting iteration. D. B. Goldman, B. Curless et. al [2] assumed each object point comprises predetermined number of materials blended at different proportions, and recovered the BRDF parameters, normals at each point, as well as the material weight map using a non-linear overall optimization. W. Matusik, H. Pfister et al [3] sampled over 100 spheres applied PCA to express any possible BRDF as a linear combination of dimension-reduced vectors.

Inspired by D.B.Goldman's algorithm [2], we proposed an improved algorithm to recover BRDF models of fundamental materials, as well as their corresponding material weight map. The material weight map reflects color variations everywhere on the object, and BRDF models express overall reflectance properties. They can be used as a special kind of texture to achieve dynamic re-lighting easily.

2 Principle

To recover the fundamental material weight map and BRDF models, an objective function is formulated [2]:

$$Q(\alpha,\gamma)=\sum_{l,p,c}(I_{l,p,c}-\sum_{m}\gamma_{p,m}f_c(n_p,L_l,v,\alpha_m))^2 \tag{1}$$

where the subscript p denotes pixel index, c color component (RGB), m material index, l light index, and $I_{l,p,c}$ represents the intensity of pixel p under the illumination of the light source at location l (in this paper, “pixel intensity” is replaced by “radiance”). $\gamma_{p,m}$ denotes the weight of material m for pixel p (actually it means object point corresponding to the pixel p); The function f_c is actually the reflectance model, and can also be considered as an imaging formulation, where $\boldsymbol{n}_p$ denotes the normal at point p, $\boldsymbol{L}$ the light source parameters (intensity / direction), $\boldsymbol{v}$ the viewpoint, and α_m the BRDF parameter set for material m. f_c is actually the product of light intensity and BRDF, where BRDF model takes the form of Isotropic Ward [4]:

$$BRDF(\theta_i,\theta_r,\sigma)=\frac{\rho_d}{\pi}+\frac{\rho_s}{\sqrt{\cos\theta_i\cos\theta_r}}\frac{\exp[-\tan\sigma^2/\beta^2]}{4\pi\beta^2} \tag{2}$$

where ρ_d and ρ_s represents the diffuse and specular coefficient, respectively, and β denotes material roughness. ρ_d and ρ_s has three independent values at color channel c, so they are 3x1 vectors. In this paper, BRDF models in objective function (1) have total 14 parameters to solve because we assume two fundamental materials. In addition, θ_i ,θ_r and σ represents the angle between the normal and the incident, reflected and halfway vector. These geometrical parameters actually take the form of $\boldsymbol{n}_p$, $\boldsymbol{L}_l$ and $\boldsymbol{v}$ in (1).

The material weight $\gamma_{p,m}$ implies that each object point p is composed of several materials. We realize that there exists a natural relation between the material weight map and the real texture, and that conventional texture mapping technologies can be applied to map the material weights to other 3D models. So, we proposed a method for extracting real textures from spherical reference spheres, including the material weight maps and BRDF models. After mapping the material weights as a texture map to 3D objects, the BRDF models recovered is used to render them, finally reaching the approximately same appearance as the sampled materials.

3 Implementation

All original images were photographed in a closed space surrounded by a piece of black curtain (Fig. 1). The camera used is Canon EOS 5D with a 200 mm lens and a remote control system, and was fixed on a tripod. A 5W halogen bulb was mounted on a metallic arm whose position was controlled precisely by a computer.

Fig. 1. Experiment setup

We use the calibration toolbox developed by Bouguet [5] to obtain the internal and external parameters of the camera; the radiance response curve of the camera was recovered by Debevec and Malik's method [6], which can be used to synthesize a single high dynamic image from a group of low dynamic ones.

The lighting directions were determined by the highlight peaks on three table tennises which were prayed with shiny green paint (Fig. 1). The light intensity was calculated easily by means of a piece of Lambert gray card with diffuse albedo 18%.

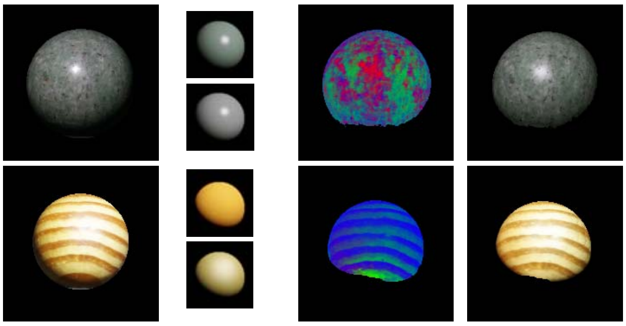
We use the camera response curve to synthesize HDRIs for each of the lighting directions. After removing the invalid pixels not belonging to the sampled spheres or in the attached shadows, we calculated geometrical parameters θ_i, θ_r and σ in Ward model using the known camera parameters and light positions.

To estimate the initial diffuse coefficients, pixels in specularity were filtered firstly. The remainder imaging points may be considered to be consistent with Lambertian and their single diffuse coefficient was averaged to form the initial values. Then, the initial diffuse coefficient of each pixel was transformed into HSV space and the V component was dropped. By means of K-means clustering according to (cos(2*PI*H), sin(2*PI*H), S), each pixel falls into either of two groups. If pixel p is grouped into material $m1$, γ_p is ($\gamma_{p,m1}$, 0), otherwise (0, $\gamma_{p,m2}$). Each group actually corresponds to a specific kind of material. Subsequently, we optimize the initial specular coefficients using Levenberg-Marquardt algorithm, using the objective function in formula (1).

By far, the optimization for BRDF parameters and material weight forms an iteration procedure. Holding BRDF parameters constant, the material weights γ_p are optimized; while holding material weight constant, the BRDF parameters are optimized. This alternate iteration will terminate until the objective function converges.

4 Experiment results

In this experiment, seven lighting direction was selected. A marble and a wooden striped sphere were selected as samples. According to the steps described in section 3, we eventually obtain a material weight map of the valid region of the spheres, and 14 parameters of two BRDF model. The results are shown in Fig. 2, and rendered objects shown in Fig. 3:



(a) (b) (c) (d)

Fig. 2. Experiment result: (a) source images (b) material reference spheres rendered using recovered BRDF parameters (c) material weight maps for two sampled spheres, where the weights of the two materials are encoded in R/G channel, and channel B denotes the shading $(1-\gamma_{p,m1}-\gamma_{p,m2})$ (d) restored spheres rendered using material weight maps and BRDF models

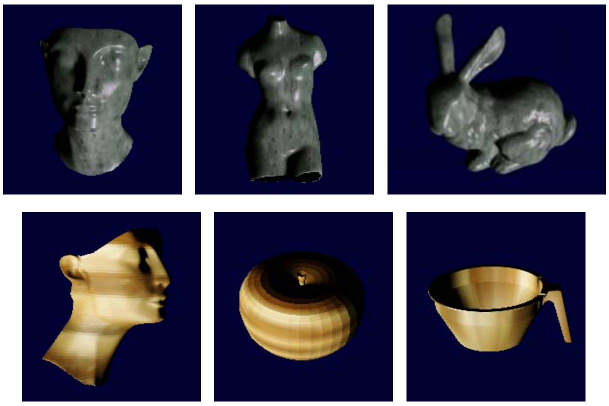


Fig. 3. Realistic rendering with the materials of the marble and wooden sphere

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