論文の内容の要旨

論文題目　Illumination Recovery and Appearance Sampling for Photorealistic Rendering (写実的な画像生成のための光源環境推定と物体表面の見えの標本化)

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Conventional *model-based rendering* techniques have been intensively developed for synthesizing the realistic appearance of objects. Model-based rendering techniques synthesize the appearance of objects based on empirically or analytically given reflection models. To use these models, the geometric and photometric information about the scene needs to be provided: the shapes of objects in the scene, their surface reflectance properties, and the lighting conditions of the scene where those objects are placed.

Regarding the geometric information of a scene, 3D shapes of objects are often manually produced by using well-designed CAD modelers. Also, for modeling the more complex shapes of real objects, a number of approaches have been developed, such as range image merging techniques and 3D photography techniques. In contrast, providing photometric information about a scene, such as surface reflectance properties and lighting conditions, has been a difficult task.

Surface reflectance properties greatly influence the appearance of an object: the appearance of a metallic surface is completely different from that of a matted surface even under the same lighting conditions. In addition, its appearance changes significantly under different lighting conditions. It is thus important to provide not only appropriate surface reflectance properties of objects in a scene but also appropriate illumination conditions so that the realistic appearance of the objects can be synthesized under these illumination conditions. Nevertheless, photometric information about a scene tends to be manually provided by a user.

Since it is difficult to imagine the appearance of an object directly from reflectance parameters, the input process of manually specifying its reflectance properties is normally non-intuitive and thus time-consuming. The correct appearance of a scene is difficult to achieve unless we stop relying on our instinct for adjusting reflectance parameters. As for providing lighting conditions, a scene generally includes both direct and indirect illumination distributed in a complex way, and it is difficult for a user to manually specify such complex illumination distribution.

In order to overcome these difficulties in providing photometric information about a scene, techniques for automatically providing the photometric models of a scene have been studied in the fields of both computer vision and computer graphics research. In particular, techniques that use a set of images of a scene provided under different viewing and/or lighting conditions for determining its geometric and photometric information are called *image-based modeling.*

This thesis addresses two issues of image-based modeling for synthesizing the photorealistic appearance of real objects under natural illumination conditions: capturing real-world illumination, and modeling the complex appearance of real objects for variable illumination. Regarding the first issue of capturing real-world illumination, both *image-based lighting* and *inverse lighting* approaches are studied.

Techniques for measuring real-world lighting from photographically acquired images of the scene are called image-based lighting. Although image-based lighting techniques have been developed successfully with practical applications, two difficulties in image-based lighting still remain to be solved: how to construct a geometric model of the scene, and how to capture a wide field of view of the scene. In this thesis, we confront these two difficulties and propose an efficient method for automatically measuring illumination distribution of a real scene by using a set of omni-directional images of the scene based on an omni-directional stereo algorithm.

The second approach, inverse lighting, assumes the knowledge of 3D shapes and reflectance properties of objects in a scene and inversely recovers incident light distribution from a photograph of that scene. In a natural illumination condition, a scene includes both direct and indirect illumination distributed in a complex way, and it is often difficult to recover an illumination distribution from image brightness observed on an object surface. The main reason for this difficulty is that there is usually not adequate variation in the image brightness observed on the object surface to reflect the subtle characteristics of the entire illumination.

In this thesis, we demonstrate the effectiveness of using occluding information of incoming light in estimating an illumination distribution of a scene. Shadows in a scene are caused by the occlusion of incoming light, and thus contain various pieces of information about the illumination of the scene. Nevertheless, shadows have been used for determining the 3D shape and orientation of an object that casts shadows onto the scene, while very few studies have focused on the illuminant information that shadows could provide. In our method, image brightness inside shadows is effectively used for providing distinct clues to estimate an illumination distribution.

As for the second issue of modeling the complex appearance of real objects for variable illumination, we carefully investigate the requirement for input images in order to correctly produce the appearance of an object under arbitrary illumination. While there may seem to be a large variety of possible appearances for a given object, it has been demonstrated in previous research that the changes in appearance of an object for varying illumination can be represented with a linear subspace spanned by a set of basis images of the object.

A set of basis images spanning such a linear subspace is often provided by applying principal-component analysis to the input images of an object taken under different lighting conditions. Since little is known about how to sample the appearance of an object in order to obtain its basis images correctly, a large number of input images taken by moving a point light source along a sphere surrounding the object are generally provided.

This thesis carefully investigates this important issue of how to sample the appearance of an object and presents a novel method for analytically obtaining a set of basis images of an object for arbitrary illumination from input images of the object taken under a point light source or extended light sources. The main contribution of our work is that we show that a set of lighting directions can be determined for sampling images of an object depending on the spectrum of the object's bidirectional reflectance distribution function in the angular frequency domain such that a set of basis images can be obtained analytically based on the sampling theorem on spherical harmonics. Unlike the previously proposed techniques based on spherical harmonics, our method does not require the 3D shape and reflectance properties of an object.

Once a set of basis images of an object is obtained, its appearance under natural illumination conditions can be synthesized simply as a linear combination of these basis images whose linear coefficients are computed from the given lighting conditions, and these lighting conditions can be modeled by our proposed image-based or inverse lighting methods.