Photometric Image-Based Rendering for Virtual Lighting Image Synthesis

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Abstract

A concept named Photometric Image-Based Rendering (PIBR) is introduced for a seamless augmented reality. The PIBR is defined as Image-Based Rendering which covers appearance changes caused by the lighting condition changes, while Geometric Image-Based Rendering (GIBR) is defined as Image-Based Rendering which covers appearance changes caused by the view point changes. The PIBR can be applied to image synthesis to keep photometric consistency between virtual objects and real scenes in an arbitrary lighting condition. We analyze the conventional IBR algorithms, and formalize the PIBR in the whole IBR framework. A specific algorithm is also presented for realizing the PIBR. The photometric linearization makes a controllable framework for the PIBR, which consists of four processes; (1) separation of environmental illumination effects, (2) estimation of lighting directions, (3) separation of specular reflections and cast-shadows, and (4) linearization of self-shadows. After the photometric linearization of input images, we can synthesize any realistic images which include not only diffuse reflections but also self-shadows, cast-shadows and specular reflections. Experimental results show that realistic images can be successfully synthesized with keeping photometric consistency.

1. Introduction

Considerable work has been made for augmented reality, which mixes a synthesized virtual object with a real scene. In order to realize a seamless augmented reality, the synthesized image should be very realistic because the synthesized objects and real scene are directly compared in the same image. Model-Based Rendering (MBR) has been investigated for the image synthesis, and it works well with a scene model which consists of a set of 3D shape models, reflection properties as well as the lighting conditions of the scene. In order to synthesize a realistic image, however, the MBR approach requires accurate models. In some applications, the accurate models can be prepared by means of CAD technology. On the other hand, image-based modeling[1] is necessary to built the model when the model cannot be prepared by CAD. It is, however, often unstable to reconstruct models from a collection of images. The accurate models often cannot easily obtained without special devices such as a high precision range finder.

To overcome the problem with the MBR approach, the Image-Based Rendering (IBR) has been widely used. The IBR does not require accurate object models. A new image is directly synthesized from a collection of input images without the unstable reconstruction of models. Since the IBR makes full use of real images, a realistic image can be synthesized.

Although a lot of IBR algorithms have been proposed, almost of them deal with only the geometric appearance changes caused by the view point changes [2][3][4][5]. They can synthesize a new image, which should be taken from a particular view position, from input images which were taken from the discrete view positions. The appearance change, however, is subject to not only geometric factors but also photometric factors. The appearance change caused by the lighting conditions is one of the most important ones in the photometric factors. Unfortunately, the conventional IBR algorithms cannot cover the photometric appearance changes. It is necessary to control the photometric factors in the IBR framework, in order to realize the seamless augmented reality which mixes real and synthesized images.

For solving this problem, we propose a new IBR called the **Photometric Image-Based Rendering** (PIBR). Using the PIBR, a new image, which should be taken in a particular lighting condition, is directly synthesized from a collection of input images taken in a variety of lighting conditions. In this paper, we show how to mix the synthesized images with real scenes keeping the photometric consistency.

This paper is organized as follows: Section 2 analyzes that the IBR framework, and shows that it is decomposed into two aspects, named Geometric Image-Based Rendering (GIBR) and PIBR. Section 3 presents the formulation of PIBR, that is, the relation between the appearance changes and the lighting condition changes. Section 4 describes how to synthesize images in the PIBR. Some experimental results are shown in Section 5. Finally, some conclusions are presented in Section 6.

2. Two Aspects of IBR

In the IBR approach, a collection of real images is used instead of 3D object models. The input images are analyzed, and a different view is directly synthesized from the input images. In other words, the IBR is based on the conversion from images to images. The IBR approach has some advantages to the MBR. Realistic images can be synthesized, if the dense input images are registered in advance. The IBR does not require unstable processes such as a reconstruction of the scene model from images, which are inevitable for the MBR approach.

On the other hand, the IBR has to treat a wide variety of appearance changes for the practical use. The appearance changes are actually dependent on both the geometric and the photometric properties of the scene as well as the lighting condition. However, the changes are mainly dominated by the relative view position and the lighting condition. Thus, they can be decomposed to the orthogonal two aspects; the geometric and photometric aspects. The **Geometric Image-Based Rendering** is defined as the Image-Based Rendering which covers the appearance changes caused by the view point changes. On the other hand, the **Photometric Image-Based Rendering** is defined as the Image-Based Rendering which covers the appearance changes caused by the lighting condition changes. We assume that the two aspects are almost independent and they work cooperatively in the whole IBR framework. We describe details of the two aspects in the following two sections.

2.1. Geometric Image-Based Rendering

A lot of algorithms have been developed to synthesize a new image, which should be taken at a particular view point, from a set of input images which were taken from different view points. These algorithms are classified in the Geometric Image-Based Rendering (GIBR), and almost of them are based on the interpolation technique [2][3][4][5]. That is, an intermediate view is synthesized from two or more input images by a linear interpolation of the corresponding points. The essential task is to find the corresponding points between input images and to predict the location of the corresponding points from a specified view point. Any 3D information, such as the 3D shape model of the scene and the view point, is not necessary.

The GIBR framework can cover the geometric appearance changes caused by the view point changes or the rotation of the object. However, the photometric appearance changes cannot be controlled in the GIBR because the lighting condition is assumed to be fixed.

2.2. Photometric Image-Based Rendering

The photometric appearance changes are the other dominant factor of the image making process. When the lighting condition changes, the appearance also changes even if the view point and the object pose are fixed. If the concept of IBR can be applied to the photometric appearance changes, the realistic image with any lighting conditions can also be synthesized in the similar framework as the GIBR. Let us call the framework the Photometric Image-Based Rendering, or PIBR in short.

In the PIBR framework, a new image in a virtual lighting condition should be synthesized from a set of input images which were taken in a variety of lighting conditions. Since the view point is fixed in the PIBR, it is not necessary to find the corresponding points between input images. Thus, the essential task is reduced to prediction of the intensity of each point on the surface without using any models of both the reflection properties and the lighting properties.

Some algorithms have already been proposed for changing lighting conditions in the PIBR framework. Shashua[6] showed that an image with any light direction can be synthesized by a linear combination of three base images. This method, however, assumes the Lambertian reflection model. Unfortunately, real scenes include more complex factors such as specular reflections and shadows. Therefore, this method cannot be applied to the real scenes. In order to deal with the real scenes, Zhang[7] used the principal component analysis and showed that an image in any light direction can be synthesized by a linear combination of the principal component images. If dense input images are prepared, realistic images can be synthesized