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Technical Section

Improved gloss depiction using the empirical highlight un-distortion method for 3D image-warping-based stereo rendering ☆

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ABSTRACT

Several methods, such as 3D image warping, have been employed to approximate the stereo effect from one image without full physically based rendering. However, these methods cannot consider the view dependence of highlight depiction, which can undermine the stereo effect. In this paper, a novel method that un-distorts the warped highlights generated by the warping method to reproduce physically plausible highlights is proposed. The nonlinear patterns of highlight distortion are analyzed through a thorough comparison of the warped and physical highlights. The distortion is decomposed into basic and general components, each of which is modeled using a mathematical function. Next, the magnitude and direction of highlight distortion at a point on an object surface are estimated. Spherical approximation of the geometric shape at a point is used to approximately describe the shape of the object. The magnitudes of the basic and general distortion are then obtained using the concept of 'coupled-sphere' geometry based on the approximated shape. The directional components of highlight distortion are estimated using the virtual-circle-tracing scheme, which uses a virtual circle that passes a point to obtain the direction for the distortion as the tangent to the circle at that point. Using the magnitudes and directions of highlight distortion, the highlights of the warping method are corrected to produce physically plausible highlights on the surface. The method is fully automatic and computationally efficient. Experimental results indicate that the proposed method greatly improves the visual quality of 3D images.

1. Introduction

In virtual 3D content generation, stereoscopic rendering is widely used because it only requires a pair of 2D images for the left and right eyes. In this configuration, a viewer can perceive depth when the two images are successfully fused in the brain.

The primary idea of generating a stereoscopic image is that an object should be rendered twice for the same scene. This is a problem in content generation because the rendering operation itself is a time-consuming process.

To avoid the above problem, '3D image warping' [1] can be considered. It can quickly produce images for the left and right eyes from a single image by transforming a 3D point cloud or depth image under stereographic projection with respect to a new view point.

When objects are made of glossy materials, reproducing the correct reflection patterns, including highlights, is important in the stereo rendering because highlight depiction on such objects significantly affects visual impressions in terms of depth, shape, and material perception. However, the results from image warping are often perceived as flat or ambiguous. The view-dependency in glossy highlights cannot be correctly captured because both the highlights and the texture are warped in the same manner and the same amount of disparity is generated. In fact, glossy highlights should have a different disparity compared to the surface disparity (binocular disparity) in the image because they have a different depth.

In this paper, a technique for correcting a highlight distortion induced by image warping is proposed without full stereo rendering. Assumptions are made to develop the technique. Information on the 3D object and the camera, which is essential for rendering, is provided. Next, only direct highlight components are considered. According to the report of lightness constancy in human vision, the areas of high intensity contrast are visually more noticeable than those of low intensity contrast [2]. This phenomenon is more evident in the direct highlight generation than in the indirect one. Finally, image-based lighting is considered for the lighting condition. The effect of highlight distortion regarding the light position is not modeled, although the highlight of a close light source would be different from that of a remote light source in reality. Nevertheless,

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image-based lighting would be sufficient to represent the complex natural illumination in many outdoor and some indoor scenes, for which the illumination in the scenes is relatively distant from the scene objects compared with the viewing distance, without increasing the complexity of the modeling.

Highlight distortion is decomposed into two components: magnitude and direction. The magnitude of the highlight distortion is computed on a curvature sphere that approximates the highlighted surface in 3D space, and the direction of the distortion is approximated using virtual circles in the 2D image. Finally, the warped highlight is un-distorted to depict physically more plausible highlights.

The contributions of this paper are as follows:

- A highlight un-distortion that can approximate physical glossy highlights from a warped image under direct illumination is proposed.
- A model is proposed for automatic control of the un-distortion with respect to the stereo baseline, object shape, camera orientation and view distance.
- The proposed method has potential for realistic 3D content conversion from a single photograph with the help of a shape inference technique [3].

2. Related work

In this section, a brief overview of stereo-optimization techniques, largely related to synthetic rendering and single-image based approaches, is presented. Next, several human-vision studies associated with gloss perception are introduced, and image-based perceptual enhancement techniques are reviewed in the context of stereo computer graphics.

2.1. Stereo-rendering optimization

Image-based rendering can accelerate stereoscopic rendering by exploiting the image coherence of two neighboring views. In this approach, a new view can be easily and efficiently synthesized from the existing one. Adelson and Hodge [4] proposed a hybrid approach that could reduce the cost of stereo-ray tracing by carefully choosing sampling points for the left eye and concurrently re-projecting them to the ray direction for the right eye while an image for the left eye is being rendered. For diffuse scenes, Fu et al. [5] introduced an image-warping and hole filling technique using pixel interpolation for their imperfect warping results. Wan et al. [6] applied fast 3D image warping in volume rendering. Fehn et al. [7] proposed depth-image-based rendering (DIBR), which is particularly useful for real-life applications, such as real-time 3D-TV conversion. Zhang et al. [8] applied a filtering technique to remove dis-occluded areas in new views resulting from DIBR. Based on the binocular suppression theory of human perception, Bulbul et al. [9] showed that stereo rendering could be accelerated by producing a high quality image for one eye and a low quality one for the other eye. Sorbier et al. [10] indicated that stereoscopic rendering can be accelerated by setting multiple rendering targets after cloning the same primitives for both views in GPUs.

None of the techniques above, however, are suitable for producing an image with glossy highlights for a new view from a single image because they assume view-independency in the scene or require extra ray-tracing operations.

2.2. Human perception of gloss

The perception of gloss by humans has been extensively investigated with the binocular theory since Kirschmann [11] first introduced the concept of highlight disparity. The rationale for his approach stems from the fact that the disparity caused by specular reflections is different from the surface disparity caused by the epipolar geometry between two eyes. Blake et al. [12] addressed a similar issue. It was demonstrated that stereo images were visually more realistic if some bias, which placed highlights behind the surface, was added to the physical highlight disparity on a convex surface. Nevertheless, creating a correct physical highlight was essential before it was replaced. Blake [13] proposed a ray equation based on the Hessian of the local surface to measure the highlight disparity generated on a smooth surface by a point light source as well as distributed light sources. The (angular) highlight disparity can be estimated if the stereo baseline is short compared to the viewing distance. However, the method requires a stereo pair of physically based images and assumes a known highlight disparity reference, which should be manually measured for each surface. Beck et al. [14] determined that highlights can produce glossiness provided that the intensity gradient near the highlights makes the surface appear curved. Obein et al. [15] studied the difference in human sensitivities between monocular and binocular vision with various degrees of glossiness. Their experiments indicate that the sensitivity to high glossiness is stronger in binocular vision than in monocular vision. Therefore, it is necessary to depict gloss more carefully in stereoscopic rendering when scenes with highly glossy objects are considered. Wendt et al. [16] indicated that highlight disparity can improve material authenticity and the strength of gloss by using several visual stimuli tests with the Phong lighting model. In computer graphics, Vangorp et al. [17] performed a psychophysical experiment related to material discrimination by rendering synthetic images with a global illumination technique under natural environment lighting. Their result is somewhat similar to that of Beck et al. [14] because they illustrated that the accuracy of material depiction is influenced by both the particular shape and the material of the object in the rendering setting. Recently, Qi et al. [18] characterized the relationship between surface roughness and the highlight area and stated that the use of realistic illumination conditions is critical for realistic rendering in terms of gloss depiction. Thus, considering only environment illumination, which captures real illumination, is a valid assumption.

2.3. Gloss depiction in rendering

Hoffman et al. [19] observed that visual fatigue and discomfort problems are caused by distortions of real scenes by 3D displays and the so-called vergence-accommodation conflict. Much of the stereo manipulation research has focused on resolving this issue by controlling disparities. Similarly, visual distraction can also occur in realistic scenes with natural lighting and glossy objects because of binocular rivalry, which returns unstable and alternative results instead of correct stereopsis. In computer vision, image-based rendering techniques that can estimate novel views for scenes with specular reflection from multiple views have been introduced [20,21]. Unfortunately, these techniques are only applicable to simple scenes due to underlying assumptions about the materials and illumination in the image; thus, the scenes suffer from abundant artifacts. Recently, Wang et al. [22] proposed a method that can accelerate glossy reflection in GPU rendering using the coherence of per-pixel reflected rays. The reflection is easily computed by checking the intersection between a ray and depth image, which contains the approximate reflected geometry. However, the method is computationally expensive because of the high computational load for computing the glossy reflection due to multiple ray intersections. Templin et al. [23] suggested an image-based technique that can produce perceptually plausible disparity for glossy objects regarding the surface curvature for both rendered