An Optical System for Single-Image Environment Maps

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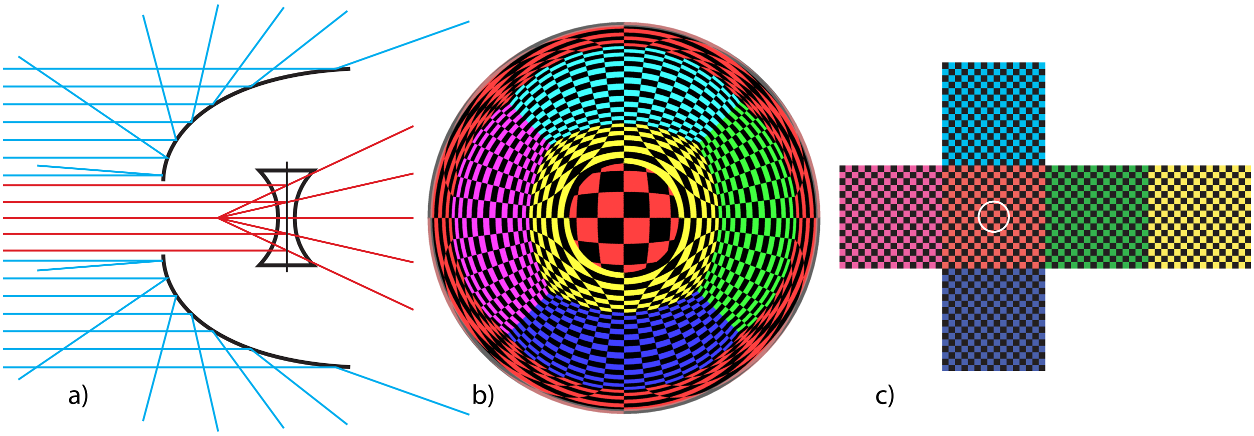

Figure 1: **a)** A principal sketch of the mirror and lens setup, with reflected and refracted rays for the parallel projection case. **b)** An image of a checkered environment map, as displayed in **c)**, as projected by the setup. The field of view of the central lens is about 30°, represented by the white circle in the cube map.

Abstract

We present an optical setup for capturing a full 360° environment map in a single image snapshot. The setup, which can be used with any camera device, consists of a curved mirror swept around a negative lens, and is suitable for capturing environment maps and light probes. The setup achieves good sampling density and uniformity for all directions in the environment.

Introduction

Image based lighting techniques using captured real world lighting as source of illumination for renderings was proposed in [Debevec 1998], and has been used successfully in recent years. In computer graphics applications, light probes are usually captured by photographing mirror spheres. A spherical mirror exhibits poor sampling, particularly for the forward-facing directions relative to the camera. The sphere is also a so called non-single viewpoint system, which means that the center of projection moves as a function of the position on the sphere. The properties of single and non-single viewpoint catadioptric systems have been investigated by [Baker and Nayar 1999] and [Swaminathan et al. 2006]. Non-single viewpoint systems are not optimal, but still useful for imaging.

Optical System

The main goal of the setup is to achieve good and uniform sampling density for all directions in the environment. We use a swept mirror surface with a hole at the center, and a negative lens in the hole to yield a wide-angle view of the problematic forward facing directions, see Figure 1 a).

The mirror reflects the backward and forward facing directions in the environment up to a certain limit. Assuming a parallel projection, the height z as a function of the radius $0 < r < 1$ of our mirror profile is given by:

$$\frac{dz}{dr} = \tan\left(\frac{\pi r}{2}\right) \Longrightarrow z = -\frac{2}{\pi} \ln\left(\cos\frac{\pi r}{2}\right) \qquad (1)$$

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This yields a linear mapping of radius to reflection angle, similar to a fisheye lens and the ”angular map” used in HDR imaging. Near forward-facing angles, the profile has a very steep slope and will be difficult to fabricate and use, but we truncate the profile to exclude the forward-facing angles covered by the central image. The example mirror profile covers about 330° of the environment, and the lens the remaining 30°. Some stretching can be noticed along the rim, but this non-uniformity is common to all circular wide-angle projection, and the radial sampling density in our setup is perfectly uniform. No contraction occurs, see Figure 1 b).

The setup with both a curved mirror and a lens gives two separate image formations of the environments, but it can easily be mapped to any convenient panorama representation. The lens is designed such that there is a small overlap between the reflected (mirror) and refracted (lens) fields of view, for better resampling and interpolation properties.

There is still a dead angle in this setup: the camera will still block out a small part of the view for back facing angles. However, this is less of a problem.

Our example uses parallel projection for clarity, and the same profile can be used with good accuracy for a telephoto lens. The profile can easily be changed to take perspective projection into account.

References

Baker, S., and Nayar, S. 1999. A Theory of Single-Viewpoint Catadioptric Image Formation. *International Journal on Computer Vision 35*, 2 (Nov), 175–196.

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Swaminathan, R., Grossberg, M. D., and Nayar, S. K. 2006. Non-Single Viewpoint Catadioptric Cameras: Geometry and Analysis. *International Journal of Computer Vision 66*, 3 (Mar), 211–229.