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Plenoptic Modeling: An Image-Based Rendering System

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ABSTRACT

Image-based rendering is a powerful new approach for generating real-time photorealistic computer graphics. It can provide convincing animations without an explicit geometric representation. We use the "plenoptic function" of Adelson and Bergen to provide a concise problem statement for image-based rendering paradigms, such as morphing and view interpolation. The plenoptic function is a parameterized function for describing everything that is visible from a given point in space. We present an image-based rendering system based on sampling, reconstructing, and resampling the plenoptic function. In addition, we introduce a novel visible surface algorithm and a geometric invariant for cylindrical projections that is equivalent to the epipolar constraint defined for planar projections.

CR Descriptors: I.3.3 [**Computer Graphics**]: Picture/Image Generation– *display algorithms, viewing algorithms*; I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism– *hidden line/ surface removal*; I.4.3 [**Image Processing**]: Enhancement– *registration*; I.4.7 [**Image Processing**]: Feature Measurement– *projections*; I.4.8 [**Image Processing**]: Scene Analysis.

1. INTRODUCTION

In recent years there has been increased interest, within the computer graphics community, in image-based rendering systems. These systems are fundamentally different from traditional geometry-based rendering systems. In image-based systems the underlying data representation (i.e model) is composed of a set of photometric observations, whereas geometry-based systems use either mathematical descriptions of the boundary regions separating scene elements (B-rep) or discretely sampled space functions (volumetric).

The evolution of image-based rendering systems can be traced through at least three different research fields. In photogrammetry the initial problems of camera calibration, two-dimensional image registration, and photometrics have progressed toward the determination of three-dimensional models. Likewise, in computer vision, problems such as robot navigation, image discrimination, and image understanding have naturally led in the same direction. In computer graphics, the progression toward image-based rendering systems was initially motivated by the desire to increase the visual realism of the approximate geometric descriptions by mapping images onto their surface (texture mapping) [7], [12]. Next, images were used to approximate global illumination effects (environment mapping) [5], and, most recently, we have seen systems where the images themselves constitute the significant aspects of the scene's description [8].

Another reason for considering image-based rendering systems in computer graphics is that acquisition of realistic surface models is a difficult problem. While geometry-based rendering technology has made significant strides towards achieving photorealism, creating accurate models is still nearly as difficult as it was ten years ago. Technological advances in three-dimensional scanning provide some promise in model building. However, they also verify our worst suspicions— the geometry of the real-world is exceedingly complex. Ironically, the primary subjective measure of image quality used by proponents of geometric rendering systems is the degree with which the resulting images are indistinguishable from photographs.

One liability of image-based rendering systems is the lack of a consistent framework within which to judge the validity of the results. Fundamentally, this arises from the absence of a clear problem definition. Geometry-based rendering, on the other hand, has a solid foundation; it uses analytic and projective geometry to describe the world's shape and physics to describe the world's surface properties and the light's interaction with those surfaces.

This paper presents a consistent framework for the evaluation of image-based rendering systems, and gives a concise problem definition. We then evaluate previous image-based rendering methods within this new framework. Finally, we present our own image-based rendering methodology and results from our prototype implementation.

2. THE PLENOPTIC FUNCTION

Adelson and Bergen [1] assigned the name *plenoptic* function (from the latin root *plenus*, meaning complete or full, and *optic* pertaining to vision) to the pencil of rays visible from any point in space, at any time, and over any range of wavelengths. They used this function to develop a taxonomy for evaluating models of low-level vision. The plenoptic function describes all of the radiant energy that can be perceived from the point of view of the observer rather than the point of view of the source. They postulate

> *"… all the basic visual measurements can be considered to characterize local change along one or two dimensions of a single function that describes the structure of the information in the light impinging on an observer."*

Adelson and Bergen further formalized this functional description by providing a parameter space over which the plenoptic function is valid, as shown in Figure 1. Imagine an idealized eye which we are free to place at any point in space (V_x, V_y, V_z). From there we can select any of the viewable rays by choosing an azimuth and elevation angle

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