A Catadioptric Projector System with Application to Pseudo HDR Display

Ryan Baumann, Qing Zhang, Ruigang Yang†
University of Kentucky

1 Introduction

It has been shown in computer vision that combining reflective components (e.g. mirrors) with refractive components (e.g. lenses) can greatly increase the flexibility and functionality of an optic imaging system, such as increased field of view and reconstruction from a single image. Cameras with both lenses and mirrors are typically referred to as catadioptric systems. A projector, as the dual of a camera, can also benefit from catadioptric optics. For example, it is possible to bend the light rays to optically compensate for distortions caused by projection [Swaminathan et al. 2004]. However, different mirror shapes have to be used for different setups.

In this paper we explore an alternative solution that trades off spatial resolution for flexibility. As shown in Figure 1, The basic idea is to insert a micro-spherical mirror array in front of the lens. Each mirror will reflect the light ray in different directions. By selectively using (turning on) a coherent subset of the bundles of rays, we can simulate reflections from mirrors with different shapes - at a reduced viewable resolution. Such a catadioptric projector has been used in auto-stereoscopic displays. In this paper, we focus on a different application: increasing the brightness and color depth of a single projector, which we have called pseudo high-dynamic range (pHDR) display. This pHDR display can in turn be combined with a secondary light modulator as described in [Seetzen et al. 2004] to increase the dynamic range and achieve a true HDR display.

![Figure 1: Left: Approximating a concave curvature mirror to focus on a point. This is used for our pHDR setup. Right: Approximating a convex curvature mirror to steer a virtual projector.](image)

2 Computing the Properties of the System

In order to display a pHDR image on a given location, we need to find the mapping of projector pixels to the display surface. This can obtained either through an exhaustive scan or by ray tracing if all the display components are calibrated. The mapping is likely to be many to one. Our pHDR image is obtained by illuminating the same display point with many pixels.

We can consider each reflecting element as a new virtual projector and form a broad generalized equation for the theoretical number of color steps $g$ in the overlaid output, $g = (g_i \times k)^n$. Here $n$ is the number of virtual projectors, $g_i$ is the number of steps for a given color channel in the input projector, and $k$ is the total number of color channels. Because the output of the virtual projectors is not individually modulated, the contrast ratio for the pHDR display remains the same. While the setup increases the brightest intensity the array can output, the minimum intensity increases at the same rate.

The luminance and resolution efficiency of the configuration depends on a number of factors. The area of the sphere mirror which we use (i.e., turning pixels on to this area), as defined by the solid angle, will be a major factor in the system’s output. Essentially, as the amount of each sphere we expose increases, so does the angle between the surface normal and the incident direction, resulting in larger pixel distortion and fewer usable pixels (but greater luminance if we do use these pixels). Thus we want to both expose and use a relatively small solid angle of the sphere in order to attain the best resolution and luminance possible. In Figure 2, we have used a relatively high solid angle for each sphere to illustrate the type of distortion which occurs towards the edges of a sphere.

![Figure 2: Left: Simulated output from a traditional projector. Right: Simulated output from a projector using a a micro-spherical image array.](image)

We have developed a simulator to study the properties of our proposed pHDR display. Simulating a projector with properties equal to those used in [Seetzen et al. 2004], we achieved a pHDR display with 80 x 80 resolution and a theoretical luminance of 9995 cd/m² when used with an LCD modulator. This is approximately equal to the luminance from the LED back lighting in [Seetzen et al. 2004], with better resolution (6400 elements compared to 760) and more addressable steps (3072 compared to 1024).

In summary we have shown in simulation that it is possible to get a pHDR image via a catadioptric projector system. The same setup can also be used to electronically steer the projection beam around, with the benefit of a brighter image. Compared to actually moving a mirror, the electronic steering can be much faster and produce several projection patterns at different locations simultaneously. We believe such a setup can be useful for out-door augmented reality applications. We are currently implementing the experiments with a real setup which may exhibit a depth-of-focus issue. This can be solved by using laser projectors. Ultimately, we hope the static micro-mirror array can be replaced by active DMD-style arrays with continuous modulation of pan and tilt. This will give us the advantage of a deformable reflective mirror without losing the spatial resolution.

References


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†e-mail: rbaum2@uky.edu, qzhan7@uky.edu, ryang@cs.uky.edu