High Dynamic Range Image Capture with Plenoptic 2.0 Camera

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Abstract: We demonstrate high dynamic range (HDR) imaging with the Plenoptic 2.0 camera. Multiple exposure capture is achieved with a single shot using microimages created by microlens array that has an interleaved set of different apertures.

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1. Introduction

The plenoptic camera, a digital realization of Lippmann's integral photography [6], was introduced in 1992 [1] as an approach to solve computer vision problems. An improved version, the Plenoptic 2.0 camera, has been independently introduced in [10, 4, 7] and also follows ideas originating from Lippmann [6]. In one realization, the camera has microlenses placed at distance b from the sensor, and focused at the image plane of the main camera lens, at a distance a in front of them (see Figure 1). In this configuration, a, b, and the focal length f satisfy the lens equation, and each microlens constructs a relay system with the main camera lens.

Capturing data with plenoptic cameras makes possible greater processing capabilities and solves many of the problems faced by photographers using conventional digital cameras. Rendering refocused images and 3D views are just two of them, and there are many others, for example the one discussed in this paper. At the same time, the Plenoptic 2.0 camera overcomes the problem of poor resolution [7] that was a main drawback for the first handheld Plenoptic camera [9].

The most common method for High Dynamic Range (HDR) image capture is the *multiple exposure technique* [2], which uses multiple images of the same scene, each taken with different exposure. If the scene is static, these images can be merged into a single HDR image. Obviously, this method doesn't work for dynamic scenes.

Other approaches to HDR capture are based on appropriate electronics and include multiple reading of the pixels, and different size/type of pixels (see for example [11, 8]), and others. These approaches capture one single frame and can be used to photograph moving scenes.

We propose a novel optics-based approach for single-frame capture of HDR that is extremely fast and works with, or independently of, any other method. We show that the Plenoptic 2.0 camera behaves as an array of microcameras, each formed by the corresponding microlens and the main lens. Based on interleaving a set of different apertures across the microlens array, we capture multiple exposures within a single shot. Prior art is [5].

2. HDR with Plenoptic 2.0

2.1. HDR with multiple exposures

Commercially available image sensors typically record energy in the range of 75 dB and offer 12 bits or less of useful image data per color channel. At the same time, natural scenes can show variation in radiance of 120 dB and more.

With the widely used multiple exposure technique, the same scene is photographed multiple times, at different exposures/apertures, with the goal of capturing dark as well as bright areas at the right levels, in different frames.

Since digital sensors are essentially linear, the result is a set of images captured at different slopes in the conversion of radiant energy into pixel value. Next, these pixel values are merged into one single floating point image with extended dynamic range. In the simplest case the final image is composed of piecewise linear transfer curves at different slopes. In the limit of large number of input images the merged image is logarithmic. Often the above is combined with tone mapping or other HDR compression techniques designed to produce low range output image while preserving contrast and image details for the purpose of display (see [2, 3] and references therein).

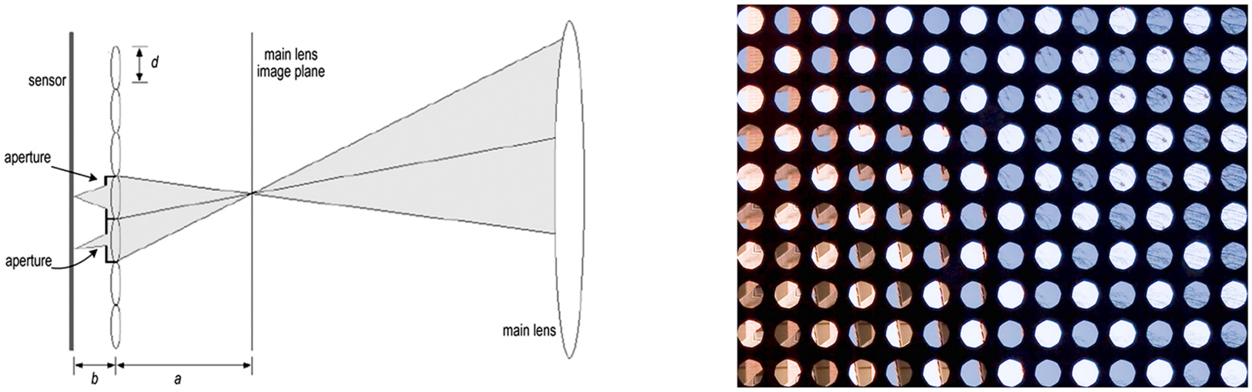

Fig. 1. Left: Plenoptic 2.0 camera as a relay system. Two microlens apertures are shown. Right: Multiple capture of the image by different microlenses. Notice the alternating brightness effect in different microimages due to alternating aperture size of microlenses.

2.2. Plenoptic 2.0 Camera Design for HDR capture

To obtain HDR image of a moving scene using multiple exposures requires that all images be taken *at the same time*—a capability that we will provide optically. As in any camera, the main lens of a Plenoptic 2.0 camera forms an image at the focal plane. Only, now there is no sensor placed there to capture it directly. Rather, the microlenses map that plane to the sensor. Each microlens creates its own image of part of the scene, as seen through the main lens aperture – which defines image shape and size. Each microlens works as a microcamera and its aperture determines the image exposure based on its F-number. By carefully adjusting the value of b, we can select different reductions in size. While there is a lot of freedom, we always choose $a/b > 1$, so every point in the main lens focal plane is captured at least in one microimage (typically, in two or more microimages). See Figure 1 (left).

In Figure 1 (right) we see the array of microimages created by the microlenses. Since aperture diameters are alternating, we observe respectively bright and dark microimages, each with the shape of the main lens aperture.

The microimages captured in this way with the thousands of microcameras are reduced in size by a factor of a/b relative to the focal plane image. Also, in our experiments we have observed that they are at very high resolution, limited only by the pixel size. Due to their small sizes, microlenses are known to be diffraction limited even at apertures as low as $F/4$. Because of that fact, typical focused microimages are extremely sharp, with resolution $1.22\lambda F$, where λ is the wavelength and F is the focal ratio. Considering that we are using image reduction factor greater than 2, the camera as a whole is difraction limited in the case of a wide range of main camera lenses that may have relatively poor modulation transfer function – and blurring the image by a related factor.

In Figure 2 we have patched together a final image using only the large aperture microlenses (left) or the small aperture microlenses (right). Aperture diameters differ by a factor of 2, so exposures differ by a factor of 4, something we have verified experimentally. For this paper we are not merging the captured images into a final HDR image.

3. Prototype

Our camera is medium format with an 80-mm lens and a 39-megapixel digital back from Phase One. The lens is mounted on the camera with a 13-mm extension tube, which provides the needed spacing a. The microlens array is custom made by Leister Axetris. The microlenses have focal length of 1.5 mm so that they can be placed directly on

Fig. 2. Left: Final image rendered from the bright microimages. Right: Final image rendered from the dark microimages. In both cases the histogram is shown, and the green rectangle indicates the area from the raw image that is displayed in Figure 1.

the cover glass of the sensor. We are able to provide additional spacing of up to 0.5 mm to enable fine tuning of the microlens focus. The pitch of the microlenses is 500 μm with precision 1 μm. The sensor pixels are 6.8 μm. The value of $b \approx 1.6$ mm was estimated with precision 0.1 mm from known sensor parameters and independently from the microlens images at different F/numbers.

Our microlens aperture diameters are 100 μm and 200 μm, interleaved in a checkerboard pattern. Apertures are circular, formed by the black chromium mask deposited on the microlenses. The relatively large pitch of the microlenses is chosen in order to match the F-number of the main camera lens, which can be as low as $F/3$. This large pitch is needed because our microlenses are at large distance $(1.6mm)$ from the sensor, defined by the cover glass.

4. Conclusion and Future Work

In this paper we have demonstrated HDR capture with interleaved microlens apertures in a Plenoptic 2.0 camera. In the experiment described, dynamic range is extended only by a factor of 4, however a larger factor can be cosen, potentially with more than two types of apertures. Much greated factor of extending the dynamic range is difficult to achieve with the aperture method because too small apertures create diffraction blur. One solution would be to use neutral density filters without reducing the apertures, as this would not create additional diffraction.

Other future work is looking at the potential of capturing different modalities of the radiance/plenoptic function. This may include spectral color and polarization capture based on a similar method with appropriately modified microlens apertures.

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