

Multiple Focal Planes using Light Field Camera

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A Concept of Multiple Focal Planes

A conventional camera has one focal plane. Hence, the captured image emphasizes subjects around the depth of the focal plane because objects out of the depth of field are blurred. Photographers leverage this effect to acquire aesthetic photographs. Recently, for easy use of this effect, Lytro, Inc. launched a light field camera to give an image an arbitrary focal plane after capturing.

However, we doubt that people always have only one subject in any scene. For example, in the zoo, we take a picture of us as foreground and animals as background with a cumbersome fence in between. In this case two subjects lie in the scene discontinuously. A conventional camera is never focused on both the subjects in one captured image with blurring the fence.

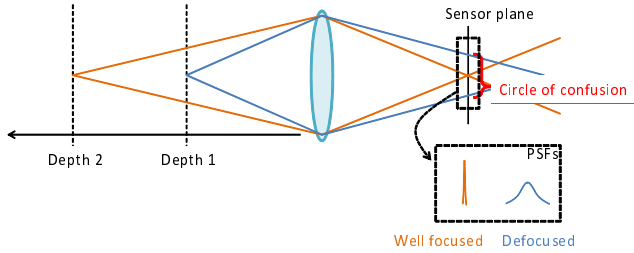


Fig. 1 Principle of lens focusing.

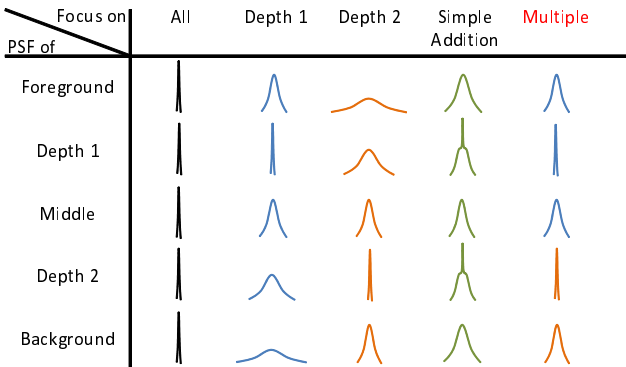


Fig. 2 Focused depth and defocusing PSF around each depth.

Figure 1 illustrates the principle of lens focusing. Lens gathers light rays from a point on a target object surface to a point on a sensor plane. Here, rays from the focused depth are clearly imaged but rays from the other unfocused depths are not clearly imaged. Hence, a simple addition of multiple images with different focal planes makes a strange image, where there are both high frequency component and blurriness at the same time. As shown in **Fig. 2**, we should not simply add images focusing on the target focal planes, but should select one suitable focal plane for each image pixel.

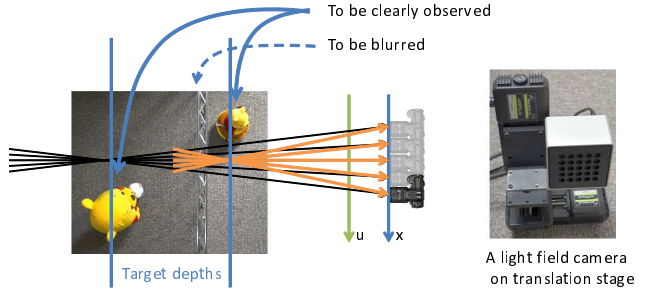
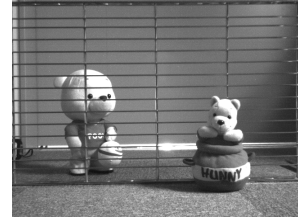


Fig. 3 Target scene: it consists of two target bears and an occluding fence..



(a) Normal image (all-in-focus like a pinhole camera image)



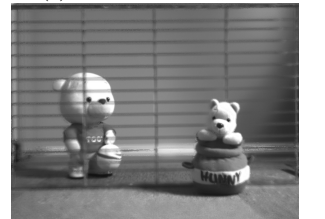
(b) Focused on Depth 1



(c) Focused on Depth 2



(d) Simple addition of (b) and (c)



(e) Multiple focal planes (our method)

Fig. 4 Comparisons of focal planes.

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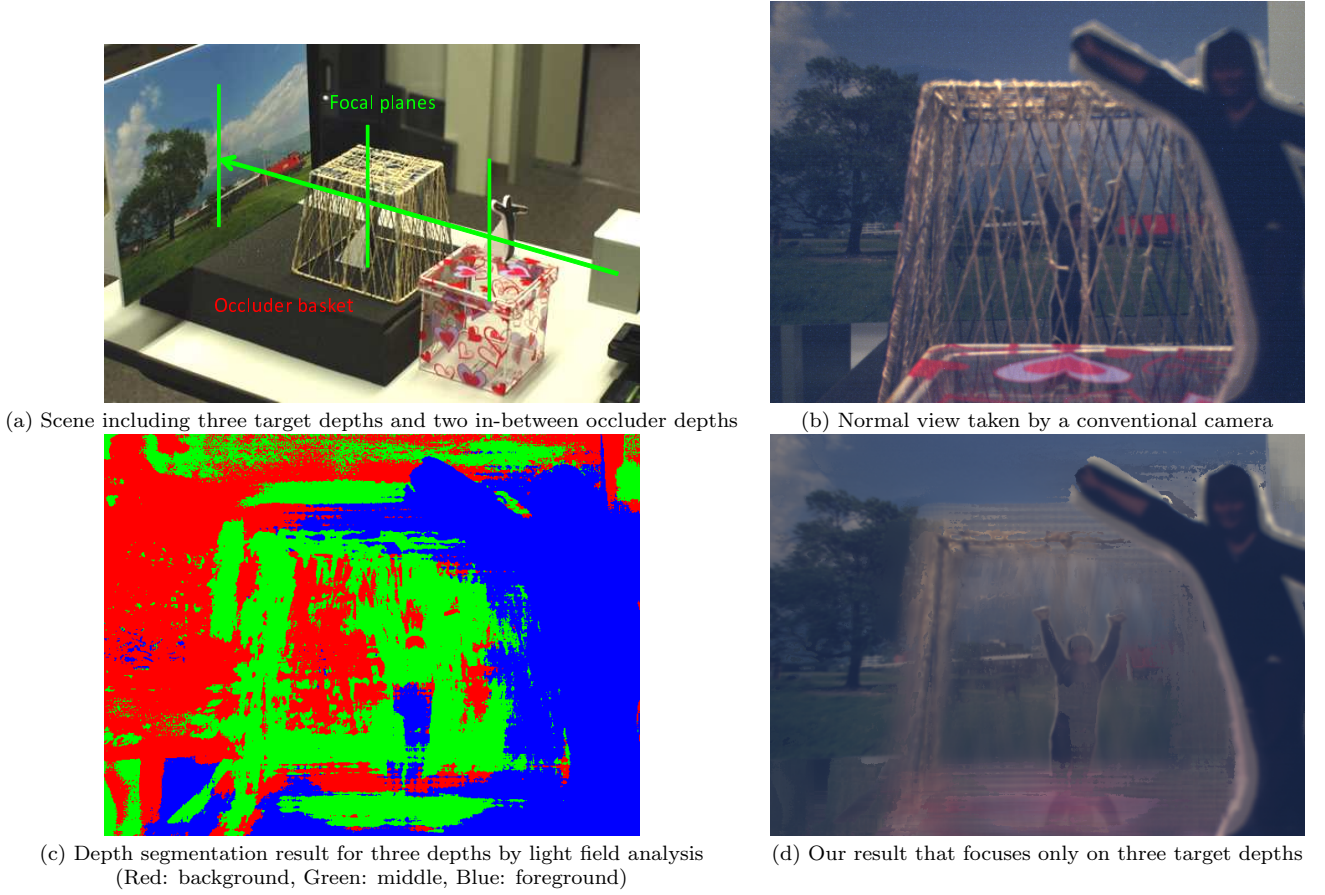


Fig. 6 Experimental results of the multiple focal planes.

Selection of Suitable Focal Plane

To select a suitable focal plane, we use a light field camera with a translation stage to capture a dense light field. Based on the light field analysis, our method selects one focal plane for each pixel. The light field has varying intensities of rays from a point in the target scene. Hence, its variation can be a clue to estimate if any object is on one of focal planes. Our method computes the variance of intensities from a point on every focal plane for each pixel. A focal plane indicating the lowest value of variances is selected as the most suitable focal plane to the pixel. Figure 6 shows the experimental results. In the experiment, the scene consisting of three target focal planes and two in-between occluder depths. Figure 6 (c) shows the result of selection of a suitable focal plane. In the segmentation image, the background and foreground focal planes are successfully selected for each pixel, while the middle focal plane is partially unsuccessful. However, the result image (d) of multiple focal planes shows a clear views of three objects at the target depths, while the center region of a man-billboard at the middle focal plane depth is blurred because of significant occlusion as we can see in (b).

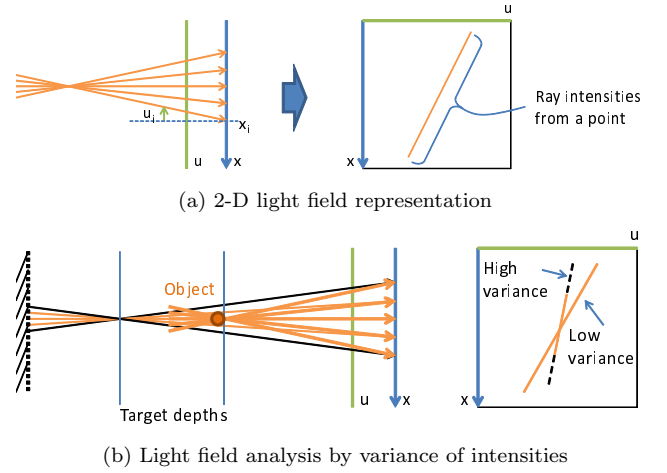


Fig. 5 Selection of the suitable focal plane.

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