

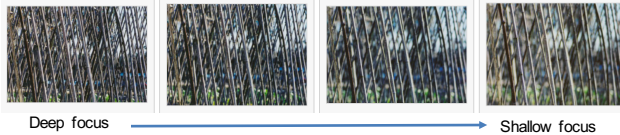
Survey of Approaches to Extended Depth of Field

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Motivation

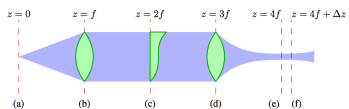
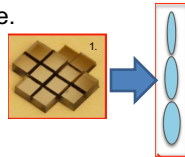
For any optics system, large numerical aperture (NA) leads to higher resolution. However, large NA also results in the shallow depth of field. For some optics system, like microscope, the shallow depth of field is not desired. Thus we try to figure out a way of maintaining large NA while expanding the depth of field of the imaging system. As we learned in class, the main principle of extended depth of field (EDOF) is to make point spread function (PSF) at pupil invariant to the distance.



Wavefront Coding

Wavefront coding adapts the idea of light field imaging by putting some optics elements at the pupil plan and uses different parts of sensor to capture different depth of the object. After that, post processing techniques are used on the captured image to get EDOF image.

Lattice focal length is a feature added to the aperture that has arrays of lenses with different focal lengths.

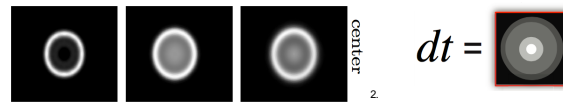


In an optical system used for extended depth of field wavefront coding, light from a single point (a) passes through a Fourier transforming convex lens (b), a cubic phase plate (c) and another Fourier transforming convex lens (d) to arrive at an intentionally aberrant point spread function. The PSF at plane (e) varies very little from the PSF at plane (f).

Cubic phase plate (left) is another form of wavefront coding, it changes focus through field uses.

Focal Sweep

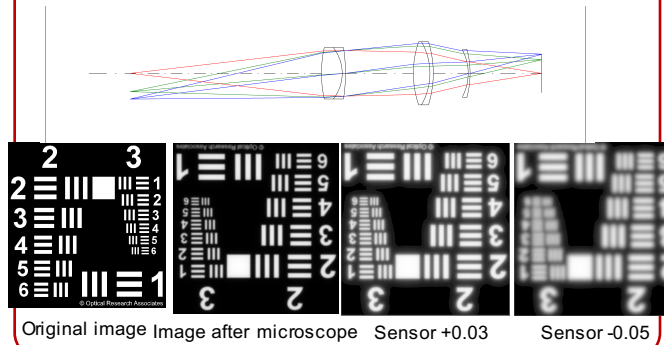
Focal sweep obtains distance invariant PSF by moving objects or sensors.



The obtained images are stacked and then post-process to make the EDOF image.

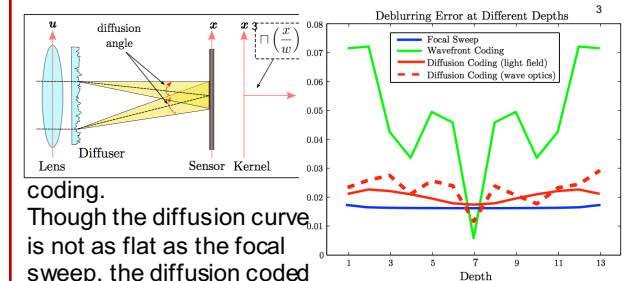
A few other application of focal sweep can be found in utilizing aberrations to de-blur image, such as spherical aberration and chromatic aberration.

A simulation using CodeV is conducted to replicate the result. The target image here used is the air force target image, and the optics imaging system used is a microscope system.



Diffusion Optics

Diffusion coded photography uses diffusion optics to achieve depth invariant PSF. The diffusion optics is implemented using the "kinoform" type diffuser, and have the wedge thickness to be $t(u) = \alpha \lambda u$. This diffuser was places right at the aperture of the lens system. As we can see from the comparison graph below, diffusion has a flatter curve compare to wavefront



coding. Though the diffusion curve is not as flat as the focal sweep, the diffusion coded photography has advantage over the focal sweep for that no physical element need to be moved.

Reference:

1. Levin, Anat, et al. "4D frequency analysis of computational cameras for depth of field extension." *ACM Transactions on Graphics (TOG)*. Vol. 28. No. 3. ACM, 2009.
2. Tang, Huixuan, and Kiriakos N. Kutulakos. "Utilizing optical aberrations for extended-depth-of-field panoramas." *Computer Vision-ACCV 2012*. Springer Berlin Heidelberg, 2012. 365-378.
3. Cossairt, Oliver, Changyin Zhou, and Shree Nayar. "Diffusion coded photography for extended depth of field." *ACM Transactions on Graphics (TOG)*. Vol. 29. No. 4. ACM, 2010.
4. Zhou, Changyin, Daniel Miau, and Shree K. Nayar. "Focal sweep camera for space-time refocusing." (2012).
5. Tang, Huixuan, and Kiriakos N. Kutulakos. "Utilizing optical aberrations for extended-depth-of-field panoramas." *Computer Vision-ACCV 2012*. Springer Berlin Heidelberg, 2012. 365-378.