DELFT UNIVERSITY OF TECHNOLOGY

Wavefront Sensing

SC4045 CONTROL FOR HIGH RESOLUTION IMAGING

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1 SINGLE LENS

Implement a function that, given a circular pupil function and phase at the pupil plane, computes the intensities in the focal plane. In other words, compute the point spread function of an imaging system composed of a single lens (using the Fraunhofer approximation [1, § 4.4.2] and the analytic expression [2, Eq. 1.1]). Besides the information in the lecture notes regarding the computation of a point spread function (PSF) (when the imaging system is subject to incoherent illumination), base your implementation on the information available in [3] and [4].

1. In [3, § 6.3], it is said that the effect of a lens is similar to use the Fraunhofer propagation expression. Explain what is the Fraunhofer approximation and in what conditions is it valid. Investigate what are the differences between the diffraction generated by the Fraunhofer approximation and the analytic expression of the PSF.
2. Using the Fraunhofer approximation instead of the analytic PSF mean that you will have to work with a discrete Fourier Transform (DFT), which means that you will have to choose the size of your imaging plane and the sampling of the plane accordingly. Observe the effects when you vary those two parameters.
3. The diameter D of the lens and its focal length z, together with the wavelength λ of the incoming light wave, are the most important parameters of your imaging system. Analyse what happens to the PSF when you change each of the parameters. What will the changes in the PSF for the different parameters imply regarding the resolution of the image?
4. Extend the function so that it works with an arbitrary type of pupil function (*e.g.*, a square aperture).
5. Corrupt the intensity distribution (after normalizing the intensity values to the interval $[0, 1]$) with additive white Gaussian noise.

In your experiments use the following nominal values:
Throughout this exercise keep in mind that you want to generalize the implementation to be able to deal with N lenses in an arbitrary configuration. Structure your code such that that generalization is straight-forward.

Table 1.1: Nominal values of the parameters. These correspond to the sensor available in the DCSC Optics lab.

Parameter		Value
Diameter	D	300×10^{-6} [m]
Focal length	f	18×10^{-3} [m]
Wavelength	λ	630×10^{-9} [m]

2 Shack-Hartmann sensor

Expand the implementation to simulate a Shack-Hartmann wavefront sensor. Define a square mesh of evenly spaced lenslets. Afterwards, attempt the following subtasks:

1. Generalize your implementation so that it can work with an arbitrary lenslet configuration.

Besides the parameters made available for the previous exercise, consider these also:

Table 2.1: Shack-Hartmann parameters.

Parameter		Value
Distance between lenses	d	10×10^{-6} [m]

References

[1] J. Goodman, *Introduction to Fourier Optics, 3rd Ed.* Roberts and Company Publishers, 2005.

[2] M. Verhaegen, “Lecture notes on control for High Resolution Imaging,” May 2012.

[3] D. Voelz, *Computational Fourier Optics.* SPIE Press, 2011.

[4] J. D. Schmidt, *Numerical Simulation of Optical Wave Propagation With Examples in MATLAB (SPIE Press Monograph Vol. PM199).* SPIE Press, Aug. 2010.