TECHNICAL NOTE TN2022_1 – DEPTH OF FIELD (DOF)

Introduction

Every optical imaging system has a depth of field (DoF). It is defined as the distance between the nearest and the farthest object that are in sharp focus.

This should not be mixed with another optical property, called the depth of focus, which is the tolerance of placement of the image plane in respect to the lens position.

DoF = DEPTH OF FIELD

Coc = CIRCLE OF CONFUSION

WD = WORKING DISTANCE; this is the distance between the sample and the first surface of the front objective.

Article

The DoF of an imaging system is crucial when one is measuring non-flat samples. It could be in a laboratory or in an industrial system, and also in remote sensing applications. The DoF can be estimated as [1]

$$DoF = \frac{2Ncuf^2(u-f)}{f^4-(Nc(u-f))^2} \quad (1)$$

where u represents the working distance (WD), N is f-number, c is the circle of confusion, f is the focal length. Note, that equation (1) does not take into account lens aberrations. In some cases when the circle of confusion is negligibly small relatively to the aperture (term c^2 tends to 0) and the working distance is significantly larger than the focal length ($u - f \approx u$), equation (1) can be approximated by [1]

$$DoF \approx \frac{2u^2Nc}{f^2} \quad (2)$$

As can be seen, the DoF depends on 4 parameters:

i) The WD: the DoF increases with the measurement distance. Notice that this is at the expense of the spatial sampling at the object.

ii) The Aperture of the lens, as F-number: a system with a large F-number would have a larger DoF. However, less light would enter the system, and that would then be at the expense of the integration time.

iii) Circle of confusion (CoC): this is often corresponding to the pixel size, in the spatial dimension, along the slit, at the slit level (also taking into account the magnification of the system). A camera with large pixels will have large DoF. It also means that spatial binning would increase the DoF.

PS: in practice the (CoC) is limited by the optical resolution of the system, but not the pixel size of the detector. Using the pixel size as CoC gives a minimum approximation for the DoF.

iv) The focal length of the front objective: the DoF decreases while the focal length increases. In practice, it means that a lens with a wider FOV with have a larger DoF.

All the above simply shows that high spatial resolution with large DoF can be only achieved at the expense of a high F number (lower throughput and longer integration time).

- With SPECIM cameras:

  Along with this table, an excel sheet is provided to compute the DoF:

  - As input, the user must fill in the CoC, F-number, working distance and focal length.
  - As an output, the user gets the hyperfocal distance, the near and far limit of focus, as well as the DoF.

  In the table below are the parameters which should be used when calculating the DoF with the SPECIM cameras:

	FX10	FX17	SWIR	FX50
CoC (µm)	10.4	19	24	30
F-number	1.8 @ 83° lens 2.4 @ 81° lens 1.8 @ 46° lens 2.1 @ 38° lens 2.8 @ 12° lens	1.8 @ 90° lens 1.4 @ 75° lens 2.0 @ 66° lens 2.1 @ 53° lens 2.1 @ 38° lens 2.0 @ 12° lens	2.0	3.6 @ 60° lens 3.8 @ 45° lens 3.6 @ 24° lens
Focal Length (mm)	6 @ 83° lens 11 @ 81° lens 12 @ 46° lens 15 @ 38° lens 50 @ 12° lens	6 @ 90° lens 8 @ 75° lens 9 @ 66° lens 12 @ 53° lens 17.5 @ 38° lens 56 @ 12° lens	15 @ 34° lens 22.5 @ 23° lens 30 @ 17° lens 56 @ 9° lens	16 @ 60° lens 23 @ 45° lens 43 @ 24° lens

- Practical hints

  i) it is difficult to define a threshold for the sharpness of an image. That is why the above results need to be considered as an approximation.

  ii) If one wants to measure a sample which is not flat, the focus should not be adjusted at the bottom of the image plane (at the sample tray level) but rather at the middle of the sample height. If we assume that DoF is 10 cm, the focus should be done at ca. 5 cm from the sample tray.

  iii) Specim cameras which are used in remote sensing (e.g. AFX - series) are always focused to infinity. Then all objects above hyperfocal distance are imaged sharply.

Disclaimer

References

1. H. Gross, F. Blechinger, and B. Achtner. *Handbook of Optical Systems. Survey of Optical Instruments*, vol. 4. Wiley, 2008.

Version history

Version	Date	Author	Comments
1.0	May 31st 2022	MMA, MBO and KKA	