Stretching the Limits of High Resolution Computed Tomography

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Innovative Microfocus X-Ray Tubes - Made in Germany

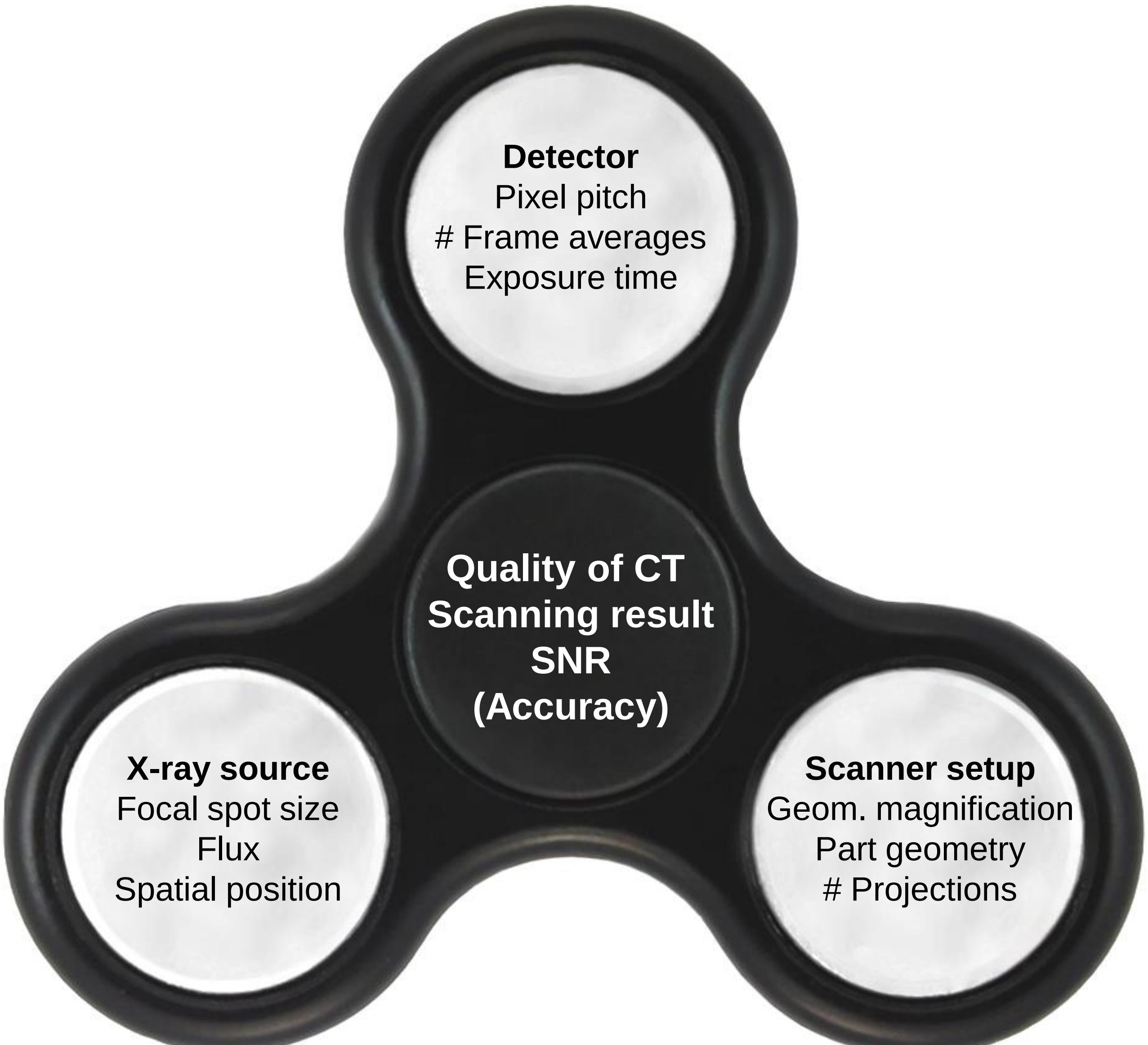
Agenda

- Motivation
- Influencing factors
- Quality of CT
- Scanner setup
- Detector
- X-ray source
- The bottleneck and stretching the limit

Motivation

- Forming a realistic expectation of the quality of CT scanning results
- Understanding the interdependence of influencing factors like magnification, focal spot size, and exposure time
- Identification of the „bottleneck“ on the way to better results

Influencing Factors



Quality of CT

$$SNR = 0.665 \cdot \mu \cdot w^{1.5} \cdot \sqrt{\frac{n \cdot v \cdot q \cdot t}{\Delta p} \cdot \exp\left(-2\pi \cdot R\right)}$$

Signal to Noise ratio (*SNR*) depending on

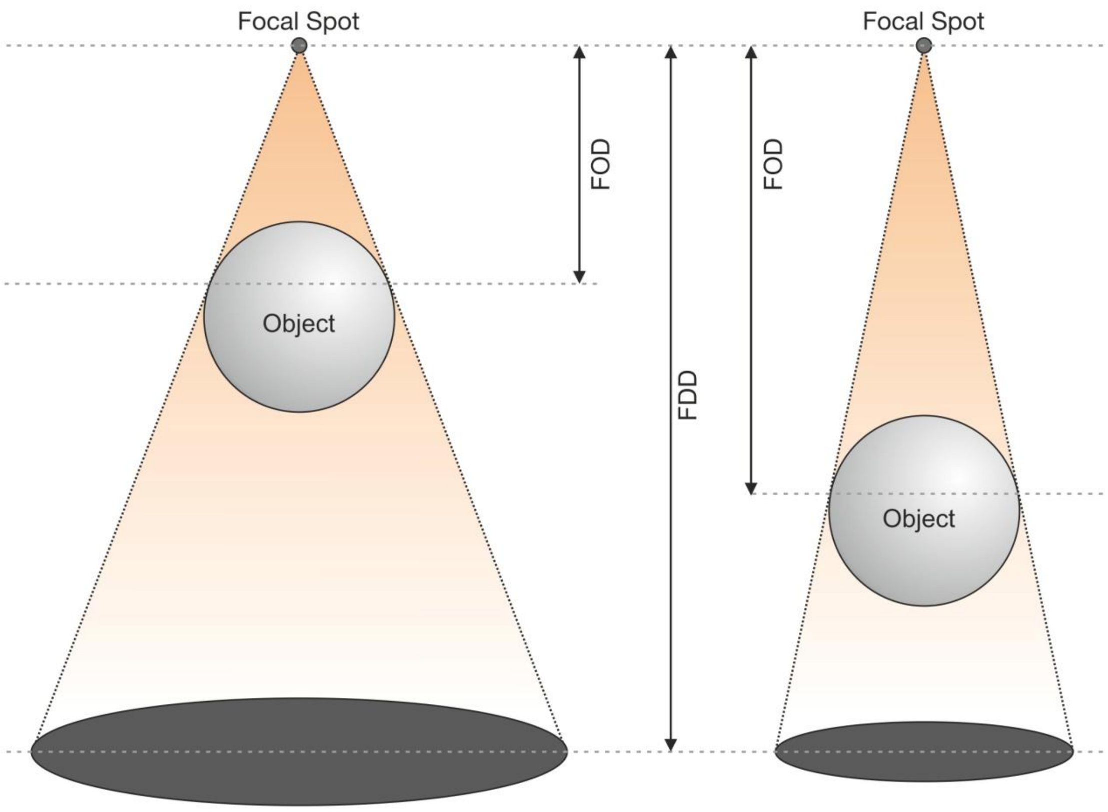
- Linear attenuation coefficient (μ)
- X-ray beam width (w)
- # of projections (v)
- # of frame averages (n)
- Photon intensity rate (q)
- Integration time of detector (t) → 1/t = frames per second
- Ray spacing (Δp)
- Radius of object (R)

Refer to NASA (2015)

Scanner setup

- Geometric magnification is limited by
  - Part geometry = diameter of enclosing cylinder resp. scanning envelope
  - Detector size
  - Maximum distance X-ray source – detector (FDD)
- Geometric magnification $\sim_L$ resolution
- SNR^2 ~ # Projections
- Higher density of part's material requires higher flux

Geometric magnification



FOD: Focus-Object-Distance | FDD: Focus-Detector-Distance

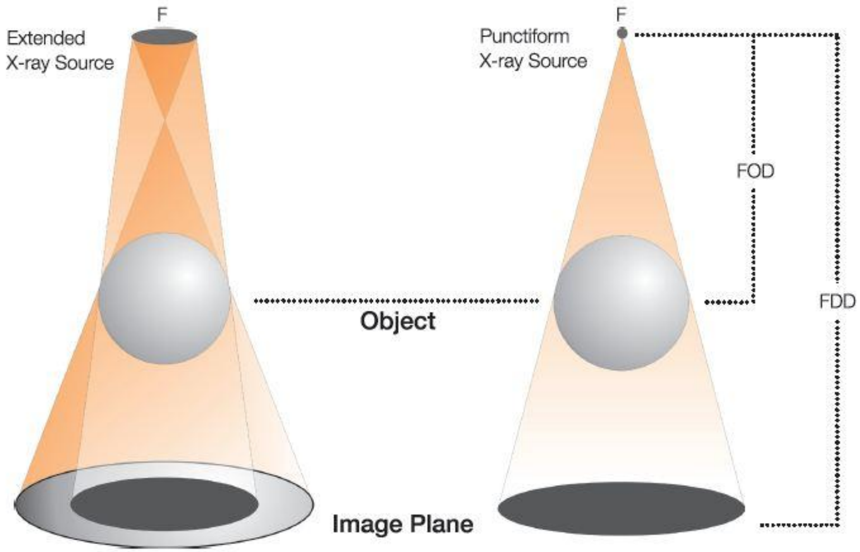
Detector

- Detector size $\sim_L$ geometric magnification
- $SNR^2 \sim$ Flux
- Pixel size $\sim Flux^2$
- Exposure time influenced by frame rate and # frame averages
- Higher exposure time increases SNR
- $SNR^2 \sim$ # frame averages

X-ray source

- Flux = intensity
- Flux ~ target power
- Flux ~ target current @ const. voltage
- Flux ~ voltage^2
- Focal spot size ~ target power
- Focal spot size ~ geom. unsharpness
- Resolution = 0.5*unsharpness
- Spatial focal spot position influenced by thermal effects

Geometric unsharpness



FOD: Focus-Object-Distance

FDD: Focus-Detector-Distance

F: Focal spot size

Geometric magnification: $M = \frac{FDD}{FOD}$

Geometric unsharpness: $U = (M-1) * F$

Magnification and Unsharpness

- Geometric magnification (M): Required to visualize very small details.
- Geometric unsharpness (U): A bigger focal spot size (F) leads to higher unsharpness.

Tradeoffs

- Increasing quality by higher integration time or higher # of frame averages increases scan time
- Larger pixel size increases SNR, but reduces resolution
- Higher flux increases SNR, but may also increase focal spot size and thus may reduce resolution

Identifying the bottleneck

- Nail down the given factors of your application (dimensions of part and detector, max. FDD)
- Define a range for your expected quality (e.g. voxel size, resolution, scanning time)
- Try to chose remaining factors (e.g. flux, resolution, pixel pitch, exposure time) in order to optimize the quality
- During this iterative procedure, the bottleneck of your particular application will appear

Stretching the limits

- Bigger flat panel to allow higher magnification
- Smaller pixel size with higher efficiency
- Higher flux X-ray tube with low focal spot size
- Efficient cooling of X-ray tube and mechanical components of the setup
- X-ray target material and target layer thickness optimized for particular voltage and part material

Literature

- Roth, D.J., Rauser, R.W. (2015): The Effect of Experimental Variables on Industrial X-Ray Micro-Computed Sensitivity, NASA GRC
- Hiller, J., Kasperl, St. (2010): Zum Verhältnis von Bildqualität und Messgenauigkeit in der CT-Metrologie, Proceeding iCT 2010, Wels