Technische Hochschule Rosenheim

Computer Vision

Image Formation

Technische Hochschule Rosenheim
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Sensors

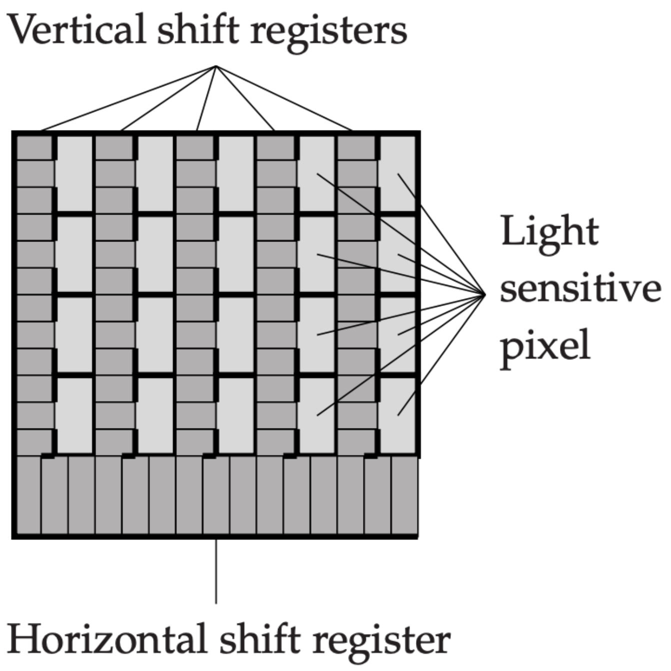
Types of Image Sensors

- Area sensor
  - e.g. CCD, CMOS chip
- Line sensor
  - Like area sensor, but pixels arranged in a line
- Point sensor
  - only records a single intensity value

- not only in the visible spectrum
  - also IR, UV, X-ray, radio waves (radar sensor), ...

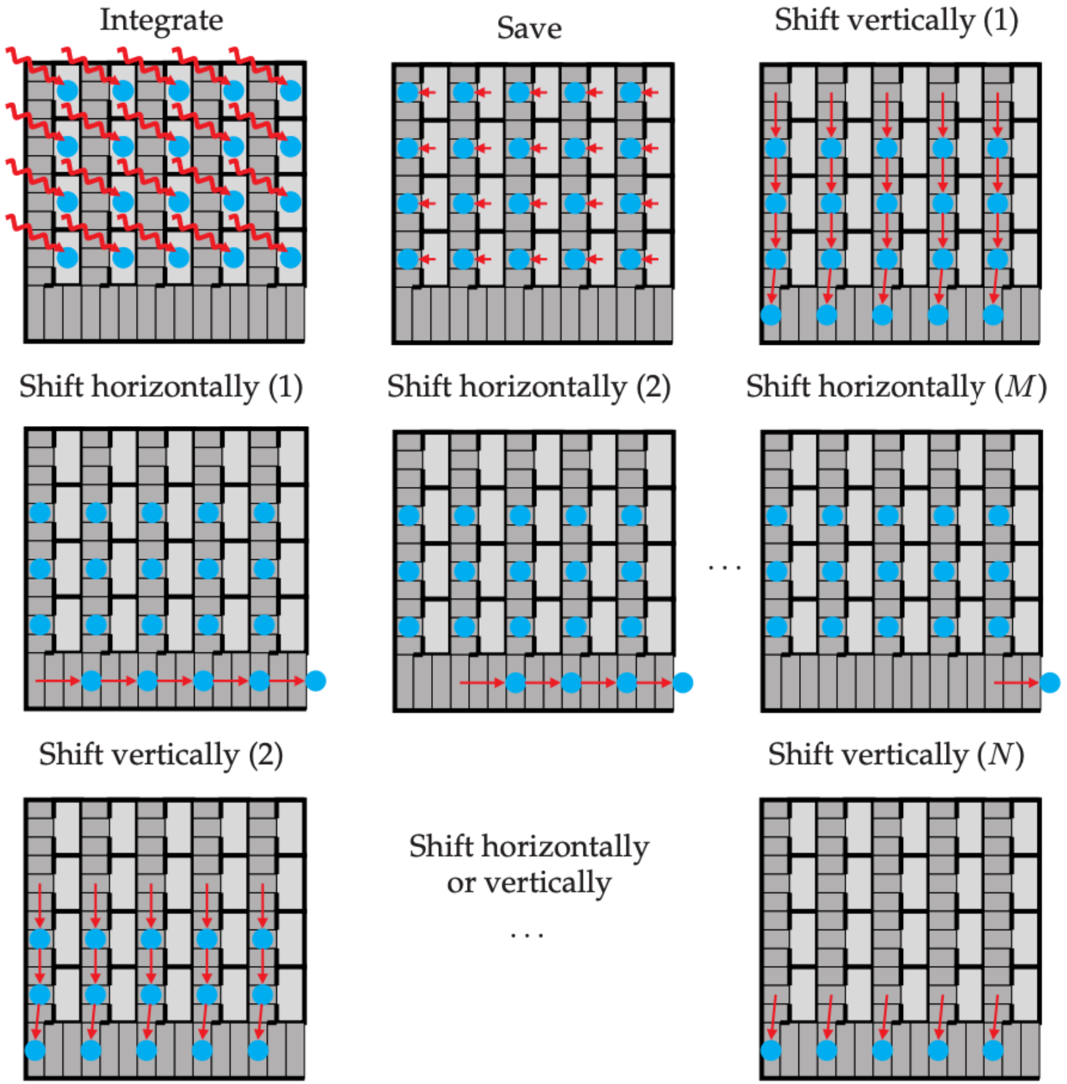
CCD Sensor

- CCD = Charge Coupled Device
- consists of (interline sensor)
  - light-sensitive pixels, separated by bars and potential barriers
  - shift registers
    - not sensitive to light
    - take up about half of the chip area
- Full-frame sensor
  - uses almost the entire surface as a sensor
  - Charges are pushed through the light-sensitive area during readout
  - therefore mechanical shutter necessary
    (avoids exposure during readout)



from: [Beyerer16]

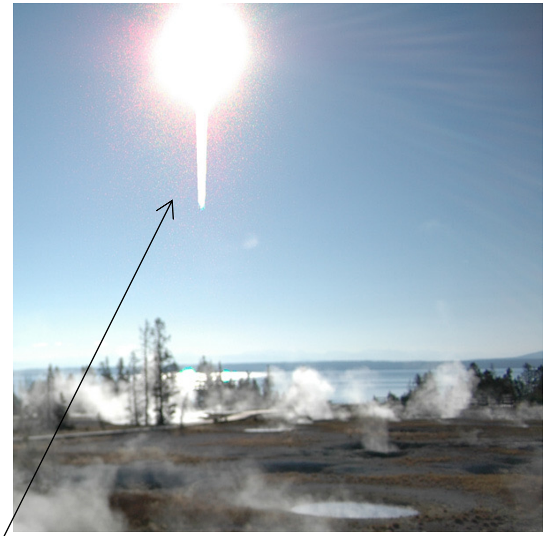
Interline CCD sensor



from: [Beyerer16]

Blooming/Smear (CCD)

Blooming



- is created during the exposure
- typically limited
- completely overexposed

Smear

- is created during the readout
- Strips always up to the edge
- not completely overexposed

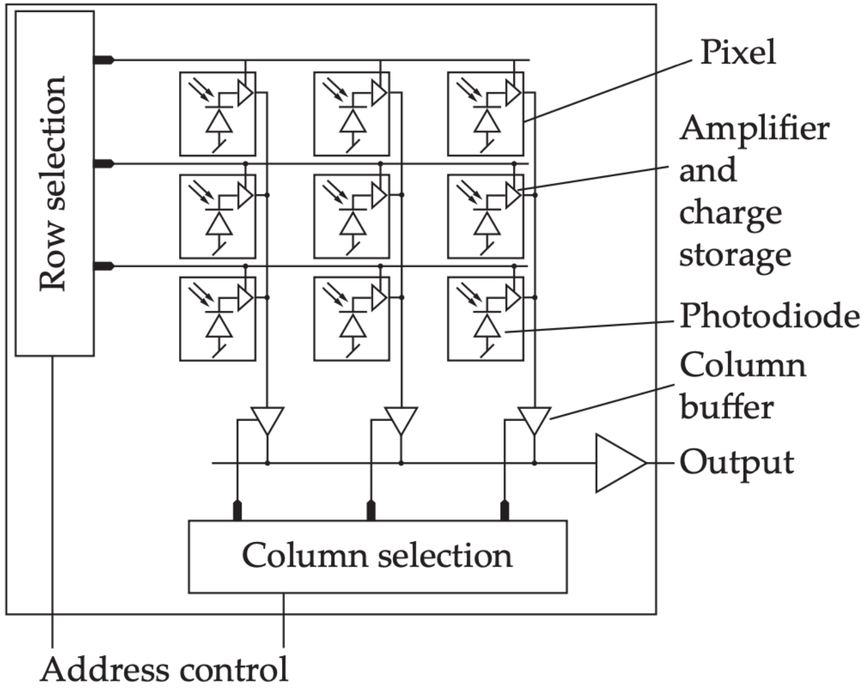
CCD Sensor

- inexpensive
- Low weight/size
- Insensitive to shocks and electromagnetic fields

CMOS Sensor

- CMOS = Complementary Metal Oxide Semiconductor
- Detection of photons as with CCD
- Reading out the values
  - Direct control of individual pixels via transistors/address lines
  - Arbitrary image regions selectable
  - No shift registers necessary

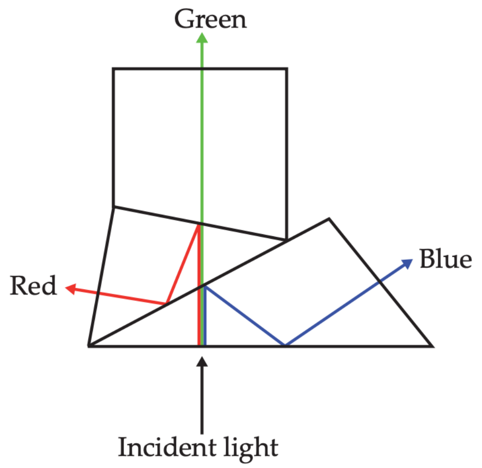
- Advantages over CCD:
  - Control/processing electronics can be integrated directly on the chip
  - Free and random pixel access
  - Greater dynamic range
  - Low power consumption
  - Wide temperature range
  - No blooming, smear, shutter lag
- Disadvantages
  - less sensitive
  - higher noise



from: [Beyerer16]

Color sensors

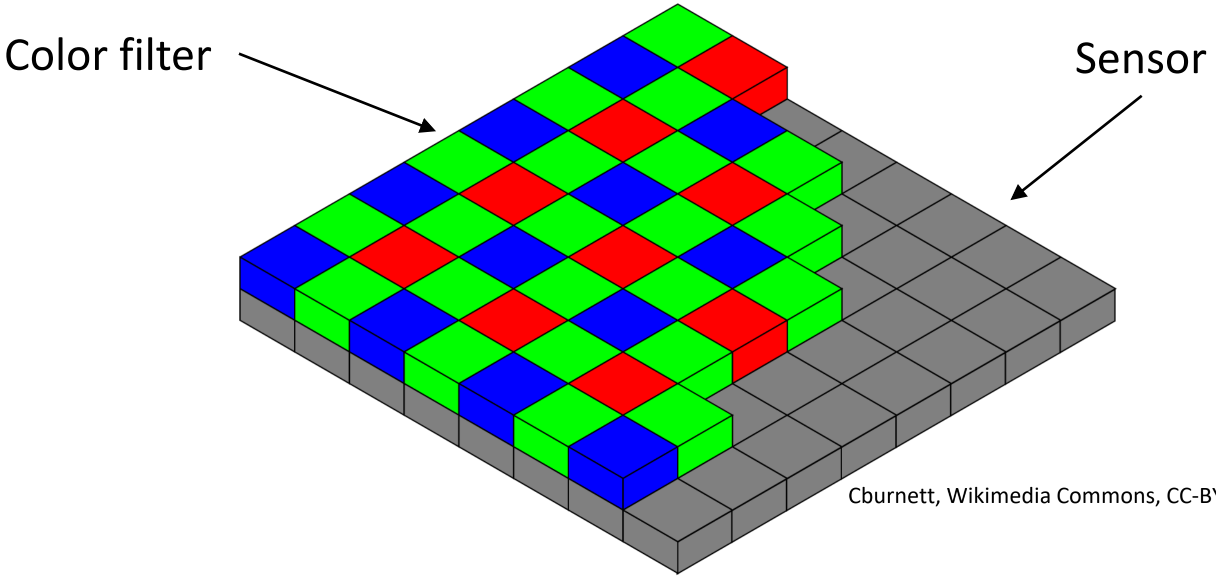
- Light sensors in cameras ("imagers") detect the intensity of the light, (almost) regardless of the wavelength
- only gray images can be acquired
- Color information:
  - either optical separation of the light according to wavelength, use 3 sensors each for R, G, B
    Disadvantage: complex



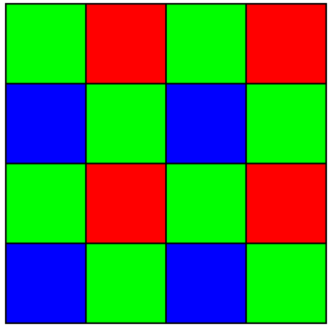
  - or use of a color filter array (CFA), i.e. filters on each individual pixel
    Disadvantage: Loss of sensitivity due to filter

from: [Beyerer16]

CFA - Examples



Cburnett, Wikimedia Commons, CC-BY-SA-3.0



Bayer (RGGB)

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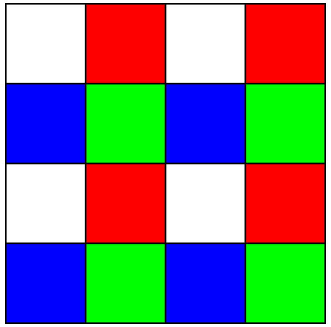


RGBW

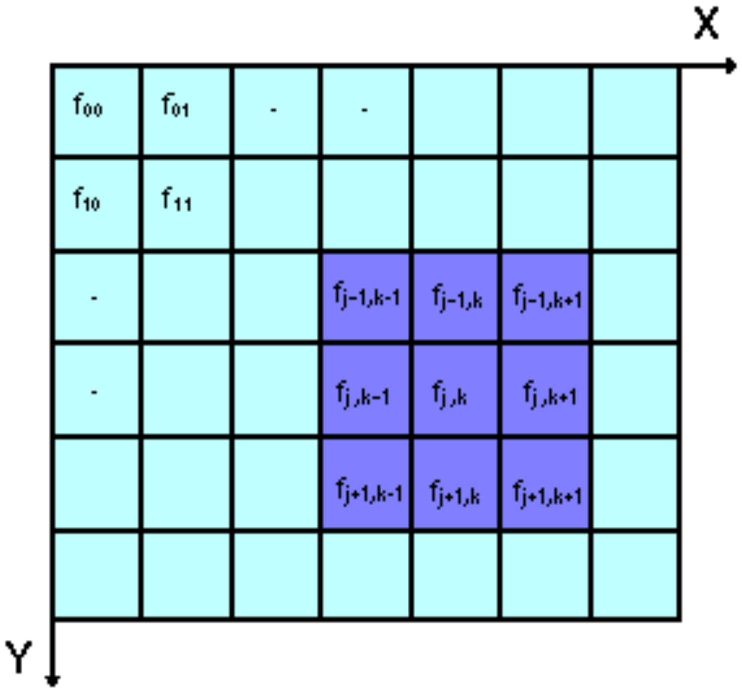
Dicklyon, Wikimedia Commons, Public Domain

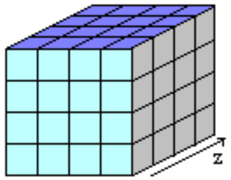
Typical Technical Specifications ...

... of commercial CCD/CMOS cameras for machine vision

Number of pixels	640 x 480 up to 4800 x 3200
Pixel size	1.4 x 1.4 μm^2 up to 10 x 10 μm^2
Sensor size	¼" to 1", more rarely up to 35mm (mostly 4:3, diagonal from 4.5mm to 43.3mm)
Exposure time (*Belichtungszeit*)	10µs to several seconds
Frame rate	3Hz to 200Hz
Color depth	8 bit to 16 bit per channel (internally often more)
Shutter (*Verschluss*)	global or rolling
Scanning Method	Interlace or Progressive Scan

Digital Images





Volume image

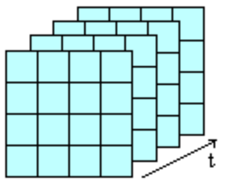
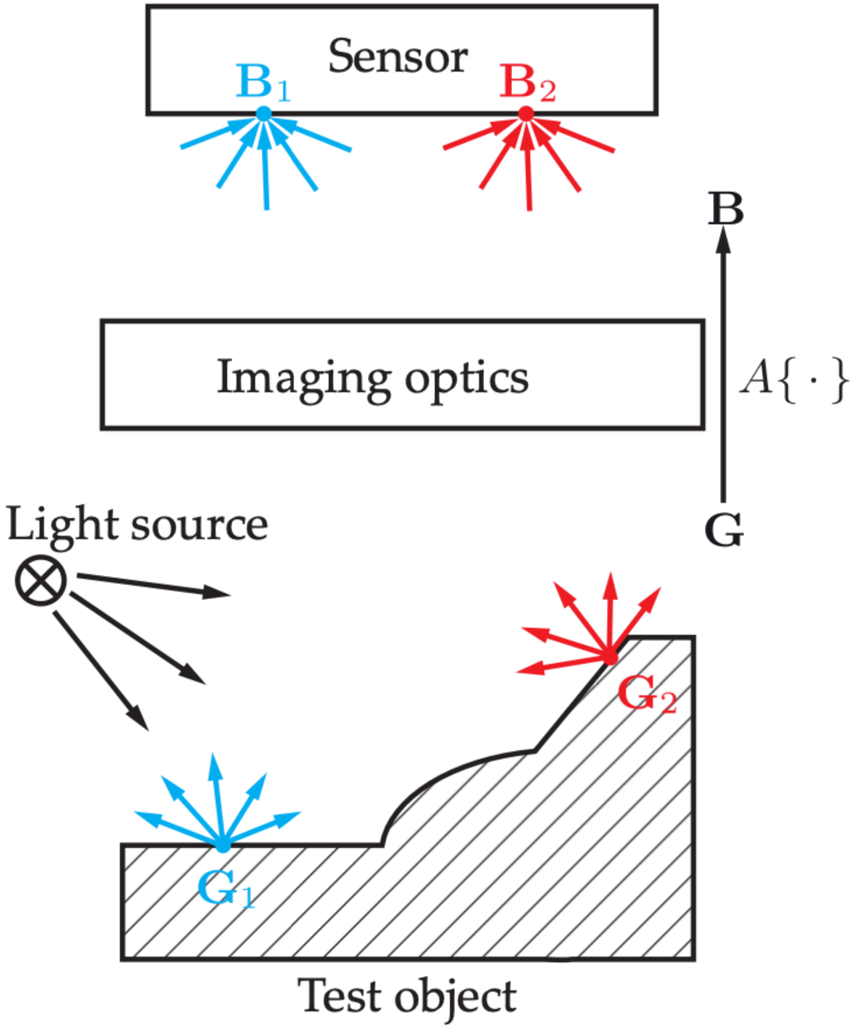


Image sequence

- Binary image
  1 bit / pixel
- Gray value image
  8 bit / pixel
  10, 12, 16 bit / pixel
- Color image (RGB)
  8 bit / color channel
  10, 12, 16 bit / color channel
  (often more internally)

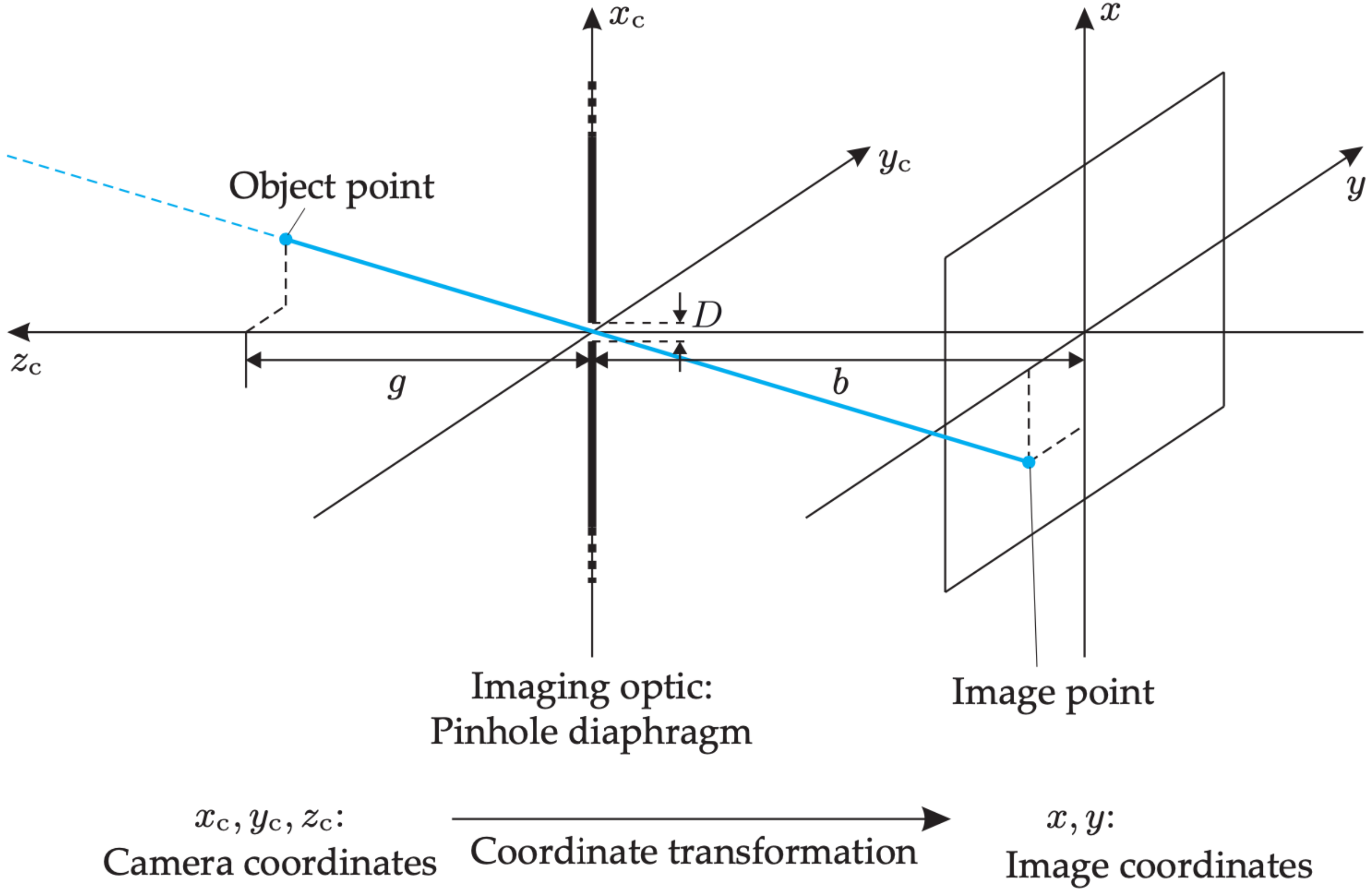
Optical Imaging

Principle



from: [Beyerer16]

Pinhole Camera Model (*Lochkameramodell*)



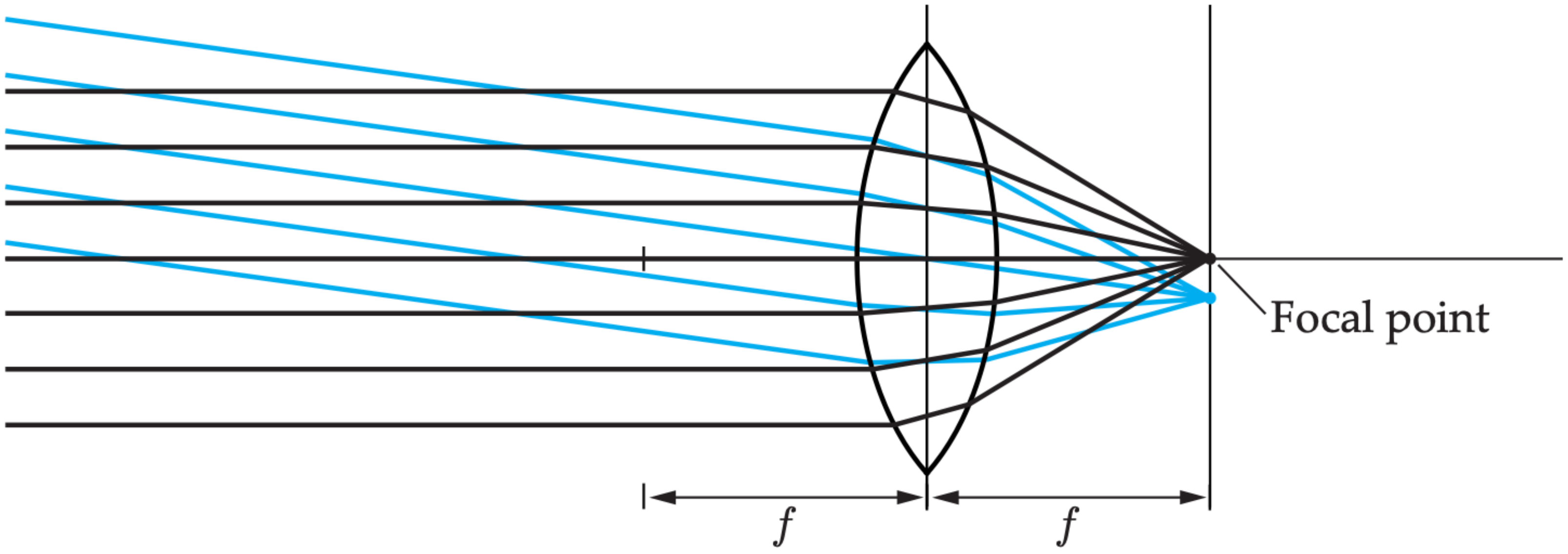
$$x = -\frac{b}{z_c} x_c$$

$$y = -\frac{b}{z_c} y_c$$

from: [Beyerer16]

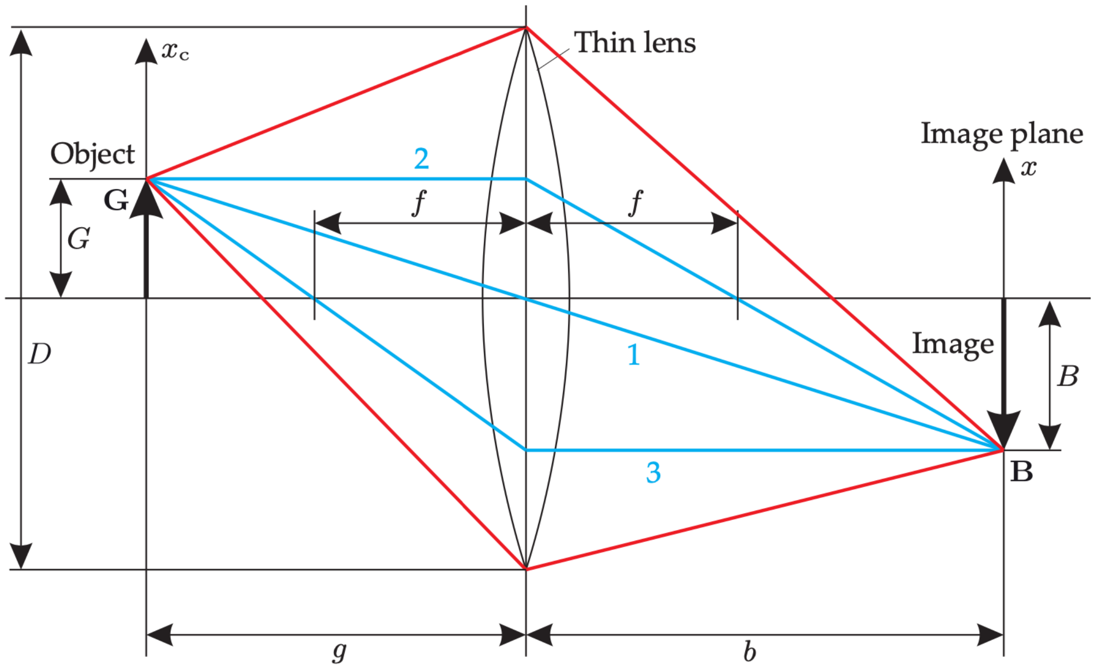
Imaging with a Single Lens

Parallel incident light beams are bundled in the focal plane



from: [Beyerer16]

Thin Lens Model



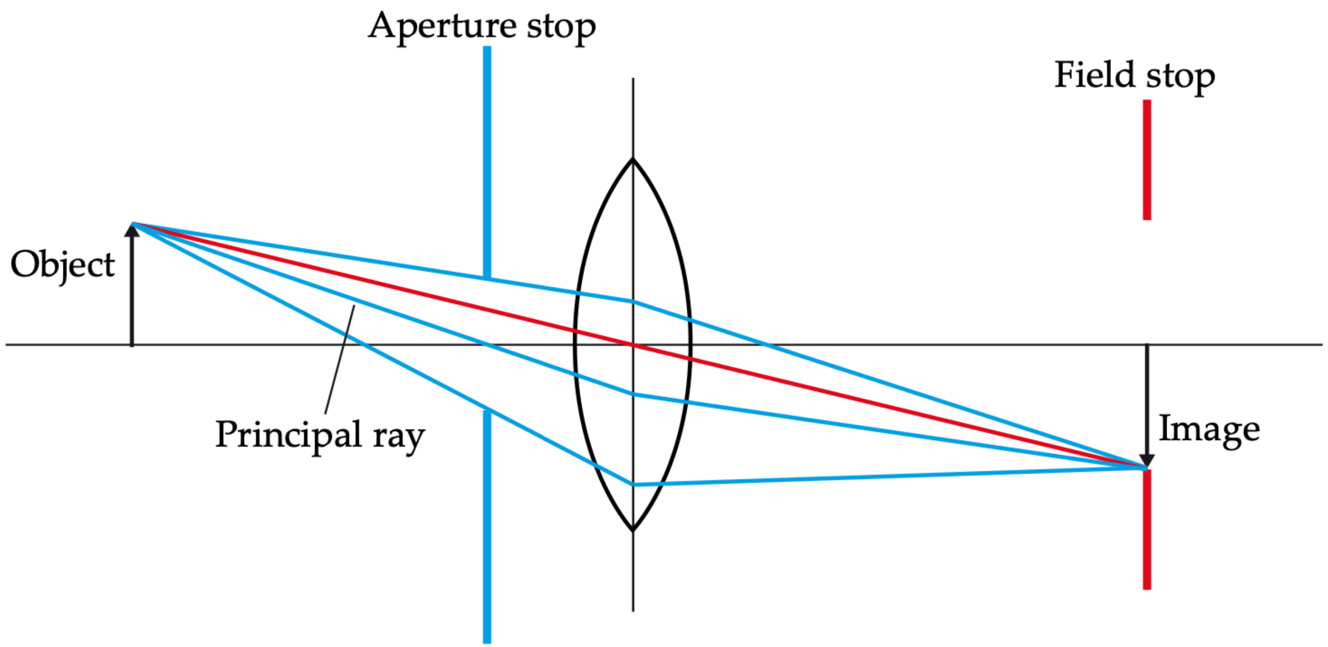
Imaging equation: $\frac{1}{f} = \frac{1}{g} + \frac{1}{b}$

Depth of field (*Schärfentiefe*) is limited

Only the plane at distance $g = \frac{bf}{b-f}$ is in focus on the image plane

from: [Beyerer16]

Bundle Limitation: Aperture and Field Stop

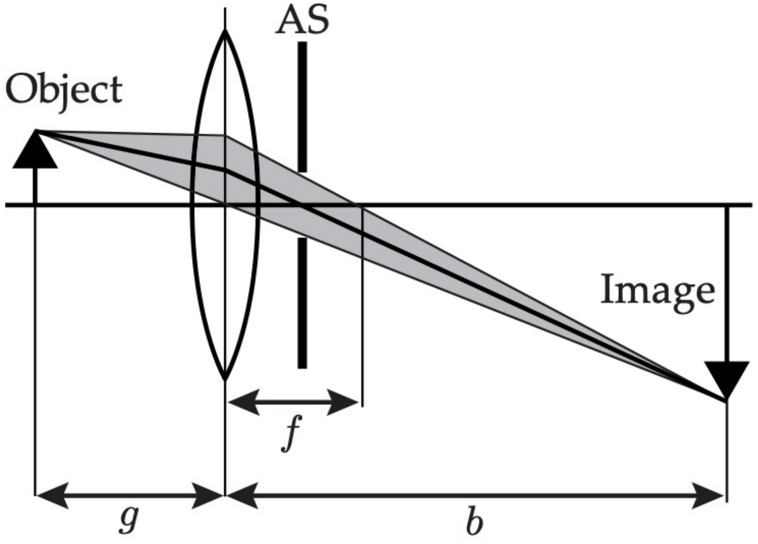


Field stop: (*Feldblende*)	limits the field of view/image field (determines image region)
Aperture stop: (*Aperturblende*)	limits the opening of the light beam position in front of/behind/between lenses determines the depth of field

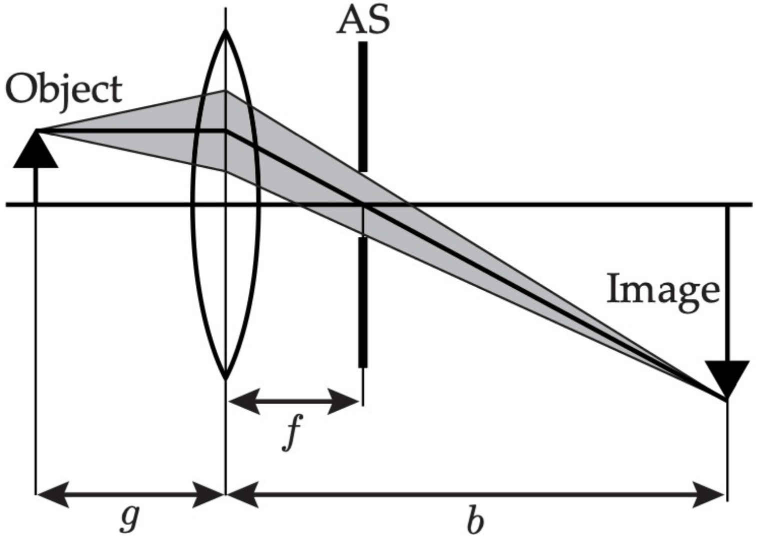
from: [Beyerer16]

Optical Paths

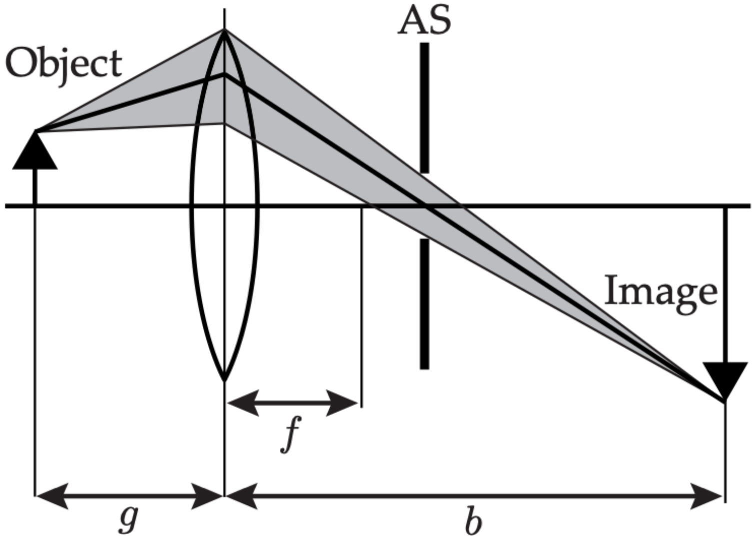
entocentric



telecentric



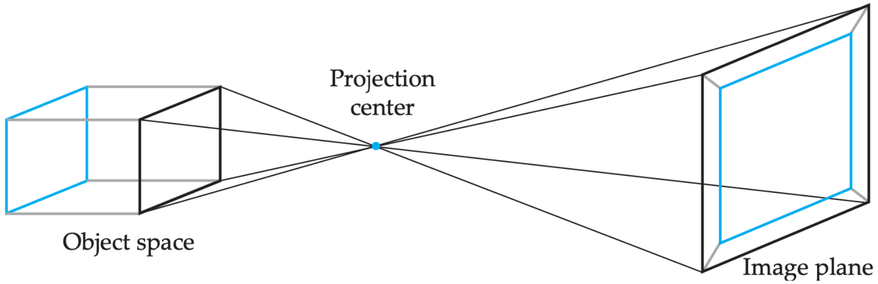
hypercentric

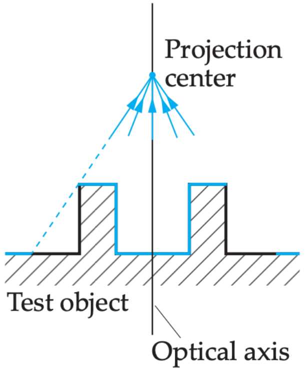


from: [Beyerer16]

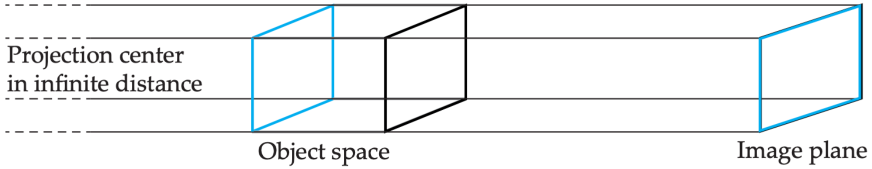
Projections/Perspectives, Visibility & Occlusion

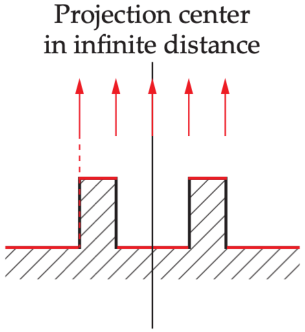
entocentric - the "normal" perspective projection/pinhole camera model



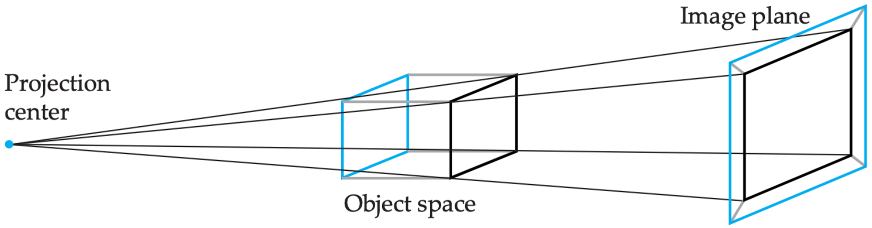


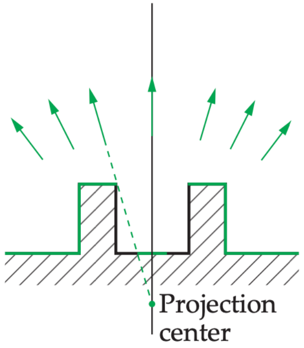
telecentric - also "parallel projection", "orthogonal projection"





hypercentric



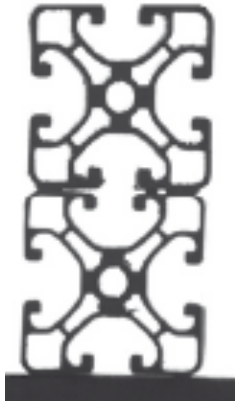


from: [Beyerer16]

Example

Scene
(aluminum profiles)

entocentric

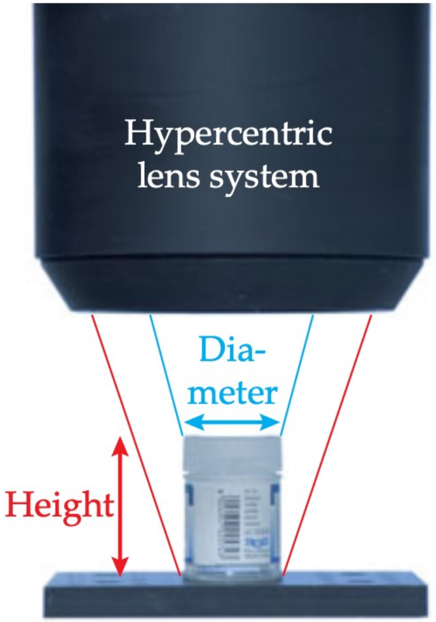


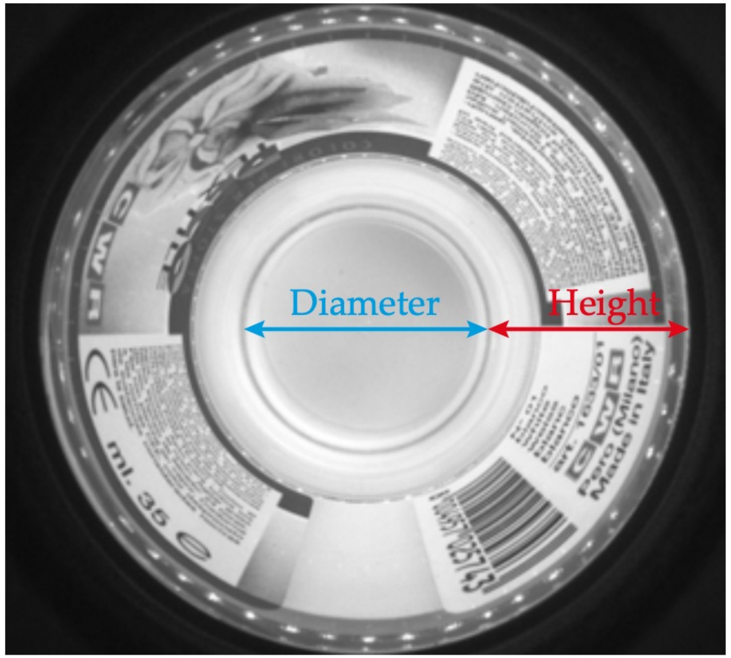
telecentric

telecentric/hypercentric: lens must be larger than the object
Telecentric lenses are available up to approx. 30cm diameter

from: [Beyerer16]

Example of a Hypercentric Perspective





from: [Beyerer16]

Selecting a lens

- Perspective
- Focal length (*Brennweite*)
  - fixed (which?) or zoom (which range? manual/motor?)
  - suitable for the image sensor
- Size matching the image sensor
- Working distance (Arbeitsabstand)
- Lens speed (*Lichtstärke*)
  - depending on aperture stop and quality of optics
- Resolution
  - suitable for the sensor
  - measured in line pairs/mm (lp/mm)
- Lens mount (*Objektivanschluss*) suitable for the camera
- Filter thread necessary? (*Filtergewinde*)
- Quality of the optics – imaging errors
  - geometric (e.g. radial distortions)
  - chromatic (refractive index depends on wavelength)

Sources

[Beyerer16] Beyerer, J., Puente Leon, F., Frese, Ch.: ***Machine Vision***, Springer, 2016.