Getting the Best Right-of-Way Image

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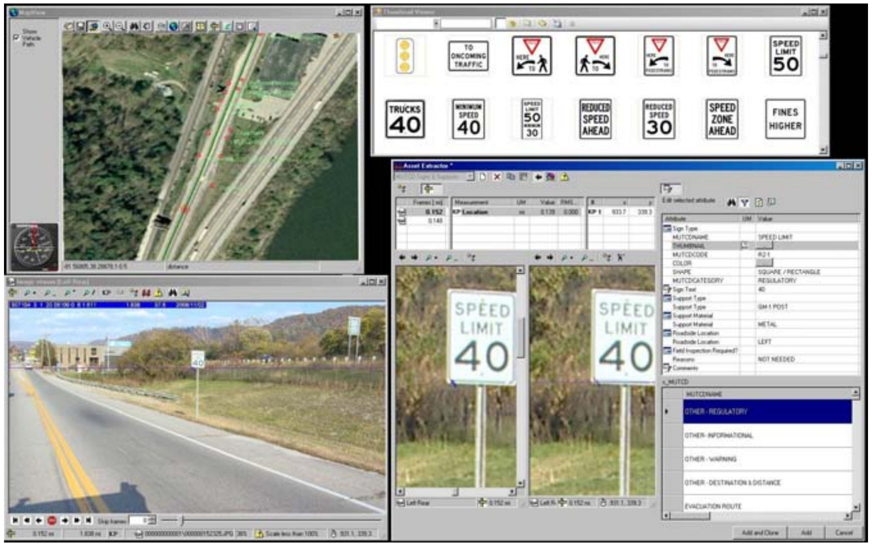
Contents

- Camera Housing
- Camera Calibration
- Optics
- Sensor
- Image Quality
- Specification on RFPs
- Conclusions

Camera Housing

Camera Calibration

- Camera calibrations are performed for Asset Extraction
  - Interior and Exterior Calibrations are performed
- Photogrammetry algorithms are used



What is Resolution?

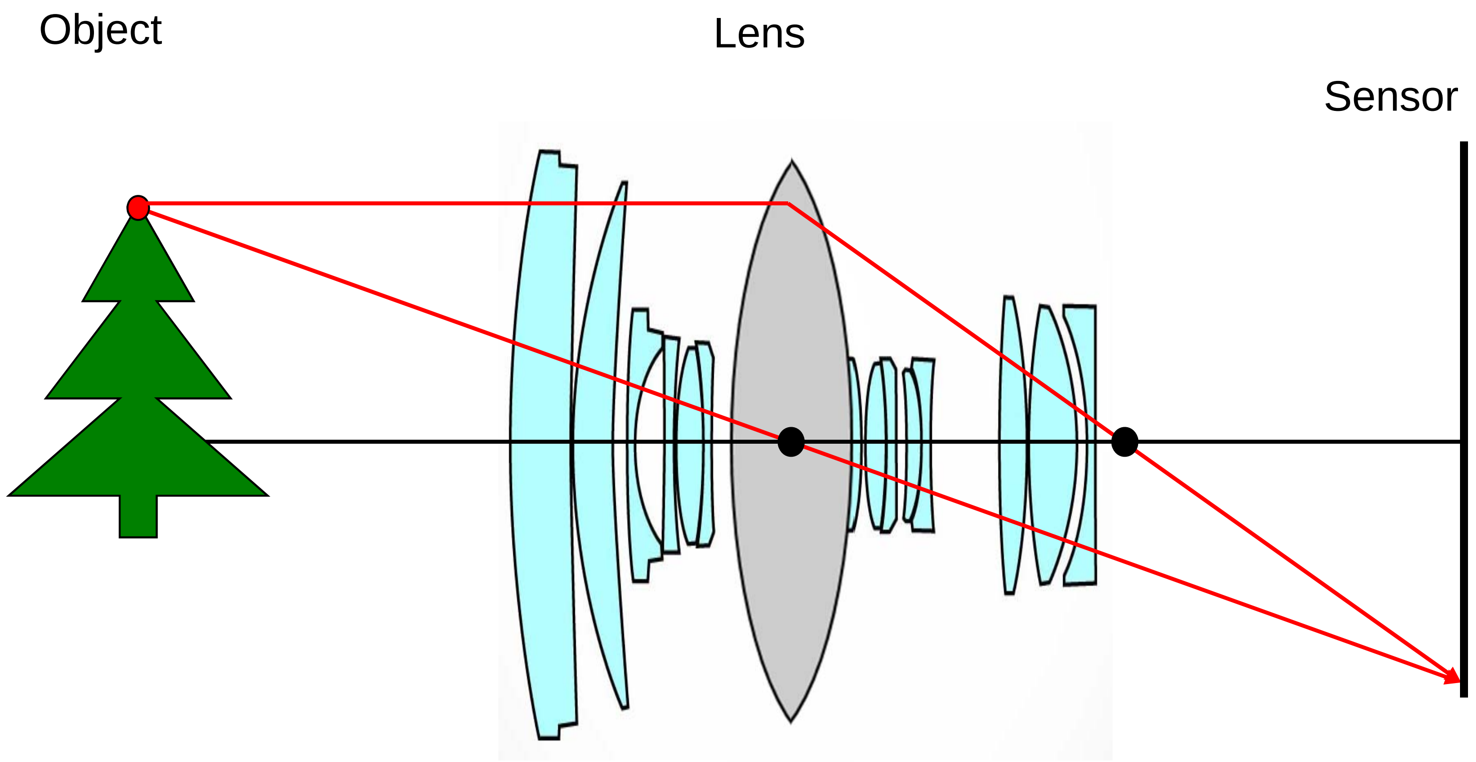
- A camera's resolution depends on the following factors:
  - Optics
  - Pixel dimensions
  - Color interpretation
  - Pixel count

- The pixel count is the **least** important parameter

OPTICS

Why do Expensive Lenses Cost So Much?

- **Goal:** A lens must obtain the sharpest image at the maximum aperture possible while minimizing distortions and aberrations



- A typical lens assembly is anything but simple!

Changes in Focal Length (11.25° FOV)

Changes in Focal Length (22.5° FOV)

Changes in Focal Length (45° FOV)

Changes in Focal Length (90° FOV)

Changes in Focal Length

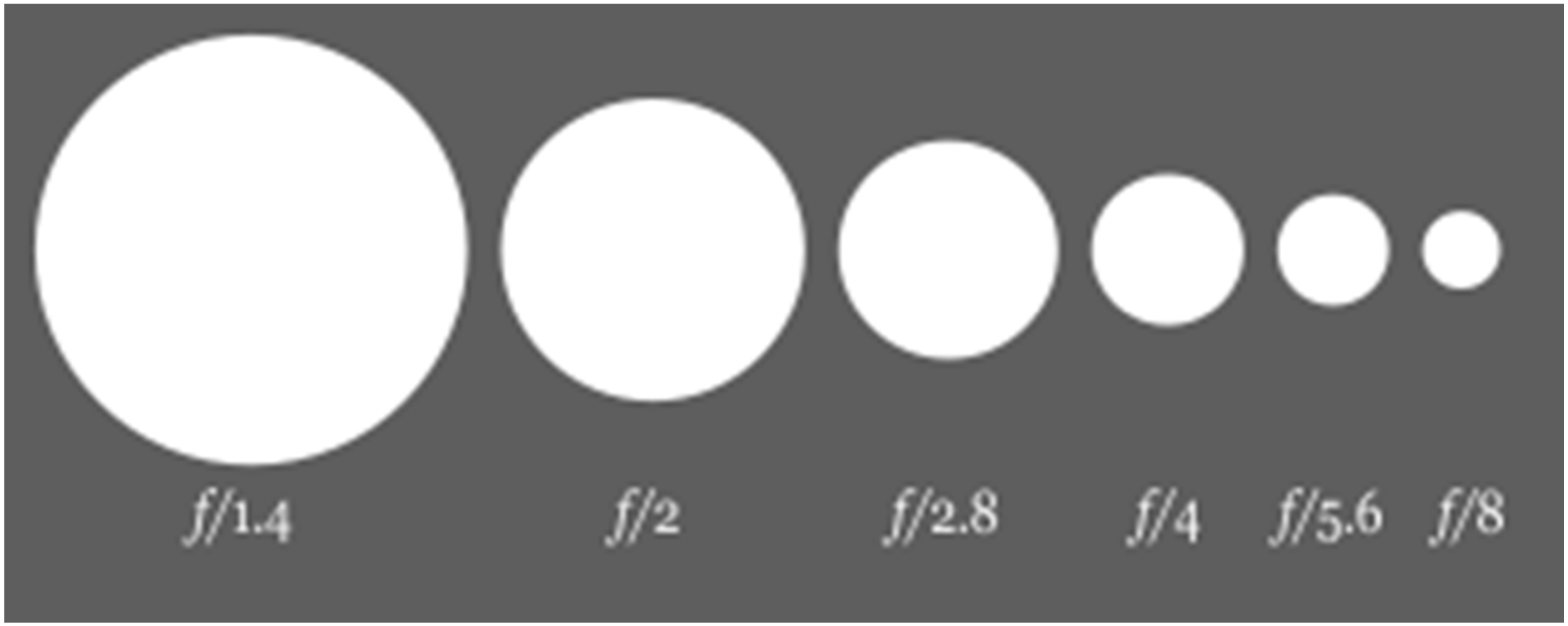
90 degree FOV

45 degree FOV

22.5 degree FOV

11.25 degree FOV

F-stop

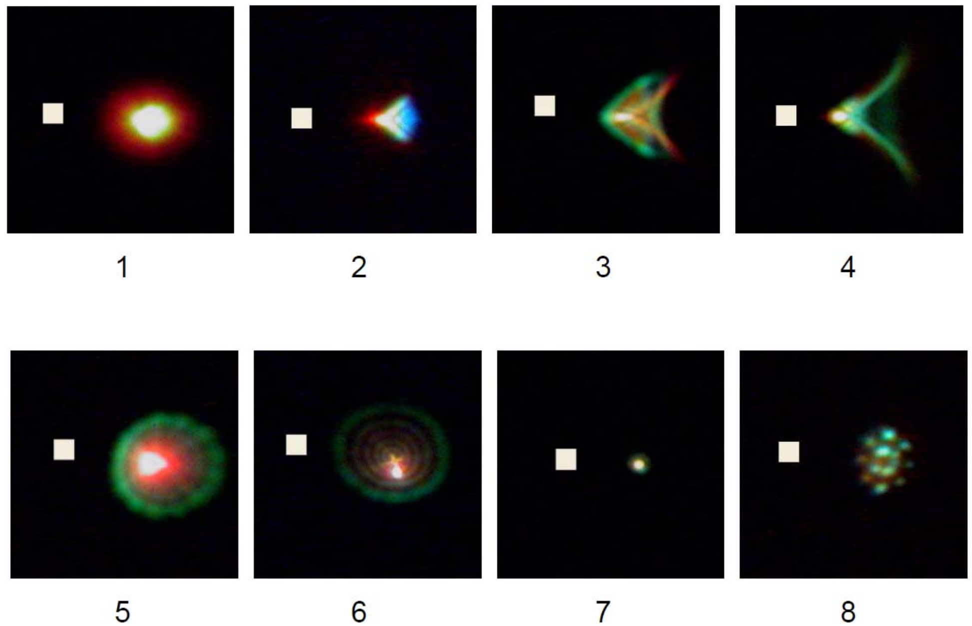


- Focal Length divided by Aperture Diameter
- Smaller F-stop, larger Aperture

Changes in F-Stops

A Good Lens is made of Good Glass!

- Real lenses are complicated!

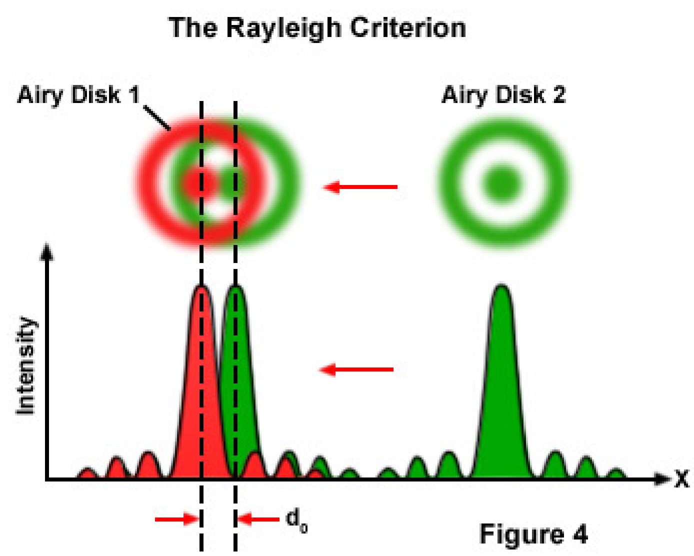


- The **point spread function** (**PSF**) describes the response of an imaging system to a point source or point object
- We always desire (7), where the PSF is smaller than one pixel

Images courtesy of Zeiss Corporation

Resolution: Rayleigh Criterion

- No lens is perfect
- As light from a sharp edge passes through a lens, it is scattered onto some of the neighboring pixels
- When two spots are close enough, their scattered light overlaps
- If it overlaps significantly, spots cannot be resolved anymore.
- If pixels are sufficient to satisfy the Rayleigh Criterion, then additional pixels are simply wasted



$$\theta_R = 1.22 \frac{\lambda}{D}$$

D is the aperture diameter, λ is wavelength

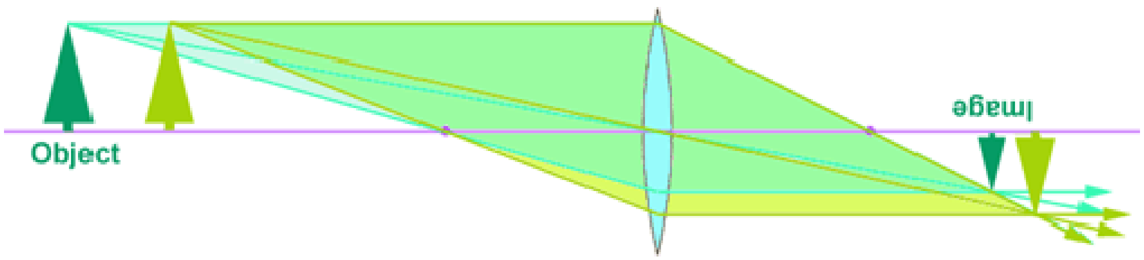
Why does it matter?

- Rayleigh Criterion is the resolution limit of the sensor
- Resolution gets worse with smaller aperture
- Example ($\lambda = 550$ nm):
  - Take a lens: A Cinegon 12 mm *f*/1.4
  - R(θ) Max open= 1.22 * 550/8.57 x 10^6 ~ 0.1 mrad
  - R(θ) at *f*/4.0 = 0.2 mrad
  - R(θ) at *f*/5.6 = 0.3 mrad
- For 2/3" sensor:
  - At 2 MP: FOV per pixel = ~ 0.3 mrad per pixel
  - At 6 MP: FOV per pixel = ~ 0.2 mrad per pixel
  - At 12 MP: FOV per pixel = ~ 0.1 mrad per pixel

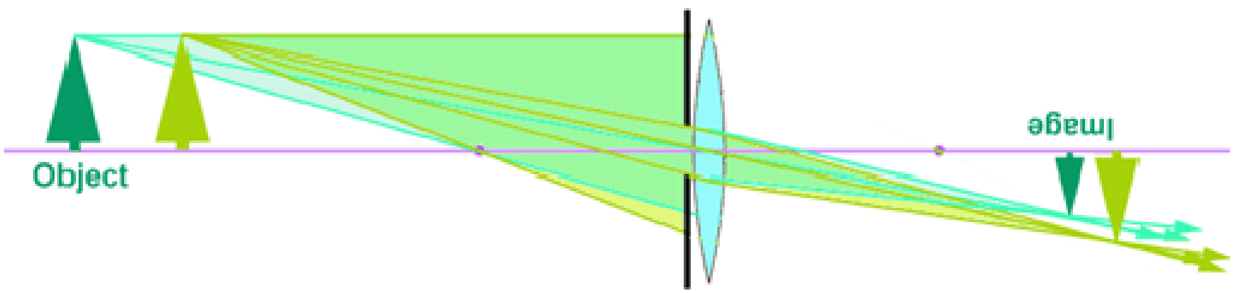
- 12 MP is unusable if you reduce the aperture
- A typical *f*/4.0 to *f*/5.6, 6 MP or below is plenty.

Depth of Field

- Definition: For a given focus distance, a *range* of object distances remains in *acceptable* focus



Focus the camera on the far tree. Near tree out of focus



Decreasing the aperture moves both into acceptable focus

- Depth of field is a direct function of the aperture:
  – Smaller aperture -> Larger depth-of-field

Images courtesy of Wikipedia.

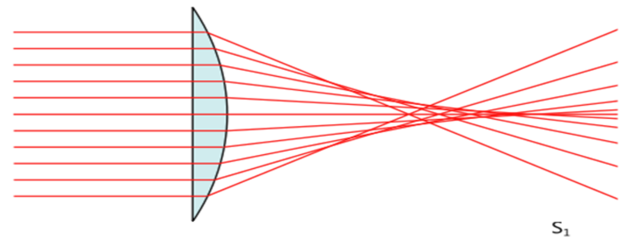
Depth of Field Example

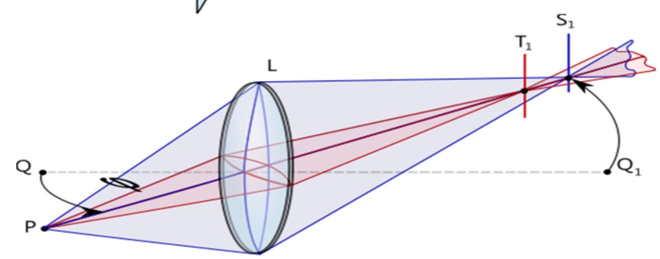
Deep DoF

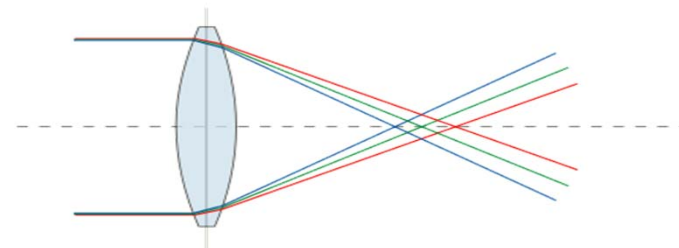
Shallow DoF

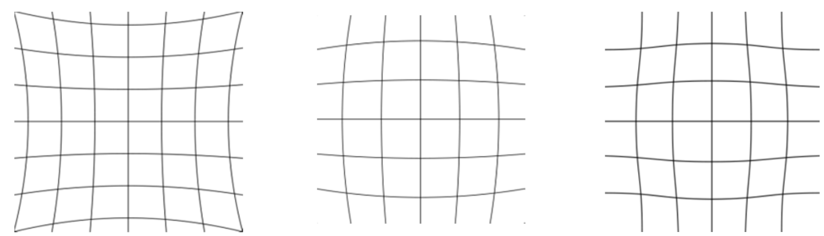
Lens Aberrations

- **Spherical**
  - Impact: Softening, halo effect
- **Astigmatism**
  - Impact: While focussing, one axis always more in-focus than the other
- **Chromatic**
  - Impact: Color fringing on sharp edges such as signs, branches
- **Distortion**
  - Impact: Reduces asset measurement accuracy (photogrammetry)





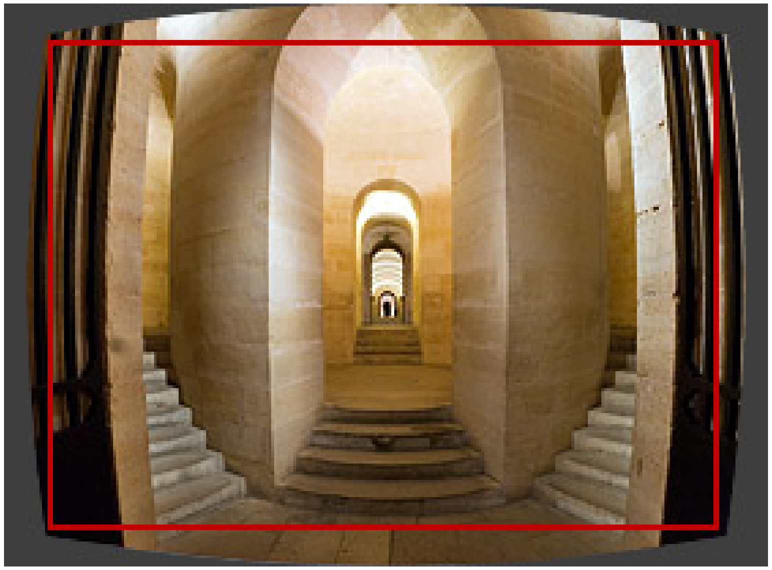


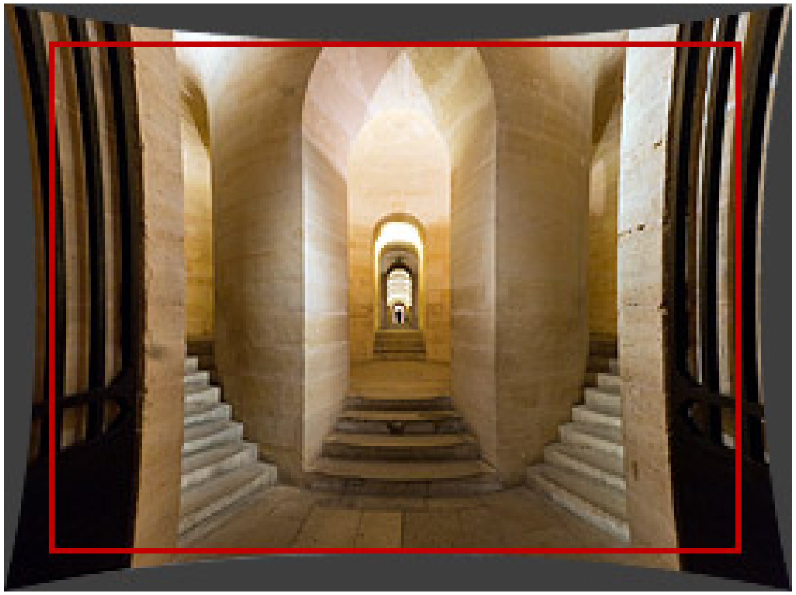


Pincushion Barrel Mustache

Images courtesy of Wikipedia.

Distortion Samples





Barrel Distortion

Pincushion Distortion

Chromatic Aberration

Engineering Trade-offs for Lens Performance

- Aperture:
  - Large: Minimize diffraction
  - Small: Minimize spherical aberrations
- Focal length:
  - Long:
    - Minimize distortion
    - Increase angular resolution per pixel
    - Minimize chromatic aberration
  - Short:
    - Wider field of view
    - Reduced resolution
    - Increased aberrations and distortions

- All lenses have a sweet-spot => good balance between diffraction and aberrations
- Typical sweet spot for most lenses occurs at *f*/8, which is too slow for mobile platforms
- Acceptable sweet-spot for outdoor scenes can be achieved at *f*/4 - 5.6

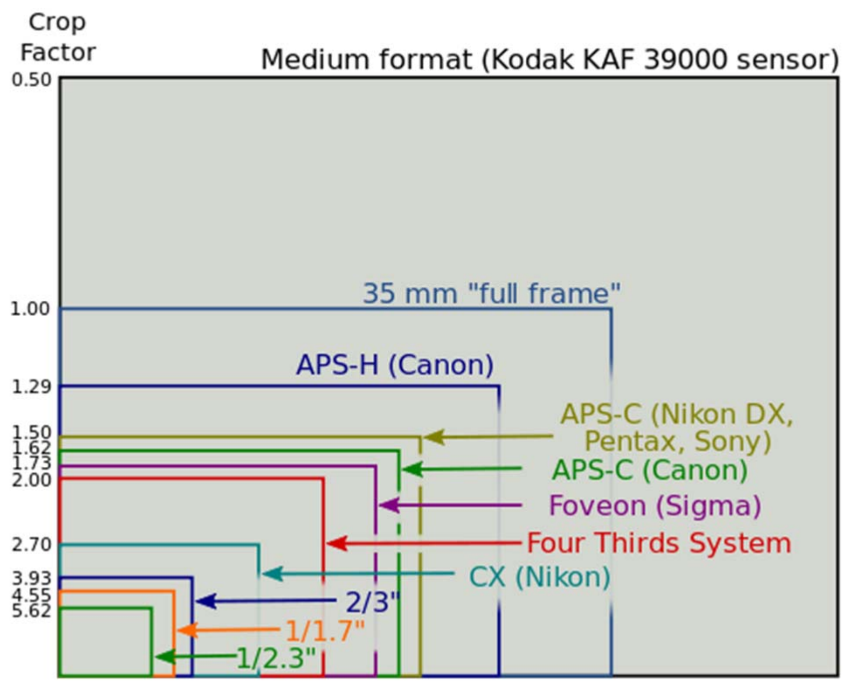
SENSOR

How does the Sensor work?

- Light hits the sensor, transduced into electrons and converted to either a voltage or a current readout

- Sensor Types:
  - CCD
  - CMOS

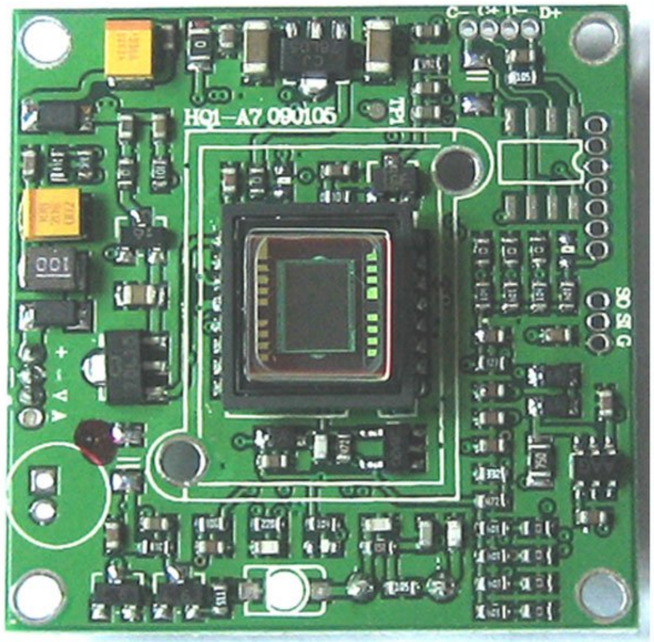
Sensor Dimensions



- Larger Sensor = More Light per pixel

CCD or CMOS

- Differences
  - Manufacturing process
  - Underlying electronics
- Both are built on semi-conductor technology
- Same wavelength response



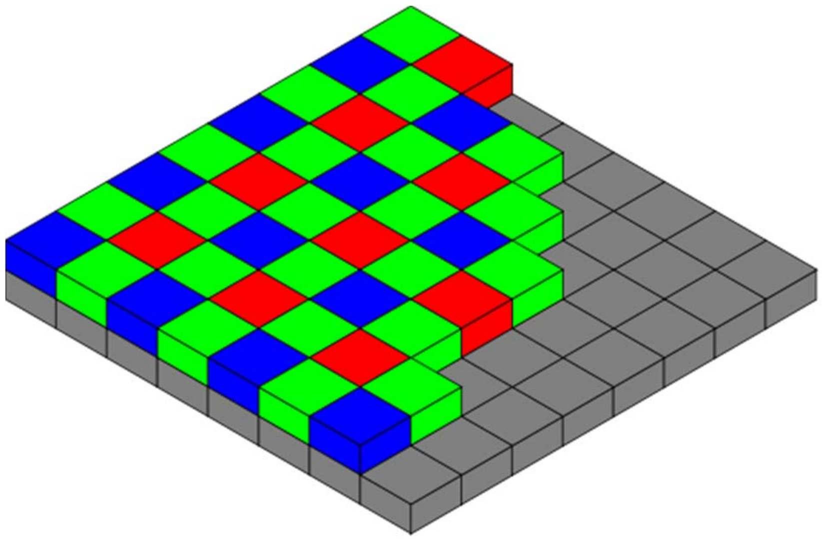
1/3” Sony CCD with an I/R cut filter

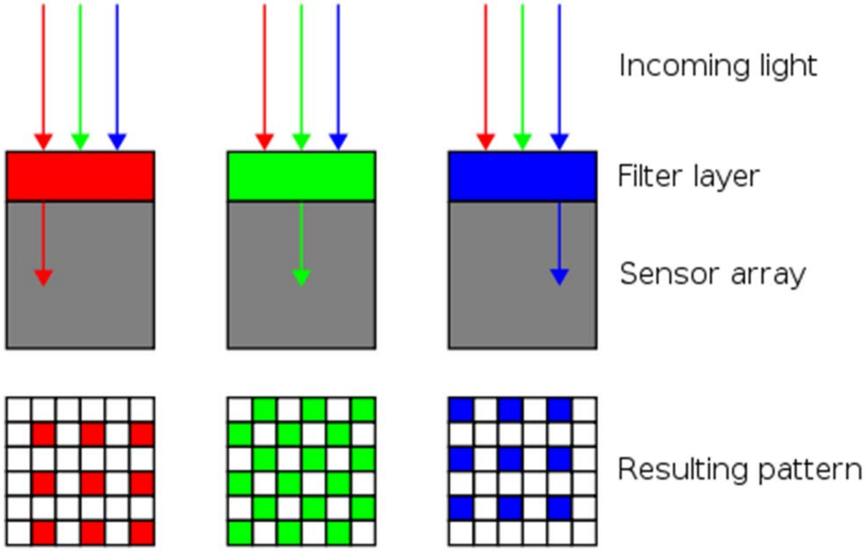
CCD or CMOS: Benefits and Drawbacks

- CCD:
  - Global shutter => Simultaneous capture of the image
  - Higher saturation limit
  - Lower noise
  - Better in low-light
  - Sometimes vulnerable to bright sources

- CMOS:
  - Cheaper, smaller electronics
  - Does not suffer from column bleed
  - Rolling shutter => Line by line capturing of the image
    - Bad for motion

Color filter array (CFA) – Single Sensor

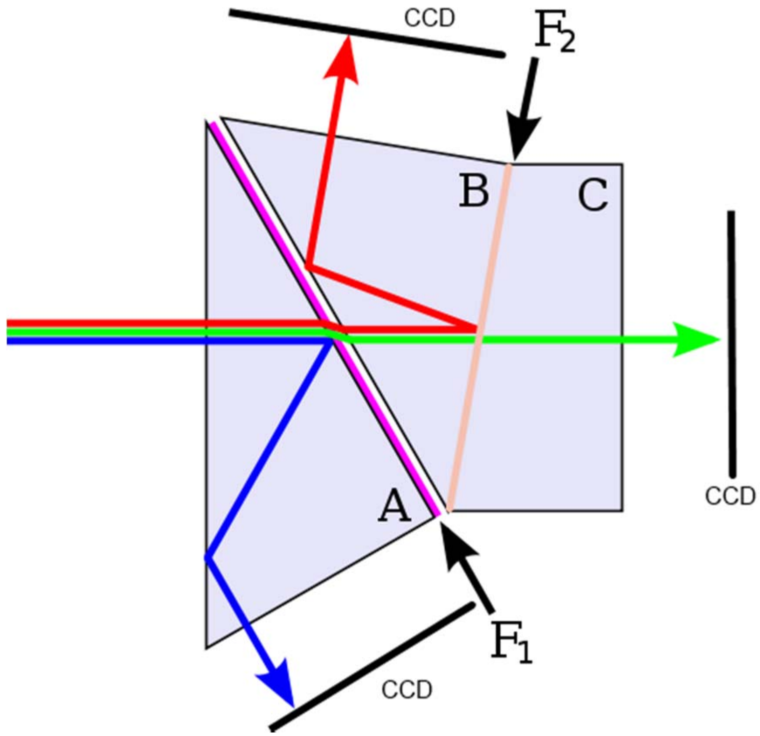




- Bayer ordering is the most common, hence Bayer filter

Images courtesy of Wikipedia.

3CCD/3CMOS design



Trichroic Prism

Image courtesy of Wikipedia.

Bayer is Lossy

- (1) is the original scene, maps one to one to a trichroic prism
- (2) and (3) are raw and colorized captures respectively.
- (4) contains the Bayer output
- Notice the loss of resolution, aliasing, and color banding

- Drawbacks:
  - Each pixel only records one color
  - Bayer filters throw out 2/3rds of the incident photons Bayer -> RGB requires interpolating non-captured colors for all pixels

- Result: Lost resolution, poor color separation

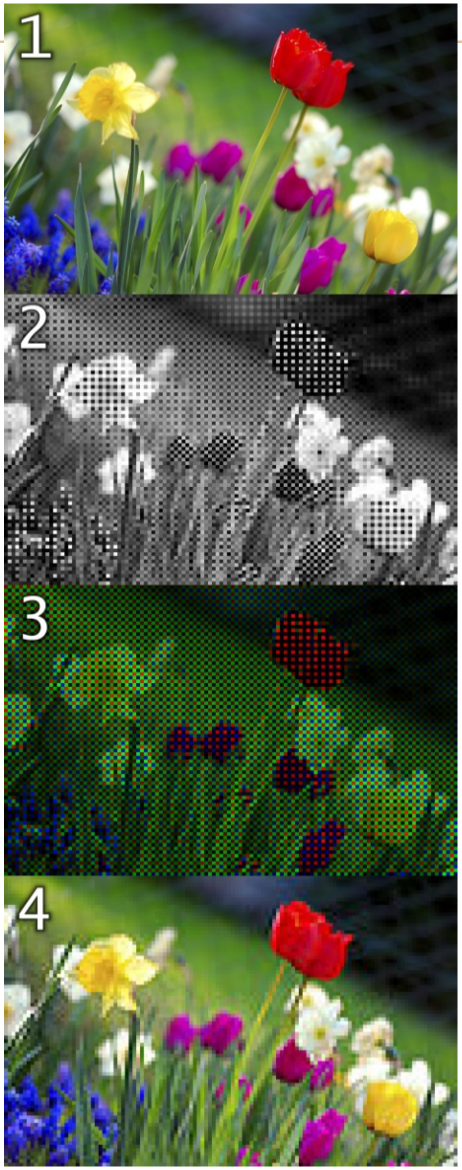


Image courtesy of Wikipedia.

Bayer Color Artifacts: Fence-posts

Video – 3 CCD

Machine Vision – Single CCD

O. Lossona, L. Macairea, Y. Yanga. "Comparison of Colour Demosaicing Methods". *Advances in Imaging and Electron Physics* 162 (2010) 173-265.

IMAGE QUALITY

Image Quality Metrics

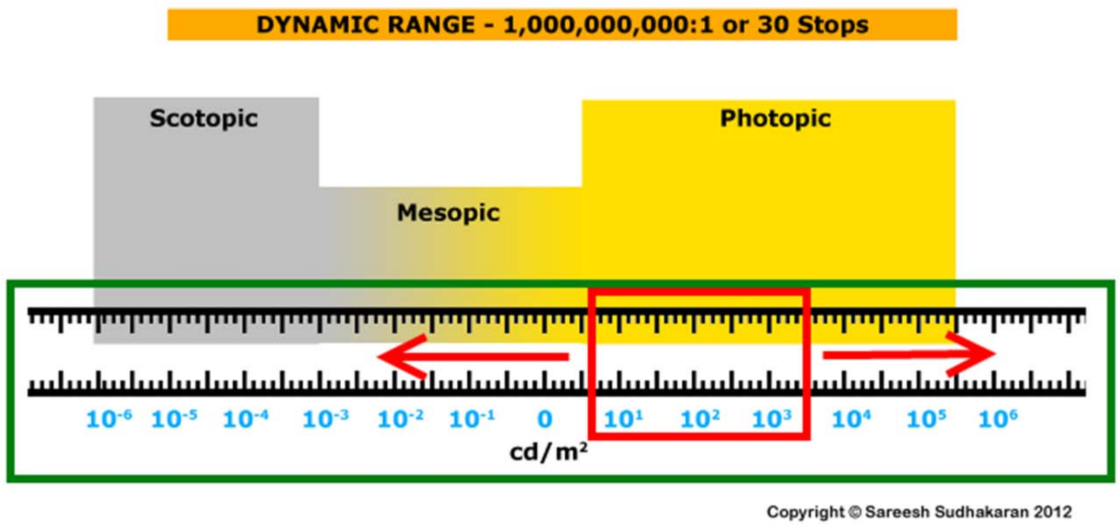
- Image quality metrics that matter most:
  - Dynamic Range
  - Noise
  - Tone
  - Focus
- Controllable camera parameters:
  - Exposure
  - Brightness
  - Contrast
  - White balance
  - Saturation
- Cheaper camera => fewer available settings

Auto-Everything: Machine Vision vs. Video

- Machine Vision:
  - Fewer auto-compensation settings
  - The ones available are basic
- Video:
  - Auto-compensation mechanisms
  - More sophisticated algorithms
  - Optimized for image quality:
    - Specific settings for tonal quality, tonal range, “warmth”

Dynamic Range

- Cameras have a narrow dynamic range:
  – Green box shows the dynamic range of the human eye
  – Red box shows the camera’s dynamic range



- What we see is not what the camera sees.
- An adaptable camera is much closer to the human eye
- Auto-compensation does this, and outdoor scenes need this!

Exposure

- Controls the shutter speed of the camera

Under-exposed

Over-exposed

- Typical shutter speed on moving cameras: 1/1000 s
- Any slower causes motion blur on off-axis elements

Gain

- Controls the Sensitivity of the sensor
- Too high a gain setting results in excessive noise
-

Too much gain

Just right

White Balance

- Controls the temperature of the white-point. Makes the image warmer or colder

Too cold

Too warm

Frame-rate

- Frame-rate: Rate at which the camera can deliver frames to a collection PC
  - Depends on shutter speed, bandwidth, recording rate
- Machine Vision cameras
  - Are restricted by bandwidth
  - Must compete with other network traffic
- Video cameras
  - Utilize a special high-speed bus with a frame-grabber card
  - Can run as fast as the camera can generate frames

Triggering and Synchronization

- Machine Vision cameras
  - Can be hardware-triggered
  - Synchronized over Ethernet to sub-millisecond

- Video cameras
  - Are free-running

Image from a Fugro Video Camera

Driving into the Sun!

Specifications on RFPs

Typical

- Collection interval
- Pixel Count
- Field of View
- Format - JPEG

What About?

- Number of Sensors
- F-Stop
- Lens Quality
- Auto Adjustments
- Compression of the JPEG Specification
- Quality Assurance

What does this all mean?

- More megapixels does not mean more quality
- More resolution does not mean more quality
- Three Sensors are better than One
- Smaller cameras typically mean
  - Smaller lens
  - Lower overall quality images
- More specifications should be used…..what did he just say….more specifications?

Thank You!

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