Introduction to Cameras for Embedded Applications

Brian Rodricks

CTO

SensorSpace LLC

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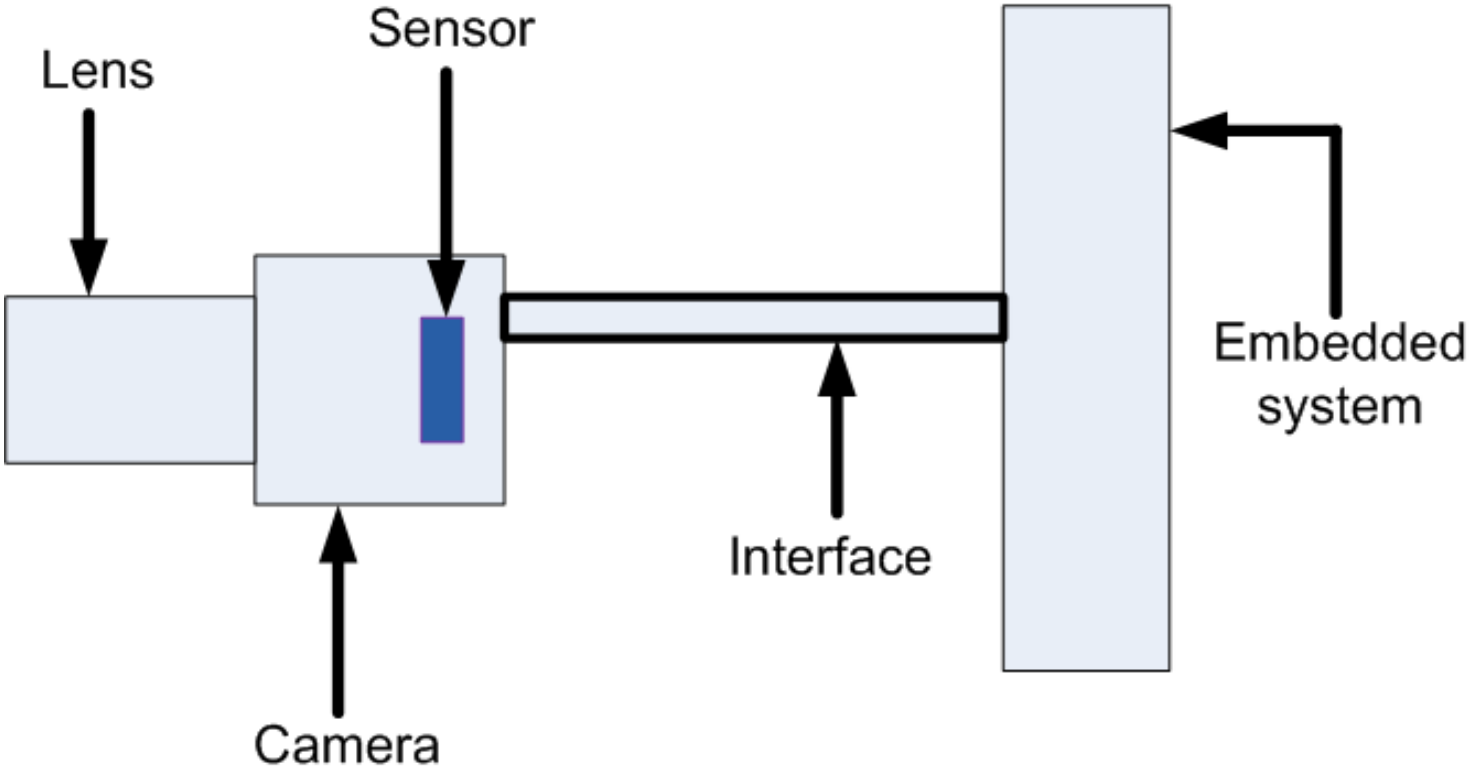
Outline

- Applications
- Camera system overview
- Camera mounts and camera sizes
- Lenses and f/# and Field of View (FOV)
- Image sensors
- Interface and communication
- Controls
- Performance/price trade-offs

Applications

- Life Sciences and Medical
- Factory Automation
- Inspections
- Transportation
- Smart City
- Measurement
- Tracking and Monitoring
- Sports and Entertainment
- People Recognition
- Agriculture

Camera System Overview



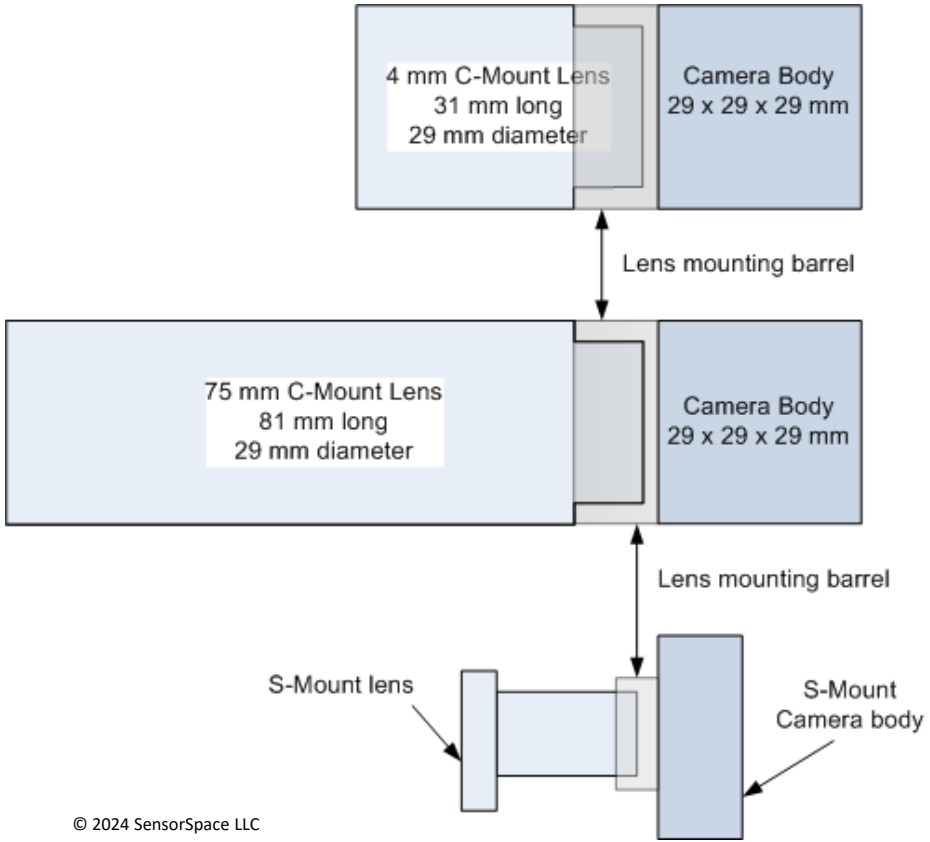
Lens Mounts

Mount	Type	Diameter (mm)	Flange focal distance (mm)	Physical size
C-Mount	Screw-type	25.4	17.523	Large
CS-Mount	Screw-type	25.4	12.526	Large
S-Mount	Screw-type	12	Variable	Small

Camera Size

As an example consider Basler Cameras: The body size is 29 mm x 29 mm x 29 mm. But the lens can be much bigger than the body depending on the focal length.

The S-Mount system is shown to scale relative to the C-Mount system



Lens f/# (f-number)

Describes the light collecting efficiency of the lens

- f/# = focal_length /effective_aperture_diameter
- Smaller the f-number, larger is its light collecting efficiency
- f-stops are settings that control the light collection in factors of 2
- $f/1 = f/((\sqrt{2})^0$
- $f/1.4 = f/(\sqrt{2})^1$ has half the light compared to f/1
- $f/2 = f/(\sqrt{2})^2$ has half the light compared to f/1.4
- $f/2.8 = f/(\sqrt{2})^3$ has half the light compared to f/2

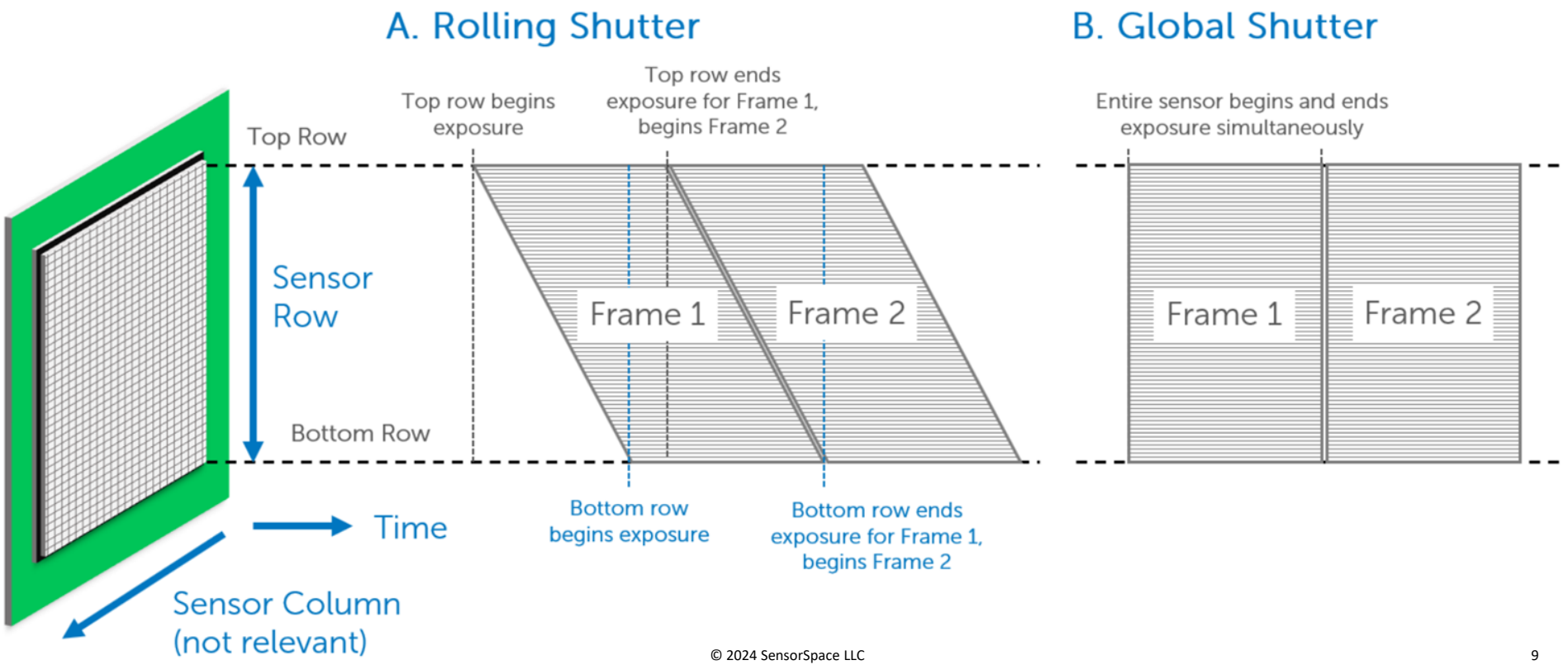
FOV ranges from few degrees to > 180 degrees

- Higher the FOV, greater is the distortion

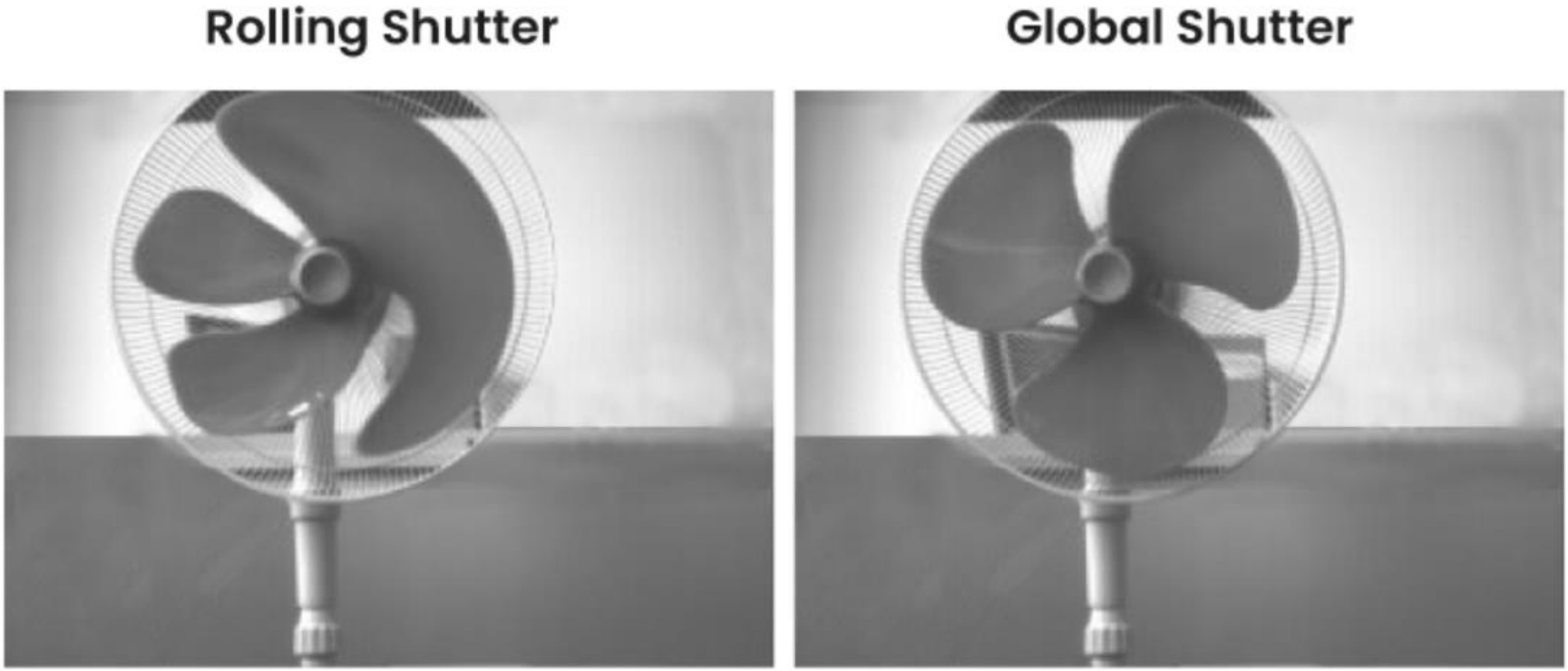
Image Sensors (CMOS-based)

- Rolling vs. global shutter
- Backside vs. front-side illumination
- Pixel size vs. array size
- Monochrome vs. color filter array (CFA)
- Special pixel architecture:
  - Phase Detection Auto-Focus (PDAF) sensor

Rolling Shutter vs. Global Shutter



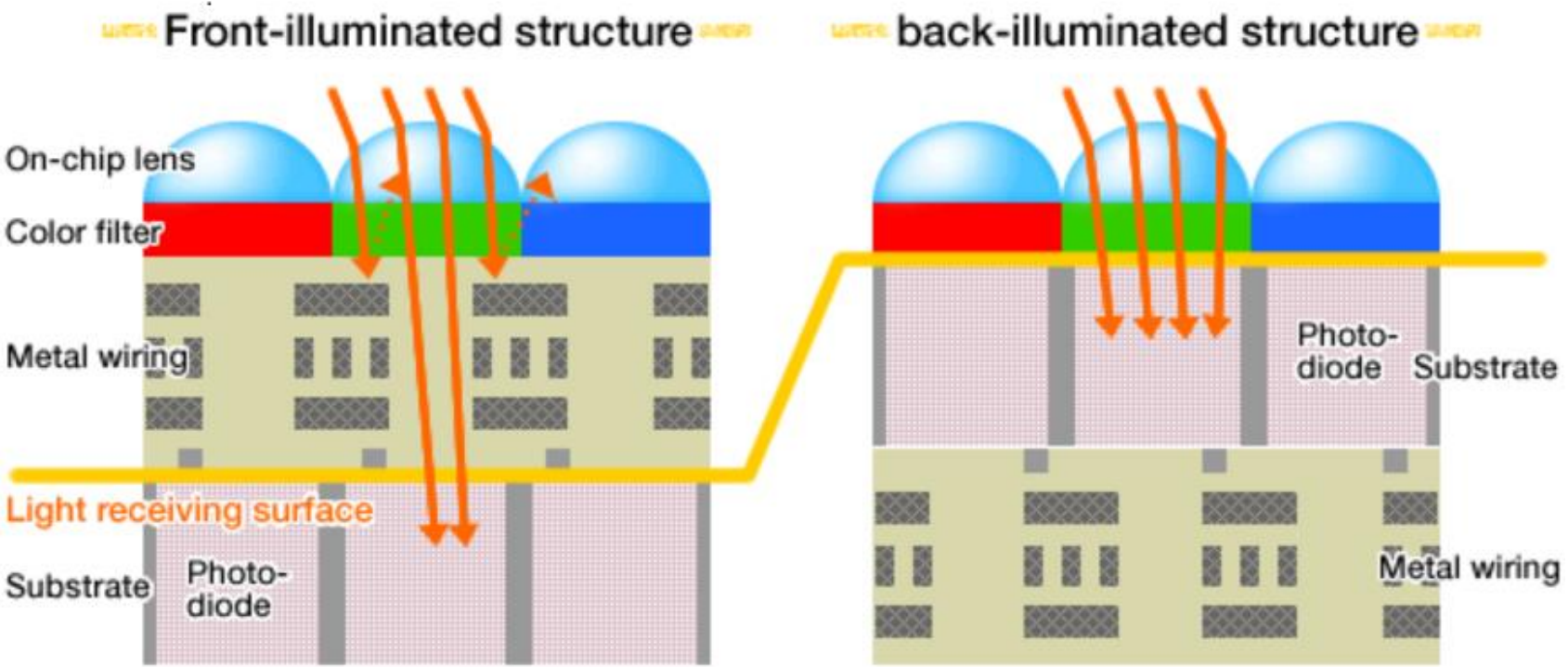
Rolling Shutter Artifacts



Rolling Shutter vs. Global Shutter

- Rolling shutter
  - Lower noise
  - Smaller pixels
  - Fewer transistors, larger fill-factor
  - Motion artifacts and missed events
- Global shutter
  - Higher noise
  - Larger pixels
  - More transistors, smaller fill-factor
  - Images with no motion artifacts

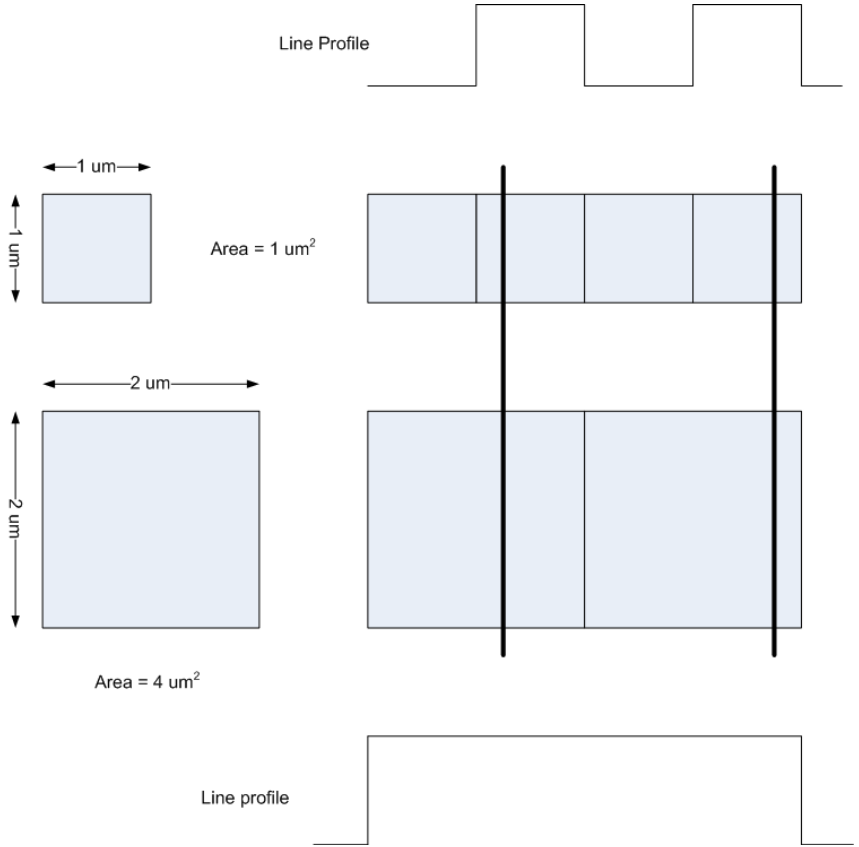
Frontside vs. Backside Illumination Sensor



Pixel Size

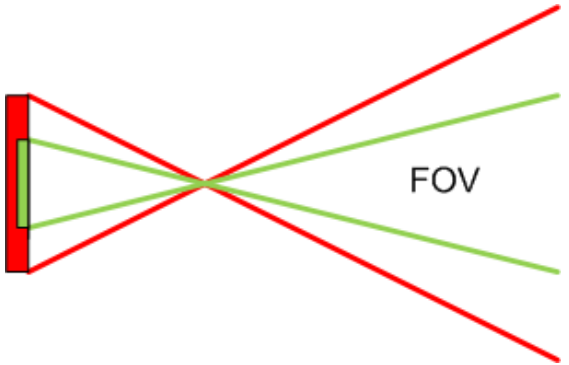
- Defines resolution and sensitivity:
  - Smaller pixels: Better resolution, less light sensitive
  - Larger pixels: less resolution, more light sensitive
- Sensitivity scales with the square of pixel size:
  - A 4 um x 4 um pixel is 4 times more sensitive than a 2 um x 2 um pixel
- Limiting resolution:
  - Nyquist limit = 1000/(2*pixel width (um))
- For small pixels, lenses may limit resolution
- Cross-talk increases with smaller pixels (degrades image quality)

Pixel Size (graphical representation)

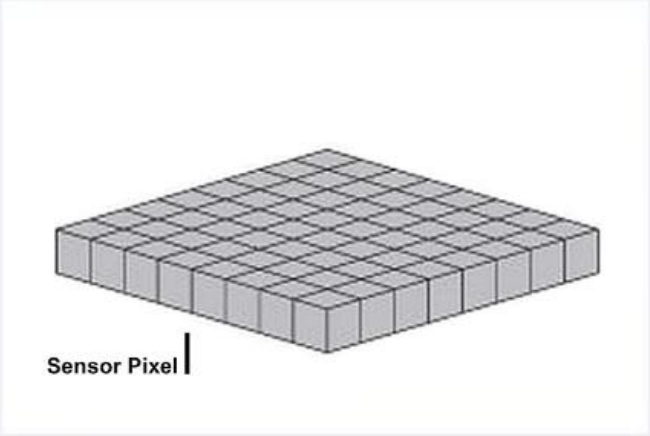


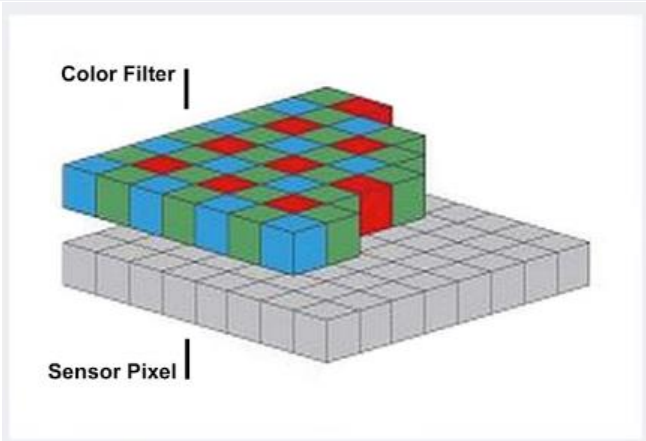
Array Size and Focal Length

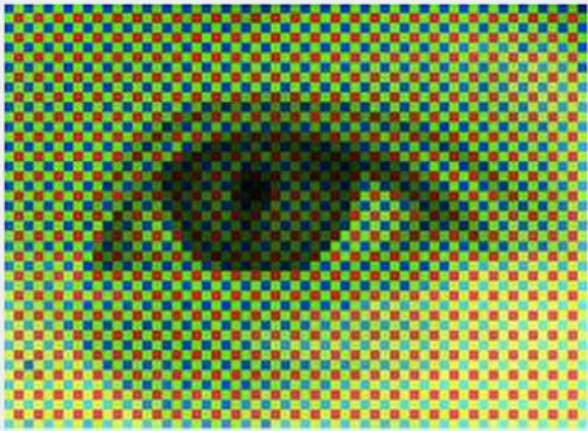
- Larger array size:
  - Can increase field of view
  - More data to process
  - May limit frame-rate
  - May need larger lenses
  - Does not increase resolution!
- Focal length:
  - < 30 mm: wide angle, higher distortion
  - ~50 mm: normal lens
  - > 70 mm: narrow FOV, lower distortion



Monochrome vs. Color Filter Array







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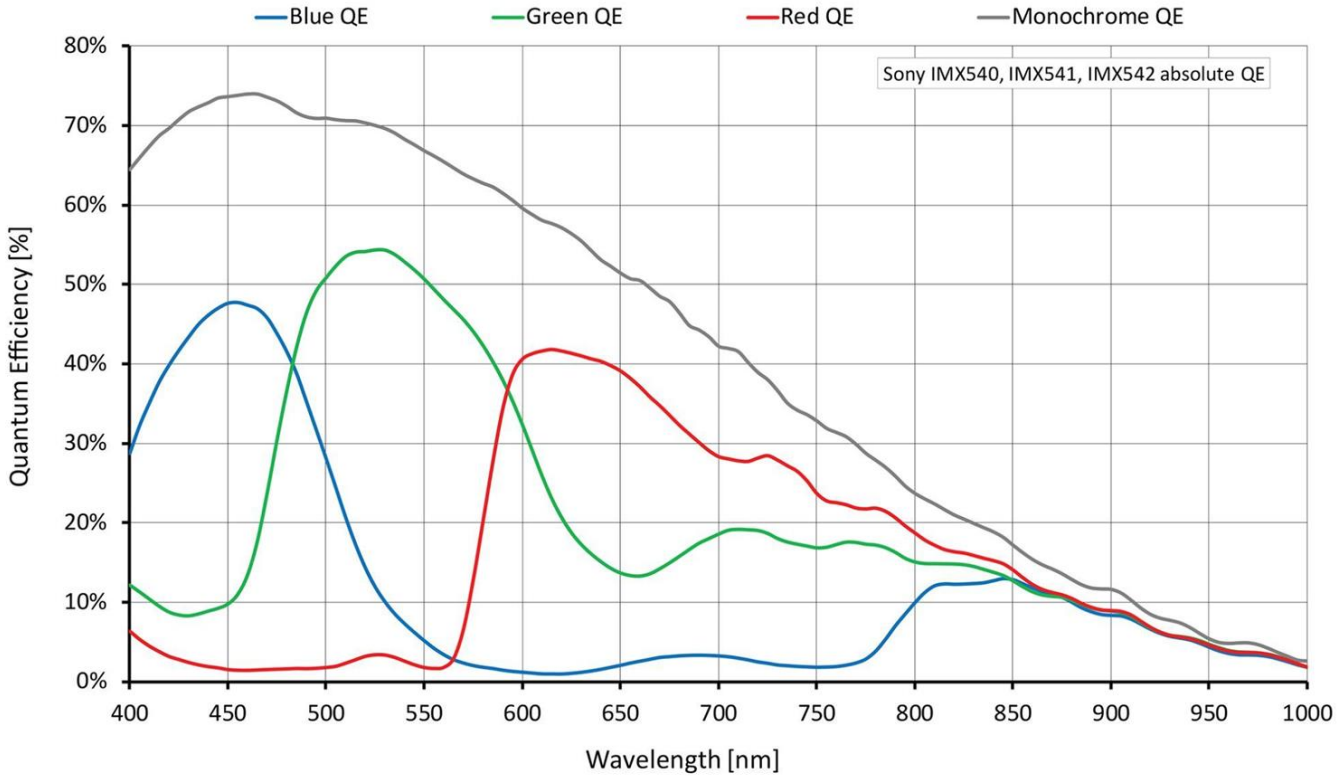
Monochrome vs. Color Filter Array Quantum Efficiency

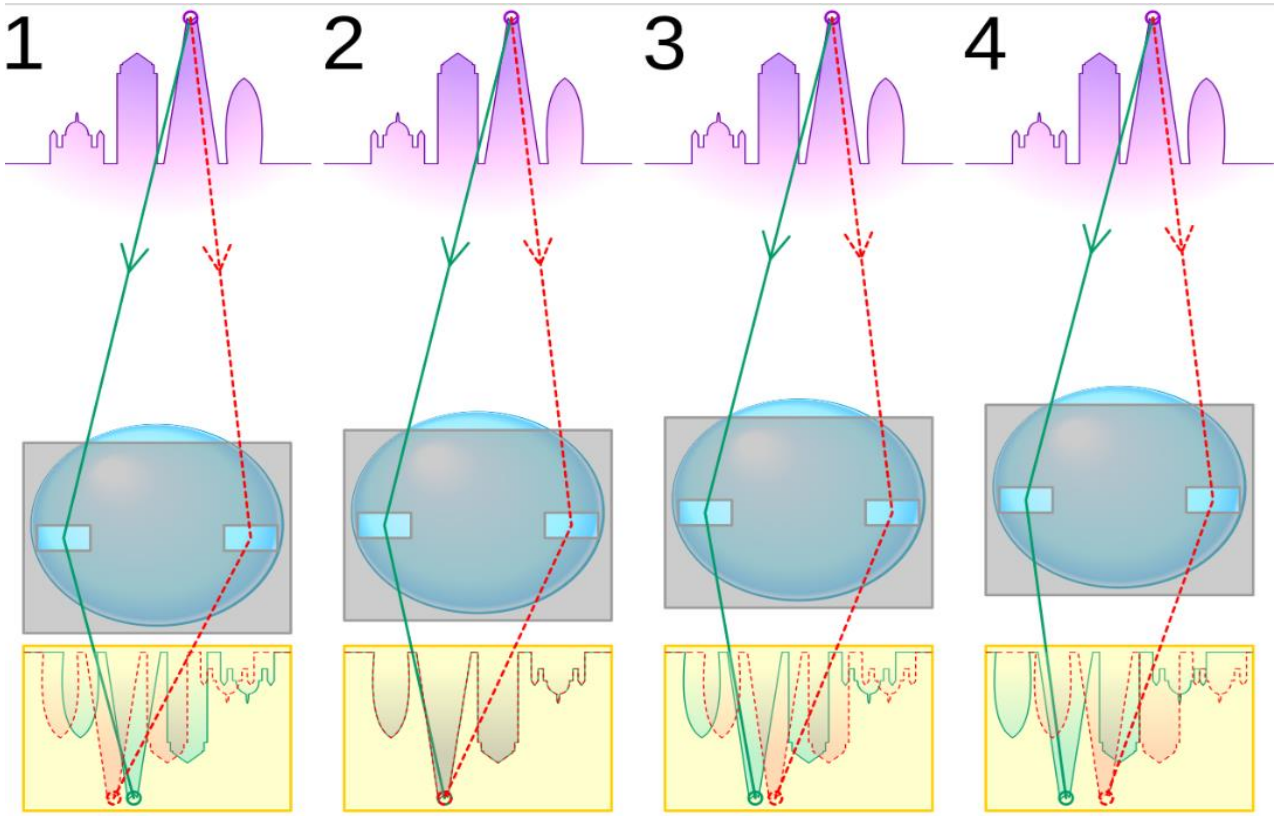


Monochrome vs. Color Filter Array

Sensor	Pros	Cons
Monochrome	Higher sensitivity, higher spatial resolution, less data to process, lower bandwidth, less memory required.	Gray scale image.
CFA	Lower sensitivity, reduced spatial resolution, more data to process, higher bandwidth, more memory needed, significantly more image processing steps.	Can reproduce true color. Better for AI and training.

Special Pixel Architecture

Phase Detection Auto Focus (PDAF) is an example of a special pixel architecture for efficient focus.



Interfaces

Interface	Bandwidth	Cable length
MIPI CSI-2	2.5-5.7 Gbps/lane	< 30 cm
USB	10 Gbps	< 5 m
GSML	6 Gbps	< 15 m
Ethernet	1 Gbps	100 m
CoaXpress (CXP-12)	12.5 Gbps	30 m

Controls

- Register access:
  - Sensor level:
    - Analog gain, exposure, binning, black-level, etc.
  - ISP level
    - Auto functions, demosaicing, sharpness, tone-map, etc.
  - Raw data:
    - Access to true raw data
- Software
  - UI-based
  - Command-line and scripting

Price/Performance Trade-offs

- Sensitivity
  - Lenses with larger f/#
  - Larger pixels
- Field of View
  - Larger sensor size
  - Complex lenses
- Bandwidth
  - Power

Summary

- Thanks to mobile imaging there has been significant improvement in
  - Optics
  - Sensors
  - Power
  - Integration of features
  - Algorithms
- Evaluation kits/prototyping for Edge-AI
  - Multi-camera system for Qualcomm Embedded platforms
  - Multi-camera systems for Raspberry PI
  - Camera modules and boards for the Nvidia Jetson platform
  - Low-cost custom camera board development

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Contact: brian.rodricks@sensorspace.biz

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