Machine Vision

FRA 626 Machine Vision in Smart Factory

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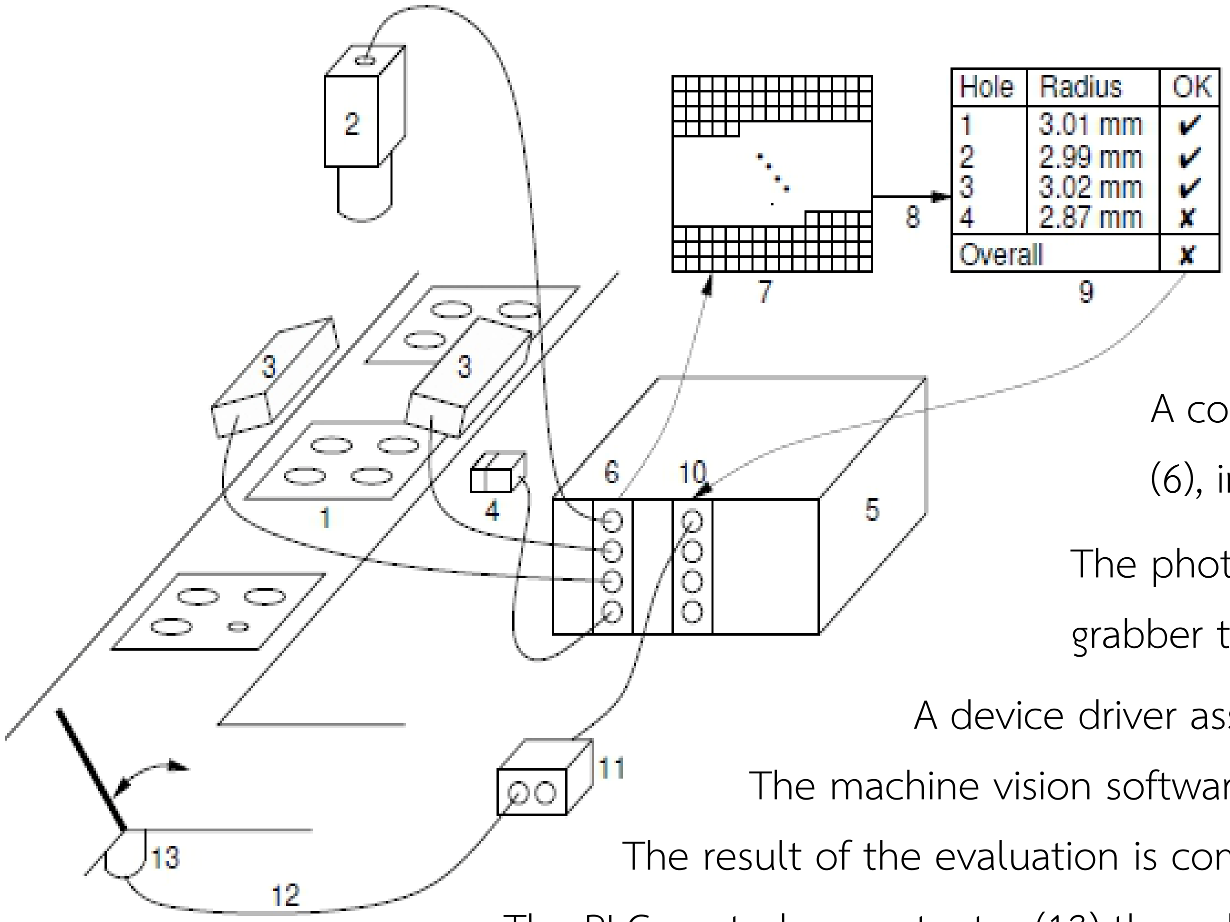
Topics

- Components of a Typical Machine Vision System
- Machine Vision Camera
- Lenses and Their Parameters
- Machine Vision Lighting
- Machine Vision Software

Components of a Typical Machine Vision System



An image of the object to be inspected (1) is acquired by a camera (2).

The object is illuminated by the illumination (3).

A photoelectric sensor (4) triggers the image acquisition.

A computer (5) acquires the image through a camera–computer interface (6), in this case a frame grabber.

The photoelectric sensor is connected to the frame grabber. The frame grabber triggers the strobe illumination.

A device driver assembles the image (7) in the memory of the computer.

The machine vision software (8) inspects the objects and returns an evaluation of the objects (9).

The result of the evaluation is communicated to a PLC (11) via a digital I/O interface (10).

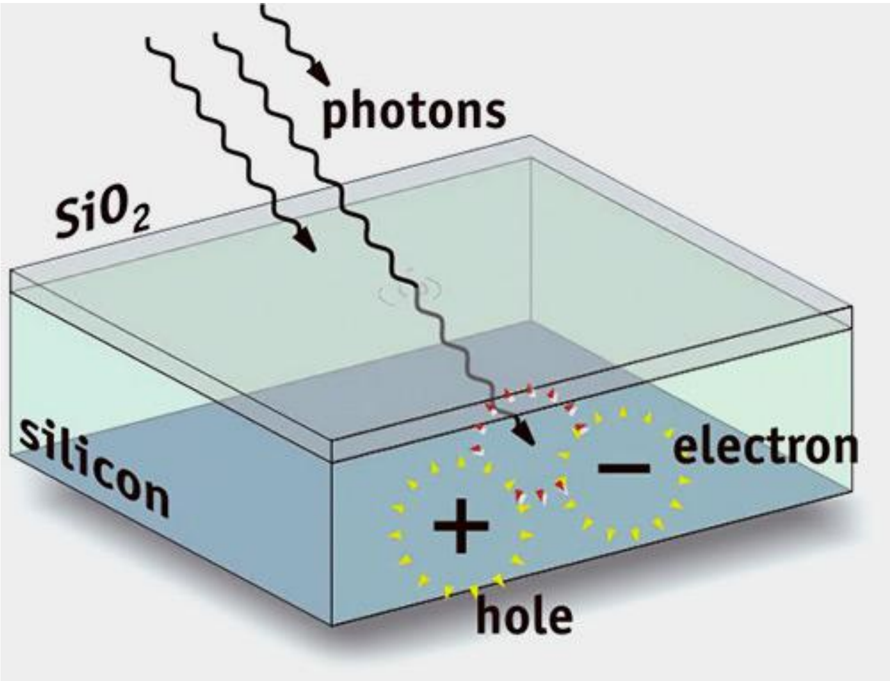
The PLC controls an actuator (13) through a fieldbus interface (12).

The actuator, e.g., an electric motor, moves a diverter that is used to remove defective objects from the production line.

Steger, C., Ulrich, M., & Wiedemann, C. (2018). Machine vision algorithms and applications. John Wiley & Sons.

Machine Vision Camera

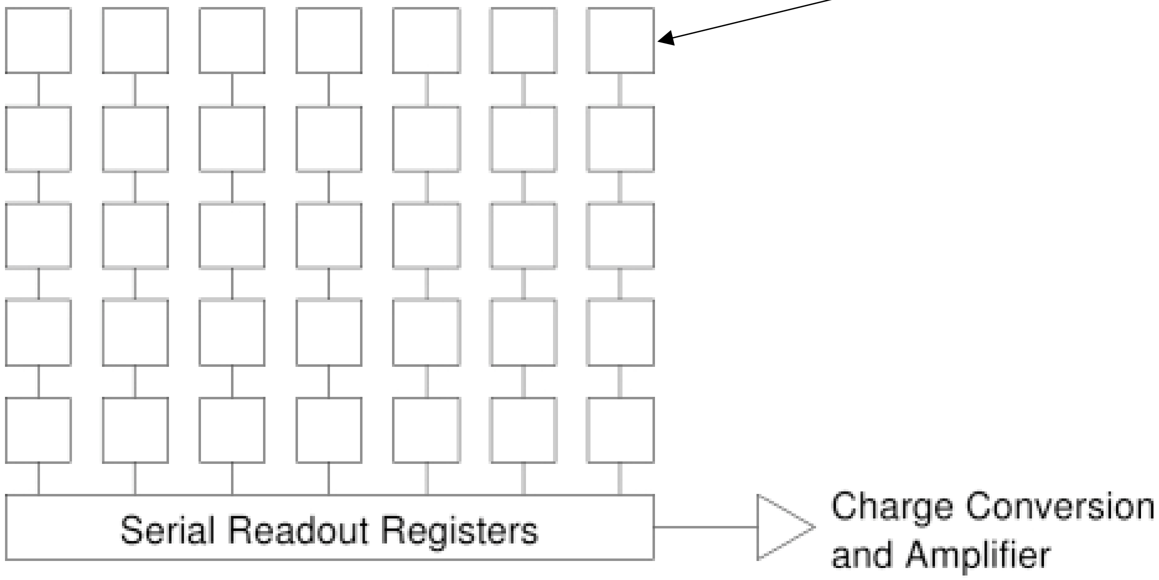
- CCD and CMOS imagers both depend on the photoelectric effect to create electrical signal from light. They convert light into electric charge and process it into electronic signals.



https://www.teledynedalsa.com/en/learn/knowledge-center/ccd-vs-cmos/

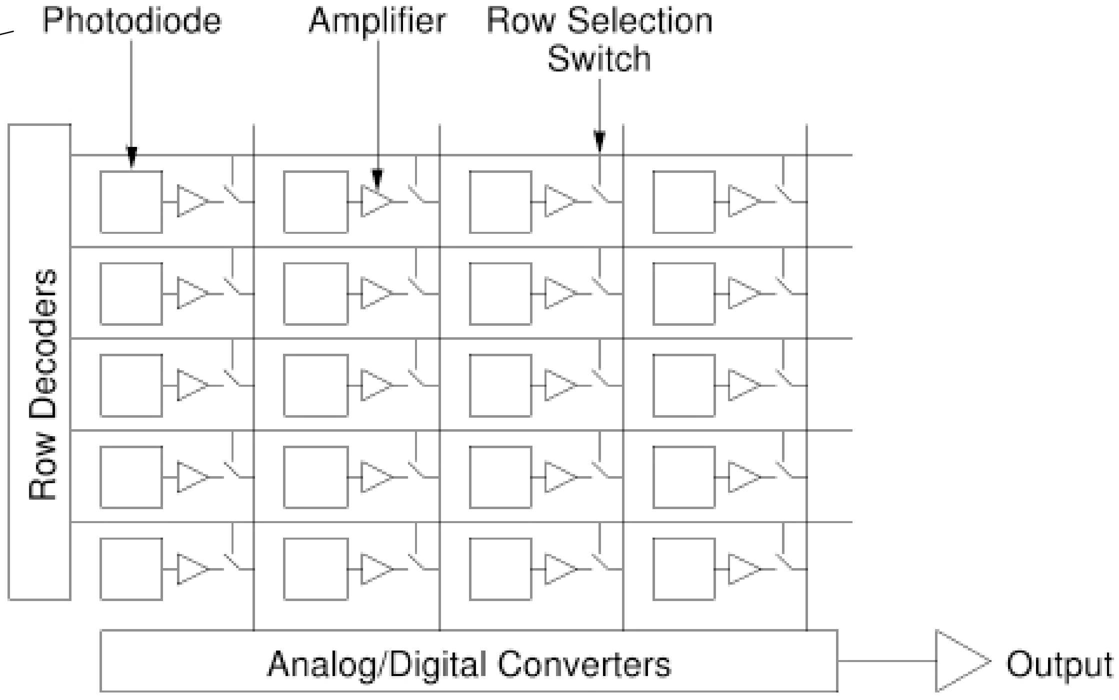
Machine Vision Camera

CCD
charge-coupled device



Sensor แต่ละพิกเซลทำหน้าที่รับแสงและแปลงค่าแสงเป็นสัญญาณอนาล็อก แล้วส่งเข้าสู่วงจรแปลงค่าอนาล็อกเป็นสัญญาณดิจิตอลอีกครั้ง

CMOS
complementary metal-oxide semiconductor

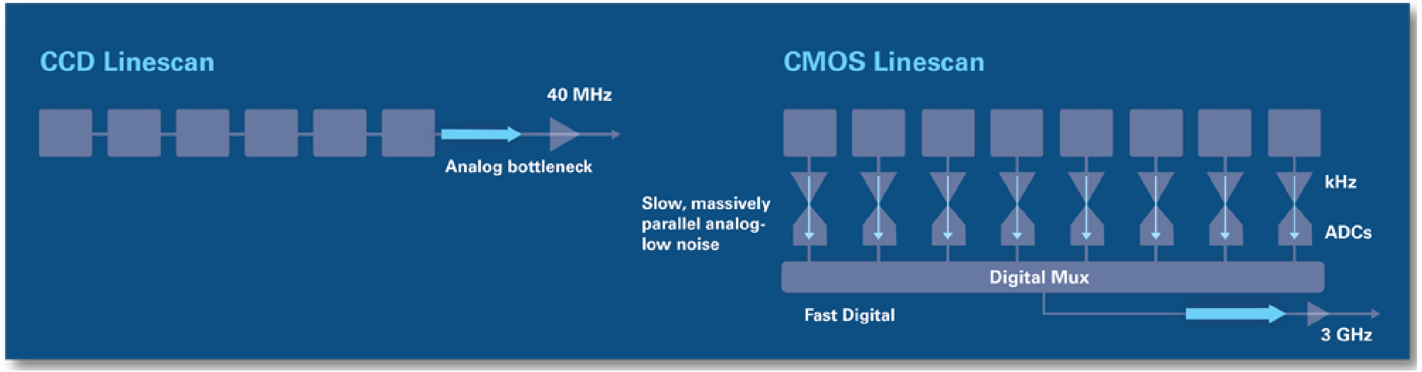


Sensor แต่ละพิกเซลจะมีวงจรย่อยๆ สำหรับแปลงค่าแสงที่เข้ามาเป็นสัญญาณดิจิตอลในตัวได้ทันที

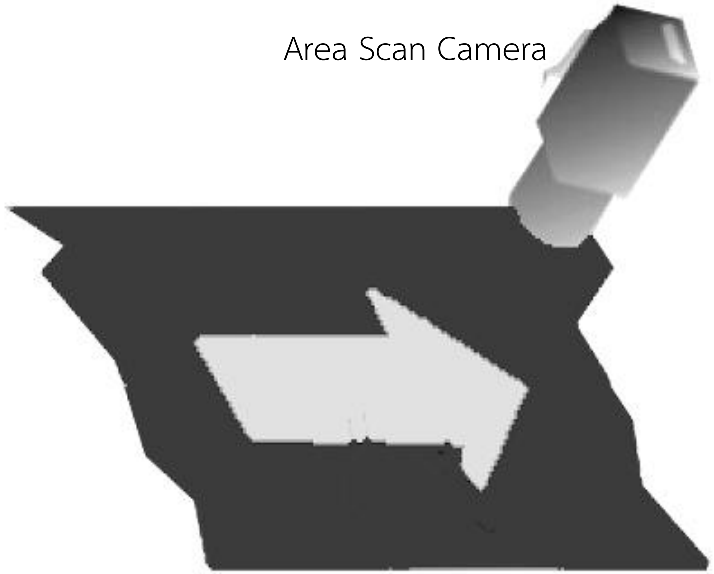
Steger, C., Ulrich, M., & Wiedemann, C. (2018). Machine vision algorithms and applications. John Wiley & Sons.

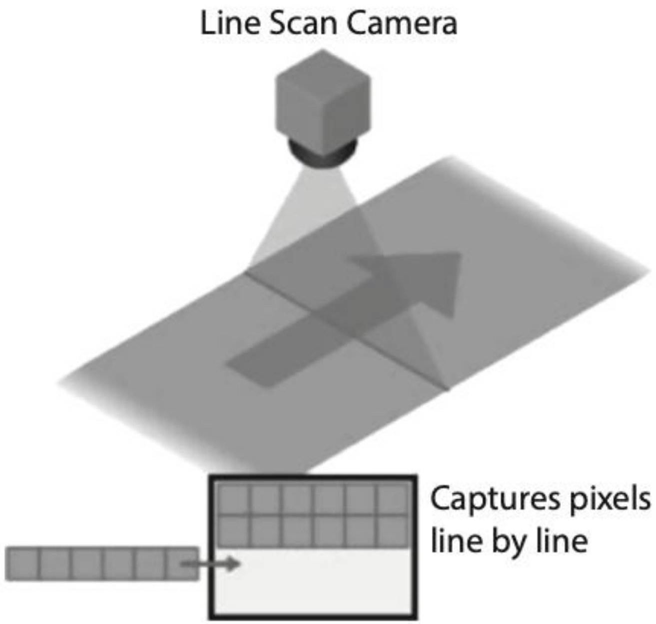
Machine Vision Camera

- Area Scan and Line Scan Cameras



https://www.teledynedalsa.com/en/learn/knowledge-center/ccd-vs-cmos/

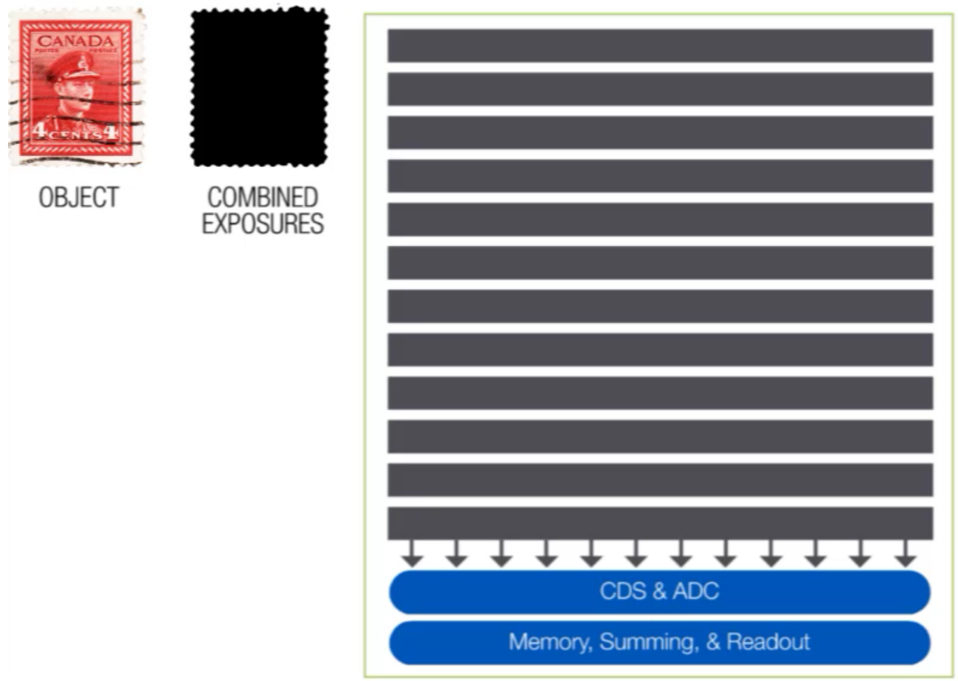




Anand, Sheila & Loganathan, Priya. (2019). A Guide for Machine Vision in Quality Control.

Machine Vision Camera

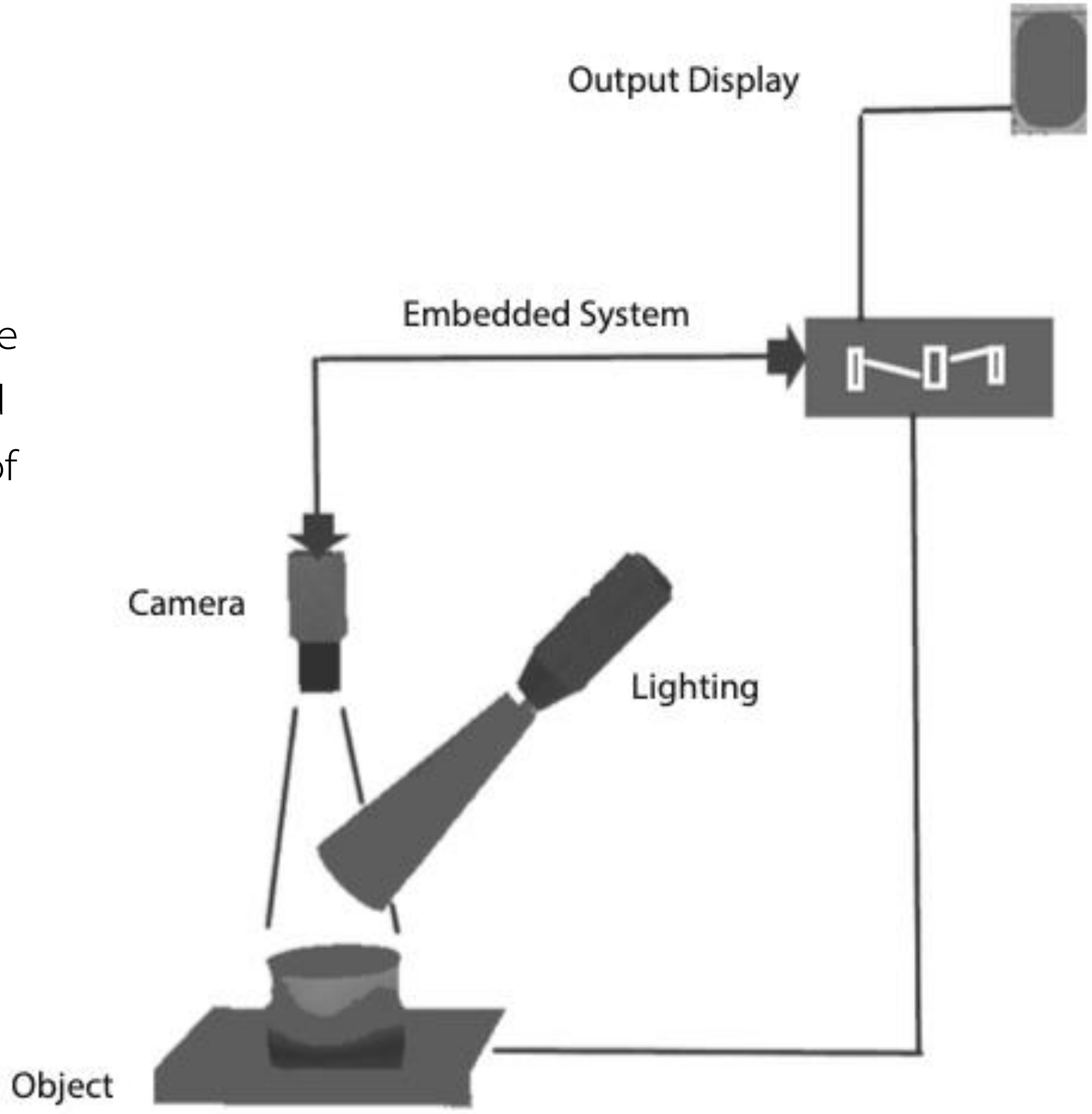
- TDI Sensor
  The time delay integration (TDI) sensor is a special kind of sensor that is used in line scan cameras. Line scan cameras scan one row of an image at a time.



https://www.teledynedalsa.com/en/learn/knowledge-center/ccd-vs-cmos/

Machine Vision Camera

- Smart Cameras
  It can be designed for a specific application. They use an embedded system for image processing. It should be robust to work reliability in industrial conditions of heat, dust, ambient light, etc.



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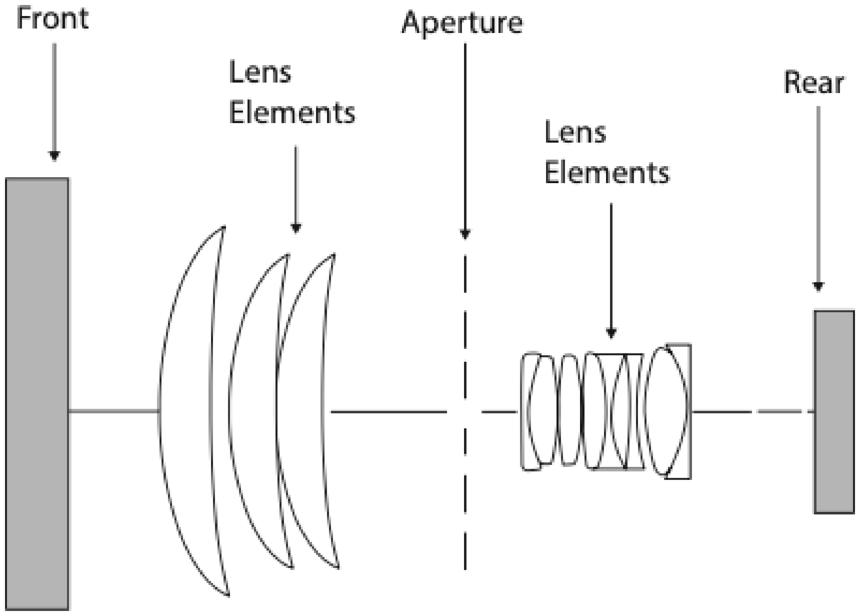
Lenses and Their Parameters

- Camera Lens
  the lens is used to focus the light reflected from a scene or object onto the image sensors in a camera.



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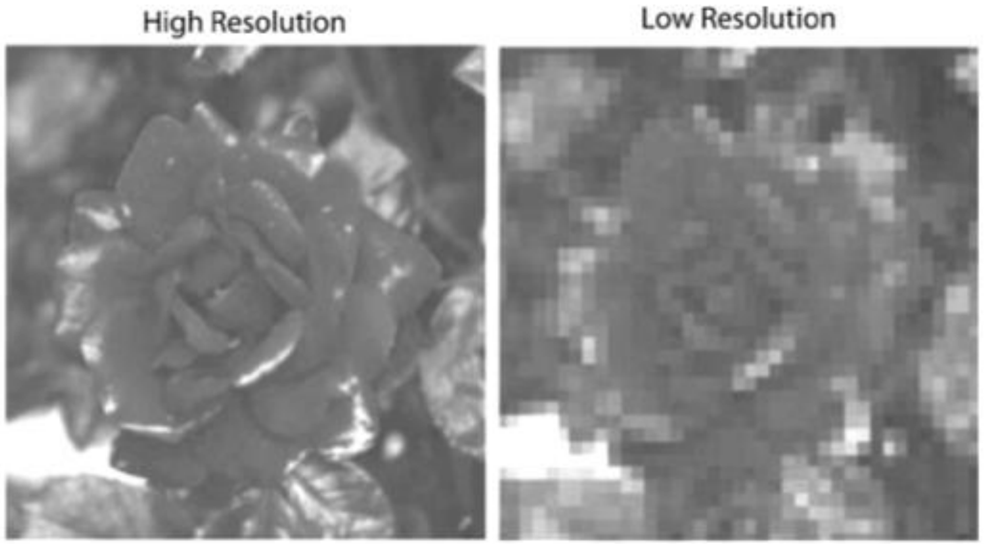
Lenses and Their Parameters

- Machine vision applications require quality images with appropriate image **resolution**, **contrast,** and **sharpness** to enable identification of the required features in the image.
- The choice of lens has a direct impact on the **speed** and **accuracy** of image capture.



Sharp Image Soft Image

http://www.generaldigital.com/blog/9-common-but-often-misunderstood-lcd-related-terms/

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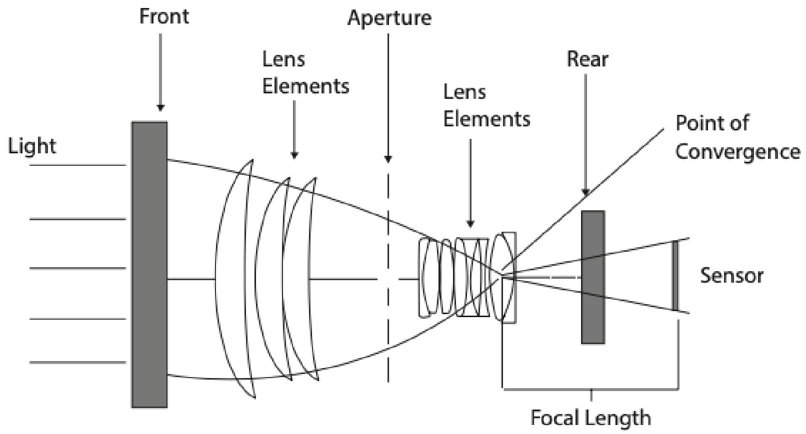
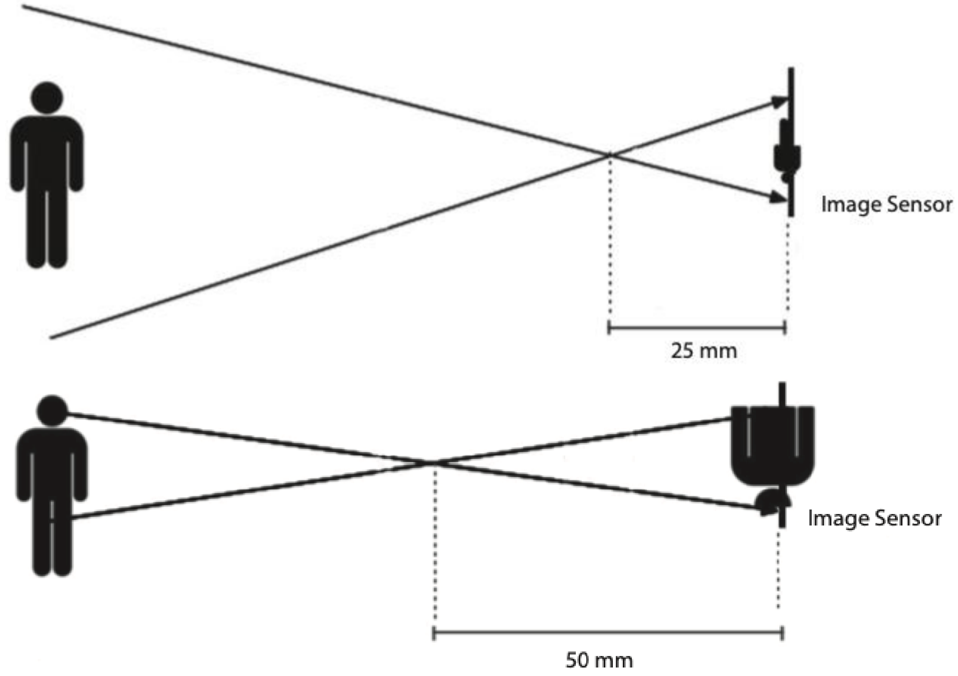
Lenses and Their Parameters

Several factors have to be considered while selecting a lens for a machine vision application. These include:

- The resolution of the camera sensor
- The distance between the object and the camera (working distance, WD)
- The size of the object
  Focal length of a lens determines the field of view. The size of object to be imaged is related to the field of view (FOV) which determines how much of the scene or object can be imaged.
  The bigger the object to be imaged, the larger the FOV should be.
- The amount of light available for image capture





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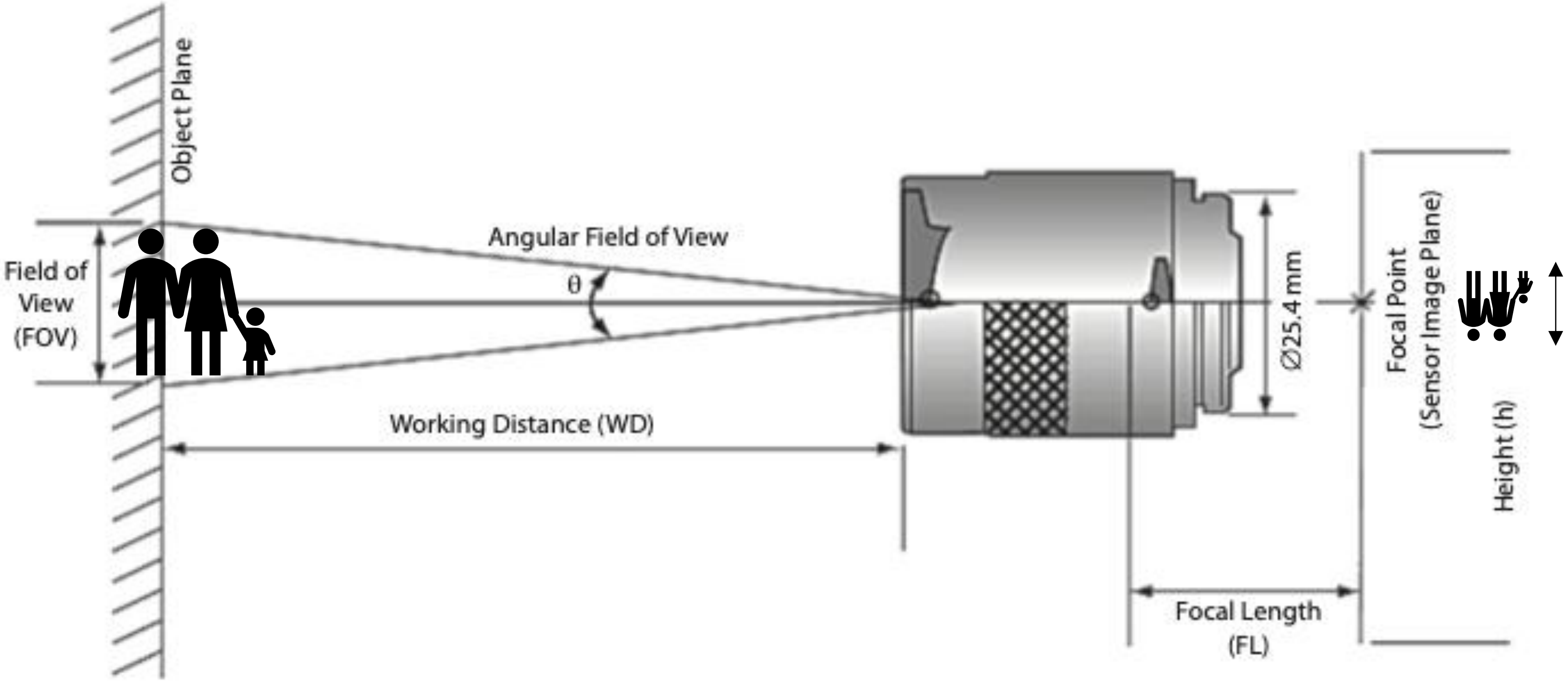
Lenses and Their Parameters

Relation between FOV and WD

$$\tan\left(\frac{\theta}{2}\right) = \frac{FOV}{(2 \times WD)}$$

$$FL = h \times \left(\frac{WD}{FOV}\right)$$



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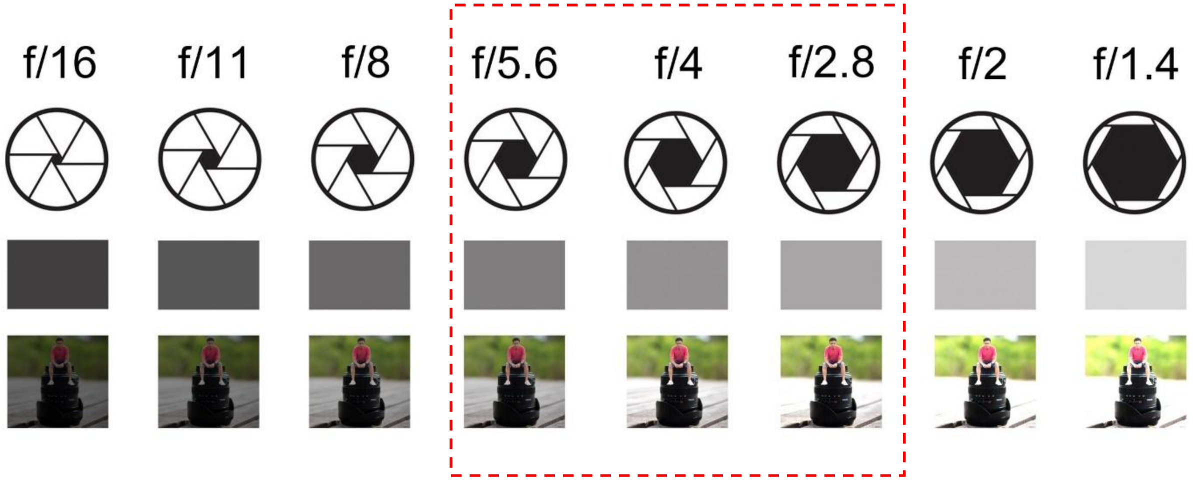
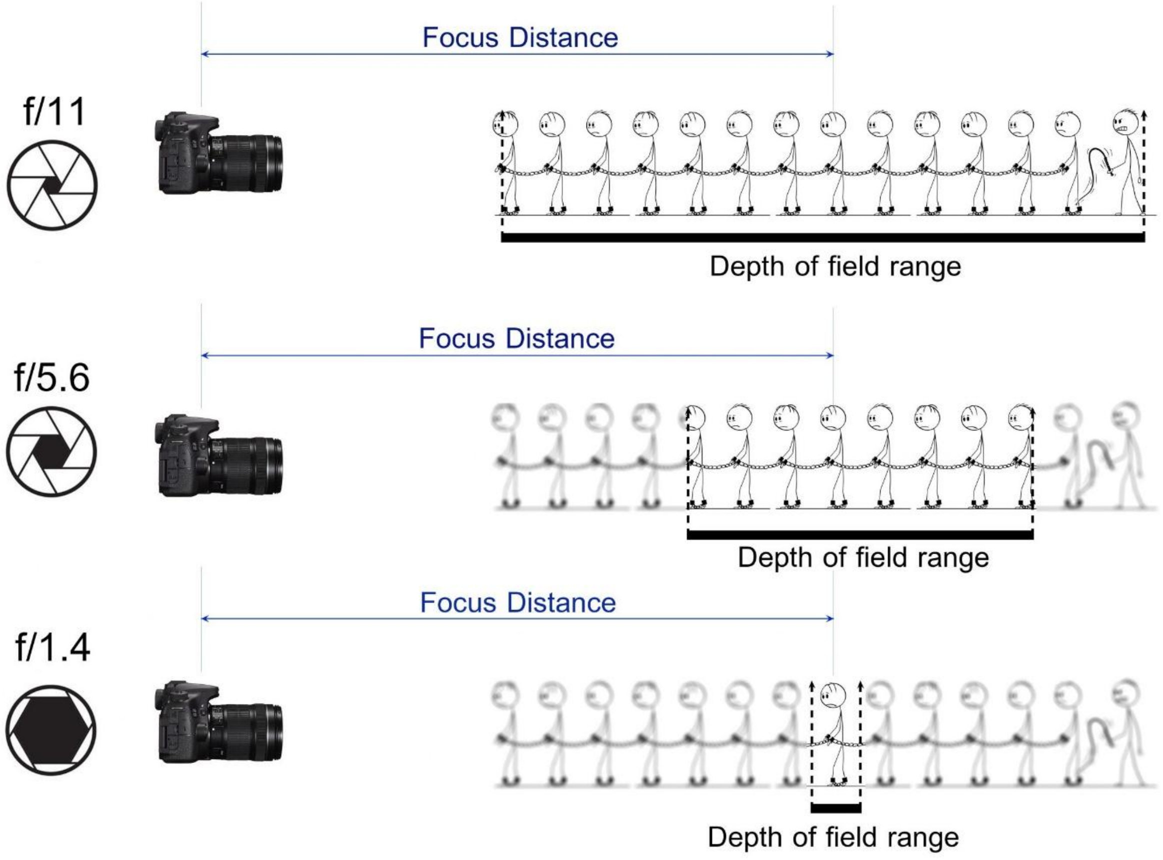
Lenses and Their Parameters

- **FOV** is the object area that is imaged by the lens onto the image sensor. It must cover all features to be measured, with additional tolerance for alignment errors. It is also a good practice to allow some margin (e.g., 10%) for uncertainties in lens magnification.
- Features within the field of view must appear large enough to be measured. This minimum feature size depends on the application. As an estimate, each feature must have 3 pixels across its width and 3 pixels between features.
- **Aperture** determines how much light is transmitted by the lens to the image sensor.
- **Shutter speed** is the length of time the digital sensor inside the camera is exposed to light.
- A lens with a larger maximum aperture is called a "**fast lens**"; in comparison, a lens with a smaller maximum aperture is called a "**slow lens**."

Lenses and Their Parameters

- The **f-number** is determined by dividing the focal length by the aperture of the lens.
- A low f-number is also known as a better-quality lens.

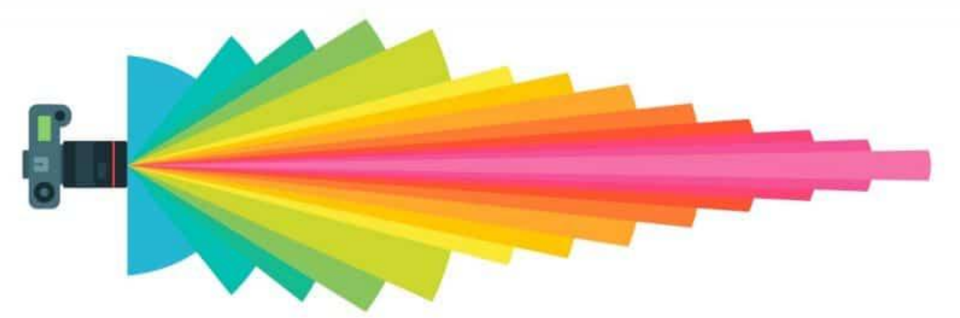




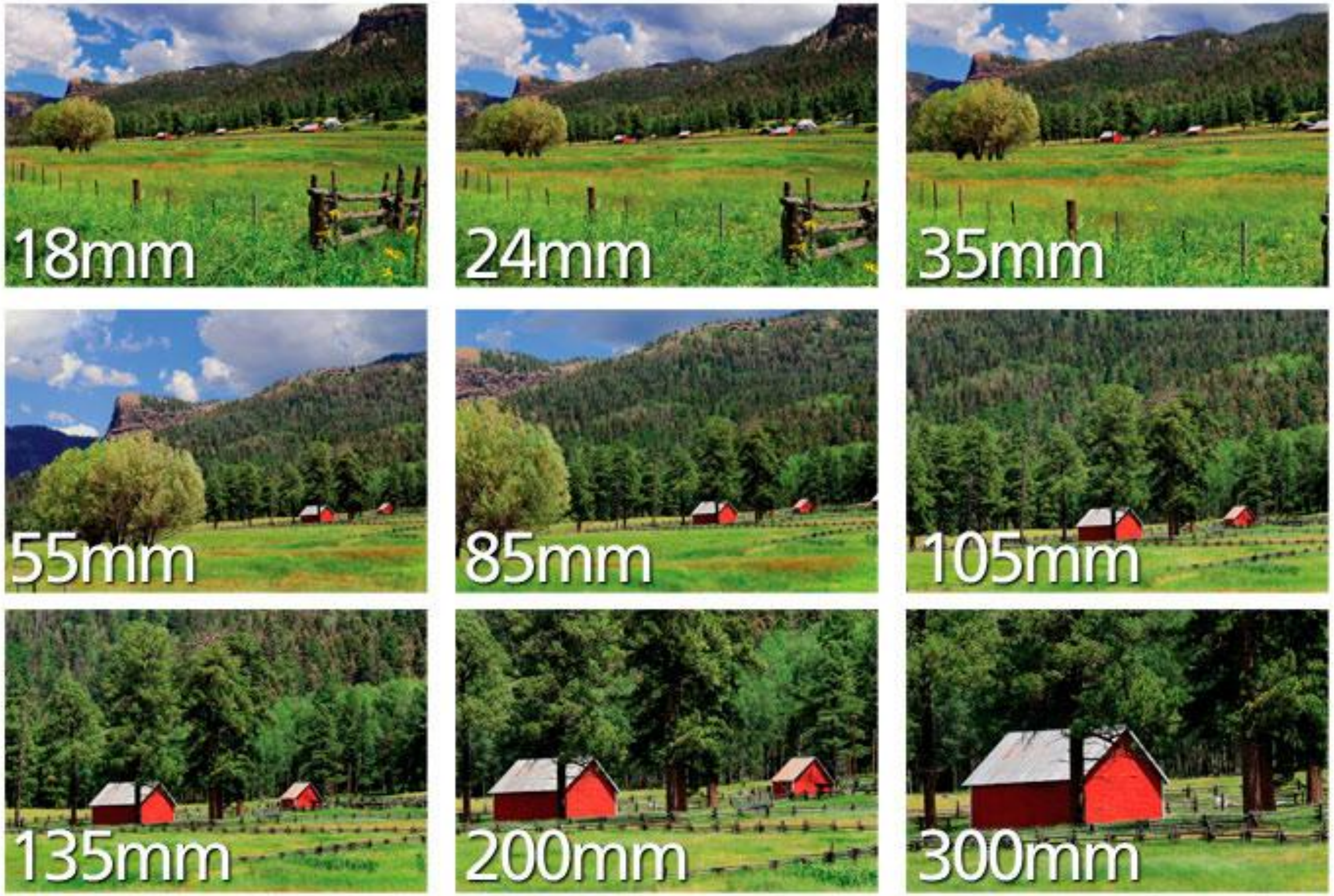
https://krupanom.com/เล่นกับแสง/

Lenses and Their Parameters

Images taken with different lenses



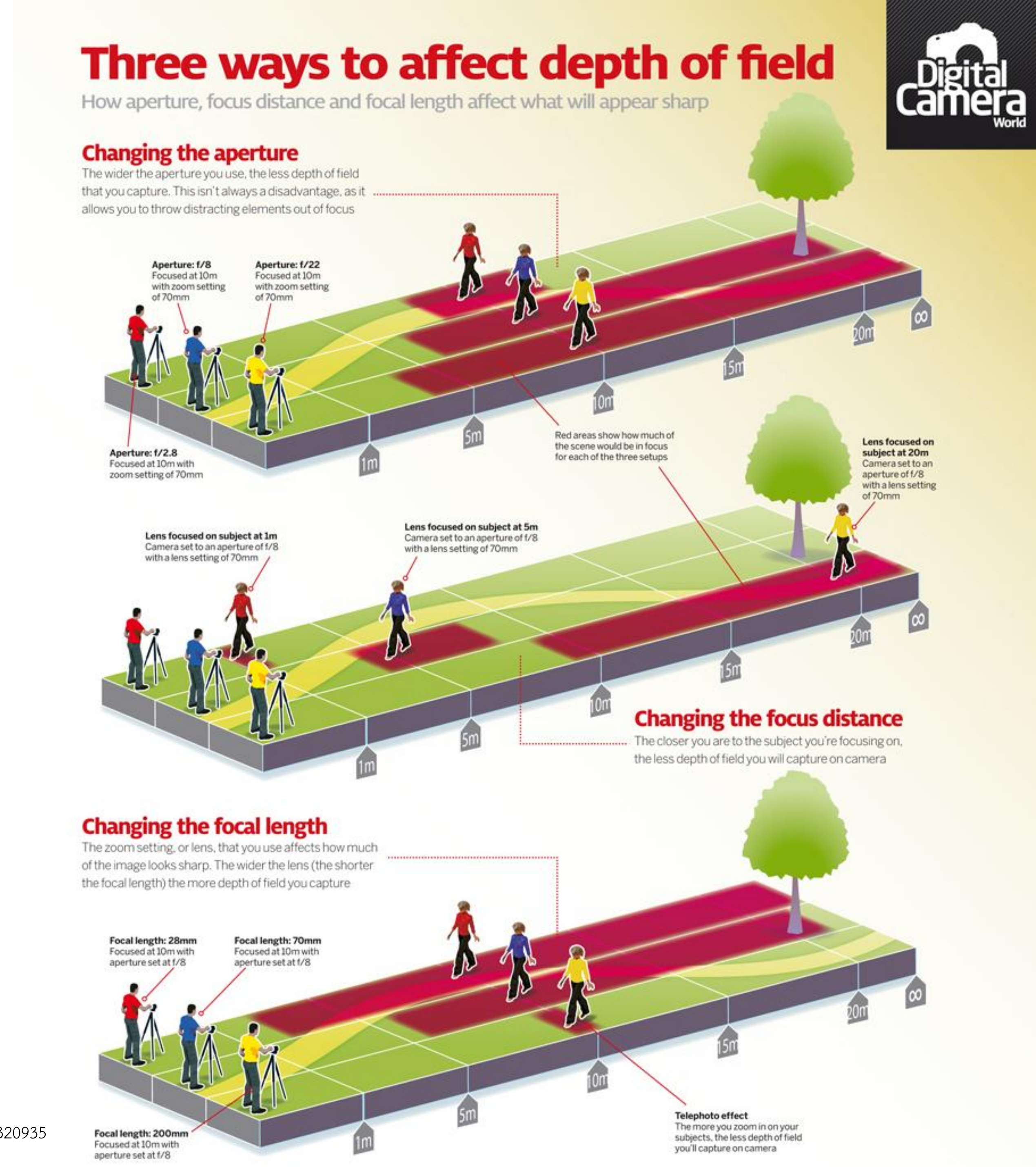
https://shuttermuse.com/angle-of-view-vs-field-of-view-fov-aov/



https://www.nikonusa.com/en/learn-and-explore/a/tips-and-techniques/understanding-focal-length.html

Lenses and Their Parameters

- **Depth of field (DoF)** is depended on aperture, focal length, and the distance between the camera and the object.
- A wide aperture, longer focal length and a short distance between the camera and object to be imaged would provide a shallow DoF. Conversely, a wider DoF can be obtained using a smaller aperture, shorter focal length and moving away from the object to be imaged.



https://www.techradar.com/how-to/photography-video-capture/cameras/3-ways-to-affect-depth-of-field-free-cheat-sheet-1320935

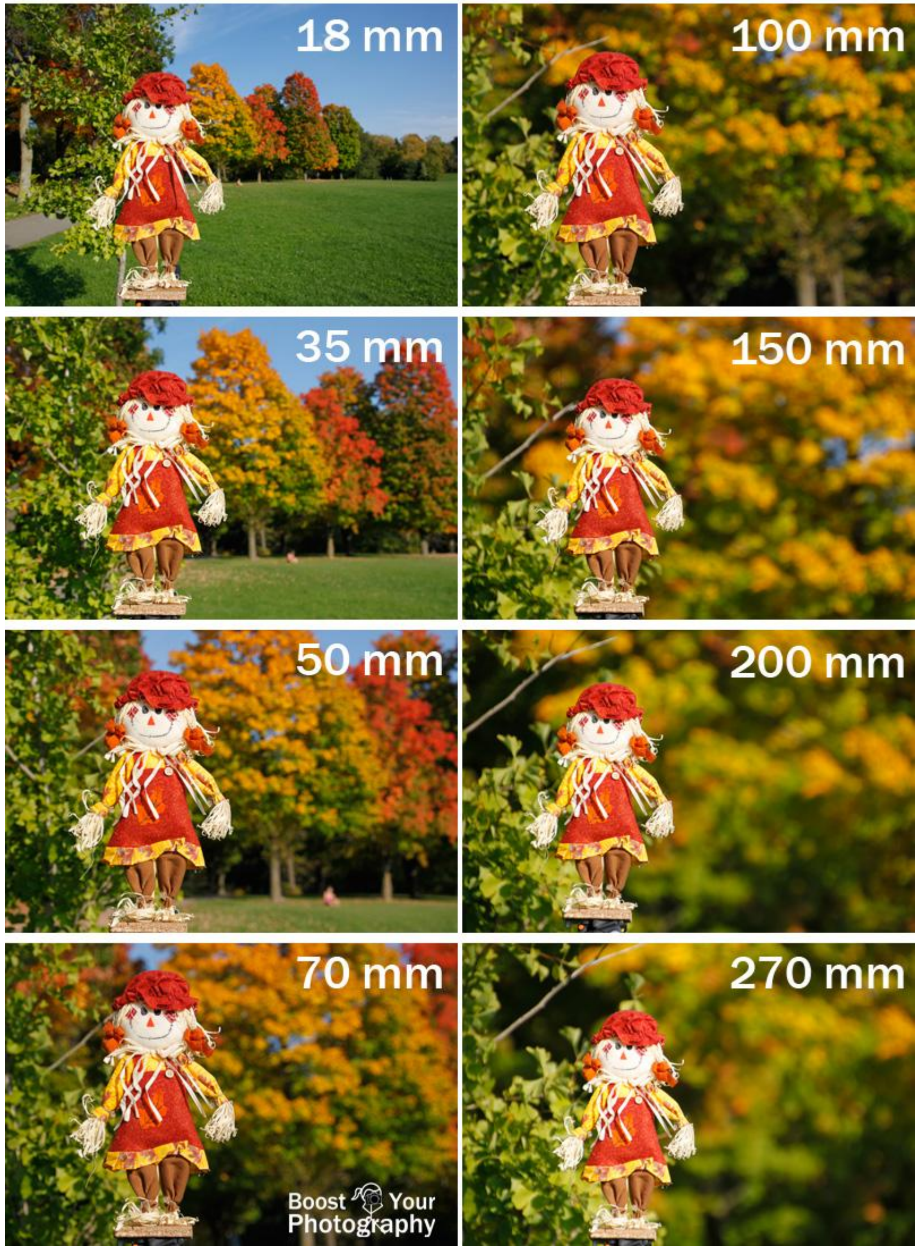
Lenses and Their Parameters

Depth of Field and Aperture

http://www.boostyourphotography.com/2014/10/depth-of-field.html

Compare How Depth of Field Changes with Focal Length (Zoom)

All photographs f/6.3

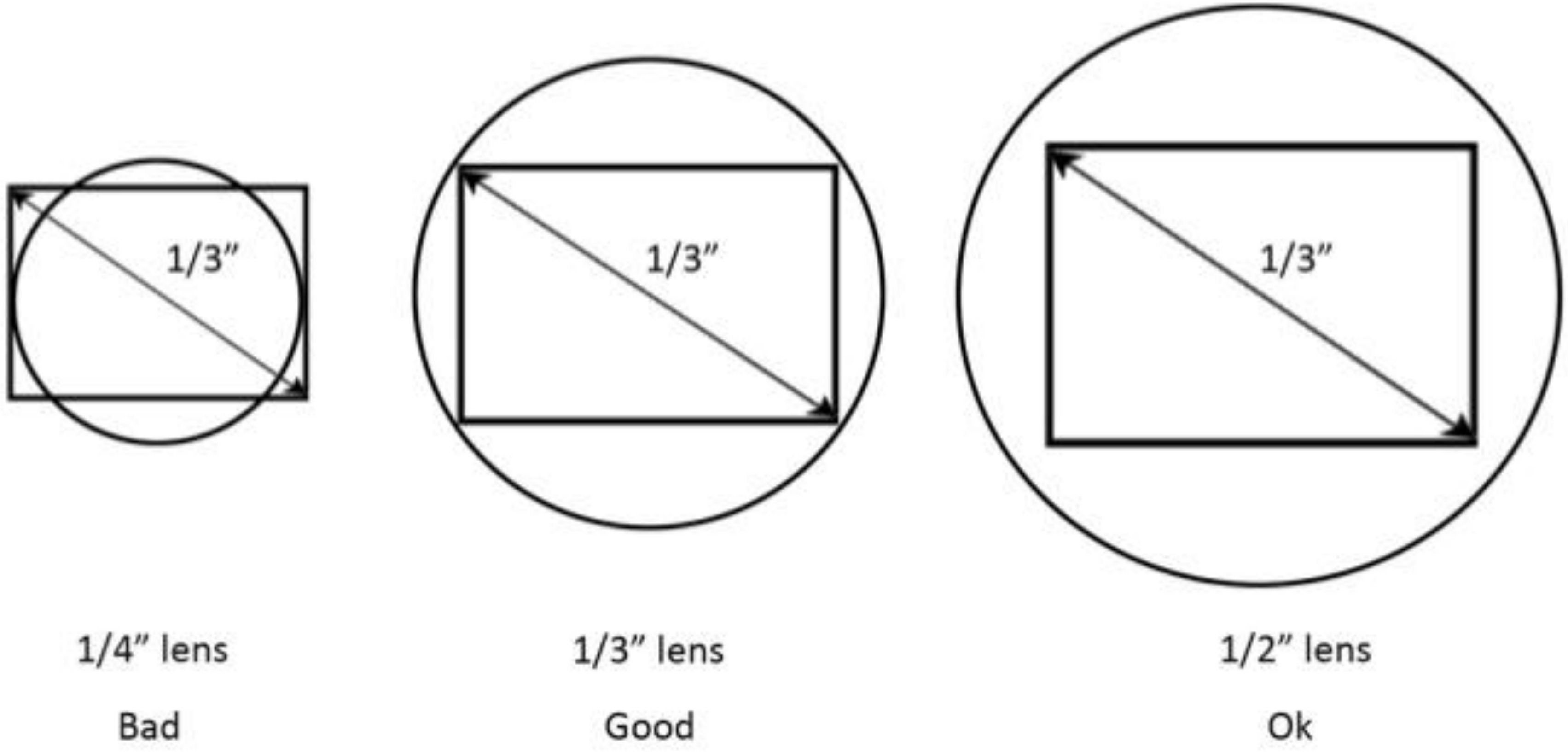


Lenses and Their Parameters

- Matching between sensor and lens

Sensor Size and Respective Diagonal Size

Size	Width	Height	Diagonal
1 inch	12.8 mm	9.3 mm	16 mm
2/3 inch	8.8 mm	6.6 mm	11 mm
1/2 inch	6.4 mm	4.8 mm	8 mm
1/3 inch	4.8 mm	3.6 mm	6 mm
1/4 inch	3.2 mm	2.4 mm	4 mm



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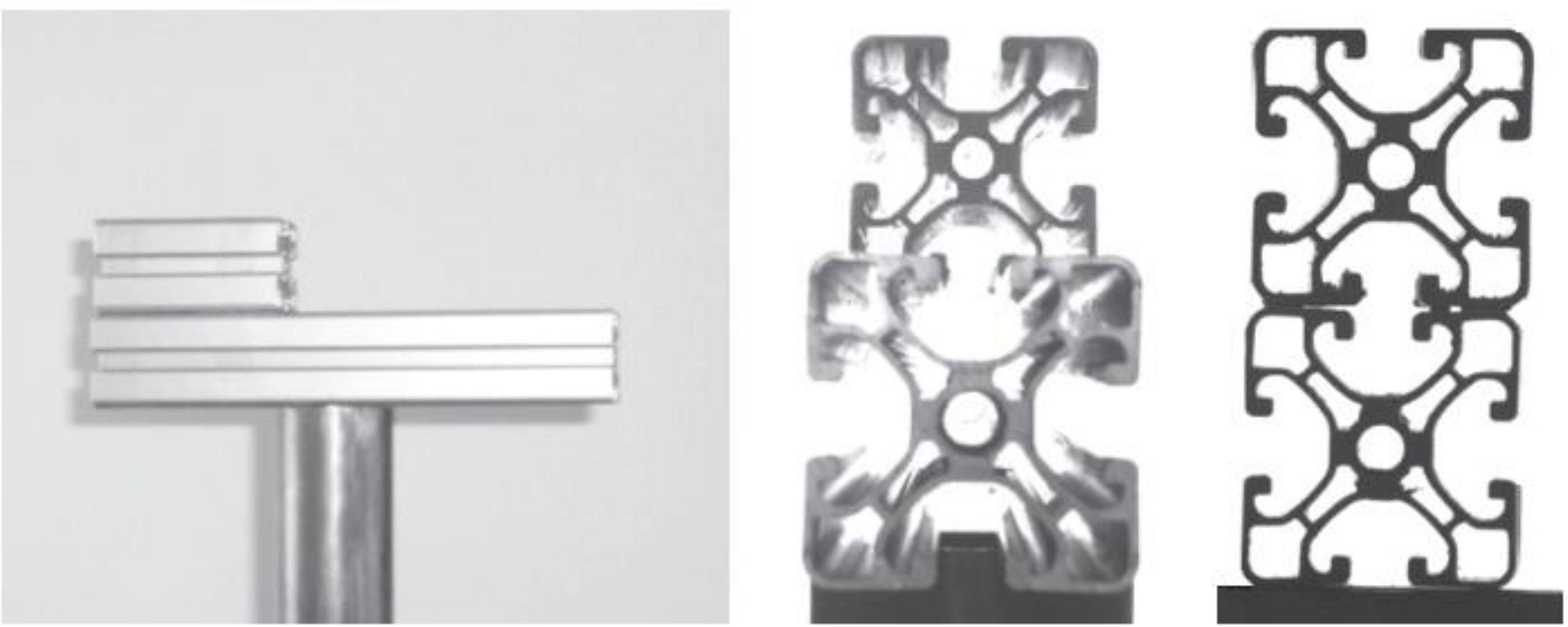
Lenses and Their Parameters

Type of Lenses

- Standard lenses
  They are prime lenses with a fixed focal length and larger maximum aperture which the image is comparable to the image as seen by the human eye.
- Zoom lenses
  They are larger, less robust, more expensive, and have smaller apertures when compared to fixed-focal length lenses.
- Wide-angle lenses
  They offer a wide field of view, there is the disadvantage of introducing distortion and a shift in perspective of the objects.
- Telecentric lenses
  They provide constant magnification for any object distance. They are useful for applications that require high accuracy gauging
- Superzoom lenses
- Macro lenses

Lenses and Their Parameters

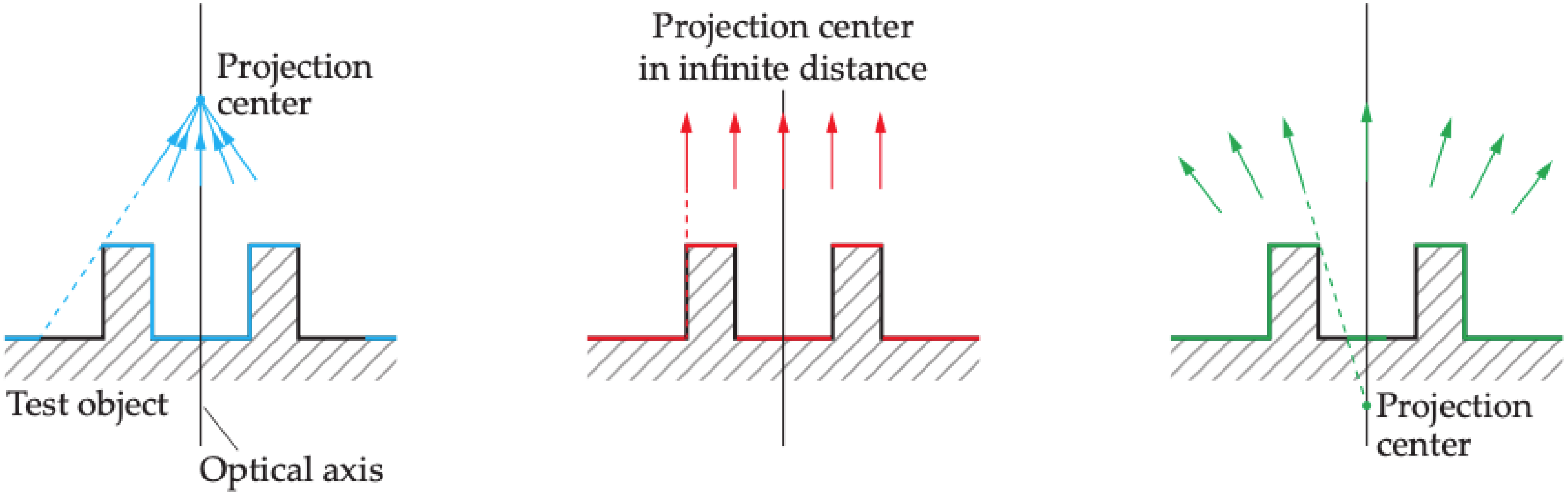


(a) (b) (c)

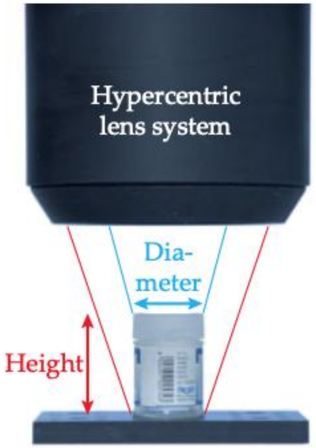
Figure 3.19. Images captured with a telecentric system: (a) Two aluminum profiles captured from the right side by a camera, (b) Images captured by a usual (entocentric) system, (c) Images captured by a telecentric system.

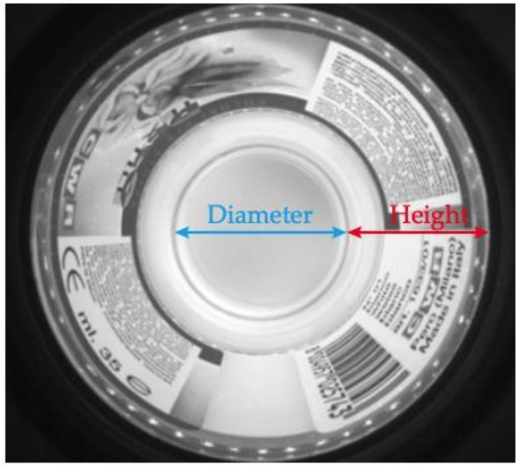
Beyerer, Jürgen & León, F.P. & Frese, C.. (2015). Machine vision: Automated visual inspection: Theory, practice and applications.

Lenses and Their Parameters



(a) entocentric (b) telecentric (c) hypercentric





Beyerer, Jürgen & León, F.P. & Frese, C.. (2015). Machine vision: Automated visual inspection: Theory, practice and applications.

Lenses and Their Parameters

(a) Tilt-shift lens (b) No tilt (c) Lens tilted

Figure 3.28. Focused imaging of tilted planes by means of a tilt-shift lens: (a) Tilted lens; (b) Image of a PCB without tilting the lens; (c) Image of a PCB with a tilted lens. Both images were acquired with an opened stop.

Beyerer, Jürgen & León, F.P. & Frese, C.. (2015). Machine vision: Automated visual inspection: Theory, practice and applications.

Lenses and Their Parameters

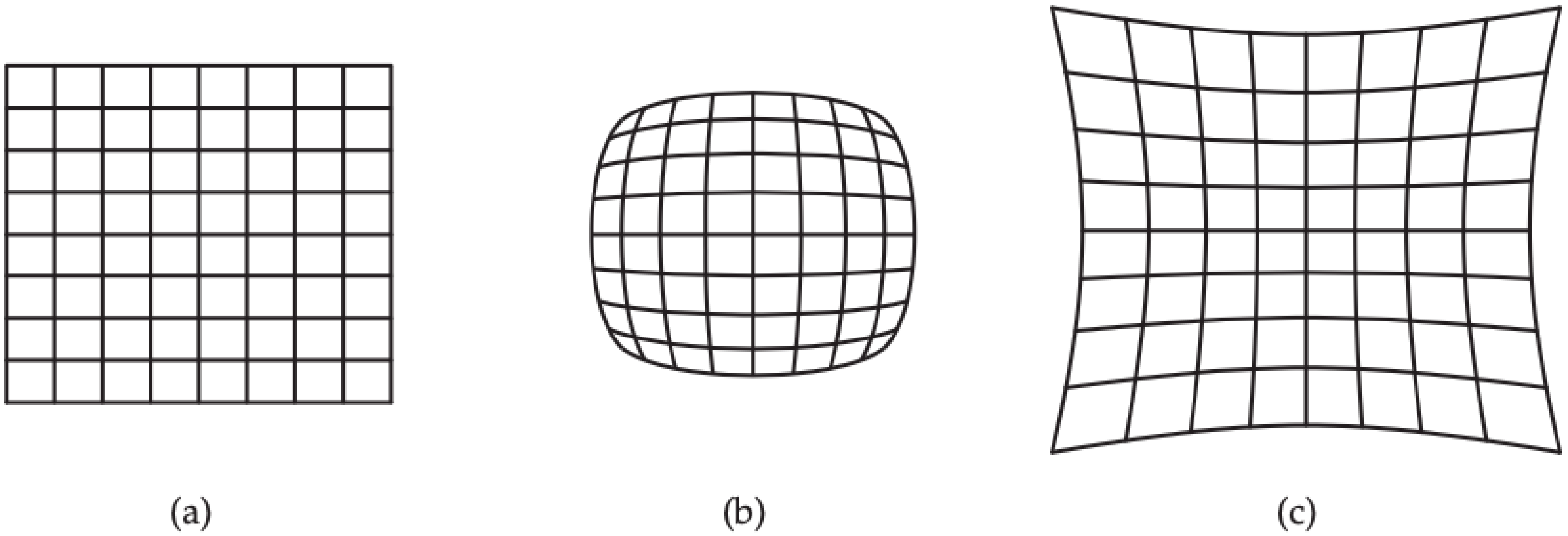


Figure 3.32. Image deformations caused by radial lens distortion: (a) Ideal, free of distortion, $a = 0$; (b) Barrel-shaped distortion, $a < 0$; (c) Pincushion distortion, $a > 0$ in (3.88).

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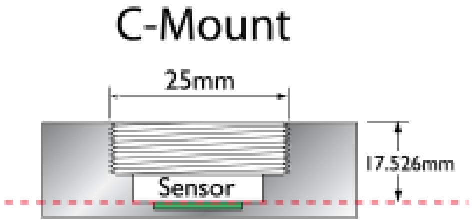
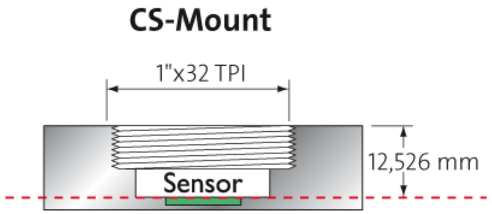
Lenses and Their Parameters

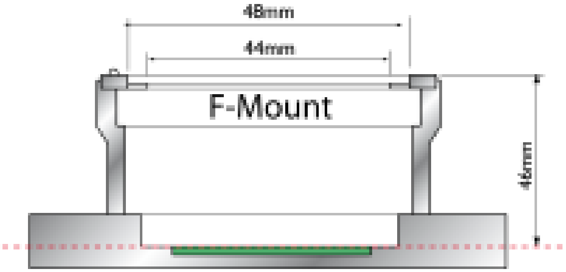
Lens Mounts

The mount size determines the shortest possible distance between the lens and the image sensor.

- C-mount
  the back focal distance of a C-mount connector is 17.526 mm.
- CS-mount
  the back focal distance of a C-mount connector is 12.526 mm.
- S-mount
  It is a standard small lens mount used in various surveillance CCTV cameras and webcams. It uses a male metric M12 thread with 0.5 mm pitch on the lens and a corresponding female thread on the lens mount
- F-mount
  It is commonly used for line scan cameras.
- T-mount or M42 mount
  It is used as an alternative to F-mount for line scan cameras or high resolution sensors as it is considered more robust.

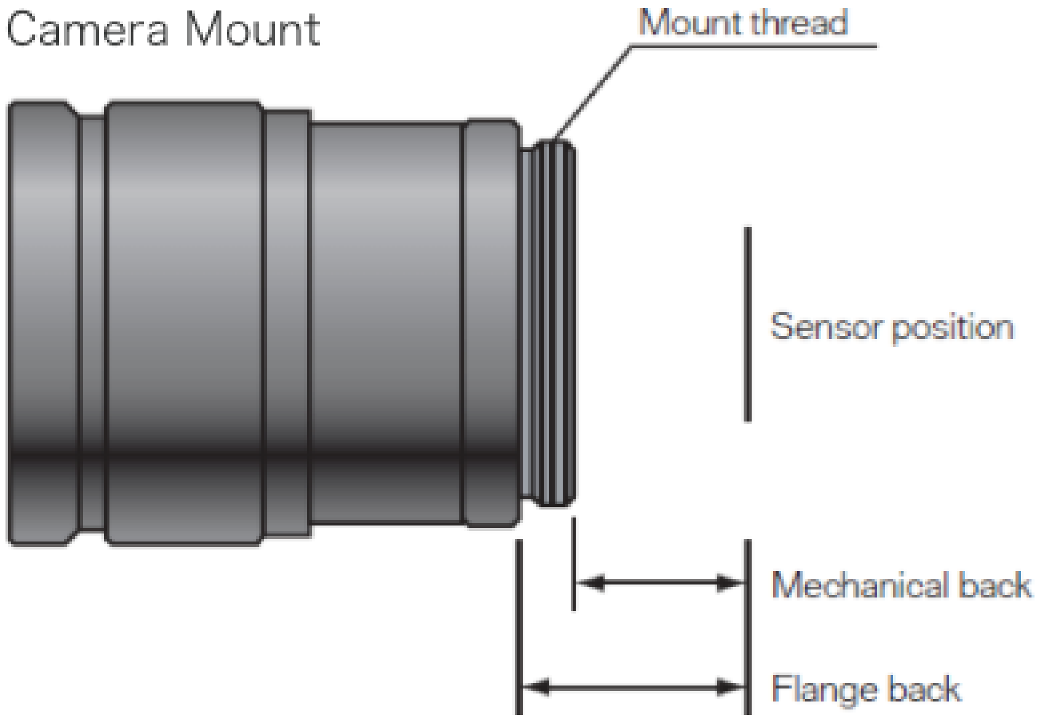






https://www.stemmer-imaging.com/en/knowledge-base/lens-mounts/

Lenses and Their Parameters



Area Camera

C-mount	FB (mm)
CS-mount	17.526
M-mount	12.526
S-mount	M15.5/P0.5
	M10.5/P0.5

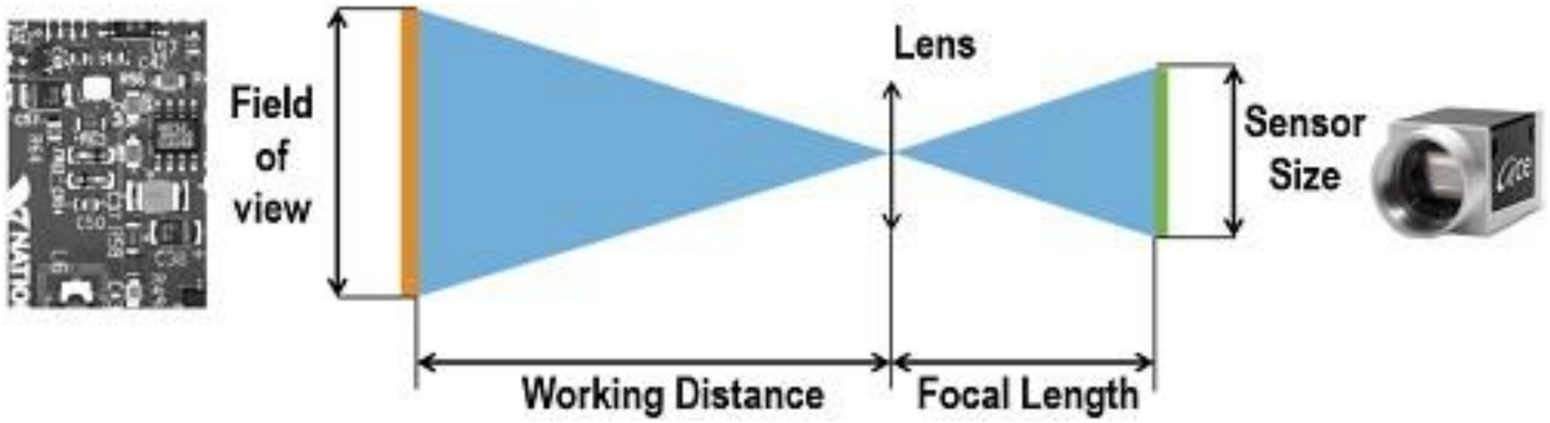
Line Camera	FB (mm)
F-mount	46.5
M42-mount	* 1
M72-mount	* 1

https://vst.co.jp/en/support/lens-choice/

Lenses and Their Parameters

Lens Selection Examples

- To choose a lens, there are three important lens parameters to consider in the selection process
  - Field of View
  - Working distance
  - Sensor size of the camera



$$Magnification = \frac{Sensor\ size\ of\ the\ camera}{Field\ of\ view}$$

$$Focal\ length = Working\ distance \times Magnification$$

$$Sensor\ Resolution = Image\ Resolution = 2\left(\frac{Field\ of\ View\ (FOV)}{Smallest\ Feature}\right)$$

https://www.ni.com/en-th/support/documentation/supplemental/18/calculating-camera-sensor-resolution-and-lens-focal-length.html

Lenses and Their Parameters

- Lens for field of view (image size) that is much larger than camera sensor size

FOV = 50 mm

Working distance = 200 mm
Sensor size = 8.8 mm (based on 2/3″ sensor size)

$$Magnification = \frac{Sensor\ size\ of\ the\ camera}{Field\ of\ view}$$

$$Focal\ length = Magnification \times Working\ distance$$

Magnification = 8.8 / 50 = 0.176
Estimated focal length = 0.176 x 200 = 35.2 mm

As lenses come with certain fixed focal distance, it would not be possible to find a lens with the exact focal length. Three options are available for the appropriate lens.

1. Select a 35 mm lens to provide your application with a bigger field of view at the expense of resolution.
2. Increase your working distance by selecting a 50 mm lens (moving your camera and lens farther away from the object you are looking at increased FOV).
3. Select a 35 mm lens and add an extension ring to it. The extension ring to be chosen to provide the additional focal length of 0.2 mm (35.2–35 mm).

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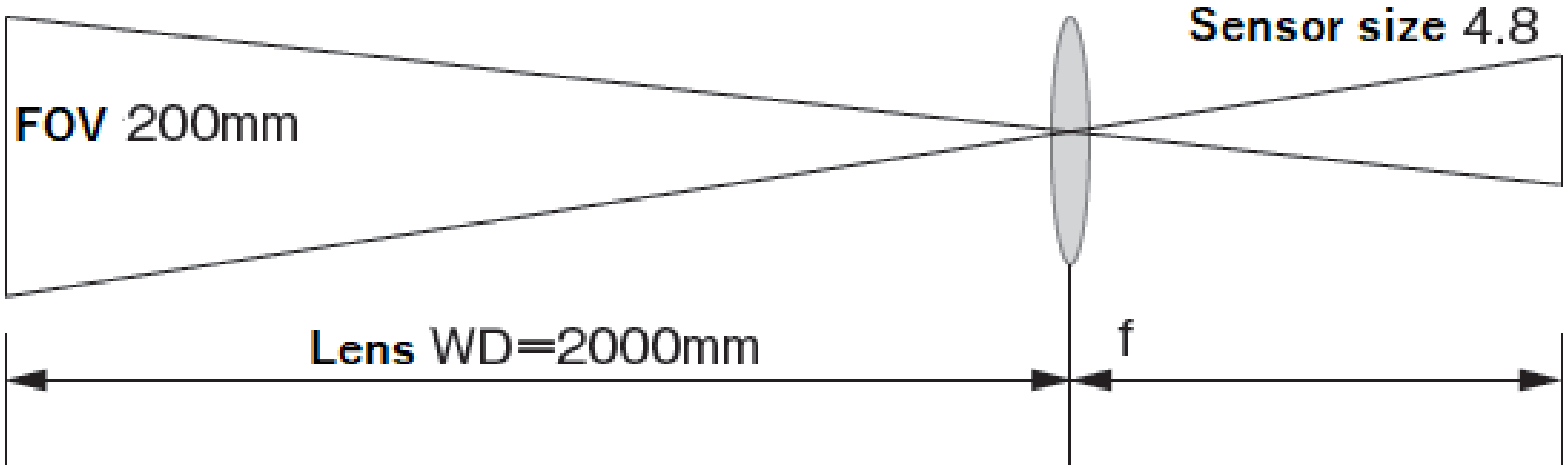
Lenses and Their Parameters

- Calculate Focal Length of a lens

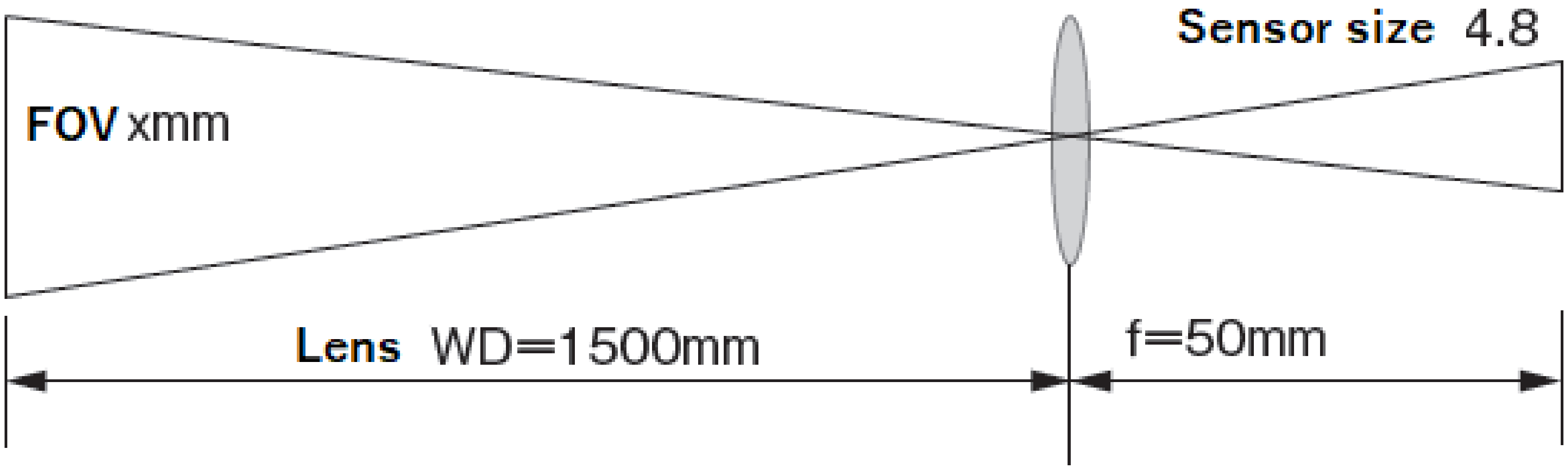


f = 2000 x 4.8 / 200 = 48 mm

https://vst.co.jp/en/support/lens-choice/

Lenses and Their Parameters

- Calculate Field of View (FOV)

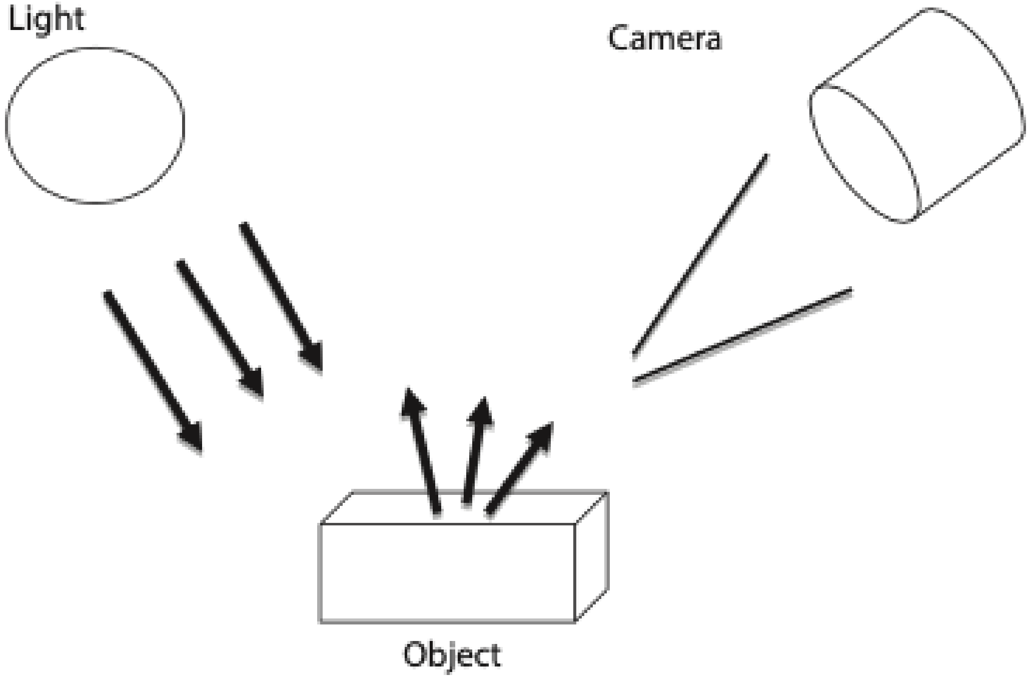


FOV = 1500 x 4.8 / 50 = 144 mm

https://vst.co.jp/en/support/lens-choice/

Machine Vision Lighting

- The lighting must be uniform and consistent and controlled to provide a clear image that is not too bright or too dark.
- Lighting is chosen based on the size, shape, color, and texture of the object to be imaged.
- To illuminating an object, we refer to two distinct aspects: the light source and the lighting technique.
- Lighting can be used to silhouette a part of an image to allow measurement of its edges.
- A diffuser can be used to spread light over an object, while a collimator is used to make the light rays parallel.
- A polarizer is used to reduce glare reflected from the surfaces of objects.



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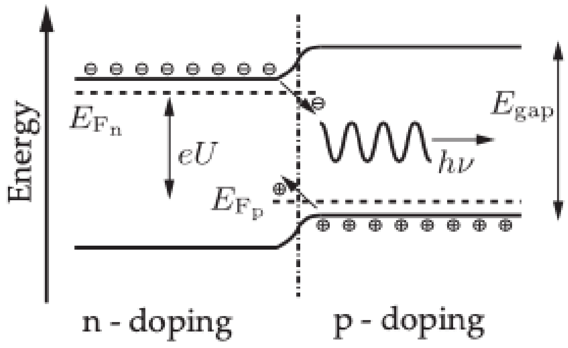
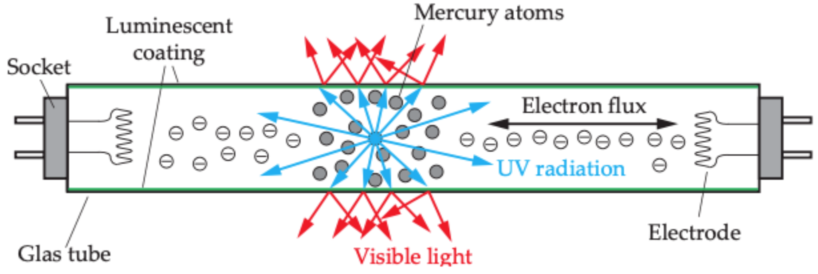
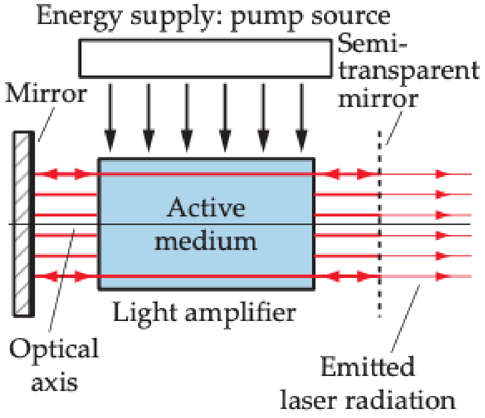
Machine Vision Lighting



Light sources

- LEDs (ligth-emitting diodes)
- Fluorescent lamps
- Halogen lights
- Lasers (Light Amplification by Stimulated Emission of Radiation)





An important consideration when choosing the light source is the ambient or background light present in the room. Common sources of ambient light are factory lights, sunlight, and other specific lighting at inspection points. Ambient light can vary depending on time of day or weather or season. The light used to illuminate the part that needs to be inspected should be bright enough to offset the ambient light to obtain a good-quality image and maintain the consistency of inspections.

Beyerer, Jürgen & León, F.P. & Frese, C.. (2015). Machine vision: Automated visual inspection: Theory, practice and applications.ç

Machine Vision Lighting

Table 2.7. Comparison of the properties of artificial light sources.

	Durability	Suitability for pulsed operation	Spectrum	Polarization	Coherence	Speckle
Halogen lamp	3,000 h	good	'gray' radiator	no	low	no
Fluorescent lamp	4,000 h up to 25,000 h	no	continuous, depending on the luminescent materials	no	low	no
Metal vapor lamps	6,000 h	no	continuous, with superposed lines	no	low	no
Xenon short-arc lamp	1,000 h	no	in the visible part: similar to the blackbody radiator	no	low	no
Light-emitting diode	100,000 h[a]	very good	monochrome: 30–40 nm line width	no	low	no
Laser	high for diode-lasers	very good, pulsed operation possible	line spectrum, monochromatic	yes	high	yes

[a]for high performance LEDs 30,000–50,000 h

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Machine Vision Lighting

Table 2.8. Luminance of different light sources [33].

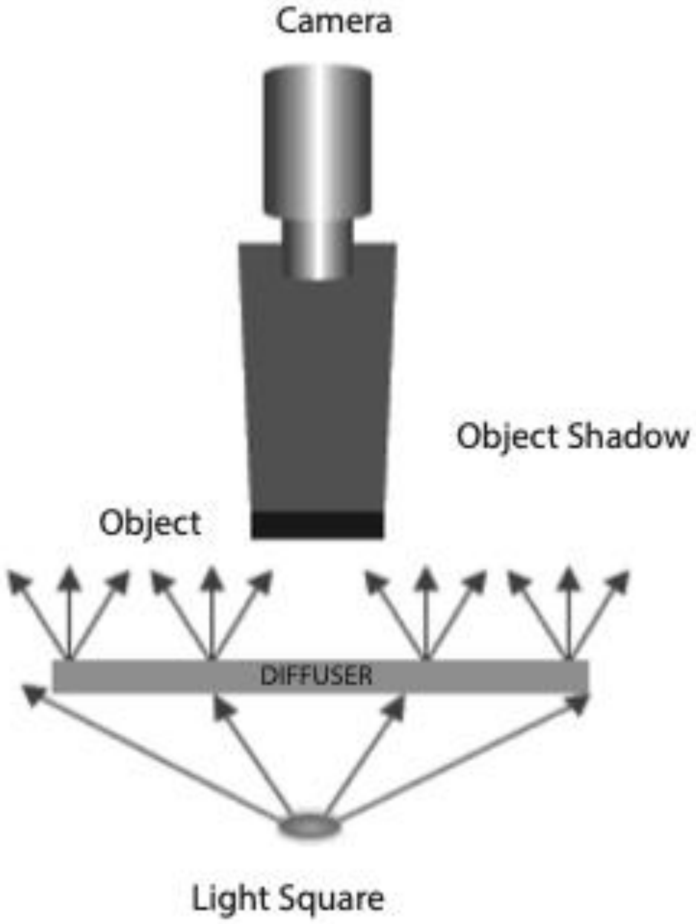
Type	Light source	Luminance L_l in cd/cm^2
Natural	Noon sun	100,000 – 150,000
	Full moon	0.25 – 0.35
	Clear sky	0.3 – 0.7
	Cloudy sky	0.01 – 0.2
Artificial	Xenon short-arc lamp	20,000 – 500,000
	Arc lamp	20,000 – 180,000
	Mercury-vapor high pressure lamp	20,000 – 40,000
	Incandescent lamp, clear	200 – 5,000
	Sodium-vapor high pressure lamp, clear	300 – 550
	Fluorescent lamp	0.3 – 3
	Light-emitting diode	0.01 – 5,000

Beyerer, Jürgen & León, F.P. & Frese, C.. (2015). Machine vision: Automated visual inspection: Theory, practice and applications.ç

Machine Vision Lighting

Illumination Techniques

- Back Lighting
  The camera is at the front of the object. The diffuser and light source are placed behind the object.
  Back lighting can be used to create a silhouette of the object. The shape of the object is outlined but surface details may not be clear. It also produces an image with high contrast.



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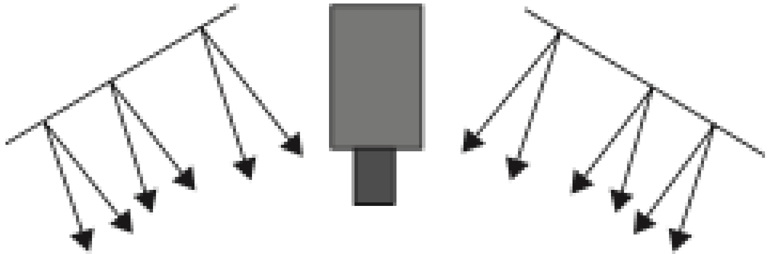
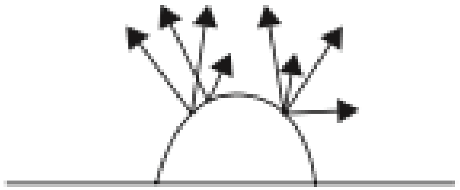
Machine Vision Lighting



Illumination Techniques



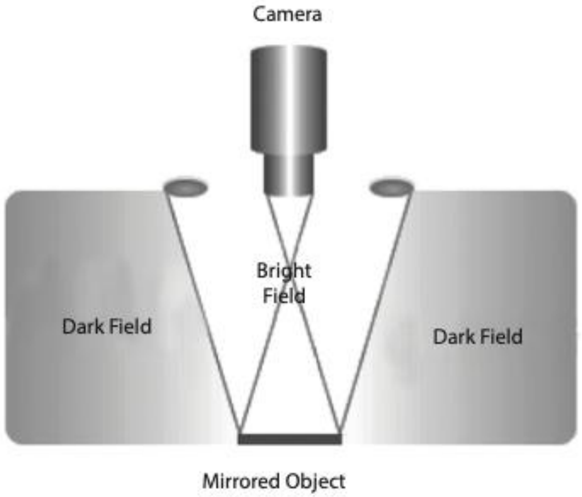
- Front Lighting

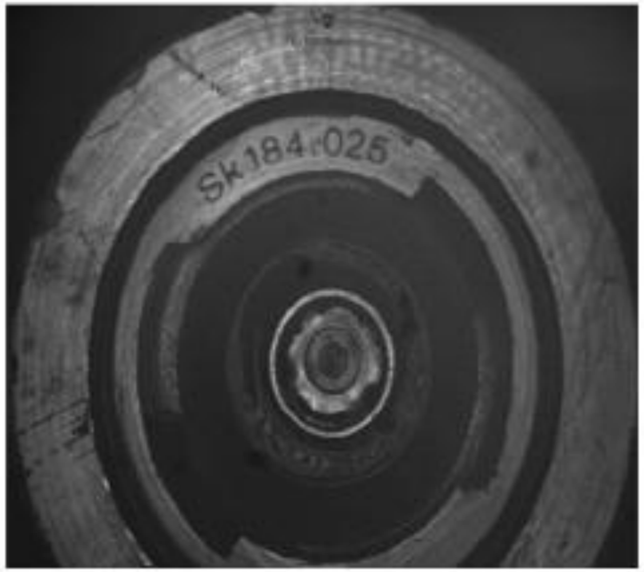
  The light source and camera are at the top of the object.

  This type of lighting is easy to set up and provides good contrast.

  Shadows may be created which can be avoided using multiple lights.

  A ring light can be used, for instance, to direct light onto the object.





Directional front lighting can be either bright field or dark field lighting.

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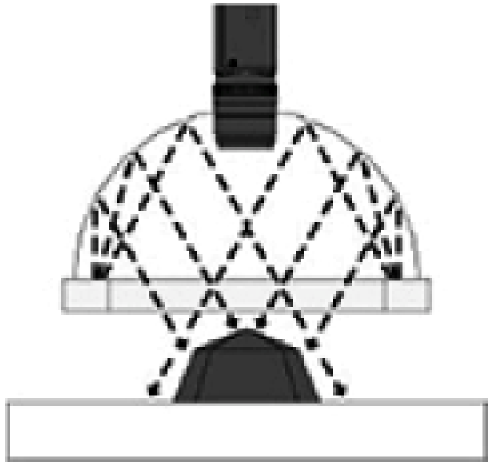
Machine Vision Lighting

Illumination Techniques

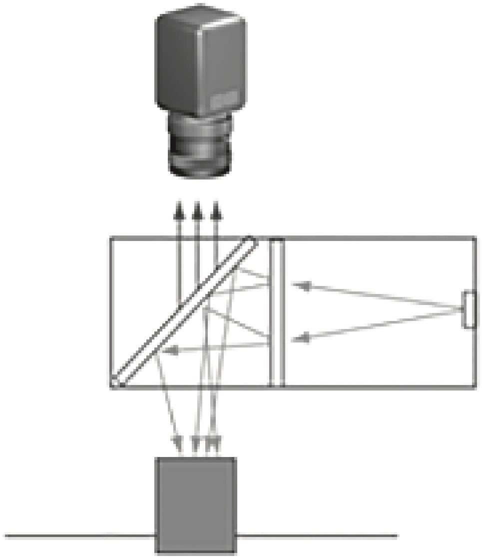
- Diffused Lighting
  It eliminates reflections and shadows, as light is directed onto the object from multiple angles.
  Diffusers provide a large illumination area that avoids glares.

  Diffused dome is used to provide evenly distributed uniform illumination to avoid shadows.

  Axial diffused lighting can be used to detect flaws on surfaces and to inspect the insides of cavities.



Diffused Dome Lighting



Axial Diffused Lighting

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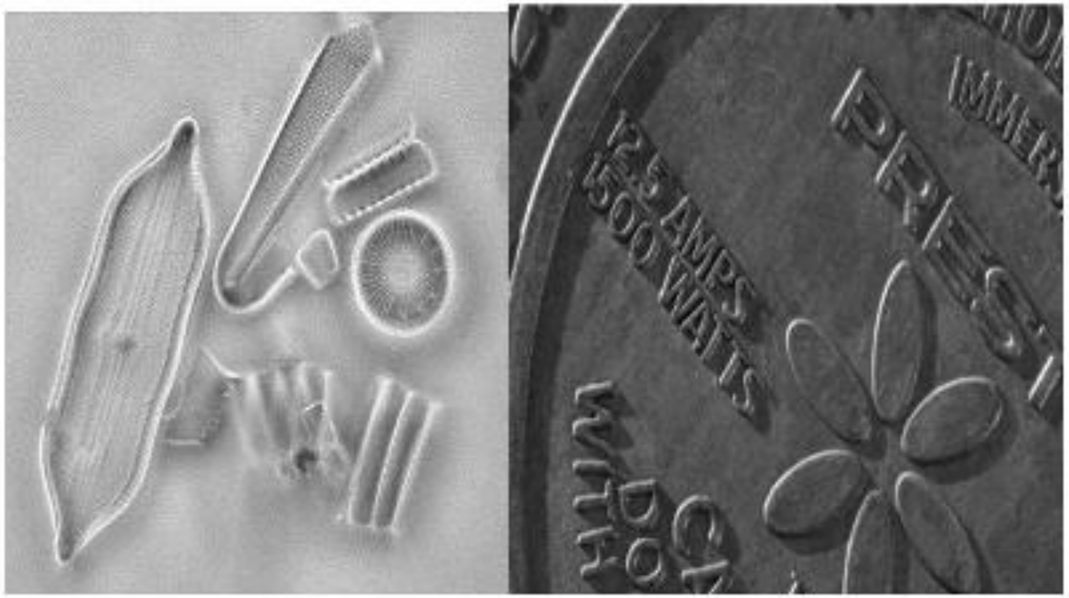
Machine Vision Lighting

Illumination Techniques

- Oblique Lighting

  The light falls with different angle of incidence from 0 to 15 degrees with respect to the object surface.

  This lighting helps to identify textural details such as dust or edges.



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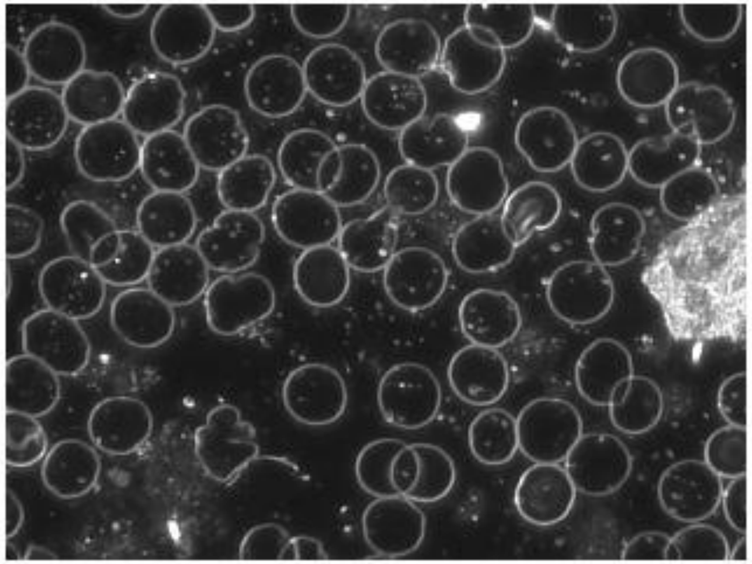
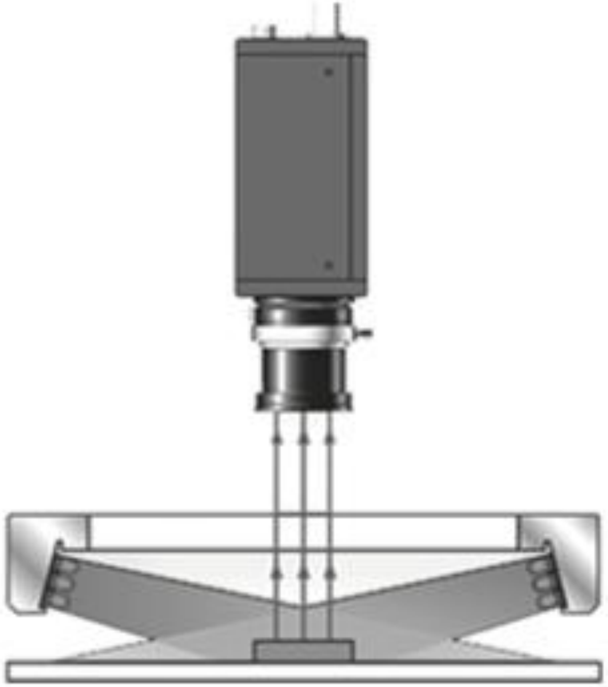
Machine Vision Lighting

Illumination Techniques

- Dark Field Lighting
  It is used to create a bright, easily detectable feature of interest within a dark background.
  Dark field lighting can be used for detecting surface defects like scratches, burrs, or other small raised features.





Dark Field Lighting

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Machine Vision Lighting

Illumination Techniques

- Infrared and Ultraviolet Light
  Light beyond the visible spectrum can be used in machine vision applications.

  Infrared light can be used to moderate the grayscale difference in colored objects. Dark objects absorb infrared light waves to obtain uniformity when there are varying shades.

  Ultraviolet (UV) rays can be used for imaging small features in an object. For example, bruises on fruit surfaces could be detected using UV light.

Machine Vision Lighting

Filters

- Color filters to emphasize or suppress specific wavelength ranges and colors
- Grey filters as “sun shades” to reduce the overall brightness
- Interference filters as band-pass filters for specific wavelength ranges
- Polarizing filters to avoid reflections on test objects
- Heat filters as protection against infrared and heat radiation
- Light control film to block diffuse background light

Machine Vision Software

- Integration and Compatibility
- Ease of Use and Cost to Operate
- Vendor Support and Stability