# 2
# Camera basics and Optics

## * Lighting

⇒ Lighting has a major influence on the image acquisition process.

↳ Controlling the lighting is important.

## * Types of Lighting

① Direct Incident light

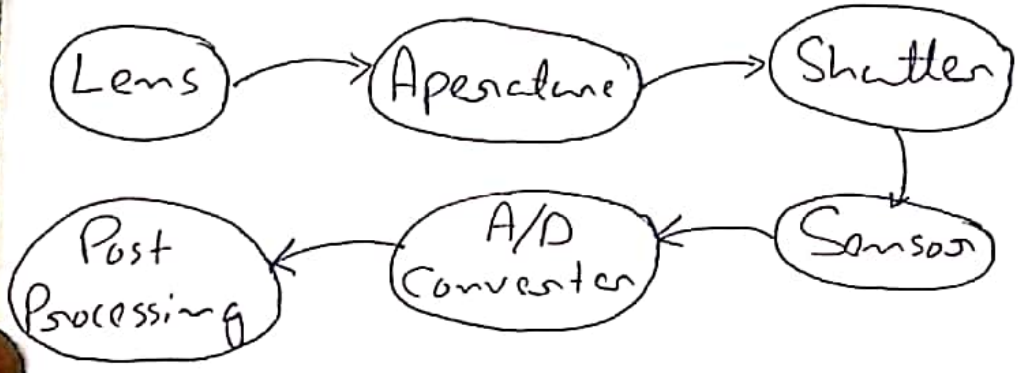
② Diffuse incident lighting

③ Lateral Illumination

④ Dark field illumination

⑤ Backlight illumination

## * Elements of a Digital Camera




## * Lens

⇒ Goal is to obtain images that are :-

- Not distorted
- Sharp
- Contrast intensive

⇒ The choice of the lens depends on

- field of view
- distance to the object
- amount of available light
- Price

# Moderate Tele Lens

→ Narrow field of view.
→ Minimal perspective distortions.
  ↳ Parallel lines remain parallel

# Wide Angle Lens

→ Useful for application that require a large field of view (70 and 120°)
→ Straight lines are roughly straight
→ Perspective distortions.
→ Proportions are not correct anymore.

# Fisheye Lens

→ Field of view of 130+ deg
→ Straight lines in the world are not straight anymore in the image.

## * Sensor

→ The image sensor converts photons to intensity values.
→ Array of light-sensitive cell.

⇒ Two main types of sensors:

- CCD: (Charge-coupled device)
  (lower noise, more expensive, global shutter)
- CMOS: (Complementary metal oxide on silicon)
  (higher noise, cheaper, rolling shutter)

* Sensor Size

→ Larger Sensor Cells can Collect more light per time interval.

→ Larger chips are more expensive to produce.

→ Larger chip produce good quality image at low lighting conditions.

* Sampling pitch

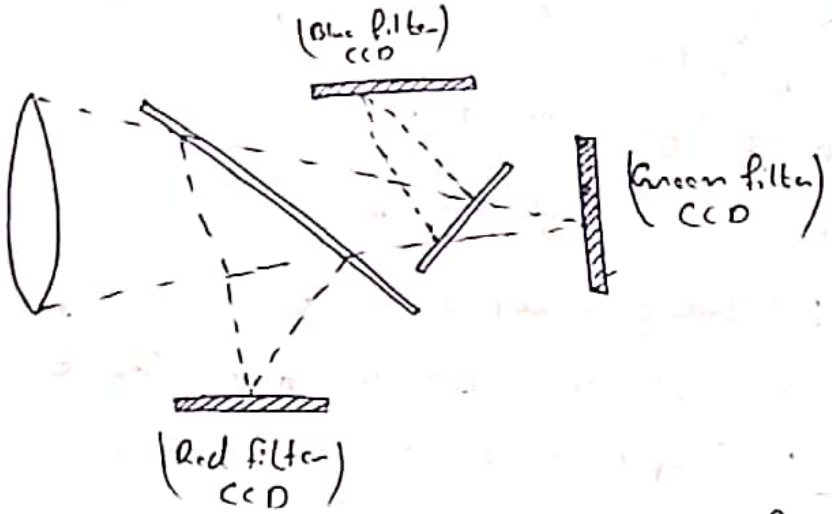
⇒ Sampling pitch is the physical spacing between (the centers of) adjacent Sensor Cell

* Fill Factor

↳ Active sensing area size as a fraction of the theoretically available sensing area.

* Three-Chip Camera

⇒ Three chips with Separate filters for red, green and blue.




* Single-Chip Camera

→ Cheaper but lower quality.

Bayer Pattern

| | | | |
|---|---|---|---|
| G | R | G | R |
| B | G | B | G |
| G | R | G | R |
| B | G | B | G |

## * Color Filter Array (CFA)

| | | | |
|---|---|---|---|
| rGb | Rgb | rGb | Rgb |
| rgB | rGb | rgB | rGb |
| rGb | Rgb | rGb | Rgb |
| rgB | rGb | rgB | rGb |

⇒ Capital letter indicate directly measured value.

⇒ Small letter indicate interpolated value.

## * Bayer Pattern

- 50% Green
- 25% red and blue

⇒ Human Visual System is very sensitive to high frequency details in luminance.

## * demosaicing ⇒ Interpolation error.

## * Shutter

### ↳ Shutter Speed

→ Controls the amount of light reaching the sensor.

→ Longer exposure time = more light = Brighter image

→ Longer exposure time leads to motion blur.

## * Rolling Shutter

↳ The shutter rolls (moves) across the exposable image area.

→ The pixels of the same line of the image are recorded at the same time.

→ Produces distortions in case of fast moving objects or camera.

↳ Often found in CMOS cameras.

## * Global Shutter

⇒ The whole image is recorded at exactly the same time.

⇒ Often found in CCD cameras.

⇒ Preferable for geometric reconstruction tasks.

## * Models for light Propagation

① Geometric or ray optics

② Wave optics based on Maxwell's equation.

③ Particle / quantum optics based on the wave-particle duality.

## * Geometric optics

### Axioms

① A light ray is a straight line in homogenous material.

② At the border between two homogenous materials, the light is reflected (Fresnel reflection) or refracted (Snell's Law).

③ The optical path is reversible

④ Intersecting light rays do not influence each other.

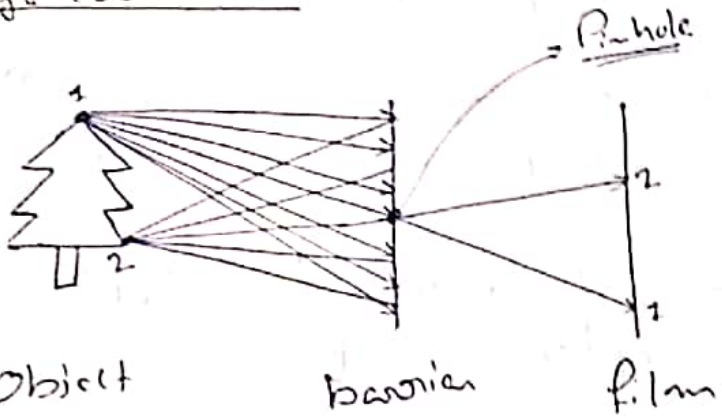
⑤ $C = 2.998 \times 10^8$ m/s

$V = \frac{C}{\eta}$ ← (Speed of light in material)

$C \longrightarrow$ (Speed in Vacuum)

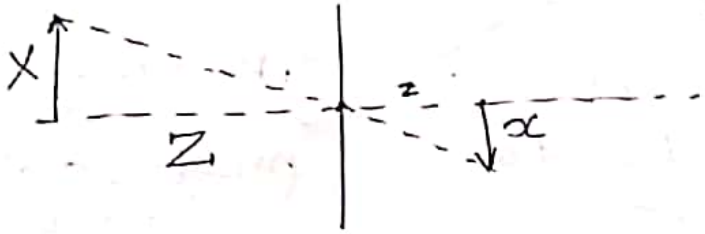
$\eta \longrightarrow$ (Refractive index)

## ★ Image Formation




## Working of Pinhole Camera

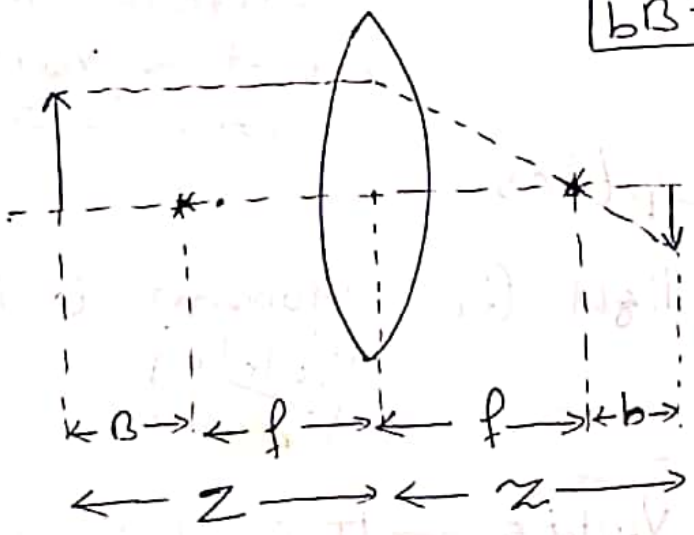
## ★ Pinhole Camera Model




* Image Scale $m = \frac{z}{Z}$
* Mapping $x = -mX$

## ★ Camera with thin lens

$$bB = -f^2$$




$$\frac{1}{f} = \frac{1}{z} - \frac{1}{Z}$$ {Law of thin lens}

* Aperture and Depth of Field

→ Controls the amount of light on the sensor chip and the depth of field.

→ Range of distance that appears acceptably sharp.

* Aberration

↳ Deviation from the ideal mapping with a thin lens is called aberration.

- Destortion → Barrel distortion
  → Pincushion distortion
  → Mustache distortion
- Spherical aberration
- Chromatic aberration
- Astigmatism → different focus Point in vertical & horizontal direction
- Comatic aberration
- Vignetting

* Wave Optics

⇒ Visible light from 400nm to 700nm (Violate blue) Red

⇒ Monitoring Vesitation → Infrared Spectrum is very useful

* Quantum optics

⇒ Useful for describing the interaction between light and matter.

$$Q = h\nu$$

$h$: $6.625 \times 10^{-34}\ W s^2$ (Planck constant)

* Reflectivity

⇒ General model of light scattering is the Bidirectional Reflectance Distribution Function (BRDF)

$$f_r(\theta_i, \phi_i, \theta_r, \phi_r, \lambda)$$

⇒ Describes how much light of each wavelength arriving at an incident direction is emitted in a reflected direction.

* Albedo
  - → Reflecting power of a surface.
  - → Values in $[0, 1]$

⇒ Most image formats (JPG, PNG, ...)
  - → Each R, G, B channel uses 1 byte
  - → $2^8 = 256$ different intensity values.