Machine Vision

Lecture Set – 09

Optics

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Robot Vision Lab

Basic Optics

- Light rays which enter the camera through an angular aperture (pupil) and hit the image plane
- Light rays are the result of reflections of the rays emitted by the light sources and hitting object surfaces
- Lenses are used to increase the light gathering power of the instrument (otherwise, pinhole camera)

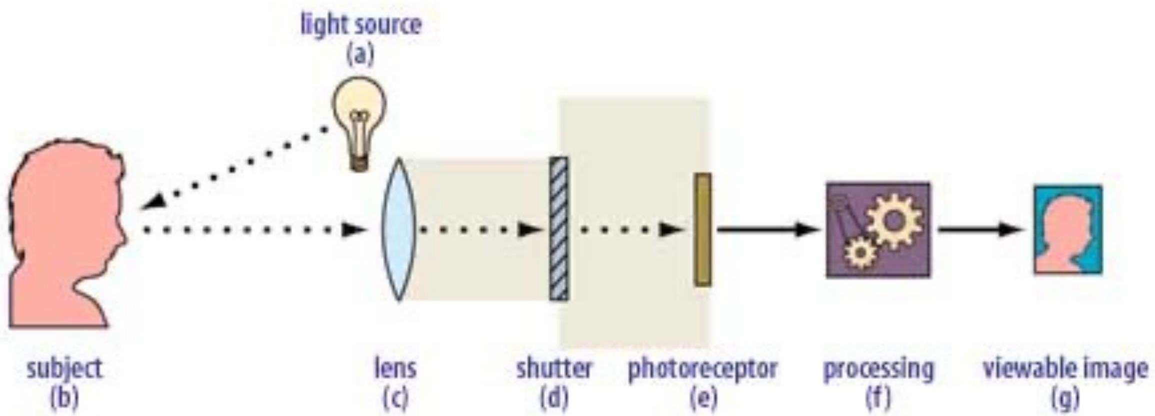
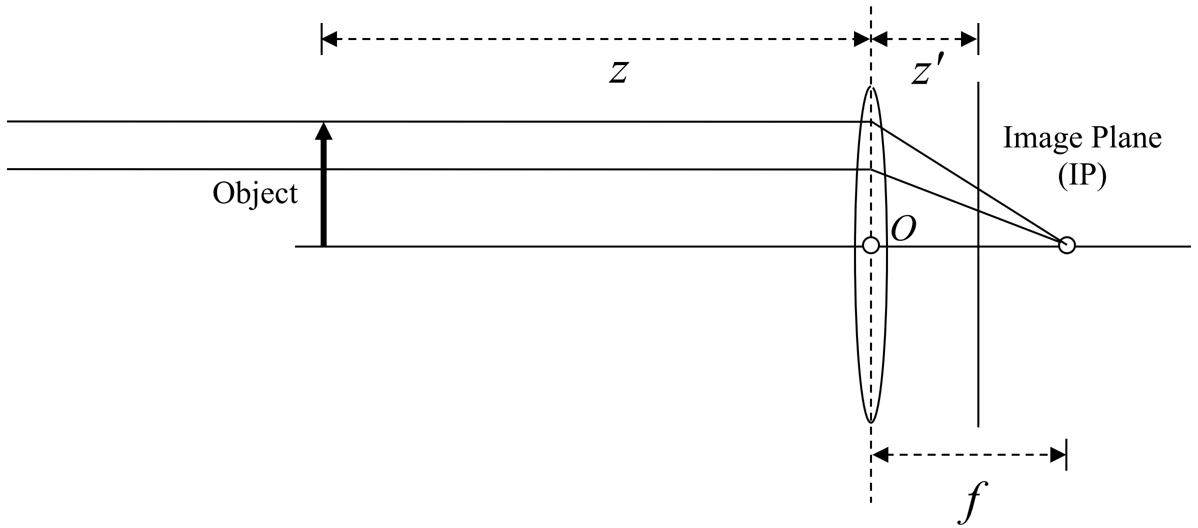


Image Focusing

- A scene point is in focus if all rays coming from the point converges to a single point on the image
  - What should be considered?
    - Pinhole model – exposure time
    - Optical system – lenses, shutter, etc.
- Thin lens (model)
  - Any ray entering the lens parallel to the axis on one side goes through the focus on the other side
  - Any ray entering the lens from the focus on one side merges parallel to the axis on the other side

Thin Lens Equation

- The fundamental equation of thin lenses: $$-\frac{1}{z}+\frac{1}{z'}=\frac{1}{f}$$
- When $z \to \infty$, $z' \to f$
  - The focal length f is the distance of the IP from the optical origin when parallel rays are focused to a single point in the IP
  - z' is called the camera constant (distance between lens and IP)



Thin Lens Model

- When the lens is focused on a point not at infinity
  - $z' < f$
  - Using f to approximate z' overestimates the camera constant
  - Should change the image plane position (or lens position)

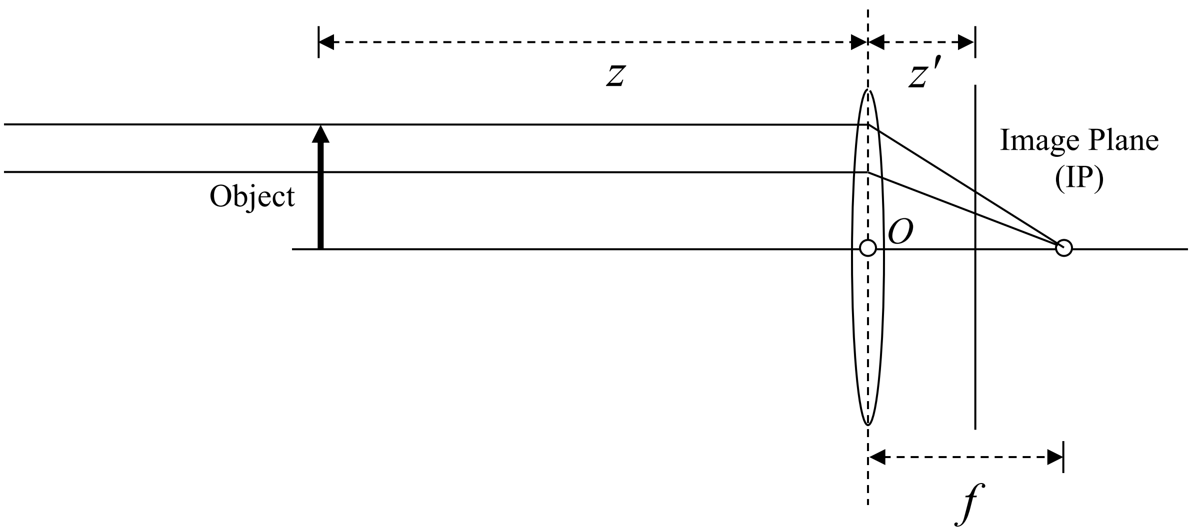


Image Resolution

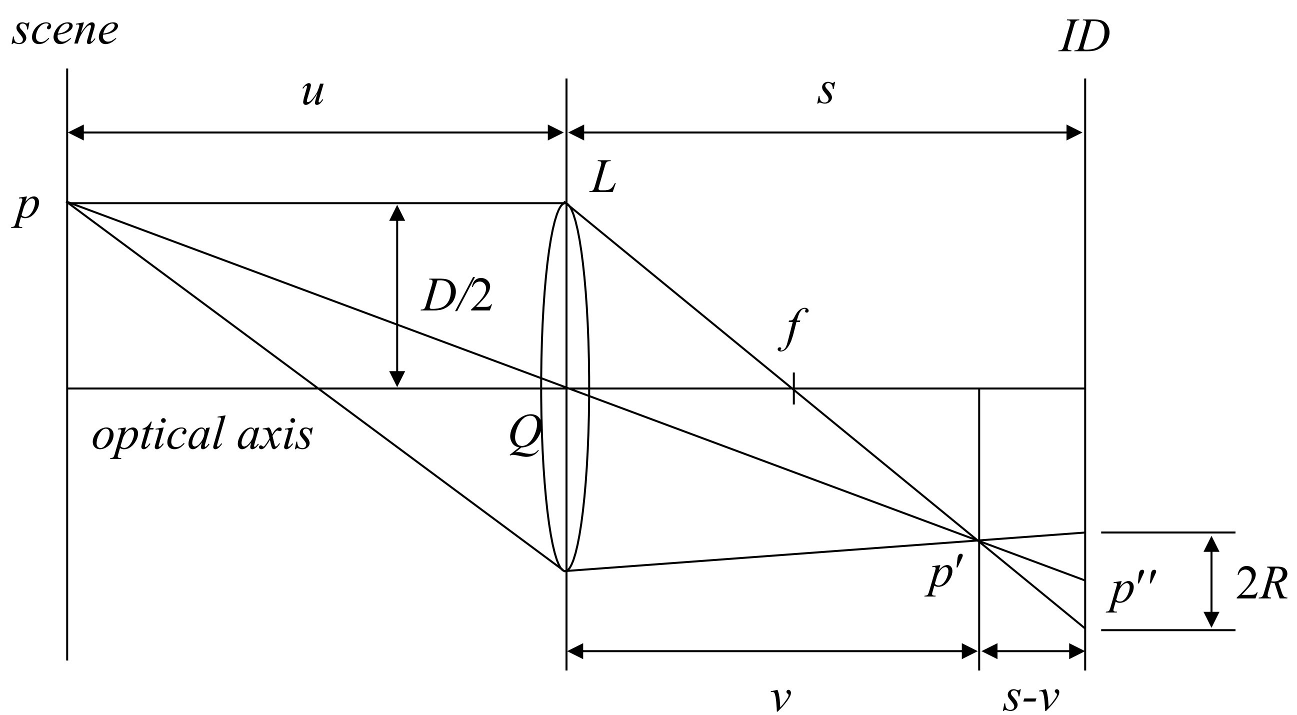
- Spatial resolution is determined by
  - Pixel spacing
  - Lens aberrations
  - Diffraction
  - Depth of field
- If the pixel spacing is Δ, then the resolution limit is 2Δ (Why? To distinguish features!)
- For photographic film, a typical spacing between grains is 5 μm
- The pixel size of current CCD is about 3~5 μm

Depth of Field

- Aperture size
  - Large – more light, faster shutter speed, small depth of field
  - Small – less light, large depth of field
- According to the lens equation, for a particular image plane at z', only points at distance z are in focus
- However, some amount of defocusing below the resolution of the imaging device can be tolerated
- Depth of field
  - A range of image plane distance z' with an acceptable level of defocusing and a corresponding range of scene distance z

Defocus

- When a scene point is out of focus, it creates a blur circle instead of a single point on the image plane



Blur Circle

- Let focal length f, aperture diameter d, blur circle diameter b, and in focus image plane distance be z'
- If the image plane is moved closer to the lens, at distance z_1', then the amount of blur is given by

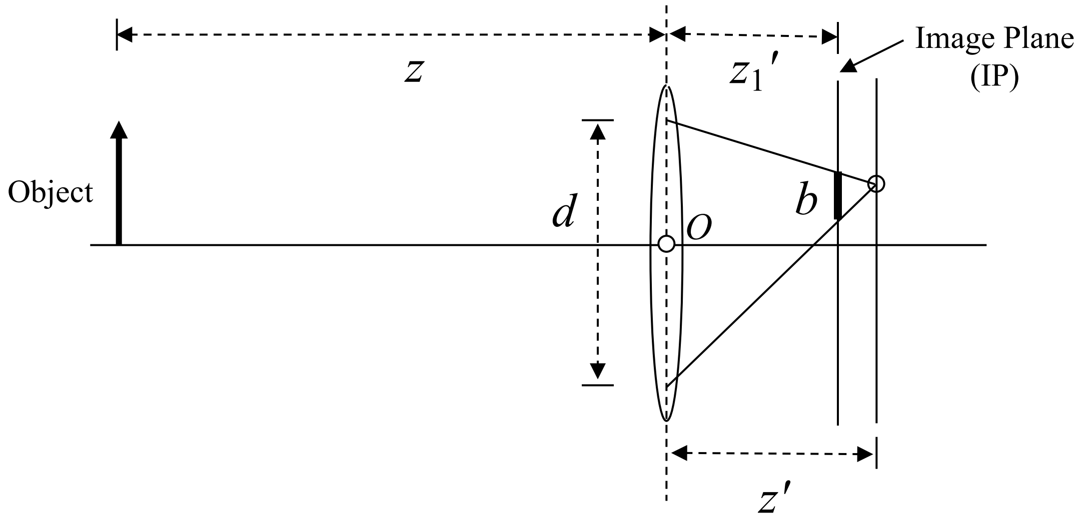
$$b_1 = \frac{d(z' - z_1')}{z'} = \frac{df(z - z_1)}{z(f + z_1)}$$

- If the image plane is moved further to the lens, at distance z_2', then the amount of blur is given by

$$b_2 = \frac{d(z_2' - z')}{z'} = \frac{df(z_2 - z)}{z(f + z_2)}$$

- See the next page for the derivation of b_1 and b_2

Derivation of Blur Circle



$$\frac{d}{b} = \frac{z'}{z'-z_1'} \Rightarrow b = \frac{d(z'-z_1')}{z'}$$

$$-\frac{1}{z} + \frac{1}{z'} = \frac{1}{f} \Rightarrow z' = \frac{zf}{z+f}$$

$$b = \frac{d(z'-z_1')}{z'} = d\left(1-\frac{z_1'}{z'}\right) = d\left(1-\frac{z_1 f}{z_1+f}\cdot\frac{z+f}{zf}\right) = \frac{df(z-z_1)}{z(z_1+f)}$$

Depth of Field

- From the above equations, z_1 and z_2 are given by

$$z_1 = \frac{fz(d - b_1)}{df + b_1 z} \quad \text{and} \quad z_2 = \frac{fz(d + b_2)}{df - b_2 z}$$

- Suppose b_1 and b_2 are the maximum acceptable defocusing for near and far scene (let it be b, i.e., $b_1 = b_2 = b$)
- Then the depth of filed D is given by

$$D = z_2 - z_1 = \frac{2bdfz(f + z)}{d^2 f^2 - b^2 z^2}$$

View Volume

- Six bounding planes for a view volume
  - Near and far planes by focus constraint
  - Four planes constrained by viewable area of an image

Exposure

- Exposure
  - The amount of light collected by the camera

$$\varepsilon = E\, t$$

  - E : image irradiance (the intensity of light falling on the image plane)
- F-number (F-stop)
  - The ratio of the focal and aperture diameter
  - F-number = $f \,/\, d$
  - Increases with multiple of $\sqrt{2}$ (light increases with multiple of 2)
  - 2.8, 4, 5.6, 8, 11, etc.

Reading

- Chapter 8 of Jain's book