OPTICS

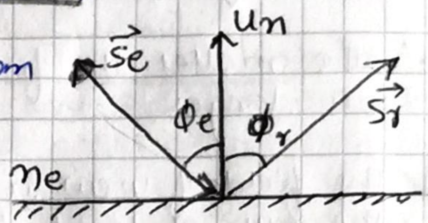
1. When we deal with technical optics, we only consider geometrical optics, where, the scale is bigger than the wavelength of light. It can be explained as the emission of light rays. (Vectors)

2. For this, we go with Fermat principle: (The optical path (distance x refract-index n of the medium), will be an extremum.

3. When considering optical imaging, we consider point to point (stigmatic imaging) which means that a ray of light after incidenting at a surface will stay a ray (or a point) and also images a point.

4. In reality, the imaging is astigmatic (i.e. point to area)

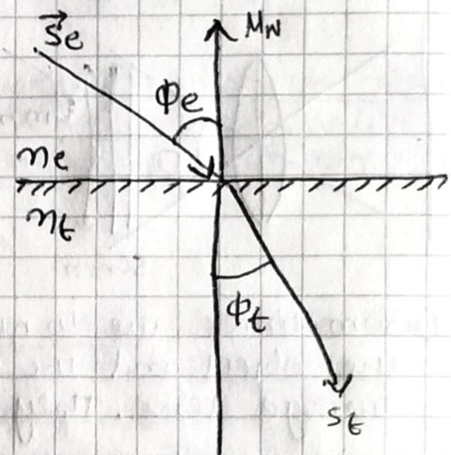
5. Reflection law: If our angle of incidence is less than the critical angle, then we would have total reflection.



$$\vec{s_r} = \vec{s_e} + 2\vec{u}_n \cos\phi_e$$

$$\vec{s_e} - 2(\vec{s_e}, \vec{u}_n)\vec{u}_n \quad \text{or} \quad \phi_e = \phi_r$$

6. Refraction law: If the angle of incidence is greater than the critical angle, we have refraction.



$$n_e \sin\phi_e = n_t \sin\phi_t$$

$$n_t \vec{s_t} = n_e \vec{s_e} + (n_t \cos\phi_t - n_e \cos\phi_e)\vec{u_n}$$

$$\cos\phi_e = (\vec{u_n}, \vec{s_e})$$

$$\boxed{n_t \cos\phi_t = \sqrt{n_t^2 - n_e^2 + n_e^2 \cos^2(\phi_e)}}$$

7. Usually, we have 2 kinds of imaging i.e. < Stigmatic / Astigmatic

Stigmatic → point in the object space is a point in the image space.

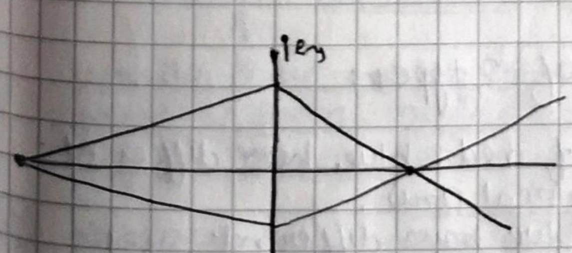
Collinear → line in the ~~image~~ object space is a line in the image space.

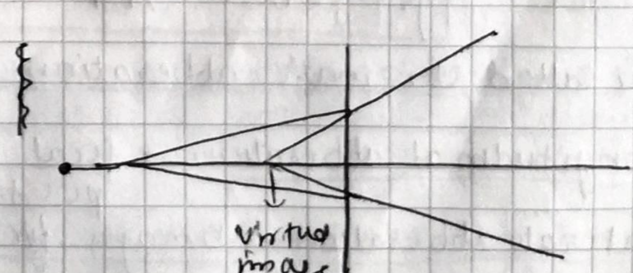
In Reality, point in the ~~image~~ object space is a area in the image space.

8. To produce this imaging, we have 2 different kinds of lenses i.e. convex and concave.

Convex lens → with convex lens, we would have a real image formed behind the lens

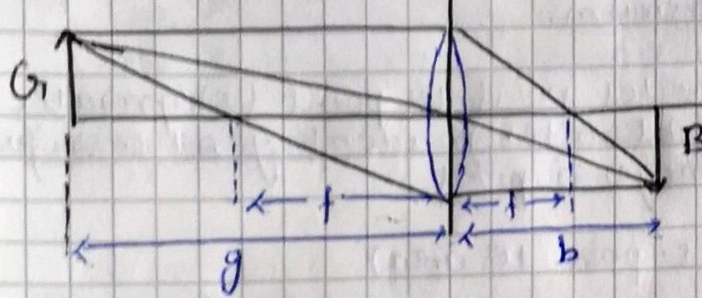
Concave lens → with a concave lens, we will have a virtual image formed in front of the lens. (focal length)





(9) In reality, we have a combination of convex and concave lenses to overcome the short comings of each lenses (such as abberation, etc)

(10) mostly, the parameters, such as refraction, magnification, etc are calculated by considering thin lenses.



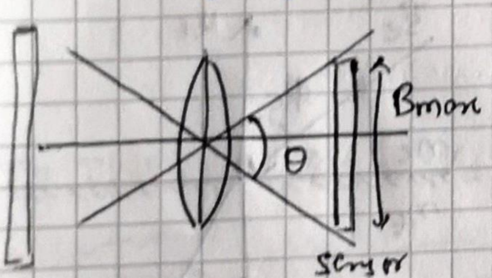
we calculate the amount of refraction in dioptrin [dpt]

$$\frac{1}{b} + \frac{1}{g} = \frac{1}{f} = D$$

$$\beta = \frac{B}{G} = \frac{b}{g} \Big\} \text{ imaging scale.}$$

∴ The smaller the focal length, the wider the FoV
larger " " , the narrower the FoV.

(11) The field of view is always in correlation with the images on which the rays of light from the object are projected to.

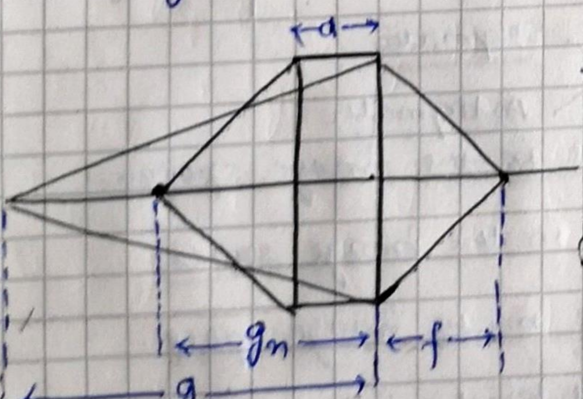


$$\boxed{\theta = 2\arctan\left(\frac{B_{max}}{2f}\right) \Big\} \text{ field of view}}$$

focal length

→ Eg (inspection tests)

(12) Sometimes, we do not have an option to reduce the distance b/w the object and the workpiece. To counteract these, we use the close range lens. They reduce the minimal object distance.



nominal object distance

$$g_n = f_N \frac{g-d}{f_N + (g-d)}$$

focal length relations $f_{N0} = \frac{1}{f_N} + \frac{1}{f_0}$

(13) During imaging, we encounter errors, called imaging errors: light is composed of several colours, which we usually don't see. when a white light enters a optically active medium (eg. glass), all components get refracted according to their wavelength. So, the refraction index depends upon the wavelength of light.

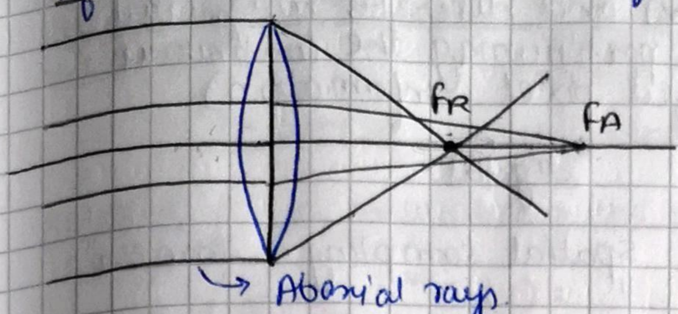
$$\boxed{f = f(\lambda) : \lambda\uparrow \sim f\downarrow}$$

This is called chromatic abberation which is of 2 types:

(a) longitudinal abberation → focal points of red & blue have different positions on optical axis.

(b) lateral abberation → Images for red and blue have different sizes.

(14) We also have **Spherical abberation**. It states that the abaxial rays are refracted more than the rays closer to the optical axis.



① At fA, we would have a clear area and at fR, we would have an blurry area in the image.

② With the spherical abberation, we get a blurry area.

③ We can use a combination of lenses to reduce the intensity of this blurriness.

(15) We also have **Coma**. It states that the point out of the optical axis is not imaged as a point, but as an oval figure with a tail.

(16) There also exists a problem of focal plane i.e. if we have 2 distances in the ~~image~~ real world, one would be projected sharp and other as blurry. By changing the focal length, we can choose which object to focus on.
This is because we are trying to project 3D objects onto a 2-D plane. Therefore, we cannot have the same focal length.

Sol: We can reduce this problem by using an aperture which remove the abaxial rays. This, in turn, also affects our image quality as the light reaching the imager is also reduced and our image becomes darker.

(17) Calculations: ① ~~degree~~ aperture $K = \frac{f}{d}$ → focal length

d → ratio b/w effective dia. and active optics diameter.

u' → ~~radius of~~ radius of the blurry circle. (size of our pixel)

(18) Numerical aperture is mainly used to specify objectives.

$N \cdot A = \eta \sin \frac{\theta}{2}$ $\boxed{K \cong \frac{1}{2 N \cdot A}}$ NA → Numerical Aperture

η → refraction index = 1 for air.

Objectives can be defined as the arrangement of different lenses. For calculation, they can be described as "bracket lens".

≈ for fish-eye cameras, the FoV is 100° ± 90°. (usually used for surround-view cameras in automotive.)

(19) In telecentric objective, the aperture is on the imager side, which can only be passed by axially parallel rays!
Therefore we dont have the distortions caused by other rays.

Usually these are big lenses because they only measure the object that is front of them. The diameter of the object is limited to the diameter of the lenses.

(20) Now the optical rays have stuck the imager after which digitization of the image take place.

(21) Digitizing the image means: discrete spatial sampling of the image scene (partitioning the continuous scene information into discrete pixel information) and discrete magnitude sampling of the image scene (partitioning the continuous color information into quantized pixel information)

Analog

spatial samping → camera

magnitude sampling → frame Grabber

{ see a Youtube video }

digital

spatial sampling → camera

magnitude sampling → camera

(22) We can have different image storing formats

RAW → each and every information is stored. Eg. 8 bits in every pixel. this increases the storage.

ASCII

Bmp

GIF

Better → RAW, BMP, ASCII

JPEG → standard because it has good compression ratio for human eye to visualize.

∴ We should not use lossy compressing formats. (JPeg, GIF, (TIFF), etc)

Software side of Image Processing.

① Image can be explained as the mapping of a physical parameter in a plane or space.

$s(x,y)$ resp. $s(x,y,t)$

Image ↲ → video

② Image processing is multidimensional signal processing.

③ grey value set $G = \{0, \dots 255\}$ (8 bits or more)

image matrix $S = [s(n,m)]$, $0 \le n \le N$, $0 \le m \le M$

Spatial coordinates (n,m) (line, column)

grey value of a pixel $g = s(n,m) \in G$

④ Image Enhancement ← Preparation for info. Retrieval → Image Restoration.

Image Enhancement:

→ operations are restricted to individual pixel.
→ we do not care what is the neighbouring pixel.

→ Histogram
→ Shading correction
→ False color representation

Image Restoration:

→ operations on clusters of pixels.
→ spatial distribution of neighbourhood counts!

→ linear filters
→ morphology
→ texture

(5) Histogram is the representation of 1st order statistics.

Absolute histogram $\rightarrow$ $H_a(g) = \sum_{m=1}^{N_1} \sum_{n=1}^{N_2} \delta(g - I(m,n))$ $\left\{ \delta(x) = \begin{cases} 1 & x=0 \\ 0 & \text{otherwise} \end{cases} \right\}$

It sums up the different grey values in an image.

Relative Histogram $\rightarrow$ Normalising the no. of pixels in the entire image.

$$H_r(g) = \frac{H_a(g)}{N_1 \cdot N_2}$$

(6) A histogram gives the relative frequency of the grey values in an image. considers only single pixel.

(7) We have 3 kinds of histograms i.e. Unimodal, Bimodal and multimodal.

(8) We use the histogram method, because.

(a) we want to calculate the brightness (given by mean grey values)

$$\eta = \sum_{g=G_u}^{G_o} g \cdot H_r(g) \qquad \eta = \frac{1}{N_1 N_2} \sum_{g=G_u}^{G_o} g \cdot H_a(g)$$

(b) we want to calculate the contrast

$$s^2 = \sum_{g=G_u}^{G_o} (g-\mu)^2 \cdot H_r(g) \qquad s^2 = \frac{1}{N_1 N_2 - 1} \sum_{g=G_u}^{G_o} (g-\eta)^2 H_a(g)$$

* The whole purpose of histogram transformation, is to rearrange the given information for better human perception

(9) The possible transformations of histogram include:

(a) Thresholding (2 grey values)
(b) linear histogram Transformation (globally shift the brightness level)
(c) Partial contrast enhancement. (

(10) Thresholding $\rightarrow$ In this, we transform all the grey values into 2 values. We define a threshold. Any value above that value is 1 and any value below that threshold is 0

$$f_{SW}(g(x,y)) = \begin{cases} 1 & g(x,y) \geq SW \\ 0 & g(x,y) < SW \end{cases}$$

→ This results in an binary image having 2 values (either 1 or 0)
→ It also results in loss of information since 256 grey values are converted to 2 grey values.
→ Eg. Segmentation. (classifying into relevant and not relevant)

(11) Linear Histogram Transformation

The goal of linear histogram transformation is to improve the visual characteristics of an image by changing the brightness or contrast.

But there is no information gain

$$f(g) = a \cdot g + b$$

new mean grey value

$$\eta^* = \sum_{g=G_0}^{G_0} (a \cdot g + b)\, H_r(g) \qquad \eta^* = a \cdot \eta + b$$

new variance

$$(s^*)^2 = \sum_{g=G_0}^{G_0} (a \cdot g + b - \mu^*)^2 \cdot H_r(g)$$

$$(s^*)^2 = a^2 \sum_{g=G_0}^{G_0} (g - \mu)^2 \cdot H_r(g)$$

$$(s^*)^2 = a^2 \cdot s^2$$

(12) The parameters a and b of a linear histogram transformation for achieving prescribed mean and variance can be calculated as

$$\boxed{a = \frac{s^*}{s}} \qquad \boxed{b = \eta^* - \frac{s^*}{s}\eta}$$

(13) Linear histogram transformation technique is used for standardizing the set of input images.

(14) Histogram spreading - is a method in which we convert a narrow histogram to a histogram in which the whole grey area is covered.

Eg. A photo with a histogram levels 100 ... 190 would not appear good. we try to map this with 0 ... 255.

(min: 100, max: 190)

we would have an improvement only if $M \geq G_0$ and $m \leq G_0$

(15) Histogram Smoothing is a method of converting grey values to an average histogram values

$$\boxed{H_r(g^*) = c}$$

(16) Partial contrast enhancement we do a ~~linear~~ piecewise linear transformation to partially enhance the contrast.

* useful, if we are inside a tunnel and we want to also see what is outside of tunnel.

(17) otsu threshold, automatically selection of threshold level. Calculating the mean & variance iteratively.