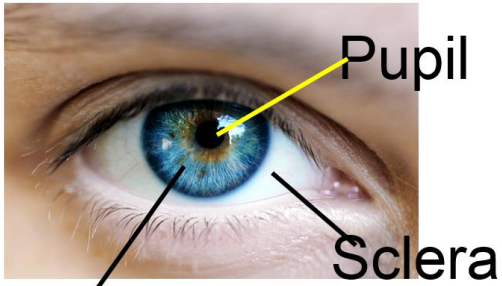
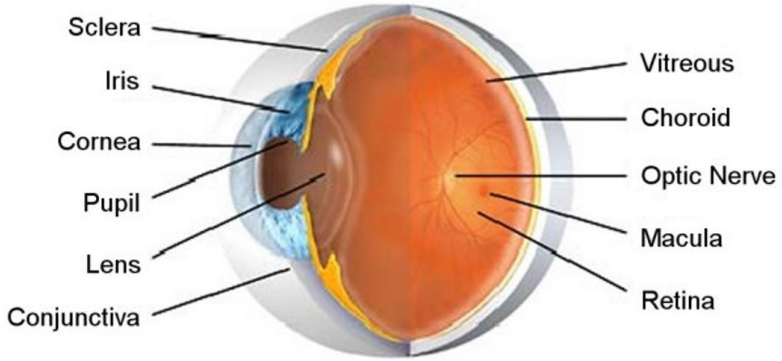
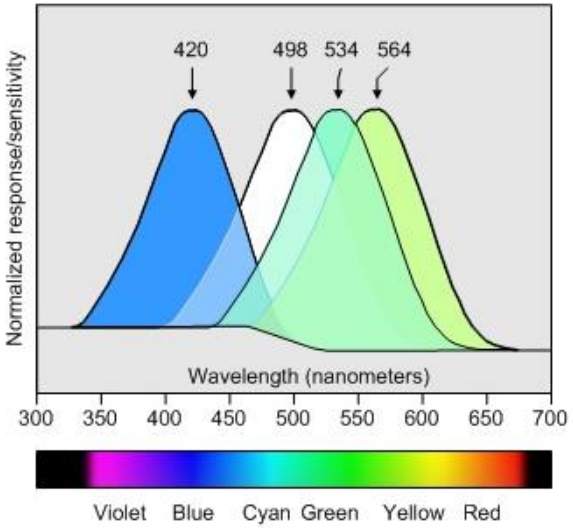
Vision

Human Eye

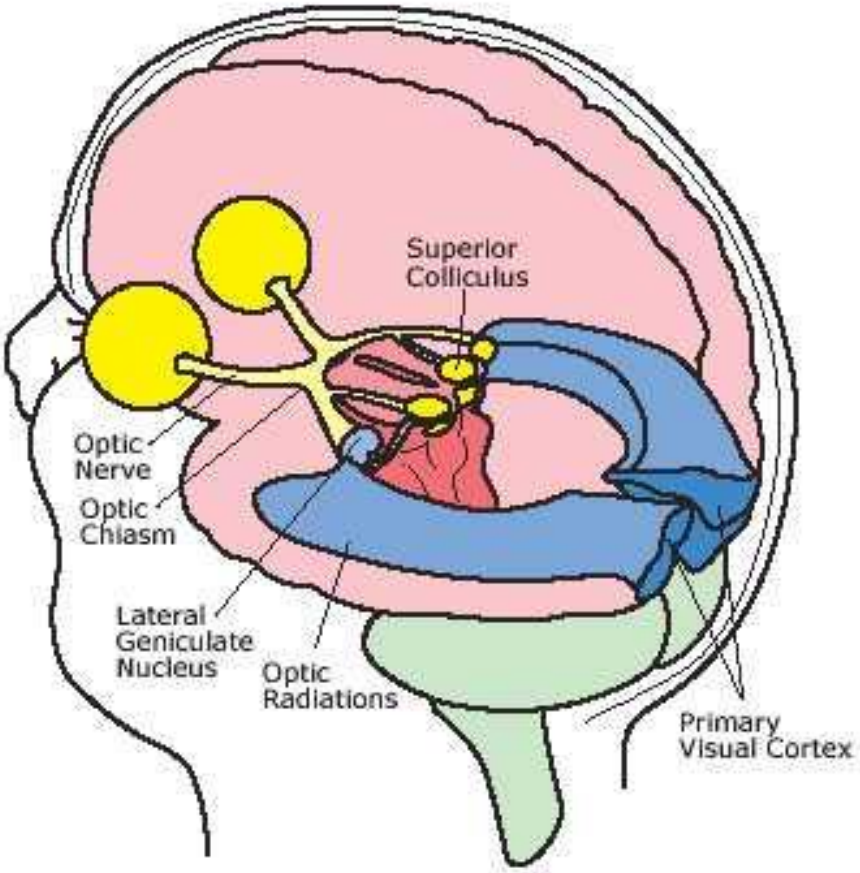






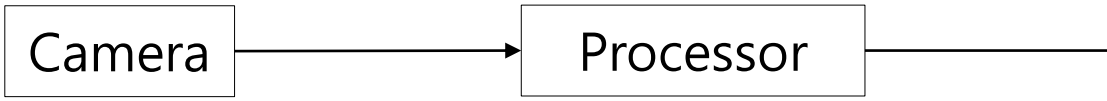
Tristimulus

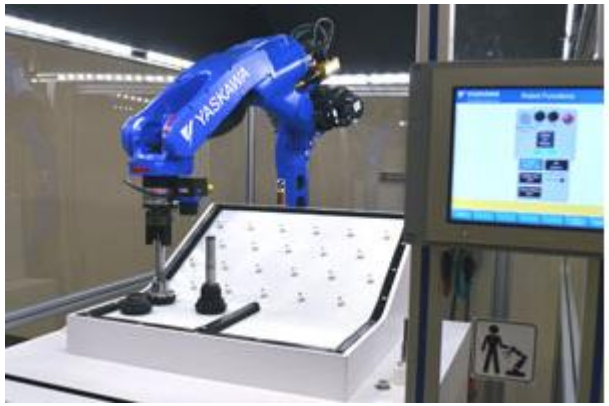
Human Vision System



- human brain
  - 1.5 kg
  - 10^{11} neurons
  - ~1/3 for vision

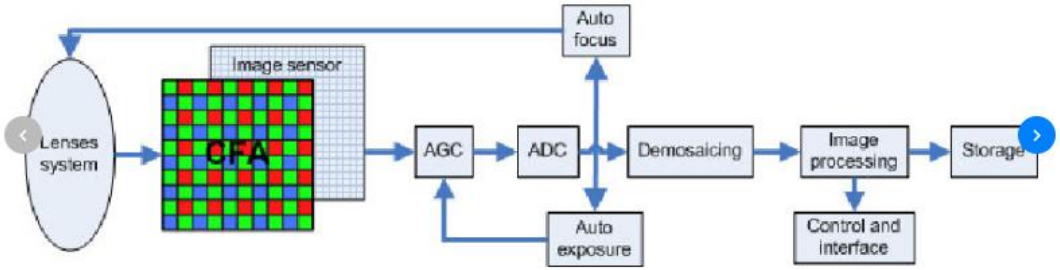
Robot Vision System





Camera

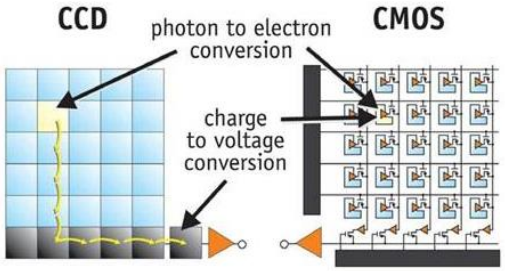
- Camera
  - Image sensor + color filter + lens + ADC + …



- Image Sensor
  - Changes light to electrons

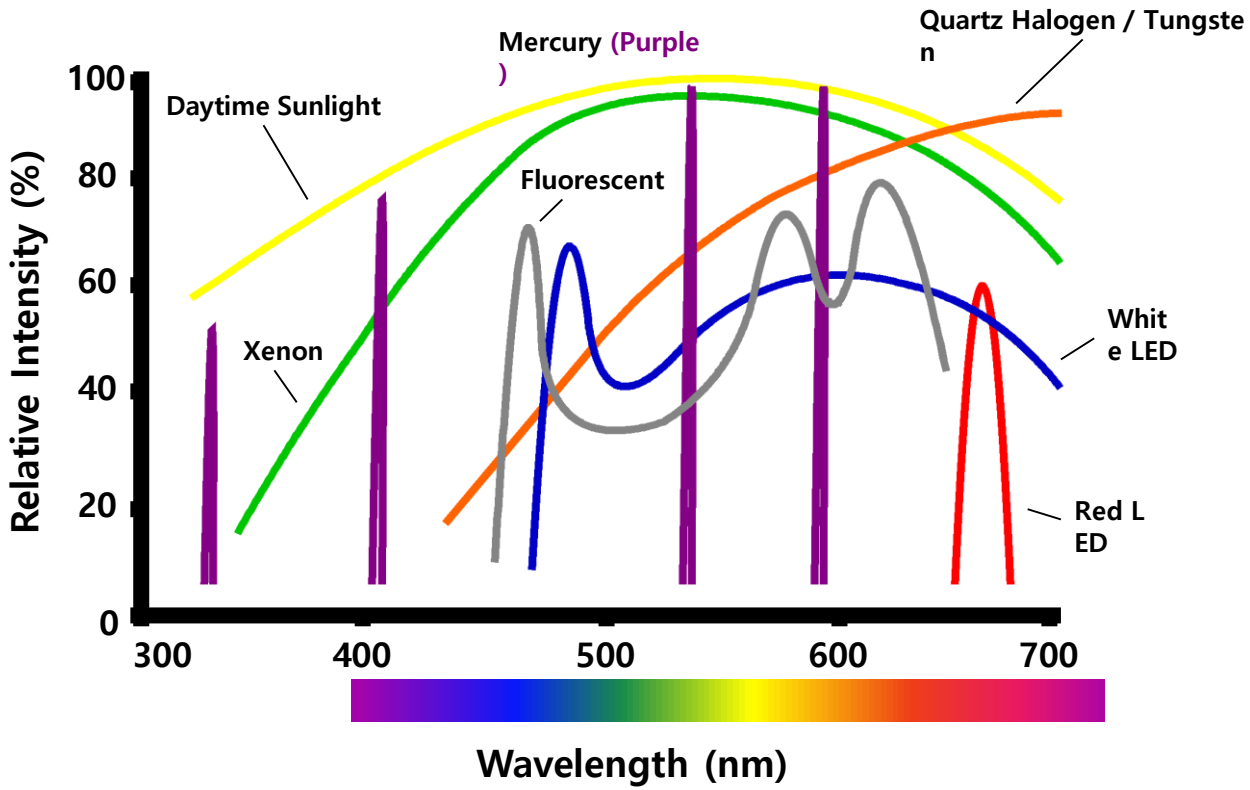
1) CCD
   - charge coupled device
   - High-quality & lower noise image

2) CMOS
   - complementary metal oxide semiconductor
   - Less expensive
   - More noise
   - Need lower power



Lighting

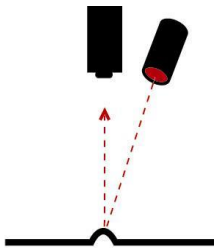
- Lighting source
  - LED (Light Emitting Diode)
  - Quartz Halogen
  - Fluorescent (형광등)
  - Xenon (High-Performance Strobing)



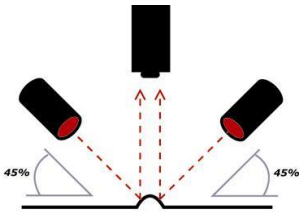
Lighting

- Type
  - Bright field lighting
  - Dark field lighting
  - Defuse lighting
  - Back lighting

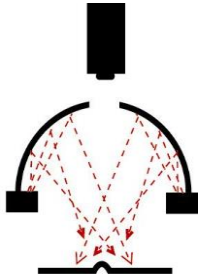
  * Structured lighting



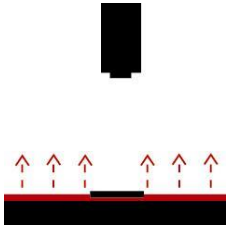
Bright field lighting



Dark field lighting



Diffuse lighting



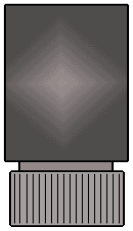
Back lighting

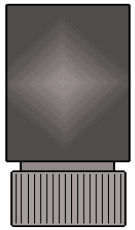
Lighting

- Bright field vs. Dark field

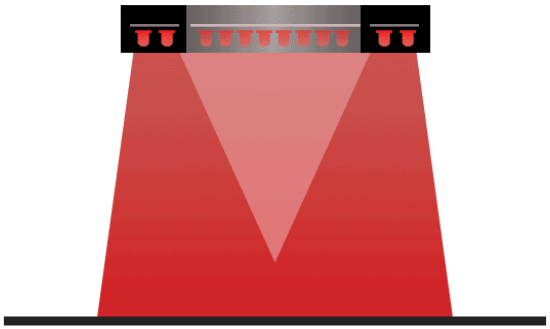
Typical Co-axial Ring Light

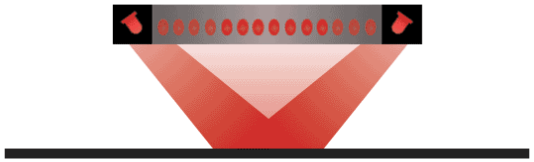
Bright Field





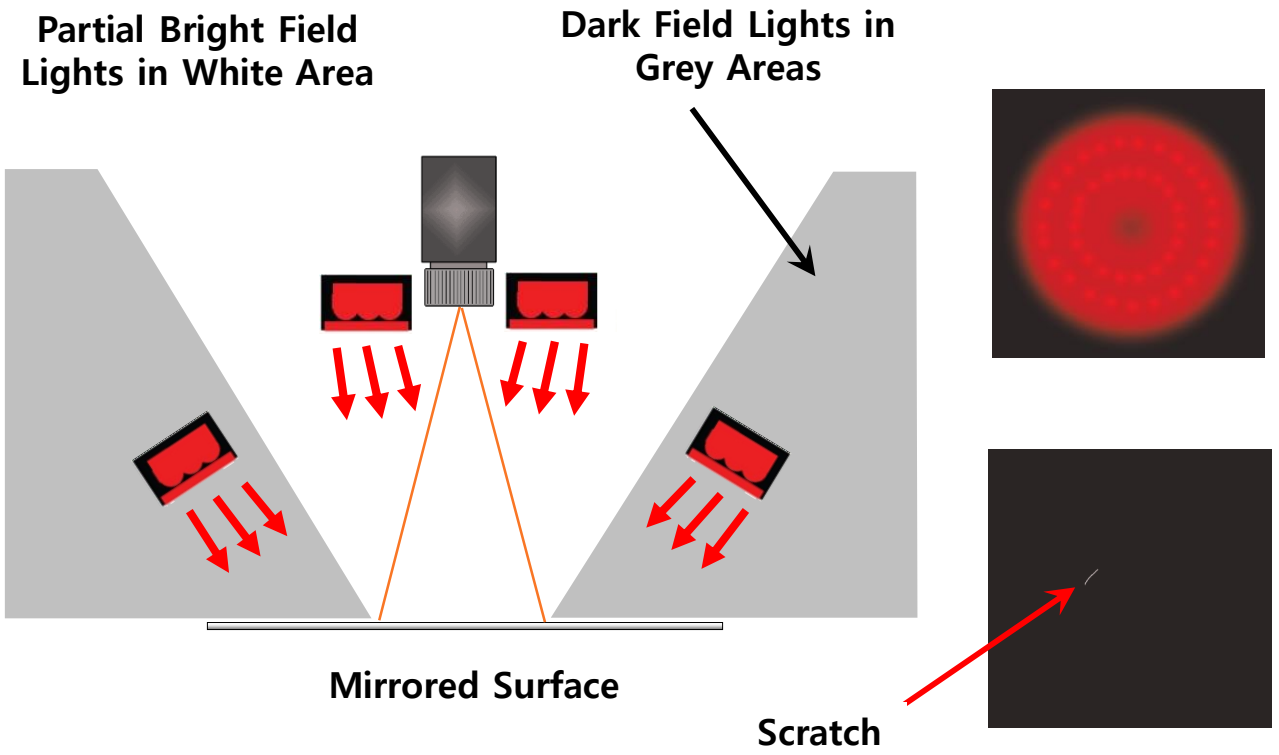
Dark Field





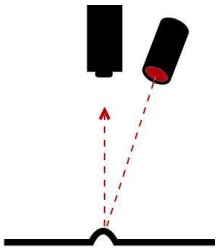
Lighting

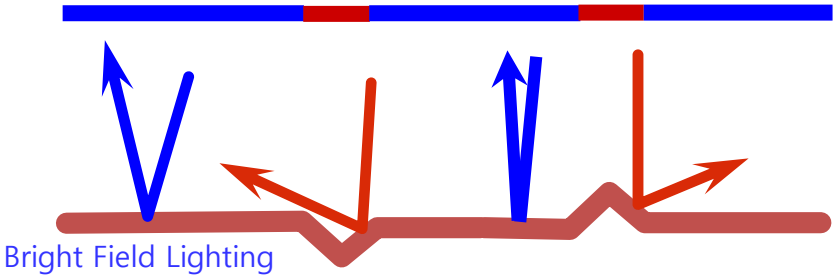
- Bright field vs. Dark field



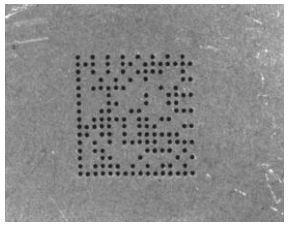
Lighting

- Bright field vs. Dark field

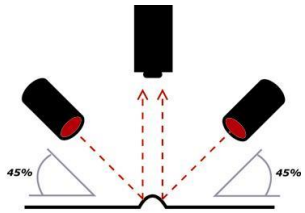


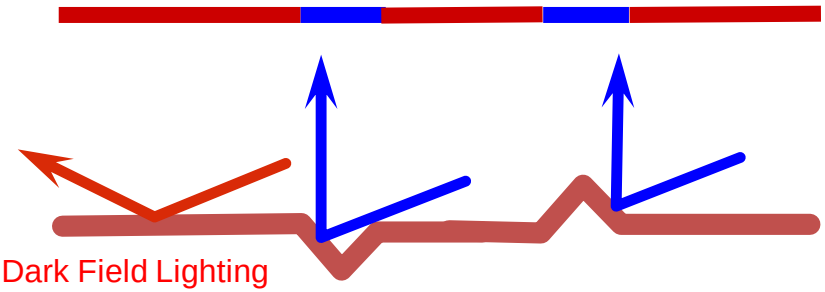


Bright Field Lighting

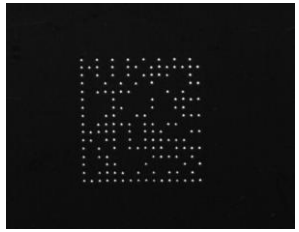


- Similar to sunlight
- Effective for flat surface





Dark Field Lighting

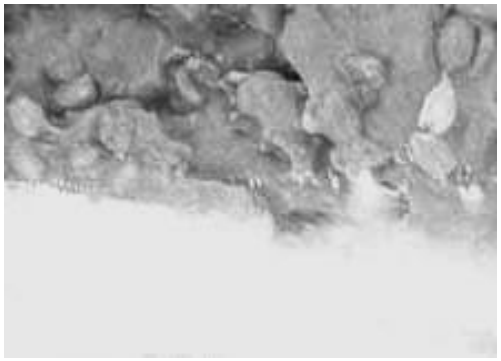


- Effective for specular surface

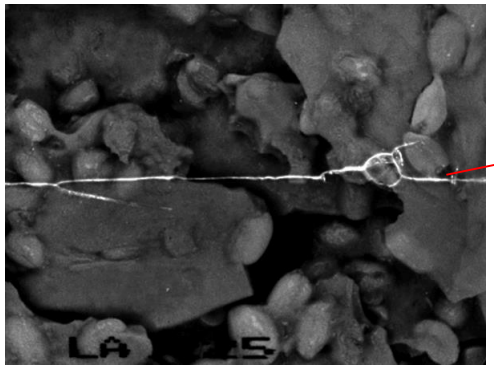
Lighting

- Bright field vs. Dark field

Peanut Brittle Bag



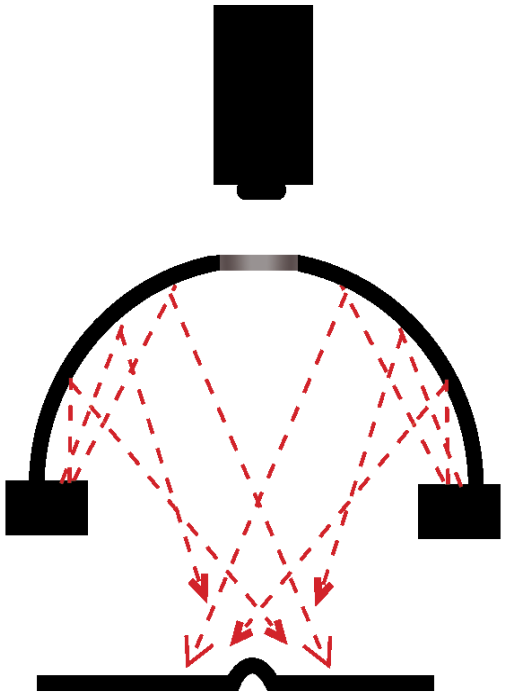
Bright field ring light



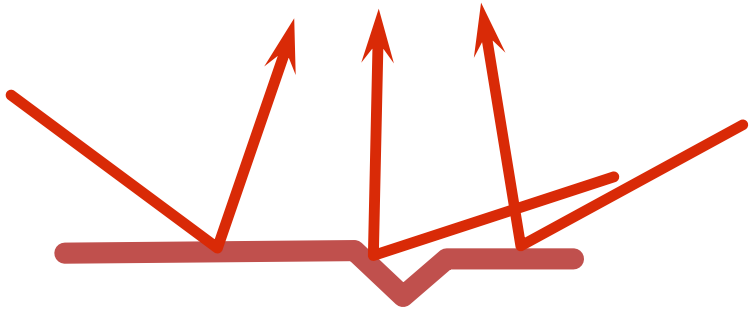
Dark field ring light

Lighting

- Diffuse lighting

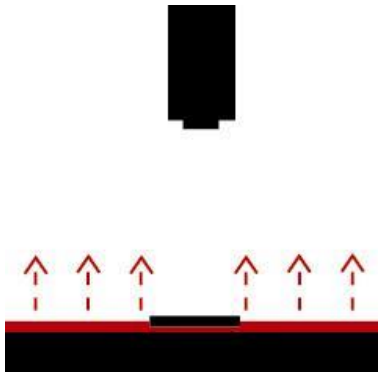


- Similar to the light on an overcast day.
- Creates minimal glare.
  - Surface Texture Is Deemphasized
  - Best Choice for Curved Shiny Parts



Lighting

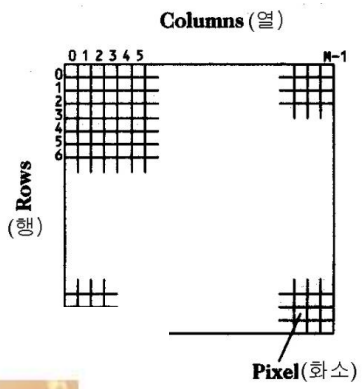
- Back lighting

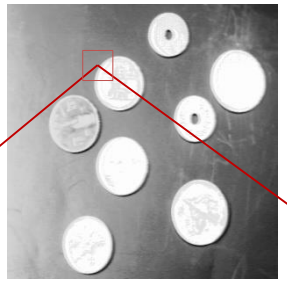


- Creates dark silhouettes against bright background
- Detecting
  - Presence / absence of holes and gaps
  - Part placement or orientation
- Measuring objects
- Useful for translucent materials

Image Data

- 1 Frame = M x N pixels
  - N bits / pixel
    - Gray image: max N = 8
    - Color image: max N = 8 (red) +8 (green) + 8 (blue)





138	138	141	138	138	138	138	138	138	138	131	131	127	127	127
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174	191	204	214	223	224	225	225	224	224	223	215	207	195	177
225	227	229	253	253	253	253	253	235	235	235	253	253	235	227
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253	229	227	226	226	226	227	227	227	227	228	229	231	235	235
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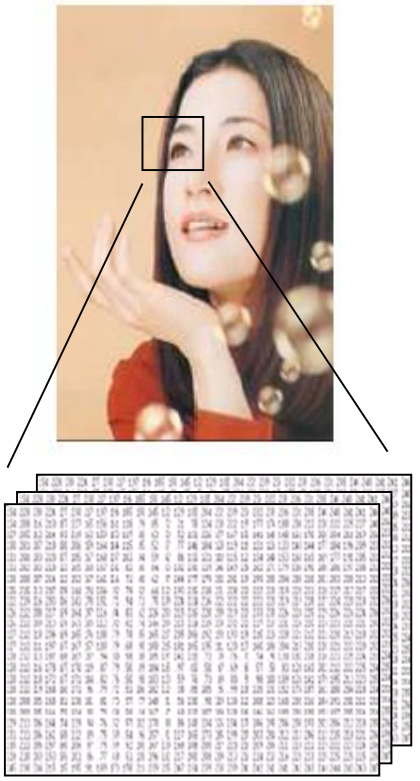


Image Processing

Filtering
Morphology

Segmentation
Line detection
Corner detection

Matching
Learning

Deep Learning

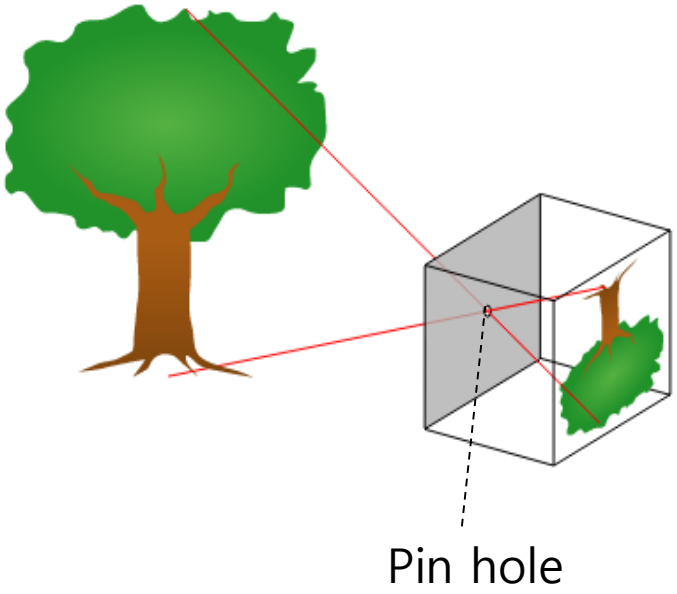
(Low level)

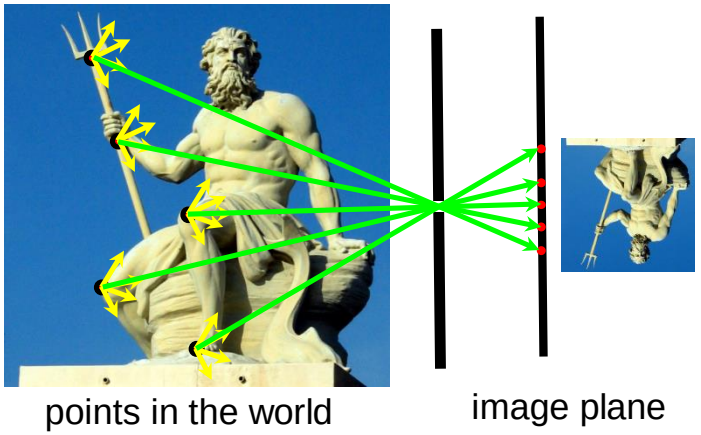
(Medium level)

(High level)

Camera Model

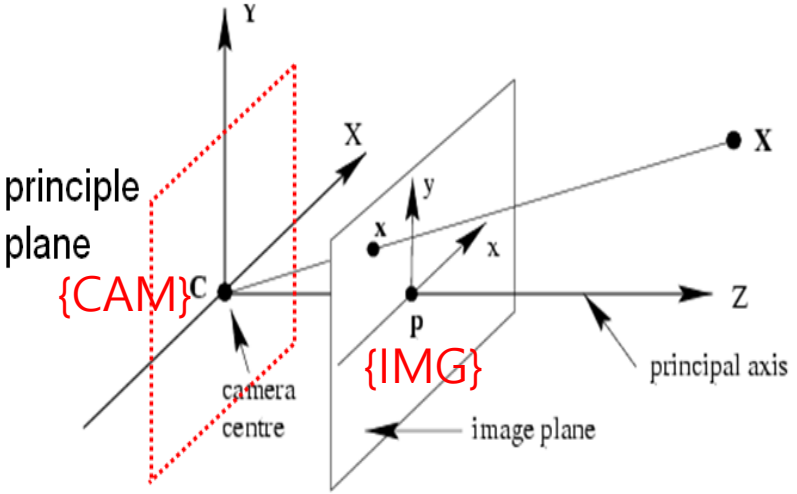
- 핀 홀 (Pin Hole) 모델
  - 카메라를 작은 바늘구멍 (pin hole) 로 모델링
  - 공간 상의 한 점이 작은 바늘 구멍을 통과하여 영상 면에 상이 맺힘



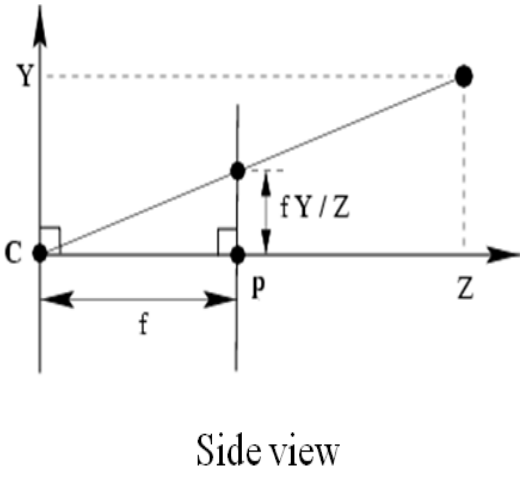


Camera Model

- 카메라 좌표계: {CAM}
  - 카메라 중심을 기준으로 하는 3차원 직교 좌표계
  - C: Projection center / optical center
  - Principal axis (주축)
- 영상 좌표계 {IMG}
  - 영상 평면에서의 2차원 직교 좌표계
  - P : principal point (주축점)



f: focal length



Side view

Camera Model

- Projection

  (X, Y, Z): {CAM} 기준 공간 상 한 점의 좌표

  (x, y): {IMG} 기준 좌표

$$f : x = Z : X \quad \rightarrow \quad x = f\frac{X}{Z}$$

$$f : y = Z : Y \quad \rightarrow \quad y = f\frac{Y}{Z}$$

- Homogeneous coordinate

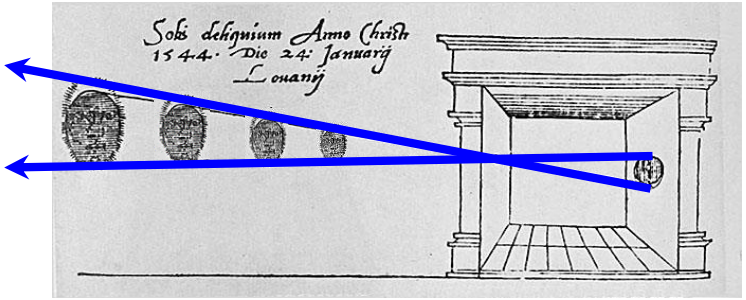
$$\begin{pmatrix} \frac{a}{s} \\ \frac{b}{s} \\ 0 \end{pmatrix} \leftrightarrow \begin{pmatrix} a \\ b \\ s \end{pmatrix}$$

$$\begin{pmatrix} x \\ y \\ 0 \end{pmatrix} = \begin{pmatrix} f\frac{X}{Z} \\ f\frac{Y}{Z} \\ 0 \end{pmatrix} = \begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

Camera Model

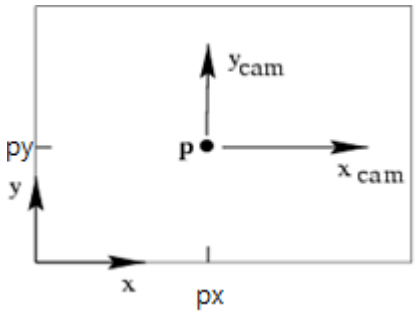
- Perspective Projection
  1) 3D → 2D : $(X, Y, Z) \rightarrow (x, y)$
  2) Straight line → straight line
  3) Parallel lines → lines that intersect at a vanishing point
  4) Conic → conic (circle → circle or ellipse)
  5) Not one-to-one mapping

     X, Y, Z → x, y (OK) , x, y → X, Y, Z (not OK)



Camera Model

- $\boldsymbol{X}_{CAM} \rightarrow \boldsymbol{x}$
  - 영상 면의 중점 편차 고려



$$\begin{pmatrix} x \\ y \\ 0 \end{pmatrix} = \begin{pmatrix} f\dfrac{X}{Z} + p_x \\ f\dfrac{Y}{Z} + p_y \\ 0 \end{pmatrix} = \begin{pmatrix} fX + Z\,p_x \\ fY + Z\,p_y \\ Z \end{pmatrix} = \begin{bmatrix} f & 0 & p_x & 0 \\ 0 & f & p_y & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

$$= \begin{pmatrix} f & 0 & p_x \\ 0 & f & p_y \\ 0 & 0 & 1 \end{pmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

$$\boldsymbol{x} = \boldsymbol{K}\,[\,\boldsymbol{I}\mid\boldsymbol{0}]\,\boldsymbol{X}_{CAM}$$

K: Camera calibration matrix

f, p_x, p_y : Intrinsic parameters (미지수 3 개)

Camera Model

- CCD 카메라
  - 단위계 변환 필요: mm → pixel

$$\boldsymbol{K} = \begin{pmatrix} m_x & 0 & 0 \\ 0 & m_y & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} f & 0 & p_x \\ 0 & f & p_y \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} \alpha_x & 0 & x_0 \\ 0 & \alpha_y & y_0 \\ 0 & 0 & 1 \end{pmatrix}$$

m_x, m_y: mm 당 pixel 수

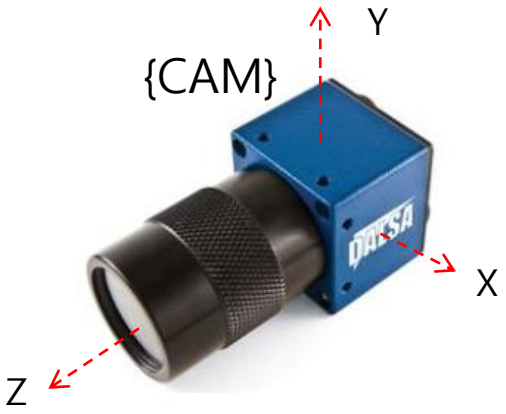
  - 영상 면의 x 축, y 축이 수직하지 않은 경우 고려

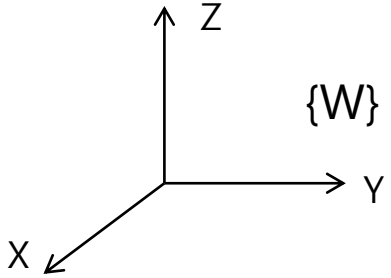
$$\boldsymbol{K} = \begin{pmatrix} \alpha_x & \gamma & x_0 \\ 0 & \alpha_y & y_0 \\ 0 & 0 & 1 \end{pmatrix}$$

미지수 5 개 (Intrinsic parameter)

Camera Model

- 월드 좌표계 (World coordinate) {W}
  - 위치 측정의 기준이 되는 좌표계
  - 카메라의 회전 및 이동 고려





P ●

$$X_{WORLD} = {}^{W}T_{CAM}\, X_{CAM}$$

$${}^{W}T_{CAM} = \begin{bmatrix} R^T & C \\ 0 & 1 \end{bmatrix}$$

R: 3 x 3 rotation matrix
C: 3 x 1 translation vector

Camera Model

- $X_{WORLD} \rightarrow X_{CAM}$

$$X_{CAM} = {}^{W}T_{CAM}{}^{-1} X_{WORLD}$$

$$= \begin{bmatrix} \boldsymbol{R} & -\boldsymbol{R}^T\boldsymbol{C} \\ 0 & 1 \end{bmatrix} X_{WORLD}$$

- $X_{WORLD} \rightarrow x$

$$x = \boldsymbol{K}\,[\,\boldsymbol{I} \mid \boldsymbol{0}]\, X_{CAM}$$
$$= \boldsymbol{K}\,[\,\boldsymbol{I} \mid \boldsymbol{0}] \begin{bmatrix} \boldsymbol{R} & -\boldsymbol{R}^T\boldsymbol{C} \\ 0 & 1 \end{bmatrix} X_{WORLD}$$
$$= \boldsymbol{K}\,[\,\boldsymbol{R} \mid -\boldsymbol{R}^T\boldsymbol{C}]\, X_{WORLD}$$
$$= \boldsymbol{K}\,[\,\boldsymbol{R} \mid \boldsymbol{t}]\, X_{WORLD}$$
$$= \boldsymbol{P}\, X_{WORLD}$$

$\boldsymbol{R}$: rotation matrix (3 x 3)
$\boldsymbol{t}$: translation matrix (3 x 1)
⇒ Extrinsic parameters
⇒ 미지수: 6개 (회전3, 평행3)

$\boldsymbol{P}$: Projection matrix

Camera Calibration

- 목적
  - 카메라를 사용한 3차원 계측을 위하여, 영상 좌표값으로 부터 월드 좌표값을 계산하여야 함
  - 이때 Projection matrix 의 원소값이 얼마나 정확한 지에 따라 계산의 정확도가 달라짐

$$x = \boldsymbol{P}\, X_{WORLD}$$

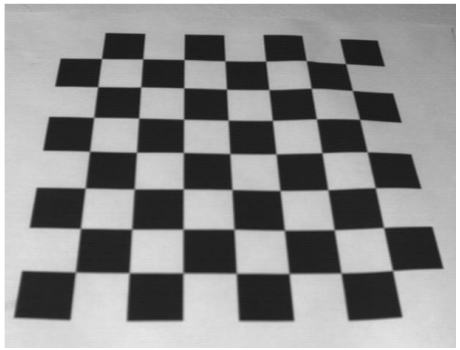
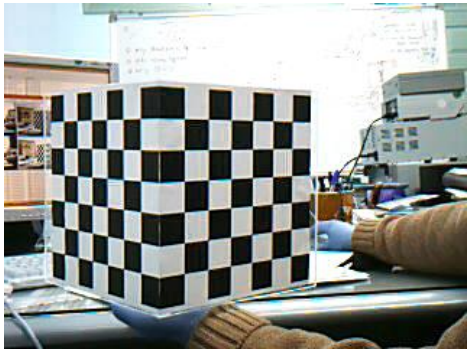
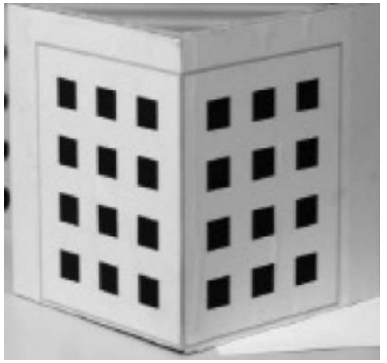
  - Projection matrix 의 원소 값을 결정하는 과정을 카메라 보정 (camera calibration) 이라고 함

$$\boldsymbol{P} = \boldsymbol{K}\,[\,\boldsymbol{R}\,|\boldsymbol{t}]$$

내부변수 5 개
외부변수 6 개

Camera Calibration

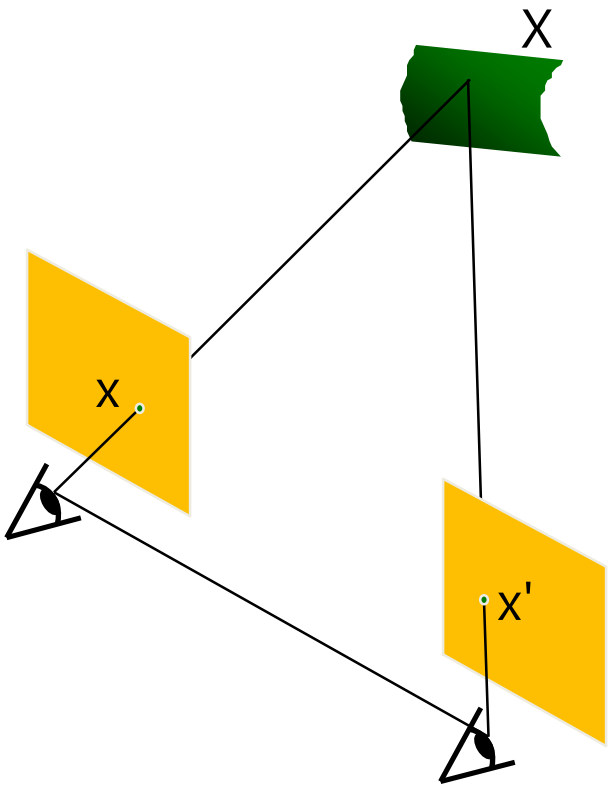
- 방법
  - 치수가 미리 알려져 있는 정밀한 보정자 (calibration scale) 사용

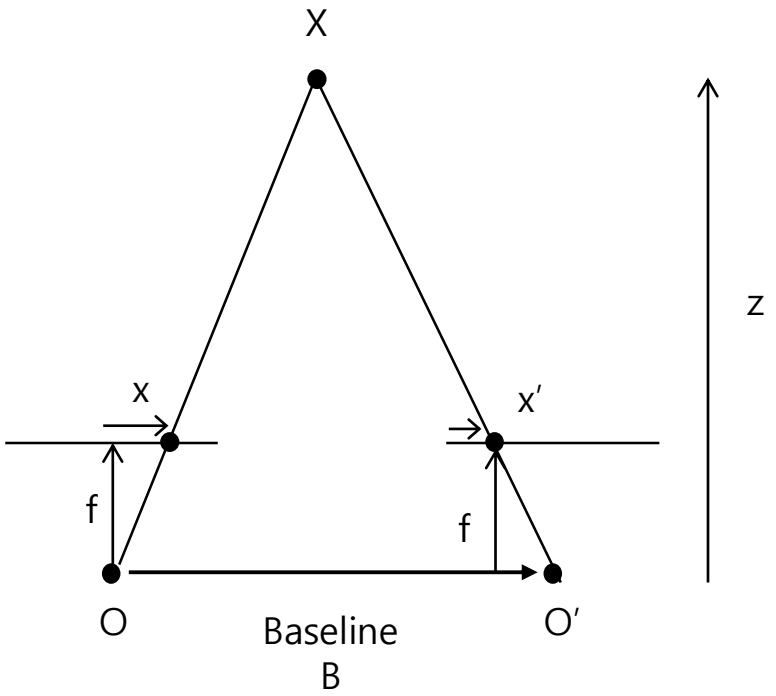
카메라 보정용 스케일의 예

Stereo Vision

- Recover depth by finding image coordinate x′ that corr esponds to x



$$\frac{x - x'}{O - O'} = \frac{f}{z}$$



$$disparity = x - x' = \frac{B \cdot f}{z}$$

Disparity is inversely proportional to depth.

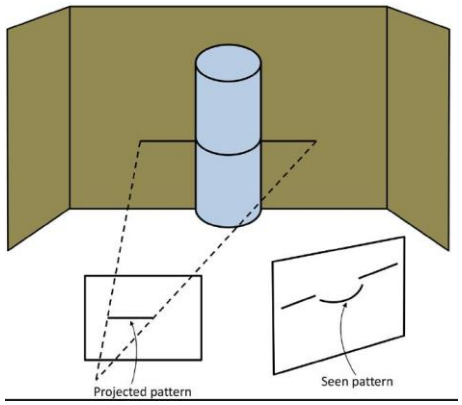
Stereo Vision

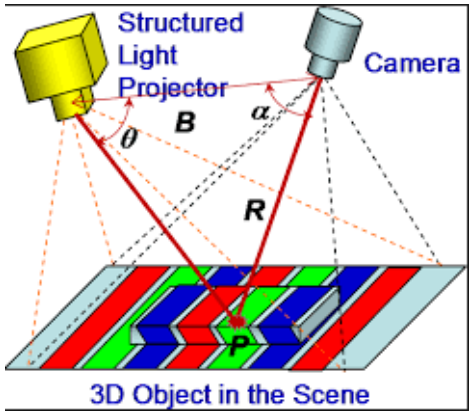
- Correspondence Problem

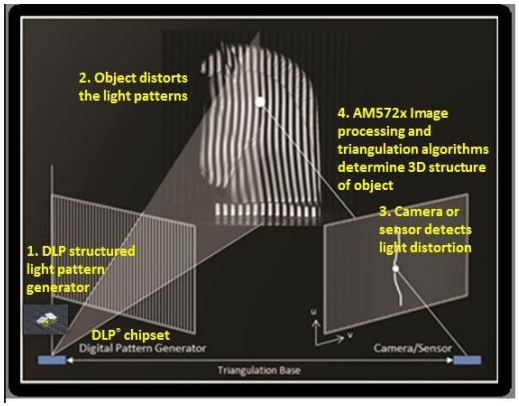
  - We have two images taken from cameras with different i ntrinsic and extrinsic parameters
  - How do we match a point in the first image to a point i n the second? How can we constrain our search?

Structured Lighting

- Recover depth from pattern by structured lighting
  - Projector + Camera
  - Restore depth data from image







Kinect sensor