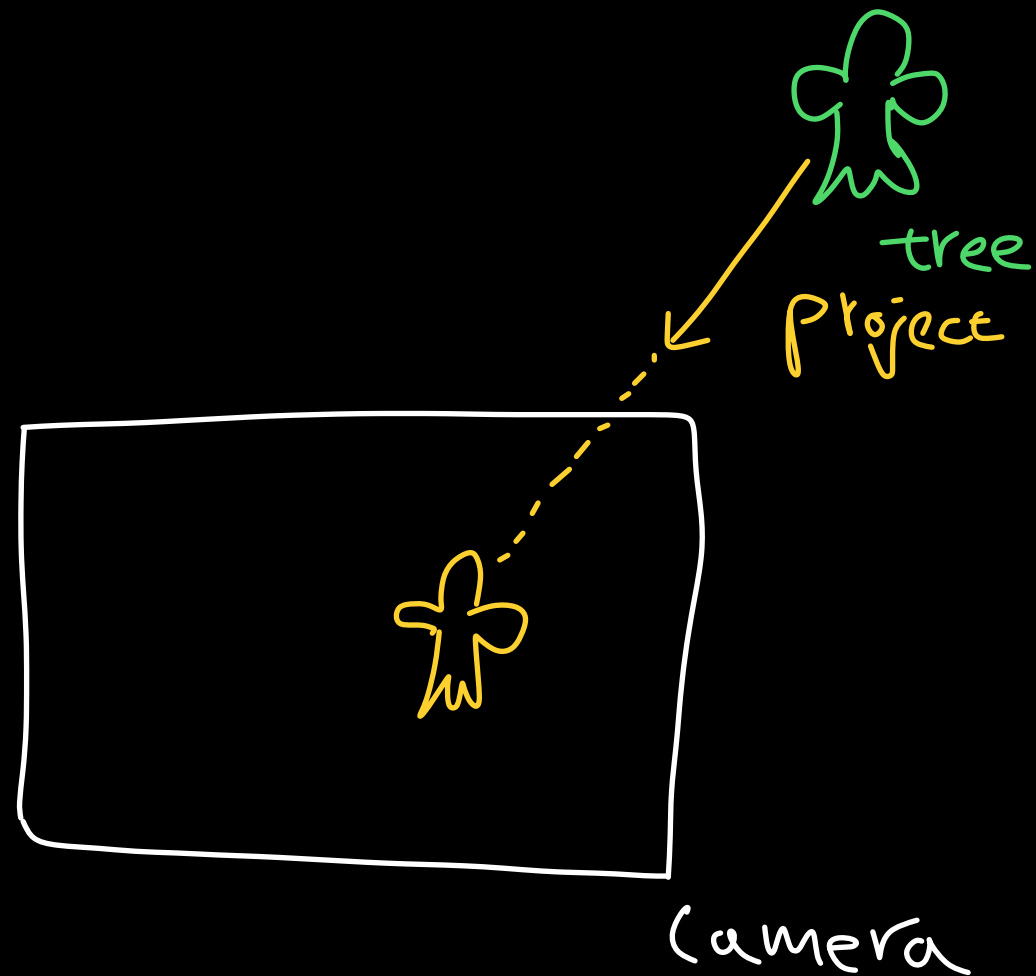


Advanced-3dv-tutorial

From Camera Calibration to Depth Estimation

Camera Calibration

직관

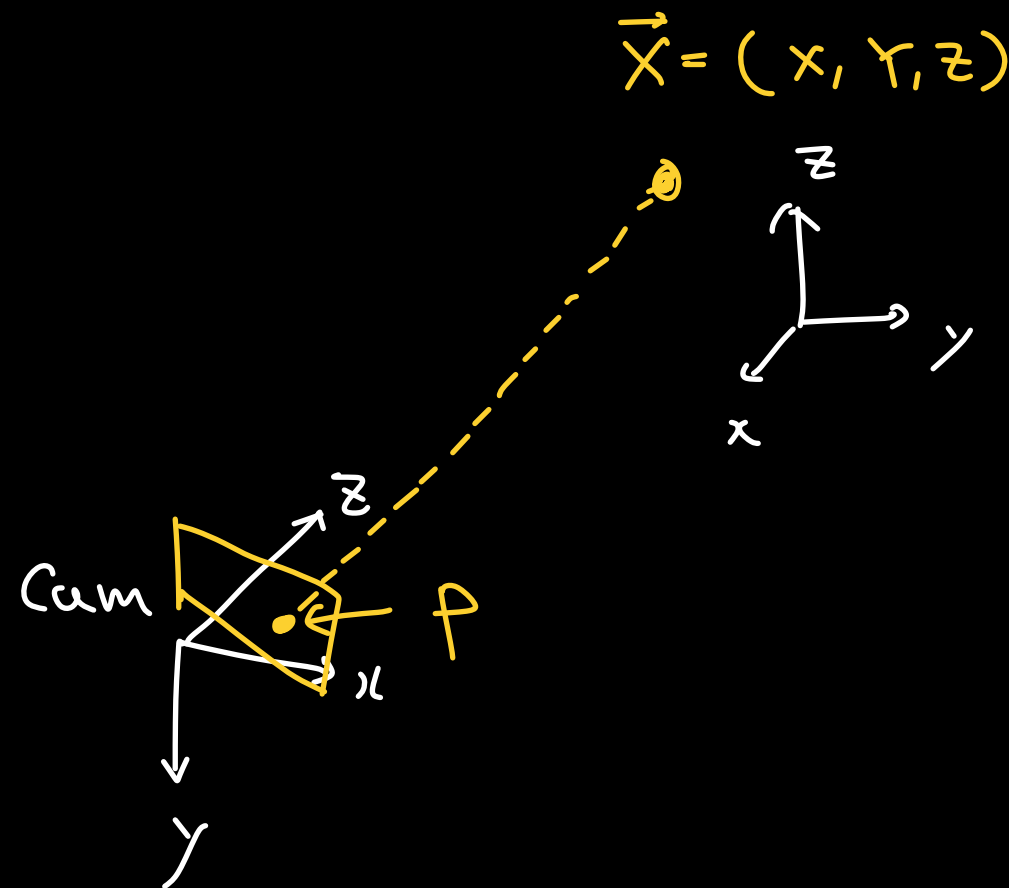


How tree project into camera?

Camera Calibration

직관

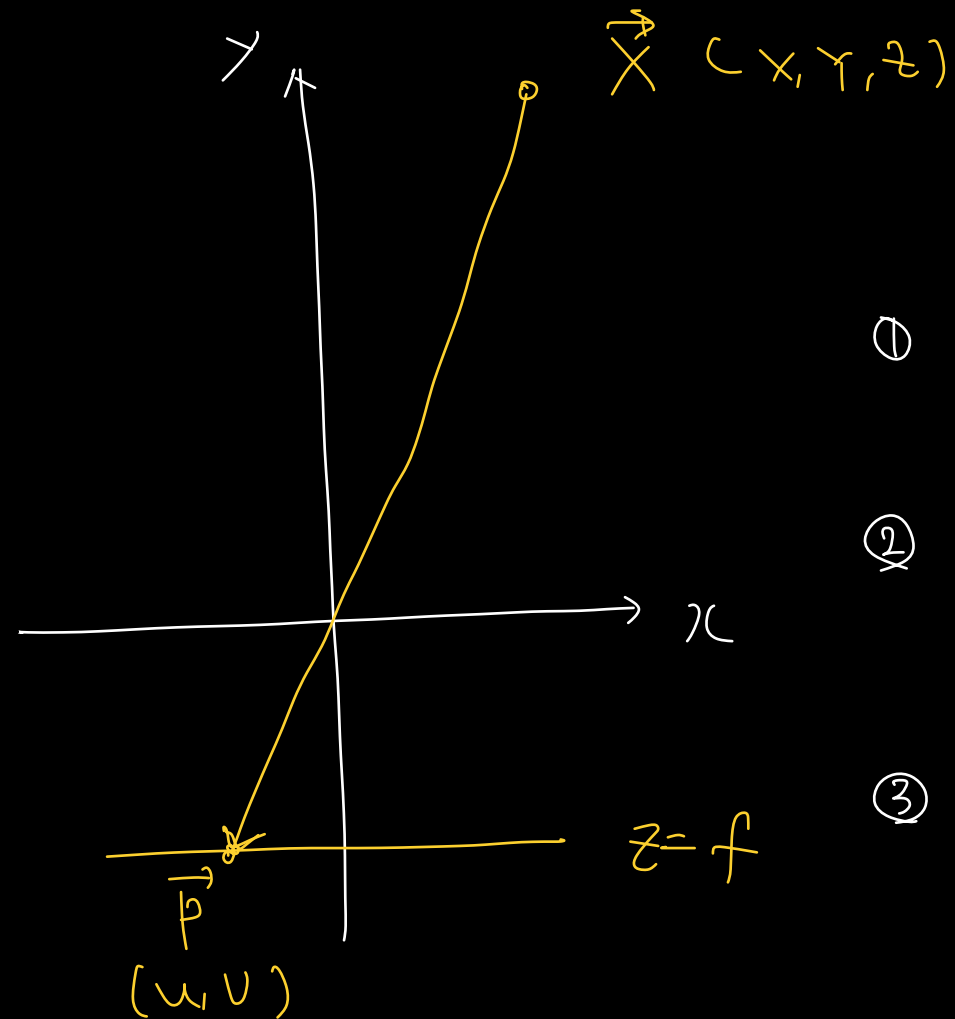
How point in World Coord projects into Camera Coordinate?



How $\vec{X} = (x, y, z) \rightarrow \vec{P} = (u, v)$?

Camera Calibration

수식



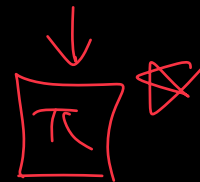
$$\vec{p} = \pi (\vec{X})$$



① normalize \vec{X} : $\vec{X} \rightarrow \frac{\vec{X}}{z} = (\frac{x}{z}, \frac{y}{z}, 1)$

② to $z=f$ plane : $\frac{\vec{X}}{z} \rightarrow f \cdot \frac{\vec{X}}{z} = (\frac{f}{z}x, \frac{f}{z}y, f)$
(image plane)

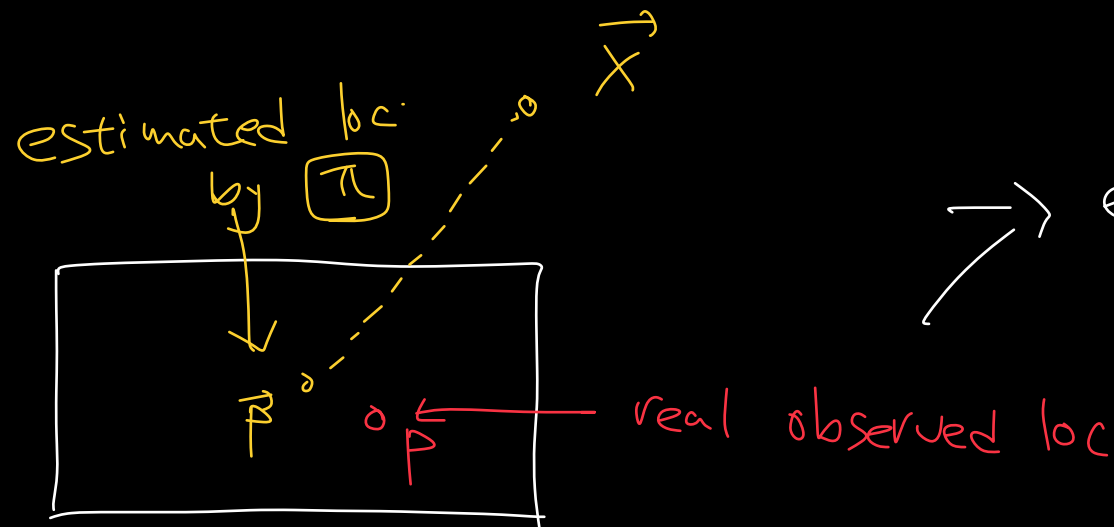
③ pixel plane : $\frac{\vec{X}}{z} + \vec{C} \rightarrow (f \frac{x}{z} + c_x, f \frac{y}{z} + c_y)$
(u , v)



Stereo Camera Calibration

수식

How to calibrate ??

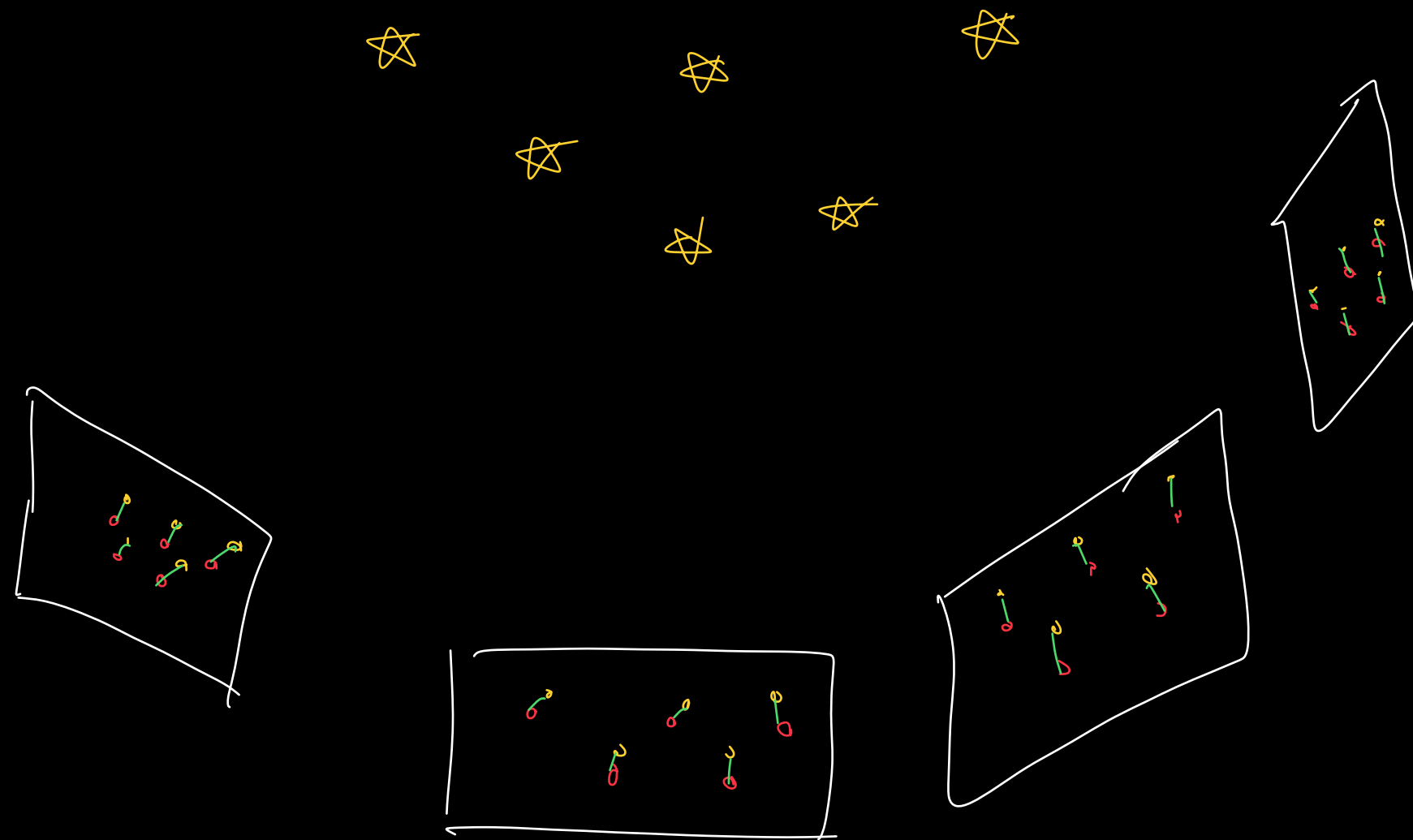


$$\begin{aligned} \text{error} &= \bar{p} - p \\ &= \bar{p} - \pi(\vec{x}) \end{aligned}$$

⇒ need to minimize error by optimizing π parameters

Stereo Camera Calibration

수식



need to minimize *error* with many datas

Stereo Camera Calibration

수식

$$\sum_{\text{all frame}} \sum_{\text{all corners}} \|\vec{p} - \pi(R_w^c \vec{x}_w + t_w^c)\|$$

\Rightarrow Optimize all frame poses + camera intrinsic

☆

Input: observed pixels loc, known 3d points

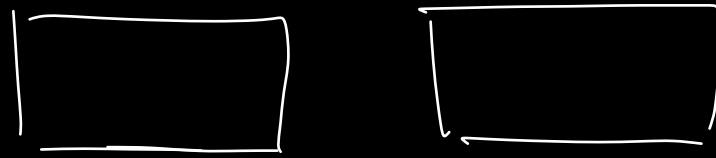
Output: all frame poses + camera intrinsic

Stereo Camera Calibration

수식

스테레오 카메라는 어떻게??

⑦



$T_{C_1}^{C_2}$

\Leftarrow

Camera 1 과 2 사이의 관계를
아는 것이 목적이다!

Stereo Camera Calibration

수식

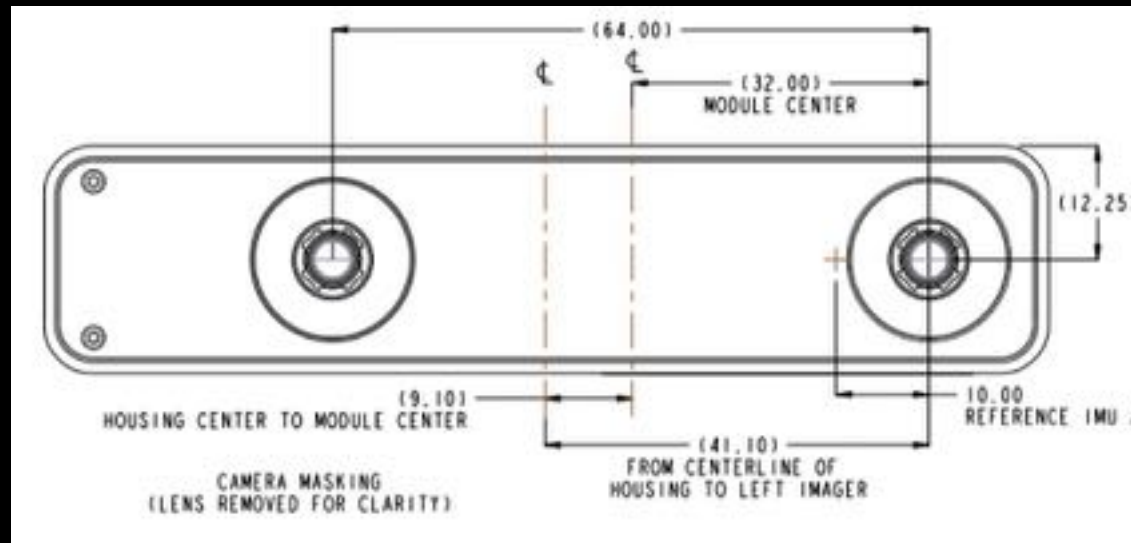
$$r = \left\| \vec{P}_l - \pi_l \left(R_w^l \vec{X}_w + t_w^l \right) \right\|^2 + \left\| \vec{P}_r - \pi_r \left(\vec{R}_l^r \left(R_w^l \vec{X}_w + t_w^l \right) + t_l^r \right) \right\|^2$$

Input: Cam l intrinsic, Cam r intrinsic, Cam l pose,
observed P_l, P_r , X_{world}

Output: R_l^r, t_l^r

Stereo Camera Calibration

실습: Realsense T265



left & right 이미지

0.4 cm!

Calibration 결과

$T_{C_1}^{C_2}$ 가 $t_{C_1}^{C_2}$ 가 (0.084, 0, 0)
에 가까워진 랐!

Depth Estimation

1. Triangulation

How do we find the exact point on the ray?

camera 1 with matrix P

camera 2 with matrix P'

$$x = PX$$

(homogeneous coordinates)

This is a similarity relation because it involves homogeneous coordinates

$$x = \alpha PX$$

(homogeneous coordinates)

Same ray direction but differs by a scale factor

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \alpha \begin{bmatrix} p_1 & p_2 & p_3 & p_4 \\ p_5 & p_6 & p_7 & p_8 \\ p_9 & p_{10} & p_{11} & p_{12} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

How do we solve for unknowns in a similarity relation?

1 $x = \alpha PX$
Same direction but differs by a scale factor

2 $\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \alpha \begin{bmatrix} p_1 & p_2 & p_3 & p_4 \\ p_5 & p_6 & p_7 & p_8 \\ p_9 & p_{10} & p_{11} & p_{12} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$

$x \times PX = 0$
Cross product of two vectors of same direction is 0
 (This equation removes the scale factor)

3 $\begin{bmatrix} yp_3^T - p_2^T X \\ p_1^T X - xp_3^T \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$

$\begin{bmatrix} yp_3^T - p_2^T \\ p_1^T - xp_3^T \end{bmatrix} X = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$

$A_4 X = 0$

Find 3D object point
 Will the lines intersect?

camera 1 with matrix P

camera 2 with matrix P'

Concatenate the 2D points from both images

$$\begin{bmatrix} yp_3^T - p_2^T \\ p_1^T - xp_3^T \\ y'p_3'^T - p_2'^T \\ p_1'^T - x'p_3'^T \end{bmatrix} X = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

verify check dimensions?

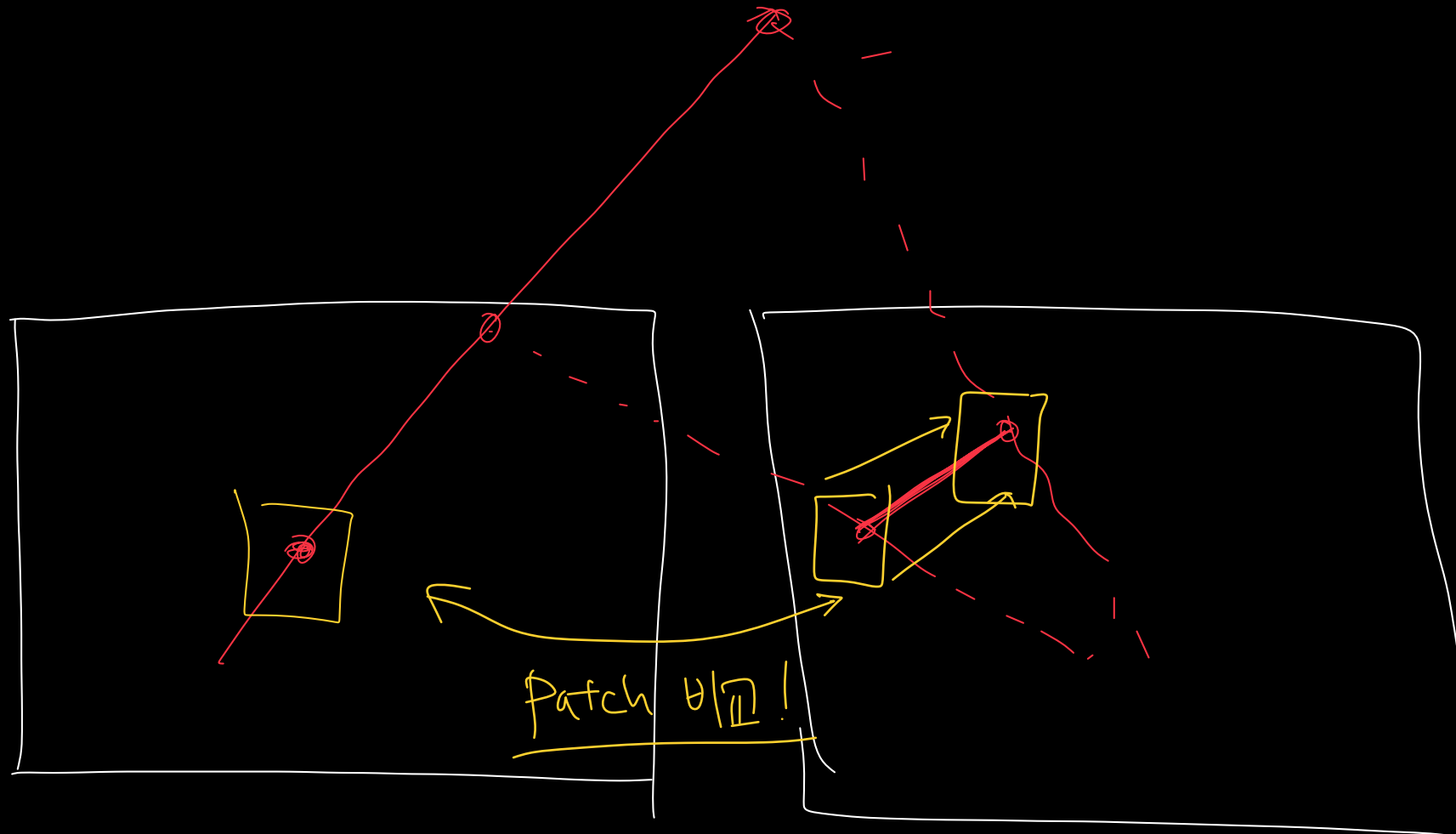
$AX = 0$

How do we solve homogeneous linear system?

조건 ! 점 매칭이 되어야 계산 가능!

Depth Estimation

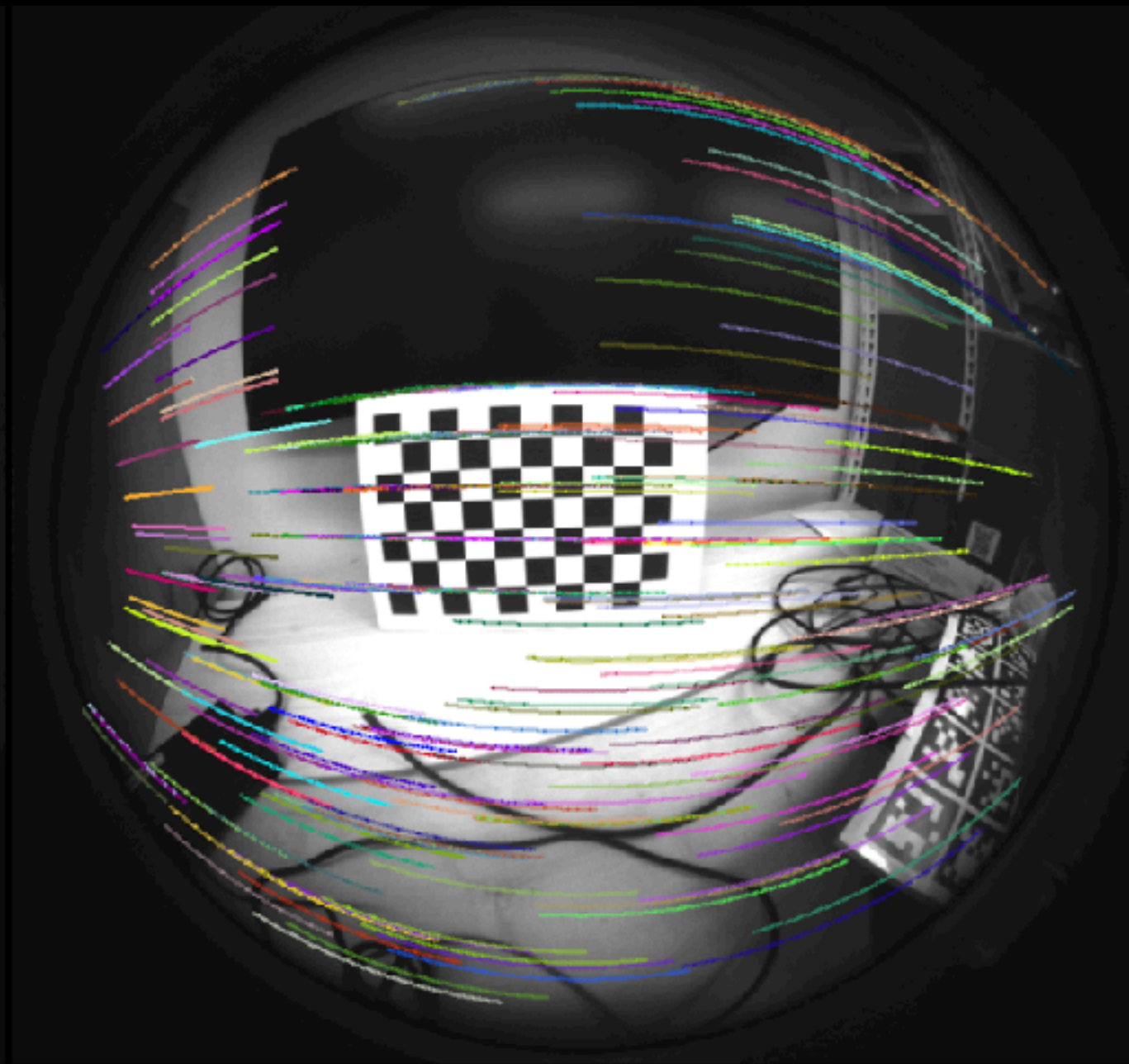
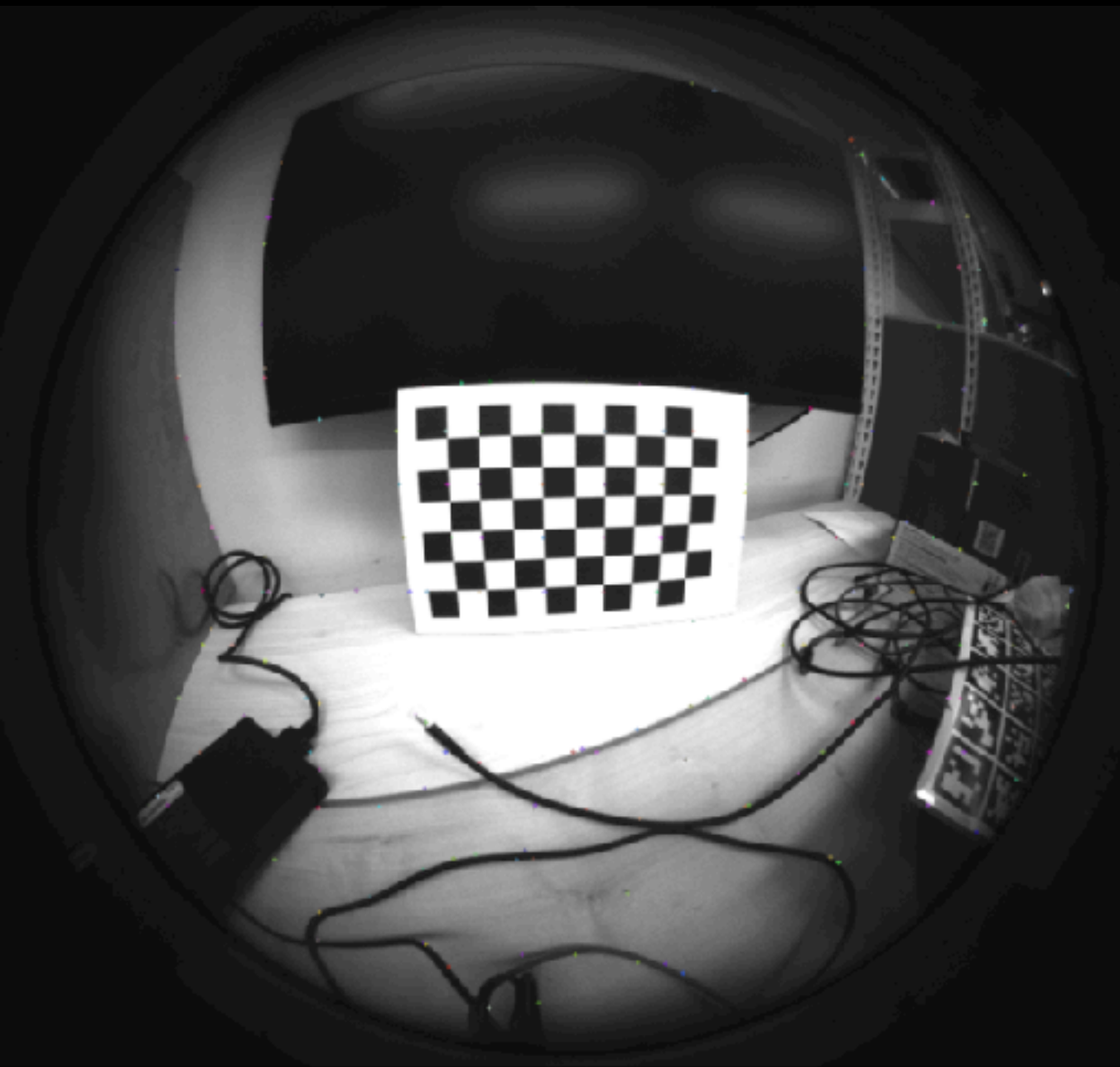
2. Patch matching



⇒ matching 화면 채움 전까지만으로
depth estimation 가능!

Depth Estimation

2. Patch matching - 실습



Depth Estimation

2. Patch matching - 실습

