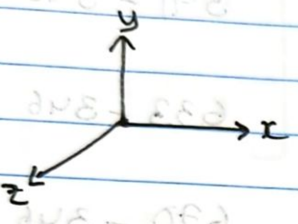
① steps to perform:

1) point camera to chessboard pattern
2) capture a series of 10 images
3) Change the orientation for every image
4) use image formation pipeline equation
5) Find Intrinsic and extrinsic parameters

Key points to consider:



$p(x_w, y_w, z_w) \rightarrow$ point in space / 3D world coordinates

$P_{im}(x_{im}, y_{im}) \rightarrow$ image coordinates

origin: corner

3D world coordinates

X (mm)	Y(mm)	Z(mm)
0	0	0
24	24	0
48	48	0
72	72	0
96	96	0
120	120	0
144	144	0

Image coordinates

	u (pixels)	v (pixels)
	origin: 432	origin: 346
1	524 - 432 = 92	432 - 346 = 86
2	632 - 432 = 200	591 - 346 = 245
3	674 - 432 = 242	633 - 346 = 287
4	741 - 432 = 309	670 - 346 = 324
5	832 - 432 = 400	747 - 346 = 401
6	921 - 432 = 489	821 - 346 = 475

projection matrix:-

$$\begin{bmatrix} x \\ v \\ w \end{bmatrix} = \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ P_{21} & P_{22} & P_{23} & P_{24} \\ P_{31} & P_{32} & P_{33} & P_{34} \end{bmatrix} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

A

$$\begin{bmatrix} x_w^{(1)} & y_w^{(1)} & z_w^{(1)} & 1 & 0 & 0 & 0 & 0 & -u_1 x_w^{(1)} & -u_1 y_w^{(1)} & -u_1 z_w^{(1)} & -u_1 \\ 0 & 0 & 0 & 0 & x_w^{(1)} & y_w^{(1)} & z_w^{(1)} & 1 & -v_1 x_w^{(1)} & -v_1 y_w^{(1)} & -v_1 z_w^{(1)} & -v_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_w^{(i)} & y_w^{(i)} & z_w^{(i)} & 1 & 0 & 0 & 0 & 0 & -u_i x_w^{(i)} & -u_i y_w^{(i)} & -u_i z_w^{(i)} & -u_i \\ 0 & 0 & 0 & 0 & x_w^{(i)} & y_w^{(i)} & z_w^{(i)} & 1 & -v_i x_w^{(i)} & -v_i y_w^{(i)} & -v_i z_w^{(i)} & \dots \end{bmatrix}$$

$$X \begin{bmatrix} P_{11} & P_{23} \\ P_{12} & P_{24} \\ P_{13} & P_{31} \\ P_{14} & P_{32} \\ P_{21} & P_{33} \\ P_{22} & P_{34} \end{bmatrix} \times \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$A^T \cdot A \cdot P = \lambda P$$

λ → Eigen value

P → Eigen vector

$$a = \begin{bmatrix}
24 & 24 & 2 & 0 & 0 & 0 & 0 & -2208 & -2208 & -184 & -92 \\
0 & 0 & 0 & 24 & 24 & 2 & 1 & -2064 & -2064 & -172 & -86 \\
48 & 48 & 2 & 0 & 0 & 0 & 0 & -9600 & -9600 & -400 & -200 \\
0 & 0 & 0 & 48 & 48 & 2 & 1 & -11760 & -11760 & -490 & -245 \\
72 & 72 & 2 & 0 & 0 & 0 & 0 & -17424 & -17424 & -484 & -242 \\
0 & 0 & 0 & 72 & 72 & 2 & 1 & -20664 & -20664 & -574 & -287 \\
96 & 96 & 2 & 0 & 0 & 0 & 0 & -29664 & -29664 & -618 & -309 \\
0 & 0 & 0 & 96 & 96 & 2 & 1 & -31104 & -31104 & -648 & -324 \\
120 & 120 & 2 & 0 & 0 & 0 & 0 & -48000 & -48000 & -800 & -400 \\
0 & 0 & 0 & 120 & 120 & 2 & 1 & -48120 & -48120 & -802 & -401 \\
144 & 144 & 2 & 0 & 0 & 0 & 0 & -70416 & -70416 & -978 & -489 \\
0 & 0 & 0 & 144 & 144 & 2 & 1 & -68400 & -68400 & -950 & -475
\end{bmatrix}$$

A^T = transpose(A)
$C = A^T \times A$
P = min(C);
$P = P^T$ (i.e. transpose(P))

Finally, projection matrix:

$$\begin{bmatrix} -15331968 \\ -15331968 \\ -268224 \\ -20711808 \\ -20711808 \\ -364224 \\ -182112 \\ -20711808 \\ -20711808 \\ -364224 \\ -182112 \end{bmatrix}$$

After QR factorization to get

i) Calibration Matrix
ii) Rotation matrix.

$$R = \begin{bmatrix} -0.4742 & 0.8088 & -0.0143 \\ -0.5425 & -0.30800 & -0.6647 \\ -0.5613 & -0.4078 & +0.7009 \end{bmatrix}$$

$$K = \begin{bmatrix} 3.1021 & 3.1021 & 0.0467 \\ 0 & 0. & -0.004 \\ 0 & 0 & -0.006 \end{bmatrix}$$

→ Formula for translation matrix.

$$t = K^{-1}\begin{bmatrix} P_{14} \\ P_{24} \\ P_{34} \end{bmatrix}$$

$$P_r = [-284224, -182112, -182112]$$

$$t = K^{-1} \times [-284224, -182112, -182112]$$

$$\text{Translation matrix} = \begin{bmatrix} 10^{13} \times 1.0643 \\ -1.0643 \\ 0. \end{bmatrix}$$