



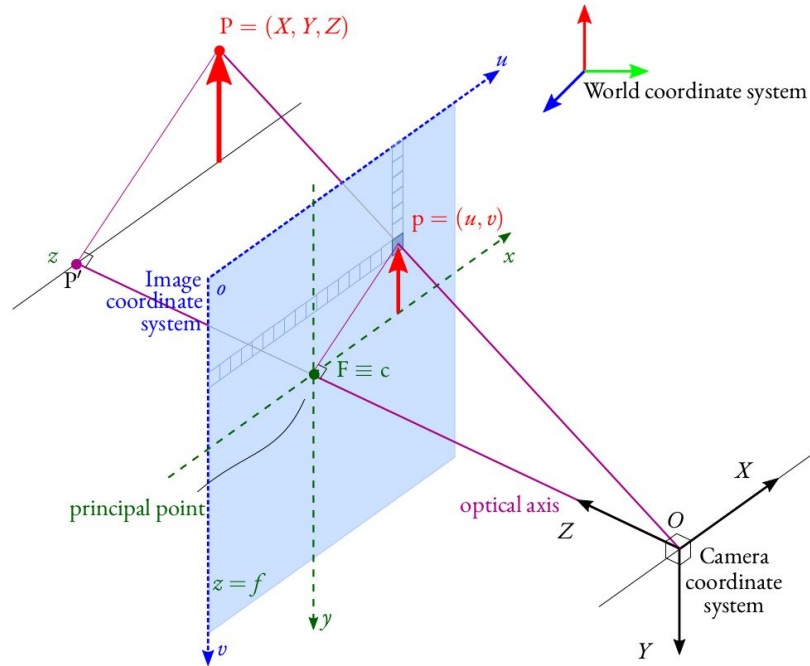
The Coding Library

Computer Vision

Camera Geometry and Calibration



Camera Pinhole Model



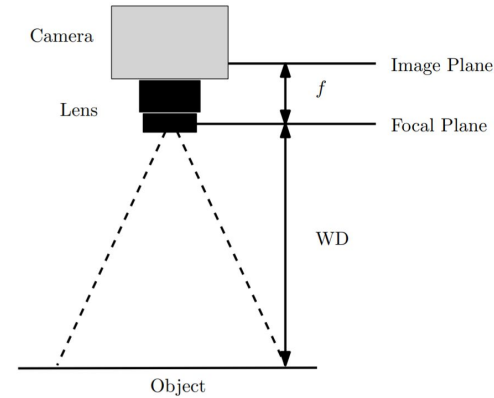
- Focal length considered as a scaling factor
- c_x, c_y - location of optical centre

$$w \cdot \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & 0 \\ 0 & f_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



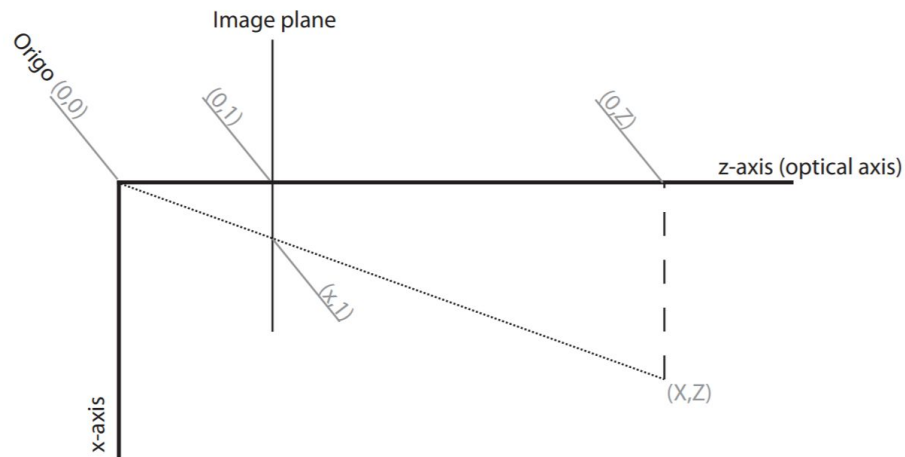
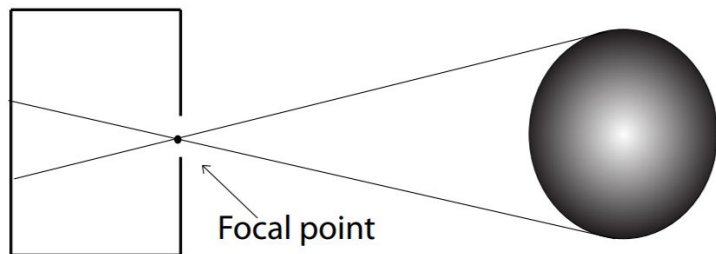
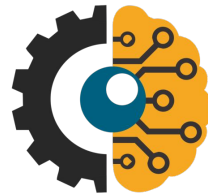
Camera Specifications

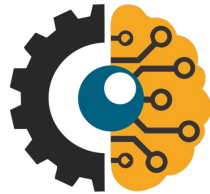
- Sensor type
 - CMOS/CCD
- Sensor Size
- Resolution (pixels)
- Lens Focal Length (f)
- Lens Aperture Range



$$\text{FOV} = \frac{d \cdot \text{WD}}{f} \quad , \text{ where } d \text{ is the sensor size}$$

Camera Geometry





Camera Geometry

- If the global coordinate system is not located in the camera

$$\mathbf{q}_i = \mathbf{A} \begin{bmatrix} \mathbf{R} & \mathbf{t} \end{bmatrix} Q_i = \mathbf{P} Q_i \quad , \quad \mathbf{P} = \mathbf{A} \begin{bmatrix} \mathbf{R} & \mathbf{t} \end{bmatrix}$$

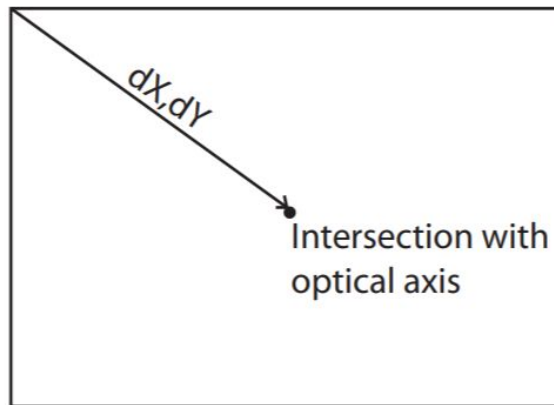
$$\mathbf{P} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \end{bmatrix}$$

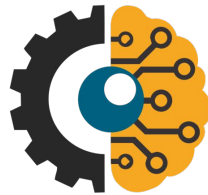


Camera Geometry

- Internal parameters
 - To account for scaling and offset
- Principle point coordinates
 - To account for the offset in the coordinate system

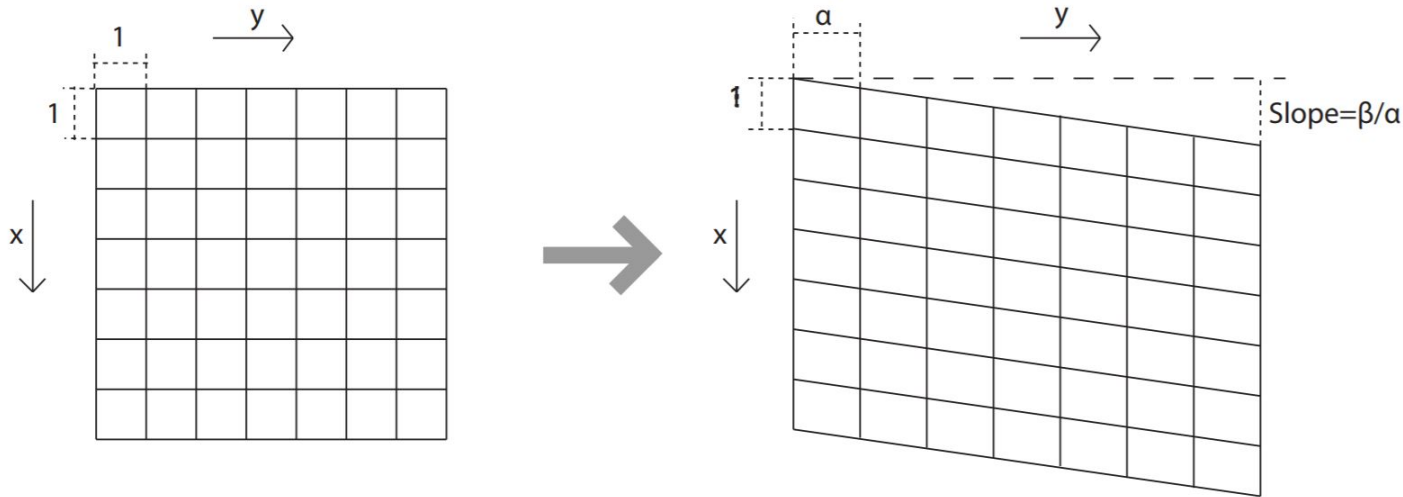
$$\mathbf{A} = \begin{bmatrix} f & f\beta & \Delta x \\ 0 & \alpha f & \Delta y \\ 0 & 0 & 1 \end{bmatrix}$$



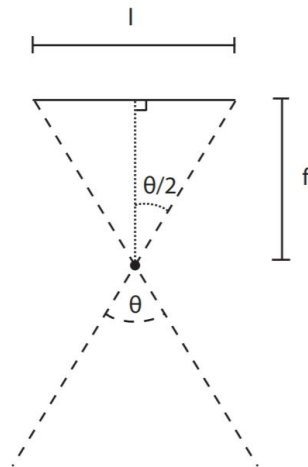
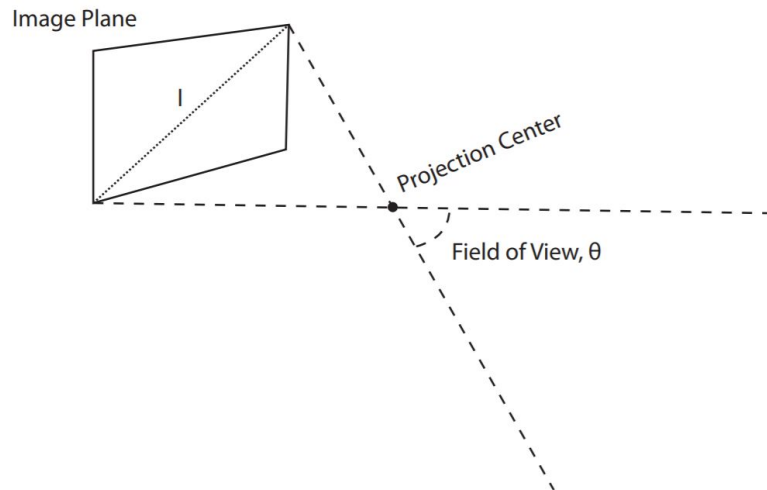
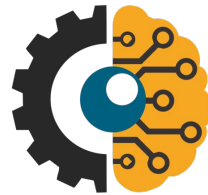


Skew and Aspect Ratio

- To account for non-square and non-rectangular pixels



Field of View (FoV)

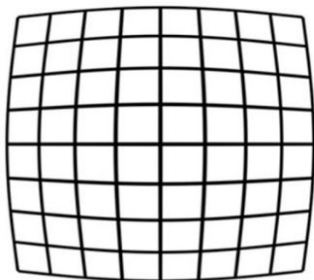


$$\begin{aligned}\tan\left(\frac{\theta}{2}\right) &= \frac{l/2}{f} \Rightarrow \\ \frac{\theta}{2} &= \arctan\left(\frac{l/2}{f}\right) \Rightarrow \\ \theta &= 2 \arctan\left(\frac{l/2}{f}\right)\end{aligned}$$

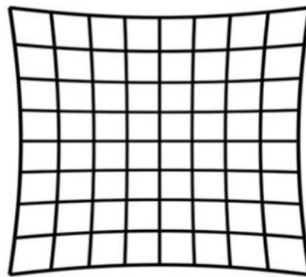


Distortion - Camera Models

- Radial Distortion
 - Radially symmetric from the optical axis
 - Change in magnification
 - Barrel distortion
 - Pincushion distortion
 - Caused by the lenses

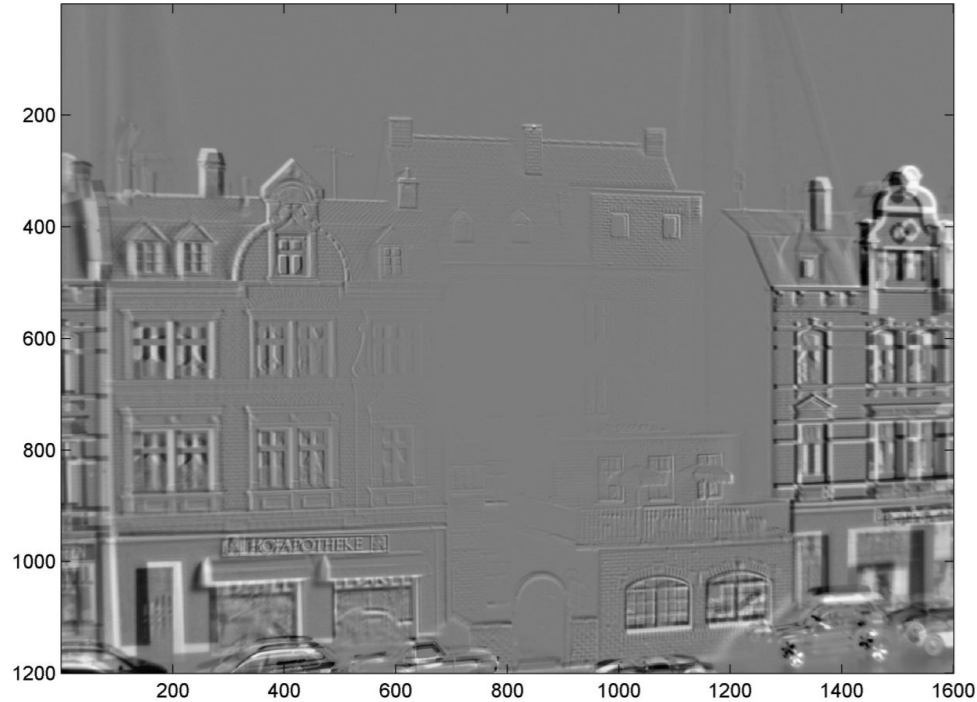


Barrel Distortion



Pincushion Distortion

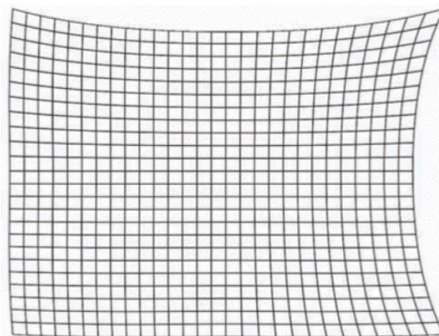
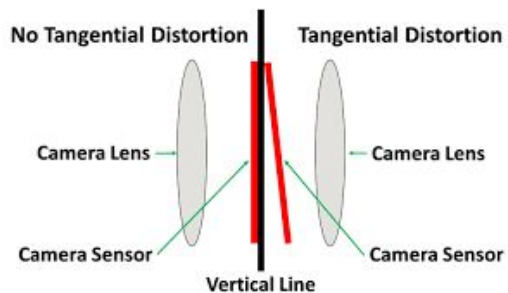
Example of Radial Distortion



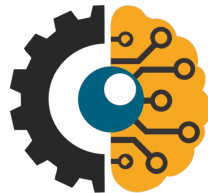


Distortion - Camera Models

- Tangential Distortion
 - Uneven magnification from one side to the other
 - Lenses not parallel to the image plane

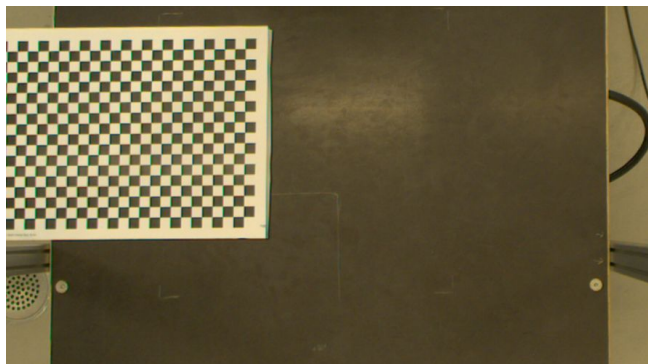


Tangential Distortion

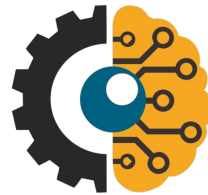


Camera Calibration

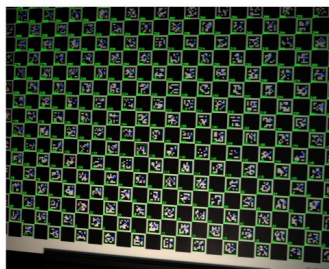
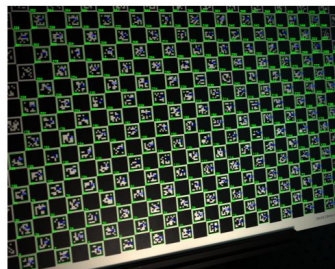
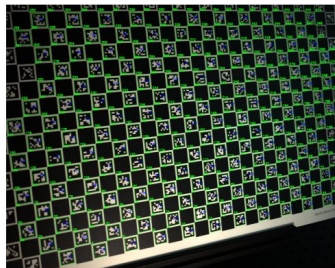
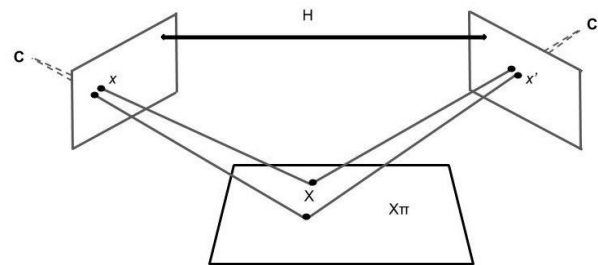
- Using multiple images
- A known object
- Different positions
 - Rotated
 - Translated
 - Tilted
- Computes camera matrix and distortion parameters
- Removes distortion



Camera Calibration - Zhang's Method



- Estimates homography to each camera plane
- Linear solutions for pinhole camera model



Camera Calibration - Zhang's Method

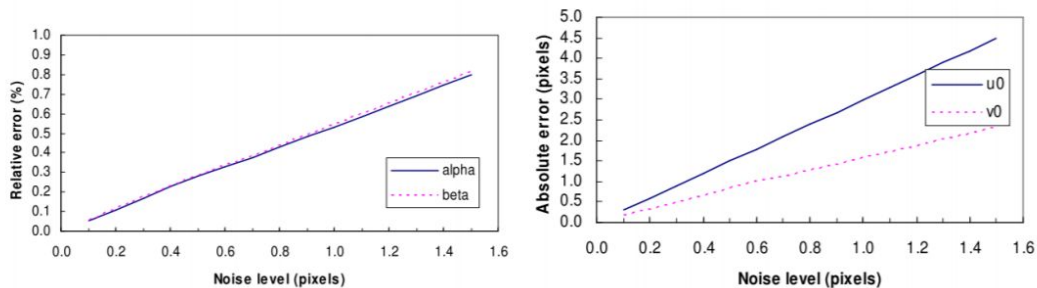


Figure 1: Errors vs. the noise level of the image points

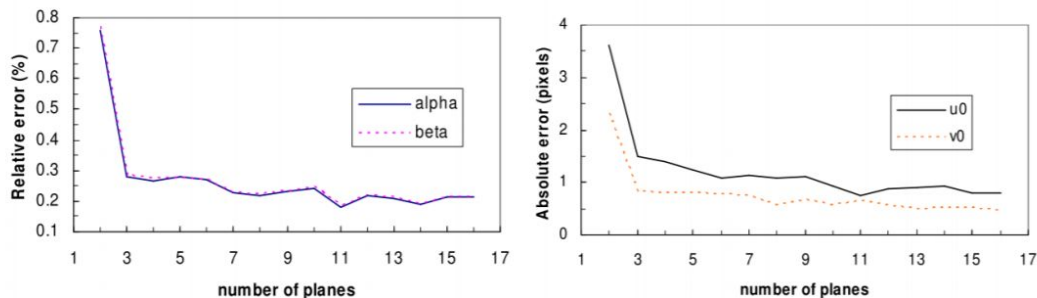


Figure 2: Errors vs. the number of images of the model plane