

Capturing, Modeling, Rendering 3D Structures

Calibration

Tsai Camera Model and Calibration

- A widely used camera model to calibrate conventional cameras based on a pinhole camera
- Reference
 - “A Versatile Camera Calibration Technique for High-Accuracy 3D Machine Vision Metrology Using Off-the-Shelf TV Cameras and Lenses”, Roger Y. Tsai, IEEE Journal of Robotics and Automation, Vol 3, No. 4, August 1987

Camera Calibration

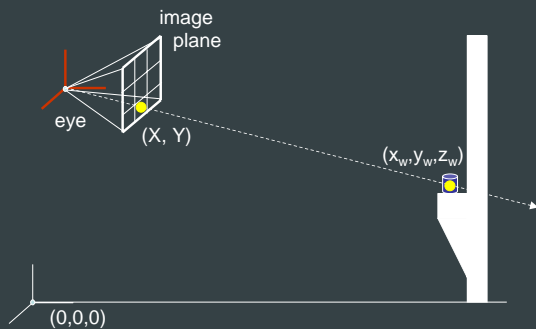
- Consists of:
 - determining the internal camera geometry and optical characteristics (**intrinsic parameters**); and,
 - finding the 3D position and orientation of the camera relative to a world coordinate frame (**extrinsic parameters**)
- Given a calibrated camera, you may
 - infer 3D information from 2D image coordinates
 - infer 2D image coordinates from 3D information

3D Coordinate Transformation

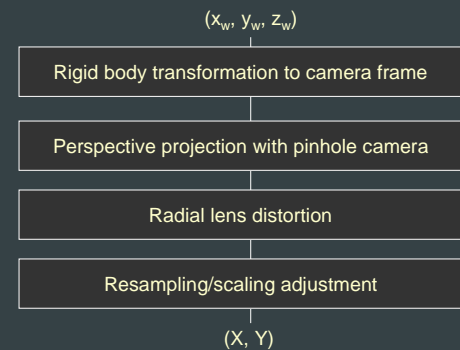
- How do you transform a 3D coordinate to an image coordinate?

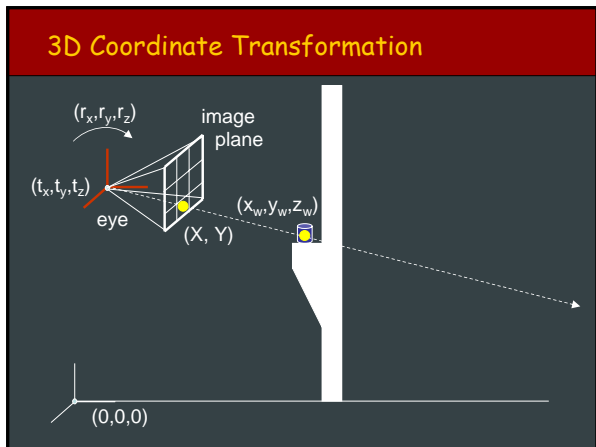
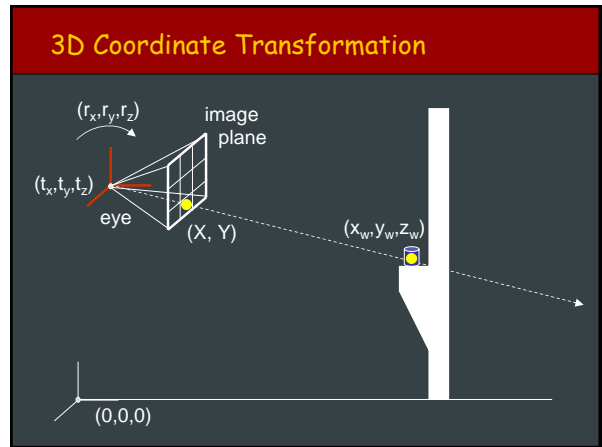
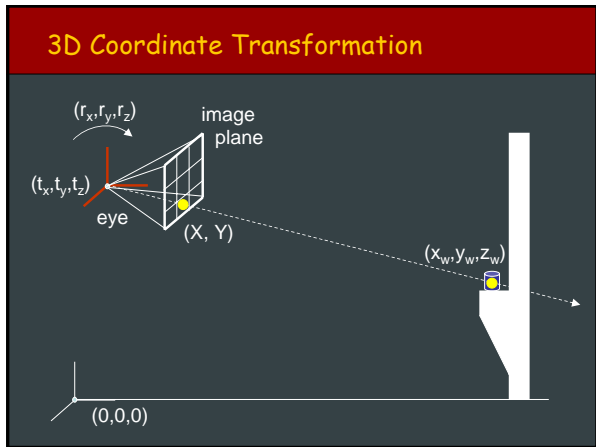
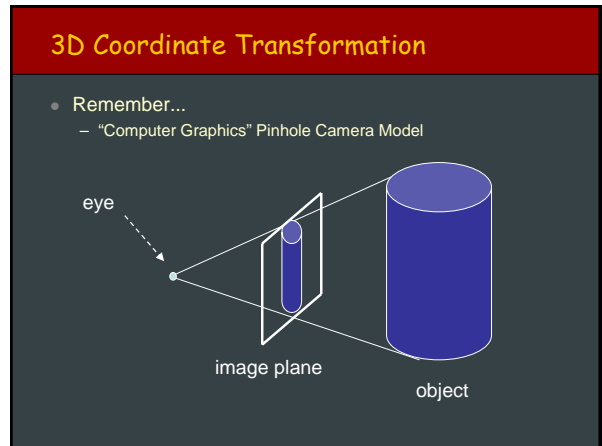
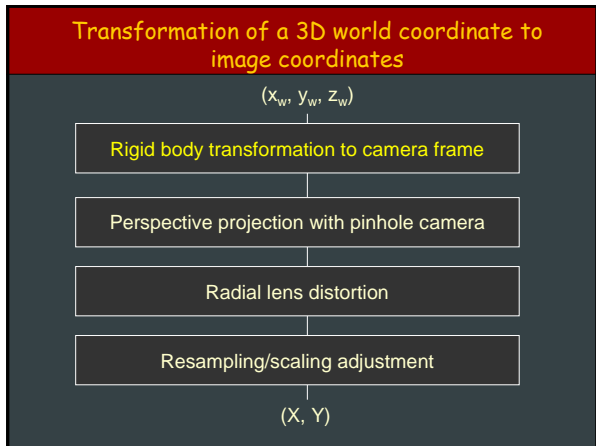


3D Coordinate Transformation



Transformation of a 3D world coordinate to image coordinates

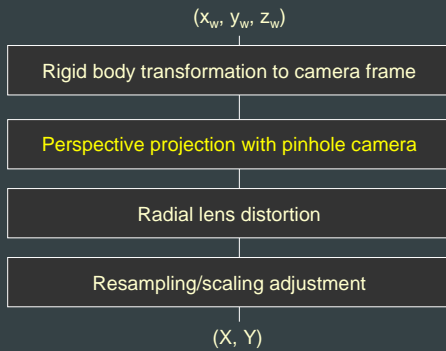




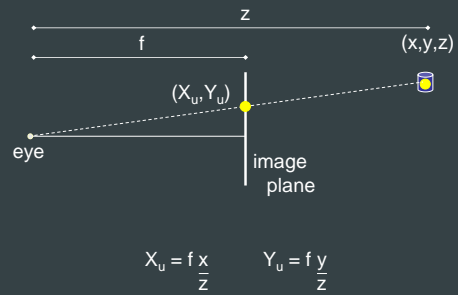
3D Coordinate Transformation

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} + T \quad \dots \text{where } R \text{ is } 3 \times 3 \text{ rotation matrix and } T \text{ is a vector}$$

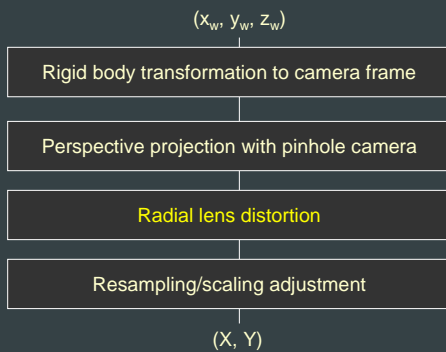
Transformation of a 3D world coordinate to image coordinates



Perspective Projection



Transformation of a 3D world coordinate to image coordinates



Radial Lens Distortion

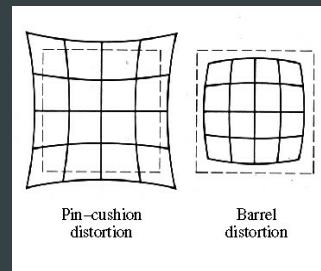
$$X_d = X_u - D_x$$

$$Y_d = Y_u - D_y$$

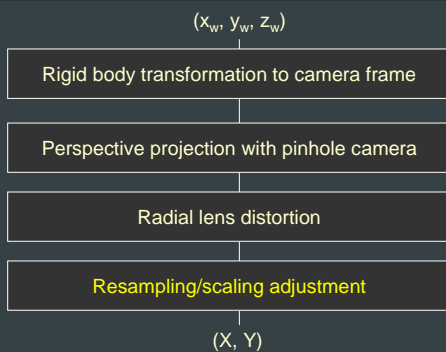
$$D_x = X_d(k_1 r^2 + k_2 r^4 + \dots)$$

$$D_y = Y_d(k_1 r^2 + k_2 r^4 + \dots)$$

$$r = (X_d^2 + Y_d^2)^{1/2}$$



Transformation of a 3D world coordinate to image coordinates



Resampling/Scaling Adjustment

$$X_f = \frac{X_d + C_x}{d_x}$$

$$Y_f = \frac{Y_d + C_y}{d_y}$$

where:
 (C_x, C_y) center coordinate
 d_x CCD x pixel size
 d_y CCD y pixel size

Resampling/Scaling Adjustment

$$X_r = \frac{X_d + C_x}{d_x}$$

$$Y_r = \frac{Y_d + C_y}{d_y}$$

where:
 (C_x, C_y) center coordinate
 d_x CCD x pixel size
 d_y CCD y pixel size

NOTE: number of "CCD pixels" does not necessarily equal the number of "image pixels"

Resampling/Scaling Adjustment

$$X_r = s_x \frac{X_d + C_x}{d_x'}$$

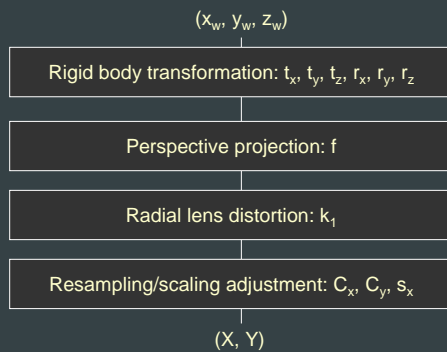
$$Y_r = \frac{Y_d + C_y}{d_y}$$

$$d_x' = d_x \frac{Nc_x}{Nf_x}$$

where:
 (C_x, C_y) center coordinate
 d_x CCD x pixel size
 d_y CCD y pixel size
 Nc_x number of CCD x pixels
 Nf_x number of image x pixels

NOTE: number of "CCD pixels" does not necessarily equal the number of "image pixels"

Transformation of a 3D world coordinate to image coordinates



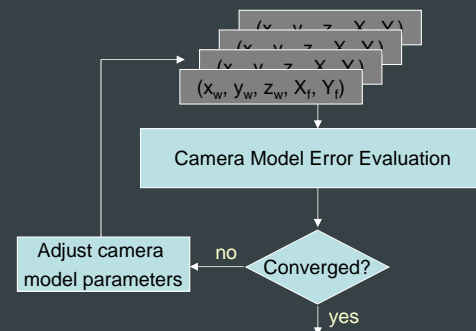
Tsai Camera Model

- 11 parameters
 - 6 extrinsic: $t_x, t_y, t_z, r_x, r_y, r_z$
 - 5 intrinsic: f, k_1, C_x, C_y, s_x
- 4 constants
 - $d_x, d_y, (, Nc_x, Nf_x)$

Tsai Camera Model Calibration

- Step 1
 - Obtain a set of tuples $(x_w, y_w, z_w, X_r, Y_r)$
- Step 2
 - Propose an initial set of camera model parameters
- Step 3
 - Perform a nonlinear optimization and refine the initial values of the camera model until system converges

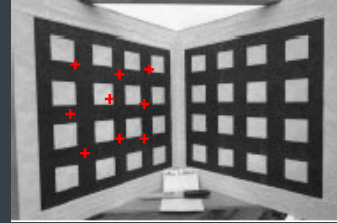
Tsai Camera Model Calibration



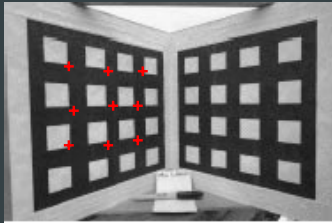
Example Calibration Object



Example Calibration Object



Example Calibration Object



Example Calibration Object

