CAMERA CALIBRATION

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INTRODUCTION

Camera calibration is the process of finding the true parameters of the camera that took your photographs. Some of these parameters are focal length, format size, principal point, and lens distortion.

INTRODUCTION

- Autonomous (*not require operator intervention*)
- Accurate
- Reasonably Efficient (*high speed implementation*)
- Versatile (operate uniformly)
- Need Only Common Off-the-Shelf Camera and Lens

PHYSICAL CAMERA PARAMETERS

- Intrinsic
  - ✓ Focal length, scale factor and lens distortion.
- Extrinsic
  - ✓ Position and orientation of the camera frame relative to world coordinate system (rotation and translation).

CAMERA CALIBRATION

- THREE Types:
  - ✓ Linear (Self-calibration)
  - ✓ Non-Linear (Photogrammetric calibration)
  - ✓ Co-Linear

CAMERA CALIBRATION
Linear (Self-calibration)

- This technique do not use any calibration object.
- Using reference points involve the determination of transformation parameters by solving linear equations with known reference parameters.
- Therefore, if images are taken by the same camera with the fixed intrinsic parameters, correspondences between three images are sufficient to reconstruct 3D structure up to a similarity.
- Algorithm fast and accurate, but reference points are hard to set in the WCS and cannot handle lens distortion.
- Abdel Aziz&Karara, Grosky and Tamburino

CAMERA CALIBRATION
Non-Linear (Photogrammetric calibration)

- Performed by observing a calibration 3D object.
- The calibration object consists of two or three planes orthogonal to each other.
- More accurate but computationally more expensive and elaborate setup
- Tsai, Zhang

CAMERA CALIBRATION

Co-Linear

- Combination of linear and non-linear technique where a linear method is employed to recover initial approximations for the parameters.
- This 2-stage approach has in most respects been super ceded for accurate camera calibration by the bundle adjustment formulation above, which is also implicitly a 2-stage process.

CAMERA CALIBRATION

Co-Linear

- Use 2 or 3 plane method (T.Echigo, Zhang)
- Geometric approach (M. Fisher & R. Ballas)
- Neural nets(J. Wen & G. Schweitzer)
- Statistical methods(R. L. Czaplewski)
- Vanishing points (B. Carprille & VTorre, K. Kanatani, R. Weiss H. Nakatani & M. Riseman)

ROGER TSAI Camera Calibration

- Assumes that some parameters of the camera are provided by manufacturer, to reduce the initial guess of the estimation.
- Suitable for a wide area of app since it can deal with coplanar and non-coplanar points.

ROGER TSAI Camera Calibration

The Tsai model is based on a pinhole perspective projection model and the following eleven parameters are to estimate:

- f - Focal length of camera,
- k - Radial lens distortion coefficient,
- C_x, C_y - Co-ordinates of centre of radial lens distortion,
- S_x - Scale factor to account for any uncertainty due to imperfections in hardware timing for scanning and digitisation,
- R_x, R_y, R_z - Rotation angles for the transformation between the world and camera co-ordinates,
- T_x, T_y, T_z - Translation components for the transformation between the world and camera co-ordinates.

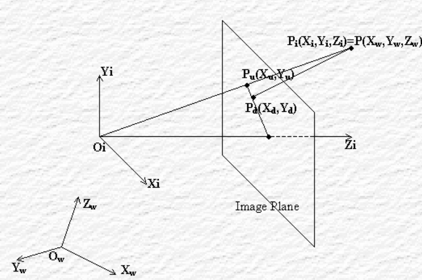


Figure 1: Tsai Camera re-projection model with perspective projection and radial distortion.

Roger Tsai :Four steps of transformation from **3D** world coordinate to computer image coordinate.

(x_w, y_w, z_w) 3D world coordinate

Step 1
Rigid body transformation **(x_w, y_w, z_w) to (x, y, z)**
Parameters to be calibrated: ***R, T***

(x, y, z) 3D camera coordinate system

Step 2
Perspective projection with pinhole geometry
Parameters to be calibrated: ***f***

(X_u, Y_u) Ideal undistorted image coordinate

Step 3
Radial lens distortion
Parameters to be calibrated: ***K_1, K_2***

(X_d, Y_d) Distorted image coordinate

Step 4
TV scanning, Sampling, computer acquisition
Parameter to be calibrated: uncertainty scale factor **s_x**, for image **X** coordinate

(X_f, Y_f) Computer image coordinate in frame memory

ROGER TSAI Camera Calibration

The transformation from world (X_w,Y_w,Z_w) to image (X_i,Y_i,Z_i) co-ordinates considers the extrinsic parameters of the camera (Translation T and Rotation R) within the equation:

$$\begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} = R \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix} + T$$

T is the translation vector

where R and T characterize the 3D transformation from the world to the camera co-ordinate system and are defined as follows:

$$R = \begin{bmatrix} r_1 & r_2 & r_3 \\ r_4 & r_5 & r_6 \\ r_7 & r_8 & r_9 \end{bmatrix} \quad T = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix}$$

R is 3 X 3 rotation matrix

with

$$r_1 = \cos(R_y)\cos(R_z)$$
$$r_2 = \cos(R_z)\sin(R_x)\sin(R_y) - \cos(R_x)\sin(R_z)$$
$$r_3 = \sin(R_x)\sin(R_z) + \cos(R_x)\cos(R_z)\sin(R_y)$$
$$r_4 = \cos(R_y)\sin(R_z)$$
$$r_5 = \sin(R_x)\sin(R_y)\sin(R_z) + \cos(R_x)\cos(R_z)$$
$$r_6 = \cos(R_x)\sin(R_y)\sin(R_z) - \cos(R_z)\sin(R_x)$$
$$r_7 = -\sin(R_y)$$
$$r_8 = \cos(R_y)\sin(R_x)$$
$$r_9 = \cos(R_x)\cos(R_y)$$

(R_x,R_y,R_z) the Euler angles of the rotation around the three axes.

(T_x,T_y,T_z) the 3D translation parameters from world to image co-ordinates.

The transformation from 3D position (in the image co-ordinate frame) to the image plane is then computed through the following steps (see Figure 1):

ROGER TSAI Camera Calibration

Transformation from 3D world co-ordinates (X_i, Y_i) to undistorted image plane (X_u, Y_u) co-ordinates

$$X_u = f\frac{X_i}{Z_i}$$

$$Y_u = f\frac{Y_i}{Z_i}$$

Transformation from undistorted (X_u, Y_u) to distorted (X_d, Y_d) image co-ordinates

$$X_u = X_d(1 + kr^2)$$

$$Y_u = Y_d(1 + kr^2)$$

where

$r = \sqrt{X_d^2 + Y_d^2}$, and k is the lens distortion coefficient.

Transformation from distorted co-ordinates in image plane (X_d, Y_d) to the final image co-ordinates (X_f, Y_f) are:

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

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

with

(d_x, d_y): distance between adjacent sensor elements in the X and Y direction. d_x and d_y are fixed parameters of the camera. They depend only on the CCD size and the image resolution, (X_f, Y_f) are the final pixel position in the image.

ZHANG Camera Calibration

- Requires the camera to observe a planar pattern shown at a few (at least two) different orientations.
- Either the camera or planar pattern can be freely moved.
- The motion need not be known.
- The procedure consists of a closed-form solution, followed by non-linear refinement based on the maximum likelihood criterion.

ZHANG Camera Calibration

- Radial distortion is modeled.

$$\tilde{x} = x + x\,[\,k_1(x^2 + y^2) + k_2(x^2+y^2)^2\,]$$

$$\tilde{y} = y + y\,[\,k_1(x^2 + y^2) + k_2(x^2+y^2)^2\,]$$

k_1, k_2 = coefficient of radial distortion.

Zhang: Using Levenberg-Marquardt Algorithm

Step 1
Print a pattern and attach it to a planar surface.

Step 2
Take a few images of the model plane under different orientations by moving either the plane or the camera.

Step 3
Detect the feature points in the images.

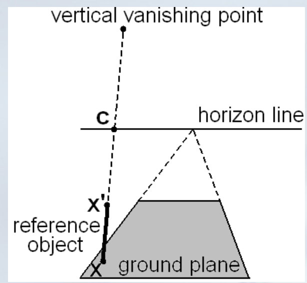
Step 4
Estimate the 5 intrinsic parameters and all the extrinsic parameters using the closed-form solution.

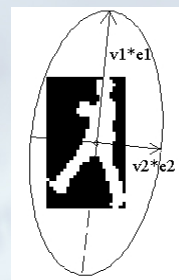
Step 5
Estimate the coefficients of the radial distortion by solving the linear least-squares

Step 6
Refine all parameters by minimizing.

VANISHING POINTS

- Estimate a camera’s intrinsic and extrinsic parameters from vertical line segments of the same height is presented.
- Detect head and feet position of walking human in his leg-crossing phases.





Vanishing Points : Calibrate Camera

1. Need to know
   - 3 intrinsic parameters (focal length *f*, principal point (u_0,v_0))
   - 4 extrinsic parameters (tilt angle β, the pan angle α and yaw angle γ that describe the rotation transform between the WCS and CCS,
   - Height of the camera H_c.

Approximate calibration using a vertical vanishing point and the horizon line

STEP1: Choose arbitrarily a point on the horizon line as V_x.

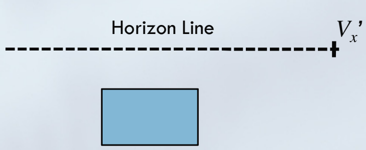
STEP2: If $\gamma \neq 0$, we rotate the image around image origin by γ such the horizon line is aligned with the horizontal line. V_x' and V_y' are two vanishing points of the new image.

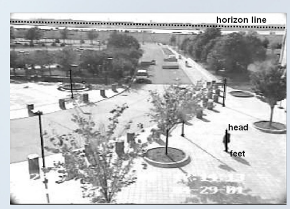
STEP3: Because the line passing through V_y' and the principal point p' is a vertical line, the x coordinate of p' approximates to half of the image height, which is reasonable because in many situations, the principal point is located near the image center.

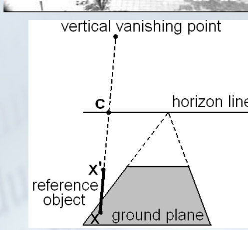
STEP4: Suppose L_1 is the line passing through V_x' and p', and L_2 is the line which passes through V_y' and is orthogonal to L_1. the intersection of L_2 and the horizon line gives another orthogonal vanishing point V_z'.

STEP5: Since all of the three vanishing points are now known, we can use the *vanishing points algorithm* to compute the camera parameters.

STEP1: Choose arbitrarily a point on the horizon line as V_x'



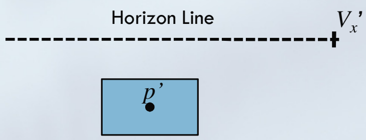


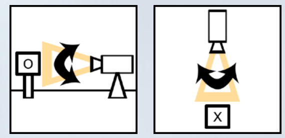


How to find Horizon line?

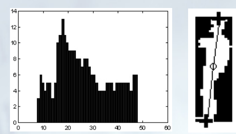
Any vertical structure like pole, truck or human body can be used to get the vertical vanishing point. If the lines are parallel to the ground plane, the vanishing line is called the *horizon line.*

STEP2: If $\gamma \neq 0$, we rotate the image around image origin by γ such the horizon line is aligned with the horizontal line. V_x' and V_y' are two vanishing points of the new image.





Tilt Pan

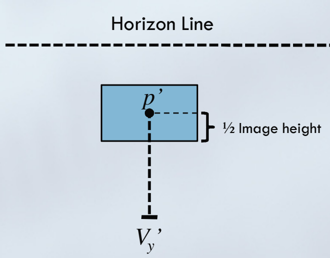


Histogram

How to get vertical vanishing points?

Find the positions of the head and fee, at the leg-crossing frame, by analyzing the histogram of the projection of human pixel. Their locations along the axis are determined by finding the FIRST POINT whose projection is ABOVE a threshold.

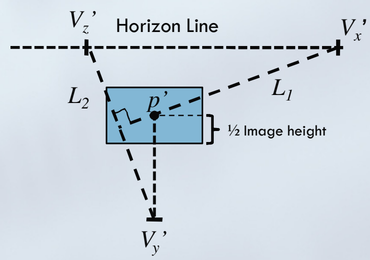
STEP3: Because the line passing through V_y' and the principal point p' is a vertical line, the x coordinate of p' approximates to half of the image height, which is reasonable because in many situations, the principal point is located near the image center.



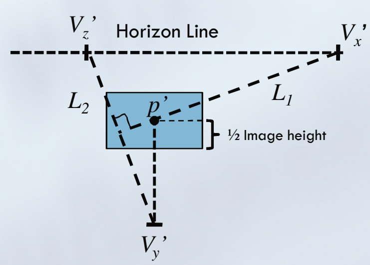
How to find Horizon line?

Any vertical structure like pole, truck or human body can be used to get the vertical vanishing point. The horizon line is apparent intersection of the earth and sky.

STEP4: Suppose L_1 is the line passing through V_x' and p', and L_2 is the line which passes through V_y' and is orthogonal to L_1. The intersection of L_2 and the horizon line gives another orthogonal vanishing point V_z'.



STEP5: Since all of the three vanishing points are now known, we can use the *vanishing points algorithm* to compute the camera parameters.



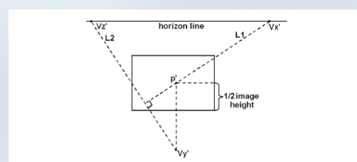


Figure 5: Get the third vanishing point V_z' from V_x', V_y' and p'.

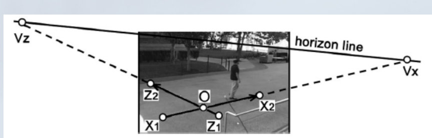
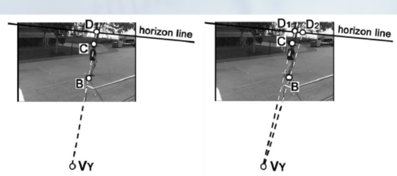


Fig. 3. Given the horizon line, two auxiliary lines X_1X_2 and Z_1Z_2 are needed to obtain the other two vanishing points. X_1X_2 and Z_1Z_2 are parallel to the ground plane and orthogonal to each other.



(a) (b)

VANISHING POINTS Algorithms

- Obtain 3 vanishing points X_1X_2 and Z_1Z_2 parallel to ground plane.
- Locate the principal point, *P*.
- Compute focal length and rotation angles
- Compute the translation vector, T_c.
- Refine the parameters by optimization.

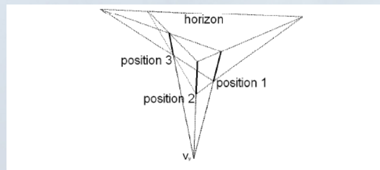


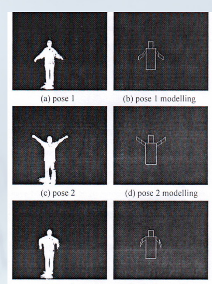
Figure 6: Using walking human to get the vertical vanishing point and the horizon line.

FUTURE WORK

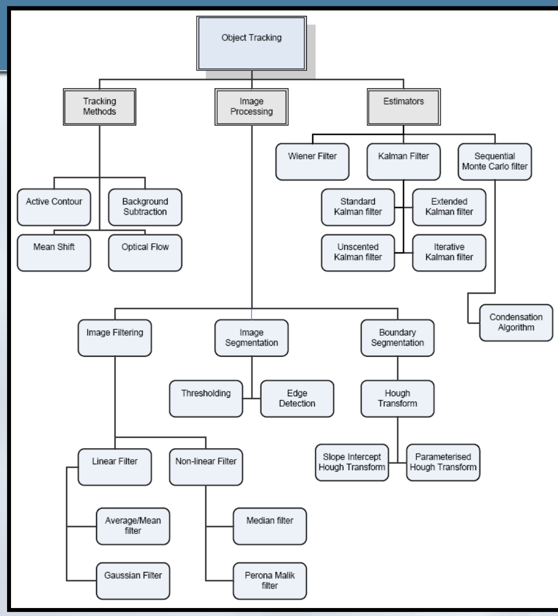
My AIM :

Perform the arm tracking using estimation method, usually Bayesian method. But at first, I have to define the arm by using cardboard model.

Tracking



Cardboard Model



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