Extrinsic Calibration of a Lidar and Camera

Calibration is basic requirement in multi-sensor platforms where data needs to be presented in a common reference frame for the purpose of data analysis and data fusion.

Camera provides intensity information in the form of an image.

Lidar provides depth information in the form of set of 3D point clouds.

External calibration allows reprojection of the 3-D points from the lidar coord frame to the 2D-coord frame of image.

The procedure proposed uses checkerboard as calibration target.

Intrinsic calibration of the camera

Camera calibration toolbox for Matlab → is used.

Algorithm: It is detailed in Matlab toolbox

a. Camera model:

focal length → 2x1 vector fc.

principle point → co-ords in 2x1 vector cc

Skew co-eff → angle between the x & y

classmate

Date

Page

pixel axes is the scalar alpha-c

Distortions: The image distortion co-eff. is the 5×1 vector K_c

In the 3D coord point observed pixel is $P = [X_c, Y_c, Z_c]$

$$x_n = \begin{bmatrix} X_c / Z_c \\ Y_c / Z_c \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix}$$

Let, $r^2 = x^2 + y^2$,

The normalized point after including lens distortion:

$$x_d = \begin{bmatrix} x_d(1) \\ x_d(2) \end{bmatrix}$$

$$= (1 + K_c(1) r^2 + K_c(2) r^4 + K_c(5) r^6) \cdot x_n + dx$$

where dx is the tangential distortion vector.

$$dx = \begin{bmatrix} 2KC(3)xy + KC(4)(r^2 + 2x^2) \\ KC(3)(r^2 + 2x^2) 2KC(4)xy \end{bmatrix}$$

Once distortion is applied, the final pixel coord's of the point are given by:

$$\begin{bmatrix} x_p \\ y_p \\ 1 \end{bmatrix} = \begin{bmatrix} fc(1) & alpha\_c \times fc(1) & cc(1) \\ 0 & fc(2) & cc(2) \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_d(1) \\ x_d(2) \\ 1 \end{bmatrix}$$

→ Let the directions along the left & top edges were choosen as x & y axis of this frame

& the direction ⊥ to the checkerboard be choosen as the Z-axis

→ Then the toolbox returns the rotation R_c and translation T_c of the target co-ord. frame.

→ These values are stored as Rc_i & Tc_i in the Calib-Results.mat

where, i → index of the observation.

→ This gives the orientation ($\theta_{c,i}$) and distance ($\alpha_{c,i}$) of the plane

$\theta_{c,i}\, x - \alpha_{c,i} = 0$ which respect to the camera origin, for each images in the camera frame of reference.

b. Extrinsic Calibration model:

A robust total least squares estimator is used to fit a plane to the set of points in 3-D corresponding to the selection.

This gives an estimate of $\theta_{l,i}$ & $\alpha_{l,i}$ in the laser coord. frame.

First find the translation that minimizes the difference in distance from the camera origin to each plane, represented in the camera coord. s/m & the laser co-ord. system.

Let:

$$\theta_c = [\theta_{c,1} \; \theta_{c,2} \; \dots \; \theta_{c,n}]^T$$

$$\alpha_c = [\alpha_{c,1} \; \alpha_{c,2}, \dots \; \alpha_{c,n}]^T$$

$$\theta_l = [\theta_{l,1}, \theta_{l,2}, \dots \; \theta_{l,n}]^T$$

$$\alpha_l = [\alpha_{l,1} \; \alpha_{l,2} \; \dots \; \alpha_{l,n}]^T$$

where, $n \rightarrow$ number of scan-image observation pairs.

Subscript, $c \rightarrow$ Camera

$l \rightarrow$ lidar.

Required estimate of translation has a closed form solution given by:

$$t_1 = (\theta_c^T \theta_c)^{-1} \theta_c^T (\alpha_c - \alpha_l)$$

Rotation between the reference frame that minimizes the difference between the normal from the origin to the corresponding planes in the 2 frames: $R_1 = VU^T$

where, $O_{c_i} O_{c_i}^T = USV^T$ is the associated Single Value decomposition.

→ The objective function to be minimized is chosen to be the distance from the user-selected linear 3-D points to the corresponding plane observed from the image.

→ The linear can be estimated as a byproduct of the least squares.

→ The minimization of the objective function can be done through an iterative optimization procedure with initial estimate choosen as a result from stage-I.

Let $x_{l,i}$ → matrix of 3-D points by the user from the i^{th} range image ordered as:

$$x_{l,i} = \left[x_{l,i}^{(0)} \quad x_{l,i}^{(1)} \cdots x_{l,i}^{(m)} \right]$$

where, $x_{l,i}^{(j)} \in R^{3 \times 1}$ and $m = m(i)$ is the number of linear for i^{th} laser scan

Then the problem takes the form:

$$\arg\min_{R,t} \sum_{i=1}^{n} \sum_{j=1}^{m(i)} \left\| O_{c,i}^T \left(R x_{l,i}^{(j)} + t \right) - \alpha_{c,i} \right)$$

classmate
Date
Page

The implementation uses only the points corresponding to the corners (4) in the range image.

→ The technique has provided o/p with accuracy sufficient to meet the demands of mobile robot perception.