Cityscapes Calibration

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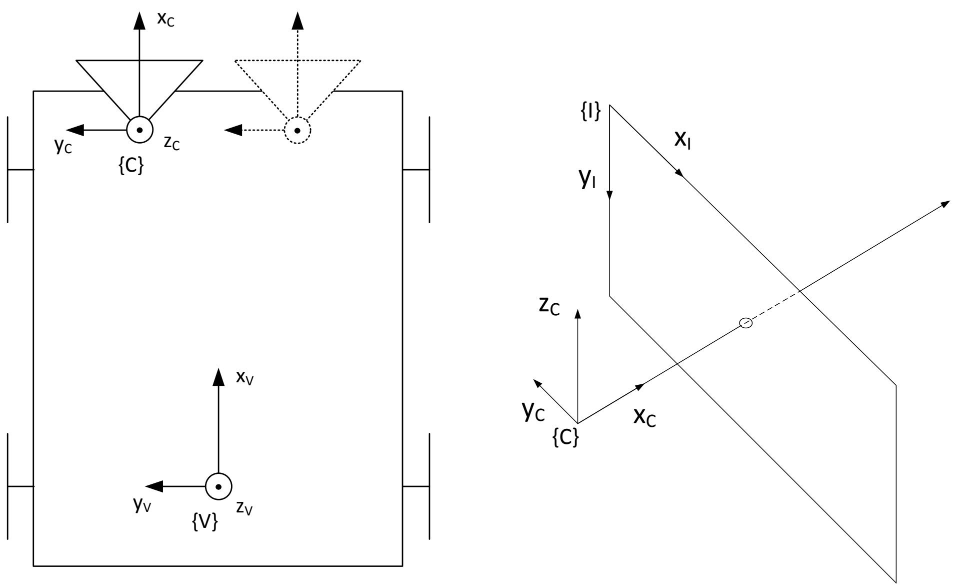
1 Coordinate Systems

We define three coordinate systems: (1) the vehicle coordinate system V according to ISO 8855 with the origin on the ground below of the rear axis center, x pointing in driving direction, y pointing left, and z pointing up; (2) the camera coordinate system C with the origin in the camera's optical center and same orientation; (3) the image coordinate system I with the origin in the top-left image pixel, u pointing right, v pointing down.



2 Coordinate Transformation

The transformation of a point (p_x^V, p_y^V, p_z^V) given in the vehicle coordinate system into a point (p_u^I, p_v^I) in the image coordinate system is given by

$$p_z^V \cdot \begin{pmatrix} p_u^I \\ p_v^I \\ 1 \end{pmatrix} = \mathbf{C} \cdot \begin{pmatrix} p_x^C \\ p_y^C \\ p_z^C \end{pmatrix} = \mathbf{C} \cdot (\mathbf{R}|\mathbf{t}) \cdot \begin{pmatrix} p_x^V \\ p_y^V \\ p_z^V \\ 1 \end{pmatrix} . \tag{1}$$

To transform a point (p_x^C, p_y^C, p_z^C) in the camera coordinate system into a point (p_x^V, p_y^V, p_z^V) in the vehicle coordinate system, we write

$$\begin{pmatrix} p_x^V \\ p_y^V \\ p_z^V \end{pmatrix} = (\mathbf{R_{C\to V}}|\mathbf{t_{C\to V}}) \cdot \begin{pmatrix} p_x^C \\ p_y^C \\ p_z^C \\ 1 \end{pmatrix} . \tag{2}$$

$\mathbf{R_{C\to V}}$ can be calculated from $\text{yaw}_{\text{extrinsic}}$, $\text{pitch}_{\text{extrinsic}}$, $\text{roll}_{\text{extrinsic}}$ as

$$\mathbf{R_{C\to V}} = \begin{pmatrix} c_y\, c_p & c_y\, s_p\, s_r - s_y\, c_r & c_y\, s_p\, c_r + s_y\, s_r \\ s_y\, c_p & s_y\, s_p\, s_r + c_y\, c_r & s_y\, s_p\, c_r - c_y\, s_r \\ -s_p & c_p\, s_r & c_p\, c_r \end{pmatrix} \tag{3}$$

with s_y, c_y, s_p ,c_p ,s_r, and c_r representing the sine and cosine of $\text{yaw}_{\text{extrinsic}}$, $\text{pitch}_{\text{extrinsic}}$ and $\text{roll}_{\text{extrinsic}}$, respectively and the translation $\mathbf{t_{C\to V}}$ is given by

$$\mathbf{t_{C\to V}} = \begin{pmatrix} x_{\text{extrinsic}} \\ y_{\text{extrinsic}} \\ z_{\text{extrinsic}} \end{pmatrix} . \tag{4}$$

To obtain $\mathbf{R}$ and $\mathbf{t}$ in equation (1) we invert equation (2) and obtain $\mathbf{R} = \mathbf{R_{C\to V}^T}$ and $\mathbf{t} = -\mathbf{R} \cdot \mathbf{t_{C\to V}}$. To map a point from camera to image pixel coordinates, the intrinsic matrix $\mathbf{K}$ is typically used, which is defined as

$$\mathbf{K} = \begin{pmatrix} f_x & 0 & u_0 \\ 0 & f_y & v_0 \\ 0 & 0 & 1 \end{pmatrix} . \tag{5}$$

This form of $\mathbf{K}$ assumes that the camera coordinate system's x, y and z axis are pointing right, down and front, respectively. To deal with the camera coordinate system described in Sec. 1, the intrinsic matrix is rotated to obtain $\mathbf{C}$, *i.e.*

$$\mathbf{C} = \mathbf{K} \cdot \begin{pmatrix} 0 & -1 & 0 \\ 0 & 0 & -1 \\ 1 & 0 & 0 \end{pmatrix} . \tag{6}$$

3 Parameters

Extrinsic and intrinsic calibration parameters of the camera are provided in the folder `camera`. The camera translation parameters $x_{\text{extrinsic}}$, $y_{\text{extrinsic}}$, $z_{\text{extrinsic}}$ are given in meters, the rotational parameters $\text{yaw}_{\text{extrinsic}}$, $\text{pitch}_{\text{extrinsic}}$, $\text{roll}_{\text{extrinsic}}$ in radians, and the intrinsic parameters f_x, f_y, u_0, v_0 in pixels.

Within the folder `vehicle`, we provide vehicle odometry consisting of speed [m/s] and yaw rate [rad/s] according to the vehicle coordinate system (V). Further, we included the outside temperature [°C], the GPS latitude [°N], and longitude [°E].