Master Project ASL

Frederike Dmbgen

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Chapter 1

Rectification

1.1 Rectification test

The following test was performed to verify the correctness of the pixel associations with respect to the rectified images given by *image_proc* of `ROS`. The difference of intensities at corresponding pixels in the original images I_j and rectified images I_j^{rect} are given by:

$$\Delta I_{i,j} = I_j(u_{i,j}) - I_j^{rect}(w_{i,j}) \qquad \text{for } i = 1 \dots n, \quad j = 1,2 \quad , \tag{1.1}$$

where $u_{i,j}$, $w_{i,j}$ denote the pixel location of the object point X_i in the original and rectified image of camera j respectively.

If the rectified pixels are computed in accordance with the rectification process given by `ROS`, this difference should be approximately zero or

$$I_j(u_{i,j}) = I_j^{rect}(w_{i,j}) + \epsilon_{i,j} \qquad \text{for } i = 1 \dots n, \quad j = 1,2 \quad , \tag{1.2}$$

with the error $\epsilon_{i,j}$ arising solely from interpolation.

The pixels of the rectified image are computed using the projection matrices $P_j = \left[K'|t_j\right]$ and rotation matrices R_j obtained from the CameraInfo message with [2]

$$\begin{aligned} w_{i,j} &= K'(R_j T_j(X_i)) \qquad \text{, where} && (1.3)\\ T_j(X_i) &= \pi({}_{C_j} r_{C_j X}) && (1.4)\\ &= \pi(C_{C_j M}(X_i - {}_M r_{M C_j})) \qquad \text{and} && (1.5)\\ \pi(\left(x,y,z\right)^T) &= \left(x/z, y/z, 1\right)^T \quad . && (1.6) \end{aligned}$$

Remember that $u_{i,j}$ are given by

$$u_{i,j} = K_j D_j(T_j(X_i))) \qquad \text{for } i = 1 \dots n, \quad j = 1,2 \quad , \tag{1.7}$$

with K_j, D_j and T_j the camera matrix, distortion function and projection transform given above.

A look at Figures 1.1a and 1.1b shows that the resulting error between the rectified image and the original image is indeed unformly small and with only very light patterns observable in both left and right images. These patterns get stronger as we approach the image border, where interpolation effects become more important. The pixel correspondence equations developed above are thereby validated for the rectified images provided by `ROS`.

1.2 Transformation test

Similar considerations can be applied for validating the interpretation of the camera parameters to compute the transformation between the left and the right camera.

The following assumptions need to be tested [3], [4, p. 523f].

$$C_{SC_j} = R_j \qquad \text{for j=1, 2} \implies C_{C_2C_1} = R_2^T R_1 \qquad \text{and} \tag{1.8}$$

$$_{C_1}r_{C_1C_2} = C_{C_1S}(_S r_{SC_2} - _S r_{SC_1}) = R_1^T \begin{pmatrix} -P_2(0,3)/P_2(0,0) & 0 & 0 \end{pmatrix}^T \quad . \tag{1.9}$$

If the above assumptions hold, then one can obtain the point coordinates in the second camera frame from the ones in the first camera frame by applying

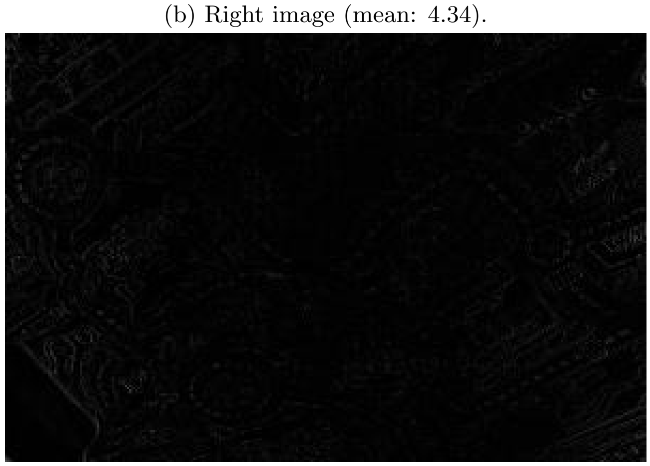
$$_{C_2}r_{C_2X} = C_{C_2C_1}(_{C_1}r_{C_1X_i} + _{C_1} r_{C_1C_2}) \quad . \tag{1.10}$$

The same transformations as before are then applied to project these points in the respective rectified images. As can be seen from Figure 1.1c, the result is identical with the one from the procedure where the pixels are directly projected from the world frame to the left and right image. Therefore, the transform between the left and right image is correctly computed. *No! This only tells me that I was consistent with my transformations and not that the transformations are indeed right... (Check with examples with correct depth information if the transformations are right.)*

The photometric error in the original and rectified image are is shown in Figures 1.2a and 1.2b. Since at this stage, no reliable depth information is available, low photometric errors cannot be expected, which explains the relatively high average value. However, we know that the photometric errors should be approximately the same in the rectified and non-rectified images. This is indeed the case as can be seen in Figure 1.2.

(a) Left image (mean: 4.78).

(b) Right image (mean: 4.34).

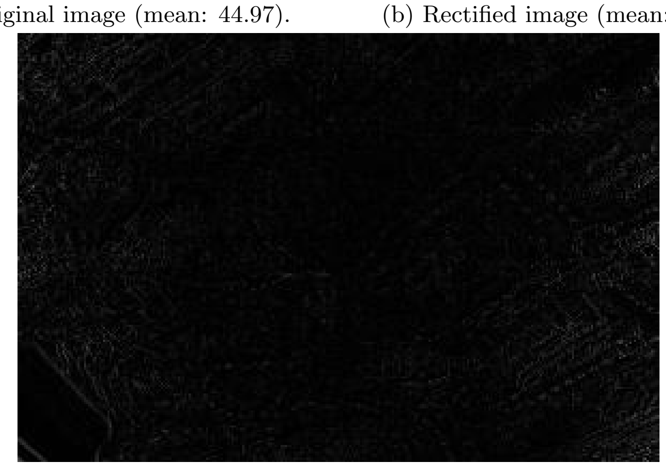


(c) Right image obtained with transformation (mean: 4.34).

Figure 1.1: Rectification intensity errors $\Delta I_{i,j}$ with $n_x = 300$ and $n_y = 200$.

(a) Original image (mean: 44.97).

(b) Rectified image (mean: 46.23).



(c) Difference of original and rectified image (mean: 6.71).

Figure 1.2: Rectification residual errors with $n_x = 300$ and $n_y = 200$.

Bibliography

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[2] ROS, *image_pipeline CameraInfo*. `http://wiki.ros.org/image_pipeline/CameraInfo`, 2011.

[3] ——, *sensor_msgs CameraInfo*. `http://docs.ros.org/api/sensor_msgs/html/msg/CameraInfo.html`, 2016.

[4] B. Siciliano and O. Khatib, *Springer, Handbook of Robotics*, Springer-Verlag New York, Inc., first ed., 2007.