Calibration Summary

```
Base directory : /root/ur_ws_sim/data
Run ID         : run_001
Camera         : realsense

Hand–eye file : /root/ur_ws_sim/data/run_001/calib/handeye_realsense.npz
Robot poses   : /root/ur_ws_sim/data/run_001/calib/robot_poses.csv
Camera params : /root/ur_ws_sim/data/run_001/calib/CameraParams_realsense.npz
PnP poses     : /root/ur_ws_sim/data/run_001/calib/poses_realsense.npz
Markdown      : /root/ur_ws_sim/data/run_001/results/calib_report_realsense.md

T_base2cam (average):
   0.0411 -0.9989 -0.0221  1.2453
  -0.9942 -0.0386 -0.1007 -0.0486
   0.0998  0.0261 -0.9947  1.3617
   0.0000  0.0000  0.0000  1.0000
```

Calibration Markdown Report

````
# Calibration report — run `run_001`, camera `realsense`

- Base directory: `/root/ur_ws_sim/data`
- Run directory : `/root/ur_ws_sim/data/run_001`

---

## 1. Camera intrinsics

- Calibration file: `/root/ur_ws_sim/data/run_001/calib/CameraParams_realsense.npz`
- Number of images used: **98**
- Image resolution: **1280 x 720**
- Chessboard inner corners (nx × ny): **7 × 10**
- Chessboard square size: **0.024000 m**
- RMS reprojection error: **0.192799 px**
- Per-image mean reprojection error: min=0.1090, mean=0.1575, max=0.2373 px

Camera matrix K:

```
[[919.18559339   0.         649.55459405]
 [  0.         920.90454306 365.54467847]
 [  0.           0.           1.        ]]
```

Distortion coefficients:

```
[[ 1.11659574e-01  8.12637857e-03  7.44873124e-04 -1.59891864e-03
  -7.89971697e-01]]
```

---

## 2. PnP board poses (board in camera frame)

- PnP file: `/root/ur_ws_sim/data/run_001/calib/poses_realsense.npz`
- Number of images with successful PnP: **98**
- Board distance from camera (min/mean/max): **0.390 / 0.559 / 0.625 m**

Example poses (first up to 3 images):

**Image:** `img_0000_pose_0000.png`
````

- t (board in camera) [m] = [-0.0016, 0.1433, 0.5908]
- rvec (Rodrigues) [rad] = [0.2766, 0.0480, -3.0640]

Image: `img_0001_pose_0001.png`

- t (board in camera) [m] = [-0.0012, 0.1430, 0.5887]
- rvec (Rodrigues) [rad] = [0.2717, 0.0156, -3.0665]

Image: `img_0002_pose_0002.png`

- t (board in camera) [m] = [-0.0008, 0.1428, 0.5853]
- rvec (Rodrigues) [rad] = [0.2569, -0.0160, -3.0691]

---

3. Hand–eye calibration

- Hand–eye file: `/root/ur_ws_sim/data/run_001/calib/handeye_realsense.npz`
- Method: **Tsai**
- Number of samples used: **98**

3.1 Camera in EE frame (T_cam^ee)

Rotation matrix R_cam2ee:

```
[[ 0.9941614   0.03865706  0.10074097]
 [-0.04107452  0.99891312  0.02203331]
 [-0.09977974 -0.02604255  0.99466868]]
```

Translation t_cam2ee [m]: [0.1024, -0.0784, 0.0439]

RPY (deg, ZYX convention) ≈ roll=-1.50, pitch=5.73, yaw=-2.37

Homogeneous transform T_cam2ee:

```
array([[ 0.9941614 ,  0.03865706,  0.10074097,  0.10243068],
       [-0.04107452,  0.99891312,  0.02203331, -0.07842157],
       [-0.09977974, -0.02604255,  0.99466868,  0.04386567],
       [ 0.        ,  0.        ,  0.        ,  1.        ]])
```

3.2 Camera in BASE frame (T_base^cam, averaged)

Homogeneous transform T_base2cam:

```
array([[-0.03868316, -0.99891242,  0.02603064,  1.09752458],
       [-0.99415935,  0.04109951,  0.09978987,  0.14687683],
       [-0.10075118, -0.02201842, -0.99466798,  1.45043942],
       [ 0.        ,  0.        ,  0.        ,  1.        ]])
```

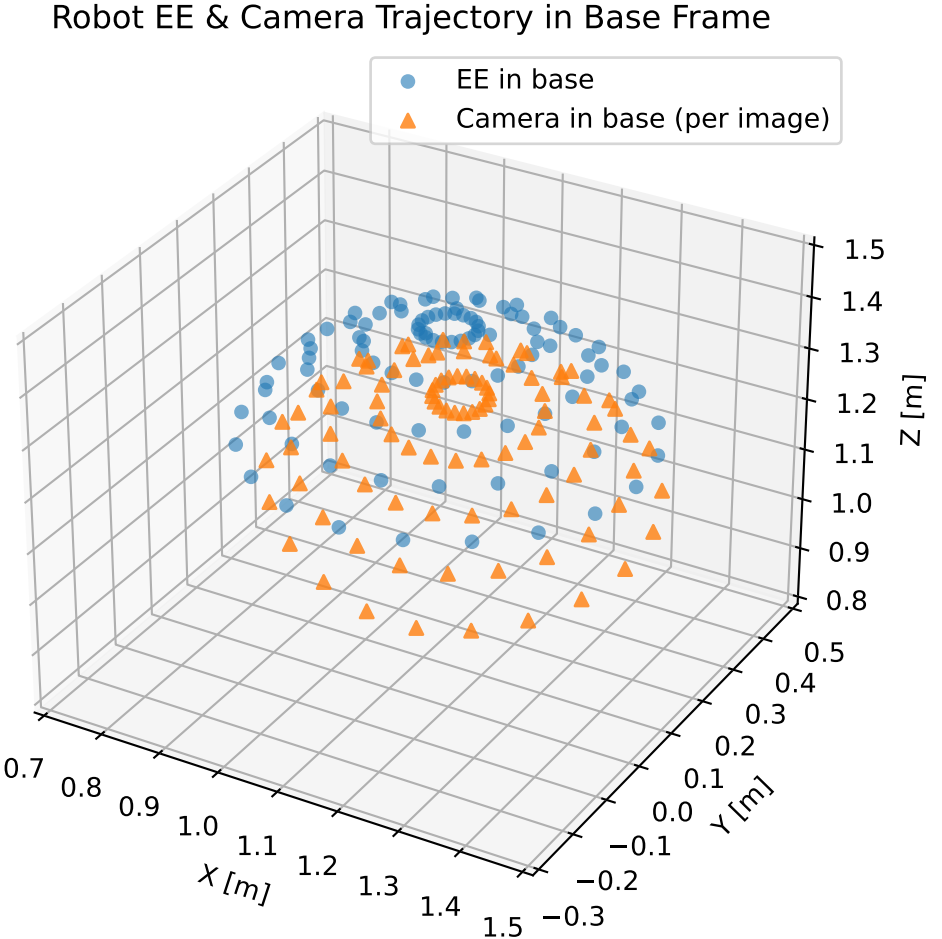
Translation base→camera [m]: [1.0975, 0.1469, 1.4504]

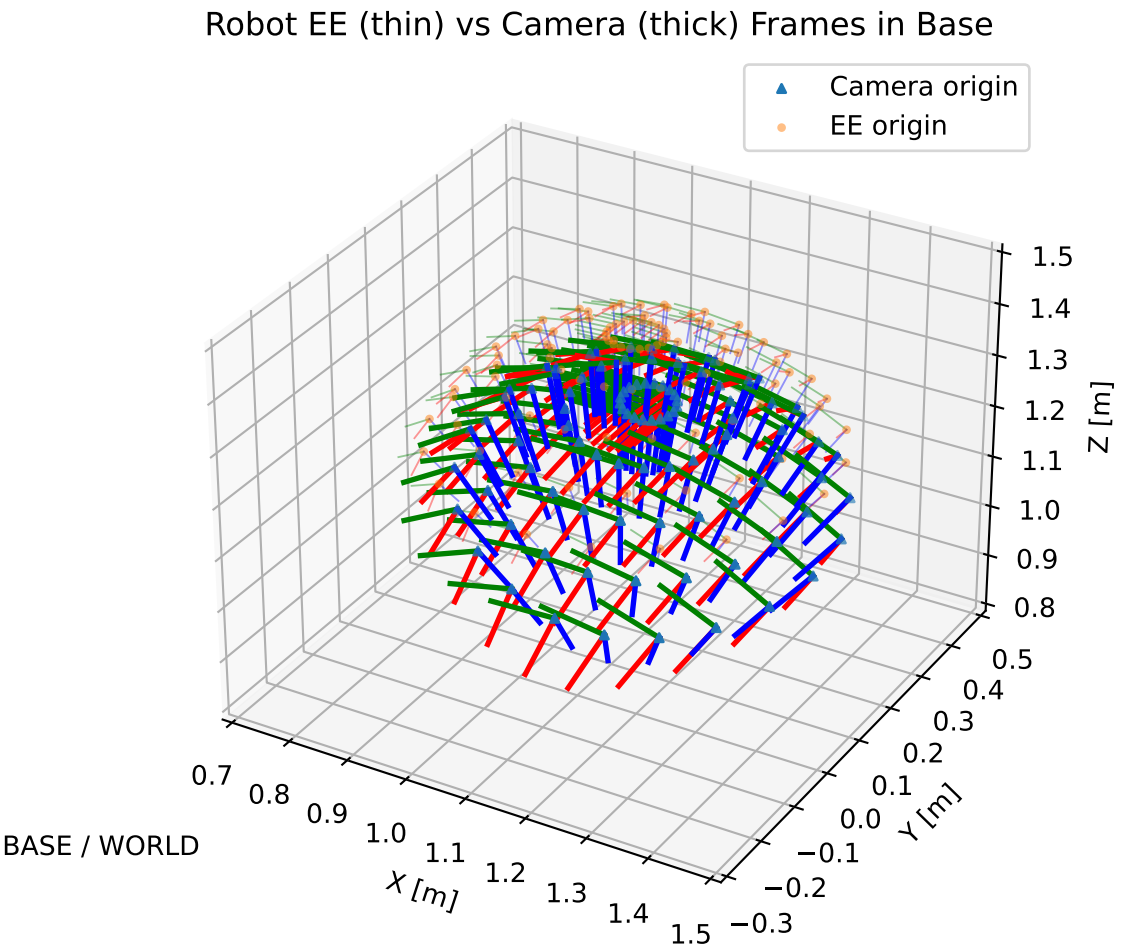
RPY (deg, ZYX convention) ≈ roll=-178.73, pitch=5.78, yaw=-92.23

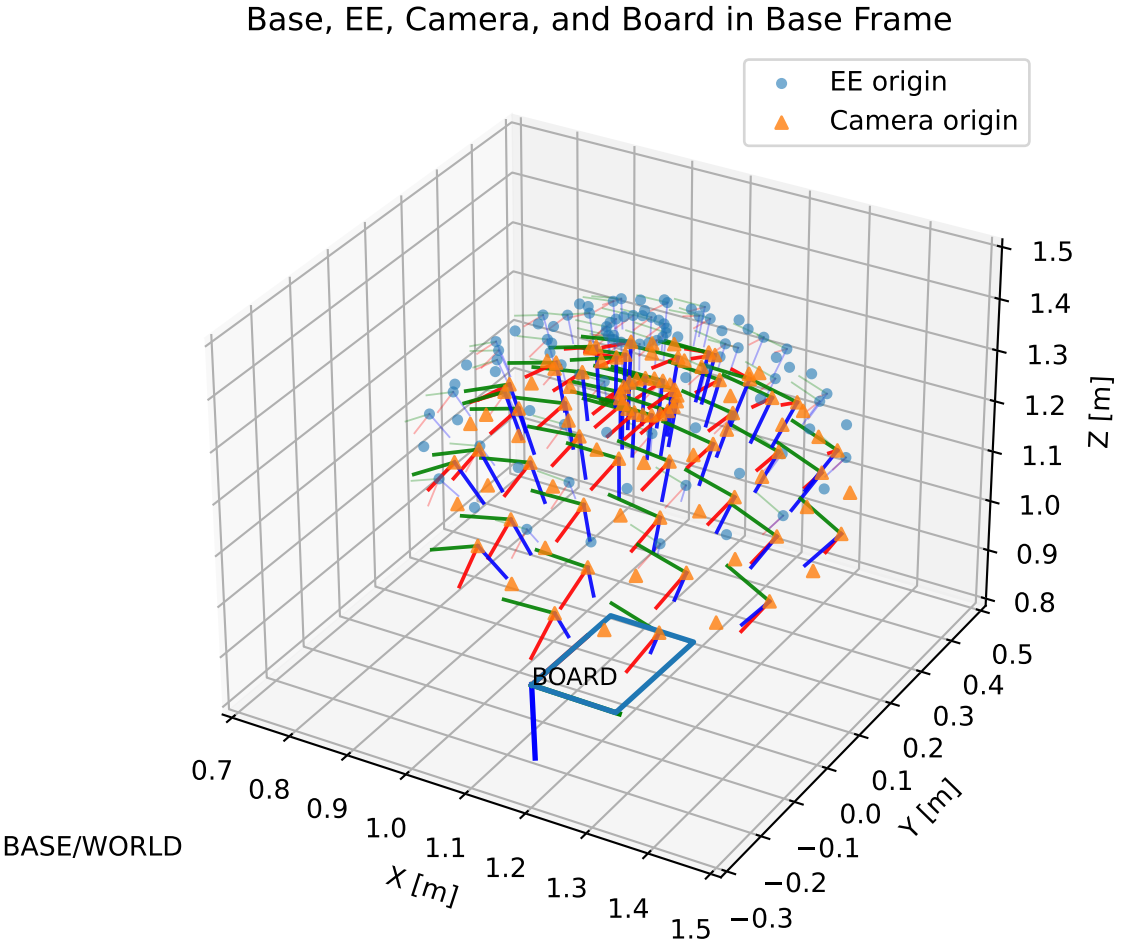
Homogeneous transform T_cam2base (inverse of T_base2cam):

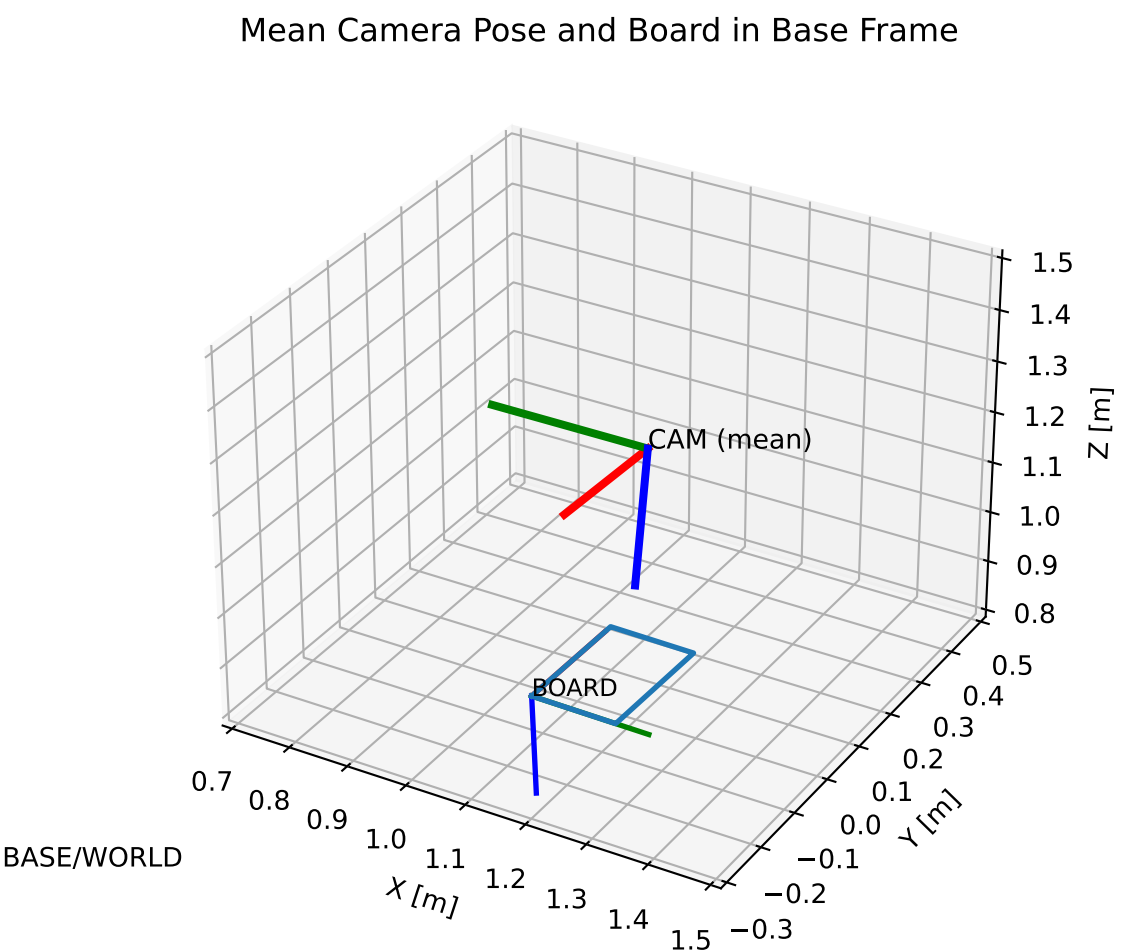
```
array([[-0.03868316, -0.99415935, -0.10075118,  0.33460817],
       [-0.99891242,  0.04109951, -0.02201842,  1.12223076],
       [ 0.02603064,  0.09978987, -0.99466798,  1.39947956],
       [ 0.        ,  0.        ,  0.        ,  1.        ]])
```

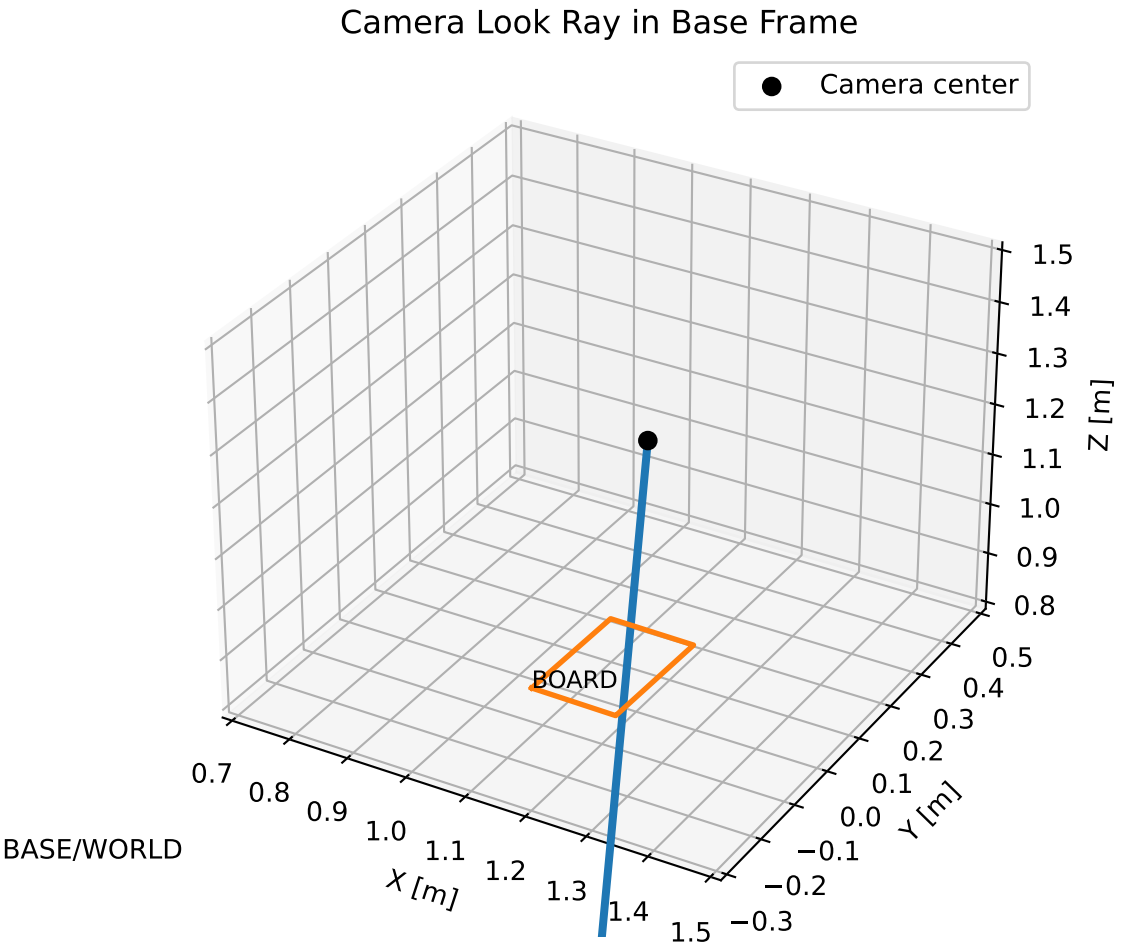
This report was auto-generated. Graphs and plots are available in the PDF: `calib_report_realsense.pdf`

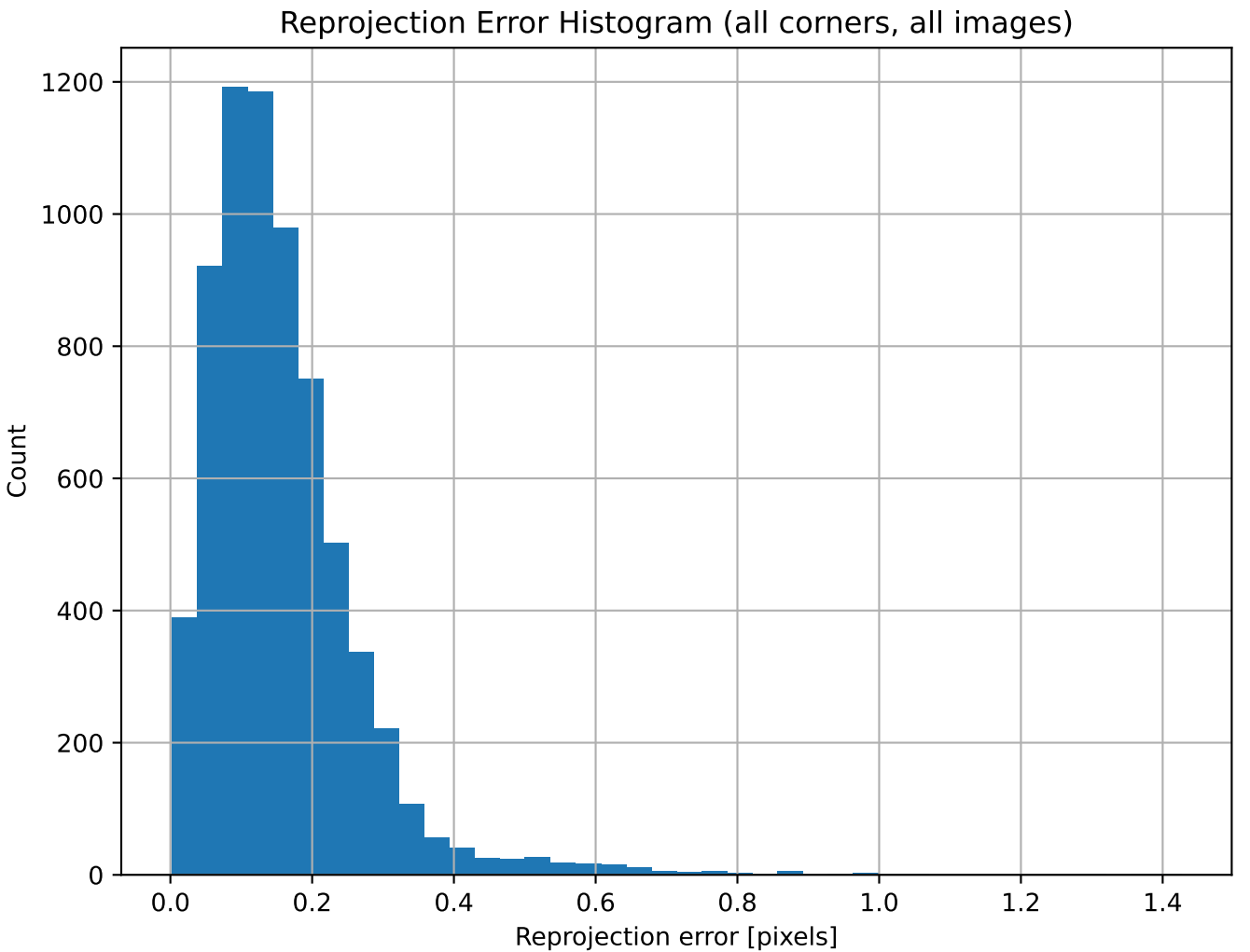

Robot EE & Camera Trajectory in Base Frame
EE in base
Camera in base (per image)
X [m]
Y [m]
Z [m]
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

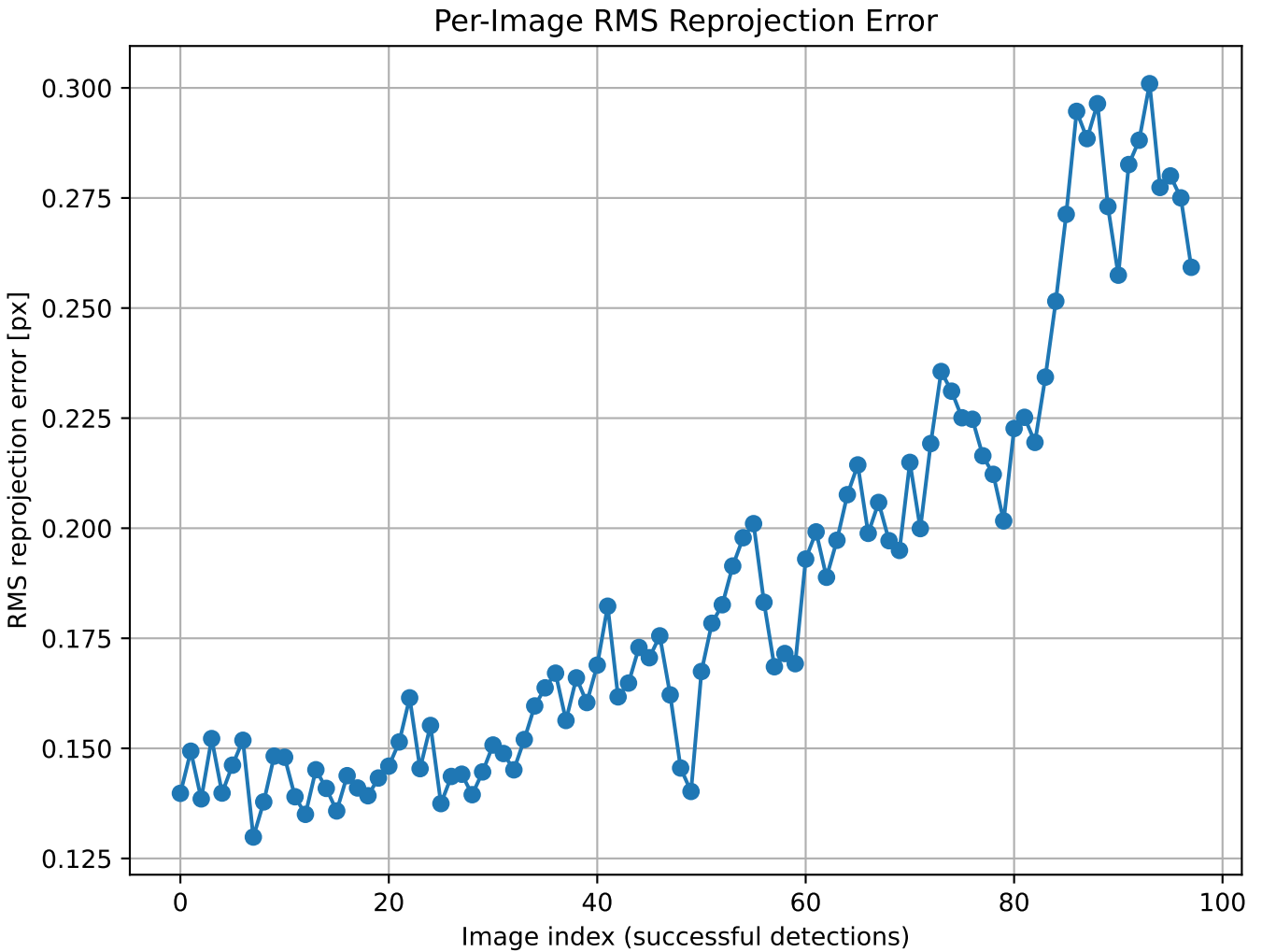

Robot EE (thin) vs Camera (thick) Frames in Base
Camera origin
EE origin
BASE / WORLD
X [m]
Y [m]
Z [m]
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

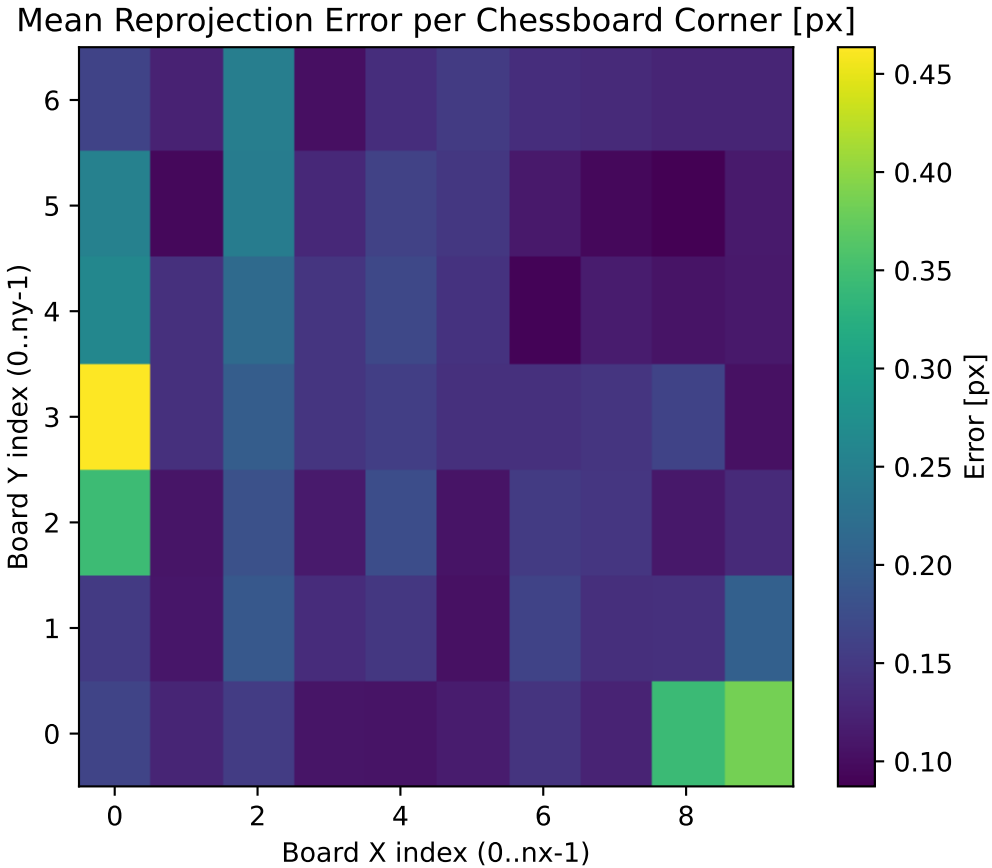

Base, EE, Camera, and Board in Base Frame
EE origin
Camera origin
BOARD
BASE/WORLD
X [m]
Y [m]
Z [m]
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

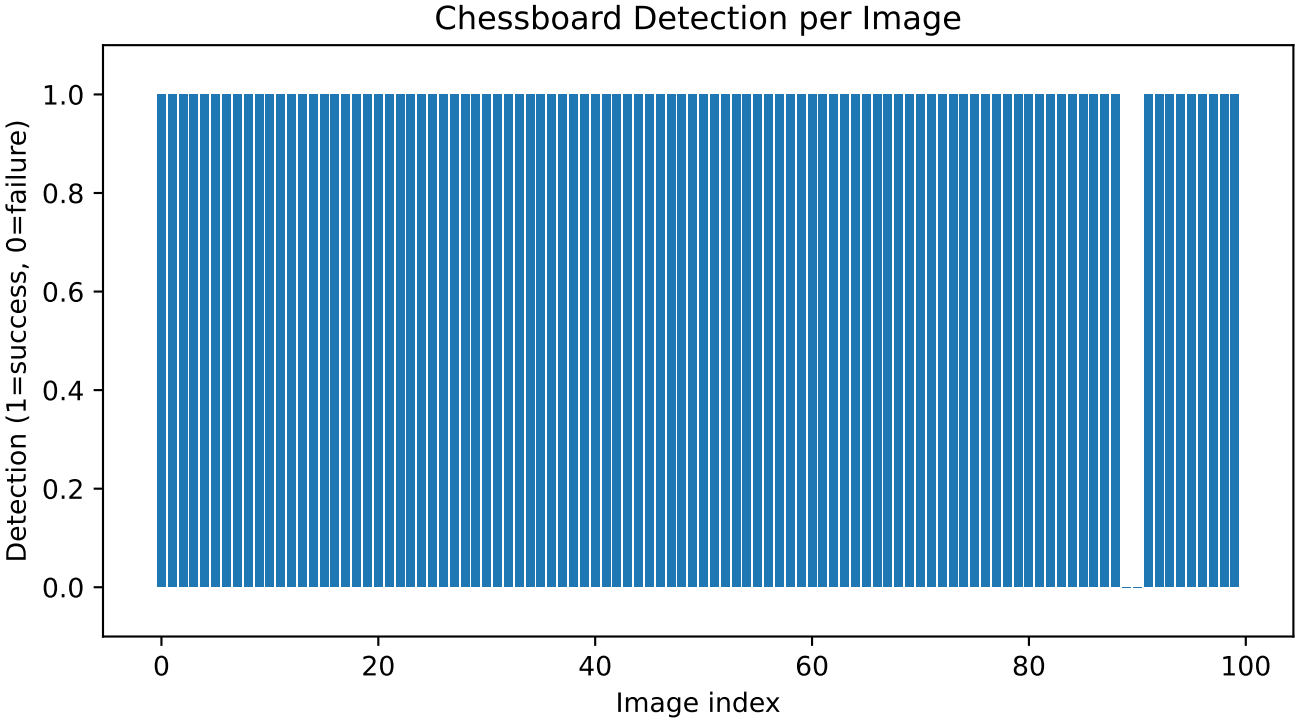

Mean Camera Pose and Board in Base Frame
CAM (mean)
BOARD
BASE/WORLD
X [m]
Y [m]
Z [m]
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

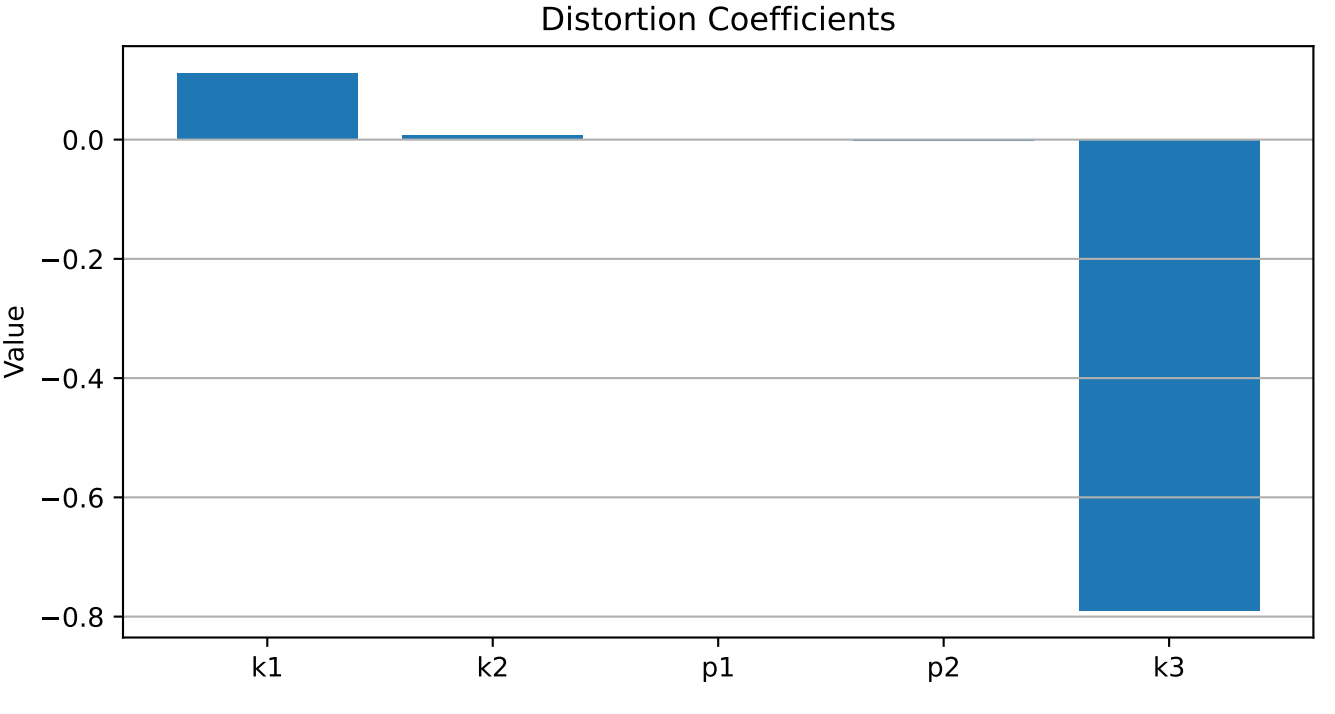

Camera Look Ray in Base Frame
Camera center
BOARD
BASE/WORLD
X [m]
Y [m]
Z [m]
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

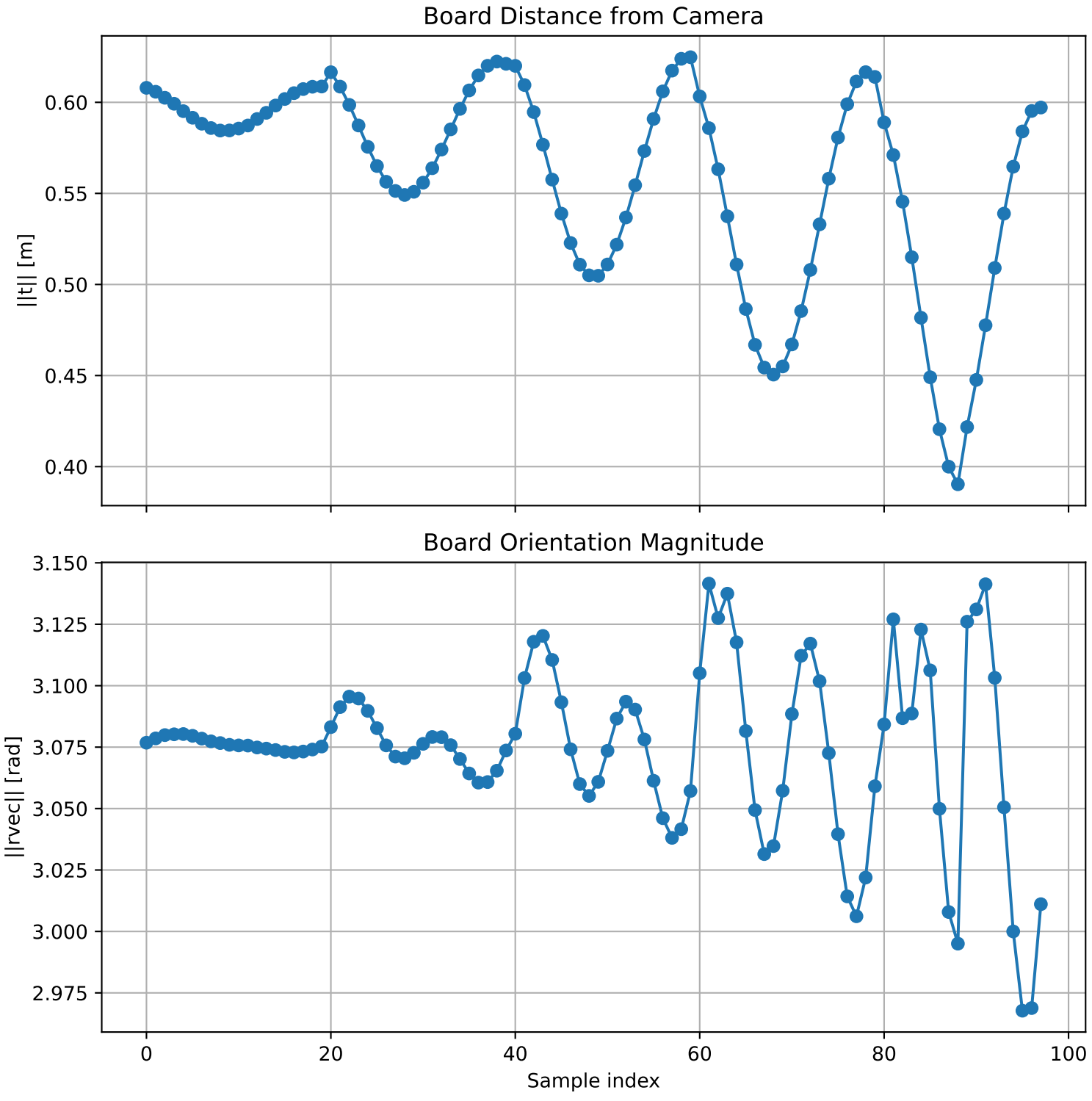

Reprojection Error Histogram (all corners, all images)
Count
Reprojection error [pixels]
0
200
400
600
800
1000
1200
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

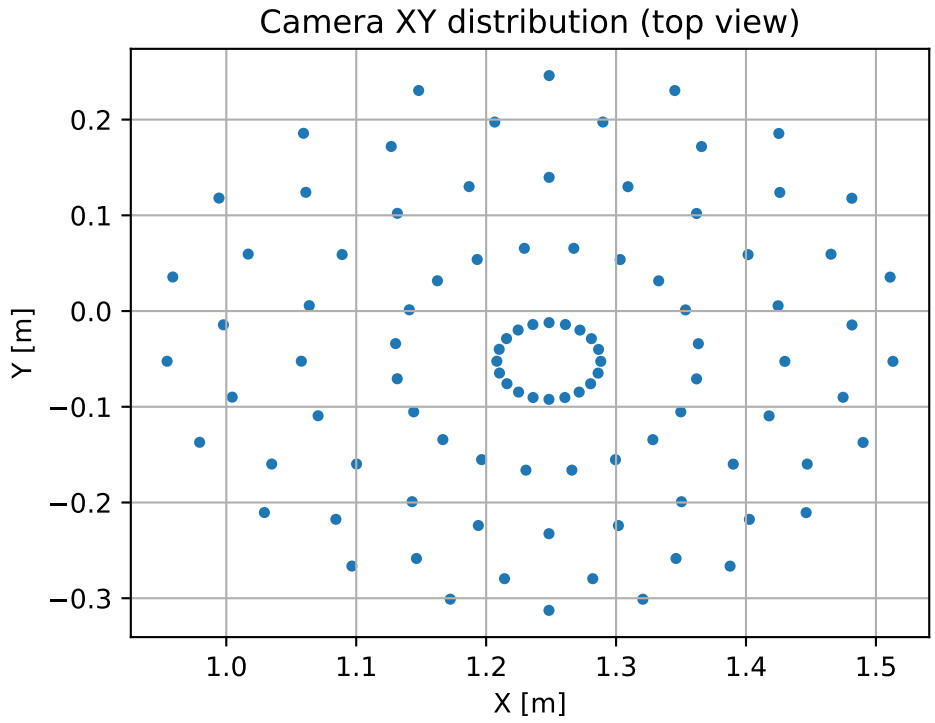

Per-Image RMS Reprojection Error
RMS reprojection error [px]
0.300
0.275
0.250
0.225
0.200
0.175
0.150
0.125
0
20
40
60
80
100
Image index (successful detections)

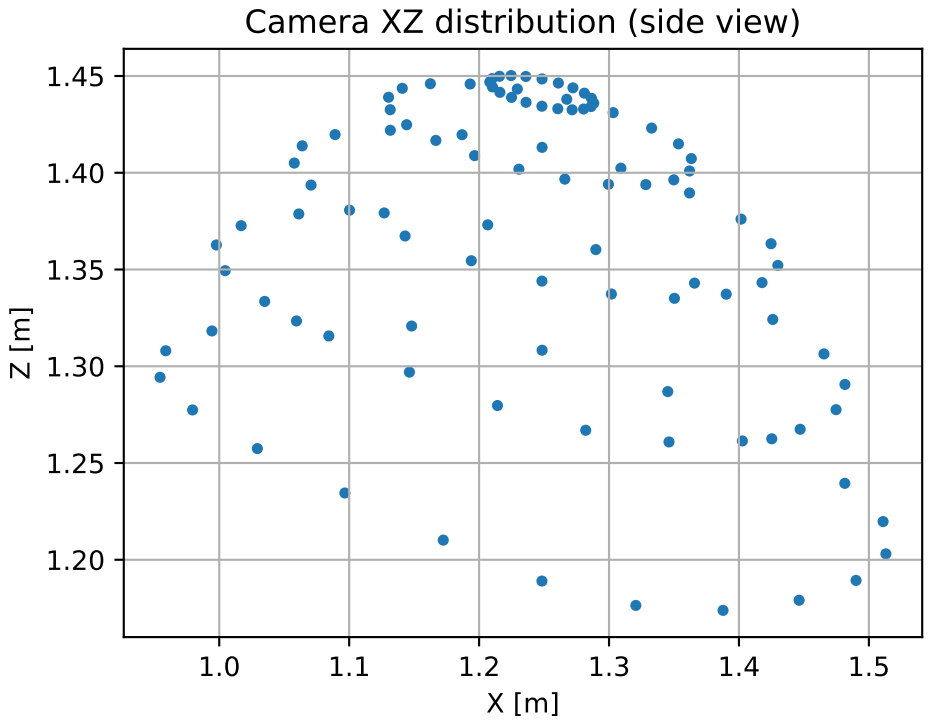

Mean Reprojection Error per Chessboard Corner [px]
Board Y index (0..ny-1)
Board X index (0..nx-1)
Error [px]
0
1
2
3
4
5
6
0
2
4
6
8
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10

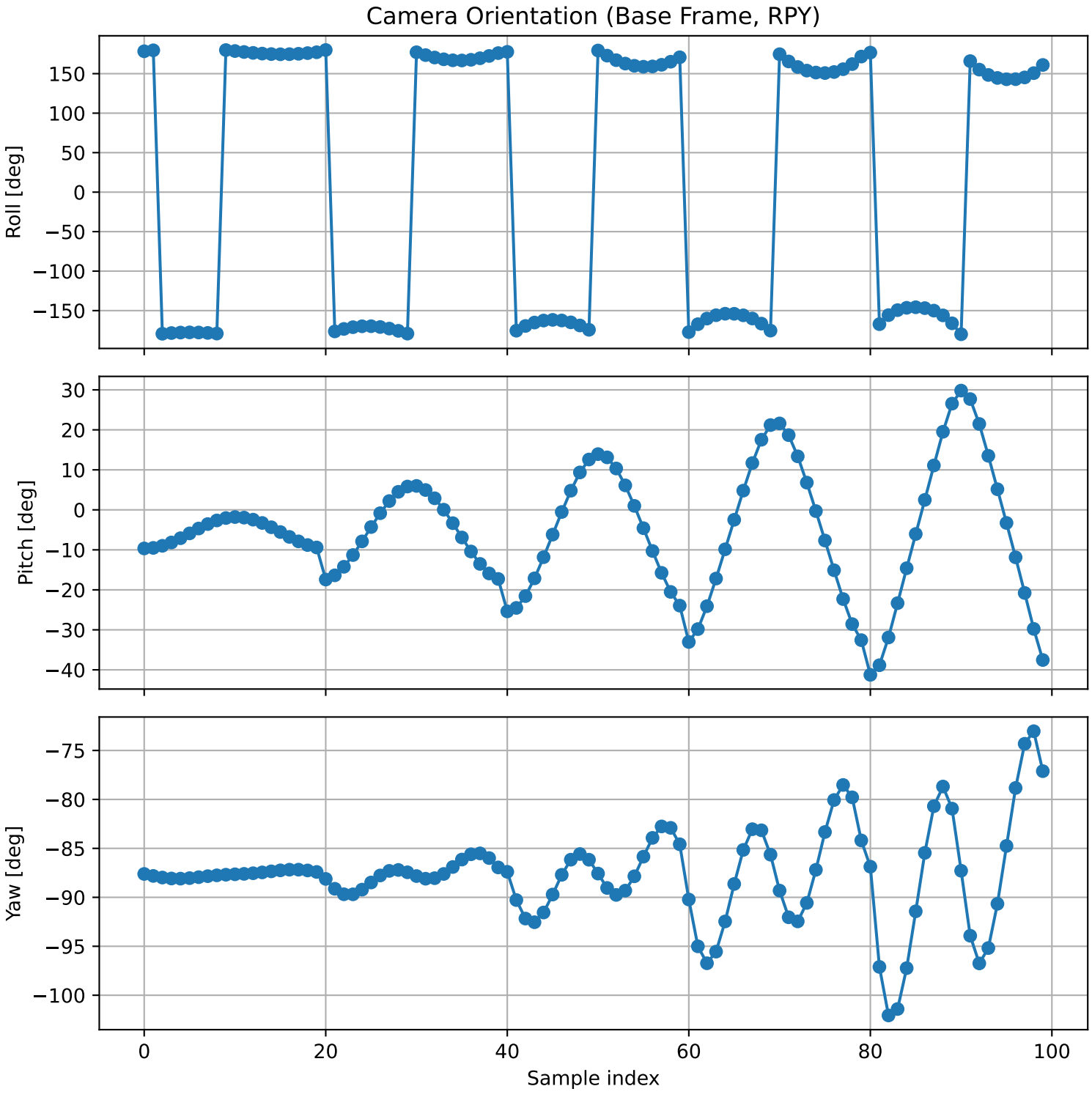

Chessboard Detection per Image
Detection (1=success, 0=failure)
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
Image index

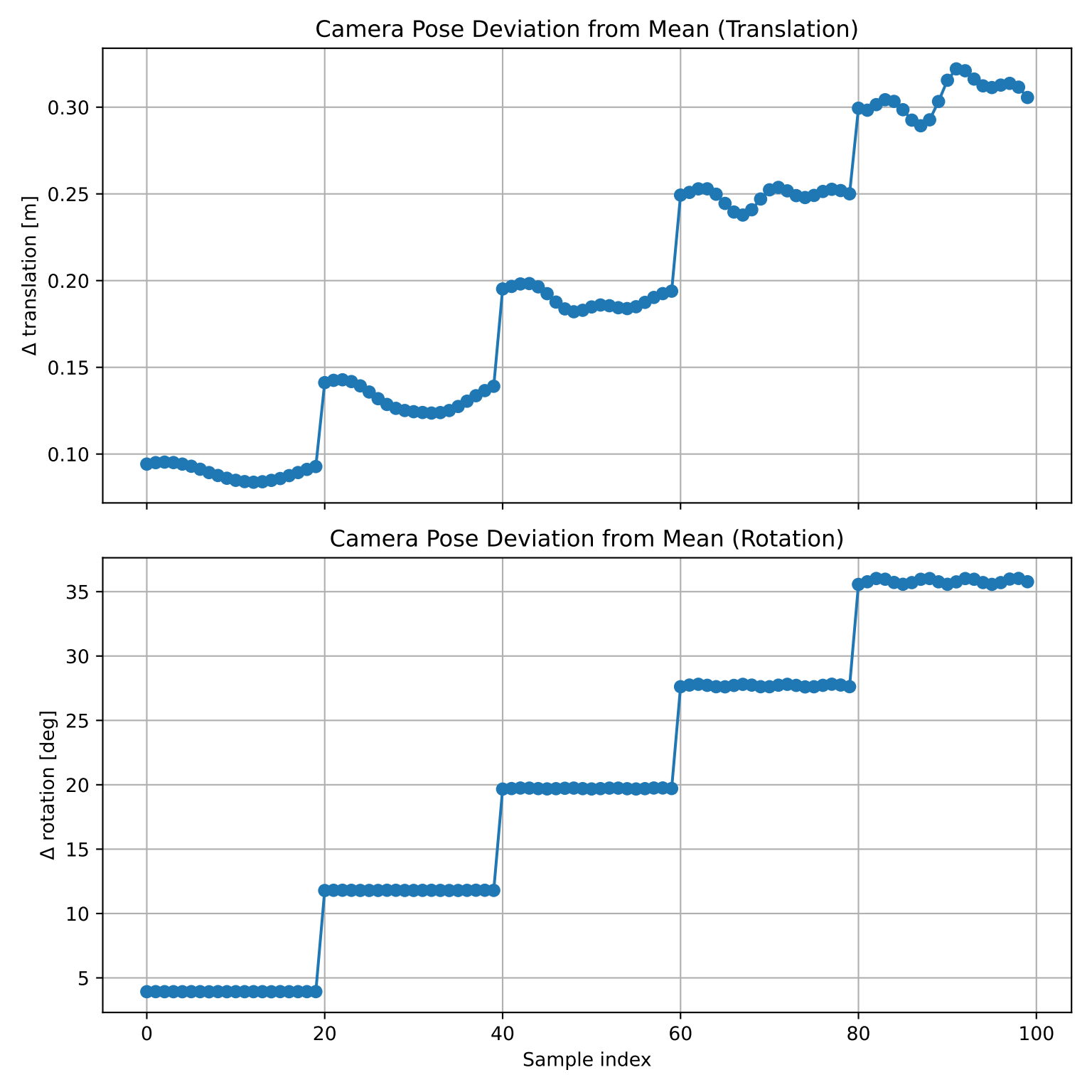

Distortion Coefficients
Value
0.0
−0.2
−0.4
−0.6
−0.8
k1
k2
p1
p2
k3


Board Distance from Camera
||t|| [m]
0.60
0.55
0.50
0.45
0.40
Board Orientation Magnitude
||rvec|| [rad]
3.150
3.125
3.100
3.075
3.050
3.025
3.000
2.975
0
20
40
60
80
100
Sample index


Camera XY distribution (top view)
Y [m]
X [m]
0.2
0.1
0.0
−0.1
−0.2
−0.3
1.0
1.1
1.2
1.3
1.4
1.5


Camera XZ distribution (side view)
Z [m]
X [m]
1.45
1.40
1.35
1.30
1.25
1.20
1.0
1.1
1.2
1.3
1.4
1.5


Camera Orientation (Base Frame, RPY)
Roll [deg]
150
100
50
0
−50
−100
−150
Pitch [deg]
30
20
10
0
−10
−20
−30
−40
Yaw [deg]
−75
−80
−85
−90
−95
−100
0
20
40
60
80
100
Sample index


Camera Pose Deviation from Mean (Translation)
Δ translation [m]
0.10
0.15
0.20
0.25
0.30
Camera Pose Deviation from Mean (Rotation)
Δ rotation [deg]
5
10
15
20
25
30
35
0
20
40
60
80
100
Sample index