Validation

1

Validation Data

- 4 Measured aruco trials for the corresponding validation path
- Compare measured vs ground truth:
  Step 1: Load 24-trial derived registration matrix (aruco→ kuka)
  Step 2: Transform all measured aruco points to kuka reference frame
  Step 3: calculate path lengths (mm) for each sequential trajectory
  Step 4: Get respective trajectory RMSE

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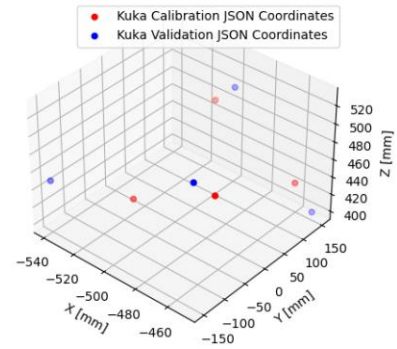# Calibration and Validation JSON

```
------ Calibration JSON-----
[[-0.5   0.1   0.5 ]
 [-0.45 -0.1   0.5 ]
 [-0.5  -0.1   0.45]
 [-0.45  0.1   0.45]]
------ Validation JSON-----
[[-0.5   0.15  0.5 ]
 [-0.45 -0.15  0.53]
 [-0.54 -0.15  0.45]
 [-0.45  0.15  0.4 ]]
```

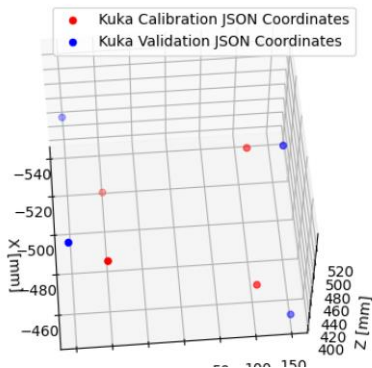Original JSON FILE data (m)

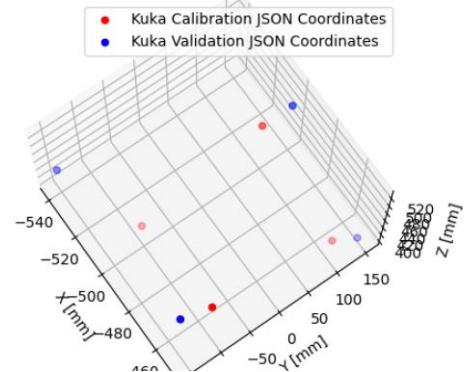Calibration and Validation Kuka Positions in Kuka Reference Frame

Plotted in millimeters!

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Calibration and Validation Kuka Positions in Kuka Reference Frame

Calibration and Validation Kuka Positions in Kuka Reference Frame

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Trajectories

- Compare ground truth trajectories (Validation JSON) to the measured aruco (transformed to kuka reference frame) coordinates.
- 4 Validation trials were used
- Trajectories

0➔ 1

1➔ 2

2➔3

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Trajectories

```
-----Ground truth in MILLIMETERS----
[[305.6141358 ]
 [120.41594579]
 [317.17503054]]
```

```
--------Aruco Derived in MILLIMETERS---
[[[299.21570388]
  [126.83710028]
  [296.30576788]]

 [[300.54827578]
  [126.36543566]
  [296.33447641]]

 [[300.63474065]
  [125.03524995]
  [286.71506516]]

 [[300.81563538]
  [125.51590307]
  [290.41719688]]]
```

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3

Trajectory RMSE ** all on validation data

```
Root Mean Square Error in Millimeters:

[[ 5.34843087]
 [ 5.56720733]
 [25.06813702]]
```

High RMS error in Z…. Need to investigate

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Look into Positional accuracy

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Positions in Kuka reference frame

- Note that validation coordinates are outside the volume of the the calibration positions

Measured Aruco and Kuka Positions in Kuka Reference Frame

- ● Kuka Calibration JSON Coordinates
- ● Kuka Validation JSON Coordinates
- ✕ Measured Aruco Validation Coordinates
- ✕ Measured Aruco Calibration Coordinates
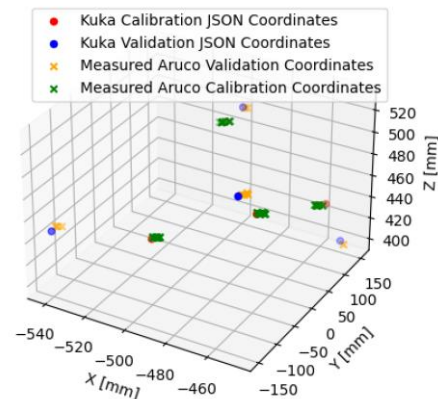
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Validation GT vs Aruco Derived Positional Measurements

```
 vs Nlist validation in mm
[[-500.  150.  500.]
 [-450. -150.  530.]
 [-540. -150.  450.]
 [-450.  150.  400.]]
```

```
----------position of equivalent validation in mm ------------
[[[-499.09494588  152.60149207  500.03070146]
  [-447.63109274 -140.48827137  531.33405329]
  [-542.07205681 -130.18328139  447.29619578]
  [-447.99785864  146.54580219  398.63237326]]

 [[-497.97054068  153.80455654  499.39409629]
  [-447.15476111 -140.79754522  530.32343936]
  [-541.87845923 -130.27053665  447.34858512]
  [-447.99785864  146.54580219  398.63237326]]

 [[-499.26636299  150.26149389  499.3570255 ]
  [-449.41453534 -144.60975375  530.13022628]
  [-541.24324578 -127.60109045  446.99174516]
  [-499.2867459   151.20366096  499.07908812]]

 [[-498.163803    151.5052659   499.39423112]
  [-448.32091004 -143.54314189  530.25147614]
  [-539.98844075 -124.55221117  446.64136739]
  [-447.42872815  146.53252419  398.80922238]]]
```
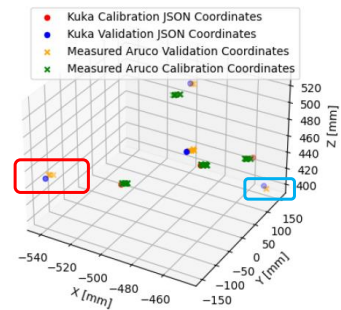
Use Transformation matrix: aruco→ kuka

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Positional RMSE

```
--------------RMSE of Validation in mm----------------
[ 2.89709858  8.13538037 22.22213737 55.45938044]
```

Point 0   Point 1   Point 2   Point 3

Points 2 and points 3 have the largest RMSE erros

Measured Aruco and Kuka Positions in Kuka Reference Frame

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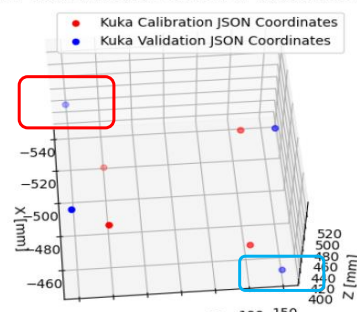# Hypothesis

- Larger error may be due to calibration volume does not cover these points

Calibration and Validation Kuka Positions in Kuka Reference Frame

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Check RMSE for Aruco measurements used for repeatability study

- Recall that in the calibration study we used 5 points from the 29-calibration trial acquisition (24 for registration matrix + 5 for quality assessment)

➔ Test hypothesis. If so, we expect better positional accuracy for point within the calibration volume space

```
--------------RMSE of Validation in mm-----------------
[ 3.94456466  3.25973863  9.40573536 13.31886751]
```

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See all together:

Using Validation data+JSON data

Using repeatability data + calibration JSON

```
--------------RMSE of Validation in mm----------------
[ 2.89709858  8.13538037 22.22213737 55.45938044]
```

```
--------------RMSE of Validation in mm----------------
[ 3.94456466  3.25973863  9.40573536 13.31886751]
```

Takeaways: Positional accuracy is better when points are located within the calibration volume space. Therefore, for future application this would need to be optimized for the working space.

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