

SCIENTIFIC EXPERIMENTATION AND
EVALUATION
ASSIGNMENT: 06

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Contents

1	Relevant Aspects of Experiment	2
1.1	Apparatus	2
1.1.1	Hardware	2
1.1.2	Software and Libraries used	2
1.2	Procedure	2
1.3	Expected Problems and Performance	3
2	Observations and Data	3
2.1	Visualization	3
2.1.1	Data Visualization	3
2.1.2	Outlier Detection And Removal From Raw Data	4
2.1.3	Pose Visualization	4
3	Results	5
3.1	Final Position & Accuracy	5
3.1.1	Numerical Results	5
3.1.2	Accuracy	6
3.2	Compare Data with Gaussian	7
3.3	Outlier Removal and Hypothesis Testing	10

List of Figures

1	poses for all objects in straight, left and right direction	3
2	pose in straight direction	4
3	pose in left direction	4
4	pose in right direction	5
5	Histogram and Gaussian distribution of data for straight run	7
6	Histogram and Gaussian distribution of data for left run	8
7	Histogram and Gaussian distribution of data for right run	9
8	Outlier removal on small object and left run	10

List of Tables

1	Ground Truth	5
2	Final Pose along straight direction	5
3	Final pose along left direction	5
4	Final pose along right direction	6

1 Relevant Aspects of Experiment

1.1 Apparatus

1.1.1 Hardware

- KUKA youBot arm ([Number: 1](#)).
- Objects of three different sizes and weights, with ArUco markers attached to the top.
- Camera (Microsoft LifeCam).
- Two computers, one to run the robot and other for data gathering from the camera.
- A fixed container or marker on the table to ensure that the initial object position is kept constant.

1.1.2 Software and Libraries used

- KUKA youBot drivers.
- Control scripts for the arm to pick and move the objects in one of the three predefined placing poses.
- Marker pose subscribed script, to gather pose of the object.
- **LibreOffice Calc** for data management.
- **Python** for data visualization and calculations
- Python libraries:
 - pandas
 - numpy
 - matplotlib
 - seaborn
 - scipy.stats

1.2 Procedure

- First we run the script to get the arm in the pre-grasp position.
- We then place the object in the container, keeping the marker's orientation constant throughout the experiment.
- We then run the script to move the arm in one of the three pre-defined positions; and repeat this twenty times for each weight and pose combination. Thus, giving us 180 readings of pose coming from three different objects in three different orientations.
- Once the object is placed and the arm moves back to a stationary position, we run the subscriber script to collect pose readings of 50 frames from the camera. This is repeated after each motion.

1.3 Expected Problems and Performance

- The picking position of the arm might differ from the ground truth, because of vibrations, motion in the table and a variety of other physical conditions.
- The placement of the object in the container might not always be aligned properly.
- The marker on top of the object might move during movement and thus will lead to improper pose data.
- After placing the object, the gripper might touch it while moving away, which will introduce distortions in [orientation](#) data.
- The light might not always be uniform, which might also cause some improper readings.

2 Observations and Data

2.1 Visualization

2.1.1 Data Visualization

- The raw data with fifty reading for each run has been filtered and saved as an average. This data is used for further visualization.
- In addition to this, data shared by other groups using the same arm has been included to get a sample size of 180 pose readings in each direction.
- The first visualization shows the pose distribution of large, medium and small objects in three directions including the initial and expected pose.
- The upper right hand corner is the left run plot and the lower left hand corner is right run plot.

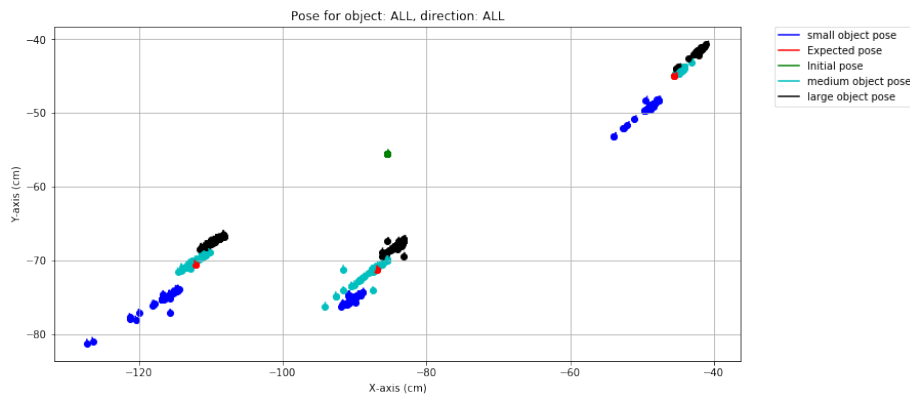
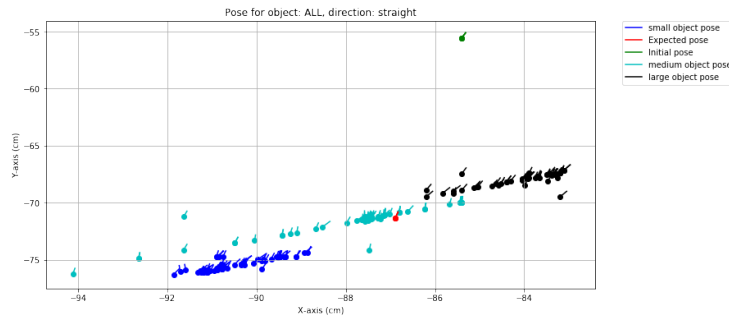


Figure 1: poses for all objects in straight, left and right direction

2.1.2 Outlier Detection And Removal From Raw Data

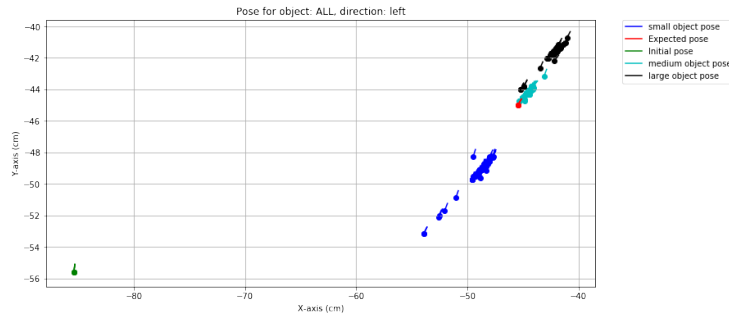
- We filtered the noisy raw data by removing all records with x, y or theta value outside the range of $\mu_x \pm 2\sigma_x$, $\mu_y \pm 2\sigma_y$, $\mu_\theta \pm 2\sigma_\theta$ respectively. We used the filtered raw data to calculate mean for each experimental trial. Total number of outlier is 495 and outlier per experimental run is 2.75

2.1.3 Pose Visualization



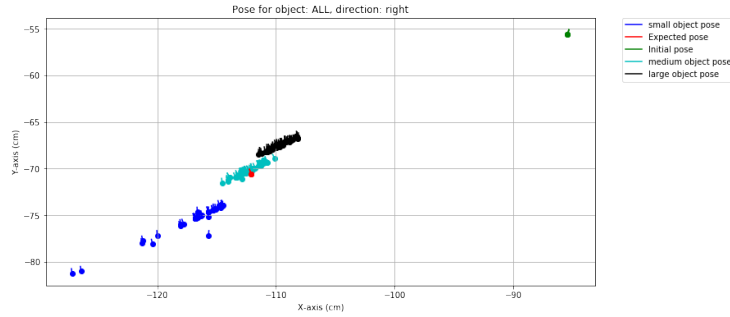
(a) object: all, direction: straight

Figure 2: pose in straight direction



(a) object: all, direction: left

Figure 3: pose in left direction



(a) object: all, direction: right

Figure 4: pose in right direction

3 Results

3.1 Final Position & Accuracy

3.1.1 Numerical Results

Direction	X (cm)	Y (cm)	θ (radians)
Straight	-86.89	-71.31	1.45
Left	-45.47	-45.00	0.88
Right	-112.13	-70.58	1.78

Table 1: Ground Truth

Object Type	X (cm)	Y (cm)	θ (radians)
Small	-90.34	-75.31	1.40
Medium	-87.85	-71.63	1.48
Large	-84.00	-67.94	1.39
Combined	-87.40	-71.63	1.42

Table 2: Final Pose along straight direction

Object Type	X (cm)	Y (cm)	θ (radians)
Small	-49.14	-49.38	1.05
Medium	-44.52	-44.19	0.88
Large	-42.25	-41.73	0.88
Combined	-45.30	-45.10	0.93

Table 3: Final pose along left direction

Object Type	X (cm)	Y (cm)	θ (radians)
Small	-116.76	-75.35	1.72
Medium	-112.28	-70.20	1.83
Large	-109.68	-67.46	1.62
Combined	-112.93	-71.03	1.72

Table 4: Final pose along right direction

3.1.2 Accuracy

- Straight Run:
 - Standard Deviation Straight: [2.89 3.13 0.09]
 - Accuracy in X: 99.42
 - Accuracy in Y: 99.56
 - Accuracy in theta: 98.06
- Left Run:
 - Standard Deviation Left: [3.00 3.26 0.17]
 - Accuracy in X: 99.62
 - Accuracy in Y: 99.80
 - Accuracy in theta: 93.83
- Right Run:
 - Standard Deviation Left: [3.32 3.40 0.146] Accuracy in X: 99.28 Accuracy in Y: 99.37 Accuracy in theta: 96.91

3.2 Compare Data with Gaussian

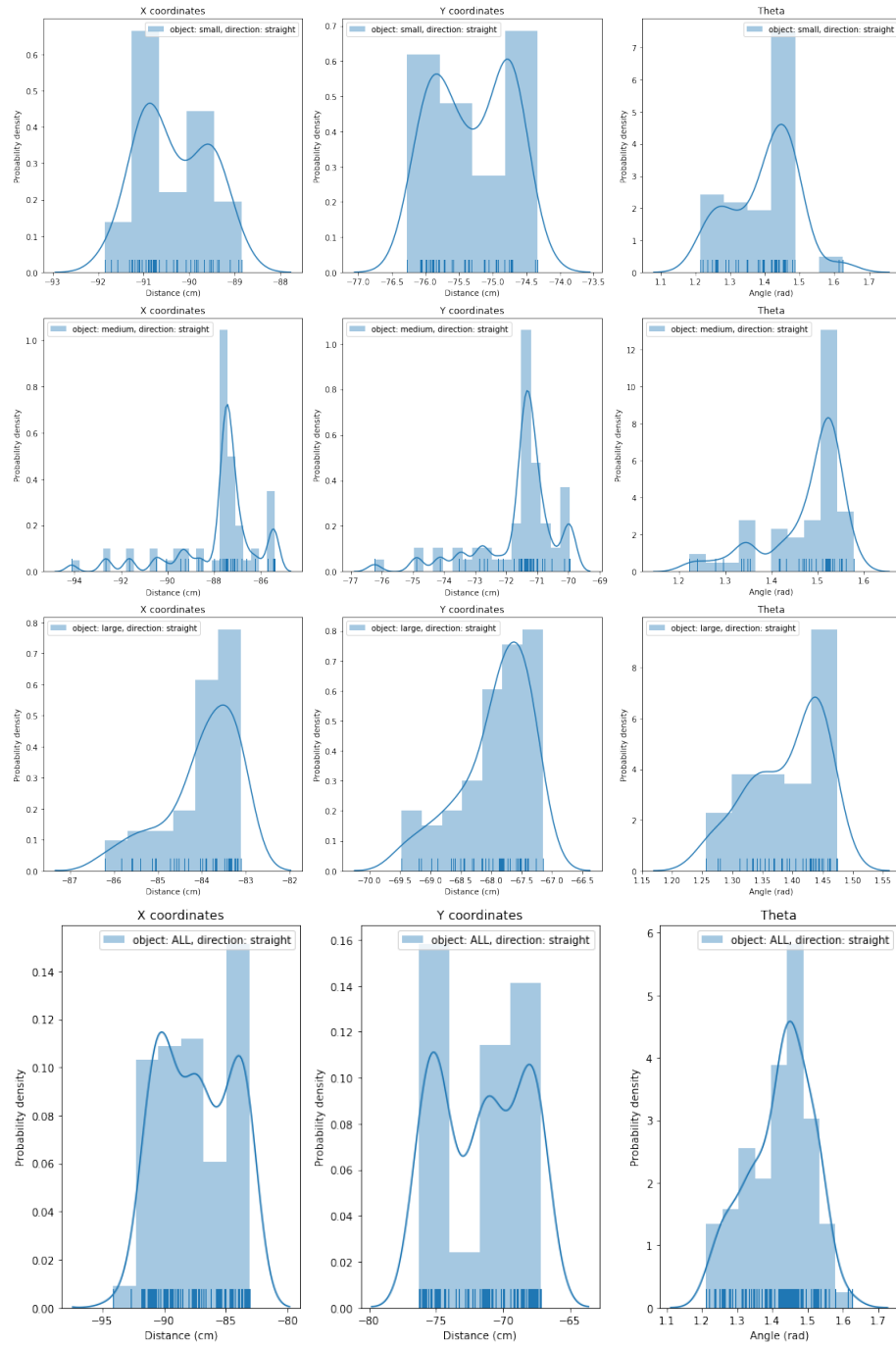


Figure 5: Histogram and Gaussian distribution of data for straight run

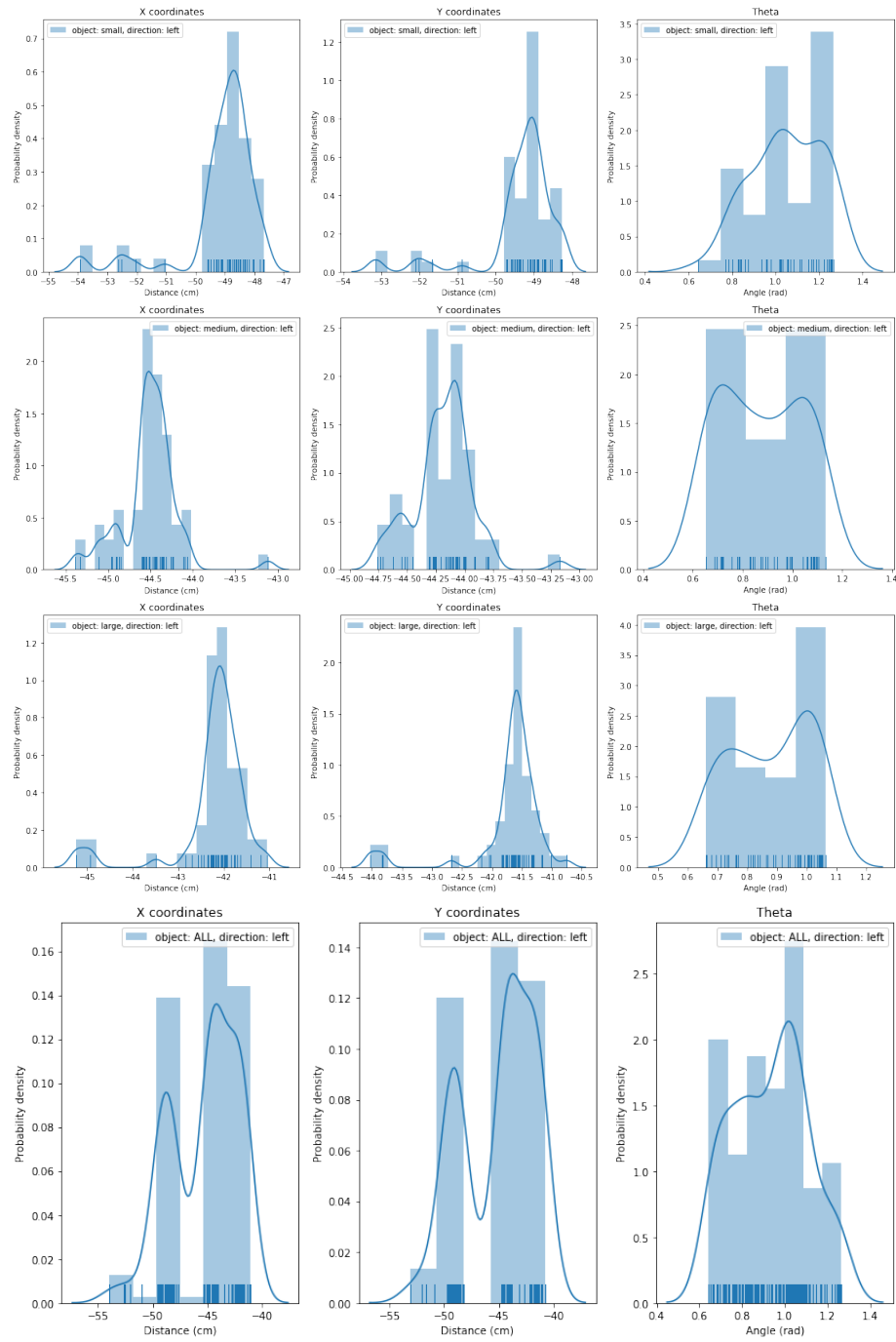


Figure 6: Histogram and Gaussian distribution of data for left run

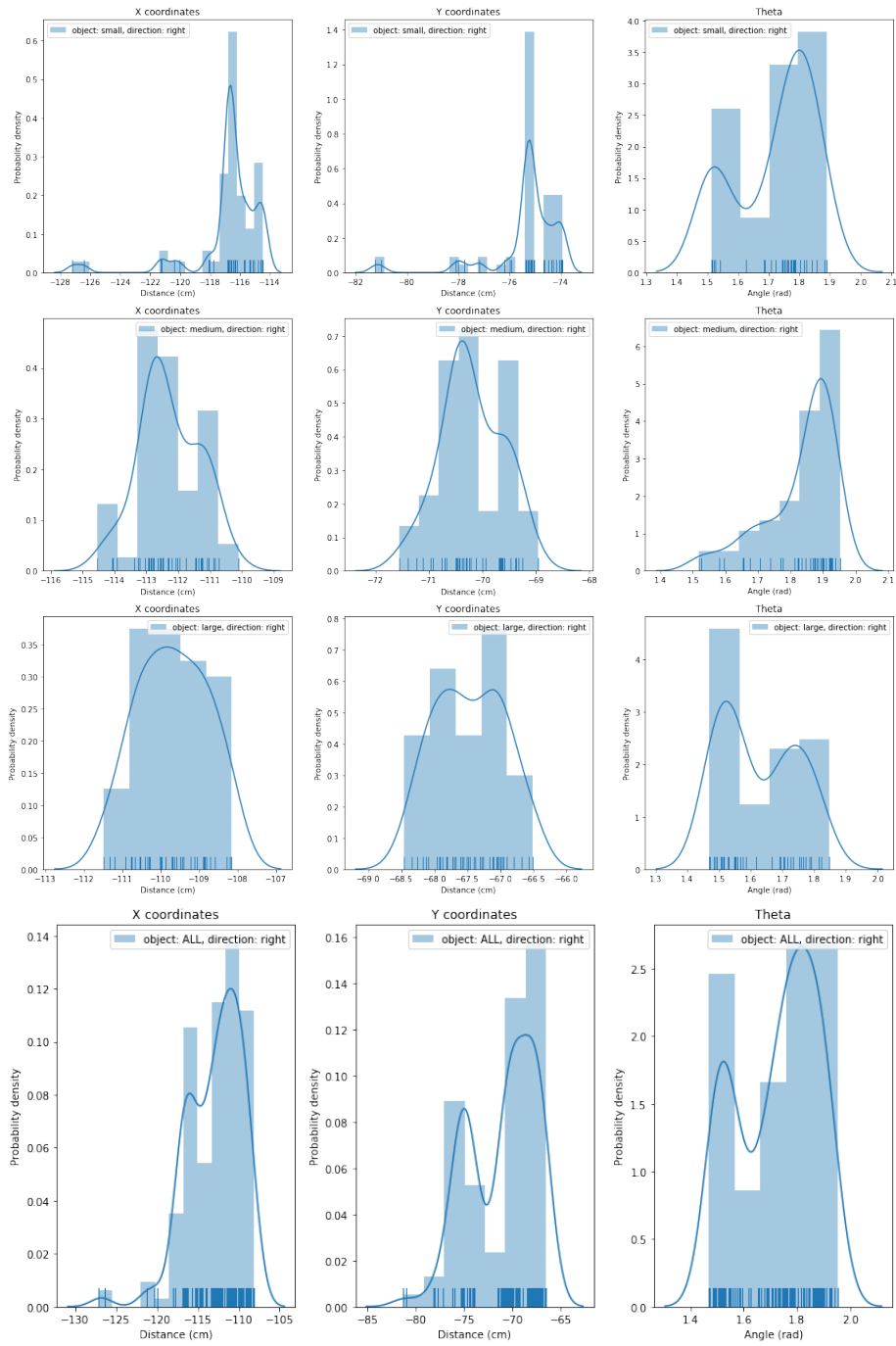


Figure 7: Histogram and Gaussian distribution of data for right run

3.3 Outlier Removal and Hypothesis Testing

- Outliers are calculated on the basis of Z-Score, as per below:

$$Z = \frac{x - \mu_0}{\frac{\sigma}{\sqrt{n}}}$$

Here, μ_0 represents the ground truth,
 x is the data point in consideration,
 σ is the standard deviation of the observed data, and
 n represents the sample size.

- Using the above formula, we iterate over all the data points, and remove any entry where the absolute Z value is greater than a critical value of 3.819.
- The limit is selected on the basis of a confidence value of $(1 - \alpha) = 0.9999$ [1]
- An example for this is given below:

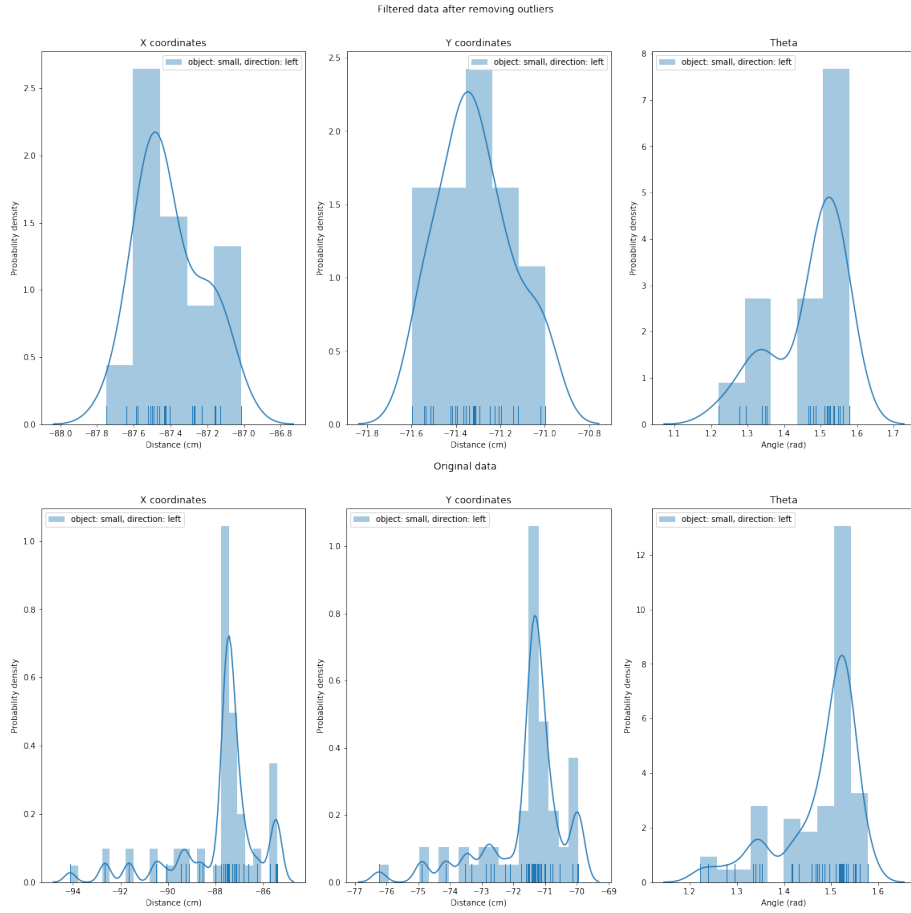


Figure 8: Outlier removal on small object and left run

References

- [1] Hypothesis testing: Upper-, lower, and two tailed tests. http://www.vision.caltech.edu/bouguetj/calib_doc/index.html. Accessed: 2018-05-28.