Scientific Experimentation and Evaluation

Assignment: 06

Anees Khan (9030423)
Debaraj Barua (9030412)
Md Zahiduzzaman (9030432)

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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.

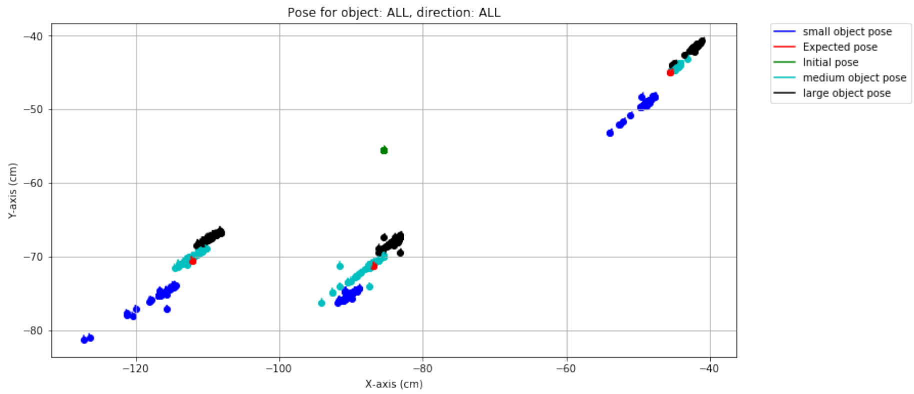
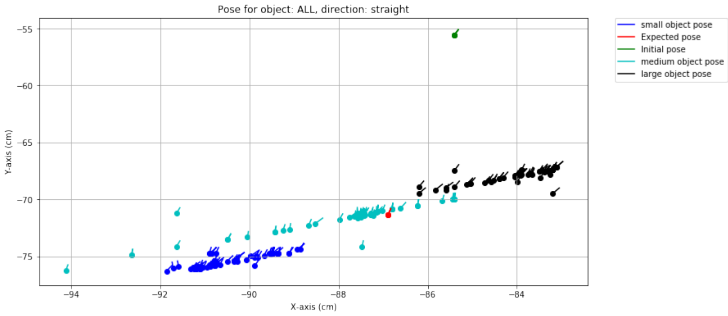


Figure 1: poses for all objects in straight, left and right direction

2.1.2 Outlier Detection And Removal From Raw Data

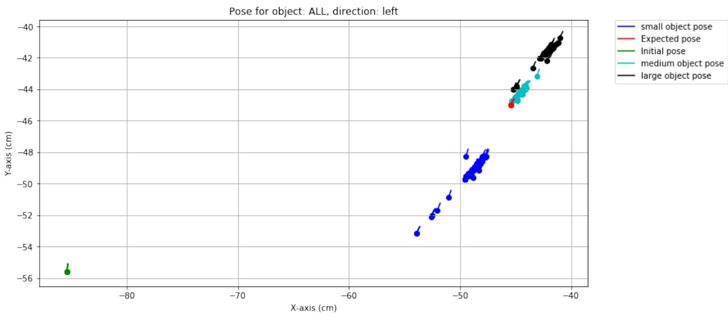
- We filtered the noisy raw data by removing all records with x, y or theta value outside the range of $\mu_x \pm 2\sigma_x$, $\mu_y \pm 2\sigma_y$, $\mu_\theta \pm 2\sigma_\theta$ respectively. We used the filtered raw data to calculate mean for each experimental trial. Total number of outlier is 495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

2.1.3 Pose Visualization



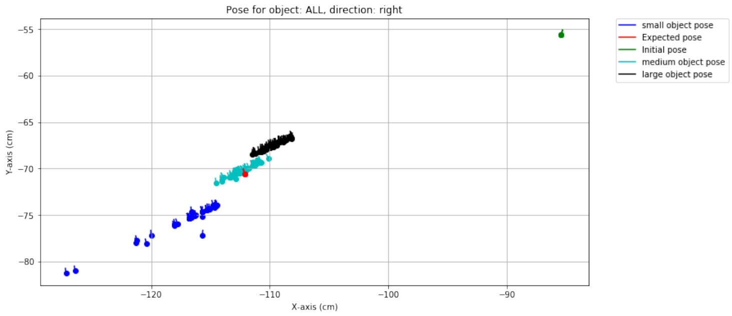
(a) object: all, direction: straight

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

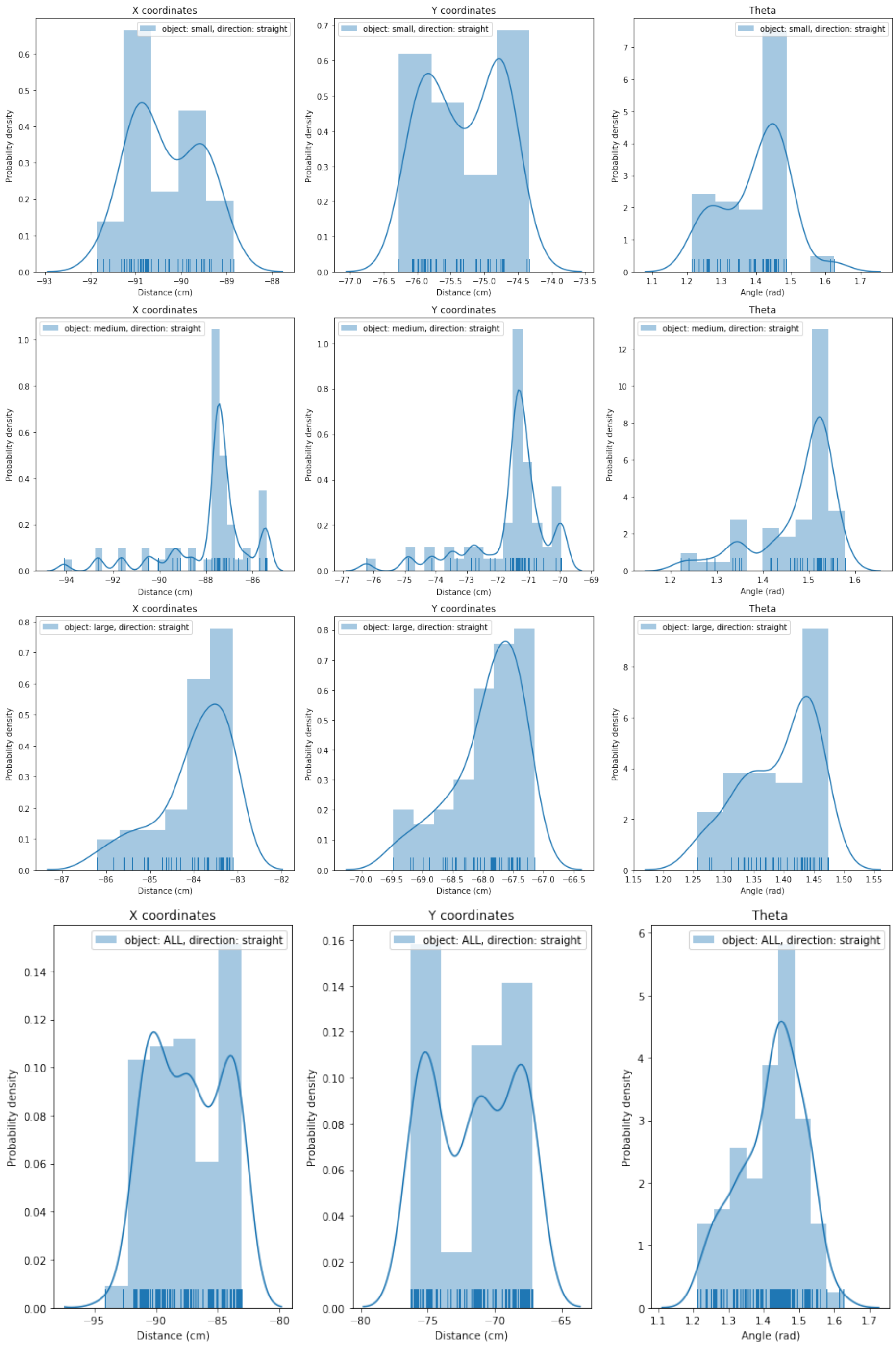


Figure 5: Histogram and Gaussian distribution of data for straight run

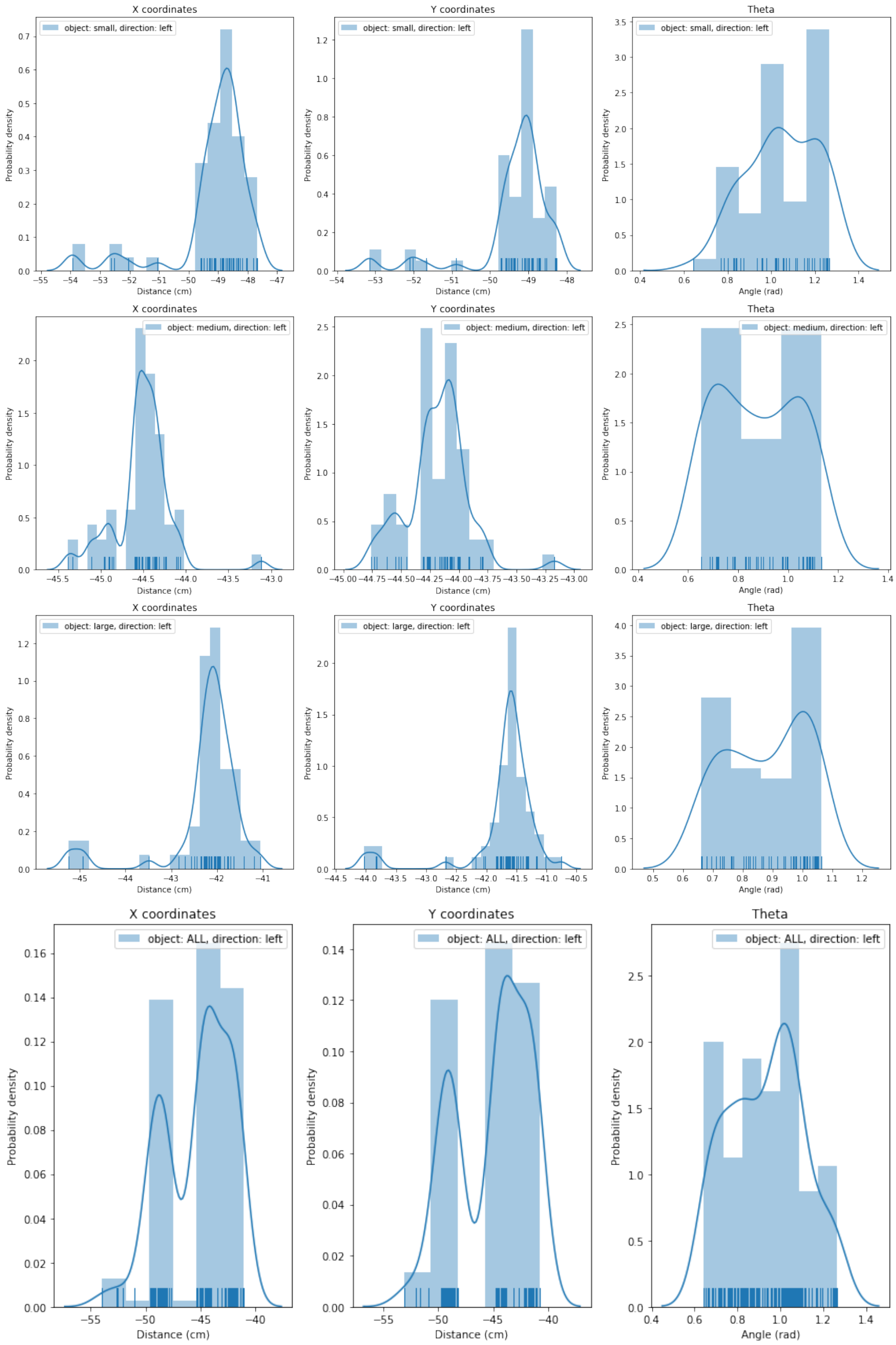


Figure 6: Histogram and Gaussian distribution of data for left run

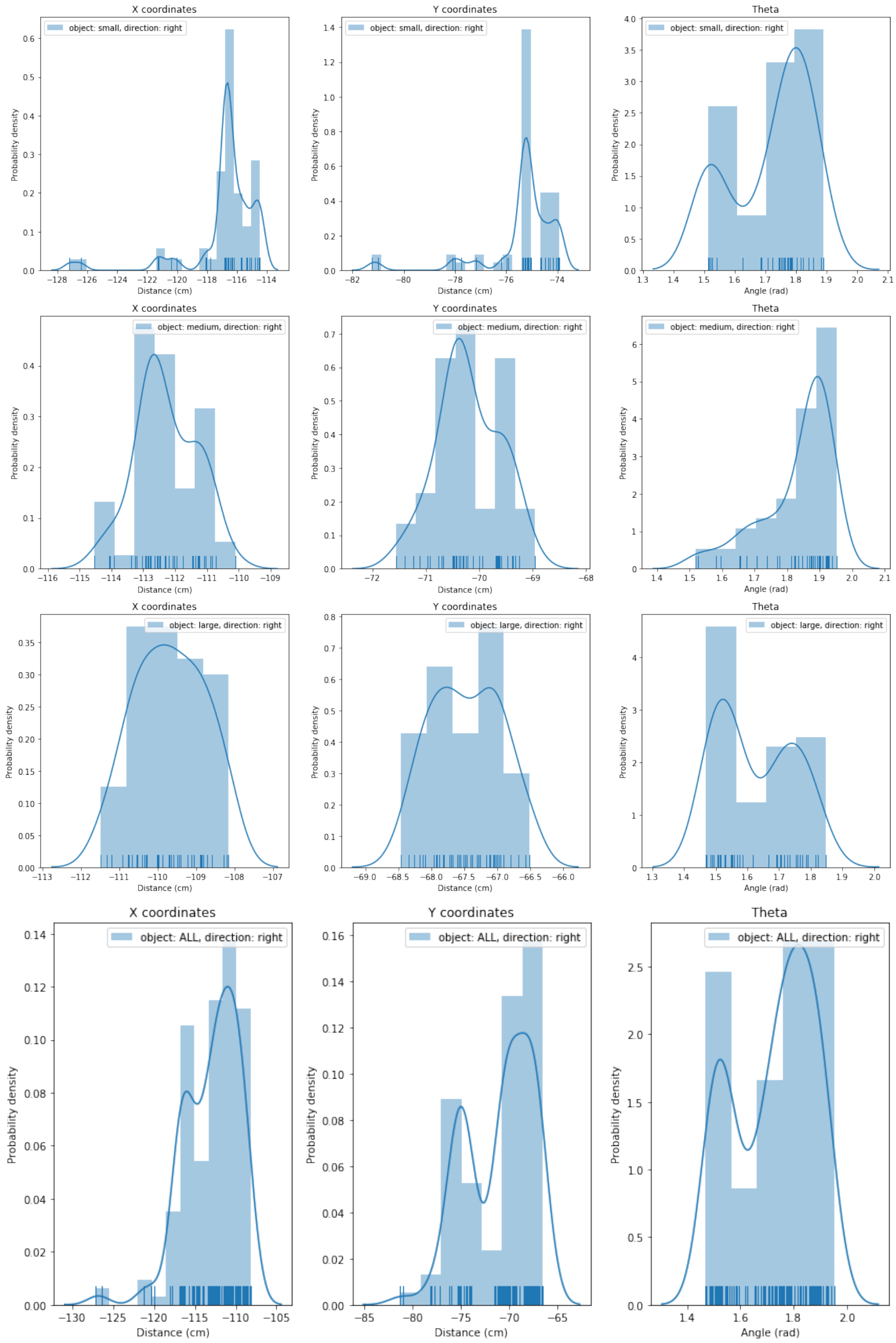


Figure 7: Histogram and Gaussian distribution of data for right run

3.3 Hypothesis Testing

Hypothesis : changing the shape and mass of an object affect the final placing pose.

- We randomly picked 20 poses for each motion (left, straight, right) for big, medium and small objects. Therefore the total number of poses n is 60.
- We consider (2.0 cm; 2.0 cm; 0.2 rad) as acceptable distance for comparison.
- The number of poses for which the hypothesis was not true was found to be k = 11.

Hence, $error_s(h) = \frac{11}{60} = 0.18$
and $error_d = \pm 1.96 \times \sqrt{\frac{error_s(h) \times (1 - error_s(h))}{n}} = \pm 0.09$

Hence it can be concluded that above hypothesis is true.

Hypothesis : Using single camera measurement does not affect the final object pose measurement.

- We randomly picked 20 poses from the raw data for each motion (left, straight, right) for big, medium and small objects. Therefore the total number of poses n is 60.
- We consider (2.0 cm; 2.0 cm; 0.2 rad) as acceptable distance for comparison.
- The number of poses for which the hypothesis was not true was found to be k = 16.

Hence, $error_s(h) = \frac{16}{60} = 0.26$
and $error_d = \pm 1.96 \times \sqrt{\frac{error_s(h) \times (1 - error_s(h))}{n}} = \pm 0.11$

Hence it can be concluded that above hypothesis is true.