

5 Implementation

5.1 Calculation of process error and measurement error

- Measure the process error \mathbf{Q} through observation: Let the robot move forward 2m under the velocity of 0.5 m/s ¹ and record its position afterwards, the ground truth coordinate should be exactly 2m forward compared to the starting point. Measure the actual stop position. Repeat e.g. 100 times, which makes it reliable, although it took quite a lot of effort, through the following method, $rmse = 0.001090280296483436$. Here in order to demonstrate the original calculation result, no round operation was conducted.
- As for the measurement error, let the robot stay at specific positions for a short time period and gather some coordinate information, its ground truth position can be measured by *BOSCH Laser measure* and the measurement result comes from the *UWB tag*. Through this we can calculate the mean error, the variance of the error and Standard Deviation. *Root Mean Square Error* is the standard deviation of the residuals, which is the measurement noise in our case.

Through *describe()* method we can get details about X-coordinates (*expected_x* = 4.045):

Listing 5.1: describe output

| | |
|-------|------------|
| count | 100.000000 |
| mean | 4.045630 |
| std | 0.022511 |
| min | 3.985000 |
| 25% | 4.033750 |
| 50% | 4.051500 |
| 75% | 4.062000 |
| max | 4.086000 |

Name: x, dtype: float64

We can also plot its *Histograms with different binwidths*, as shown in Figure 5.1:

Its density plot is in Figure 5.3, which is essentially a smooth version of Histogram:

¹0.5 m/s is a proper velocity, lower velocity will make experiments less efficient and higher velocity will increase the process error because the robot move a specific distance in an accumulative way, the faster it would be harder to move exactly the specified distance.

According to [Nil18], the spatial RMSE can be calculated separately for X- and Y-axis through:

$$RMSE_i = \sqrt{\frac{1}{n} \sum_{m=1}^n (Est_i - Actual_i)^2} \quad (5.1)$$

where i is the coordinate axis. And a net RMSE can be calculated through:

$$RMSE_{Net} = \sqrt{RMSE_X^2 + RMSE_Y^2} \quad (5.2)$$

The ground truth of the points we randomly choose are:

1. pose1: (x = 3.916, y = 2.465)
2. pose2: (x = 5.143, y = 1.947)
3. pose3: (x = 6.641, y = 4.788)

We gathered their measurements from *UWB tag* and write the coordinate information into csv files and calculate the MSE using *mean_squared_error()* method from *sklearn.metrics*. And the calculation result is: *rmse* = 0.01422606083083504. Their separate and concatenated density plot are in Figure 5.3.

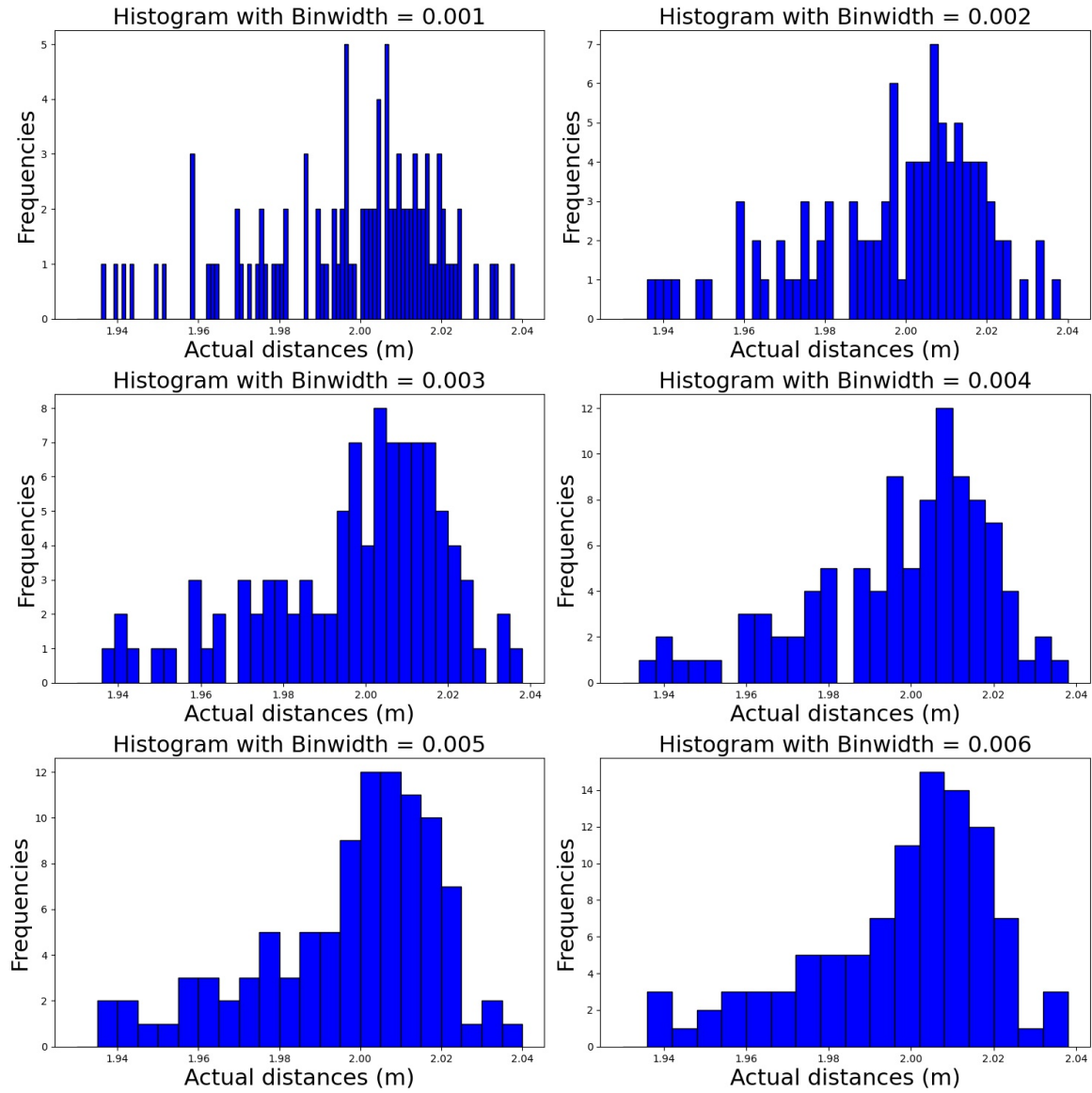


Figure 5.1: Histograms with different bin-widths for 2m movement

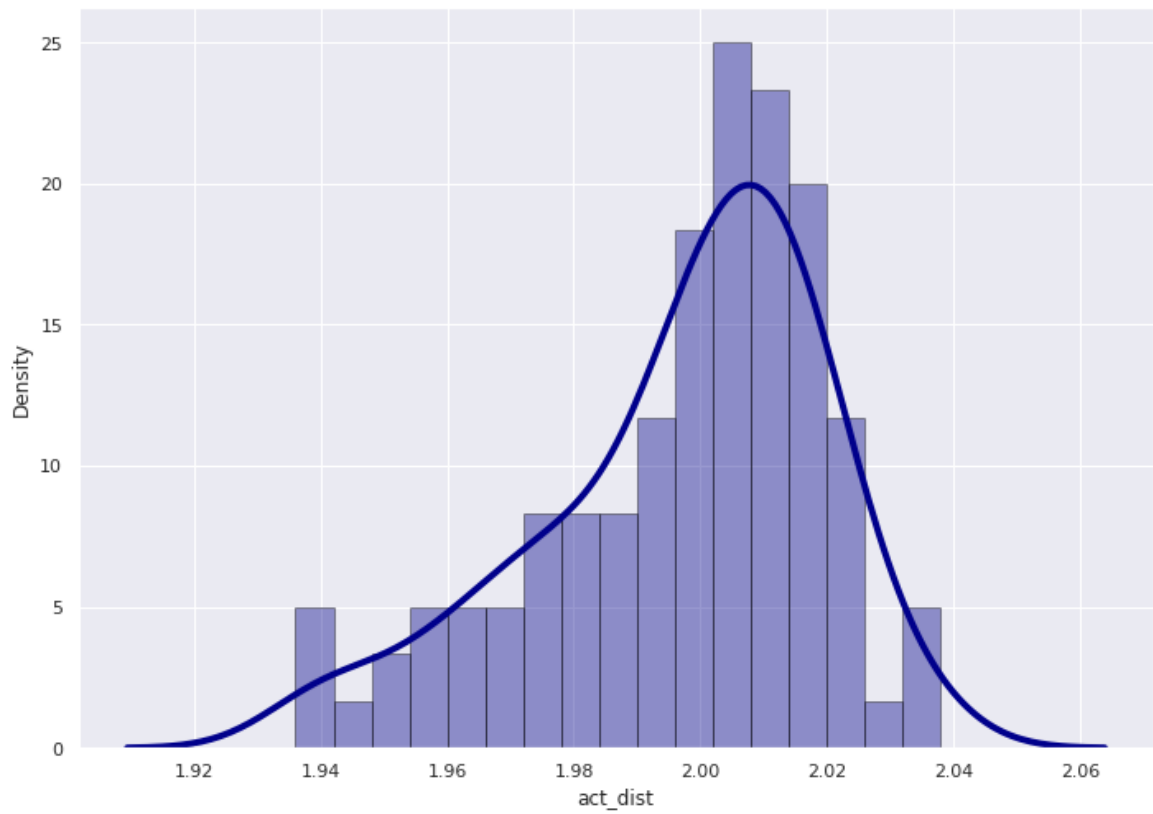
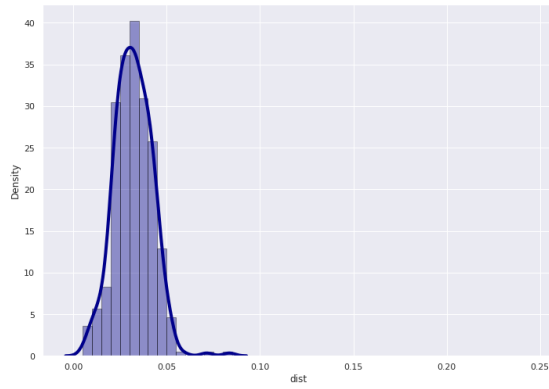
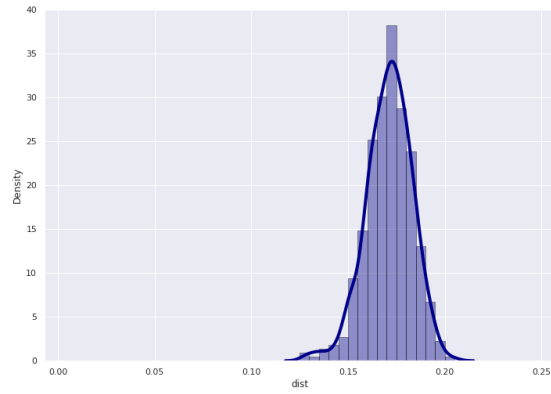


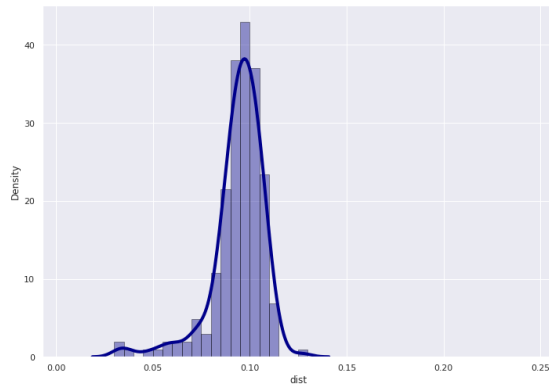
Figure 5.2: Density plot and histogram for process error of 2m movement



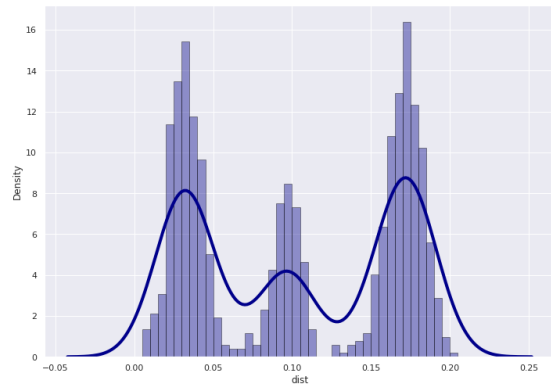
(a) Density plot for pose1



(b) Density plot for pose2



(c) Density plot for pose3



(d) Density plot for all three poses

Figure 5.3: Density plots for measurement error for UWB tag at three randomly chosen positions