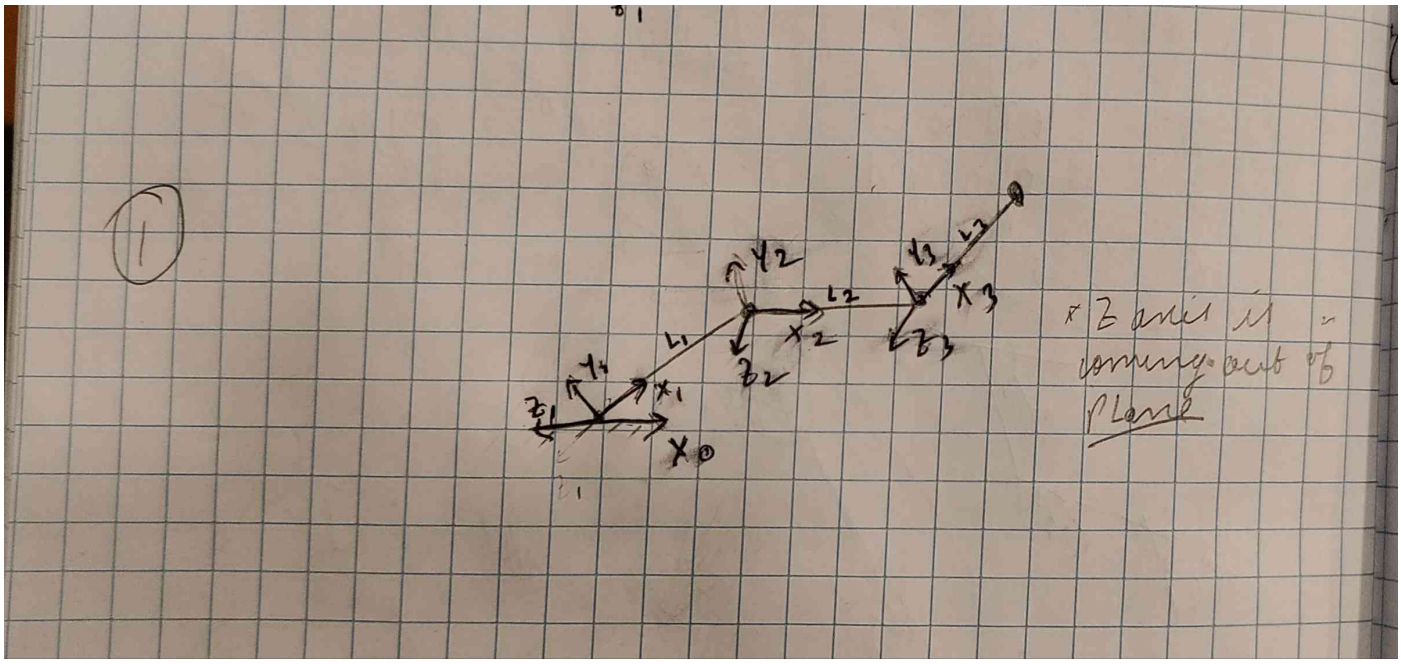
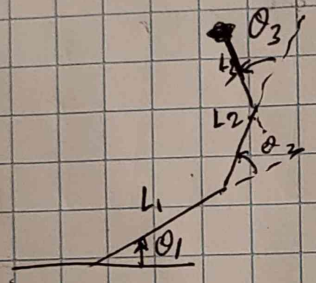

(1)
Y2
L2
Y3
L3
X3
L1
X2
Z3
Z2
Y1
X1
Z1
X0
* Z axis is coming out of Plane

② Kinematics eqn



$\theta_e = \theta_1 + \theta_2 + \theta_3$

$x_e = L_1 \cos\theta_1 + L_2 \cos(\theta_2 + \theta_1) + L_3 \cos(\theta_1 + \theta_2 + \theta_3)$

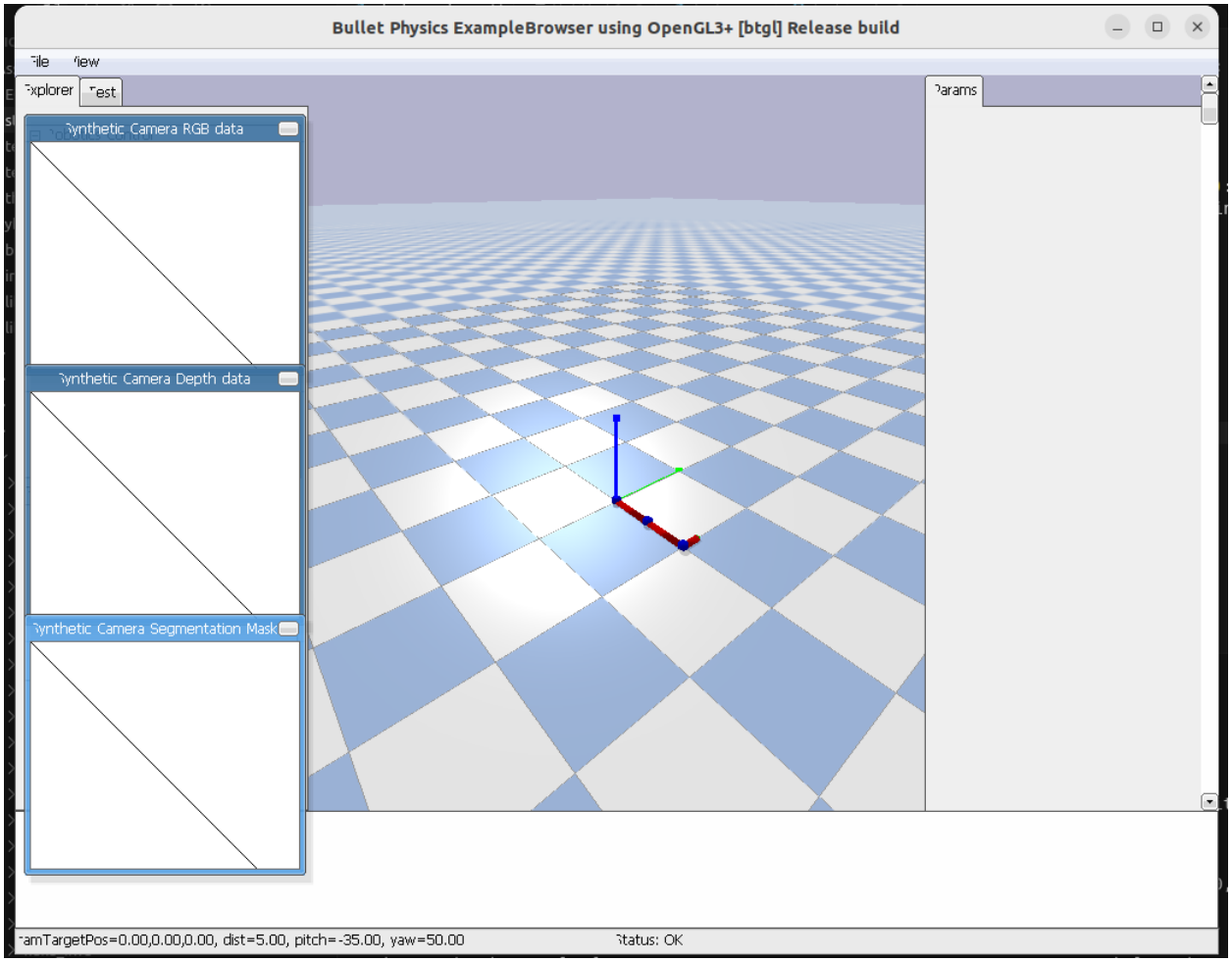
$y_e = L_1 \sin\theta_1 + L_2 \sin(\theta_1 + \theta_2) + L_3 \sin(\theta_1 + \theta_2 + \theta_3)$

While running the code set variable

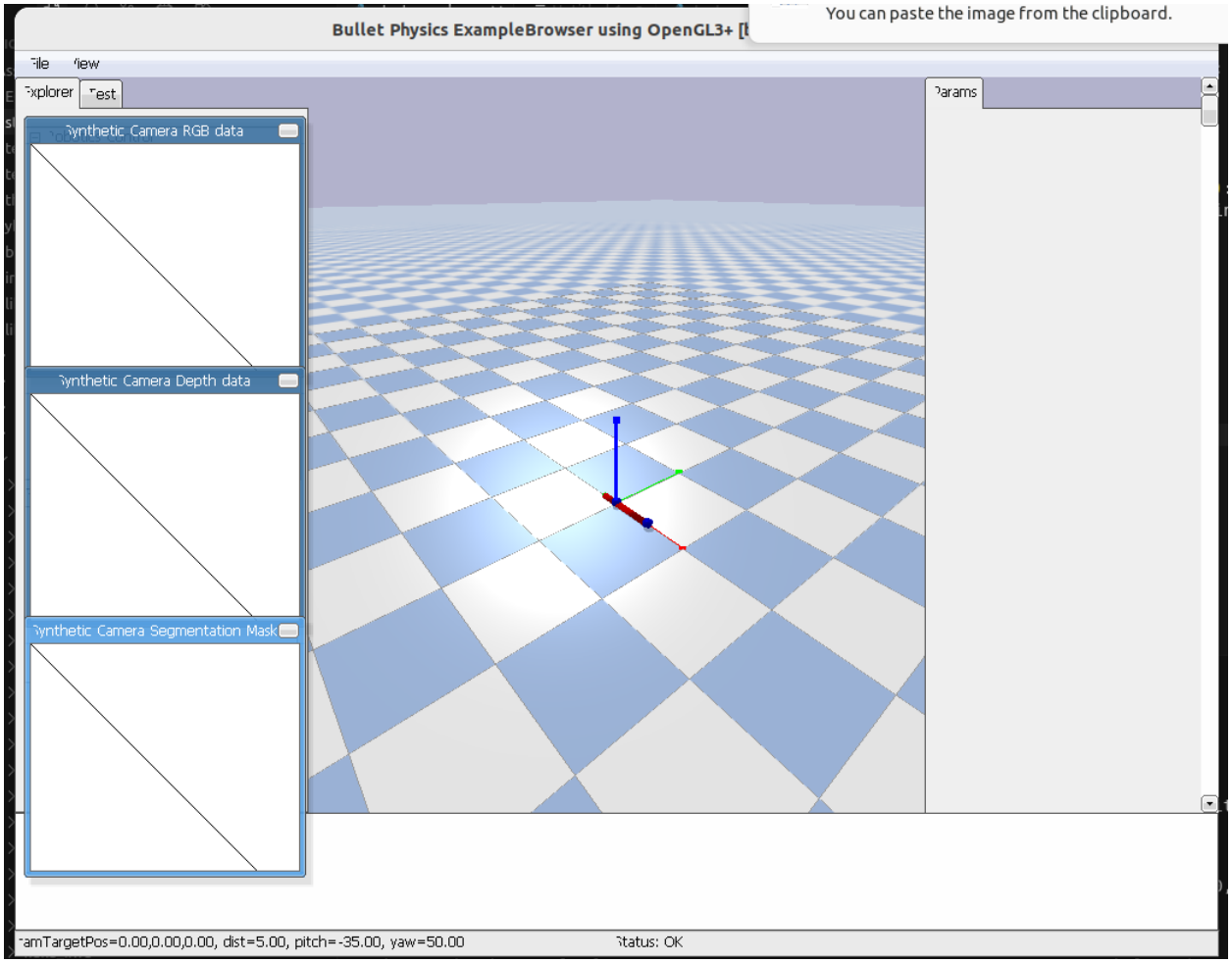
```
run_part_no = None # 1 for open loop, 2 for closed loop, 3 for null space control
```

Q3)

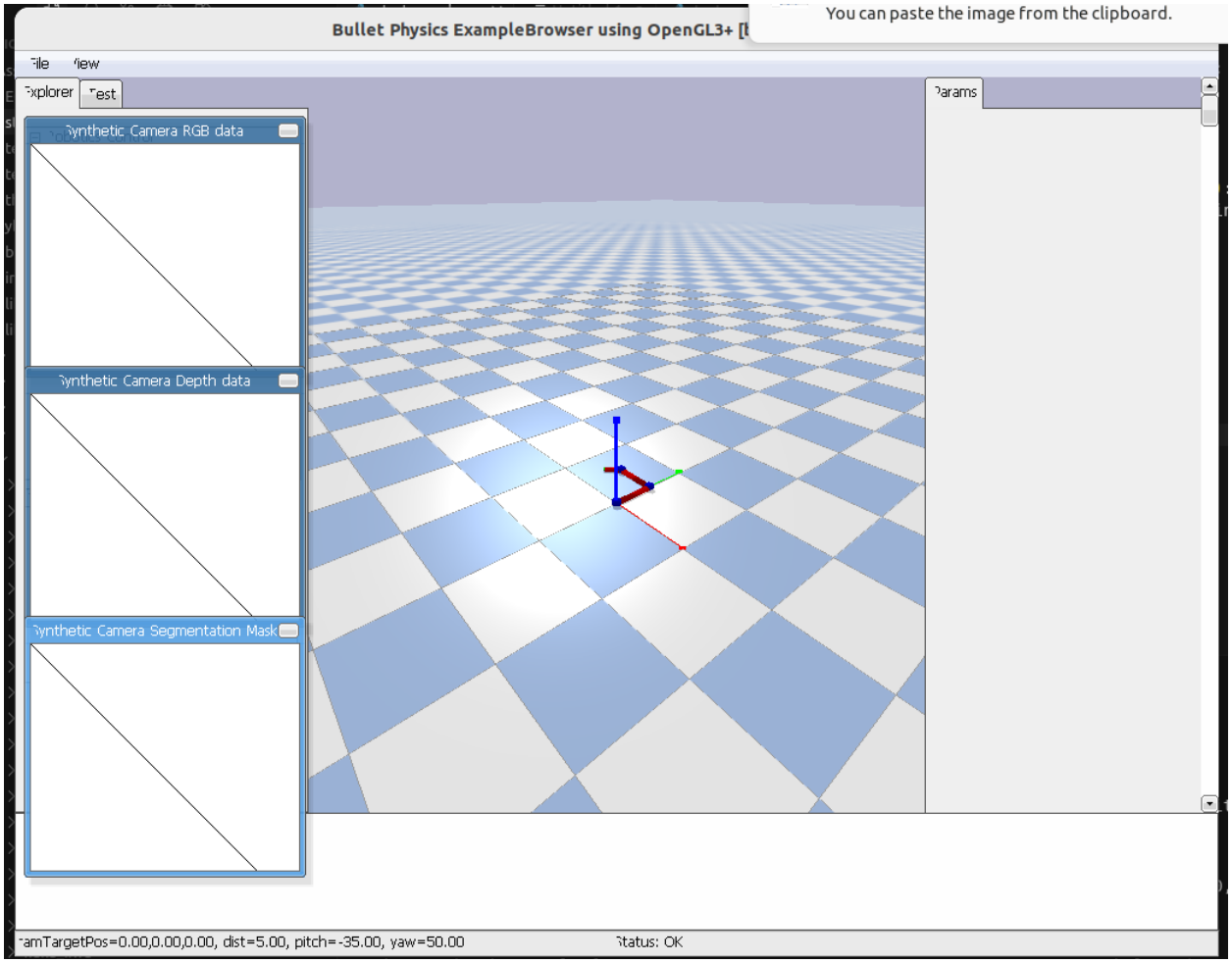
Config1



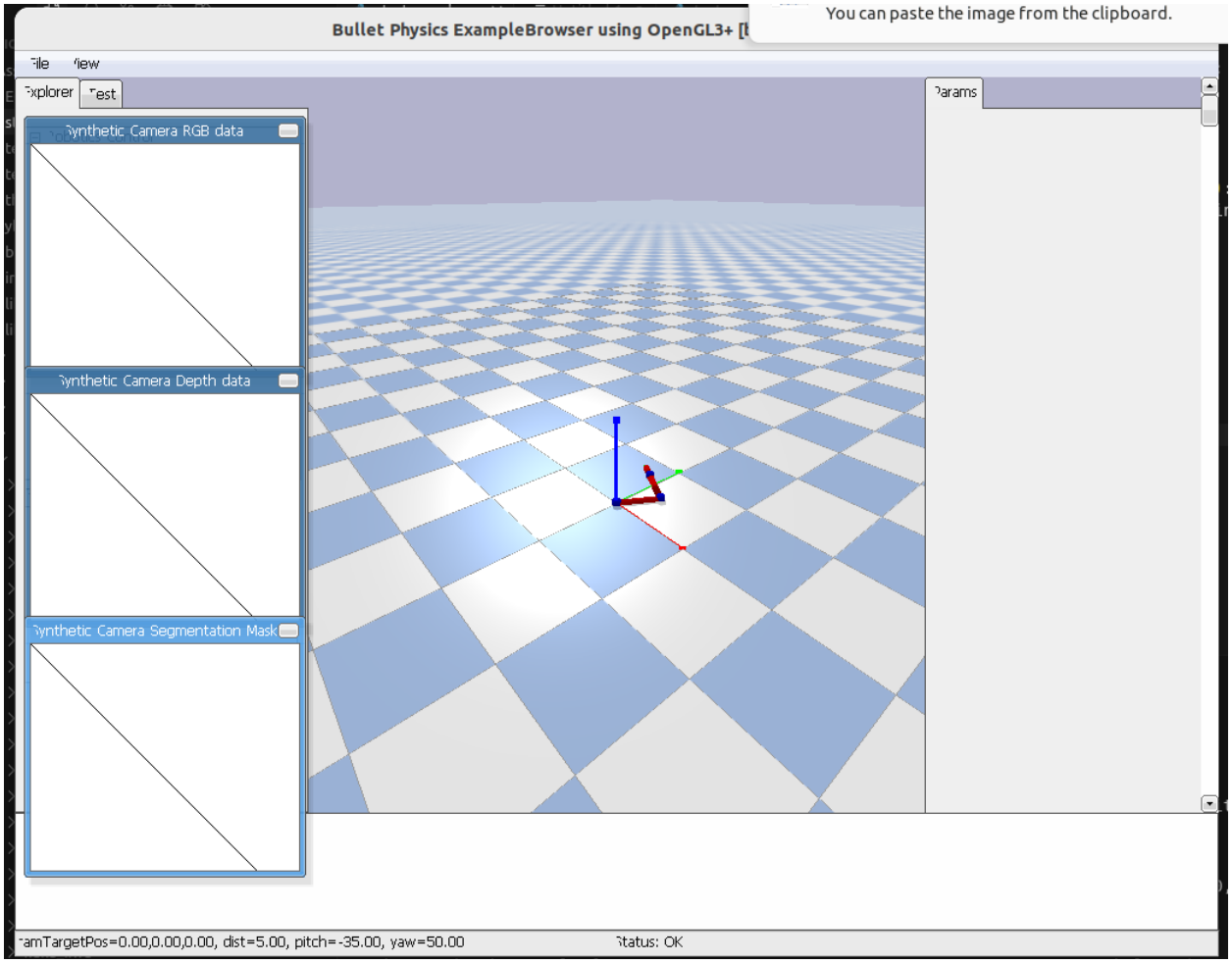
Config2


You can paste the image from the clipboard.
Bullet Physics ExampleBrowser using OpenGL3+ [
File
View
Explorer
Test
Synthetic Camera RGB data
Synthetic Camera Depth data
Synthetic Camera Segmentation Mask
Params
amTargetPos=0.00,0.00,0.00, dist=5.00, pitch=-35.00, yaw=50.00
tatus: OK

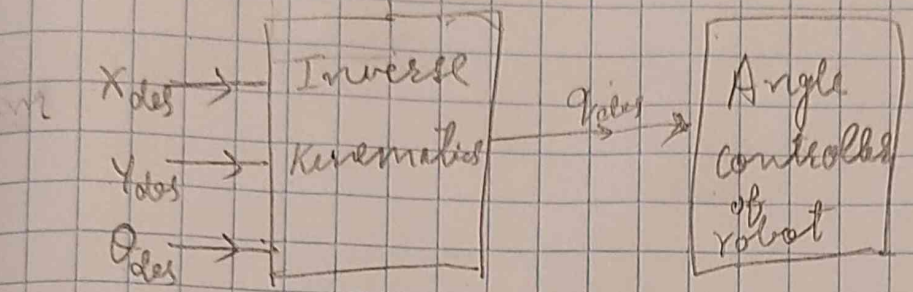
Config3


You can paste the image from the clipboard.
Bullet Physics ExampleBrowser using OpenGL3+ [
File
View
Explorer
Test
Synthetic Camera RGB data
Synthetic Camera Depth data
Synthetic Camera Segmentation Mask
Params
amTargetPos=0.00,0.00,0.00, dist=5.00, pitch=-35.00, yaw=50.00
Status: OK

Config4


You can paste the image from the clipboard.
Bullet Physics ExampleBrowser using OpenGL3+ [
File
View
Explorer
Test
Synthetic Camera RGB data
Synthetic Camera Depth data
Synthetic Camera Segmentation Mask
Params
CamTargetPos=0.00,0.00,0.00, dist=5.00, pitch=-35.00, yaw=50.00
Status: OK

Open Loop.

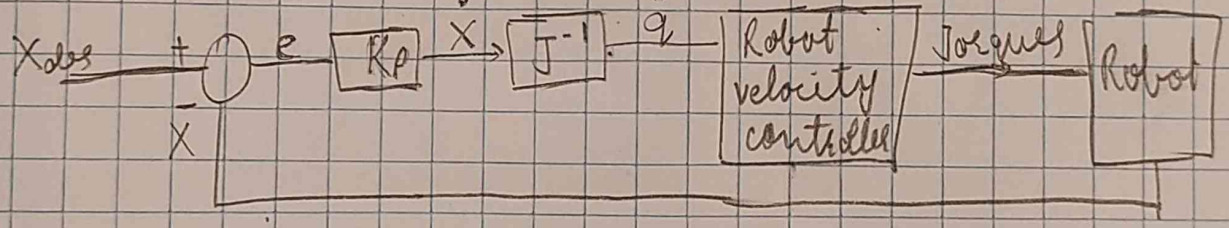


q_{des} → joint angle commands.

closed loop

$X_{des} = (x_{des}, y_{des}, \theta_{des})$ → desired state

$X = (x, y, \theta)$ → current state



$e = \dot{X}_{des} - X$

$\dot{X} = K_p \cdot e$

$\dot{q} = J^{-1} K_p e$ → velocity commands for joints

(5) $x_{des} = at^3 + bt^2 + ct + d$

$\theta_{des} = kx$

s.t $x(0) = x_0 \qquad x(t) = x_1$

$\dot{x}(0) = 0 \qquad \dot{x}(1) = 0$

$$\begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 3 & 2 & 1 & 0 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} = \begin{bmatrix} x_0 \\ x_1 \\ 0 \\ 0 \end{bmatrix}$$

$$k = \frac{y_1 - y_0}{x_1 - x_0}$$

6) closed loop

$\theta_{des} = \theta = \theta_1 + \theta_2 + \theta_3$

$$X_{des} = \begin{bmatrix} x_{des} \\ y_{des} \\ \theta_{des} \end{bmatrix}$$

$e = X_{des} - X$

$\dot{q}_{des} = J^{-1} K_p e \Leftarrow$ where $J^{-1} = J^T \left[JJ^T + \lambda^2 I \right]$

(6) for null space

cost function

$J(\theta) = \theta_2^2 + \theta_3^2$ → Minimize

$\theta_2 \to 0$, $\theta_3 \to 0$ ensures links are far apart

$$\nabla J(\theta) = \begin{bmatrix} 0 \\ 2\theta_2 \\ 2\theta_3 \end{bmatrix}$$

Minimize $J(\theta)$ for max separation

$$\dot{q}_{null} = -\left(I - J^{-1}J\right) \nabla J(\theta) * k$$

↑ tuning parameter

$\dot{q} = \dot{q}_{des} + \dot{q}_{null}$

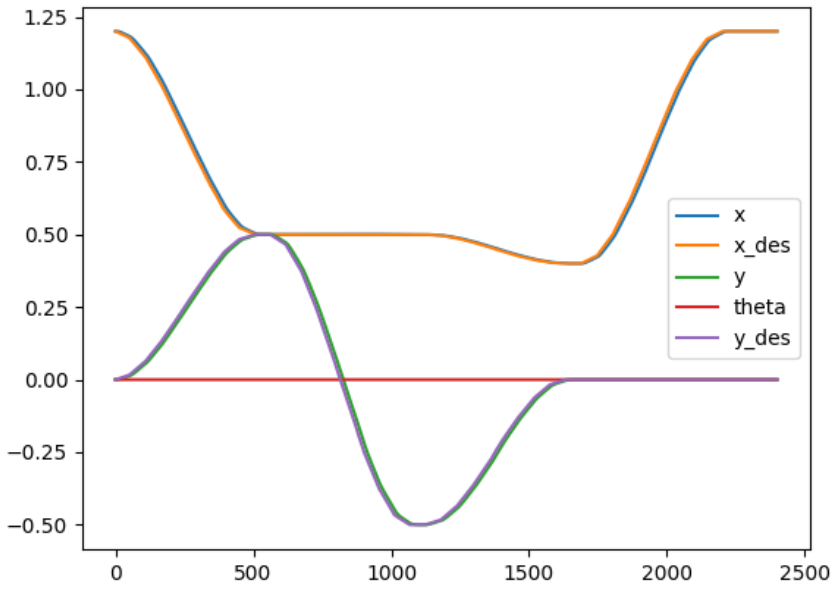
↑ desired loop

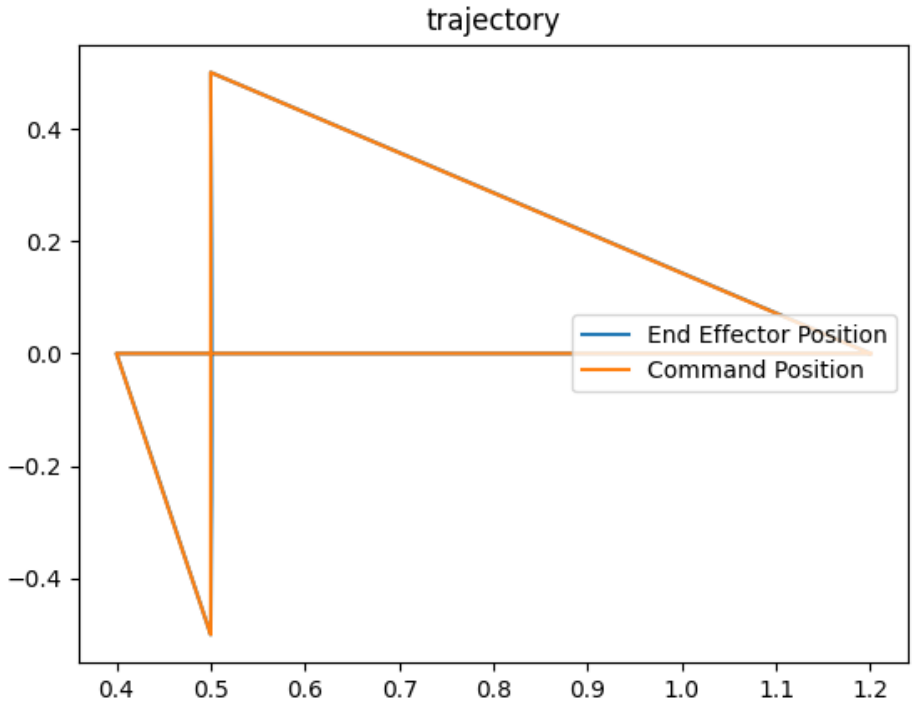
↑ Null space

Q5) Open loop control

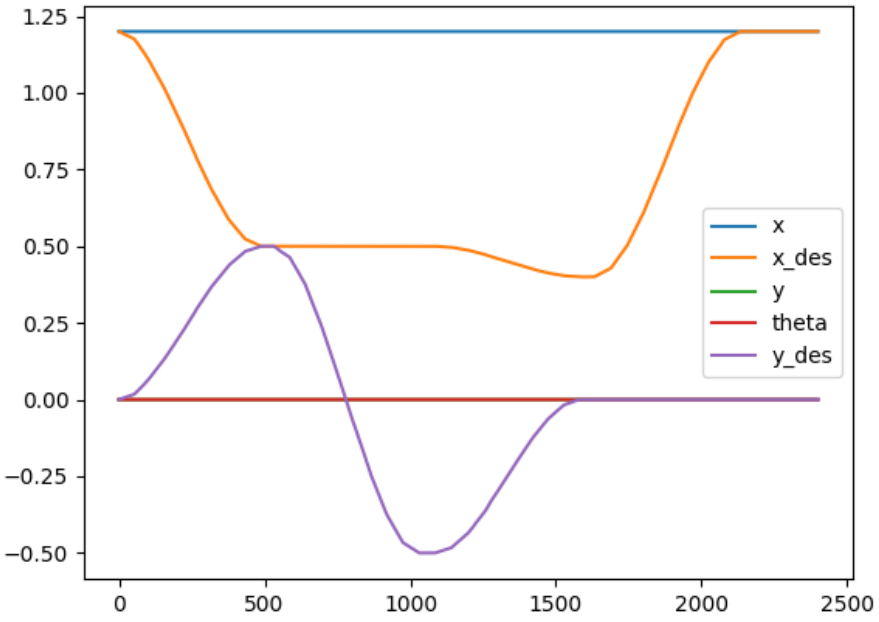
While running the code set variable

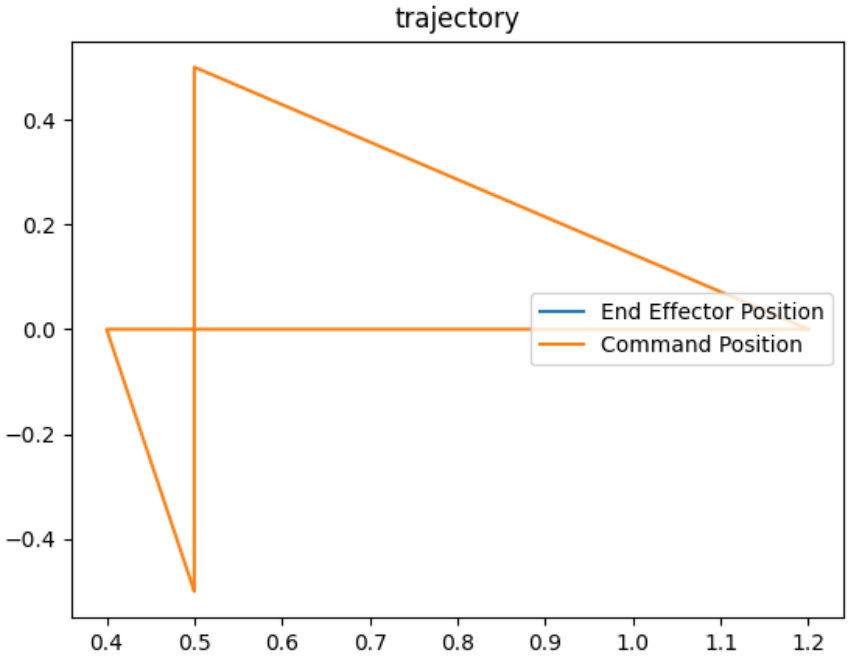
```
run_part_no = None # 1 for open loop, 2 for closed loop, 3 for null space control
```





Q6) a) Closed loop control





Q6) b) Null space control