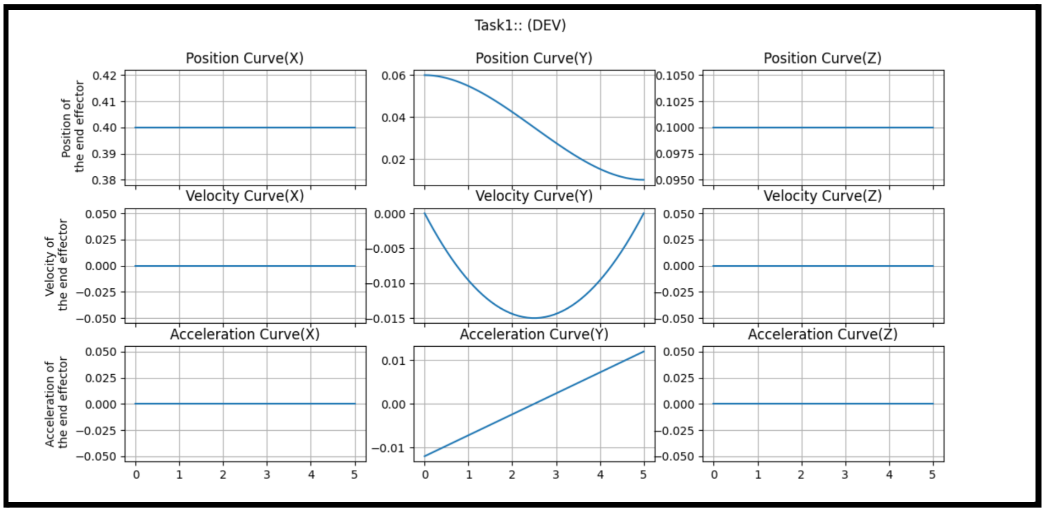
ITR Assignment 6-7

Secret Code:- DEV

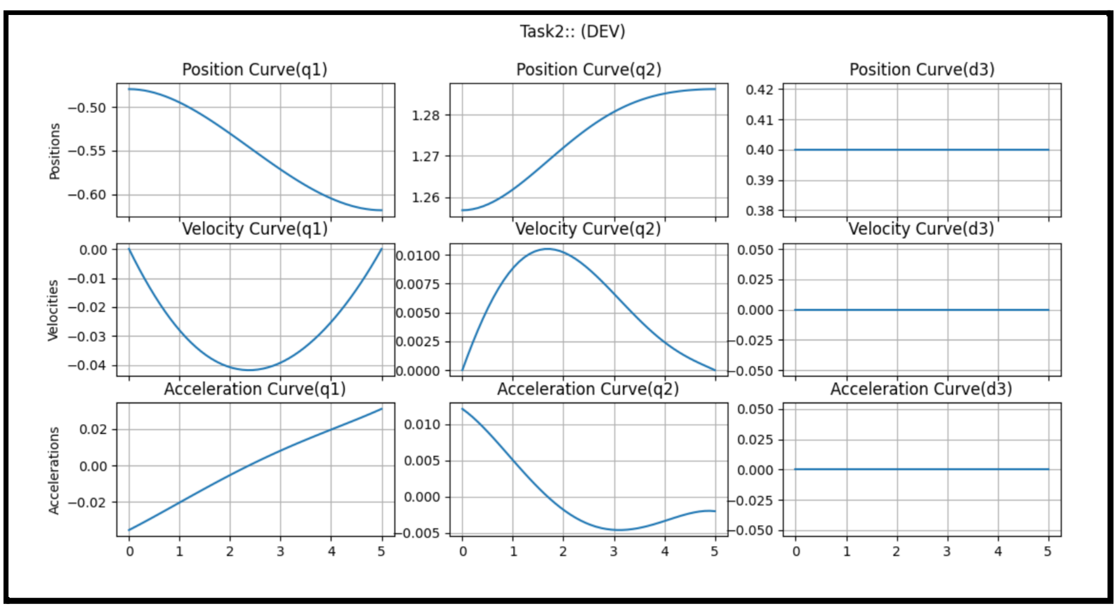
Task1



Plots for end effector positions generated in Task1

Task2

Manipulator Chosen: SCARA



Plots for joint variables generated in Task2

Task3

3.a. PD Control

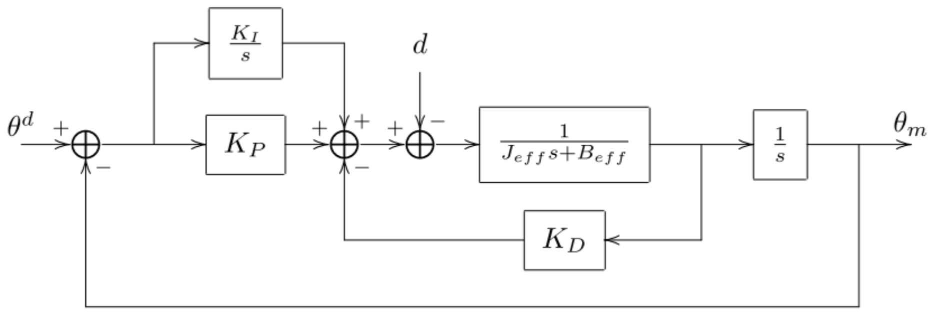


Fig. 7.14 Closed loop system with PID control.

PD Control Loop (Taking Ki = 0) | Image from Textbook, Spong and Vidyasagar

- Equations Used: $V = K_p(\theta_d - \theta) + K_d(\dot{\theta}_d - \dot{\theta})$
- K_p and K_d calculation:
  - Determined K_p's for each joint individually through trial and error. Used the K_p that was able to move the joint with enough speed.
  - Calculated the J_{eff} and B_{eff} near the path (since J_{eff} depends on the configuration too) and computed the K_d in the following manner (to achieve critical damping), for each joint:

$$\omega_n = \sqrt{\frac{K_m K_p}{J_{eff} R}} \qquad K_d = \frac{2\,\omega_n J_{eff} - B_{eff}}{K_m/R}$$

3.b. FeedForward + PD Control

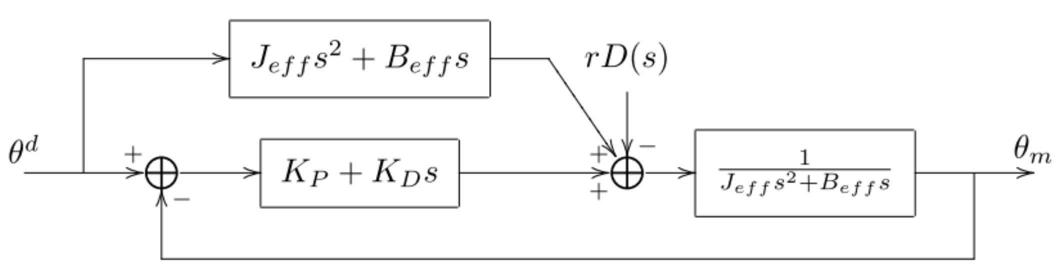


Fig. 7.20 Feedforward compensator for second order system.

FeedForward + PD Control Loop | Image from Textbook, Spong and Vidyasagar

- ➔ Equations Used: $V = K_p(\theta_d - \theta) + K_d(\dot{\theta}_d - \dot{\theta}) + \frac{J_{eff}}{K_m}\ddot{\theta} + \frac{B_{eff}}{K_m}\dot{\theta}$
- ➔ Used K_p and K_d same as 3.a.

3.c. Computed Torques Cancellation

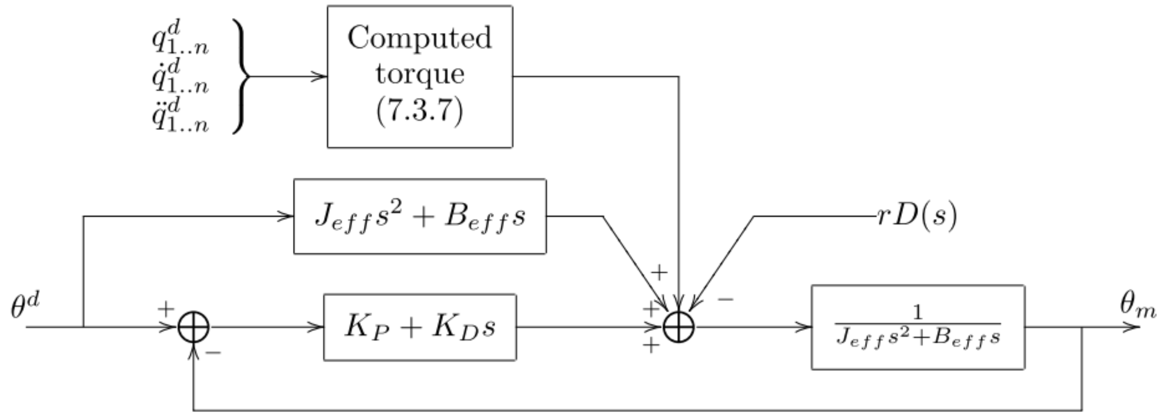


Fig. 7.21 Feedforward computed torque compensation.

FeedForward using Computed Torques + PD Control Loop | Image from Textbook, Spong and Vidyasagar

- ➔ Equations Used: $V = K_p(\theta_d - \theta) + K_d(\dot{\theta}_d - \dot{\theta}) + \frac{J_{eff}}{K_m}\ddot{\theta} + \frac{B_{eff}}{K_m}\dot{\theta} + \tau_k$

  τ_k is the torque computed for joint using the following matrix dynamic equation:

  $$\tau = D(q)\ddot{q} + C(q,\dot{q})\dot{q} + g(q)$$

- ➔ Used K_p and K_d same as 3.a.

3.c. Multivariable Control

- ➔ Equations Used:

  $h = C(q,\dot{q})@\dot{q} + Beff@\dot{q} + g(q)$

  $r = \ddot{q}_d + K_1\dot{q}_d + K_0 q_d$

  $v = -K_0 q - K1\dot{q} + r$

  $u = (D + Jeff)v + h$

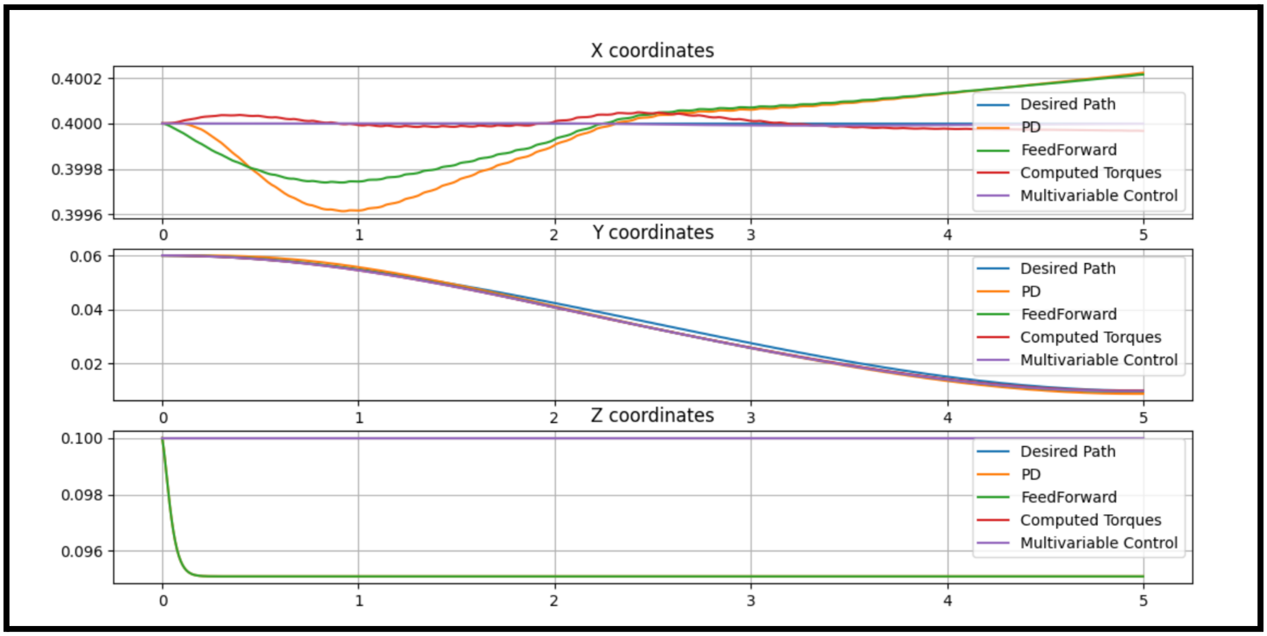
  $V = \frac{u \times K_m}{Rr}$

- ➔ Calculation of K1 and K0

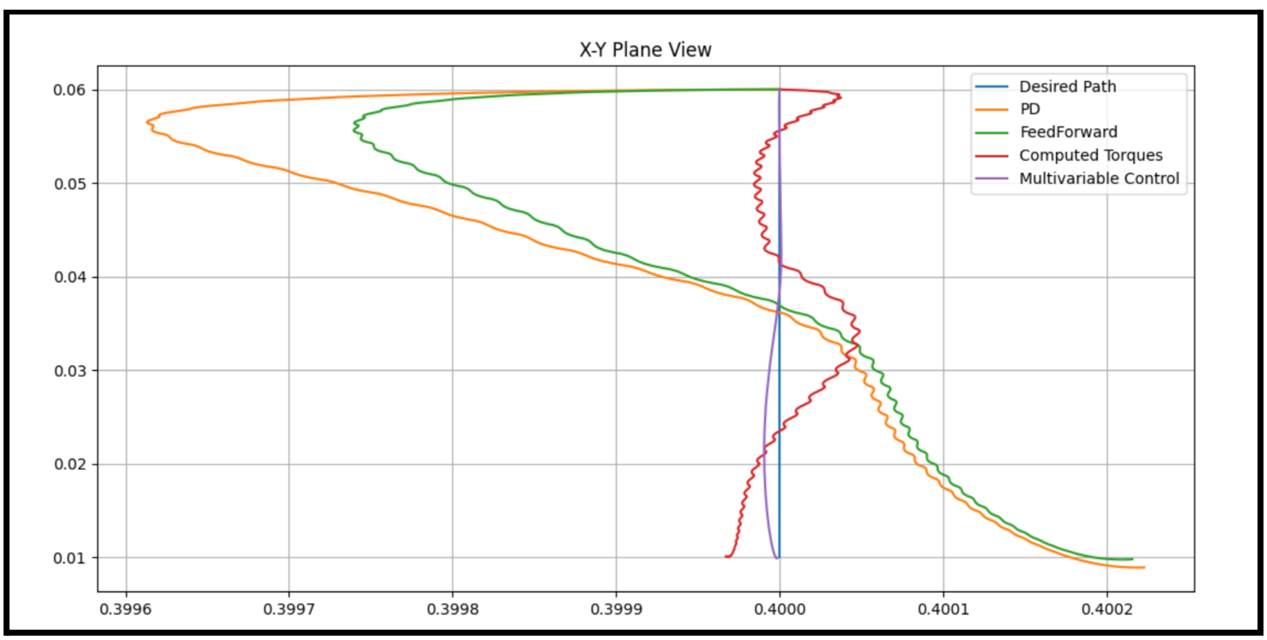
- Determined K_0's for each joint individually through trial and error. Used the K_0 that was able to move the joints with enough speed.
- Calculated K_1 using (for critical damping)

$$K_1 = 2\sqrt{K_0}$$

Comparision of all four controller

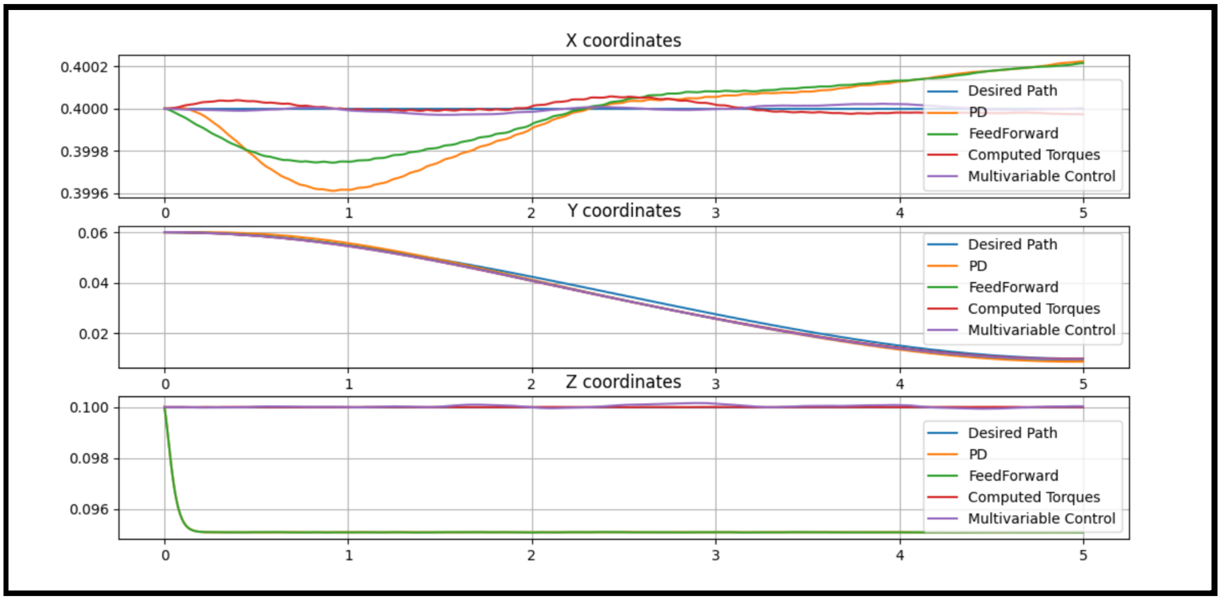


Comparing the responses of all four controllers (X-Y-Z Coordinates)

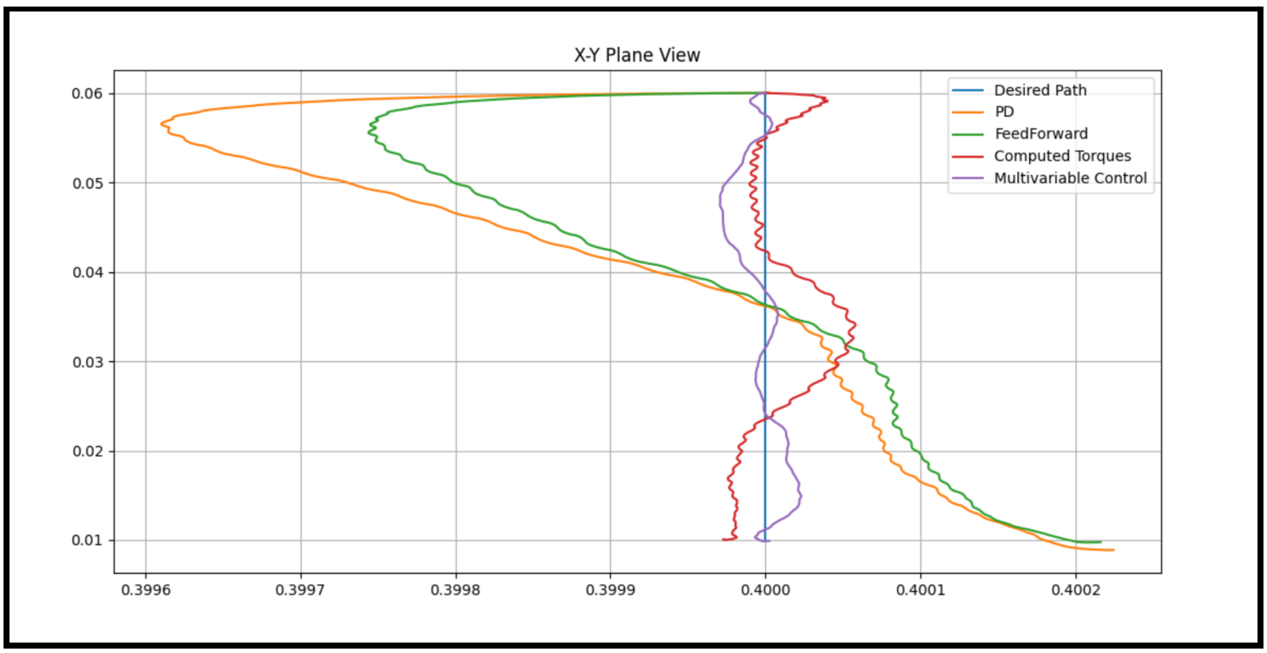


Comparing the responses of all four controllers (X-Y Plane View)

Task 5



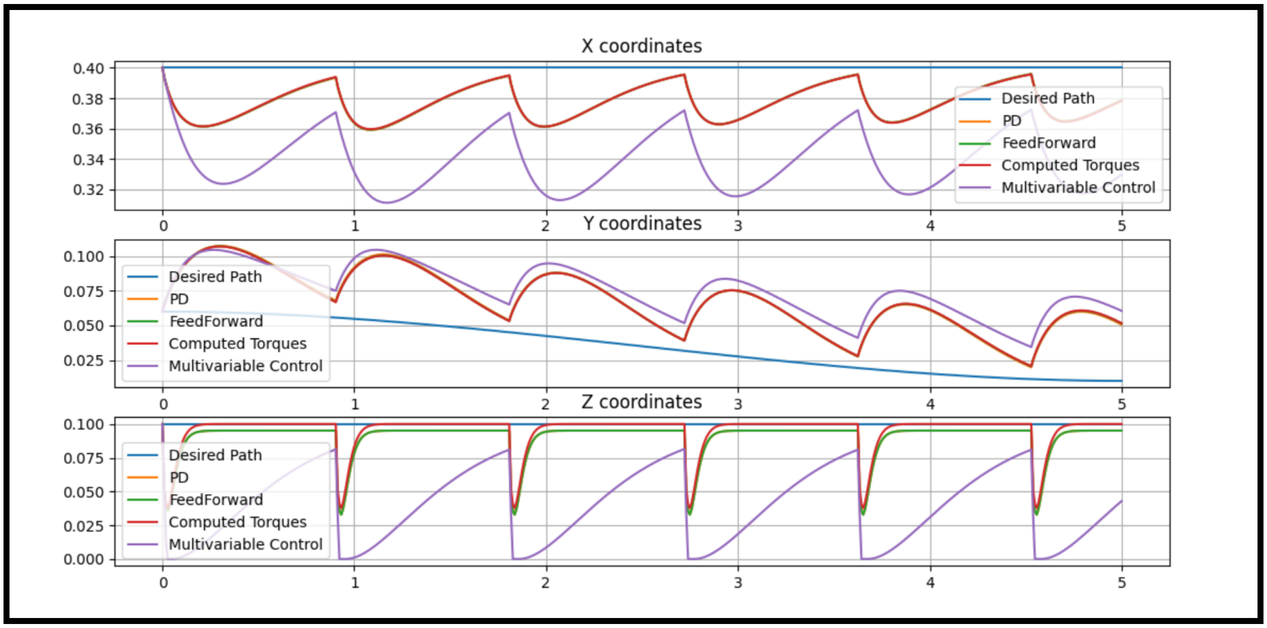
Comparing the responses of all four controllers with noise in manipulator(X-Y-Z Coordinates)



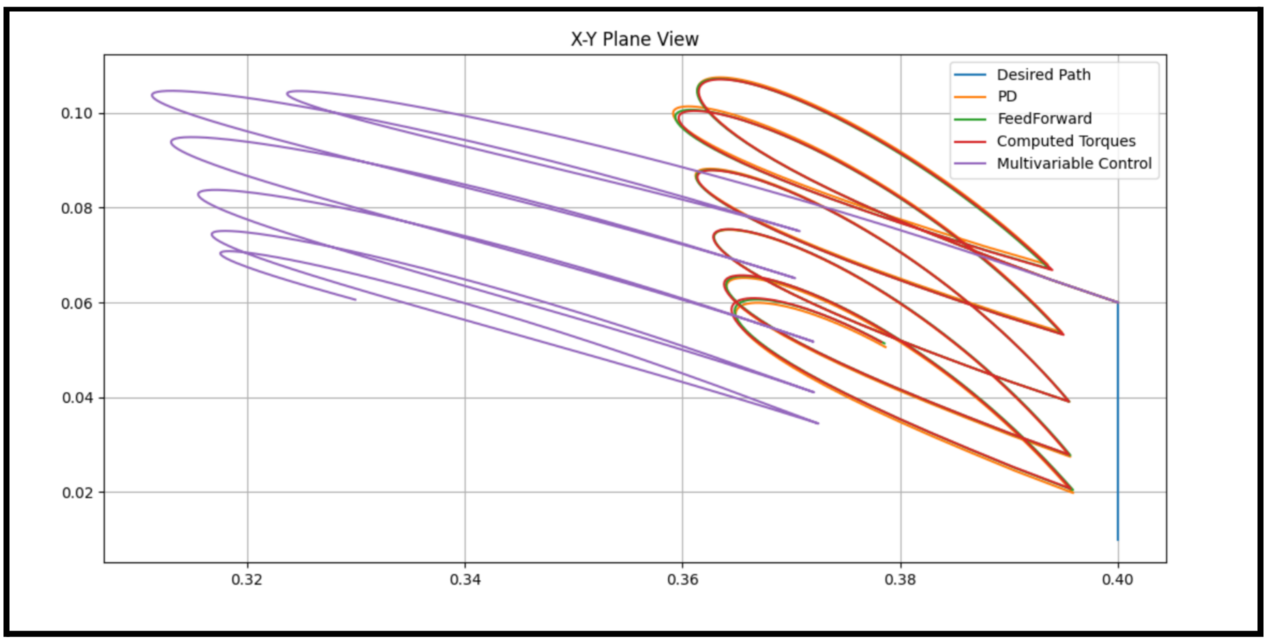
Comparing the responses of all four controllers with noise in manipulator (X-Y Plane View)

NOTE: Plots in task 5 and 6 might be different when running the code again due to random functions used in the code.

Task 6



Comparing the responses of all four controllers with impulses given in manipulator(X-Y-Z Coordinates)



Comparing the responses of all four controllers with impulses in manipulator (X-Y Plane View)

Task7. Closing Comments

As we can see, the overall response of the multivariable controller is best, followed by computed torques feed forward, followed by normal feed-forward and worst in the case of PD control. Thus, the error in following the path reduces with the sophistication of the control method used. We can also observe the steady state error in the PD controller and the (Feedforward + PD).

Also, in the response of PD and feedforward control to an impulse appears to be better than the multivariable Controller in the given graphs, however, even the multivariable controller can show such a response if the values of K_1 and K_0 are appropriately increased.