

ELEC-E8126 Robot manipulation

Exercise 4

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1. the mathematical equation of torques computation

1.1

$$\tau = J^T(\theta)F_d$$

—— τ is the torque

—— $J^T(\theta)$ is the Jacobian matrix

—— F_d is the Desired force of end effector

1.2

$$\tau = J^T(\theta)(F_d + K_p F_e + K_i \int F_e(t) dt)$$

—— τ is the torque

—— $J^T(\theta)$ is the Jacobian matrix

—— F_d is the Desired force of end effector

—— F_e is Error in force

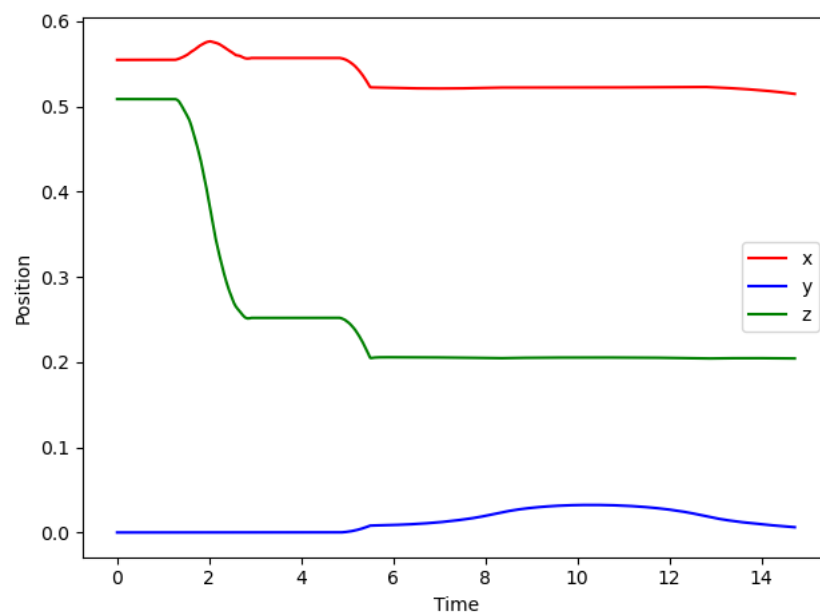
—— K_p and K_i are tuning constants for the controller

2. plots of position/force profiles of the controllers for ideal/real robot

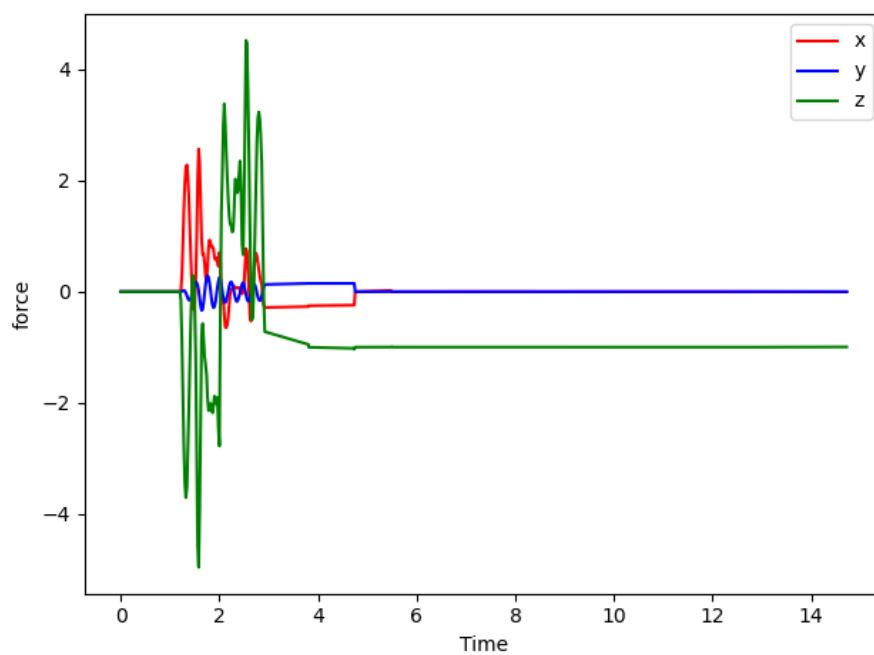
2.1 Ideal Robot

1) FeedForward controller

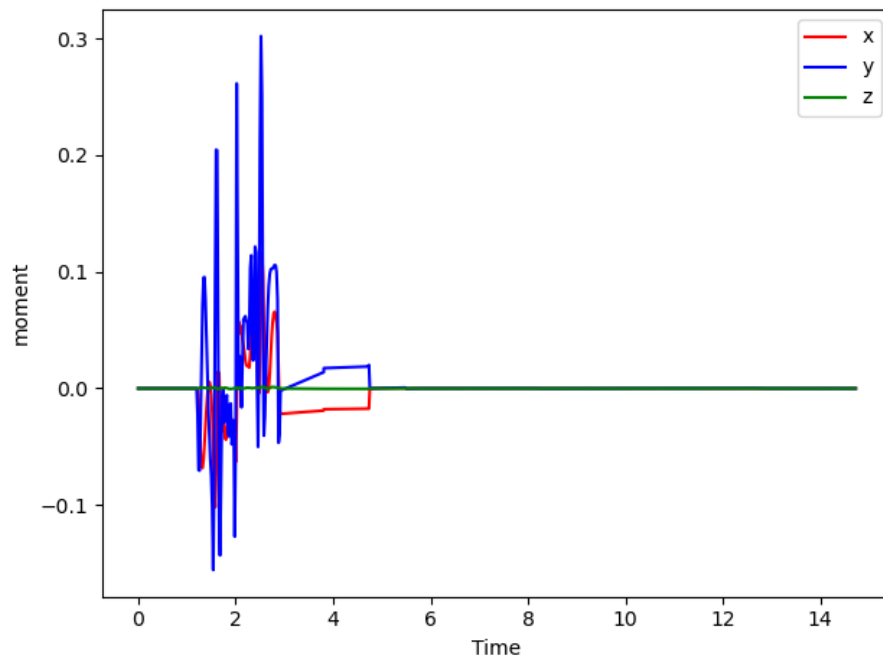
a) Ideal Robot with Feedforward controller position graph



b) Ideal Robot with Feedforward controller force graph of end effector

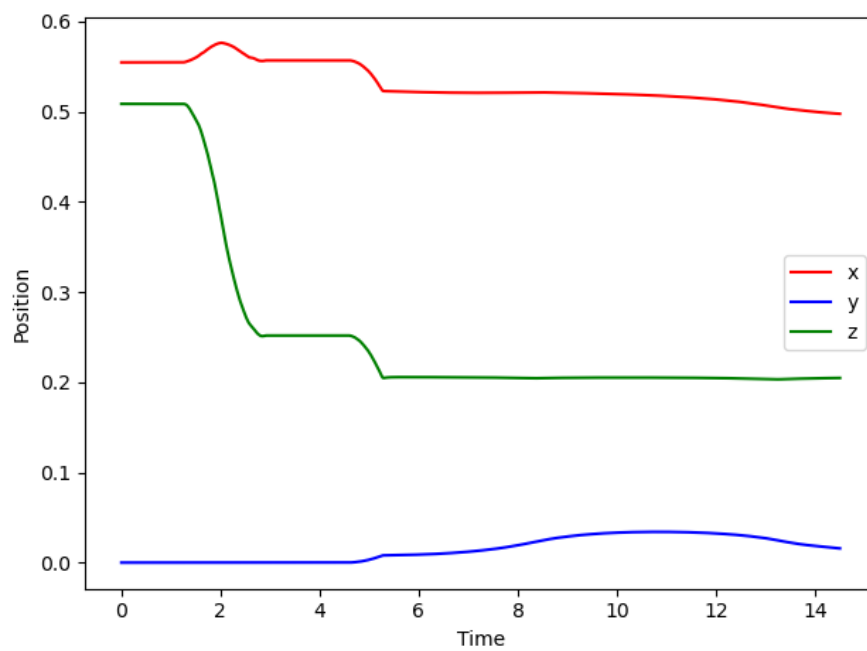


c) Ideal Robot with Feedforward controller force graph of end effector Zoomed for Steady state value

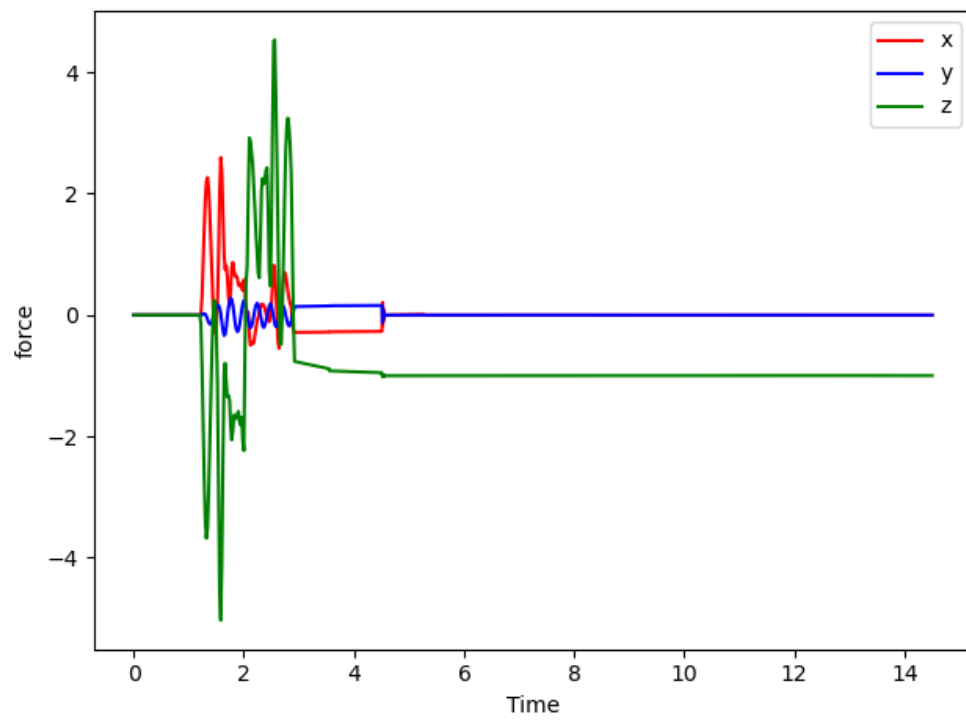


2) PI-controller

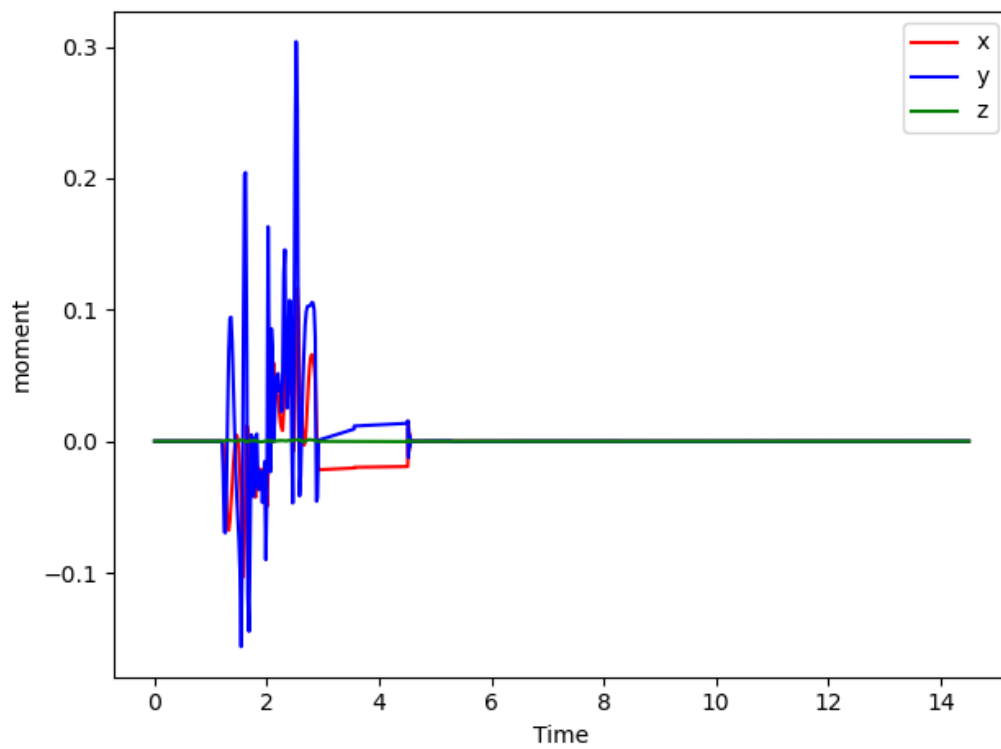
a) Ideal Robot with feedforward plus feedback PI controller position graph



b) Ideal Robot with feedforward plus feedback PI force graph of end effector



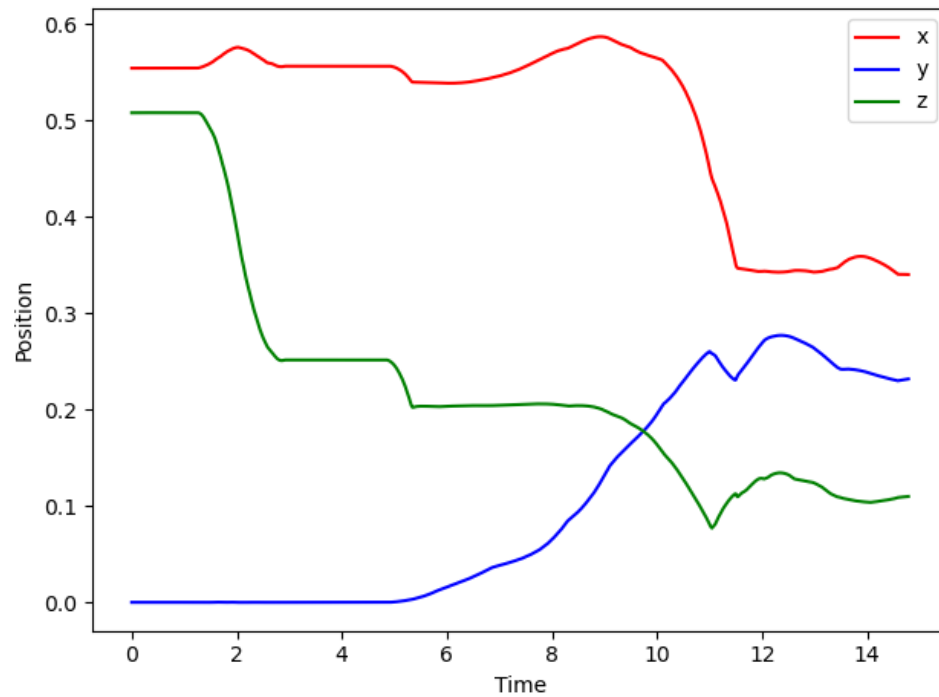
c) Ideal Robot feedforward plus feedback PI force graph of end effector Zoomed for Steady state value



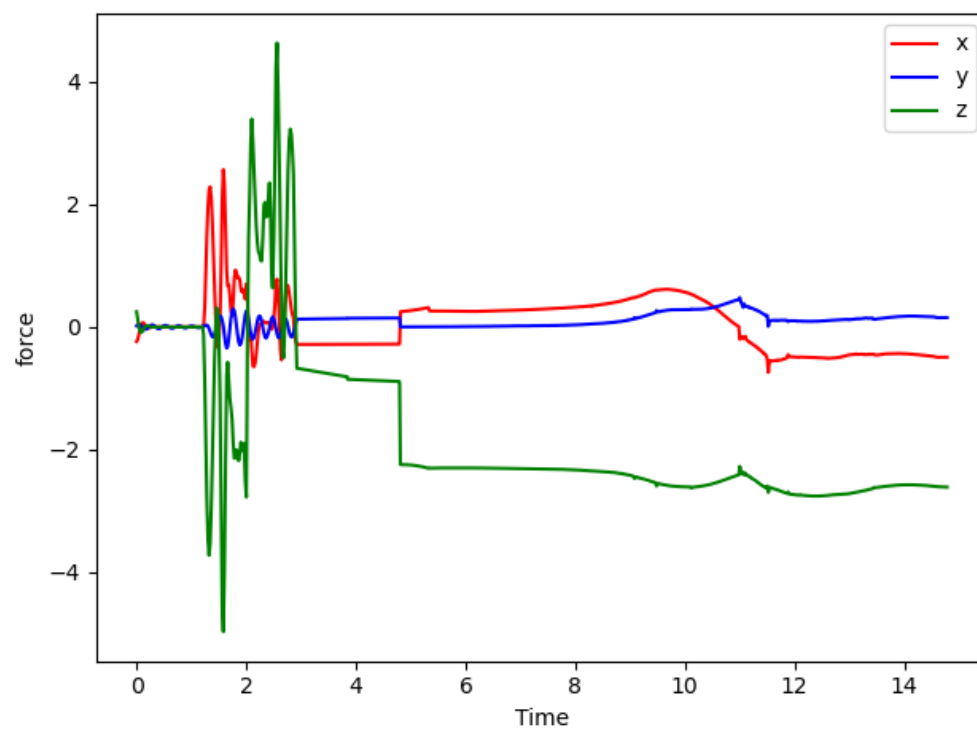
2.2 Real Robot

1) FeedForward controller

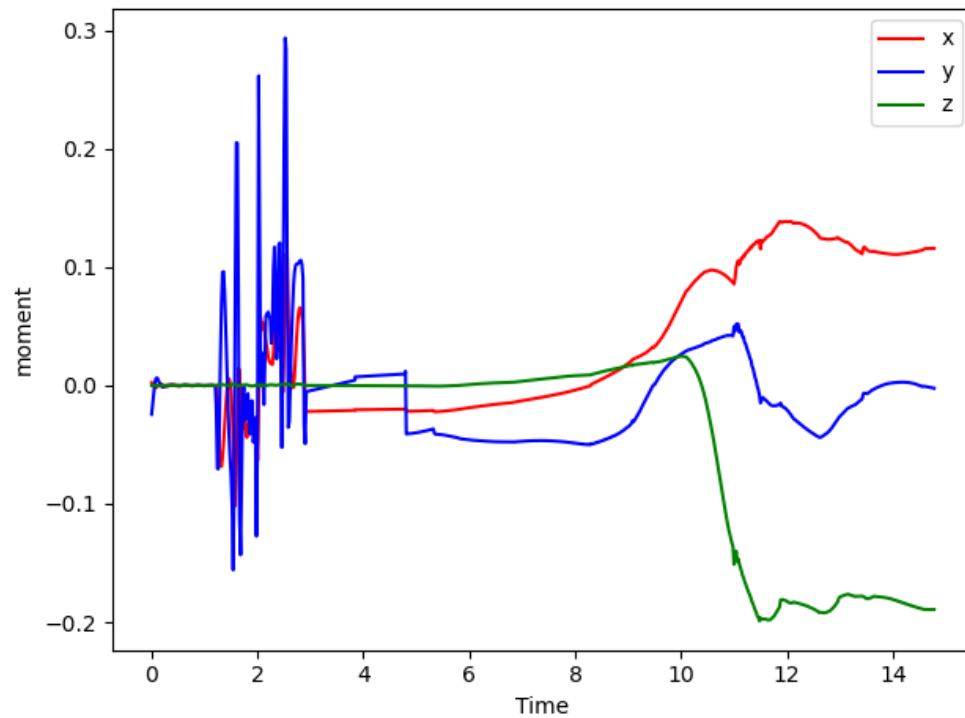
a) Real Robot with Feedforward controller position graph



b) Real Robot with Feedforward controller force graph of end effector

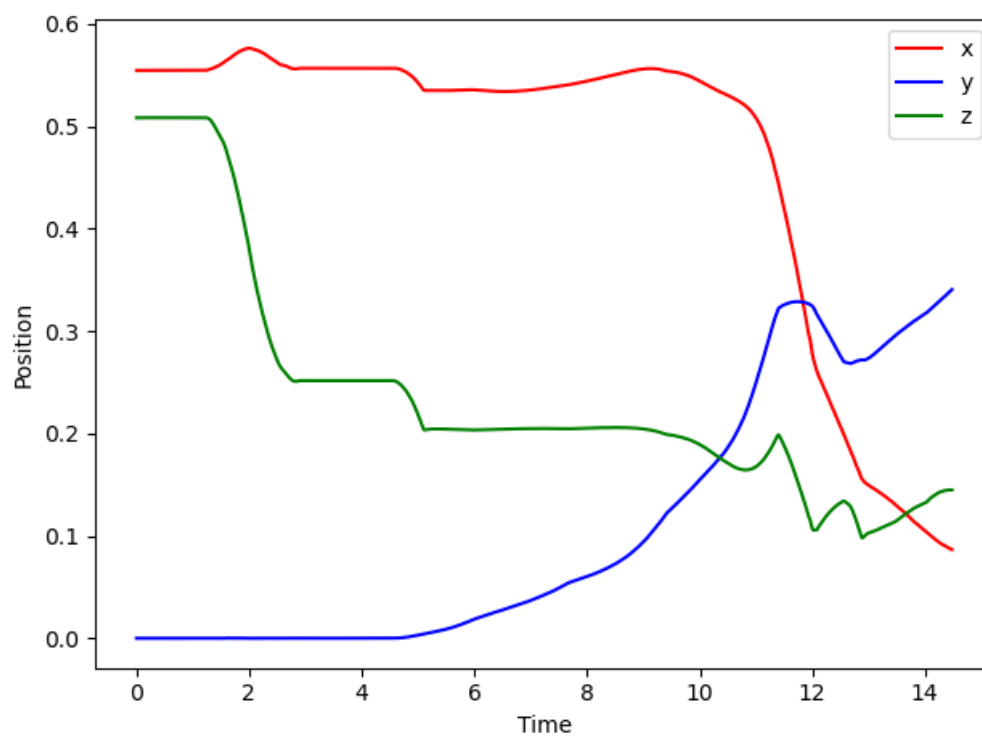


c) Real Robot with Feedforward controller force graph of end effector Zoomed for Steady state value

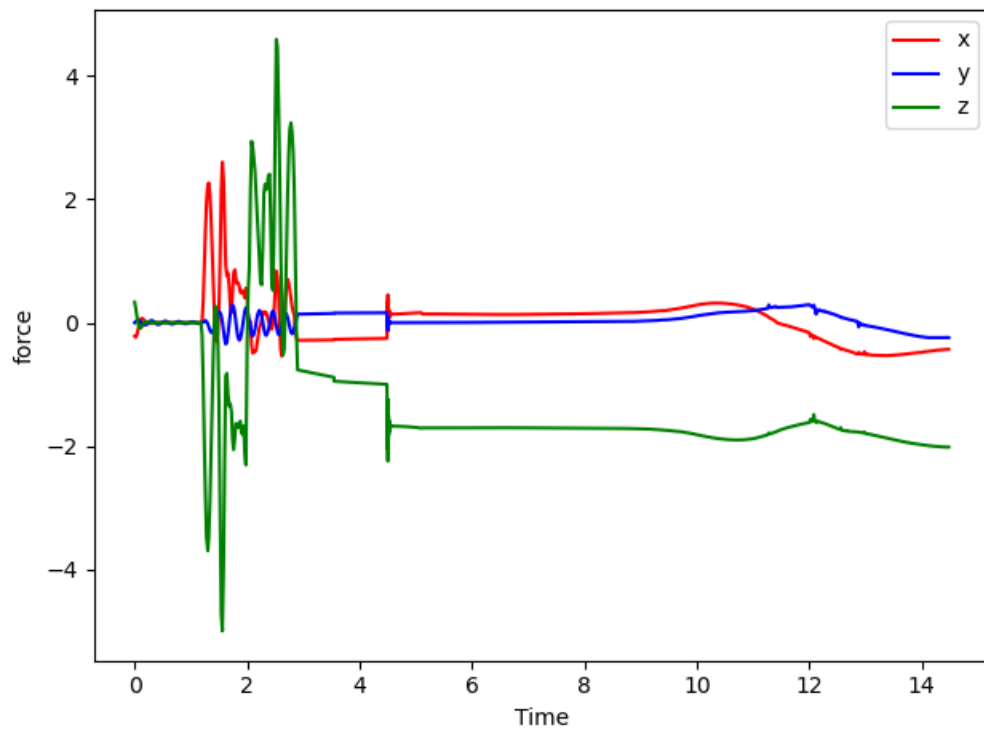


2) PI-controller

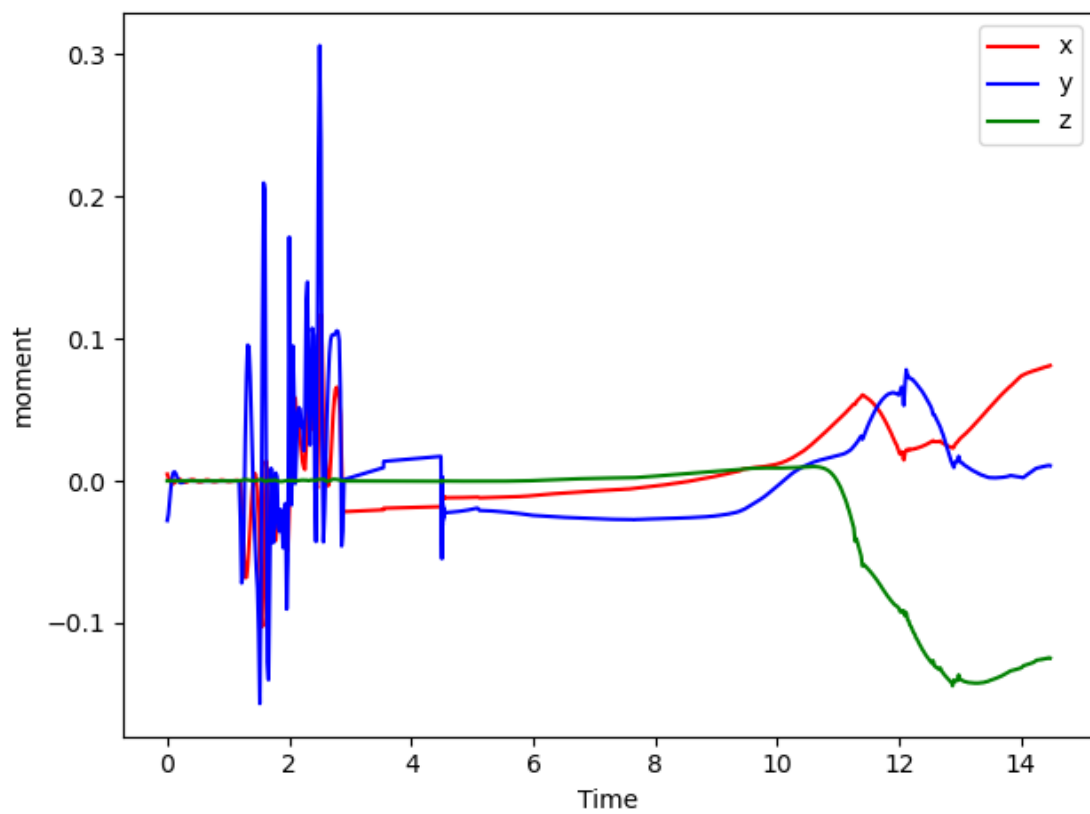
a) Real Robot with feedforward plus feedback PI controller position graph



b) Real Robot with feedforward plus feedback PI force graph of end effector



c) Real Robot feedforward plus feedback PI force graph of end effector Zoomed for Steady state value



3. discussion of the results

- 1) It takes about 4-5 seconds for the end effector to reach the required force
- 2) After 5 seconds, the robot will fall
- 3) Using the PI controller is better than just using the feedforward controller

4. answers to the following questions

-In which coordinate frame is the force/torque specified?

the force or torque is specified is in Robot's end effector frame

– Is your force controller stable such that the robot remains in single stable robot configuration for a long time? If not, what technique can be used to stabilise it?

Not stable. We should use a Hybrid controller controlling the force and the position of joints

– What is the benefit of the feedforward plus feedback-based controller compared to the feedforward only?

Adding feedback control can react quickly and suppress the disturbance when the system encounters disturbance, so the stability is better

– In which cases the integral term of feedback based controller is necessary?

The integral term is used to eliminate the steady-state error of the system. A simple proportional system will oscillate and change back and forth around a predetermined value because the system cannot eliminate redundant corrections. By adding a negative average error value, the average systematic error value will gradually decrease.

5. Estimate of time spent on this exercise

About 4 day. 35 hours.

Spent a lot of time in reading 《MODERN ROBOTICS MECHANICS, PLANNING, AND CONTROL》