Practice Final Exam – Simulation Results

ECEn 483/ ME 431

Winter 2023

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At the end of the exam, print this file and staple it to the handout portion of the exam.

To print to the digital lab Caedm printer, go to <https://webprint.et.byu.edu/> and then select EB423.

|  |  |
| --- | --- |
|  |  |
| Part I (25 pts) |  |
| Part II (25 pts) |  |
| Part III (25 pts) |  |
| Part IV (25 pts) |  |
| Total: (100 pts) |  |

# Part 1. Design models

1.2 Insert plot of the output of the simulation model with initial condition and input directly below this line.

Chart, calendar

Description automatically generated with medium confidence

# Part 2. PID Control

2.4 Insert a plot that shows both and when is a square wave with magnitude meters and frequency 0.05 Hz, and when using a PD controller.

Chart, line chart

Description automatically generated

2.5 Insert a plot that shows both and when is a square wave with maginitude meters and frequency 0.05 Hz, and when using a PID controller.

Chart, line chart, scatter chart

Description automatically generated

*\*\*\*If you set tr = 0.25 (and leave everything else the same) you get a bit better performance although some more tuning would need to be done to get rid of the wee bit of steady state error lingering*

Chart, line chart

Description automatically generated

2.6 Insert the Python code for ctrlPID.py that implements PID control directly below this line.

import numpy as np

import slopedMassParam as P

class ctrlPID:

    def \_\_init\_\_(self):

        tr = 0.5 #sec

        wn = 2.2/tr

        zeta = 2.0

        a1 = P.b/ (P.m)

        b0 = 1.0 / (P.m)

        a0 = P.k1 / (P.m)

        self.kd = (2.0\*zeta\*wn - a1) / b0 #these are general equations and should work for all PD systems

        self.kp = (wn\*\*2 - a0) / b0

        self.ki = 5.0 #Integrator gain that I tune

        print("kd: ", self.kd, " kp: ", self.kp, " ki: ", self.ki)

        #other needed parameters

        self.sigma = P.sigma #0.05 I believe

        self.Ts = P.Ts

        self.beta = (2.0 \* self.sigma - P.Ts) / (2.0 \* self.sigma + P.Ts) #dirty derivative gain

        self.limit = P.F\_max #his built in saturation function uses self.limit

        #variables and delayed variables for calculation

        self.zdot = 0.0

        self.integrator = 0.0

        self.error\_d1 = 0.0

        self.z\_d1 = 0.0 #delayed z

    def update(self, z\_r, z):

        z = z #[0][0]

        error = z\_r - z

        #integrate on error

        self.integrator = self.integrator + (P.Ts/2.0)\*(error + self.error\_d1)

        #compute derivative

        self.zdot = self.beta\*self.zdot + (1.0-self.beta) \* ((z - self.z\_d1) / P.Ts)

        F\_tilde = self.kp \* error - self.kd \* self.zdot + self.ki \* self.integrator

        z\_eq = 0.0

        F\_eq = P.k1 \* z\_eq + P.k2 \* z\_eq\*\*3 - P.m \* P.g \* np.sin(np.pi/4)

        F = self.saturate(F\_tilde+F\_eq)

        #integrator anti windup

        if self.ki != 0.0:

            self.integrator =  self.integrator + P.Ts/self.ki\*(F - (F\_tilde+F\_eq)) #?ie if it is saturating decrease the integrator

        #update delayed variables

        self.error\_d1 = error

        self.z\_d1 = z

        return F

    def saturate(self, u):

        if abs(u) > self.limit:

            u = self.limit\*np.sign(u)

        return u

    #this is the saturate function he gave us, I will use the one from the practice final

    # def saturate(u, limit):

    #     if abs(u) > limit:

    #         u = limit\*np.sign(u)

    #     return u

# Part 3. Observer based control

3.5. Insert a plot of the step response of the system for the complete observer based control.

Chart

Description automatically generated with low confidence

3.6 Insert a plot of the state estimation error.

A picture containing line chart

Description automatically generated

3.7 Insert a copy of ctrlObsv.py that implements the observer based controller directly below this line.

import numpy as np

import slopedMassParam as P

import control as cnt

class ctrlObsv:

    def \_\_init\_\_(self):

        tr = 0.5

        tr\_obs = tr/5.0 #this satisfies the 5x faster requirment

        zeta = 0.707

        wn = 2.2/tr

        wn\_obs = 2.2/tr\_obs

        integrator\_pole = -2.0 #make sure when I make the poly this is a positive value so it comes out negative in the left hand plane

        zeta\_obs = 0.707

        self.limit = P.F\_max

        #State Space Matrices

        self.A = np.array([[0.0, 1.0],

                      [-P.k1/(P.m), -P.b/(P.m)]])

        self.B = np.array([[0.0],

                      [1/(P.m)]])

        self.C = np.array([[1.0, 0.0]])

        self.D = np.array([[0.0]])

        #form augmented system

        A1 = np.vstack((np.hstack((self.A, np.zeros((np.size(self.A, 1),1)))),

                        np.hstack((-self.C, np.array([[0.0]]))) ))

        self.B1 = np.vstack((self.B, 0.0))

        #gain calculation

        des\_char\_poly = np.convolve([1, 2 \* zeta\*wn, wn\*\*2],

                                    [1, -integrator\_pole]) #!when is the integrator pole negative vs positive?

        des\_poles = np.roots(des\_char\_poly)

        # Compute the gains if the system is controllable

        if np.linalg.matrix\_rank(cnt.ctrb(A1, self.B1)) != 3:

            print("The system is not controllable")

        else:

            self.K1 = (cnt.place(A1, self.B1, des\_poles))

            self.K = self.K1[0][0:2]

            self.Ki = self.K1[0][2]

        print('K: ', self.K)

        print('ki: ', self.Ki)

        #print(des\_poles)

        #?3.3 for disturbance observer

        #do this

        #augmented matrices for observer design

        self.A2 = np.concatenate((

                            np.concatenate((self.A, self.B), axis=1),

                            np.zeros((1, 3))),

                            axis=0)

        self.B2 = np.concatenate((self.B, np.zeros((1, 1))), axis=0)

        self.C2 = np.concatenate((self.C, np.zeros((1, 1))), axis=1)

        #disturbance observer design

        dist\_obs\_pole = -20.0 #same as above, both negative or both positive

        wn\_obs = 2.2/tr\_obs

        des\_obs\_char\_poly = np.convolve([1, 2\*zeta\_obs\*wn\_obs, wn\_obs\*\*2],

                                        [1.0, -dist\_obs\_pole]) #! should this pole input be negative or positive?

        des\_obs\_poles = np.roots(des\_obs\_char\_poly)

        #compute the gains if the system is observable

        if np.linalg.matrix\_rank(cnt.ctrb(self.A2.T, self.C2.T)) != 3:

            print("The system is not observable")

        else:

            self.L2 = cnt.acker(self.A2.T, self.C2.T, des\_obs\_poles).T

        print('L2: ', self.L2)

        print("\n")

        print('A2: ', self.A2)

        print("\n")

        print('B1: ', self.B1)

        print("\n")

        print("C2: ", self.C2)

        #variables to stay behind

        self.zdot = 0.0 #estimated derivative of z

        self.z\_d1 = 0.0 #z delayed by one sample

        self.integrator = 0.0

        self.error\_d1 = 0.0

        self.x\_hat = np.array([[0.0], #z\_hat\_0

                               [0.0]]) #zdot\_hat\_0

        self.F\_d1 = 0.0

        self.obs\_state = np.array([

            [0.0], #z\_hat

            [0.0], #zdot\_hat

            [0.0], # estimate of the disturbance

        ])

    def update(self, z\_r, y):

        x\_hat, d\_hat = self.update\_observer(y)

        z\_hat = x\_hat[0][0]

        error = z\_r -z\_hat

        #integrate the error

        self.integrator = self.integrator + (P.Ts/2.0)\*(error + self.error\_d1)

        self.error\_d1 = error #update the error

        #copmute the state feedback controller

        z\_eq = 0.0 #do I use 0.0 or z\_hat?

        F\_eq = P.k1 \* z\_eq + P.k2 \* z\_eq\*\*3 - P.m \* P.g \* np.sin(np.pi/4)

        F\_tilde = -self.K @ x\_hat - self.Ki \* self.integrator - d\_hat

        F = self.saturate(F\_tilde.item(0)+F\_eq)

        # self.F\_d1 = F

        self.F\_d1 = F\_tilde #make sure down below in the observer that F\_d1 \*does not\* include F\_eq

        return F, x\_hat, d\_hat

    def update\_observer(self, y):

        # update the observer using RK4 integration

        F1 = self.observer\_f(self.obs\_state, y)

        F2 = self.observer\_f(self.obs\_state + P.Ts / 2 \* F1, y)

        F3 = self.observer\_f(self.obs\_state + P.Ts / 2 \* F2, y)

        F4 = self.observer\_f(self.obs\_state + P.Ts \* F3, y)

        self.obs\_state += P.Ts / 6 \* (F1 + 2 \* F2 + 2 \* F3 + F4)

        x\_hat = self.obs\_state[0:2]

        d\_hat = self.obs\_state[2][0]

        return x\_hat, d\_hat

    def observer\_f(self, x\_hat, y):

        #this is called in the update observer function for RK4

        # xhat = [z\_hat, zdot\_hat]

        # xhatdot = A\*(xhat-xe) + B\*(u-ue) + L(y-C\*xhat)

        #!is it always going to be B1 and A2 and C2 etc????

        xhat\_dot = self.A2 @ x\_hat\

                   + self.B1 \* (self.F\_d1)\

                   + self.L2 \* (y - self.C2 @ x\_hat)

        return xhat\_dot

    def saturate(self,u):

        if abs(u) > self.limit:

            u = self.limit\*np.sign(u)

        return u

#this is the saturate function he gave us, I am going to use the one from the practice final

# def saturate(u, limit):

#     if abs(u) > limit:

#         u = limit \* np.sign(u)

#     return u

# Part 4. Loopshaping

4.6 Insert the Bode plots for the PID controlled plant, and the loopshaped controlled plant below this line.

Chart, line chart

Description automatically generated

*This plot below I used to help tune etc…*

Chart, line chart

Description automatically generated

4.7 Insert simulation results for the loopshaping controller below this line.

Chart

Description automatically generated

4.8 Insert the file loopshapeRodMass.py for the controller below this line.

import slopedMassParam as P

import matplotlib.pyplot as plt

from control import TransferFunction as tf

from control import tf, bode, margin, step\_response, mag2db

import numpy as np

import loopshape\_tools as ls

from ctrlPID import ctrlPID

PID = ctrlPID()

# Compute plant transfer functions

Plant = tf([1.0/(P.m )], #numerator

           [1.0, P.b/(P.m), P.k1 / (P.m)]) #this comes from the plant, make sure each term has something, even if a 0.0

C\_pid = tf([(PID.kd+PID.kp\*PID.sigma),

            (PID.kp+PID.ki\*PID.sigma),

            PID.ki],

           [PID.sigma, 1, 0]) # this should be the same for every PID controller I believe

PLOT = True

dB\_flag = True

#######################################################################

#   Control Design

#######################################################################

C = C\_pid \* ls.lead(w=14.7769,M=125.0) \* ls.lag(z=12.0, M =120.0) \* ls.lpf(p=27.0)

#lead is for phase margin, lag is for disturbances/tracking, lpf is for noise

print('C(s)= ', C)

###########################################################

# add a prefilter to eliminate the overshoot

###########################################################

F = tf(1, 1) \* ls.lpf(p=3.0) #originally this was p=3.0 from the example I think?

print('F(s)= ', F)

##############################################

#  Convert Controller to State Space Equations if following method in 18.1.7

##############################################

C\_num = np.asarray(C.num[0])

C\_den = np.asarray(C.den[0])

F\_num = np.asarray(F.num[0])

F\_den = np.asarray(F.den[0])

if \_\_name\_\_ == "\_\_main\_\_":

    # calculate bode plot and gain and phase margin for just the plant dynamics

        #for the above see the quick code just below

    #### Code added to find gammaN and gammaR and to plot the noise and tracking specifications

    #for the controller

    # #Also quick code to plot just the plant

    mag, phase, omega = bode(Plant, dB=True,

                             omega=np.logspace(-3, 5),

                             Plot=True, label="$P(s)$")

    gm, pm, Wcg, Wcp = margin(Plant \* C\_pid)

    magCP, phaseCP, omegaCP = bode(Plant\*C\_pid, plot=False,

                            omega = [0.01, 1000.0], dB=dB\_flag) #TODO fill out these omega's for gammaN and gammaR

    mag4Plt, phase4Plt, omega4Plt = bode(Plant\*C\_pid, plot=False,

                            omega = [0.1, 1000.0], dB=dB\_flag) #TODO fill out these omegas for the tracking and noise specifications

    #Tracking and noise specifications

    ls.spec\_tracking(gamma=0.1\*1.0/mag4Plt[0], omega=0.1, flag=dB\_flag) #tracking specification, the 0.1 is a "factor of 10", omega is at where

    ls.spec\_noise(gamma=0.1\*mag4Plt[1], omega=1000.0, flag=dB\_flag)

    print("MagCP: ", magCP)

    print("for original C\_pid system:")

    #It will spit out absolute magnitude, so I will not need to convert

    print(" pm: ", pm, " Wcp: ", Wcp, "gm: ", gm, " Wcg: ", Wcg)

    print("gammaR = ", 1.0/magCP[0])

    print("gammaN = ", magCP[1])

    #A few additional print statements

    print("\n")

    print("C(s): ", C)

    print("\n")

    print("F(s): ", F)

    ##### End of my input stuff

    # calculate bode plot and gain and phase margin for original PID \* plant dynamics

    mag, phase, omega = bode(Plant \* C\_pid, dB=True,

                             omega=np.logspace(-3, 5),

                             Plot=True, label="$P(s)C\_{pid}(s)$")

    gm, pm, Wcg, Wcp = margin(Plant \* C\_pid)

    print("for original C\_pid system:")

    if dB\_flag is True:

        print(" pm: ", pm, " Wcp: ", Wcp, "gm: ", mag2db(gm), " Wcg: ", Wcg)

    elif dB\_flag is False:

        print(" pm: ", pm, " Wcp: ", Wcp, "gm: ", gm, " Wcg: ", Wcg)

    #########################################

    #   Define Design Specifications

    #########################################

    # specs go here

    # ls.spec\_...

    # plot the effect of adding the new compensator terms

    mag, phase, omega = bode(Plant \* C, dB=dB\_flag,

                             omega=np.logspace(-4, 5),

                             Plot=True, label="$P(s)C\_{final}(s)$")

    gm, pm, Wcg, Wcp = margin(Plant \* C)

    print("for final P\*C:")

    if dB\_flag is True:

        print(" pm: ", pm, " Wcp: ", Wcp, "gm: ", mag2db(gm), " Wcg: ", Wcg)

    elif dB\_flag is False:

        print(" pm: ", pm, " Wcp: ", Wcp, "gm: ", gm, " Wcg: ", Wcg)

    plt.figure(1)

    fig = plt.gcf()

    fig.axes[0].legend()

    ############################################

    # now check the closed-loop response with prefilter

    ############################################

    # Closed loop transfer function from R to Y - no prefilter

    CLOSED\_R\_to\_Y = (Plant \* C / (1.0 + Plant \* C))

    # Closed loop transfer function from R to Y - with prefilter

    CLOSED\_R\_to\_Y\_with\_F = (F \* Plant \* C / (1.0 + Plant \* C))

    # Closed loop transfer function from R to U - no prefilter

    CLOSED\_R\_to\_U = (C / (1.0 + Plant \* C))

    # Closed loop transfer function from R to U - with prefilter

    CLOSED\_R\_to\_U\_with\_F = (F \* C / (1.0 + Plant \* C))

    fig = plt.figure(2)

    plt.clf()

    plt.grid(True)

    mag, phase, omega = bode(CLOSED\_R\_to\_Y, dB=dB\_flag, Plot=True,

                             color=[0, 0, 1], label='closed-loop $\\frac{Y}{R}$ - no pre-filter')

    mag, phase, omega = bode(CLOSED\_R\_to\_Y\_with\_F, dB=dB\_flag, Plot=True,

                             color=[0, 1, 0], label='closed-loop $\\frac{Y}{R}$ - with pre-filter')

    fig.axes[0].set\_title('Closed-Loop Bode Plot')

    fig.axes[0].legend()

    plt.figure(4)

    plt.clf()

    plt.subplot(211), plt.grid(True)

    T = np.linspace(0, 2, 100)

    \_, yout\_no\_F = step\_response(CLOSED\_R\_to\_Y, T)

    \_, yout\_F = step\_response(CLOSED\_R\_to\_Y\_with\_F, T)

    plt.plot(T, yout\_no\_F, 'b', label='response without prefilter')

    plt.plot(T, yout\_F, 'g', label='response with prefilter')

    plt.legend()

    plt.ylabel('Step Response')

    plt.subplot(212), plt.grid(True)

    \_, Uout\_no\_F = step\_response(CLOSED\_R\_to\_U, T)

    \_, Uout\_F = step\_response(CLOSED\_R\_to\_U\_with\_F, T)

    plt.plot(T, Uout\_no\_F, color='b', label='control effort without prefilter')

    plt.plot(T, Uout\_F, color='g', label='control effort with prefilter')

    plt.ylabel('Control Effort')

    plt.legend()

    plt.show()