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SOLUTIONS MANUAL

to accompany

DIGITAL CONTROL OF DYNAMIC SYSTEMS

Third Edition

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Solutions Manual to accompany Fraklin/Powell's DIGITAL CONTROL OF DYNAMIC SYSTEMS, Third Edition

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SOLUTIONS TO CHAPTER 1 PROBLEMS

1.1 Suppose a radar search antenna at the San Francisco airport rotates at 6 rev/min, and data points corresponding to the position of flight 1081 are plotted on the controller's screen once per antenna revolution. Flight 1081 is traveling directly toward the airport at 540 mi/hr. A feedback control system is established through the controller who gives course corrections to the pilot. He wishes to do so each 9 mi of travel of the aircraft, and his instructions consist of course headings in integral degree values.

(a) What is the sampling rate, in seconds, of the range signal plotted on the radar screen?

(b) What is the sampling rate, in seconds, of the controller's instructions?

(c) Identify the following signals as continuous, discrete, or digital:

i. the aircraft's range from the airport,

ii. the range data as plotted on the radar screen,

iii. the controller's instructions to the pilot,

iv. the pilot's actions on the aircraft control surfaces.

(d) Is this a continuous, sampled-data, or digital control system?

(e) Show that it is possible for the pilot of flight 1081 to fly a zigzag course which would show up as a straight line on the controller's screen. What is the (lowest) frequency of a sinusoidal zigzag course which will be hidden from the controller's radar?

Solution:

(1.1) a) Range sampling $= \frac{1\text{ rev.}}{1\text{ sample}} \cdot \frac{1\text{ min}}{6\text{ rev.}} \cdot \frac{60\text{ sec}}{1\text{ min.}} = \frac{10\text{ sec.}}{\text{sample}} = 0.1$ Hz

b) Instruction sampling $= \frac{9\text{ mi.}}{1\text{ sample}} \cdot \frac{1\text{ hr.}}{540\text{ mi.}} \cdot \frac{60\text{ min.}}{1\text{ hr}} \cdot \frac{60\text{ sec}}{1\text{ min.}} = \frac{60\text{ sec}}{\text{sample}}$

$= 0.0167$ Hz

c) i) Range is continuous.

ii) Display of range is discrete.

iii) Instructions are digital.

iv) Pilot's actions are continuous.

d) This is a sampled-data control system.

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3.8 The read arm on a computer disk drive has the transfer function

$$G(s) = \frac{500}{s^2}.$$

Design a continuous lead compensation so that the closed-loop system has a bandwidth of 100 Hz and a phase margin of 50°. Modify the MATLAB file fig32.m so that you can evaluate the digital version of your lead compensation using Euler's forward retangular method. Try different sample rates, and find the slowest one where the overshoot does not exceed 30%.

Solution:

Easiest is to design a single lead with 10:1 lead ratio ($b/a = 10$) for $\sim 50°$ PM where $D(s) = K\frac{s+a}{s+b}$. For $\omega_{BW} = 100\ Hz = 630\ r/sec$, pick crossover freq $\simeq 400\ r/sec$, so

$$a = \frac{400}{\sqrt{10}} \simeq 125$$

$$b = 400 * \sqrt{10} \simeq 1250$$

then iterate on K until max phase @ ω_{co} — find that $K = 1000$. ($PM = 54.9°$).

To modify Fig32.m, ① need to change plant from $\frac{1}{s(s+1)}$ to $\frac{500}{s^2}$ $\Rightarrow$ denG = [1 0 0], numG = 500

② need to change D(s) to $= 1000\ \frac{s+125}{s+1250}$

i.e., $K_0 = 1000$, $a = 125$, $b = 1250$

③ need to change t_f (final time) to $\sim 0.01 sec$ since this rise time is approx 0.04 sec, and step size to ~ 0.0001

④ change "axis" to consistent size

⑤ try different sample rates.

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4.27

```
[a b c d]=tf2ss(npd,dpd)
```

$$a = \begin{bmatrix} 2.9048 & -2.8097 & 0.9048 \\ 1.0000 & 0 & 0 \\ 0 & 1.0000 & 0 \end{bmatrix}$$

$$b = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$c = 1.0e\text{-}003 * \begin{bmatrix} 0.4854 & -0.0095 & -0.4663 \end{bmatrix}$$

$$d = 0$$

4.28

$$\frac{G(s)}{s} = \frac{10(s+1)}{s(s^2+s+10)} = \frac{1}{s} - \frac{s+\frac{1}{2}}{(s+\frac{1}{2})^2+9.75} + \frac{9.5}{3.1225} \cdot \frac{3.1225}{(s+\frac{1}{2})^2+(3.1225)^2}$$

These can be looked up in the Tables.

The result is:

$$G(z) = \frac{0.1z - 0.099}{z^2 - 1.9891z + 0.99}$$

Using MATLAB:

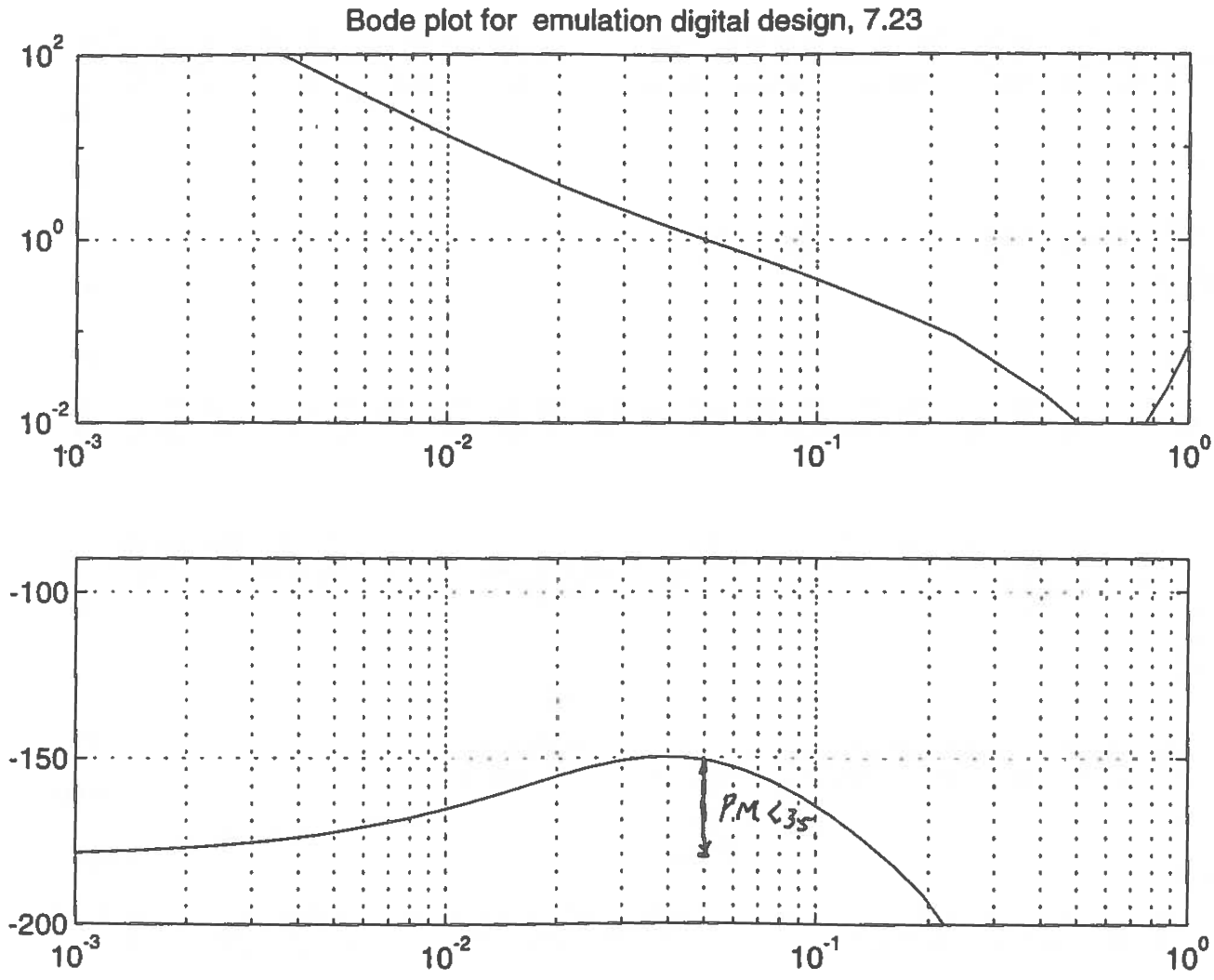
```
np = [0   10   10]
dp = [1    1   10]
[npd,dpd]=c2dm(np,dp,.01)

npd = [0   0.1000   -0.0990]
dpd = [1.0000   -1.9891   0.9900]
polyval(npd,1)/polyval(dpd,1)

ans =  1   = d.c. gain
```


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```
%  Prob 9.10,

clear
clf
f=[0 1 0 0;
-.91 -.036 .91 .036
0 0 0 1
.091 .0036 -.091 -.0036];
g=[0;0;0;1];
h=[1 0 0 0];
j=0;
T=.4;
sysC=ss(f,g,h,j);
sysD=c2d(sysC,T);
[phi,gam,h,j]=ssdata(sysD);

r=1;
Hw=[1 0 0 0];
  Qbar=20;
  Q=Hw'*Qbar*Hw;
  [k,s,ev]=dlqr(phi,gam,Q,r);
subplot(2,2,1)
  plot(real(ev(1)),imag(ev(1)),'*')
  axis([-1 1 -1 1])
  axis('square')
  hold on
plot(real(ev(2)),imag(ev(2)),'*')
plot(real(ev(3)),imag(ev(3)),'*')
plot(real(ev(4)),imag(ev(4)),'*')
zgrid
pzmap(phi,gam,h,j)
title('controller roots for Problem 9.10')
hold off

% do controller w/o estimator first
[Nx,Nu,Nbar] = refi(phi,gam,h,k);
phiCL=phi-gam*k;
gamCL=gam*Nbar;
sysCL=ss(phiCL,gamCL,h,j,T);
%subplot(2,1,2)
%step(sysCL)
%axis([0 8 0 1.2])

% now add estimator

sysDe=ss(phi,[gam gam],h,j,T);
[Kest,L]=kalman(sysDe,10000,1);
[a,b,c,d]=ssdata(Kest);
ev=eig(a);
subplot(2,2,2)
  plot(real(ev(1)),imag(ev(1)),'*')
  axis([-1 1 -1 1])
  axis('square')
  hold on
plot(real(ev(2)),imag(ev(2)),'*')
plot(real(ev(3)),imag(ev(3)),'*')
plot(real(ev(4)),imag(ev(4)),'*')
zgrid
title('estimator roots for Problem 9.10')
hold off

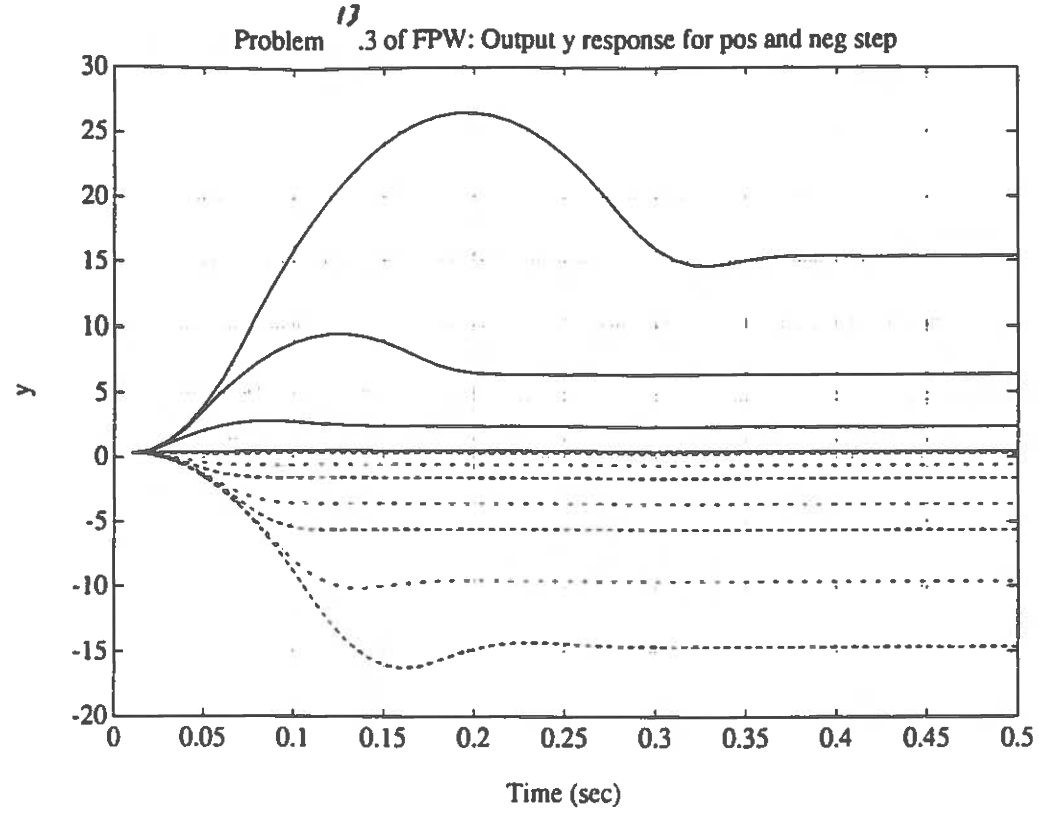
A=[phi -gam*k;L*h phi-gam*k-L*h];
B=[gam*Nbar;gam*Nbar];
C=[h 0 0 0 0];
sysCL=ss(A,B,C,j,T);
subplot(2,1,2)
step(sysCL)
axis([0 8 0 1.2])
```

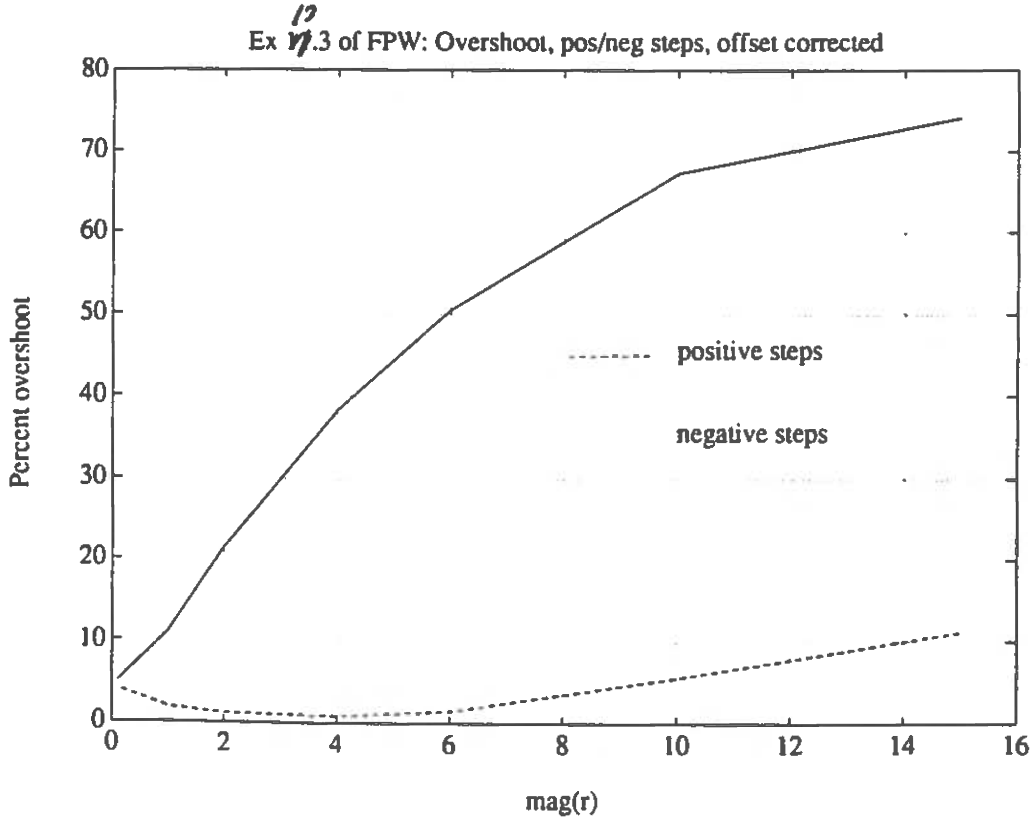

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cont'd

13.3





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