

Scilab Textbook Companion for  
Digital Control  
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# Book Description

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Scilab numbering policy used in this document and the relation to the above book.

**Exa** Example (Solved example)

**Eqn** Equation (Particular equation of the above book)

**AP** Appendix to Example(Scilab Code that is an Appednix to a particular Example of the above book)

For example, Exa 3.51 means solved example 3.51 of this book. Sec 2.3 means a scilab code whose theory is explained in Section 2.3 of the book.

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## Chapter 2

# Modelling of Sampled Data Systems

Scilab code Exa 2.1 Model of inverted pendulum

```
1 // Model of inverted pendulum
2 // 2.1
3
4 Km = 0.00767;
5 Kg = 3.7;
6 Rm = 2.6;
7 r = 0.00635;
8 M = 0.522;
9 m = 0.231;
10 g = 9.81;
11 L = 0.305;
12 J = 0;
13
14 D1 = (J+m*L^2)*(M+m)-m^2*L^2;
15 alpha = m*g*L*(M+m)/D1;
16 beta1 = m*L/D1;
17 gamma1 = m^2*g*L^2/D1;
18 delta = (J+m*L^2)/D1;
19
```

```

20 alpha1 = Km*Kg/Rm/r;
21 alpha2 = Km^2*Kg^2/Rm/r^2;
22
23 A = zeros(4,4);
24 A(1,3) = 1;
25 A(2,4) = 1;
26 A(3,2) = -gamma1;
27 A(3,3) = -alpha2*delta;
28 A(4,2) = alpha;
29 A(4,3) = alpha2*beta1;
30
31 B = zeros(4,1);
32 B(3) = alpha1*delta;
33 B(4) = -alpha1*beta1;

```

---

#### Scilab code Exa 2.2 Exponential of the matrix

```

1 // Exponential of the matrix
2 // 2.2
3
4 F = [-1 0;1 0];
5 expm(F)

```

---

#### Scilab code Exa 2.3 ZOH equivalent state space system

```

1 // ZOH equivalent state space system
2 // 2.3
3
4 F = [-1 0;1 0]; G = [1; 0];
5 C = [0 1]; D = 0; Ts=1;
6 sys = syslin('c',F,G,C,D);
7 sysd = dscri(sys,Ts)

```

---

# Chapter 3

## Linear Systems

Scilab code Exa 3.1 Energy of a signal

```
1 // Energy of a signal
2 // 3.1
3
4 u = [4 5 6];
5 Eu = norm(u)^2;
6 ruu = xcorr(u);
7 Lu = length(ruu);
8 Eu = ruu(ceil(Lu/2));
```

---

Scilab code Exa 3.2 Convolution of two sequences

```
1 // Convolution of two sequences
2 // 3.2
3
4 h = [1 2 3];
5 u = [4 5 6];
6 y = convol(u,h)
```

---

# Chapter 4

## Z Transform

Scilab code Exa 4.1 To produce a sequence

```
1 // To produce  $a^n 1(n)$ 
2 // 4.1
3
4 exec('stem.sci',-1);
5 exec('label.sci',-1);
6
7 a = 0.9;
8 n = -10:20;
9 y = zeros(1,size(n,'*'));
10 for i = 1:length(n)
11     if n(i)>=0,
12         y(i) = a^n(i);
13     end
14 end
15 stem(n,y)
16 label('u1',4,'Time(n)', '0.9^n1(n)',4)
```

---

Scilab code Exa 4.2 To produce a sequence

```

1 // Plot of  $-0.9^{n1(-n-1)}$ 
2 // 4.2
3
4 exec('stem.sci',-1);
5 exec('label.sci',-1);
6
7 a = 0.9;
8 n = -10:20;
9 y = zeros(1,size(n,'*'));
10 for i = 1:length(n)
11     if n(i) <= -1,
12         y(i) = -(a^n(i));
13     else y(i) = 0;
14     end
15 end
16 stem(n,y)
17 label('u2',4,'Time(n)', '-0.9^n1(-n-1)',4)

```

---

**Scilab code Exa 4.3** To produce pole zero plots

```

1 // To produce pole-zero plots
2 // 4.3
3
4 exec('label.sci',-1);
5
6 zero = [0 5/12];
7 num = poly(zero,'z','roots');
8 pole = [1/2 1/3];
9 den = poly(pole,'z','roots');
10 h = syslin('d',num./den);
11 plzr(h);
12
13 label('Pole-Zero Plot',4,'Real(z)', 'Imaginary(z)',4)
    ;

```

---



**Scilab code Exa 4.4** Discrete transfer function of the continuous state space system

```
1 // Discrete transfer function of the continuous
   state space system
2 // 4.4
3
4 F = [0 0; 1 -0.1]; G = [0.1; 0];
5 C = [0 1]; dt = 0.2;
6 sys = syslin('c',F,G,C);
7 sysd = dscr(sys,dt);
8 H = ss2tf(sysd);
```

---

**Scilab code Exa 4.5** Computation of residues

```
1 // Computation of residues
2 // 4.5
3 // Numerator and denominator coefficients
4 // are passed in decreasing powers of z(say)
5
6 function [res,pol,q] = respol(num,den)
7 len = length(num);
8 if num(len) == 0
9     num = num(1:len-1);
10 end
11
12 [resi,q] = pfe(num,den);
13 res = resi(:,2);
14 res = int(res) + (clean(res - int(res),1.d-04));
15 pol = resi(:,1);
16 pol = int(pol) + (clean(pol - int(pol),1.d-04));
17 endfunction;
```

```

18
19 ///////////////////////////////////////////////////////////////////
20 // Partial fraction expansion
21
22 function [resid1,q] = pfe(num,den)
23 x = poly(0,'x');
24 s = %s;
25
26 num2 = flip(num);
27 den2 = flip(den);
28 num = poly(num2,'s','coeff');
29 den = poly(den2,'s','coeff');
30 [fac,g] = factors(den);
31 polf = polfact(den);
32 n = 1;
33
34 r = clean(real(roots(den)),1.d-5);
35 //disp(r);
36 l = length(r);
37 r = gsort(r,'g','i');
38 r = [r; 0];
39 j = 1;
40 t1 = 1; q = [];
41 rr = 0;
42 rr1 = [0 0];
43 m = 1;
44
45 for i = j:l
46     if abs(r(i)- r(i+1)) < 0.01 then
47         r(i);
48         r(i+1);
49         n = n+1;
50         m = n;
51         //pause
52         t1 = i;
53         //disp('Repeated roots ')
54     else
55         m = n;

```

```

56         //pause
57         n = 1;
58     end
59     i;
60     if n == 1 then
61         rr1 = [rr1; r(i) m];
62         //pause
63     end;
64     j = t1 + 1;
65 end;
66 rr2 = rr1(2:$,:);
67 [r1,c1] = size(rr2);
68 den1 = 1;
69
70 for i = 1:r1
71     den1 = den1 * ((s-rr2(i,1))^(rr2(i,2)));
72 end;
73 [rem,quo] = pdiv(num,den);
74 q = quo;
75 if quo ~= 0
76     num = rem;
77 end
78
79 tf = num/den1;
80 res1 = 0;
81 res3 = [s 0];
82 res5 = [0 0];
83 for i = 1:r1
84     j = rr2(i,2) + 1;
85     tf1 = tf; //strictly proper
86     k = rr2(i,2);
87     tf2 = ((s-rr2(i,1))^k)*tf1;
88     rr2(i,1);
89     res1 = horner(tf2,rr2(i,1));
90     res2 = [(s - rr2(i,1))^(rr2(i,2)) res1];
91     res4 = [rr2(i,1) res1];
92     res3 = [res3; res2];
93     res5 = [res5; res4];

```

```

94   res = res1;
95   for m = 2:j-1
96       k;
97       rr2(i,1);
98       tf1 = derivat(tf2)/factorial(m-1); //ith
           derivative
99       res = horner(tf1,rr2(i,1));
100      res2 = [(s - rr2(i,1))^(j-m) res];
101      res4 = [rr2(i,1) res];
102      res5 = [res5; res4];
103      res3 = [res3; res2];
104      tf2 = tf1;
105   end;
106 end;
107 resid = res3(2:$,:); //with s terms
108 resid1 = res5(2:$,:); //only poles(in decreasing no.
           of repetitions)
109 endfunction;
110 //
           //////////////////////////////////////

```

---

#### Scilab code Exa 4.6 Partial fraction expansion

```

1 // Partial fraction expansion for Example 4.24
2 // 4.6
3
4 //
5 // G(z) =  $\frac{2z^2 + 2z}{z^2 + 2z - 3}$ 
6 //
7
8 exec('respol.sci',-1);
9 exec('flip.sci',-1);
10
11 num = [2 2 0];

```

```

12 den = [1 2 -3];
13 [res,pol] = respol(num,den) //respol is a user
    defined function

```

---

#### Scilab code Exa 4.7 Partial fraction expansion

```

1 // Partial fraction expansion for Example 4.26
2 // 4.7
3
4 //
5 // 
$$G(z) = \frac{z^2 + z}{(z-1)^3} = \frac{A}{(z-1)} + \frac{B}{(z-1)^2} + \frac{C}{(z-1)^3}$$

6 //
7
8 exec('respol.sci',-1);
9 exec('flip.sci',-1);
10
11 num = [1 1 0];
12 den = convol([1 -1],convol([1 -1],[1 -1])); // poly
    multiplication
13 [res,pol] = respol(num,den)
14
15 // Output interpretation
16 // res =
17 //C = 2
18 //B = 1
19 //A = 0
20
21 // pol =
22 // 1 (z - 1)^3
23 // 1 (z - 1)^2
24 // 1 (z - 1)

```

---

#### Scilab code Exa 4.8 Partial fraction expansion

```
1 // Partial fraction expansion for Example 4.27
2 // 4.8
3
4 //          11z^2 - 15z + 6      A1      A2
5 //          B
6 // G(z) = ----- = ----- + ----- +
7 //          (z - 2) (z - 1)^2   (z - 1)  (z - 1)^2
8 exec('respol.sci',-1);
9 exec('flip.sci',-1);
10
11 num = [11 -15 6];
12 den = convol([1 -2],convol([1 -1],[1 -1]));
13 [res,pol] = respol(num,den) //User defined function
```

---

#### Scilab code Exa 4.9 Partial fraction expansion

```
1 // Partial fraction expansion for Example 4.29
2 // 4.9
3
4 //          z^2 + 2z
5 // G(z) = -----
6 //          (z + 1)^2 (z - 2)
7
8 exec('respol.sci',-1);
9 exec('flip.sci',-1);
10
11 num = [1 2 0];
```

```

12 den = convol(convol([1 1],[1 1]),[1 -2]);
13 [res,pol] = respol(num,den)

```

---

#### Scilab code Exa 4.10 Partial fraction expansion

```

1 // Partial fraction expansion for Example 4.30
2 // 4.10
3
4 //
5 // 
$$G(z) = \frac{3 - (5/6)z^{-1}}{3z^2 - (5/6)z} =$$

6 // 
$$\frac{(1 - (1/4)z^{-1})(1 - (1/3)z^{-1})}{(1/4)(z - (1/3))} \quad (z -$$

7
8 // No equivalent of residuez
9
10 exec('respol.sci',-1);
11 exec('flip.sci',-1);
12
13 num = [3 -5/6 0];
14 den = convol([1 -1/4],[1 -1/3]);
15 [res,pol,q] = respol(num,den)

```

---

#### Scilab code Exa 4.11 Long division of problems

```

1 // Long division of problems discussed in Example
2 // 4.32 on page 102
3
4 exec('tf.sci',-1);
5 exec('label.sci',-1);
6

```

```
7 num = [11 -15 6];
8 den = convol([1 -2], convol([1 -1],[1 -1]));
9 u = [1 zeros(1,4)];
10 y = filter(num,den,u);
11 G = tf(num,den,-1);
12 u1=zeros(1,90); u1(1)=1;
13 x1=dsimul(tf2ss(G),u1);
14 plot2d(x1)
15 label('Impulse Response',4,'Time(seconds)', '
    Amplitude',4)
```

---



# Chapter 5

## Frequency Domain Analysis

Scilab code Exa 5.1 Sinusoidal plots for increasing frequency

```
1 // Sinusoidal plots for increasing frequency
2 // 5.1
3
4 exec('stem.sci',-1);
5
6 n=0:16;
7 subplot(2,2,1), stem(n,cos(n*pi/8))
8 xgrid,xtitle('', 'n', 'cos(n*pi/8)')
9 subplot(2,2,2), stem(n,cos(n*pi/4))
10 xgrid,xtitle('', 'n', 'cos(n*pi/4)')
11 subplot(2,2,3), stem(n,cos(n*pi/2))
12 xgrid,xtitle('', 'n', 'cos(n*pi/2)')
13 subplot(2,2,4), stem(n,cos(n*pi))
14 xgrid,xtitle('', 'n', 'cos(n*pi)')
```

---

Scilab code Exa 5.2 Bode plots

```
1 // Bode plots for Example 5.7 on page 141
```

```

2 // 5.2
3
4 exec('label.sci',-1);
5
6 omega = linspace(0,%pi);
7 g1 = 0.5 ./ (cos(omega)-0.5+%i*sin(omega));
8 mag1 = abs(g1);
9 angle1 = phasemag(g1);
10 g2 = (0.5+0.5*cos(omega)-1.5*%i*sin(omega)) ...
11     * 0.25 ./ (1.25-cos(omega));
12 mag2 = abs(g2);
13 angle2 = phasemag(g2);
14 subplot(2,1,1)
15 plot(omega,mag1,omega,mag2,'—');
16 label('',4,'','Magnitude',4);
17 subplot(2,1,2);
18 plot(omega,angle1,omega,angle2,'—');
19 label('',4,'w (rad/s)','Phase',4);

```

---

### Scilab code Exa 5.3 Bode plot of the moving average filter

```

1 // Bode plot of the moving average filter , discussed
   in Example 5.5 on page 129
2 // 5.3
3
4 exec('label.sci',-1);
5
6 w = 0.01:0.01:%pi;
7 subplot(2,1,1);
8 mag = abs(1+2*cos(w))/3;
9 plot2d("ll",w,mag,2);
10 label('',4,'','Magnitude',4);
11 subplot(2,1,2);
12 plot2d("ln",w,phasemag(1+2*cos(w)),style = 2,rect
   =[0.01 -0.5 10 200]);

```

```
13 label(' ',4,'w','Phase',4)
```

---

**Scilab code Exa 5.4** Bode plot of the differencing filter

```
1 // Bode plot of the differencing filter , discussed
  in Example 5.6 on page 130
2 // 5.4
3
4 exec('label.sci',-1);
5
6 w = 0.01:0.01:%pi;
7 G = 1-exp(-%i*w);
8 subplot(2,1,1)
9 plot2d1("gll",w,abs(G),style = 2);
10 label(' ',4,' ','Magnitude',4);
11 subplot(2,1,2)
12 plot2d1("gln",w,phasemag(G),style = 2);
13 label(' ',4,'w','Phase',4)
```

---

**Scilab code Exa 5.5** Bode plot of minimum and nonminimum phase filters

```
1 // Bode plot of minimum and nonminimum phase filters
  , discussed in Example 5.9 on page 145
2 // 5.5
3
4 exec('label.sci',-1);
5
6 omega = linspace(0,%pi);
7 ejw = exp(-%i*omega);
8 G1 = 1.5*(1-0.4*ejw);
9 mag1 = abs(G1); angle1 = phasemag(G1);
10 G2 = -0.6*(1-2.5*ejw);
11 mag2 = abs(G2); angle2 = phasemag(G2);
```

```
12 subplot(2,1,1);
13 plot(omega,mag1,omega,mag2,'--');
14 label(' ',4,' ', 'Magnitude',4);
15 subplot(2,1,2);
16 plot(omega,angle1,omega,angle2,'--');
17 label(' ',4,'w (rad/s)', 'Phase',4);
```

---

# Chapter 6

## Identification

Scilab code Exa 6.1 Least squares solution

```
1 // Least squares solution of the simple problem
   discussed in Example 6.4 on page 164
2 // 6.1
3
4 Mag = 10; V = 10; No_pts = 100; theta = 2;
5 Phi = Mag * (1-2*rand(No_pts,1));
6 E = V * (1-2*rand(No_pts,1));
7 Z = Phi*theta + E;
8 LS = Phi \ Z
9 Max = max(Z ./ Phi), Min = min(Z ./ Phi)
```

---

Scilab code Exa 6.2 ACF calculation

```
1 // ACF calculation for the problem discussed in
   Example 6.5 on page 167
2 // 6.2
3
4 u = [1 2];
```

```
5 r = xcov(u);
6 rho = xcov(u,"coeff");
```

---

**Scilab code Exa 6.3** To demonstrate the periodicity property of ACF

```
1 // To demonstrate the periodicity property of ACF as
  // discussed in Example 6.7 on page 173
2 // 6.3
3
4 exec('plotacf.sci',-1);
5 exec('label.sci',-1);
6
7 L = 500;
8 n = 1:L;
9 w = 0.1;
10 S = sin(w*n);
11 m = 1;
12 xi = m*rand(L,1,'normal');
13 Spxi = S+xi';
14 xset('window',0);
15 plot(Spxi);
16 label('',4,'n','y',4)
17 xset('window',1);
18 plotacf(Spxi,1,L,1);
```

---

**Scilab code Exa 6.4** To demonstrate the maximum property of ACF at zero lag

```
1 // To demonstrate the maximum property of ACF at
  // zero lag, as discussed in Example 6.8 on page
  // 175.
2 // 6.4
3
```

```

4  exec('label.sci',-1);
5
6  S1 = [1 2 3 4];
7  S2 = [1,-2,3,-4];
8  S3 = [-1,-2,3,4];
9  len = length(S1)-1;
10 xv = -len:len;
11 m = 1;
12 xi = rand(4,1,'normal');
13 Spxi1 = S1 + m*xi';
14 Spxi2 = S2 + m*xi';
15 Spxi3 = S3 + m*xi';
16 n = 1:length(S1);
17 plot(n,Spxi1,'o-',n,Spxi2,'x—',n,Spxi3,'*');
18 label('',4,'n','y',4);
19 ACF1 = xcov(Spxi1,"coeff");
20 ACF2 = xcov(Spxi2,"coeff");
21 ACF3 = xcov(Spxi3,"coeff");
22 xset('window',1);
23 a = gca();
24 a.data_bounds = [-len -1; len 1];
25 plot(xv,ACF1,'o-',xv,ACF2,'x—',xv,ACF3,'*');
26 label('',4,'Lag','ACF',4);

```

---

### Scilab code Exa 6.5 Demonstrate the order of MA

```

1  // Demonstrate the order of MA(q) as discussed in
   // Example 6.11 on page 182.
2  // 6.5
3
4  exec('plotacf.sci',-1);
5  exec('label.sci',-1);
6
7  xi = 0.1*rand(1,10000,'normal');
8  a = 1; b = [];

```

```

 9 d = [1 1 -0.5];
10 ar = armac(a,b,d,1,1,1);
11 v = arsimul(ar,xi);
12 z = [v xi];
13
14 // Plot noise , plant output and ACF
15 subplot(2,1,1), plot(v(1:500))
16 label(' ',4, ' ', 'v ',4)
17 subplot(2,1,2), plot(xi(1:500))
18 label(' ',4, 'n ', 'xi ',4)
19 xset('window',1)
20 plotacf(v,1,11,1);

```

---

#### Scilab code Exa 6.6 Procedure to plot the ACF

```

1 // Procedure to plot the ACF, as discussed in Sec.
  6.4.3. An example usage is given in 6.5.
2 // 6.6
3
4 // PLOTACF: Plots normalized autocorrelation
  function
5 //
6 // USAGE:: [acf]=plotacf(x,errlim,len,print_code)
7 //
8 // WHERE:: acf = autocorrelation values
9 // x = time series data
10 // errlim > 0; error limit = 2/sqrt(data_len)
11 // len = length of acf that need to to be plotted
12 // NOTE: if len=0 then len=data_length/2;
13 // print_code = 0 ==> does not plot OR ELSE plots
14 //
15 // Pranob Banerjee
16
17 function [x]=plotacf(y,errlim,len,code)
18 exec('label.sci',-1)

```



```

19 x = xcov(y); l = length(y); x = x/x(l);
20 r=1:2*(l-1); lim=2/sqrt(l); rl=1:length(r) ;
21 N=length(rl); x=x(r);
22 if len>0 & len<N, rl=1:len; x=x(rl); N=len; end;
23 if(code > 0 )
24     if(errlim > 0 )
25         rl=rl-1;
26         plot(rl,x,rl,x,'o' , rl,lim*ones(N,1),'—', ...
27             rl,-lim*ones(N,1),'—')
28         xgrid
29     else
30         plot(rl,x)
31     end
32 end;
33 a = gca();
34 a.data_bounds = [0 min(min(x),-lim-0.1); len-1 1.1];
35 label(' ',4,'Lag','ACF',4)
36 endfunction;

```

---

**Scilab code Exa 6.7** Illustration of nonuniqueness in estimation of MA model parameters using ACF

```

1 // Illustration of nonuniqueness in estimation of MA
   model parameters using ACF, discussed in Example
   6.14 on page 184
2 // 6.7
3
4 exec('plotacf.sci',-1);
5 exec('pacf.sci',-1);
6 exec('label.sci',-1);
7
8 xi = 0.1*rand(1,10000);
9
10 // Simulation and estimation of first model
11 m1 = armac(1,0,[1,-3,1.25],1,1,1);

```

```

12 v1 = arsimul(m1,xi);
13 M1 = armax1(0,0,2,v1,zeros(1,10000))
14 disp(M1)
15
16 // Simulation and estimation of second model
17 m2 = armac(1,0,[1,-0.9,0.2],1,1,1);
18 v2 = arsimul(m2,xi);
19 M2 = armax1(0,0,2,v2,zeros(1,10000))
20 disp(M2)
21
22 // ACF and PACF of both models
23 plotacf(v1,1,11,1);
24 xset('window',1), plotacf(v2,1,11,1);
25 xset('window',2), pacf(v1,11);
26 xset('window',3), pacf(v2,11);

```

---

**Scilab code Exa 6.8** Estimation with a larger order model results in large uncertainty

```

1 // Estimation with a larger order model results in
  large uncertainty, as discussed in Example 6.15
  on page 185.
2 // 6.8
3
4 m = armac(1,0,[1 -0.9 0.2],1,1,1);
5 xi = 0.1*rand(1,10000);
6 v = arsimul(m,xi);
7 M1 = armax1(0,0,2,v,zeros(1,10000))
8 disp(M1)
9 M2 = armax1(0,0,3,v,zeros(1,10000))
10 disp(M2)

```

---

**Scilab code Exa 6.9** Determination of order of AR process

```

1 // Determination of order of AR(p) process , as
   discussed in Example 6.18 on page 189.
2 // 6.9
3
4 exec('pacf.sci',-1);
5 exec('label.sci',-1);
6
7 // Define model and generate data
8 m = armac([1,-1,0.5],0,1,1,1,1);
9 xi = 0.1*rand(1,10000,'normal');
10 v = arsimul(m,xi);
11
12 // Plot noise , plant output and PACF
13 subplot(2,1,1), plot(v(1:500));
14 label('',6,'v',6);
15 subplot(2,1,2), plot(xi(1:500));
16 label('',6,'xi',6);
17 xset('window',1)
18 pacf(v,10);

```

---

**Scilab code Exa 6.10** Determination of the PACF of AR process

```

1 // Determination of the PACF of AR(p) process , as
   explained in Sec. 6.4.5.
2 // 6.10
3
4 function [ajj] = pacf(v,M)
5 exec('label.sci',-1);
6 rvvn = xcorr(v,'coeff');
7 len = length(rvvn);
8 zero = (len+1)/2;
9 rvvn0 = rvvn(zero);
10 rvvn_one_side = rvvn(zero+1:len);
11 ajj = [];
12 exec('pacf_mat.sci',-1);

```

```

13 for j = 1:M,
14     ajj = [ajj pacf_mat(rvv0,rvvn_one_side,j,1)];
15 end
16 p = 1:length(ajj);
17 N = length(p);
18 lim = 2/sqrt(length(v));
19
20 // Plot the figure
21 plot(p,ajj,p,ajj,'o',p,lim*ones(N,1),'--',...
22      p,-lim*ones(N,1),'--');
23 label('',4,'Lag','PACF',4);
24 endfunction;

```

---

**Scilab code Exa 6.11** Construction of square matrix required to compute PACF ajj

```

1 // Construction of square matrix required to compute
  PACF ajj, useful for the calculations in Sec.
  6.4.5.
2 // 6.11
3
4 function ajj = pacf_mat(rvv0,rvv_rest,p,k)
5 if argn(2) == 3,
6     k = 1;
7 end
8 for i = 1:p
9     for j = 1:p
10        index = (k+i-1)-j;
11        if index == 0,
12            A(i,j) = rvv0;
13        elseif index < 0,
14            A(i,j) = rvv_rest(-index);
15        else
16            A(i,j) = rvv_rest(index);
17        end

```

```

18   end
19   b(i) = -rvv_rest(k+i-1);
20 end
21 a = A\b;
22 ajj = a(p);
23 endfunction;

```

---

**Scilab code Exa 6.12** PACF plot of an MA process decays slowly

```

1 // PACF plot of an MA process decays slowly , as
  // discussed in Example 6.19 on page 190.
2 // 6.12
3
4 exec('plotacf.sci',-1);
5 exec('pacf.sci',-1);
6 exec('label.sci',-1);
7
8 m = armac(1,0,[1,-0.9,0.2],1,1,1);
9 xi = 0.1*rand(1,10000);
10 v = arsimul(m,xi);
11 plotacf(v,1,11,1);
12 xset('window',1);
13 pacf(v,11);

```

---

**Scilab code Exa 6.13** Implementation of trial and error procedure to determine ARMA process

```

1 // Implementation of trial and error procedure to
  // determine ARMA(1,1) process , presented in Example
  // 6.20 on page 191.
2 // 6.13
3
4 exec('plotacf.sci',-1);

```

```

5 exec('pacf.sci',-1);
6 exec('label.sci',-1);
7
8 // Set up the model for simulation
9 arma_mod = armac([1 -0.8],0,[1 -0.3],1,1,1);
10
11 // Generate the inputs for simulation
12 // Deterministic Input can be anything
13 u = zeros(1,2048);
14 e = rand(1,2048,'normal');
15
16 // Simulate the model
17 v = arsimul(arma_mod,[u e]);
18
19 // Plot ACF and PACF for 10 lags
20 plotacf(v,1e-03,11,1);
21 xset('window',1), pacf(v,10);
22
23 // Estimate AR(1) model and present it
24 // compute the residuals
25 [mod_est1,err_mod1] = armax1(1,0,0,v,zeros(1,length(
    v)));
26 disp(mod_est1);
27
28 // Plot ACF and PACF for 10 lags
29 xset('window',2), plotacf(err_mod1,1e-03,11,1);
30 xset('window',3), pacf(err_mod1,10);
31
32 // Check ACF and PACF of residuals
33 [mod_est2,err_mod2] = armax1(1,0,1,v,zeros(1,length(
    v)));
34 disp(mod_est2);
35
36 // Plot ACF and PACF for 10 lags
37 xset('window',4), plotacf(err_mod2,1e-03,11,1);
38 xset('window',5), pacf(err_mod2,10);

```

---

### Scilab code Exa 6.14 Determination of FIR parameters

```
1 // Determination of FIR parameters as described in
   Example 6.22 on page 200.
2 // 6.14
3
4 exec('cra.sci',-1);
5 exec('filt.sci',-1);
6 exec('covf.sci',-1);
7
8 sig = 0.05;
9 process_mod = armac([1 -0.5],[0 0.6 -0.2],1,1,1,sig)
   ;
10
11 u = prbs_a(2225,40);
12 xi = rand(1,2225,'normal');
13 y = arsimul(process_mod,[u xi]);
14 u = [u zeros(1,length(y)-length(u))];
15 z = [y' u'];
16
17 // Plot y as a function of u and xi
18 exec('label.sci',-1)
19 subplot(3,1,1), plot(y(1:500)),
20 label('',4,'','y',4)
21 subplot(3,1,2), plot(u(1:500))
22 label('',4,'','u',4)
23 subplot(3,1,3), plot(sig*xi(1:500))
24 label('',4,'n','xi',4)
25
26 xset('window',1);
27 [ir,r,cl_s] = cra(detrend(z,'constant'));
28 ir_act = filt([0 0.6 -0.2],[1 -0.5],...
29             [1 zeros(1,9)]);
30 replot([0,min(min(ir),min(ir_act)) - 0.1,9,max(max(
```

```

    ir),max(ir_act)) + 0.1]);
31 t = 0:9;
32 plot(t,ir_act,'ko');
33 plot2d3(t,ir_act);
34 legends(['Estimated'; 'Actual'], [2;-9], 'ur');

```

---

### Scilab code Exa 6.15 Determination of ARX parameters

```

1 // Determination of ARX parameters as described in
  Example 6.25 on page 203.
2 // 6.15
3
4 exec('armac1.sci',-1);
5 exec('cra.sci',-1);
6 exec('arx.sci',-1);
7 exec('filt.sci',-1);
8 exec('covf.sci',-1);
9 exec('stem.sci',-1);
10
11 process_arx = armac1([1 -0.5],[0 0 0.6
    -0.2],1,1,1,0.05);
12 u = prbs_a(5000,250);
13 xi = rand(1,5000,'normal');
14 y = arsimul(process_arx,[u xi]);
15 z = [y(1:length(u))' u'];
16 zd = detrend(z,'constant');
17
18 // Compute IR for time-delay estimation
19 [ir,r,cl_s] = cra(detrend(z,'constant'));
20
21 // Time-delay = 2 samples
22 // Estimate ARX model (assume known orders)
23 na = 1; nb = 2; nk = 2;
24 [theta_arx,cov_arx,nvar,resid] = arx(zd,na,nb,nk);
25

```



```

26 // Residual plot
27 [cov1,m1] = xcov(resid,24,"coeff");
28 xset('window',1);
29 subplot(2,1,1)
30 stem(0:24,cov1(25:49)');xgrid();
31 xtitle('Correlation function of residuals from
        output y1','lag');
32 [cov2,m2] = xcov(resid, zd(:,2),24,"coeff");
33 subplot(2,1,2)
34 stem(-24:24,cov2');xgrid();
35 xtitle('Cross corr. function between input u1 and
        residuals from output y1','lag');

```

---

#### Scilab code Exa 6.16 Determination of ARMAX parameters

```

1 // Determination of ARMAX parameters as described in
  Example 6.27 on page 206.
2 // 6.16
3
4 exec('cra.sci',-1);
5 exec('stem.sci',-1);
6 exec('filt.sci',-1);
7 exec('covf.sci',-1);
8
9 process_armax = armac([1 -0.5],[0 0 0.6 -0.2],[1
  -0.3],1,1,0.05);
10 u = prbs_a(5000,250);
11 xi = rand(1,5000);
12 y = arsimul(process_armax,[u xi]);
13 z = [y(1:length(u))' u'];
14 zd = detrend(z,'constant');
15
16 //Compute IR for time-delay estimation
17 [ir,r,cl_s] = cra(detrend(z,'constant'));
18

```

```

19 //Estimate ARMAX model (assume known orders)
20 na = 1; nb = 3; nc = 1; nk = 2;
21 [theta_armax, resid] = armax1(na, nb, nc, zd(:,1)', zd
    (:,2)', 1);
22 disp(theta_armax)
23
24 // Residual plot
25 [cov1, m1] = xcov(resid, 24, "coeff");
26 xset('window', 1);
27 subplot(2, 1, 1)
28 stem(0:24, cov1(25:49)); xgrid();
29 xtitle('Correlation function of residuals from
    output y1', 'lag');
30 [cov2, m2] = xcov(resid, zd(:,2), 24, "coeff");
31 subplot(2, 1, 2)
32 stem(-24:24, cov2); xgrid();
33 xtitle('Cross corr. function between input u1 and
    residuals from output y1', 'lag');

```

---

#### Scilab code Exa 6.17 Determination of OE parameters

```

1 // Determination of OE parameters as described in
    Example 6.28 on page 209.
2 // 6.17
3
4 exec('armacl.sci', -1);
5 exec('oe.sci', -1);
6 exec('cra.sci', -1);
7 exec('stem.sci', -1);
8 exec('filt.sci', -1);
9 exec('covf.sci', -1);
10 exec('deconvol.sci', -1);
11
12 b = [0 0 0.6 -0.2];
13 f = [1 -0.5];

```

```

14 c = 1; d = 1;
15 process_oe = armac1(1,b,c,d,f,0.05);
16 u = prbs_a(2555,250);
17 xi = rand(1,2555,'normal');
18 y = arsimul(process_oe,[u xi]);
19 z = [y(1:length(u))' u'];
20 zd = detrend(z,'constant');
21
22 // Compute IR for time-delay estimation
23 [ir,r,cl_s] = cra(zd);
24
25 // Time-delay = 2 samples
26 // Estimate ARX model (assume known orders)
27 nb = 2; nf = 1; nk = 2;
28 [thetaN,covfN,nvar,resid] = oe(zd,nb,nf,nk);
29
30 // Residual plot
31 [cov1,m1] = xcov(resid,24,"coeff");
32 xset('window',1);
33 subplot(2,1,1)
34 stem(0:24,cov1(25:49)');xgrid();
35 xtitle('Correlation function of residuals from
        output y1','lag');
36 [cov2,m2] = xcov(resid, zd(:,2),24,"coeff");
37 subplot(2,1,2)
38 stem(-24:24,cov2');xgrid();
39 xtitle('Cross corr. function between input u1 and
        residuals from output y1','lag');

```

---

# Chapter 7

## Structures and Specifications

**Scilab code Exa 7.1** Procedure to draw root locus for the problem

```
1 // Procedure to draw root locus for the problem
   discussed in Example 7.1 on page 247.
2 // 7.1
3
4 exec('tf.sci',-1);
5
6 H = tf(1,[1 -1 0],-1);
7 evans(H)
```

---

**Scilab code Exa 7.2** Procedure to draw the Nyquist plot

```
1 // Procedure to draw the Nyquist plot , as discussed
   in Example 7.2 on page 250.
2 // 7.2
3
4 exec('tf.sci',-1);
5
6 H = tf(1,[1 -1 0],-1);
7 nyquist(H,0.1,0.5)
```

---

**Scilab code Exa 7.3** Procedure to draw Bode plots

```
1 // Procedure to draw Bode plots in Fig. 7.11 on page
   255.
2 // 7.3
3
4 exec('tf.sci',-1);
5
6 pol1 = [1 -0.9]; pol2 = [1 -0.8];
7 G1 = tf(pol1,[1 0],-1);
8 G2 = tf(pol2,[1 0],-1);
9 w = linspace(0.001,0.5,1000);
10 xset('window',1);
11 bode([G1;G2],w);
12 G = tf(pol1,pol2,-1);
13 xset('window',2);
14 bode(G,w);
```

---

**Scilab code Exa 7.4** A procedure to design lead controllers

```
1 // A procedure to design lead controllers , as
   explained in Fig. 7.12 on page 257.
2 // 7.4
3
4 exec('tf.sci',-1)
5
6 w = linspace(0.001,%pi,1000);
7 a = linspace(0.001,0.999,100);
8 lena = length(a);
9 omega = []; lead = [];
10 for i = 1:len,
```

```

11     zero = a(i);
12     pole = 0.9*zero;
13     sys = tf([1 -zero],[1 -pole],-1);
14     frq = w/(2*%pi);
15     [frq,repf]=repfreq(sys, frq);
16     [db,phase] =dbphi(repff);
17     [y,j] = max(phase);
18     omega = [omega w(j)];
19     lead = [lead y];
20     comeaga = (pole+zero)/(pole*zero+1);
21     clead = zero-pole;
22     clead1 = sqrt((1-zero^2)*(1-pole^2));
23     clead = clead/clead1;
24 //     [w(j) acos(comeaga) y atan(clead)*180/pi]
25 end
26 subplot(2,1,1), plot(lead,omega)
27 xtitle('','','Frequency, in radians'), xgrid;
28 halt;
29 subplot(2,1,2), plot(lead,a)
30 xtitle('','Lead generated, in degrees','Zero
    location'), xgrid;

```

---

#### Scilab code Exa 7.5 Bode plot of a lead controller

```

1 // Bode plot of a lead controller , as shown in Fig.
   7.13 on page 257.
2 // 7.5
3
4 exec('tf.sci',-1);
5
6 w = linspace(0.001,0.5,1000);
7 G = tf([1 -0.8],[1 -0.24],-1);
8 bode(G,w)

```

---

**Scilab code Exa 7.6** Verification of performance of lead controller on antenna system

```
1 // Verification of performance of lead controller on
   antenna system, as discussed in Example 7.3.
2 // 7.6
3
4 // Continuous time antenna model
5 a = 0.1;
6 F = [0 1;0 -a]; g = [0; a]; c = [1 0]; d = 0;
7 Ga = syslin('c',F,g,c,d); [ds,num,den] = ss2tf(Ga);
8 Num = clean(num); Den = clean(den);
9 Ts = 0.2;
10 G = dscr(Ga,Ts);
11
12 // lead controller
13 beta1 = 0.8;
14 N = [1 -0.9802]*(1-beta1)/(1-0.9802); Rc = [1 -beta1
   ];
15
16 // simulation parameters using g_s_cl2.cos
17 gamm = 1; Sc = 1; Tc = 1; C = 0; D = 1;
18 st = 1; st1 = 0;
19 t_init = 0; t_final = 20;
20
21 // u1: -4 to 11
22 // y1: 0 to 1.4
23 exec('cosfil_ip.sci',-1);
24 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
25 [Np,Rcp] = cosfil_ip(N,Rc); // N/Rc
26 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
27 [Cp,Dp] = cosfil_ip(C,D); // C/D
```

---

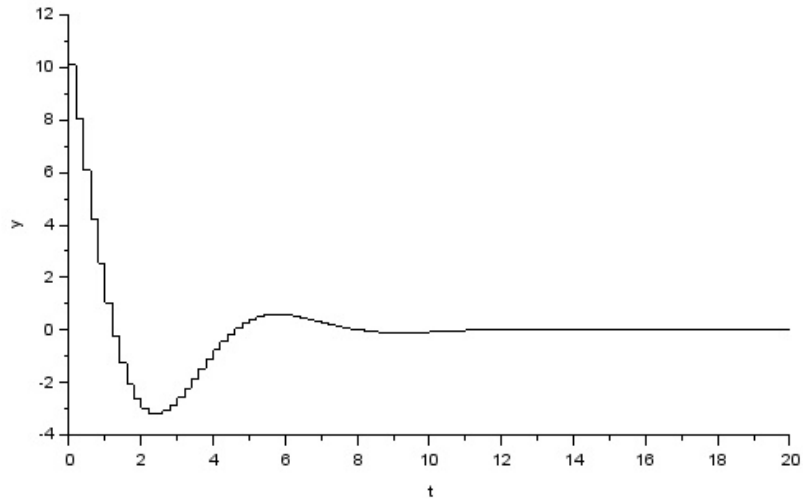


Figure 7.1: Verification of performance of lead controller on antenna system

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

**Scilab code Exa 7.7** Illustration of system type

```

1 // Illustration of system type, as explained in
  Example 7.10 on page 275.
2 // 7.7
3
4 exec('rowjoin.sci',-1);

```



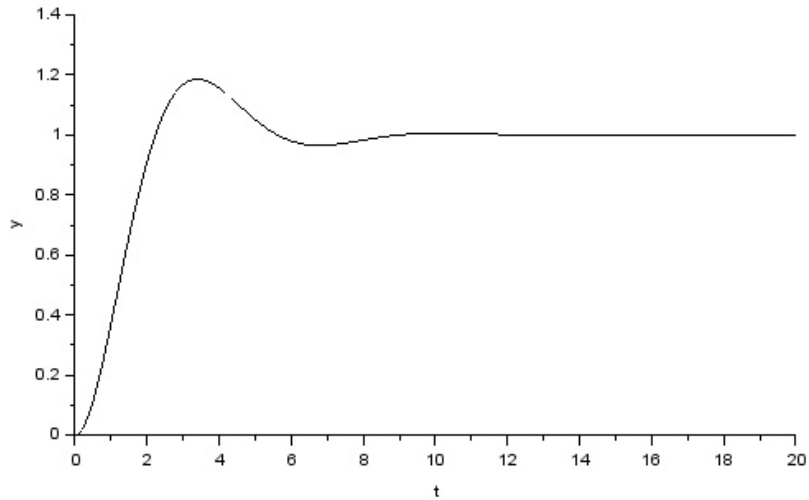


Figure 7.2: Verification of performance of lead controller on antenna system

```

5  exec('zpowk.sci',-1);
6  exec('polmul.sci',-1);
7  exec('polsize.sci',-1);
8  exec('indep.sci',-1);
9  exec('t1calc.sci',-1);
10 exec('makezero.sci',-1);
11 exec('move.sci.sci',-1);
12 exec('clcoef.sci',-1);
13 exec('colsplit.sci',-1);
14 exec('seshft.sci',-1);
15 exec('left_prm.sci',-1);
16 exec('cindep.sci',-1);
17 exec('xdync.sci',-1);
18 exec('pp_pid.sci',-1);
19 exec('cosfil_ip.sci');
20
21 // Plant
22 B = 1; A = [1 -1]; zk = [0 1]; Ts = 1; k = 1;
23 // Value of k absent in original code
24 // Specify closed loop characteristic polynomial

```

```

25 phi = [1 -0.5];
26
27 // Design the controller
28 reject_ramps = 1;
29   if reject_ramps == 1,
30       Delta = [1 -1]; // to reject ramps another Delta
31   else
32       Delta = 1; // steps can be rejected by plant
           itself
33   end
34 [Rc,Sc] = pp_pid(B,A,k,phi,Delta);
35
36 // parameters for simulation using stb_disc.mdl
37 Tc = Sc; gamm = 1; N = 1;
38 C = 0; D = 1; N_var = 0;
39 st = 1; t_init = 0; t_final = 20;
40
41 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
42 [Rcp1,Rcp2] = cosfil_ip(1,Rc); // 1/Rc
43 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
44 [Bp,Ap] = cosfil_ip(B,A); // B/A
45 [zkp1,zkp2] = cosfil_ip(zk,1); // zk/1
46 [Cp,Dp] = cosfil_ip(C,D); // C/D
47
48 // Give appropriate path
49 //xcos('stb_disc.xcos');

```

---

### Scilab code Exa 7.8 Solution to Aryabhata identity

```

1 // Solution to Aryabhata's identity , presented in
   Example 7.12 on page 293.

```

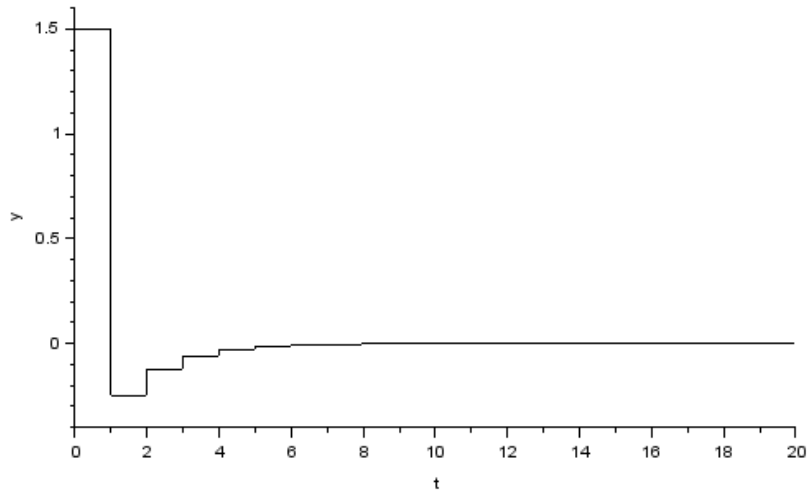


Figure 7.3: Illustration of system type

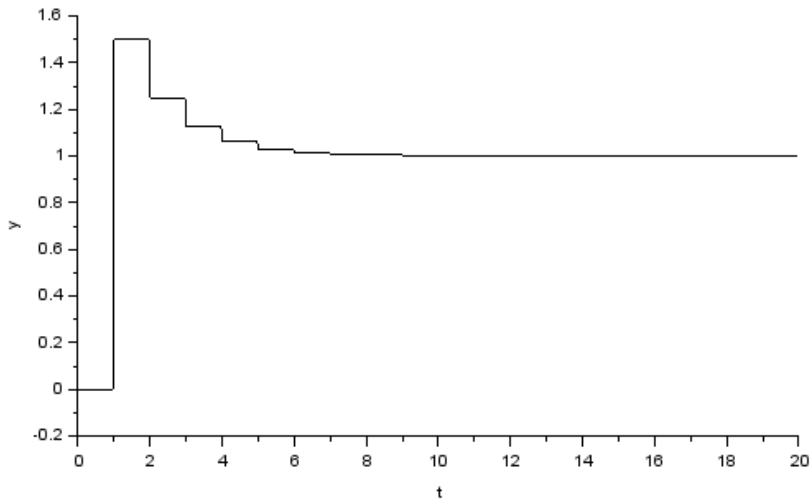


Figure 7.4: Illustration of system type

```

2 // 7.8
3
4 exec('indep.sci',-1);
5 exec('rowjoin.sci',-1);
6 exec('polsize.sci',-1);
7 exec('makezero.sci',-1);
8 exec('clcoef.sci',-1);
9 exec('cindep.sci',-1);
10 exec('seshft.sci',-1);
11 exec('move_sci.sci',-1);
12 exec('colsplit.sci',-1);
13 exec('left_prm.sci',-1);
14 exec('t1calc.sci',-1);
15 exec('xdync.sci',-1);
16
17 N = convol([0 1],[1 1]);
18 D = convol([1 -4],[1 -1]);
19 dN = 2; dD = 2;
20 C = [1 -1 0.5];
21 dC = 2;
22 [Y,dY,X,dX,B,dB,A,dA] = xdync(N,dN,D,dD,C,dC)

```

---

### Scilab code Exa 7.9 Left coprime factorization

```

1 // Left coprime factorization as discussed in
   Example 7.13 on page 295.
2 // 7.9
3
4 exec('rowjoin.sci',-1);
5 exec('makezero.sci',-1);
6 exec('colsplit.sci',-1);
7 exec('clcoef.sci',-1);
8 exec('polsize.sci',-1);
9 exec('seshft.sci',-1);
10 exec('indep.sci',-1);

```

```

11 exec('move_sci.sci',-1);
12 exec('t1calc.sci',-1);
13 exec('left_prm.sci',-1);
14
15 D = [1 0 0 0 0 0
16 0 1 0 1 0 0
17 0 0 1 1 1 0];
18 N = [
19 1 0 0
20 0 1 0
21 0 0 1];
22 dD = 1;
23 dN = 0;
24 [B,dB,A,dA] = left_prm(N,dN,D,dD)

```

---

### Scilab code Exa 7.10 Solution to polynomial equation

```

1 // Solution to polynomial equation, as discussed in
  // Example 7.14 on page 295.
2 // 7.10
3
4 exec('move_sci.sci',-1);
5 exec('makezero.sci',-1);
6 exec('seshft.sci',-1);
7 exec('colsplit.sci',-1);
8 exec('clcoef.sci',-1);
9 exec('cindep.sci',-1);
10 exec('indep.sci',-1);
11 exec('t1calc.sci',-1);
12 exec('left_prm.sci',-1);
13 exec('polsize.sci',-1);
14 exec('rowjoin.sci',-1);
15 exec('xdync.sci',-1);
16
17 N = [0 4 0 1

```

```
18         -1 8 0 3];
19 dN = 1;
20 D = [0 0 1 4 0 1
21      0 0 -1 0 0 0];
22 dD = 2;
23 C = [1 0 1 1
24      0 2 0 1];
25 dC = 1;
26 [Y,dY,X,dX,B,dB,A,dA] = xdync(N,dN,D,dD,C,dC)
```

---

# Chapter 8

## Proportional Integral Derivative Controllers

Scilab code Exa 8.1 Continuous to discrete time transfer function

```
1 // Continuous to discrete time transfer function
2 // 8.1
3
4 exec('tf.sci');
5
6 sys = tf(10,[5 1]);
7 sysd = ss2tf(dscr(sys,0.5));
```

---

# Chapter 9

## Pole Placement Controllers

**Scilab code Exa 9.1** Pole placement controller for magnetically suspended ball problem

```
1 // Pole placement controller for magnetically
   suspended ball problem, discussed in Example 9.3
   on page 331.
2 // 9.1
3
4 exec('myc2d.sci',-1);
5 exec('desired.sci',-1);
6 exec('zpowk.sci',-1);
7 exec('polsplit2.sci',-1);
8 exec('polsize.sci',-1);
9 exec('t1calc.sci',-1);
10 exec('indep.sci',-1);
11 exec('move.sci.sci',-1);
12 exec('colsplitt.sci',-1);
13 exec('clcoef.sci',-1);
14 exec('cindep.sci',-1);
15 exec('polmul.sci',-1);
16 exec('seshft.sci',-1);
17 exec('makezero.sci',-1);
18 exec('xdync.sci',-1);
```



```

19 exec('left_prm.sci',-1);
20 exec('rowjoin.sci',-1);
21 exec('pp_basic.sci',-1);
22 exec('polyno.sci',-1);
23 exec('cosfil_ip.sci',-1);
24
25 // Magnetically suspended ball problem
26 // Operating conditions
27 M = 0.05; L = 0.01; R = 1; K = 0.0001; g = 9.81;
28
29 //Equilibrium conditions
30 hs = 0.01; is = sqrt(M*g*hs/K);
31
32 // State space matrices
33 a21 = K*is^2/M/hs^2; a23 = - 2*K*is/M/hs; a33 = - R/
    L;
34 b3 = 1/L;
35 a1 = [0 1 0; a21 0 a23; 0 0 a33];
36 b1 = [0; 0; b3]; c1 = [1 0 0]; d1 = 0;
37
38 // Transfer functions
39 G = syslin('c',a1,b1,c1,d1); Ts = 0.01;
40 [B,A,k] = myc2d(G,Ts);
41
42 //polynomials are returned
43 [Ds,num,den] = ss2tf(G);
44 num = clean(num); den = clean(den);
45
46 // Transient specifications
47 rise = 0.15; epsilon = 0.05;
48 phi = desired(Ts,rise,epsilon);
49
50 // Controller design
51 [Rc,Sc,Tc,gamm] = pp_basic(B,A,k,phi);
52
53 // Setting up simulation parameters for basic.xcos
54 st = 0.0001; // desired change in h, in m.
55 t_init = 0; // simulation start time

```

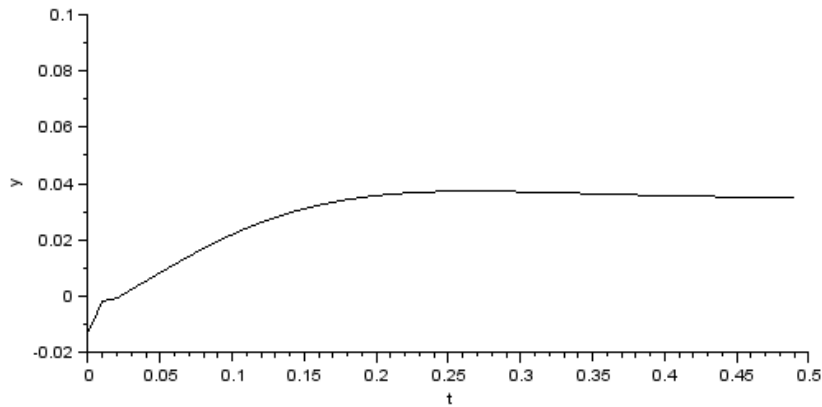


Figure 9.1: Pole placement controller for magnetically suspended ball problem

```

56 t_final = 0.5; // simulation end time
57
58 // Setting up simulation parameters for c_ss_cl.xcos
59 N_var = 0; xInitial = [0 0 0]; N = 1; C = 0; D = 1;
60
61 [Tc1,Rc1] = cosfil_ip(Tc,Rc); // Tc/Rc
62 [Sc2,Rc2] = cosfil_ip(Sc,Rc); // Sc/Rc
63
64 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
65 [Np,Rcp] = cosfil_ip(N,Rc); // 1/Rc
66 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
67 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in) This code

can be downloaded from the website [www.scilab.in](http://www.scilab.in)

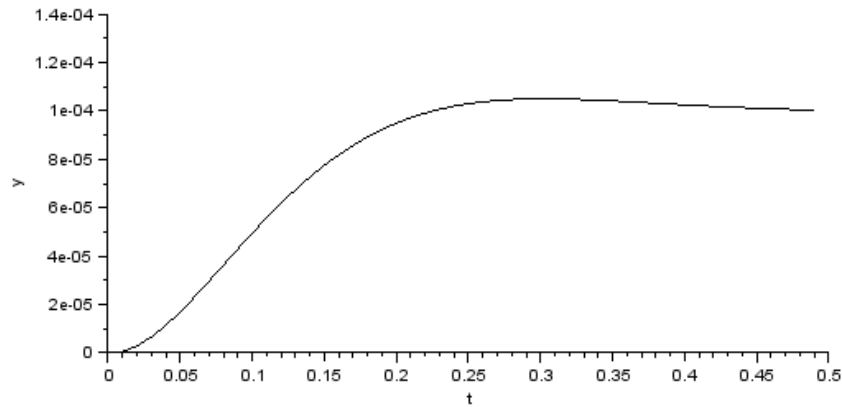


Figure 9.2: Pole placement controller for magnetically suspended ball problem

**Scilab code Exa 9.2** Discretization of continuous transfer function

```

1 // Discretization of continuous transfer function.
  The result is numerator and denominator in powers
  of  $z^{-1}$  and the delay term k.
2 // 9.2
3 // function [B,A,k] = myc2d(G,Ts)
4 // Produces numerator and denominator of discrete
  transfer
5 // function in powers of  $z^{-1}$ 
6 // G is continuous transfer function; time delays
  are not allowed
7 // Ts is the sampling time, all in consistent time
  units
8
9 function [B,A,k] = myc2d(G,Ts)

```

```

10 H = ss2tf(dscr(G,Ts));
11 num1 = coeff(H('num'));
12 den1 = coeff(H('den')); //-----
13 A = den1(length(den1):-1:1);
14 num2 = num1(length(num1):-1:1); //flip
15 nonzero = find(num1);
16 first_nz = nonzero(1);
17 B = num2(first_nz:length(num2)); //-----
18 k = length(den1) - length(num1);
19 endfunction

```

---

**Scilab code Exa 9.3** Procedure to split a polynomial into good and bad factors

```

1 // Procedure to split a polynomial into good and bad
  // factors , as discussed in Sec. 9.2.
2 // 9.3
3 // function [goodpoly,badpoly] = polsplit2(fac,a)
4 // Splits a scalar polynomial of  $z^{-1}$  into good
  // and bad
5 // factors.
6 // Input is a polynomial in increasing degree of  $z$ 
  //  $^{-1}$ 
7 // Optional input is a, where  $a \leq 1$ .
8 // Factor that has roots of  $z^{-1}$  outside a is
  // called
9 // good and the rest bad.
10 // If a is not specified , it will be assumed as
  // 1-1.0e-5
11
12 function [goodpoly,badpoly] = polsplit2(fac,a)
13 if argn(2) == 1, a = 1-1.0e-5; end
14 if a>1 error('good polynomial is unstable'); end
15 fac1 = poly(fac(length(fac):-1:1),'z','coeff');
16 rts1 = roots(fac1);

```

```

17 rts = rts1(length(rts1):-1:1);
18
19 // extract good and bad roots
20 badindex = find(abs(rts)>=a); // mtlb_find has been
    replaced by find
21 badpoly = coeff(poly((rts(badindex)), "z", "roots"));
22 goodindex = find(abs(rts)<a); // mtlb_find has been
    replaced by find
23 goodpoly = coeff(poly(rts(goodindex), "z", "roots"));
24
25 // scale by equating the largest terms
26 [m, index] = max(abs(fac));
27 goodbad = convol(goodpoly, badpoly);
28 goodbad1 = goodbad(length(goodbad):-1:1); //--
29 factor1 = fac(index)/goodbad1(index); //--
30 goodpoly = goodpoly * factor1;
31 goodpoly = goodpoly(length(goodpoly):-1:1);
32 badpoly = badpoly(length(badpoly):-1:1);
33 endfunction;

```

---

**Scilab code Exa 9.4** Calculation of desired closed loop characteristic polynomial

```

1 // Calculation of desired closed loop characteristic
    polynomial, as discussed in Sec. 7.7.
2 // 9.4
3
4 // function [phi, dphi] = desired(Ts, rise, epsilon)
5 // Based on transient requirements,
6 // calculates closed loop characteristic polynomial
7
8 function [phi, dphi] = desired(Ts, rise, epsilon)
9 Nr = rise/Ts; omega = %pi/2/Nr; rho = epsilon^(omega
    /%pi);
10 phi = [1 -2*rho*cos(omega) rho^2]; dphi = length(phi

```

```
    )-1;  
11 endfunction;
```

---

**Scilab code Exa 9.5** Design of 2 DOF pole placement controller

```
1 // Design of 2-DOF pole placement controller , as  
  discussed in Sec. 9.2.  
2 // 9.5  
3  
4 // function [Rc,Sc,Tc,gamma] = pp_basic(B,A,k,phi)  
5 // calculates pole placement controller  
6  
7  
8 function [Rc,Sc,Tc,gamm] = pp_basic(B,A,k,phi)  
9  
10 // Setting up and solving Aryabhatta identity  
11 [Ag,Ab] = polysplit2(A); dAb = length(Ab) - 1;  
12 [Bg,Bb] = polysplit2(B); dBb = length(Bb) - 1;  
13  
14 [zk,dzk] = zpowk(k);  
15  
16 [N,dN] = polmul(Bb,dBb,zk,dzk);  
17 dphi = length(phi) - 1;  
18  
19 [S1,dS1,R1,dR1] = xdync(N,dN,Ab,dAb,phi,dphi);  
20  
21 // Determination of control law  
22 Rc = convol(Bg,R1); Sc = convol(Ag,S1);  
23 Tc = Ag; gamm = sum(phi)/sum(Bb);  
24  
25 endfunction;
```

---

**Scilab code Exa 9.6** Evaluates  $z$  to the power  $k$

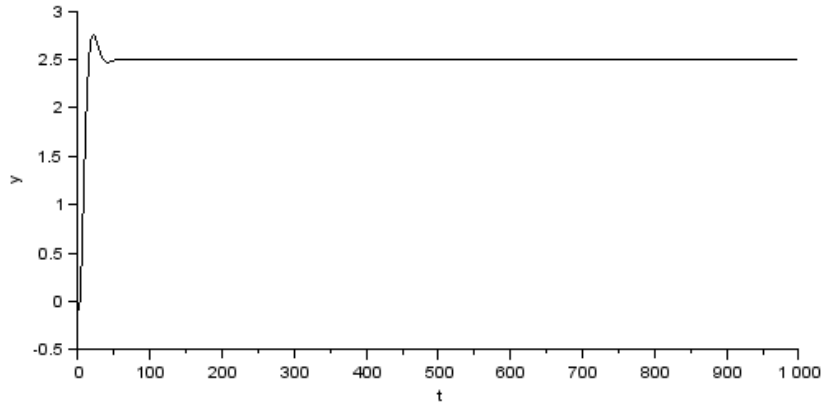


Figure 9.3: Simulation of closed loop system with an unstable controller

```

1 // Evaluates  $z^{-k}$ .
2 // 9.6
3
4 function [zk,dzk] = zpowk(k)
5 zk = zeros(1,k+1); zk(1,k+1) = 1;
6 dzk = k;
7 endfunction

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in) This code

can be downloaded from the website [www.scilab.in](http://www.scilab.in)

**Scilab code Exa 9.7** Simulation of closed loop system with an unstable controller

```

1 // Simulation of closed loop system with an unstable

```

```

        controller , as discussed in Example 9.5 on page
        335.
2 // 9.7
3
4 exec('desired.sci',-1);
5 exec('zpowk.sci',-1);
6 exec('polmul.sci',-1);
7 exec('polsplit2.sci',-1);
8 exec('polsize.sci',-1);
9 exec('xdync.sci',-1);
10 exec('rowjoin.sci',-1);
11 exec('left_prm.sci',-1);
12 exec('t1calc.sci',-1);
13 exec('indep.sci',-1);
14 exec('makezero.sci',-1);
15 exec('move_sci.sci',-1);
16 exec('colsplit.sci',-1);
17 exec('clcoef.sci',-1);
18 exec('cindep.sci',-1);
19 exec('seshft.sci',-1);
20 exec('cosfil_ip.sci',-1);
21 exec('pp_basic.sci',-1);
22
23 Ts = 1; B = [1 -3]; A = [1 2 -8]; k = 1;
24 // Since k=1, tf is of the form z^-1
25 [zk,dzk] = zpowk(k); // int1 = 0;/-- int1
26
27 // Transient specifications
28 rise = 10; epsilon = 0.1;
29 phi = desired(Ts, rise, epsilon);
30
31 // Controller design
32 [Rc,Sc,Tc,gamm] = pp_basic(B,A,k,phi);
33
34 // simulation parameters for basic_disc.xcos
35 //While simulating for t_final = 100, set the limit
    of Y axis of each scope
36 //u1: -0.2 to 3

```



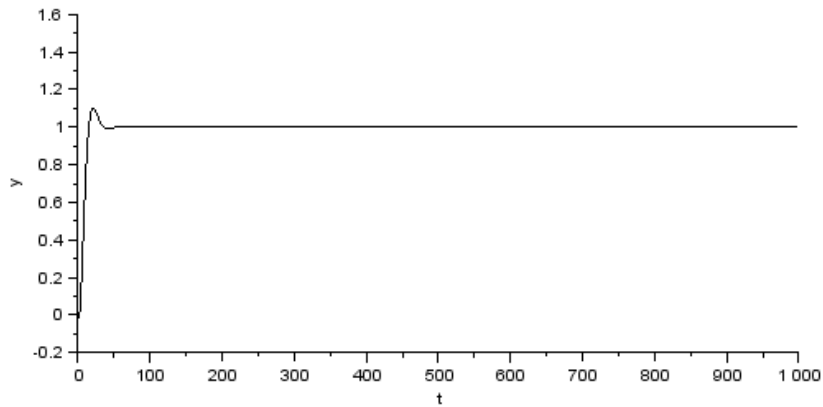


Figure 9.4: Simulation of closed loop system with an unstable controller

```

37 //y1: -0.1 to 1.2
38 st = 1.0; // Desired change in setpoint
39 t_init = 0; // Simulation start time
40 t_final = 1000; // Simulation end time
41
42 // Simulation parameters for stb_disc.xcos
43 N_var = 0; C = 0; D = 1; N = 1;
44
45 [Tc1,Tc2] = cosfil_ip(Tc,1); // Tc/1
46 [Rcp1,Rcp2] = cosfil_ip(1,Rc); // 1/Rc
47 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
48 [Bp,Ap] = cosfil_ip(B,A); // B/A
49 [zcp1,zcp2] = cosfil_ip(zk,1); // zk/1
50 [Cp,Dp] = cosfil_ip(C,D); // C/D
51
52 [Tc_p,Rc_p] = cosfil_ip(Tc,Rc); // Tc/Rc
53 [Sc_b,Rc_b] = cosfil_ip(Sc,Rc); // Sc/Rc

```

---

**Scilab code Exa 9.8** Pole placement controller using internal model principle

```
1 // Pole placement controller using internal model
  principle , as discussed in Sec. 9.4.
2 // 9.8
3
4 // function [Rc,Sc,Tc,gamma,phit] = pp-im(B,A,k,phi,
  Delta)
5 // Calculates 2-DOF pole placement controller.
6
7 function [Rc,Sc,Tc,gamm] = pp_im(B,A,k,phi,Delta)
8
9 // Setting up and solving Aryabhata identity
10 [Ag,Ab] = polysplit3(A); dAb = length(Ab) - 1;
11 [Bg,Bb] = polysplit3(B); dBb = length(Bb) - 1;
12
13 [zk,dzk] = zpowk(k);
14
15 [N,dN] = polmul(Bb,dBb,zk,dzk);
16 dDelta = length(Delta)-1;
17 [D,dD] = polmul(Ab,dAb,Delta,dDelta);
18 dphi = length(phi)-1;
19
20 [S1,dS1,R1,dR1] = xdync(N,dN,D,dD,phi,dphi);
21
22 // Determination of control law
23 Rc = convol(Bg,convol(R1,Delta)); Sc = convol(Ag,S1)
  ;
24 Tc = Ag; gamm = sum(phi)/sum(Bb);
25 endfunction;
```

---

**Scilab code Exa 9.9** Pole placement controller with internal model of a step for the magnetically suspended ball problem

```

1 // Pole placement controller , with internal model of
    a step , for the magnetically suspended ball
    problem , as discussed in Example 9.8 on page 339.
2 // 9.9
3
4 // PP control with internal model for ball problem
5 exec('desired.sci',-1);
6 exec('pp_im.sci',-1);
7 exec('myc2d.sci',-1);
8 exec('polsplit3.sci',-1);
9 exec('zpowk.sci',-1);
10 exec('rowjoin.sci',-1);
11 exec('left_prm.sci',-1);
12 exec('t1calc.sci',-1);
13 exec('indep.sci',-1);
14 exec('cindep.sci',-1);
15 exec('seshft.sci',-1);
16 exec('makezero.sci',-1);
17 exec('move_sci.sci',-1);
18 exec('colsplit.sci',-1);
19 exec('clcoef.sci',-1);
20 exec('polmul.sci',-1);
21 exec('polsize.sci',-1);
22 exec('xdync.sci',-1);
23 exec('cosfil_ip.sci',-1);
24 exec('polyno.sci',-1);
25
26 // Operating conditions
27 M = 0.05; L = 0.01; R = 1; K = 0.0001; g = 9.81;
28
29 // Equilibrium conditions
30 hs = 0.01; is = sqrt(M*g*hs/K);
31
32 // State space matrices
33 a21 = K*is^2/M/hs^2; a23 = - 2*K*is/M/hs; a33 = - R/
    L;
34 b3 = 1/L;
35 a1 = [0 1 0; a21 0 a23; 0 0 a33];

```

```

36 b1 = [0; 0; b3]; c1 = [1 0 0]; d1 = 0;
37
38 // Transfer functions
39 G = syslin('c',a1,b1,c1,d1); Ts = 0.01; [B,A,k] =
    myc2d(G,Ts);
40
41 // Transient specifications
42 rise = 0.1; epsilon = 0.05;
43 phi = desired(Ts,rise,epsilon);
44
45 // Controller design
46 Delta = [1 -1]; //internal model of step used
47 [Rc,Sc,Tc,gamm] = pp_im(B,A,k,phi,Delta);
48
49 // simulation parameters for c_ss_cl.xcos
50 st = 0.0001; //desired change in h, in m.
51 t_init = 0; // simulation start time
52 t_final = 0.5; //simulation end time
53 xInitial = [0 0 0];
54 N = 1; C = 0; D = 1; N_var = 0;
55
56 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
57 [Np,Rcp] = cosfil_ip(N,Rc); // 1/Rc
58 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
59 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

**Scilab code Exa 9.10** Pole placement controller IBM Lotus Domino server

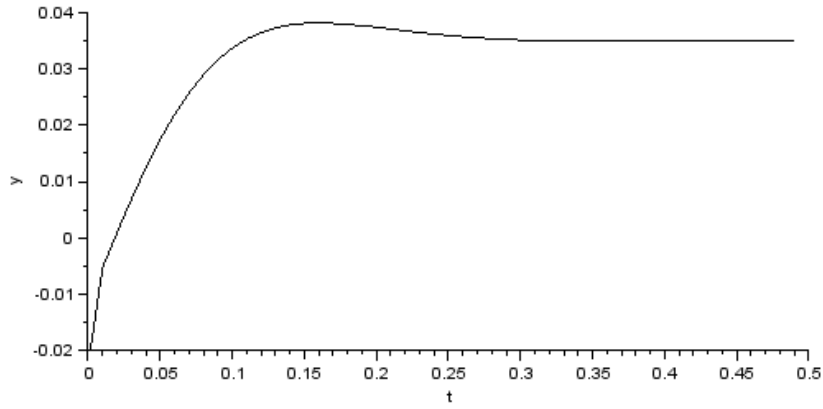


Figure 9.5: Pole placement controller with internal model of a step for the magnetically suspended ball problem

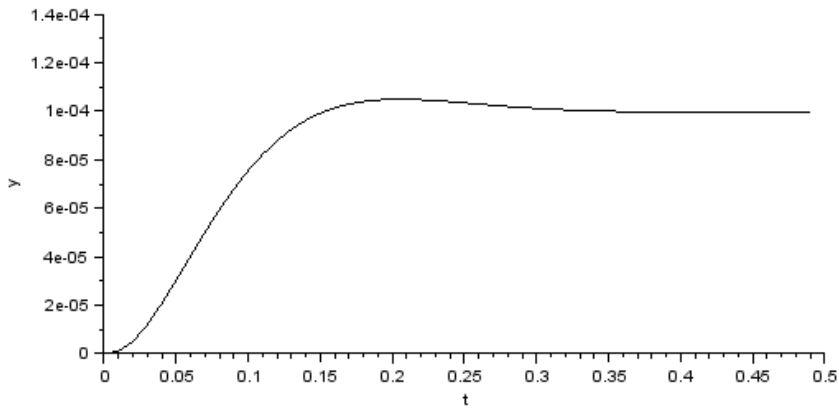


Figure 9.6: Pole placement controller with internal model of a step for the magnetically suspended ball problem

```

1 // Pole placement controller IBM Lotus Domino server
   , discussed in Example 9.9 on page 341.
2 // 9.10
3
4 exec('desired.sci',-1);
5 exec('pp_im.sci',-1);
6 exec('zpowk.sci',-1);
7 exec('cosfil_ip.sci',-1);
8 exec('polsplit3.sci',-1);
9 exec('polmul.sci',-1);
10 exec('polsize.sci',-1);
11 exec('xdync.sci',-1);
12 exec('rowjoin.sci',-1);
13 exec('left_prm.sci',-1);
14 exec('t1calc.sci',-1);
15 exec('polmul.sci',-1);
16 exec('indep.sci',-1);
17 exec('seshft.sci',-1);
18 exec('makezero.sci',-1);
19 exec('move_sci.sci',-1);
20 exec('colsplit.sci',-1);
21 exec('clcoef.sci',-1);
22 exec('cindep.sci',-1);
23 exec('polyno.sci',-1);
24
25 // Control of IBM lotus domino server
26 // Transfer function
27 B = 0.47; A = [1 -0.43]; k = 1;
28 [zk,dzk] = zpowk(k);
29
30 // Transient specifications
31 rise = 10; epsilon = 0.01; Ts = 1;
32 phi = desired(Ts,rise,epsilon);
33
34 // Controller design
35 Delta = [1 -1]; // internal model of step used
36 [Rc,Sc,Tc,gamm] = pp_im(B,A,k,phi,Delta);
37

```

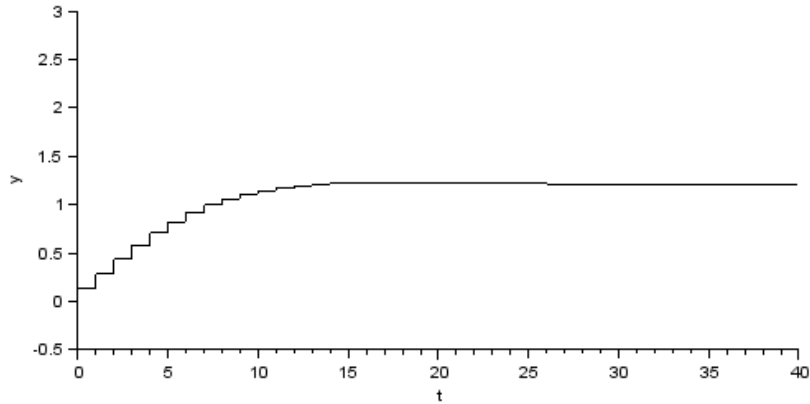


Figure 9.7: Pole placement controller IBM Lotus Domino server

```

38 // Simulation parameters for stb_disc.xcos
39 st = 1; // desired change
40 t_init = 0; // simulation start time
41 t_final = 40; // simulation end time
42 C = 0; D = 1; N_var = 0;
43
44 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
45 [Rcp1,Rcp2] = cosfil_ip(1,Rc); // 1/Rc
46 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
47 [Bp,Ap] = cosfil_ip(B,A); // B/A
48 [zkp1,zkp2] = cosfil_ip(zk,1); // zk/1
49 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

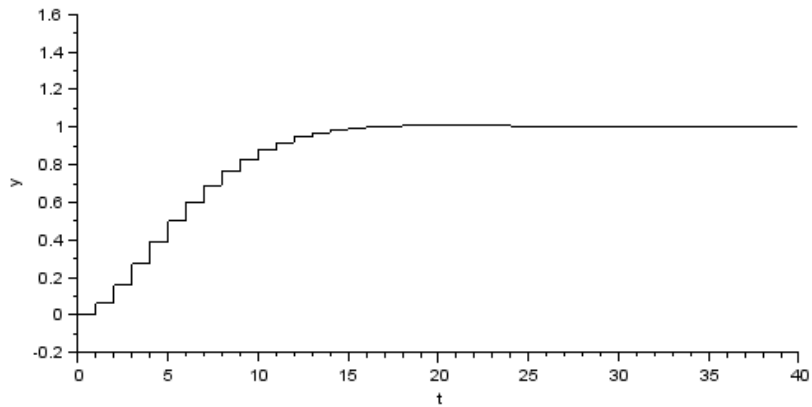


Figure 9.8: Pole placement controller IBM Lotus Domino server

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

### Scilab code Exa 9.11 Pole placement controller for motor problem

```

1 // Pole placement controller for motor problem ,
  discussed in Example 9.10 on page 343.
2 // 9.11
3
4 exec('desired.sci',-1);
5 exec('pp_im.sci',-1);
6 exec('myc2d.sci',-1);
7 exec('cosfil_ip.sci',-1);
8 exec('polsplit3.sci',-1);
9 exec('zpowk.sci',-1);
10 exec('polmul.sci',-1);
11 exec('polsize.sci',-1);
12 exec('xdync.sci',-1);
13 exec('rowjoin.sci',-1);

```



```

14 exec('left_prm.sci',-1);
15 exec('t1calc.sci',-1);
16 exec('indep.sci',-1);
17 exec('seshft.sci',-1);
18 exec('makezero.sci',-1);
19 exec('move_sci.sci',-1);
20 exec('colsplit.sci',-1);
21 exec('clcoef.sci',-1);
22 exec('cindep.sci',-1);
23 exec('polyno.sci',-1);
24
25 // Motor control problem
26 // Transfer function
27 a1 = [-1 0; 1 0]; b1 = [1; 0]; c1 = [0 1]; d1 = 0;
28 G = syslin('c',a1,b1,c1,d1); Ts = 0.25;
29 [B,A,k] = myc2d(G,Ts);
30
31 // Transient specifications
32 rise = 3; epsilon = 0.05;
33 phi = desired(Ts,rise,epsilon);
34
35 // Controller design
36 Delta = 1; // No internal model of step used
37 [Rc,Sc,Tc,gamm] = pp_im(B,A,k,phi,Delta);
38
39 // simulation parameters for c_ss_cl.xcos
40 st = 1; //desired change in position
41 t_init = 0; //simulation start time
42 t_final = 10; //simulation end time
43 xInitial = [0 0]; //initial conditions
44 N = 1; C = 0; D = 1; N_var = 0;
45
46 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
47 [Np,Rcp] = cosfil_ip(N,Rc); // 1/Rc
48 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
49 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

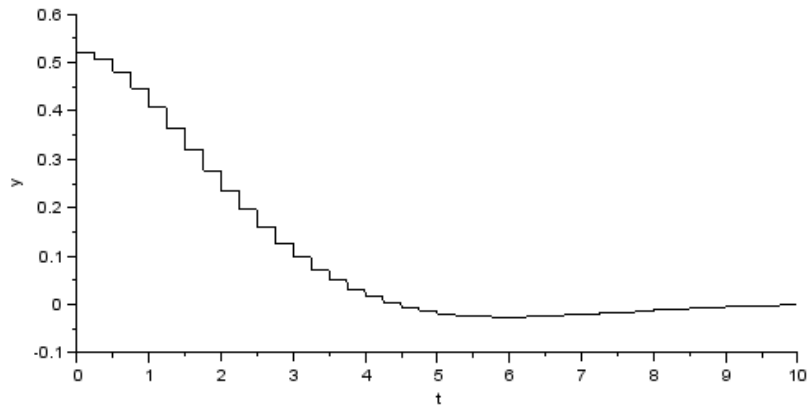


Figure 9.9: Pole placement controller for motor problem

**Scilab code Exa 9.12** Procedure to split a polynomial into good and bad factors

```

1 // Procedure to split a polynomial into good and bad
  factors , as discussed in Sec. 9.5. The factors
  that have roots outside unit circle or with
  negative real parts are defined as bad.
2 // 9.12
3
4 // function [goodpoly , badpoly] = polsplit3(fac , a)
5 // Splits a scalar polynomial of  $z^{-1}$  into good
  and bad
6 // factors. Input is a polynomial in increasing
  degree of
7 //  $z^{-1}$ . Optional input is a, where  $a \leq 1$ .

```

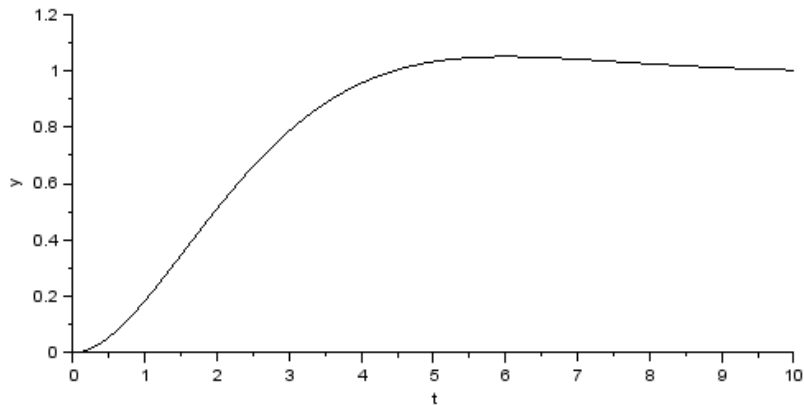


Figure 9.10: Pole placement controller for motor problem

```

8 // Factors that have roots outside a circle of
  radius a or
9 // with negative roots will be called bad and the
  rest
10 // good. If a is not specified, it will be assumed
    as 1.
11
12 function [goodpoly,badpoly] = polsplit3(fac,a)
13 if argn(2) == 1, a = 1; end
14 if a>1 error('good polynomial also is unstable');
    end
15 fac1 = poly(fac(length(fac):-1:1),'z','coeff');
16 rts = roots(fac1);
17 rts = rts(length(rts):-1:1);
18
19 // extract good and bad roots
20 badindex = mtlb_find((abs(rts)>=a-1.0e-5)|(real(rts)
    <-0.05));
21 badpoly = coeff(poly(rts(badindex),'z'));
22 goodindex = mtlb_find((abs(rts)<a-1.0e-5)&(real(rts)
    >=-0.05));
23 goodpoly = coeff(poly(rts(goodindex),'z'));
24

```

```

25 // scale by equating the largest terms
26 [m,index] = max(abs(fac));
27 goodbad = convol(goodpoly,badpoly);
28 goodbad = goodbad(length(goodbad):-1:1);
29 factor1 = fac(index)/goodbad(index);
30 goodpoly = goodpoly * factor1;
31 goodpoly = goodpoly(length(goodpoly):-1:1);
32 badpoly = badpoly(length(badpoly):-1:1);
33 endfunction;

```

---

**Scilab code Exa 9.13** Pole placement controller without intra sample oscillations

```

1 // Pole placement controller without intra sample
  oscillations , as discussed in Sec. 9.5.
2 // 9.13
3
4 // function [Rc,Sc,Tc,gamma,phit] = pp_im2(B,A,k,phi
  ,Delta,a)
5 // 2-DOF PP controller with internal model of Delta
  and without
6 // hidden oscillations
7
8 function [Rc,Sc,Tc,gamm,phit] = pp_im2(B,A,k,phi,
  Delta,a)
9
10 if argn(2) == 5, a = 1; end
11 dphi = length(phi)-1;
12
13 // Setting up and solving Aryabhatta identity
14 [Ag,Ab] = polysplit3(A,a); dAb = length(Ab) - 1;
15 [Bg,Bb] = polysplit3(B,a); dBb = length(Bb) - 1;
16
17 [zk,dzk] = zpowk(k);
18

```

```

19 [N,dN] = polmul(Bb,dBb,zk,dzk);
20 dDelta = length(Delta)-1;
21 [D,dD] = polmul(Ab,dAb,Delta,dDelta);
22
23 [S1,dS1,R1,dR1] = xdync(N,dN,D,dD,phi,dphi);
24
25 // Determination of control law
26 Rc = convol(Bg,convol(R1,Delta)); Sc = convol(Ag,S1)
    ;
27 Tc = Ag; gamm = sum(phi)/sum(Bb);
28
29 // Total characteristic polynomial
30 phit = convol(phi,convol(Ag,Bg));
31 endfunction;

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

#### Scilab code Exa 9.14 Controller design

```

1 // Controller design for the case study presented in
    Example 9.12 on page 347.
2 // 9.14
3
4 exec('tf.sci',-1);
5 exec('desired.sci',-1);
6 exec('zpowk.sci',-1);
7 exec('myc2d.sci',-1);
8 exec('polsplit3.sci',-1);
9 exec('polmul.sci',-1);
10 exec('polsize.sci',-1);
11 exec('xdync.sci',-1);
12 exec('rowjoin.sci',-1);
13 exec('left_prm.sci',-1);
14 exec('t1calc.sci',-1);

```

```

15 exec('indep.sci',-1);
16 exec('pp_im2.sci',-1);
17 exec('seshft.sci',-1);
18 exec('makezero.sci',-1);
19 exec('move_sci.sci',-1);
20 exec('colsplit.sci',-1);
21 exec('clcoef.sci',-1);
22 exec('cindep.sci',-1);
23 exec('cosfil_ip.sci',-1);
24
25 num = 200;
26 den = convol([0.05 1],[0.05 1]);
27 den = convol([10 1],den);
28 G = tf(num,den); Ts = 0.025;
29 num = G('num'); den = G('den');
30 // iodel = 0;
31 [B,A,k] = myc2d(G,Ts);
32 [zk,dzk] = zpowk(k); //int1 = 0;
33
34 // Transient specifications
35 a = 0.9; rise = 0.24; epsilon = 0.05;
36 phi = desired(Ts,rise,epsilon);
37
38 // Controller design
39 Delta = [1 -1]; // internal model of step is present
40 [Rc,Sc,Tc,gamm] = pp_im2(B,A,k,phi,Delta,a);
41
42 // margin calculation
43 Lnum = convol(Sc,convol(B,zk));
44 Lden = convol(Rc,A);
45 L = tf(Lnum,Lden,Ts);
46 Gm = g_margin(L); //----- Does not match
         _____ (in dB)
47 Pm = p_margin(L); //----- Convergence problem
         _____ (in degree)
48
49 num1 = 100; den1 = [10 1];
50 Gd = tf(num1,den1); //-----

```

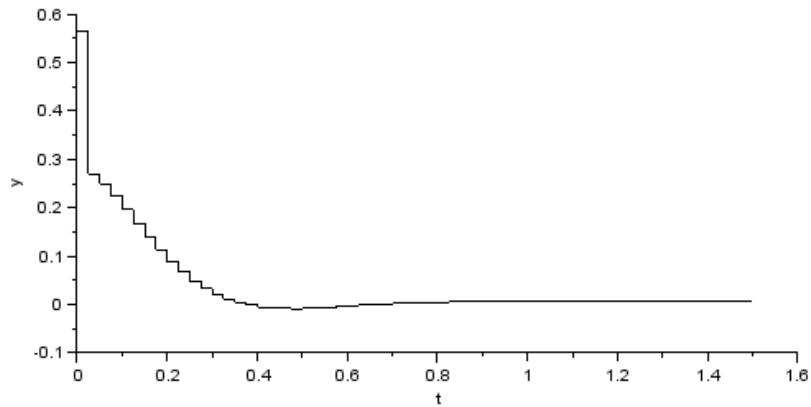


Figure 9.11: Controller design

```

51 [C,D,k1] = myc2d(Gd,Ts);
52 [zk,dzk] = zpowk(k);
53 C = convol(C,zk);
54
55 // simulation parameters g_s_cl2.xcos
56 N = 1;
57 st = 1; // desired change in setpoint
58 st1 = 0; // magnitude of disturbance
59 t_init = 0; // simulation start time
60 t_final = 1.5; // simulation end time
61
62 [Tc1,Tc2] = cosfil_ip(Tc,1); // Tc/1
63 [Np,Rc] = cosfil_ip(N,Rc); // N/Rc
64 [Sc1,Sc2] = cosfil_ip(Sc,1); // Sc/1
65 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

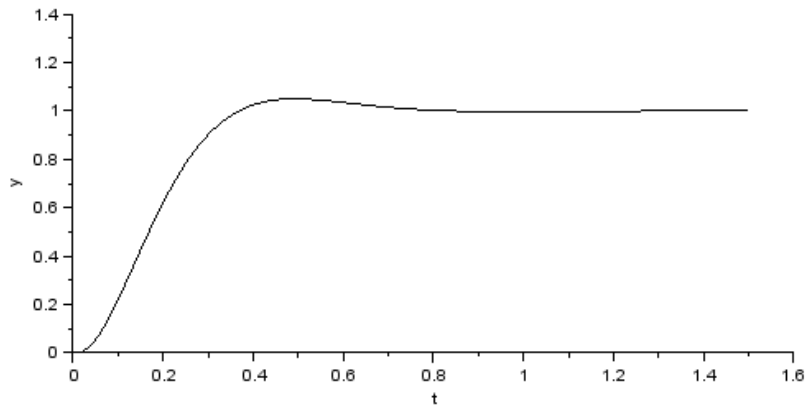


Figure 9.12: Controller design

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in) This code

can be downloaded from the website [www.scilab.in](http://www.scilab.in)

#### Scilab code Exa 9.15 Evaluation of continuous time controller

```

1 // Evaluation of continuous time controller for the
   case study presented in Example 9.13 on page 349.
2 // 9.15
3
4 clear
5 exec('tf.sci',-1);
6 exec('myc2d.sci',-1);
7 exec('zpowk.sci',-1);
8 exec('cosfil_ip.sci',-1);
9 exec('polyno.sci',-1);
10

```



```

11 num = 200;
12 den = convol([0.05 1],[0.05 1]);
13 den = convol([10 1],den);
14 G = tf(num,den); Ts = 0.005;
15 [B,A,k] = myc2d(G,Ts);
16 [zk,dzk] = zpowk(k); //int = 0;
17
18 // Sigurd's feedback controller'
19 numb = 0.5*convol([1 2],[0.05 1]);
20 denb = convol([1 0],[0.005 1]);
21 Gb = tf(numb,denb);
22 [Sb,Rb,kb] = myc2d(Gb,Ts);
23 [zkb,dzkb] = zpowk(kb);
24 Sb = convol(Sb,zkb);
25
26 // Sigurd's feed forward controller'
27 numf = [0.5 1];
28 denf = convol([0.65 1],[0.03 1]);
29 Gf = tf(numf,denf);
30 [Sf,Rf,kf] = myc2d(Gf,Ts);
31 [zkf,dzkf] = zpowk(kf);
32 Sf = convol(Sf,zkf);
33
34 // Margins
35 simp_mode(%f);
36 L = G*Gb;
37 Gm = g_margin(L); // -----
38 Pm = p_margin(L); // -----
39 Lnum = convol(Sb,convol(zk,B));
40 Lden = convol(Rb,A);
41 L = tf(Lnum,Lden,Ts);
42 DGm = g_margin(L); // -----
43 DPm = p_margin(L); // -----
44
45 // Noise
46 num1 = 100; den1 = [10 1];
47
48 // simulation parameters for

```

```

49 // entirely continuous simulation: g_s_cl3.xcos
50 // hybrid simulation: g_s_cl6.xcos
51 st = 1; // desired change in setpoint
52 st1 = 0;
53 t_init = 0; // simulation start time
54 t_final = 5; // simulation end time
55
56 num = polyno(num, 's'); den = polyno(den, 's');
57 Numb = polyno(numb, 's'); Denb = polyno(denb, 's');
58 Numf = polyno(numf, 's'); Denf = polyno(denf, 's');
59 Num1 = polyno(num1, 's'); Den1 = polyno(den1, 's');
60
61 [Sbp, Rbp] = cosfil_ip(Sb, Rb);
62 [Sfp, Rfp] = cosfil_ip(Sf, Rf);

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

#### Scilab code Exa 9.16 System type with 2 DOF controller

```

1 // System type with 2-DOF controller. It is used to
  // arrive at the results Example 9.14.
2 // 9.16
3
4 exec('polsplit3.sci', -1);
5 exec('polmul.sci', -1);
6 exec('polsize.sci', -1);
7 exec('pp_im.sci', -1);
8 exec('xdync.sci', -1);
9 exec('rowjoin.sci', -1);
10 exec('left_prm.sci', -1);
11 exec('t1calc.sci', -1);
12 exec('indep.sci', -1);
13 exec('makezero.sci', -1);
14 exec('move.sci.sci', -1);

```

```

15 exec('colsplit.sci',-1);
16 exec('clcoef.sci',-1);
17 exec('cindep.sci',-1);
18 exec('seshft.sci',-1);
19 exec('zpowk.sci',-1);
20 exec('cosfil_ip.sci',-1);
21 exec('polyno.sci',-1);
22
23 B = 1; A = [1 -1]; k = 1; zk = zpowk(k); Ts = 1;
24 phi = [1 -0.5];
25
26 Delta = 1; // Choice of internal model of step
27 [Rc,Sc,Tc,gamm] = pp_im(B,A,k,phi,Delta);
28
29 // simulation parameters for stb_disc.xcos
30 st = 1; // desired step change
31 t_init = 0; // simulation start time
32 t_final = 20; // simulation end time
33 xInitial = [0 0];
34 C = 0; D = 1; N_var = 0;
35
36 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
37 [Rcp1,Rcp2] = cosfil_ip(1,Rc); // 1/Rc
38 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
39 [Bp,Ap] = cosfil_ip(B,A); // B/A
40 [zkp1,zkp2] = cosfil_ip(zk,1); // zk/1
41 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

**Scilab code Exa 9.17** Illustrating the benefit of cancellation

```

1 // Illustrating the benefit of cancellation. It is
  used to arrive at the results of Example 9.15.
2 // 9.17
3
4 exec('pp_im.sci',-1);

```

```

5  exec('pp_pid.sci',-1);
6  exec('zpowk.sci',-1);
7  exec('polmul.sci',-1);
8  exec('polsize.sci',-1);
9  exec('xdync.sci',-1);
10 exec('rowjoin.sci',-1);
11 exec('left_prm.sci',-1);
12 exec('t1calc.sci',-1);
13 exec('indep.sci',-1);
14 exec('seshft.sci',-1);
15 exec('makezero.sci',-1);
16 exec('move_sci.sci',-1);
17 exec('colsplit.sci',-1);
18 exec('clcoef.sci',-1);
19 exec('cindep.sci',-1);
20 exec('polyno.sci',-1);
21 exec('cosfil_ip.sci',-1);
22
23
24 // test problem to demonstrate benefits of 2_dof
25 // Ts = 1; B = [1 0.9]; A = conv([1 -1],[1 -0.8]); k
   = 1;
26 Ts = 1; k = 1;
27 B = convol([1 0.9],[1 -0.8]); A = convol([1 -1],[1
   -0.5]);
28
29 // closed loop characteristic polynomial
30 phi = [1 -1 0.5];
31
32 Delta = 1; // Choice of internal model of step
33 control = 1;
34 if control == 1, // 1-DOF with no cancellation
35     [Rc,Sc] = pp_pid(B,A,k,phi,Delta);
36     Tc = Sc; gamm = 1;
37 else // 2-DOF
38     [Rc,Sc,Tc,gamm] = pp_im(B,A,k,phi,Delta);
39 end
40

```

```

41 // simulation parameters for stb_disc.mdl
42 [zk,dzk] = zpowk(k);
43 st = 1; // desired step change
44 t_init = 0; // simulation start time
45 t_final = 20; // simulation end time
46 xInitial = [0 0];
47 C = 0; D = 1; N_var = 0;
48
49 [Tc1,Tc2] = cosfil_ip(Tc,1); // Tc/1
50 [Rcp1,Rcp2] = cosfil_ip(1,Rc); // 1/Rc
51 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
52 [Bp,Ap] = cosfil_ip(B,A); // B/A
53 [zcp1,zcp2] = cosfil_ip(zk,1); // zk/1
54 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

#### Scilab code Exa 9.18 Anti windup control of IBM Lotus Domino server

```

1 // Anti windup control (AWC) of IBM Lotus Domino
  server, studied in Example 9.16 on page 357. It
  can be used for the following situations: with
  and without saturation, and with and without AWC.
2 // 9.18
3
4 exec('pp_im2.sci',-1);
5 exec('desired.sci',-1);
6 exec('zpowk.sci',-1);
7 exec('cosfil_ip.sci',-1);
8 exec('polsplit3.sci',-1);
9 exec('polmul.sci',-1);
10 exec('polsize.sci',-1);
11 exec('xdync.sci',-1);
12 exec('rowjoin.sci',-1);

```

```

13 exec('left_prm.sci',-1);
14 exec('t1calc.sci',-1);
15 exec('indep.sci',-1);
16 exec('seshft.sci',-1);
17 exec('makezero.sci',-1);
18 exec('move_sci.sci',-1);
19 exec('colsplit.sci',-1);
20 exec('clcoef.sci',-1);
21 exec('polyno.sci',-1);
22 exec('cindep.sci',-1);
23 exec('poladd.sci',-1);
24
25 // Transfer function
26 B = 0.47; A = [1 -0.43]; k = 1;
27 [zk,dzk] = zpowk(k);
28
29 // Transient specifications
30 rise = 10; epsilon = 0.01; Ts = 1;
31 phi = desired(Ts,rise,epsilon);
32
33 // Controller design
34 delta = [1 -1]; // internal model of step used
35 [Rc,Sc,Tc,gamm,F] = pp_im2(B,A,k,phi,delta);
36
37 // Study of Antiwindup Controller
38
39 key = x_choose(['Simulate without any saturation
    limits';
40     'Simulate saturation , but do not use AWC';
41     'Simulate saturation with AWC in place';
42     'Simulate with AWC, without saturation
    limits'],...
43     ['Please choose one of the following']);
44
45 if key ==0
46     disp('Invalid choice');
47     return;
48 elseif key == 1

```

```

49   U = 2; L = -2; P = 1; F = Rc; E = 0; PSc = Sc; PTc
      = Tc;
50   elseif key == 2
51     U = 1; L = -1; P = 1; F = Rc; E = 0; PSc = Sc; PTc
      = Tc;
52   else
53     if key == 3 // Antiwindup controller and with
      saturation
54       U = 1; L = -1;
55     elseif key == 4 // Antiwindup controller , but no
      saturation
56       U = 2; L = -2;
57     end
58     P = A;
59     dF = length(F) - 1;
60     PRc = convol(P,Rc); dPRc = length(PRc) - 1;
61     [E,dE] = poladd(F,dF,-PRc,dPRc);
62     PSc = convol(P,Sc); PTc = convol(P,Tc);
63   end
64
65   // Setting up simulation parameters for stb_disc_sat
66   t_init = 0; // first step begins
67   st = 1; // height of first step
68   t_init2 = 500; // second step begins
69   st2 = -2; // height of second step
70   t_final = 1000; // simulation end time
71   st1 = 0; // no disturbance input
72   C = 0; D = 1; N_var = 0;
73
74   [PTcp1,PTcp2] = cosfil_ip(PTc,1); // PTc/1
75   [Fp1,Fp2] = cosfil_ip(1,F); // 1/F
76   [Ep,Fp] = cosfil_ip(E,F); // E/F
77   [PScp1,PScp2] = cosfil_ip(PSc,1); // PSc/1
78   [Bp,Ap] = cosfil_ip(B,A); // B/A
79   [zkp1,zkp2] = cosfil_ip(zk,1); // zk/1
80   [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in) This code

can be downloaded from the website [www.scilab.in](http://www.scilab.in)

**Scilab code Exa 9.19** Demonstration of usefulness of negative PID parameters

```
1 // Demonstration of usefulness of negative PID
  parameters, discussed in Example 9.17 on page
  361.
2 // 9.19
3
4 exec('iodelay.sci',-1);
5 exec('delc2d.sci',-1);
6 exec('desired.sci',-1);
7 exec('pp_pid.sci',-1);
8 exec('cosfil_ip.sci',-1);
9 exec('tf.sci',-1);
10 exec('flip.sci',-1);
11 exec('zpowk.sci',-1);
12 exec('polmul.sci',-1);
13 exec('polsize.sci',-1);
14 exec('xdync.sci',-1);
15 exec('rowjoin.sci',-1);
16 exec('left_prm.sci',-1);
17 exec('t1calc.sci',-1);
18 exec('indep.sci',-1);
19 exec('seshft.sci',-1);
20 exec('makezero.sci',-1);
21 exec('move_sci.sci',-1);
22 exec('colsplit.sci',-1);
23 exec('clcoef.sci',-1);
```



```

24 exec('cindep.sci',-1);
25
26 // Discretize the continuous plant
27 num = 1; den = [2 1]; tau = 0.5;
28 G1 = tf(num,den);
29 G = iodelay(G1,tau);
30 Ts = 0.5;
31 [B,A,k] = delc2d(G,G1,Ts);
32
33 // Specify transient requirements
34 epsilon = 0.05; rise = 5;
35 phi = desired(Ts,rise,epsilon);
36
37 // Design the controller
38 Delta = [1 -1];
39 [Rc,Sc] = pp_pid(B,A,k,phi,Delta);
40
41 // parameters for simulation using g_s_cl
42 Tc = Sc; gamm = 1; N = 1;
43 C = 0; D = 1; N_var = 0;
44 st = 1; t_init = 0; t_final = 20;
45
46 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
47 [Np,Rcp] = cosfil_ip(N,Rc); // N/Rc
48 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
49 [Cp,Dp] = cosfil_ip(C,D); // C/D
50 Num = numer(G1);
51 Den = denom(G1);

```

---

Scilab code Exa 9.20 PID controller design

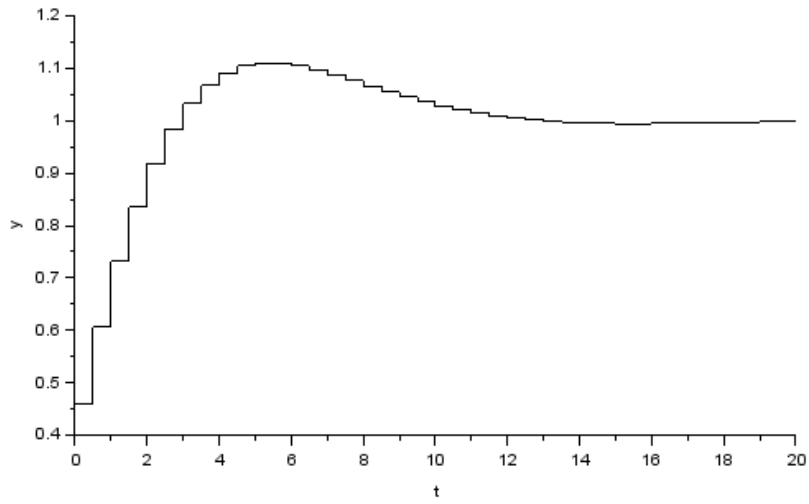


Figure 9.13: Demonstration of usefulness of negative PID parameters

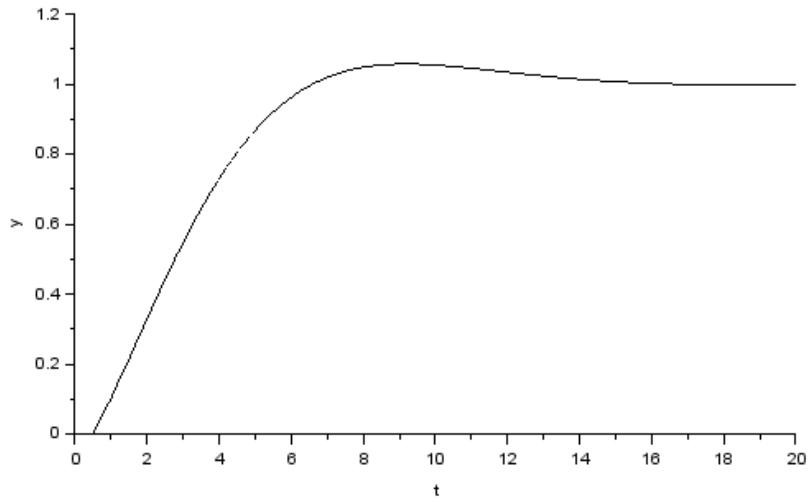


Figure 9.14: Demonstration of usefulness of negative PID parameters

```

1 // Solution to Aryabhata's identity arising in PID
  controller design, namely Eq. 9.37 on page 363.
2 // 9.20
3
4 function [Rc,Sc] = pp_pid(B,A,k,phi,Delta)
5
6 // Setting up and solving Aryabhata identity
7 dB = length(B) - 1; dA = length(A) - 1;
8 [zk,dzk] = zpowk(k);
9 [N,dN] = polmul(B,dB,zk,dzk);
10 dDelta = length(Delta)-1;
11 [D,dD] = polmul(A,dA,Delta,dDelta);
12 dphi = length(phi)-1;
13 [Sc,dSc,R,dR] = xdync(N,dN,D,dD,phi,dphi);
14 Rc = convol(R,Delta);
15 endfunction;

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in) This code

can be downloaded from the website [www.scilab.in](http://www.scilab.in)

**Scilab code Exa 9.21** DC motor with PID control tuned through pole placement technique

```

1 // DC motor with PID control, tuned through pole
  placement technique, as in Example 9.18.
2 // 9.21
3
4 exec('desired.sci',-1);
5 exec('pp_pid.sci',-1);
6 exec('cosfil_ip.sci',-1);
7 exec('pd.sci',-1);
8 exec('polyno.sci',-1);

```

```

 9  exec('myc2d.sci',-1);
10  exec('zpowk.sci',-1);
11  exec('polmul.sci',-1);
12  exec('polsize.sci',-1);
13  exec('xdync.sci',-1);
14  exec('rowjoin.sci',-1);
15  exec('left_prm.sci',-1);
16  exec('t1calc.sci',-1);
17  exec('indep.sci',-1);
18  exec('seshft.sci',-1);
19  exec('makezero.sci',-1);
20  exec('move_sci.sci',-1);
21  exec('colsplit.sci',-1);
22  exec('clcoef.sci',-1);
23  exec('cindep.sci',-1);
24
25  // Motor control problem
26  // Transfer function
27
28  a = [-1 0; 1 0]; b = [1; 0]; c = [0 1]; d = 0;
29  G = syslin('c',a,b,c,d); Ts = 0.25;
30  [B,A,k] = myc2d(G,Ts);
31  [Ds,num,den] = ss2tf(G);
32
33  // Transient specifications
34  rise = 3; epsilon = 0.05;
35  phi = desired(Ts,rise,epsilon);
36
37  // Controller design
38  Delta = 1; //No internal model of step used
39  [Rc,Sc] = pp_pid(B,A,k,phi,Delta);
40
41  // continuous time controller
42  [K,taud,N] = pd(Rc,Sc,Ts);
43  numb = K*[1 taud*(1+1/N)]; denb = [1 taud/N];
44  numf = 1; denf = 1;
45
46  // simulation parameters

```

```

47 st = 1; // desired change in position
48 t_init = 0; // simulation start time
49 t_final = 20; // simulation end time
50 st1 = 0;
51
52 // continuous controller simulation: g-s-cl3.xcos
53 num1 = 0; den1 = 1;
54
55 // discrete controller simulation: g-s-cl2.xcos
56 // ul: -0.1 to 0.8
57 // yl: 0 to 1.4
58 C = 0; D = 1; N = 1; gamm = 1; Tc = Sc;
59
60 [Tc1,Tc2] = cosfil_ip(Tc,1); // Tc/1
61 [Np,Rcp] = cosfil_ip(N,Rc); // N/Rc
62 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
63 [Cp,Dp] = cosfil_ip(C,D); // C/D
64 Numb = polyno(numb, 's');
65 Denb = polyno(denb, 's');
66 Numf = polyno(numf, 's');
67 Denf = polyno(denf, 's');
68 Num1 = polyno(num1, 's');
69 Den1 = polyno(den1, 's');

```

---

**Scilab code Exa 9.22** PD control law from polynomial coefficients

```

1 // PD control law from polynomial coefficients , as
  explained in Sec. 9.8.
2 // 9.22
3
4 function [K,taud,N] = pd(Rc,Sc,Ts)

```

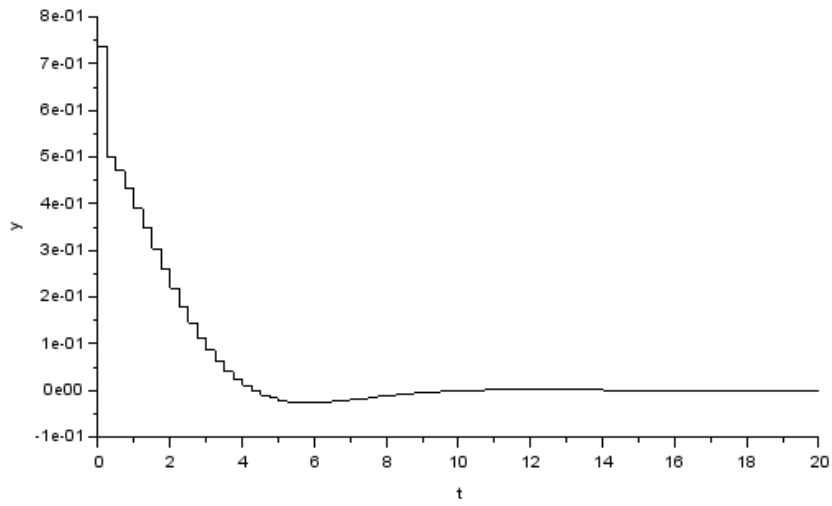


Figure 9.15: DC motor with PID control tuned through pole placement technique

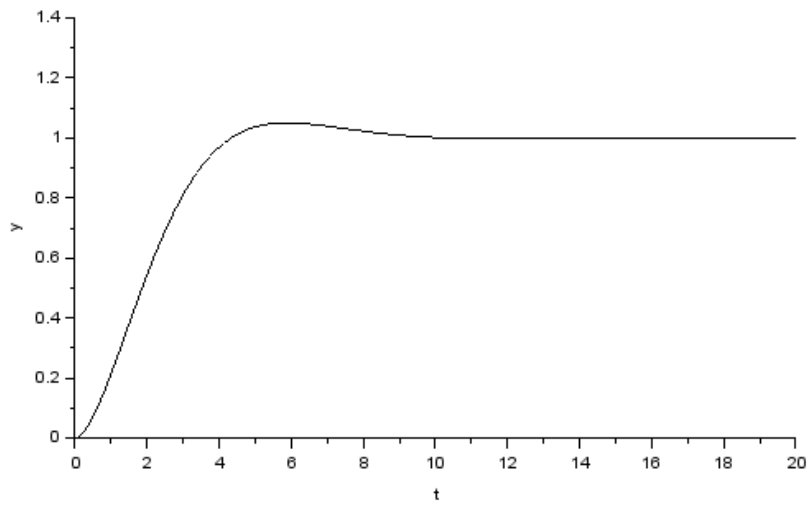


Figure 9.16: DC motor with PID control tuned through pole placement technique

```
5
6 // Both Rc and Sc have to be degree one polynomials
7
8 s0 = Sc(1); s1 = Sc(2);
9 r1 = Rc(2);
10 K = (s0+s1)/(1+r1);
11 N = (s1-s0*r1)/r1/(s0+s1);
12 taudbyN = -Ts*r1/(1+r1);
13 taud = taudbyN * N;
14 endfunction;
```

---

# Chapter 10

## Special Cases of Pole Placement Control

Scilab code Exa 10.1 Effect of delay in control performance

```
1 // Effect of delay in control performance
2 // 10.1
3
4 exec('zpowk.sci',-1);
5 exec('pp_im.sci',-1);
6 exec('cosfil_ip.sci',-1);
7 exec('polsplit3.sci',-1);
8 exec('polmul.sci',-1);
9 exec('polsize.sci',-1);
10 exec('xdync.sci',-1);
11 exec('rowjoin.sci',-1);
12 exec('left_prm.sci',-1);
13 exec('t1calc.sci',-1);
14 exec('indep.sci',-1);
15 exec('seshft.sci',-1);
16 exec('makezero.sci',-1);
17 exec('move_sci.sci',-1);
18 exec('colsplit.sci',-1);
19 exec('clcoef.sci',-1);
```



```

20 exec('cindep.sci',-1);
21 exec('polyno.sci',-1);
22
23 Ts = 1; B = 0.63; A = [1 -0.37];
24 k = input('Enter the delay as an integer: ');
25 if k<=0, k = 1; end
26 [zk,dzk] = zpowk(k);
27
28 // Desired transfer function
29 phi = [1 -0.5];
30 delta = 1; // internal model of step introduced
31
32 // Controller design
33 [Rc,Sc,Tc,gamm] = pp_im(B,A,k,phi,delta);
34
35 // simulation parameters for stb_disc.xcos
36 // yl: 0 to 1; ul: 0 to 1.2
37 st = 1.0; // desired change in setpoint
38 t_init = 0; // simulation start time
39 t_final = 20; // simulation end time
40
41 // simulation parameters for stb_disc.xcos
42 N_var = 0; C = 0; D = 1; N = 1;
43
44 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
45 [Rcp1,Rcp2] = cosfil_ip(1,Rc); // 1/Rc
46 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
47 [Bp,Ap] = cosfil_ip(B,A); // B/A
48 [zkp1,zkp2] = cosfil_ip(zk,1); // zk/1
49 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

**Scilab code Exa 10.2** Smith predictor for paper machine control

```

1 // Smith predictor for paper machine control in
   Example 10.2 on page 385.
2 // 10.2
3
4 exec('zpowk.sci',-1);
5 exec('poladd.sci',-1);
6 exec('polsize.sci',-1);
7 exec('pp_im.sci',-1);
8 exec('polsplit3.sci',-1);
9 exec('polmul.sci',-1);
10 exec('xdync.sci',-1);
11 exec('rowjoin.sci',-1);
12 exec('left_prm.sci',-1);
13 exec('t1calc.sci',-1);
14 exec('indep.sci',-1);
15 exec('makezero.sci',-1);
16 exec('move_sci.sci',-1);
17 exec('colsplit.sci',-1);
18 exec('clcoef.sci',-1);
19 exec('cindep.sci',-1);
20 exec('seshft.sci',-1);
21 exec('cosfil_ip.sci',-1);
22 exec('polyno.sci',-1);
23
24 Ts = 1; B = 0.63; A = [1 -0.37]; k = 3;
25 Bd = convol(B,[0 1]);
26 kd = k - 1;
27 [zkd,dzkd] = zpowk(kd);
28 [mzkd,dmzkd] = poladd(1,0,-zkd,dzkd);
29
30 // Desired transfer function
31 phi = [1 -0.5]; delta = 1;
32
33 // Controller design
34 [Rc,Sc,Tc,gamm] = pp_im(B,A,1,phi,delta);
35
36 // simulation parameters for smith_disc.xcos
37 st = 1.0; // desired change in setpoint

```

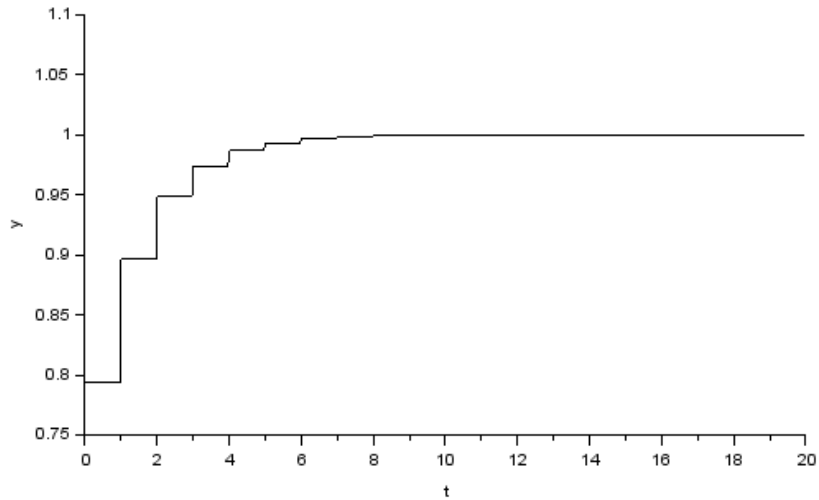


Figure 10.1: Smith predictor for paper machine control

```

38 t_init = 0; // simulation start time
39 t_final = 20; // simulation end time
40
41 // simulation parameters for smith_disc.xcos
42 N_var = 0; C = 0; D = 1; N = 1;
43
44 [Tc1,Tc2] = cosfil_ip(Tc,1); // Tc/1
45 [Rc1,Rc2] = cosfil_ip(1,Rc); // 1/Rc
46 [Sc1,Sc2] = cosfil_ip(Sc,1); // Sc/1
47 [Bd,Ap] = cosfil_ip(Bd,A); // Bd/Ad
48 [zkd1,zkd2] = cosfil_ip(zkd,1); // zkd/1
49 [mzkd1,mzkd2] = cosfil_ip(mzkd,1); // mzkd/1
50 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

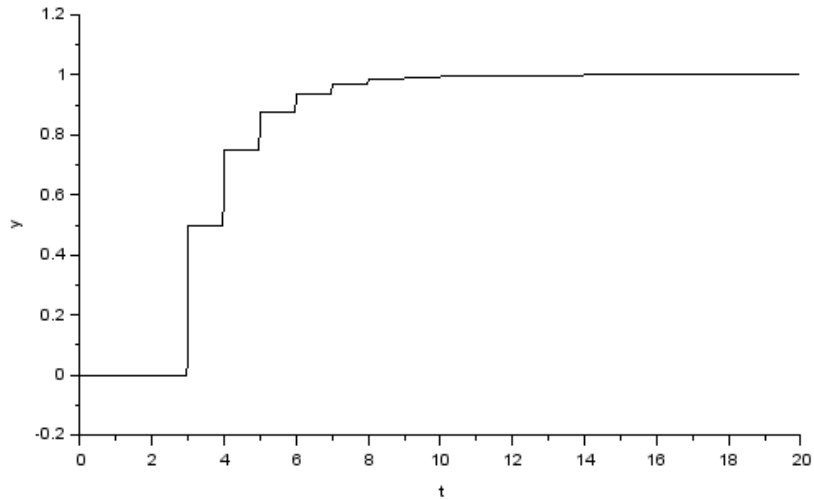


Figure 10.2: Smith predictor for paper machine control

### Scilab code Exa 10.3 Splitting a polynomial B

```

1 // Splitting a polynomial B(z)
2 // 10.3
3 // Splits a polynomial B into good, nonminimum with
4 // positive real & with negative real parts.
5 // All are returned in polynomial form.
6 // Gain is returned in Kp and delay in k.
7
8 function [Kp,k,Bg,Bnmp,Bm] = imcsplit(B,polynomial)
9 k = 0;
10 Kp = 1;
11 if(polynomial)
12     rts = roots(B);

```

```

13   Kp = sum(B)/sum(coeff(poly(rts,'z')));
14   else
15     rts = B;
16   end
17   Bg = 1; Bnmp = 1; Bm = 1;
18   for i = 1:length(rts),
19     rt = rts(i);
20     if rt == 0,
21       k = k+1;
22     elseif (abs(rt)<1 & real(rt)>=0)
23       Bg = convol(Bg,[1 -rt]);
24     elseif (abs(rt)>=1 & real(rt)>=0)
25       Bnmp = convol(Bnmp,[1 -rt]);
26     else
27       Bm = convol(Bm,[1 -rt]);
28     end
29   end

```

---

#### Scilab code Exa 10.4 Design of internal model controller

```

1 // Design of internal model controller
2 // 10.4
3 // Designs Discrete Internal Model Controller
4 // for transfer function  $z^{-k}B(z^{-1})/A(z^{-1})$ 
5 // Numerator and Denominator of IMC HQ are outputs
6 // Controller is also given in R,S form
7
8 function [k,HiN,HiD] = imc_stable1(B,A,k,alpha)
9
10 [Kp,d,Bg,Bnmp,Bm] = imcsplit(B,mtlb_logical(1));
11 Bg = Kp * Bg;
12 Bnmpr = flip(Bnmp);
13 Bms = sum(Bm);
14 HiN = A;
15 HiD = Bms * convol(Bg,Bnmpr);

```

```
16 k = k+d;
17 endfunction;
```

---

#### Scilab code Exa 10.5 Flipping a vector

```
1 // 10.5
2 function b = flip(a)
3 b = a(length(a):-1:1);
4 endfunction;
```

---

#### Scilab code Exa 10.6 IMC design for viscosity control problem

```
1 // IMC design for viscosity control problem
2 // 10.6
3
4 exec('imc_stable1.sci',-1);
5 exec('zpowk.sci',-1);
6 exec('imesplit.sci',-1);
7 exec('flip.sci',-1);
8
9 B = [0.51 1.21];
10 A = [1 -0.44];
11 k = 1;
12 alpha = 0.5;
13
14 [k,GiN,GiD] = imc_stable1(B,A,k,alpha);
15
16 [zk,dzk] = zpowk(k);
17 Bp = B; Ap = A;
18 Ts = 0.1; t0 = 0; tf = 20; Nvar = 0.01;
```

---

**Scilab code Exa 10.7** IMC design for the control of van de Vusse reactor

```
1 // IMC design for the control of van de Vusse
   reactor
2 // 10.7
3
4 exec('tf.sci');
5 exec('myc2d.sci');
6 exec('imc_stable1.sci');
7 exec('imcsplit.sci',-1);
8 exec('flip.sci',-1);
9 exec('zpowk.sci',-1);
10
11 num = [-1.117 3.1472]; den = [1 4.6429 5.3821];
12 G = tf(num,den);
13 Ts = 0.1;
14 [B,A,k] = myc2d(G,Ts);
15 alpha = 0.9;
16 [k,GiN,GiD] = imc_stable1(B,A,k,alpha);
17 [zk,dzk] = zpowk(k);
18 Bp = B; Ap = A;
19 t0 = 0; tfi = 10; st = 1; Nvar = 0;
```

---

**Scilab code Exa 10.8** IMC design for an example by Lewin

```
1 // IMC design for Lewin's example
2 // 10.8
3
4 exec('tf.sci');
5 exec('myc2d.sci');
6 exec('imc_stable1.sci');
7 exec('zpowk.sci',-1);
8 exec('imcsplit.sci',-1);
9 exec('flip.sci',-1);
10
```

```

11 num = 1; den = [250 35 1]; Ts = 3;
12 G = tf(num,den);
13
14 [B,A,k] = myc2d(G,Ts);
15
16 alpha = 0.9;
17 [k,GiN,GiD] = imc_stable1(B,A,k,alpha);
18
19 [zk,dzk] = zpowk(k);
20 Bp = B; Ap = A;
21 t0 = 0; tfi = 100; st = 1; Nvar = 0;

```

---

**Scilab code Exa 10.9** Design of conventional controller which is an equivalent of internal model controller

```

1 // Design of conventional controller which is an
   // equivalent of internal model controller
2 // 10.9
3
4 // Designs Discrete Internal Model Controller
5 // for transfer function  $z^{-k}B(z^{-1})/A(z^{-1})$ 
6 // Numerator and Denominator of IMC HQ are outputs
7 // Controller is also given in R,S form
8
9
10 function [k,HiN,HiD,R,S,mu] = imc_stable(B,A,k,alpha
   )
11
12 [Kp,d,Bg,Bnmp,Bm] = imcsplit(B,mtlb_logical(1));
13 Bg = Kp * Bg;
14
15 Bnmpr = flip(Bnmp);
16 Bms = sum(Bm);
17 HiN = A;
18 HiD = Bms * convol(Bg,Bnmpr);

```



```

19 k = k+d;
20
21 [zk,dzk] = zpowk(k);
22 Bf = (1-alpha);
23 Af = [1 -alpha];
24 S = convol(Bf,A);
25 R1 = convol(Af,convol(Bnmpr,Bms));
26 R2 = convol(zk,convol(Bf,convol(Bnmp,Bm)));
27
28 [R,dR] = poladd(R1,length(R1)-1,-R2,length(R2)-1);
29 R = convol(Bg,R);
30 endfunction;

```

---

**Scilab code Exa 10.10** Design of conventional controller for van de Vusse reactor problem

```

1 // Design of conventional controller for van de
  Vusse reactor problem
2 // 10.10
3
4 exec('tf.sci');
5 exec('myc2d.sci');
6 exec('imcsplit.sci',-1);
7 exec('imc_stable.sci');
8 exec('zpowk.sci',-1);
9 exec('flip.sci',-1);
10 exec('poladd.sci',-1);
11 exec('polsize.sci',-1);
12
13 num = [-1.117 3.1472]; den = [1 4.6429 5.3821];
14 G = tf(num,den);
15 Ts = 0.1;
16 [B,A,k] = myc2d(G,Ts);
17 alpha = 0.5;
18 [k,HiN,HiD,R,S] = imc_stable(B,A,k,alpha);

```

```
19 [zk,dzk] = zpowk(k);  
20 Bp = B; Ap = A;
```

---

# Chapter 11

## Minimum Variance Control

Scilab code Exa 11.1 Recursive computation of  $E_j$  and  $F_j$

```
1 // Recursive computation of  $E_j$  and  $F_j$ 
2 // 11.1
3
4 function [Fj,dFj,Ej,dEj] = recursion(A,dA,C,dC,j)
5 Fo = C; dFo = dC;
6 Eo = 1; dEo = 0;
7 A_z = A(2:dA+1); dA_z = dA-1;
8 zi = 1; dzi = 0;
9 for i = 1:j-1
10     if (dFo == 0)
11         Fn1 = 0;
12     else
13         Fn1 = Fo(2:(dFo+1));
14     end
15     dFn1 = max(dFo-1,0);
16     Fn2 = -Fo(1)*A_z; dFn2 = dA-1;
17     [Fn,dFn] = poladd(Fn1,dFn1,Fn2,dFn2);
18     zi = convol(zi,[0,1]); dzi = dzi + 1;
19     En2 = Fn(1)*zi; dEn2 = dzi;
20     [En,dEn] = poladd(Eo,dEo,En2,dEn2);
21     Eo = En; Fo = Fn;
```

```

22     dEo = dEn; dFo = dFn;
23 end
24 if (dFo == 0)
25     Fn1 = 0;
26 else
27 Fn1 = Fo(2:(dFo+1));
28 end;
29 dFn1 = max(dFo-1,0);
30 Fn2 = -Fo(1)*A_z; dFn2 = dA-1;
31 [Fn,dFn] = poladd(Fn1,dFn1,Fn2,dFn2);
32 Fj = Fn; dFj = dFn;
33 Ej = Eo; dEj = dEo;
34 endfunction;

```

---

**Scilab code Exa 11.2** Recursive computation of  $E_j$  and  $F_j$  for the system presented in Example

```

1 // Recursive computation of  $E_j$  and  $F_j$  for the system
  // presented in Example 11.2 on page 408.
2 // 11.2
3
4 exec('poladd.sci',-1);
5 exec('polsize.sci',-1);
6 exec('recursion.sci',-1);
7
8 C = [1 0.5]; dC = 1;
9 A = [1 -0.6 -0.16]; dA = 2;
10 j = 2;
11 [Fj,dFj,Ej,dEj] = recursion(A,dA,C,dC,j)

```

---

**Scilab code Exa 11.3** Solution of Aryabhata identity

```

1 // Solution of Aryabhata's identity Eq. 11.8, as
   discussed in Example 11.3 on page 409.
2 // 11.3
3
4 exec('xdync.sci',-1);
5 exec('rowjoin.sci',-1);
6 exec('polsize.sci',-1);
7 exec('left_prm.sci',-1);
8 exec('t1calc.sci',-1);
9 exec('indep.sci',-1);
10 exec('seshft.sci',-1);
11 exec('makezero.sci',-1);
12 exec('move_sci.sci',-1);
13 exec('colsplit.sci',-1);
14 exec('clcoef.sci',-1);
15 exec('cindep.sci',-1);
16
17 C = [1 0.5]; dC = 1; j=2;
18 A = [1 -0.6 -0.16]; dA = 2;
19 zj = zeros(1,j+1); zj(j+1) = 1;
20 [Fj,dFj,Ej,dEj] = xdync(zj,j,A,dA,C,dC)

```

---

**Scilab code Exa 11.4** 1st control problem by MacGregor

```

1 // MacGregor's first control problem, discussed in
   Example 11.4 on page 213.
2 // 11.4
3
4 exec('mv.sci',-1);
5 exec('cl.sci',-1);
6 exec('cosfil_ip.sci',-1);
7 exec('zpowk.sci',-1);
8 exec('xdync.sci',-1);
9 exec('rowjoin.sci',-1);
10 exec('polsize.sci',-1);

```

```

11 exec('left_prm.sci',-1);
12 exec('t1calc.sci',-1);
13 exec('indep.sci',-1);
14 exec('seshft.sci',-1);
15 exec('makezero.sci',-1);
16 exec('move_sci.sci',-1);
17 exec('colsplit.sci',-1);
18 exec('clcoef.sci',-1);
19 exec('cindep.sci',-1);
20 exec('polmul.sci',-1);
21 exec('poladd.sci',-1);
22 exec('tfvar.sci',-1);
23 exec('l2r.sci',-1);
24 exec('transp.sci',-1);
25 exec('tf.sci',-1);
26 exec('covar_m.sci',-1);
27 exec('polyno.sci',-1);
28
29 // MacGregor's first control problem
30 A = [1 -1.4 0.45]; dA = 2; C = [1 -0.5]; dC = 1;
31 B = 0.5*[1 -0.9]; dB = 1; k = 1; int1 = 0;
32 [Sc,dSc,Rc,dRc] = mv(A,dA,B,dB,C,dC,k,int1);
33 [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] = ...
34 cl(A,dA,B,dB,C,dC,k,Sc,dSc,Rc,dRc,int1);
35
36 // Simulation parameters for stb_disc.xcos
37 Tc = Sc; gamm = 1; [zk,dzk] = zpowk(k);
38 D = 1; N_var = 1; Ts = 1; st = 0;
39 t_init = 0; t_final = 1000;
40
41 [Tcp1,Tcp2] = cosfil_ip(Tc,1); // Tc/1
42 [Rcp1,Rcp2] = cosfil_ip(1,Rc); // 1/Rc
43 [Scp1,Scp2] = cosfil_ip(Sc,1); // Sc/1
44 [Bp,Ap] = cosfil_ip(B,A); // B/A
45 [zkp1,zkp2] = cosfil_ip(zk,1); // zk/1
46 [Cp,Dp] = cosfil_ip(C,D); // C/D

```

---

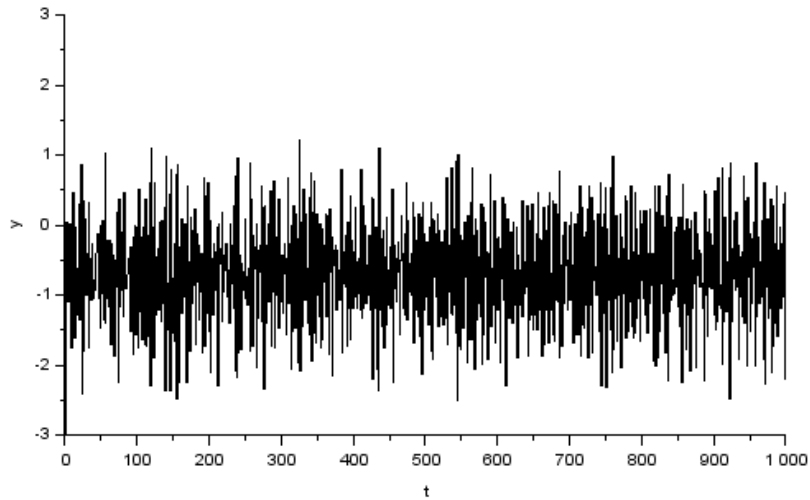


Figure 11.1: 1st control problem by MacGregor

This code can be downloaded from the website [www.scilab.in](http://www.scilab.in)

**Scilab code Exa 11.5** Minimum variance control law design

```

1 // Minimum variance control law design , given by Eq.
  // 11.40 on page 413.
2 // 11.5
3
4 // function [S,dS,R,dR] = mv(A,dA,B,dB,C,dC,k,int)
5 // implements the minimum variance controller
6 // if int>=1, integrated noise is assumed; otherwise
  ,

```

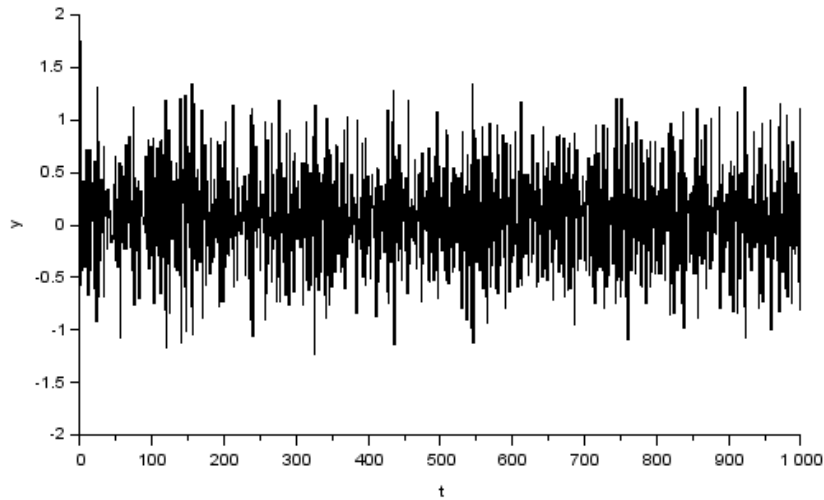


Figure 11.2: 1st control problem by MacGregor

```

7 // it is not integrated noise
8
9 function [S,dS,R,dR] = mv(A,dA,B,dB,C,dC,k,int1)
10 zk = zeros(1,k+1); zk(k+1) = 1;
11 if int1>=1, [A,dA] = polmul([1 -1],1,A,dA); end
12 [Fk,dFk,Ek,dEk] = xdync(zk,k,A,dA,C,dC);
13
14 [Gk,dGk] = polmul(Ek,dEk,B,dB);
15 S = Fk; dS = dFk; R = Gk; dR = dGk;
16 endfunction;

```

---

#### Scilab code Exa 11.6 Calculation of closed loop transfer functions

```

1 // Calculation of closed loop transfer functions
2 // 11.6
3
4 // function [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar]
   = ...

```



```

5 //      cl(A,dA,B,dB,C,dC,k,S,dS,R,dR,int)
6 // int>=1 means integrated noise and control law:
7 // delta u = - (S/R)y
8 // Evaluates the closed loop transfer function and
9 // variances of input and output
10
11 function [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] =
    ...
12      cl(A,dA,B,dB,C,dC,k,S,dS,R,dR,int1)
13 [zk,dzk] = zpowk(k);
14
15 [BS,dBS] = polmul(B,dB,S,dS);
16 [zBS,dzBS] = polmul(zk,dzk,BS,dBS);
17 [RA,dRA] = polmul(R,dR,A,dA);
18 if int1>=1, [RA,dRA] = polmul(RA,dRA,[1 -1],1); end
19
20 [D,dD] = poladd(RA,dRA,zBS,dzBS);
21
22 [Ny,dNy] = polmul(C,dC,R,dR);
23 [Nu,dNu] = polmul(C,dC,S,dS);
24
25 [Nu,dNu,Du,dDu,uvar] = tfvar(Nu,dNu,D,dD);
26 [Ny,dNy,Dy,dDy,yvar] = tfvar(Ny,dNy,D,dD);
27
28 endfunction;

```

---

**Scilab code Exa 11.7** Cancellation of common factors and determination of covariance

```

1 // Cancellation of common factors and determination
  // of covariance
2 // 11.7
3
4 // function [N,dN,D,dD,yvar] = tfvar(N,dN,D,dD)
5 // N and D polynomials in z-1 form; discrete case

```

```

6
7 function [N,dN,D,dD,yvar] = tfvar(N,dN,D,dD)
8
9 [N,dN,D,dD] = l2r(N,dN,D,dD);
10 N = N/D(1); D = D/D(1);
11 LN = length(N); LD = length(D);
12 D1 = D;
13 if LD<LN, D1 = [D zeros(1,LN-LD)]; dD1 = dD+LN-LD;
    end
14 H = tf(N,D1,1); //TS=1 (sampling time) has been taken
    constant in tfvar
15 yvar = covar_m(H,1);
16 endfunction;

```

---

#### Scilab code Exa 11.8 Computing sum of squares

```

1 // Computing sum of squares , as presented in Example
    11.5 on page 415.
2 // 11.8
3
4 exec('tf.sci',-1);
5 exec('covar_m.sci',-1);
6
7 Y = tf([1 0],[1 -0.9],-1);
8 covar_m(Y,1)

```

---

#### Scilab code Exa 11.9 Minimum variance control for nonminimum phase systems

```

1 // Minimum variance control for nonminimum phase
    systems
2 // 11.9
3

```

```

4 // function [Sc,dSc,Rc,dRc] = mv_mv(A,dA,B,dB,C,dC,k
    ,int)
5 // implements the minimum variance controller
6 // if int>=1, integrated noise is assumed; otherwise
    ,
7 // it is not integrated noise
8
9 function [Sc,dSc,Rc,dRc] = mv_nm(A,dA,B,dB,C,dC,k,
    int1)
10 if int1>=1, [A,dA] = polmul([1 -1],1,A,dA); end
11 [zk,dzk] = zpowk(k);
12 [Bzk,dBzk] = polmul(B,dB,zk,dzk);
13 [Bg,Bb] = polysplit3(B); Bbr = flip(Bb);
14 RHS = convol(C,convol(Bg,Bbr)); dRHS = length(RHS)
    -1;
15 [Sc,dSc,Rc,dRc] = xdync(Bzk,dBzk,A,dA,RHS,dRHS);
16 endfunction;

```

---

**Scilab code Exa 11.10** Minimum variance control for nonminimum phase example

```

1 // Minimum variance control for nonminimum phase
    example of Example 11.6 on page 416.
2 // 11.10
3
4 exec('mv_nm.sci',-1);
5 exec('cl.sci',-1);
6 exec('zpowk.sci',-1);
7 exec('polmul.sci',-1);
8 exec('polsize.sci',-1);
9 exec('polsplit3.sci',-1);
10 exec('flip.sci',-1);
11 exec('xdync.sci',-1);
12 exec('rowjoin.sci',-1);
13 exec('left_prm.sci',-1);

```

```

14 exec('t1calc.sci',-1);
15 exec('indep.sci',-1);
16 exec('seshft.sci',-1);
17 exec('makezero.sci',-1);
18 exec('move_sci.sci',-1);
19 exec('colsplitt.sci',-1);
20 exec('clcoef.sci',-1);
21 exec('cindep.sci',-1);
22 exec('poladd.sci',-1);
23 exec('tfvar.sci',-1);
24 exec('l2r.sci',-1);
25 exec('transp.sci',-1);
26 exec('tf.sci',-1);
27 exec('covar_m.sci',-1);
28
29 A = convol([1 -1],[1 -0.7]); dA = 2;
30 B = [0.9 1]; dB = 1; k = 1;
31 C = [1 -0.7]; dC = 1; int1 = 0;
32 [Sc,dSc,Rc,dRc] = mv_nm(A,dA,B,dB,C,dC,k,int1);
33 [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] = ...
34 cl(A,dA,B,dB,C,dC,k,Sc,dSc,Rc,dRc,int1);

```

---

**Scilab code Exa 11.11** Minimum variance control of viscosity control problem

```

1 // Minimum variance control of viscosity control
  problem
2 // 11.11
3
4 // Viscosity control problem of MacGregor
5
6 exec('mv_nm.sci',-1);
7 exec('polmul.sci',-1);
8 exec('polsize.sci',-1);
9 exec('zpowk.sci',-1);

```

```

10 exec('polsplit3.sci',-1);
11 exec('flip.sci',-1);
12 exec('xdync.sci',-1);
13 exec('rowjoin.sci',-1);
14 exec('left_prm.sci',-1);
15 exec('t1calc.sci',-1);
16 exec('indep.sci',-1);
17 exec('seshft.sci',-1);
18 exec('makezero.sci',-1);
19 exec('move_sci.sci',-1);
20 exec('colsplit.sci',-1);
21 exec('clcoef.sci',-1);
22 exec('cindep.sci',-1);
23 exec('cl.sci',-1);
24 exec('poladd.sci',-1);
25 exec('tfvar.sci',-1);
26 exec('l2r.sci',-1);
27 exec('transp.sci',-1);
28 exec('tf.sci',-1);
29 exec('covar_m.sci',-1);
30
31 A = [1 -0.44]; dA = 1; B = [0.51 1.21]; dB = 1;
32 C = [1 -0.44]; dC = 1; k = 1; int1 = 1;
33 [Sc,dSc,Rc,dRc] = mv_nm(A,dA,B,dB,C,dC,k,int1);
34 [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] = ...
35 cl(A,dA,B,dB,C,dC,k,Sc,dSc,Rc,dRc,int1);

```

---

### Scilab code Exa 11.12 General minimum variance controller design

```

1 // General minimum variance controller design, as
  // given by Eq. 11.66 on page 421 and Eq. 11.70 on
  // page 422.
2 // 11.12
3
4 // function [Sc,dSc,Rc,dRc] = gmv(A,dA,B,dB,C,dC,k,

```

```

    rho, int)
5 // implements the generalized minimum variance
  controller
6 // if int>=1, integrated noise is assumed; otherwise
  ,
7 // it is not integrated noise
8
9 function [Sc,dSc,R,dR] = gmv(A,dA,B,dB,C,dC,k,rho,
  int1)
10 zk = zeros(1,k+1); zk(k+1) = 1;
11 if int1>=1, [A,dA] = polmul([1 -1],1,A,dA); end
12 [Fk,dFk,Ek,dEk] = xdync(zk,k,A,dA,C,dC);
13 [Gk,dGk] = polmul(Ek,dEk,B,dB);
14 alpha0 = Gk(1)/C(1);
15 Sc = alpha0 * Fk; dSc = dFk;
16 [R,dR] = poladd(alpha0*Gk,dGk,rho*C,dC);
17 endfunction;

```

---

**Scilab code Exa 11.13** GMVC design of first example by MacGregor

```

1 // GMVC design of MacGregor's first example, as
  discussed in Example 11.9 on page 421.
2 // 11.13
3
4 // MacGregor's first control problem by gmv
5
6 exec('gmv.sci',-1);
7 exec('cl.sci',-1);
8 exec('xdync.sci',-1);
9 exec('rowjoin.sci',-1);
10 exec('polsize.sci',-1);
11 exec('left_prm.sci',-1);
12 exec('t1calc.sci',-1);
13 exec('indep.sci',-1);
14 exec('seshft.sci',-1);

```

```

15 exec('makezero.sci',-1);
16 exec('move_sci.sci',-1);
17 exec('colsplit.sci',-1);
18 exec('clcoef.sci',-1);
19 exec('cindep.sci',-1);
20 exec('polmul.sci',-1);
21 exec('zpowk.sci',-1);
22 exec('poladd.sci',-1);
23 exec('tfvar.sci',-1);
24 exec('l2r.sci',-1);
25 exec('transp.sci',-1);
26 exec('tf.sci',-1);
27 exec('covar_m.sci',-1);
28
29 A = [1 -1.4 0.45]; dA = 2; C = [1 -0.5]; dC = 1;
30 B = 0.5*[1 -0.9]; dB = 1; k = 1; int1 = 0;
31 rho = 1;
32 [Sc,dSc,Rc,dRc] = gmv(A,dA,B,dB,C,dC,k,rho,int1);
33 [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] = ...
34     cl(A,dA,B,dB,C,dC,k,Sc,dSc,Rc,dRc,int1);

```

---

#### Scilab code Exa 11.14 GMVC design of viscosity problem

```

1 // GMVC design of viscosity problem, as described in
   // Example 11.10 on page 423.
2 // 11.14
3
4 // MacGregor's Viscosity control problem by gmv
5
6 exec('gmv.sci',-1);
7 exec('cl.sci',-1);
8 exec('polmul.sci',-1);
9 exec('polsize.sci',-1);
10 exec('xdync.sci',-1);
11 exec('rowjoin.sci',-1);

```

```

12 exec('left_prm.sci',-1);
13 exec('t1calc.sci',-1);
14 exec('indep.sci',-1);
15 exec('seshft.sci',-1);
16 exec('makezero.sci',-1);
17 exec('move_sci.sci',-1);
18 exec('colsplit.sci',-1);
19 exec('clcoef.sci',-1);
20 exec('cindep.sci',-1);
21 exec('poladd.sci',-1);
22 exec('zpowk.sci',-1);
23 exec('tfvar.sci',-1);
24 exec('l2r.sci',-1);
25 exec('transp.sci',-1);
26 exec('tf.sci',-1);
27 exec('covar_m.sci',-1);
28
29 A = [1 -0.44]; dA = 1; B = [0.51 1.21]; dB = 1;
30 C = [1 -0.44]; dC = 1; k = 1; int1 = 1;
31 rho = 1;
32 [Sc,dSc,R1,dR1] = gmv(A,dA,B,dB,C,dC,k,rho,int1);
33 [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] = ...
34         cl(A,dA,B,dB,C,dC,k,Sc,dSc,R1,dR1,int1);

```

---

### Scilab code Exa 11.15 PID tuning through GMVC law

```

1 // PID tuning through GMVC law, as discussed in
  // Example 11.11.
2 // 11.15
3
4 exec('gmvc_pid.sci',-1);
5 exec('zpowk.sci',-1);
6 exec('ch_pol.sci',-1);
7 exec('polmul.sci',-1);
8 exec('polsize.sci',-1);

```



```

 9  exec('xdync.sci',-1);
10  exec('rowjoin.sci',-1);
11  exec('left_prm.sci',-1);
12  exec('t1calc.sci',-1);
13  exec('indep.sci',-1);
14  exec('seshft.sci',-1);
15  exec('makezero.sci',-1);
16  exec('move_sci.sci',-1);
17  exec('colsplit.sci',-1);
18  exec('clcoef.sci',-1);
19  exec('cindep.sci',-1);
20  exec('filtval.sci',-1);
21  exec('polyno.sci',-1);
22
23  // GMVC PID tuning of example given by Miller et al.
24  // Model
25  A = [1 -1.95 0.935]; B = -0.015; k = 1; Ts = 1;
26
27  // Transient specifications
28  N = 15; epsilon = 0.1;
29  T = ch_pol(N,epsilon);
30
31  // Controller Design
32  [Kc,tau_i,tau_d,L] = gmvc_pid(A,B,k,T,Ts);
33  L1 = filtval(L,1);
34  zk = zpowk(k);

```

---

**Scilab code Exa 11.16** Value of polynomial p evaluated at x

```

1  // Value of polynomial p(x), evaluated at x
2  // 11.16
3
4  // finds the value of a polynomial in powers of z
   ^{-1}
5  // function Y = filtval(P,z)

```

```

6
7 function Y = filtval(P,z)
8 N = length(P)-1;
9 Q = polyno(P,'x');
10 Y = horner(Q,z)/z^N;
11 endfunction;

```

---

### Scilab code Exa 11.17 PID tuning through GMVC law

```

1 // PID tuning through GMVC law
2 // 11.17
3
4 // function [Kc,tau_i,tau_d,L] = gmvc_pid(A,B,k,T,Ts
5 )
6 // Determines p,i,d tuning parameters using GMVC
7 // Plant model: Integrated white noise
8 // A, B in discrete time form
9
10 function [Kc,tau_i,tau_d,L] = gmvc_pid(A,B,k,T,Ts)
11
12 dA = length(A)-1; dB = length(B)-1;
13 dT = length(T)-1;
14 if dA > 2,
15     disp('degree of A cannot be more than 2')
16     exit
17 elseif dB > 1,
18     disp('degree of B cannot be more than 1')
19     exit
20 elseif dT > 2,
21     disp('degree of T cannot be more than 2')
22     exit
23 end
24 delta = [1 -1]; ddelta = 1;
25 [Adelta,dAdelta] = polmul(A,dA,delta,ddelta);

```

```

26
27 [Q,dQ,P,dP] = ...
28 xdync(Adelta,dAdelta,B,dB,T,dT);
29 PAdelta = P(1)*Adelta;
30
31 [zk,dzk] = zpowk(k);
32 [E,degE,F,degF] = ...
33 xdync(PAdelta,dAdelta,zk,dzk,P,dP);
34 nu = P(1)*E(1)*B(1);
35 Kc = -1/nu*(F(2)+2*F(3));
36 tau_i = -(F(2)+2*F(3))/(F(1)+F(2)+F(3))*Ts;
37 tau_d = -F(3)/(F(2)+2*F(3))*Ts;
38 L(1) = 1+Ts/tau_i+tau_d/Ts;
39 L(2) = -(1+2*tau_d/Ts);
40 L(3) = tau_d/Ts;
41 L = Kc * L';
42 endfunction;

```

---

# Chapter 12

## Model Predictive Control

Scilab code Exa 12.1 Model derivation for GPC design

```
1 // Model derivation for GPC design in Example 12.1
   on page 439.
2 // 12.1
3
4 exec('xdync.sci',-1);
5 exec('polmul.sci',-1);
6 exec('flip.sci',-1);
7 exec('rowjoin.sci',-1);
8 exec('polsize.sci',-1);
9 exec('left_prm.sci',-1);
10 exec('t1calc.sci',-1);
11 exec('indep.sci',-1);
12 exec('seshft.sci',-1);
13 exec('makezero.sci',-1);
14 exec('move_sci.sci',-1);
15 exec('colsplit.sci',-1);
16 exec('clcoef.sci',-1);
17 exec('cindep.sci',-1);
18
19 // Camacho and Bordón's GPC example; model formation
20
```

```

21 A=[1 -0.8]; dA=1; B=[0.4 0.6]; dB=1; N=3; k=1;
22 D=[1 -1]; dD=1; AD=convol(A,D); dAD=dA+1; Nu=N+k;
23 zj = 1; dzj = 0; G = zeros(Nu);
24 H1 = zeros(Nu,k-1+dB); H2 = zeros(Nu,dA+1);
25
26 for j = 1:Nu,
27     zj = convol(zj,[0,1]); dzj = dzj + 1;
28     [Fj,dFj,Ej,dEj] = xdync(zj,dzj,AD,dAD,1,0);
29     [Gj,dGj] = polmul(B,dB,Ej,dEj);
30     G(j,1:dGj) = flip(Gj(1:dGj));
31     H1(j,1:k-1+dB) = Gj(dGj+1:dGj+k-1+dB);
32     H2(j,1:dA+1) = Fj;
33 end
34
35 G,H1,H2

```

---

Scilab code Exa 12.2 Calculates the GPC law

```

1 // Calculates the GPC law given by Eq. 12.19 on page
  441.
2 // 12.2
3
4 function [K,KH1,KH2,Tc,dTc,Sc,dSc,R1,dR1] = ...
5 gpc_bas(A,dA,B,dB,N,k,rho)
6 D=[1 -1]; dD=1; AD=convol(A,D); dAD=dA+1; Nu=N+1;
7 zj = 1; dzj = 0; G = zeros(Nu,Nu);
8 H1 = zeros(Nu,k-1+dB); H2 = zeros(Nu,dA+1);
9 for j = 1:Nu,
10     zj = convol(zj,[0,1]); dzj = dzj + 1;
11     [Fj,dFj,Ej,dEj] = xdync(zj,dzj,AD,dAD,1,0);
12     [Gj,dGj] = polmul(B,dB,Ej,dEj);
13     G(j,1:dGj) = flip(Gj(1:dGj));
14     H1(j,1:k-1+dB) = Gj(dGj+1:dGj+k-1+dB);
15     H2(j,1:dA+1) = Fj;
16 end

```

```

17 K = inv(G'*G+rho*eye(Nu,Nu))*G';
18 // Note: inverse need not be calculated
19 KH1 = K * H1; KH2 = K * H2;
20 R1 = [1 KH1(1,:)]; dR1 = length(R1)-1;
21 Sc = KH2(1,:); dSc = length(Sc)-1;
22 Tc = K(1,:); dTc = length(Tc)-1;
23 endfunction;

```

---

**Scilab code Exa 12.3** GPC design for the problem discussed on page 441

```

1 // GPC design for the problem discussed in Example
  12.2 on page 441.
2 // 12.3
3
4 exec('gpc_bas.sci',-1);
5 exec('xdync.sci',-1);
6 exec('rowjoin.sci',-1);
7 exec('polsize.sci',-1);
8 exec('left_prm.sci',-1);
9 exec('t1calc.sci',-1);
10 exec('indep.sci',-1);
11 exec('seshft.sci',-1);
12 exec('makezero.sci',-1);
13 exec('move_sci.sci',-1);
14 exec('colsplit.sci',-1);
15 exec('clcoef.sci',-1);
16 exec('cindep.sci',-1);
17 exec('polmul.sci',-1);
18 exec('flip.sci',-1);
19 exec('filtval.sci',-1);
20
21 // Camacho and Bordón's GPC example; Control law
22 A=[1 -0.8]; dA=1; B=[0.4 0.6]; dB=1; N=3; k=1; rho
   =0.8;
23 [K,KH1,KH2,Tc,dTc,Sc,dSc,R1,dR1] = ...

```

```

24 gpc_bas(A,dA,B,dB,N,k,rho)
25 // C=1; dC=0; [K,KH1,KH2,Tc,dTc,Sc,dSc,R1,dR1] = ...
26 // gpc_col(A,dA,B,dB,C,dC,N,k,rho)

```

---

#### Scilab code Exa 12.4 GPC design

```

1 // GPC design for the problem discussed in Example
  12.3.
2 // 12.4
3
4 exec('gpc_N.sci',-1);
5 exec('xdync.sci',-1);
6 exec('rowjoin.sci',-1);
7 exec('polsize.sci',-1);
8 exec('left_prm.sci',-1);
9 exec('t1calc.sci',-1);
10 exec('indep.sci',-1);
11 exec('seshft.sci',-1);
12 exec('makezero.sci',-1);
13 exec('move.sci.sci',-1);
14 exec('colsplit.sci',-1);
15 exec('clcoef.sci',-1);
16 exec('cindep.sci',-1);
17 exec('polmul.sci',-1);
18 exec('flip.sci',-1);
19
20 A=[1 -0.8]; dA=1; B=[0.4 0.6]; dB=1;
21 rho = 0.8; k = 1;
22 N1 = 0; N2 = 3; Nu = 2;
23
24 [K,KH1,KH2,Tc,dTc,Sc,dSc,R1,dR1] = ...
25 gpc_N(A,dA,B,dB,k,N1,N2,Nu,rho)

```

---

Scilab code Exa 12.5 Calculates the GPC law

```

1 // Calculates the GPC law given by Eq. 12.36 on page
  446.
2 // 12.5
3
4 function [K,KH1,KH2,Tc,dTc,Sc,dSc,R1,dR1] = ...
5 gpc_N(A,dA,B,dB,k,N1,N2,Nu,rho)
6 D=[1 -1]; dD=1; AD=convol(A,D); dAD=dA+1;
7 zj = 1; dzj = 0;
8 for i = 1:N1+k-1
9     zj = convol(zj,[0,1]); dzj = dzj + 1;
10 end
11 G = zeros(N2-N1+1,Nu+1);
12 H1 = zeros(N2-N1+1,k-1+dB); H2 = zeros(N2-N1+1,dA+1)
    ;
13 for j = k+N1:k+N2
14     zj = convol(zj,[0,1]); dzj = dzj + 1;
15     [Fj,dFj,Ej,dEj] = xdync(zj,dzj,AD,dAD,1,0);
16     [Gj,dGj] = polmul(B,dB,Ej,dEj);
17     if (j-k >= Nu)
18         G(j-(k+N1-1),1:Nu+1) = flip(Gj(j-k-Nu+1:j-k+1));
19     else
20         G(j-(k+N1-1),1:j-k+1) = flip(Gj(1:j-k+1));
21     end
22     H1(j-(k+N1-1),1:k-1+dB) = Gj(j-k+2:j+dB);
23     H2(j-(k+N1-1),1:dA+1) = Fj;
24 end
25 K = inv(G'*G+rho*eye(Nu+1,Nu+1))*G';
26 // Note: inverse need not be calculated
27 KH1 = K * H1; KH2 = K * H2;
28 R1 = [1 KH1(1,:)]; dR1 = length(R1)-1;
29 Sc = KH2(1,:); dSc = length(Sc)-1;
30 Tc = K(1,:); dTc = length(Tc)-1;
31 endfunction;

```

---



Scilab code Exa 12.6 Calculates the GPC law

```

1 // Calculates the GPC law given by Eq. 12.36 on page
   446.
2 // 12.6
3
4 function [K,KH1,KH2,Tc,dTc,Sc,dSc,R1,dR1] = ...
5 gpc_col(A,dA,B,dB,C,dC,N,k,rho)
6 D=[1 -1]; dD = 0; AD=convol(A,D); dAD=dA+1; zj=1;
   dzj=0;
7 Nu = N+1; G=zeros(Nu,Nu); H1=zeros(Nu,2*k+N-2+dB);
8 H2 = zeros(Nu,k+N+dA);
9 for j = 1:Nu,
10     zj = convol(zj,[0,1]); dzj = dzj + 1;
11     [Fj,dFj,Ej,dEj] = ...
12         xdync(zj,dzj,AD,dAD,C,dC);
13     [Nj,dNj,Mj,dMj] = ...
14         xdync(zj,dzj,C,dC,1,0);
15     [Gj,dGj] = polmul(Mj,dMj,Ej,dEj);
16     [Gj,dGj] = polmul(Gj,dGj,B,dB);
17     [Pj,dPj] = polmul(Mj,dMj,Fj,dFj);
18     [Pj,dPj] = poladd(Nj,dNj,Pj,dPj);
19     j,Fj,Ej,Mj,Nj,Gj,Pj
20     G(j,1:j) = flip(Gj(1:j));
21     H1(j,1:dGj-j+1) = Gj(j+1:dGj+1);
22     H2(j,1:dPj+1) = Pj;
23 end
24 K = inv(G'*G+rho*eye(Nu,Nu))*G'
25 // Note: inverse need not be calculated
26 KH1 = K * H1; KH2 = K * H2;
27 R1 = [1 KH1(1,:)]; dR1 = length(R1)-1;
28 Sc = KH2(1,:); dSc = length(Sc)-1;
29 Tc = K(1,:); dTc = length(Tc)-1;
30 endfunction;

```

### Scilab code Exa 12.7 GPC design for viscosity control

```
1 // GPC design for viscosity control in Example 12.4
   on page 446.
2 // 12.7
3
4 exec('gpc_col.sci',-1);
5 exec('poladd.sci',-1);
6 exec('xdync.sci',-1);
7 exec('rowjoin.sci',-1);
8 exec('polsize.sci',-1);
9 exec('left_prm.sci',-1);
10 exec('t1calc.sci',-1);
11 exec('indep.sci',-1);
12 exec('seshft.sci',-1);
13 exec('makezero.sci',-1);
14 exec('move_sci.sci',-1);
15 exec('colsplit.sci',-1);
16 exec('clcoef.sci',-1);
17 exec('cindep.sci',-1);
18 exec('polmul.sci',-1);
19 exec('flip.sci',-1);
20
21 // GPC control of viscosity problem
22 A=[1 -0.44]; dA=1; B=[0.51 1.21]; dB=1; N=2; k=1;
23 C = [1 -0.44]; dC = 1; rho = 1;
24
25 [K,KH1,KH2,Tc,dTc,Sc,dSc,R1,dR1] = ...
26 gpc_col(A,dA,B,dB,C,dC,N,k,rho)
```

---

### Scilab code Exa 12.8 GPC design

```

1 // GPC design for the problem discussed in Example
   12.3.
2 // 12.8
3
4 exec('gpc_Nc.sci',-1);
5 exec('xdync.sci',-1);
6 exec('rowjoin.sci',-1);
7 exec('polsize.sci',-1);
8 exec('left_prm.sci',-1);
9 exec('t1calc.sci',-1);
10 exec('indep.sci',-1);
11 exec('seshft.sci',-1);
12 exec('makezero.sci',-1);
13 exec('move_sci.sci',-1);
14 exec('colsplit.sci',-1);
15 exec('clcoef.sci',-1);
16 exec('cindep.sci',-1);
17 exec('polmul.sci',-1);
18 exec('poladd.sci',-1);
19 exec('flip.sci',-1);
20
21 A=[1 -0.44]; dA=1; B=[0.51 1.21]; dB=1;
22 C = [1 -0.44]; dC = 1;
23 k=1; N1 = 0; N2 = 2; Nu = 0; rho = 1;
24
25 [K,KH1,KH2,Tc,dTc,Sc,dSc,R1,dR1] = ...
26 gpc_Nc(A,dA,B,dB,C,dC,k,N1,N2,Nu,rho)

```

---

**Scilab code Exa 12.9** Calculates the GPC law

```

1 // Calculates the GPC law for different prediction
   and control horizons
2 // 12.9
3
4 function [K,KH1,KH2,Tc,dTc,Sc,dSc,R1,dR1] = ...

```

```

5 gpc_Nc(A,dA,B,dB,C,dC,k,N1,N2,Nu,rho)
6 D=[1 -1]; dD=1; AD=convol(A,D); dAD=dA+1;
7 zj = 1; dzj = 0;
8 for i = 1:N1+k-1
9     zj = convol(zj,[0,1]); dzj = dzj + 1;
10 end
11 M = 2*k+N2-2+dB; P = max(k+N2+dA-1,dC-1)
12 G = zeros(N2-N1+1,Nu+1); H1 = zeros(N2-N1+1,M);
13 H2 = zeros(N2-N1+1,P+1);
14 for j = k+N1:k+N2
15     zj = convol(zj,[0,1]); dzj = dzj + 1;
16     [Fj,dFj,Ej,dEj] = xdync(zj,dzj,AD,dAD,C,dC);
17     [Nj,dNj,Mj,dMj] = xdync(zj,dzj,C,dC,1,0);
18     [Gj,dGj] = polmul(Mj,dMj,Ej,dEj);
19     [Gj,dGj] = polmul(Gj,dGj,B,dB);
20     [Pj,dPj] = polmul(Mj,dMj,Fj,dFj);
21     [Pj,dPj] = poladd(Nj,dNj,Pj,dPj);
22     if (j-k >= Nu)
23         G(j-(k+N1-1),1:Nu+1) = flip(Gj(j-k-Nu+1:j-k+1));
24     else
25         G(j-(k+N1-1),1:j-k+1) = flip(Gj(1:j-k+1));
26     end
27     H1(j-(k+N1-1),1:j+k-2+dB) = Gj(j-k+2:2*j+dB-1);
28     dPj = max(j-1+dA,dC-1);
29     H2(j-(k+N1-1),1:dPj+1) = Pj;
30 end
31 K = inv(G'*G+rho*eye(Nu+1,Nu+1))*G';
32 // Note: inverse need not be calculated
33 KH1 = K * H1; KH2 = K * H2;
34 R1 = [1 KH1(1,:)]; dR1 = length(R1)-1;
35 Sc = KH2(1,:); dSc = length(Sc)-1;
36 Tc = K(1,:); dTc = length(Tc)-1;
37 endfunction;

```

---

Scilab code Exa 12.10 PID controller tuned with GPC

```

1 // PID controller , tuned with GPC, as discussed in
   Example 12.5 on page 452.
2 // 12.10
3
4 exec('gpc_pid.sci',-1);
5 exec('zpowk.sci',-1);
6 exec('xdync.sci',-1);
7 exec('rowjoin.sci',-1);
8 exec('polsize.sci',-1);
9 exec('left_prm.sci',-1);
10 exec('t1calc.sci',-1);
11 exec('indep.sci',-1);
12 exec('seshft.sci',-1);
13 exec('makezero.sci',-1);
14 exec('move_sci.sci',-1);
15 exec('colsplit.sci',-1);
16 exec('clcoef.sci',-1);
17 exec('cindep.sci',-1);
18
19 A = [1 -1.95 0.935];
20 B=-0.015;
21 C=1;
22 degA=2;
23 degB=0;
24 degC=0;
25 N1=1;
26 N2=5;
27 Nu=2;
28 gamm=0.05;
29 gamma_y=1;
30 lambda=0.02;
31
32 [Kp,Ki,Kd] = ...
33 gpc_pid(A,degA,B,degB,C,degC,N1,N2,Nu,lambda,gamm,
   gamma_y)

```

---

### Scilab code Exa 12.11 Predictive PID tuned with GPC

```
1 // Predictive PID, tuned with GPC, as explained in
   // Sec. 12.2.3.
2 // 12.11
3
4 function [Kp,Ki,Kd] = ...
5 gpc_pid(A,dA,B,dB,C,dC,N1,N2,Nu,lambda,gamm,gamma_y)
6 Adelta=convol(A,[1 -1]); G=[];
7 for i=N1:N2
8     zi=zpowk(i);
9     [E,dE,F,dF]=xdync(Adelta,dA+1,zi,i,C,dC);
10    [Gtilda,dGtilda,Gbar,dGbar] = ...
11    xdync(C,dC,zi,i,E*B,dE+dB);
12    for j = 1:i, Gtilda1(j)=Gtilda(i+1-j); end
13    Gtilda2 = Gtilda1.'; // Added because Scilab
   // forms a column vecor
14    // while Matlab forms a row vector, by default
15    if i<=Nu-1
16        G=[G;[Gtilda2,zeros(1,Nu-i)]];
17    else
18        G=[G;Gtilda2(1:Nu)];
19    end
20 end
21 es=sum(C)/sum(A); gs=sum(B)/sum(A); F_s=es*A; G_s
   =[];
22 for i=1:Nu
23     if ((Nu - i) == 0)
24         row=gs*ones(1,i);
25     else
26         row=gs*ones(1,i); row=[row,zeros(Nu-i,Nu-i)];
27     end;
28     G_s=[G_s;row];
29 end
```

```

30 lambda_mat=lambda*(diag(ones(1,Nu)));
31 gamma_mat=gamm*(diag(ones(1,Nu)));
32 gamma_y_mat=gamma_y*(diag(ones(1,N2-N1+1)));
33 mat1=inv(G'*gamma_y_mat*G+lambda_mat+G_s'*gamma_mat*
    G_s);
34 mat2=mat1*(G'*gamma_y_mat);
35 mat2_s=mat1*(G_s'*gamma_mat);
36 h_s=sum(mat2_s(1,:)); h=mat2(1,:);
37 T=C; R=C*(sum(h(:))+h_s); S=0;
38 for i=N1:N2
39     zi=zpowk(i);
40     [E,dE,F,dF]=xdync(Adelta,dA+1,zi,i,C,dC);
41     [Gtilde,dGtilde,Gbar,dGbar]=...
42     xdync(C,dC,zi,i,E*B,dE+dB);
43     S=S+F*h(i);
44 end
45 S=S+F_s*h_s;
46 if length(A)==3
47     Kp=S(1)-R-S(3); Ki=R; Kd=S(3);
48 else
49     Kp=S(1)-R; Ki=R; Kd=0;
50 end
51
52 endfunction;

```

---

# Chapter 13

## Linear Quadratic Gaussian Control

Scilab code Exa 13.1 Spectral factorization

```
1 // Spectral factorization , as discussed in Example
   13.3 on page 467.
2 // 13.1
3
4 exec('spec1.sci',-1);
5 exec('flip.sci',-1);
6 exec('polmul.sci',-1);
7 exec('polsize.sci',-1);
8 exec('poladd.sci',-1);
9
10 A = convol([-0.5 1],[-0.9 1]); dA = 2;
11 B = 0.5*[-0.9 1]; dB = 1; rho = 1;
12 [r,beta1,sigma] = spec1(A,dA,B,dB,rho)
```

---

Scilab code Exa 13.2 Function to implement spectral factorization



```

1 // Function to implement spectral factorization , as
  // discussed in sec. 13.1.
2 // 13.2
3
4 function [r,b,rbbr] = spec1(A,dA,B,dB,rho)
5 AA = rho * convol(A,flip(A));
6 BB = convol(B,flip(B));
7 diff1 = dA - dB;
8 dBB = 2*dB;
9 for i = 1:diff1
10     [BB,dBB] = polmul(BB,dBB,[0 1],1);
11 end
12 [rbbr,drbbr] = poladd(AA,2*dA,BB,dBB);
13 rts = roots(rbbr); // roots in descending order of
  // magnitude
14 rts = flip(rts);
15 rtsin = rts(dA+1:2*dA);
16 b = 1;
17 for i = 1:dA,
18     b = convol(b,[1 -rtsin(i)]);
19 end
20 br = flip(b);
21 bbr = convol(b,br);
22 r = rbbr(1) / bbr(1);
23 endfunction;

```

---

### Scilab code Exa 13.3 Spectral factorization

```

1 // Spectral factorization , to solve Eq. 13.47 on
  // page 471.
2 // 13.3
3
4 // function [r,b,dAFW] = ...
5 //     specfac(A,degA,B,degB,rho,V,degV,W,degW,F,degF
  // )

```

```

6 // Implements the spectral factorization for use
  with LQG control
7 // design method of Ahlen and Sternard
8
9 function [r,b,dAFW] = ...
10     specfac(A,degA,B,degB,rho,V,degV,W,degW,F,degF)
11 AFW = convol(A,convol(W,F));
12 dAFW = degA + degF + degW;
13 AFWWFA = rho * convol(AFW,flip(AFW));
14 BV = convol(B,V);
15 dBV = degB + degV;
16 BVVB = convol(BV,flip(BV));
17 diff1 = dAFW - dBV;
18 dBVVB = 2*dBV;
19 for i = 1:diff1
20     [BVVB,dBVVB] = polmul(BVVB,dBVVB,[0 1],1);
21 end
22 [rbb,drbb] = poladd(AFWWFA,2*dAFW,BVVB,dBVVB);
23 Rbb = polyno(rbb,'z');
24 rts = roots(Rbb);
25 rtsin = rts(dAFW+1:2*dAFW);
26 b = 1;
27 for i = 1:dAFW,
28     b = convol(b,[1 -rtsin(i)]);
29 end
30 b = real(b);
31 br = flip(b);
32 bbr = convol(b,br);
33 r = rbb(1) / bbr(1);
34 endfunction;

```

---

**Scilab code Exa 13.4** LQG control design by polynomial method

```

1 // LQG control design by polynomial method, to solve
  Eq. 13.51 on page 472.

```

```

2 // 13.4
3
4 // LQG controller design by method of Ahlen and
   Sternad
5 // function [R,degR,S,degS] = ...
6 // lqg(A,degA,B,degB,C,degC,k,rho,V,degV,W,degW,F,
   degF)
7
8 function [R,degR,S,degS] = ...
9 lqg1(A,degA,B,degB,C,degC,k,rho,V,degV,W,degW,F,degF
   )
10
11 [r,b,degb] = ...
12 specfac(A,degA,B,degB,rho,V,degV,W,degW,F,degF);
13
14 WFA = flip(convol(A,convol(F,W)));
15 dWFA = degW + degF + degA;
16
17 [rhs1,drhs1] = polmul(W,degW,WFA,dWFA);
18 [rhs1,drhs1] = polmul(rhs1,drhs1,C,degC);
19 rhs1 = rho * rhs1;
20 rhs2 = convol(C,convol(V,flip(convol(B,V))));
21 drhs2 = degC + 2*degV + degB;
22 for i = 1:degb-degB-degV,
23     rhs2 = convol(rhs2,[0,1]);
24 end
25 drhs2 = drhs2 + degb-degB-degV;
26 C1 = zeros(1,2);
27
28 [C1,degC1] = putin(C1,0,rhs1,drhs1,1,1);
29 [C1,degC1] = putin(C1,degC1,rhs2,drhs2,1,2);
30 rbf = r * flip(b);
31 D1 = zeros(2,2);
32 [D1,degD1] = putin(D1,0,rbf,degb,1,1);
33 for i = 1:k,
34     rbf = convol(rbf,[0 1]);
35 end
36 [D1,degD1] = putin(D1,degD1,rbf,degb+k,2,2);

```

```

37 N = zeros(1,2);
38 [N,degN] = putin(N,0,-B,degB,1,1);
39 [AF,dAF] = polmul(A,degA,F,degF);
40 [N,degN] = putin(N,degN,AF,dAF,1,2);
41
42 [Y,degY,X,degX] = xdync(N,degN,D1,degD1,C1,degC1);
43
44 [R,degR] = ext(X,degX,1,1);
45 [S,degS] = ext(X,degX,1,2);
46 X = flip(Y);
47
48 endfunction;

```

---

### Scilab code Exa 13.5 LQG design

```

1 // LQG design for the problem discussed in Example
   13.4 on page 472.
2 // 13.5
3
4 // MacGregor's first control problem
5
6 exec('lqg1.sci',-1);
7 exec('cl.sci',-1);
8 exec('specfac.sci',-1);
9 exec('flip.sci',-1);
10 exec('polmul.sci',-1);
11 exec('polsize.sci',-1);
12 exec('poladd.sci',-1);
13 exec('polyno.sci',-1);
14 exec('putin.sci',-1);
15 exec('xdync.sci',-1);
16 exec('rowjoin.sci',-1);
17 exec('left_prm.sci',-1);
18 exec('t1calc.sci',-1);
19 exec('indep.sci',-1);

```

```

20 exec('seshft.sci',-1);
21 exec('makezero.sci',-1);
22 exec('move_sci.sci',-1);
23 exec('colsplit.sci',-1);
24 exec('clcoef.sci',-1);
25 exec('cindep.sci',-1);
26 exec('ext.sci',-1);
27 exec('zpowk.sci',-1);
28 exec('tfvar.sci',-1);
29 exec('l2r.sci',-1);
30 exec('transp.sci',-1);
31 exec('tf.sci',-1);
32 exec('covar_m.sci',-1);
33
34 A = [1 -1.4 0.45]; dA = 2; C = [1 -0.5]; dC = 1;
35 B = 0.5*[1 -0.9]; dB = 1; k = 1; int1 = 0; F = 1; dF
    = 0;
36 V = 1; W = 1; dV = 0; dW = 0;
37 rho = 1;
38 [R1,dR1,Sc,dSc] = lqg1(A,dA,B,dB,C,dC,k,rho,V,dV,W,
    dW,F,dF)
39 [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] = ...
40     cl(A,dA,B,dB,C,dC,k,Sc,dSc,R1,dR1,int1);

```

---

**Scilab code Exa 13.6** LQG control design for viscosity control problem

```

1 // LQG control design for viscosity control problem
  // discussed in Example 13.5.
2 // 13.6
3
4
5 exec('lqg1.sci',-1);
6 exec('cl.sci',-1);
7 exec('specfac.sci',-1);
8 exec('flip.sci',-1);

```

```

9  exec('polmul.sci',-1);
10 exec('polsize.sci',-1);
11 exec('poladd.sci',-1);
12 exec('polyno.sci',-1);
13 exec('putin.sci',-1);
14 exec('xdync.sci',-1);
15 exec('rowjoin.sci',-1);
16 exec('left_prm.sci',-1);
17 exec('tlcalc.sci',-1);
18 exec('indep.sci',-1);
19 exec('seshft.sci',-1);
20 exec('makezero.sci',-1);
21 exec('move_sci.sci',-1);
22 exec('colsplit.sci',-1);
23 exec('clcoef.sci',-1);
24 exec('cindep.sci',-1);
25 exec('ext.sci',-1);
26 exec('zpowk.sci',-1);
27 exec('tfvar.sci',-1);
28 exec('l2r.sci',-1);
29 exec('transp.sci',-1);
30 exec('tf.sci',-1);
31 exec('covar_m.sci',-1);
32
33 // Viscosity control problem of MacGregor
34 A = [1 -0.44]; dA = 1; B = [0.51 1.21]; dB = 1;
35 C = [1 -0.44]; dC = 1; k = 1; int1 = 1; F = [1 -1];
    dF = 1;
36 V = 1; W = 1; dV = 0; dW = 0;
37 rho = 1;
38 [R1,dR1,Sc,dSc] = lqg1(A,dA,B,dB,C,dC,k,rho,V,dV,W,
    dW,F,dF);
39 [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] = ...
40    cl(A,dA,B,dB,C,dC,k,Sc,dSc,R1,dR1,int1);

```

---

### Scilab code Exa 13.7 Simplified LQG control design

```
1 // Simplified LQG control design , obtained by the
   // solution of Eq. 13.53 on page 476.
2 // 13.7
3
4 // LQG controller simple design by method of Ahlen
   // and Sternad
5 // function [R1,dR1,S,dS] = ...
6 // lgg_simple(A,dA,B,dB,C,dC,k,rho,V,dV,W,dW,F,dF)
7
8 function [R1,dR1,S,dS] = ...
9 lgg_simple(A,dA,B,dB,C,dC,k,rho,V,dV,W,dW,F,dF)
10 [r,b,db] = specfac(A,dA,B,dB,rho,V,dV,W,dW,F,dF);
11 [D,dD] = polmul(A,dA,F,dF);
12 [zk,dzk] = zpowk(k);
13 [N,dN] = polmul(zk,dzk,B,dB);
14 [RHS,dRHS] = polmul(C,dC,b,db);
15 [S,dS,R1,dR1] = xdync(N,dN,D,dD,RHS,dRHS);
16 endfunction;
```

---

### Scilab code Exa 13.8 LQG control design

```
1 // LQG control design for the problem discussed in
   // Example 13.6 on page 474.
2 // 13.8
3
4 // Solves Example 3.1 of Ahlen and Sternad in Hunt's
   // book
5 exec('lqg1.sci',-1);
6 exec('specfac.sci',-1);
7 exec('flip.sci',-1);
8 exec('polmul.sci',-1);
9 exec('polsize.sci',-1);
10 exec('poladd.sci',-1);
```

```

11 exec('polyno.sci',-1);
12 exec('putin.sci',-1);
13 exec('clcoef.sci',-1);
14 exec('xdync.sci',-1);
15 exec('rowjoin.sci',-1);
16 exec('left_prm.sci',-1);
17 exec('t1calc.sci',-1);
18 exec('indep.sci',-1);
19 exec('seshft.sci',-1);
20 exec('makezero.sci',-1);
21 exec('move_sci.sci',-1);
22 exec('colsplit.sci',-1);
23 exec('cindep.sci',-1);
24 exec('ext.sci',-1);
25
26 A = [1 -0.9]; dA = 1; B = [0.1 0.08]; dB = 1;
27 k = 2; rho = 0.1; C = 1; dC = 0;
28 V = 1; dV = 0; F = 1; dF = 0; W = [1 -1]; dW = 1;
29 [R1,dR1,Sc,dSc] = ...
30 lqg1(A,dA,B,dB,C,dC,k,rho,V,dV,W,dW,F,dF)

```

---

**Scilab code Exa 13.9** Performance curve for LQG control design of viscosity problem

```

1 // Performance curve for LQG control design of
  // viscosity problem
2 // 13.9
3
4 exec('lqg1.sci',-1);
5 exec('specfac.sci',-1);
6 exec('flip.sci',-1);
7 exec('polmul.sci',-1);
8 exec('polsize.sci',-1);
9 exec('poladd.sci',-1);
10 exec('polyno.sci',-1);

```



```

11 exec('putin.sci',-1);
12 exec('clcoef.sci',-1);
13 exec('xdync.sci',-1);
14 exec('rowjoin.sci',-1);
15 exec('left_prm.sci',-1);
16 exec('t1calc.sci',-1);
17 exec('indep.sci',-1);
18 exec('seshft.sci',-1);
19 exec('makezero.sci',-1);
20 exec('move_sci.sci',-1);
21 exec('colsplit.sci',-1);
22 exec('cindep.sci',-1);
23 exec('ext.sci',-1);
24 exec('cl.sci',-1);
25 exec('zpowk.sci',-1);
26 exec('tfvar.sci',-1);
27 exec('l2r.sci',-1);
28 exec('transp.sci',-1);
29 exec('tf.sci',-1);
30 exec('covar_m.sci',-1);
31
32 // MacGregor's Viscosity control problem
33 A = [1 -0.44]; dA = 1; B = [0.51 1.21]; dB = 1;
34 C = [1 -0.44]; dC = 1; k = 1; int1 = 1; F = [1 -1];
    dF = 1;
35 V = 1; W = 1; dV = 0; dW = 0;
36 u_lqg = []; y_lqg = []; uy_lqg = [];
37
38 for rho = 0.001:0.1:3,
39     [R1,dR1,Sc,dSc] = lqg1(A,dA,B,dB,C,dC,k,rho,V,dV
        ,W,dW,F,dF);
40     [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] = ...
41         cl(A,dA,B,dB,C,dC,k,Sc,dSc,R1,dR1,int1);
42     u_lqg = [u_lqg uvar]; y_lqg = [y_lqg yvar];
43     uy_lqg = [uy_lqg; [rho uvar yvar]];
44 end
45 plot(u_lqg,y_lqg,'g')
46 save('lqg_visc.dat','uy_lqg');

```

---

**Scilab code Exa 13.10** Performance curve for GMVC design of first control problem by MacGregor

```
1 // Performance curve for GMVC design of MacGregor's
   first control problem
2 // 13.10
3
4 exec('gmv.sci',-1);
5 exec('xdync.sci',-1);
6 exec('rowjoin.sci',-1);
7 exec('polsize.sci',-1);
8 exec('left_prm.sci',-1);
9 exec('t1calc.sci',-1);
10 exec('indep.sci',-1);
11 exec('seshft.sci',-1);
12 exec('makezero.sci',-1);
13 exec('move_sci.sci',-1);
14 exec('colsplitt.sci',-1);
15 exec('clcoef.sci',-1);
16 exec('cindep.sci',-1);
17 exec('polmul.sci',-1);
18 exec('poladd.sci',-1);
19 exec('cl.sci',-1);
20 exec('zpowk.sci',-1);
21 exec('tfvar.sci',-1);
22 exec('l2r.sci',-1);
23 exec('transp.sci',-1);
24 exec('tf.sci',-1);
25 exec('covar_m.sci',-1);
26
27 // MacGregor's first control problem
28 A = [1 -1.4 0.45]; dA = 2; C = [1 -0.5]; dC = 1;
29 B = 0.5*[1 -0.9]; dB = 1; k = 1; int1 = 0;
30 u_gmv = []; y_gmv = []; uy_gmv = [];
```

```
31
32 for rho = 0:0.1:10,
33     [S,dS,R,dR] = gmv(A,dA,B,dB,C,dC,k,rho,int1);
34     [Nu,dNu,Du,dDu,Ny,dNy,Dy,dDy,yvar,uvar] = ...
35         cl(A,dA,B,dB,C,dC,k,S,dS,R,dR,int1);
36     u_gmv = [u_gmv uvar]; y_gmv = [y_gmv yvar];
37     uy_gmv = [uy_gmv; [rho uvar yvar]];
38 end
39 plot(u_gmv,y_gmv,'b')
40 save('gmv_macl.dat','uy_gmv');
```

---

# Chapter 14

## State Space Techniques in Controller Design

Scilab code Exa 14.1 Pole placement controller for inverted pendulum

```
1 // Pole placement controller for inverted pendulum,  
  // discussed in Example 14.1 on page 490. 2.1 should  
  // be executed before starting this code  
2 // 14.1  
3  
4 exec('pol2cart.sci',-1);  
5  
6 C = eye(4,4);  
7 D = zeros(4,1);  
8 Ts = 0.01;  
9 G = syslin('c',A,B,C,D);  
10 H = dscl(G,Ts);  
11 [a,b,c,d] = H(2:5);  
12 rise = 5; epsilon = 0.1;  
13 N = rise/Ts;  
14 omega = %pi/2/N;  
15 r = epsilon^(omega/%pi);  
16 r1 = r; r2 = 0.9*r;  
17 [x1,y1] = pol2cart(omega,r1);
```

```

18 [x2,y2] = pol2cart(omega,r2);
19 p1 = x1+%i*y1;
20 p2 = x1-%i*y1;
21 p3 = x2+%i*y2;
22 p4 = x2-%i*y2;
23 P = [p1;p2;p3;p4];
24 K = ppol(a,b,P)

```

---

### Scilab code Exa 14.2 Compensator calculation

```

1 // Compensator calculation for Example 14.6 on page
  507.
2 // 14.2
3
4 exec('polyno.sci',-1);
5 exec('polmul.sci',-1);
6 exec('polsize.sci',-1);
7
8 A = [1 2; 0 3]; c = [1 0];
9 p = roots(polyno([1 -0.5 0.5], 'z'));
10 b = [0; 1];
11 K = ppol(A,b,p);
12
13 p1=0.1+0.1*%i; p2=0.1-0.1*%i;
14 phi = real(convol([1 -p1],[1 -p2]));
15 Obs = [c; c*A];
16 alphae = A^2-0.2*A+0.02*eye(2,2);
17 Lp = alphae*inv(Obs)*[0; 1];
18 Lp = ppol([1 0;2 3], ...
19 [1; 0],[0.1+0.1*%i 0.1-0.1*%i]);
20 Lp = Lp';
21
22 C = [1 0 0.5 2;0 1 -4.71 2.8];
23 dC = 1;
24

```

```
25 [HD,dHD] = polmul(K,0,C,dC);
26 [HD,dHD] = polmul(HD,dHD,Lp,0);
```

---

**Scilab code Exa 14.3** Kalman filter example of estimating a constant

```
1 // Kalman filter example of estimating a constant ,
  // discussed in Example 14.7.
2 // 14.3
3
4 exec('kal_ex.sci',-1);
5
6 x = 5; xhat = 2; P = 1; xvec = x;
7 xhat_vec = xhat; Pvec = P; yvec = x;
8 for i = 1:200,
9     xline = xhat; M = P;
10    [xhat,P,y] = kal_ex(x,xline,M);
11    xvec = [xvec;x];
12    xhat_vec = [xhat_vec;xhat];
13    Pvec = [Pvec;P]; yvec = [yvec;y];
14 end
15 n = 1:201;
16 plot(Pvec);
17 xtitle('', 'n');
18 halt();
19 clf();
20 plot(n,xhat_vec',n,yvec',n,xvec');
21 xtitle('', 'n');
```

---

**Scilab code Exa 14.4** Kalman filter example of estimating a constant

```
1 // Kalman filter example of estimating a constant
2 // 14.4
3
```

```
4 function [xhat,P,y] = kal_ex(x,xline,M)
5 y = x + rand();
6 Q = 0; R = 1;
7 xhat_ = xline;
8 P_ = M + Q;
9 K = P_/(P_+R);
10 P = (1-K)*P_;
11 xhat = xhat_ + K*(y-xhat_);
12 endfunction;
```

---