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LAMPIRAN

Lampiran 1. Perbandingan Solusi Sistem Tanpa Kontrol dan dengan Kontrol Optimal Menggunakan Matlab R2013a

➢ Program Utama

```
clear all;
clc;
global a1 a2 b1 b2 b3 Lambda omega alpha miu beta gamma tau theta
rho eta J
% Nilai parameter model
Lambda=12000; omega=0.0021; alpha=0.95; miu=0.016;rho=0.95;
eta=0.95; beta=0.0234; gamma=0.125; tau=0.06; theta=0.2;
%Nilai Bobot
a1=40; a2=60; b1=20; b2=40; b3=40;
% Nilai awal state
x10=600000;
x20=10000;
x30=1600;
x40=482;
x50=130000;
x0=[x10;x20;x30;x40;x50];
%Nilai akhir Costate (syarat transversalitas)
nx=5;
lambdaT=zeros(nx,1);
%Interval waktu
Ntime=1000;
tf=40;
ti=linspace(0,tf,Ntime);
%Batas kontrol
M1=0.1;
M2=1;
nv=3;
Lb=M1.*ones(nv,Ntime);
%Parameter Sweep
Ub=M2.*ones(nv,Ntime);
test=-1;
deltaa=0.0001;
k=0;
%tebakan awal untuk fungsi kontrol u1, u2 dan u3
u=0*ones(nv,Ntime);
%solving sistem tanpa kontrol (u1=0 u2=0 u3=0)
options = odeset('AbsTol',1e-3,'RelTol',1e-3);
xc=ode45(@(t,x) state1(t, x, u, ti),[0 tf],x0,options);
xc=deval(xc,ti);
%Awal Metode Sweep
x=zeros(nx,Ntime);
p=zeros(nx,Ntime);
while(test<0)
 k=k+1;
 oldx=x;
 oldp=p;
 oldu=u;
 %Forward Runge Kutta
 x=deval(ode45(@(t,x) state1(t, x, u, ti), [0 tf], x0),ti);
 %Backward Runge Kutta %yg digunakan nilai akhir lambdaT=0
```

```
 p=deval(ode45(@(t,p) costate1(t, p, x, u, ti),[tf
0],lambdaT),ti);

 %menghitung nilai u dari syarat optimal sistem
 u1=kontrol1(x,p); %menggunakan u dH/du=0
 %membuat u berada dalam interval yang diharapkan
 u1=f_simplebounds(u1,Lb,Ub);
 %mengupdate nilau u dalam metode sweep menggunakan kombinasi
konveks
 u=0.5*(u1+oldu);
 %uji Konvergensi u yang pertama
 %menghitung nilai error
 temp1=deltaa*sum(abs(u))-sum(abs(oldu-u));
 temp2=deltaa*sum(abs(x))-sum(abs(oldx-x));
 temp3=deltaa*sum(abs(p))-sum(abs(oldp-p));
 test=min(temp1,min(temp2,temp3)); %Buku Lenhart Hal:55
 %menghitung nilai fungsi tujuan menggunakan u akhir
 J(k)=objektif1(x,u,ti);

 disp(['it:',num2str(k),'||'',Test:',num2str(test)])
end
 %menghitung nilai fungsi tujuan menggunakan u optimal
 [m,n]=size(J);
 Ju=objektif1(x,u,ti);

figure (1)
    plot(ti, x(1,:),'g-','LineWidth',3)
    plot(ti,xc(1,:),'k--',ti, x(1,:),'g-','LineWidth',3)
    plot(ti, x(1,:),'r-','LineWidth',3)
    xlabel('Waktu (hari)')
    ylabel('S(t)')
    legend('Tanpa Kontrol','Kontrol Optimal')
    legend('Tanpa Kontrol', 'Kontrol
Optimal','u_1=u_2=u_3=0.56','u_1=u_2=u_3=0.26')
    axis('tight')
    grid on
% title('Solusi Optimasi Menggunakan Metode Sweep')
    hold on;

figure (2)
    plot(ti, x(2,:),'g-','LineWidth',3)
    plot(ti,xc(2,:),'k--',ti, x(2,:),'g-','LineWidth',3)
    plot(ti, x(2,:),'r-','LineWidth',3)
    xlabel('Waktu (hari)')
    ylabel('E(t)')
    legend('Tanpa Kontrol','Kontrol Optimal')
    legend('Tanpa Kontrol', 'Kontrol
Optimal','u_1=u_2=u_3=0.56','u_1=u_2=u_3=0.26')
    axis('tight')
    grid on
    title('Solusi Optimasi Menggunakan Metode Sweep')
    hold on;

figure(3)
    plot(ti, x(3,:),'g-','LineWidth',3)
    plot(ti,xc(3,:),'k--',ti, x(3,:),'g-','LineWidth',3)
    plot(ti, x(3,:),'r-','LineWidth',3)
    xlabel('Waktu (hari)')
```

```
    ylabel('C(t)')
    legend('Tanpa Kontrol','Kontrol Optimal')
    legend('Tanpa Kontrol','Kontrol
Optimal','u_1=u_2=u_3=0.56','u_1=u_2=u_3=0.26')
    title('Solusi Optimasi Menggunakan Metode Sweep')
    axis('tight')
    grid on
    hold on;

figure (4)
   plot(ti, x(4,:),'g-','LineWidth',3)
   plot(ti,xc(4,:),'k--',ti, x(4,:),'g-','LineWidth',3)
   plot(ti, x(4,:),'r-','LineWidth',3)
   xlabel('Waktu (hari)')
   ylabel('J(t)')
   legend('Tanpa Kontrol','Kontrol Optimal')
   legend('Tanpa Kontrol','Kontrol
Optimal','u_1=u_2=u_3=0.56','u_1=u_2=u_3=0.26')
   title('Solusi Optimasi Menggunakan Metode Sweep')
   axis('tight')
   grid on
   hold on;

figure (5)
  plot(ti, x(5,:),'g-','LineWidth',3)
  plot(ti,xc(5,:),'k--',ti, x(5,:),'g-','LineWidth',3)
  plot(ti, x(5,:),'r-','LineWidth',3)
  xlabel('Waktu (hari)')
  ylabel('H(t)')
  legend('Tanpa Kontrol','Kontrol Optimal')
  legend('Tanpa Kontrol','Kontrol
Optimal','u_1=u_2=u_3=0.56','u_1=u_2=u_3=0.26')
  title('Solusi Optimasi Menggunakan Metode Sweep')
  axis ('tight')
  grid on
  hold on;

%Fungsi Kontrol
figure (6)
subplot(221)
plot(ti,u(1,:),'b-','LineWidth',3)%,ti,u(2,:),'g-',ti,u(3,:),'r-
','LineWidth',2)
legend('kontrol u_1 (Edukasi dan Kampanye)','kontrol u_2(Perbaikan
Sistem)','kontrol u_3 (Strategi Represif)')
xlabel('Waktu ')
ylabel('u_1(t), u_2(t), u_3(t)')
title('Fungsi Kontrol')
axis('tight')
grid on
```

- State

```
function dx=state1(t, x, u, ti) %ti adalah inputan %t,x,u adalah
variabel
global Lambda omega alpha miu beta gamma tau theta rho eta
x1=x(1);
x2=x(2);
```

```
x3=x(3);
x4=x(4);
x5=x(5);

u1=u(1,:);
u1=interp1(ti,u1',t);
u2=u(2,:);
u2=interp1(ti,u2',t);
u3=u(3,:);
u3=interp1(ti,u3',t);

dx=zeros(5,1);

dx(1)=Lambda+omega.*x5+(1-tau).*gamma.*x4-beta.*(-
alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5)-rho.*u2.*x1-miu.*x1;
dx(2)=beta.*(-alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5)-theta.*(-
rho.*u2+1).*x2-rho.*u2.*x2-miu*x2;
dx(3)=theta.*(-rho.*u2+1).*x2-eta.*u3.*x3-miu.*x3;
dx(4)=eta.*u3.*x3-tau.*gamma.*x4-(1-tau).*gamma.*x4-miu.*x4;
dx(5)=x2.*rho.*u2+x4.*gamma.*tau+x1.*rho.*u2-x5.*miu-x5.*omega;

end
```

- Costate

```
function dp=costate1(t, p, x, u, ti)
global a1 a2 tau alpha omega delta miu beta gamma theta rho eta
x = interp1(ti,x',t);
x1 = x(1);
x2 = x(2);
x3 = x(3);
x4 = x(4);
x5 = x(5);
u1 = u(1,:);
u2 = u(2,:);
u3 = u(3,:);
u1 = interp1(ti,u1',t);
u2 = interp1(ti,u2',t);
u3 = interp1(ti,u3',t);
p1=p(1,:);
p2=p(2,:);
p3=p(3,:);
p4=p(4,:);
p5=p(5,:);
dp=zeros(5,1);

dp(1)=-p1.*(-beta.*(-alpha.*u1+1).*x3./(x1+x2+x3+x4+x5)+beta.*(-
alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2-rho.*u2-miu)-
p2.*(beta.*(-alpha.*u1+1).*x3./(x1+x2+x3+x4+x5)-beta.*(-
alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2)-p5.*rho.*u2;
dp(2)=-a1-p1.*beta.*(-alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2-
p2.*(-beta.*(-alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2-theta.*(-
rho.*u2+1)-rho.*u2-miu)-p3.*theta.*(-rho.*u2+1)-p5.*rho.*u2;
dp(3)=-a2-p1.*(-beta.*(-
alpha.*u1+1).*x1./(x1+x2+x3+x4+x5)+beta.*(-
alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2)-p2.*(beta.*(-
```

```
alpha.*u1+1).*x1./(x1+x2+x3+x4+x5)-beta.*(-
alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2)-p3.*(-eta.*u3-miu)-
p4.*eta.*u3;
dp(4)=-p1.*((1-tau).*gamma+beta.*(-
alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2)+p2.*beta.*(-
alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2-p4.*(-tau.*gamma-(1-
tau).*gamma-miu)-p5.*tau.*gamma;
dp(5)=-p1.*(omega+beta.*(-
alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2)+p2.*beta.*(-
alpha.*u1+1).*x1.*x3./(x1+x2+x3+x4+x5).^2-p5.*(-miu-omega);

end
```

- Simple bounds

```
function s=f_simplebounds(s,Lb,Ub)

% untuk batas bawah
 ns_tmp=s;
 I=ns_tmp<Lb;
 ns_tmp(I)=Lb(I);

 % untuk batas atas
 J=ns_tmp>Ub;
 ns_tmp(J)=Ub(J);

 % Update u
 s=ns_tmp;
```

- Objektif

```
function J=objektif1(x,u,ti)
global a1 a2 b1 b2 b3
x2=x(2,:);
x3=x(3,:);
u1=u(1,:);
u2=u(2,:);
u3=u(3,:);
obj=a1.*x2 + a2.*x3 + (b1/2).*u1.^2 + (b2/2).*u2.^2 +
(b3/2).*u3.^2  ;
J=trapz(ti,obj);
```

- Kontrol

```
function u = kontrol1(x,p)
global b1 b2 b3 theta alpha delta beta rho eta
p1 = p(1,:);
p2 = p(2,:);
p3 = p(3,:);
p4 = p(4,:);
p5 = p(5,:);
x1 = x(1,:);
x2 = x(2,:);
```

```
x3 = x(3,:);
x4 = x(4,:);
x5 = x(5,:);

% u1=0.26*ones(1,1000);
% u2=0.26*ones(1,1000);
% u3=0.26*ones(1,1000);

u1=x3.*x1.*alpha.*beta.*(-p1+p2)./((x1+x2+x3+x4+x5).*b1);
u2=rho.*(-x2.*theta.*p2+x2.*theta.*p3+x2.*p2-x2.*p5+x1.*p1-
x1.*p5)./b2;
u3=-eta.*x3.*(p4-p3)./b3;

% u1=0.56*ones(1,1000);
% u2=0.56*ones(1,1000);
% u3=0.56*ones(1,1000);
u=[u1;u2;u3];

end
```

Lampiran 2. Titik Kesetimbangan Adanya Korupsi

> *restart* :

> *with*(*linalg*) : *with*(*plots*) : *with*(*DEtools*) :
> *with*(*plots*) : *with*(*linalg*) : *with*(*VectorCalculus*) :
>

$\Lambda := 12000 : \omega := 0.0021 : \alpha := 0.95 : \mu := 0.016 : \rho := 0.95 : \eta := 0.95 :$
$\beta := 0.0234 :$ **local** $\gamma := 0.125 : \tau := 0.06 : \theta := 0.2 : u_1 := 0 : u_2 := 0 : u_3 := 0 :$

> $P1 := \Lambda + \omega \cdot H + (1 - \tau) \cdot \gamma \cdot J - \dfrac{\beta \cdot (1 - \alpha \cdot u_1) \cdot S \cdot C}{S + E + C + J + H} - \rho \cdot u_2 \cdot S - \mu \cdot S$

$$P1 := 12000. + 0.0021\,H + 0.11750\,J - \frac{0.0234\,S\,C}{S + E + C + J + H} - 0.016\,S$$

> $P2 := \dfrac{\beta \cdot (1 - \alpha \cdot u_1) \cdot S \cdot C}{S + E + C + J + H} - \theta \cdot (1 - \rho \cdot u_2) \cdot E - \rho \cdot u_2 \cdot E - \mu \cdot E$

$$P2 := \frac{0.0234\,S\,C}{S + E + C + J + H} - 0.216\,E$$

> $P3 := \theta \cdot (1 - \rho \cdot u_2) \cdot E - \eta \cdot u_3 \cdot C - \mu \cdot C$

$$P3 := 0.2\,E - 0.016\,C$$

> $P4 := \eta \cdot u_3 \cdot C - \tau \cdot \gamma \cdot J - (1 - \tau) \cdot \gamma \cdot J - \mu \cdot J$

$$P4 := -0.14100\,J$$

> $P5 := \rho \cdot u_2 \cdot S + \tau \cdot \gamma \cdot J + \rho \cdot u_2 \cdot E - \omega \cdot H - \mu \cdot H$

$$P5 := 0.00750\,J - 0.0181\,H$$

> $fixpoint := solve(\{P1, P2, P3, P4, P5\}, \{S, E, C, J, H\})$

$$fixpoint := \{C = 0., E = 0., H = 0., J = 0., S = 7.50000\,10^5\}, \{C = 1.8162393\,16\,10^5, E = 14529.91453, H = 0., J = 0., S = 5.538461538\,10^5\}$$

> $fix1 := fixpoint[1];$

$$fix1 := \{C = 0., E = 0., H = 0., J = 0., S = 7.50000\,10^5\}$$

> $jb := Jacobian([P1, P2, P3, P4, P5], [S, E, C, J, H]);$

$$jb := \left[\left[-\frac{0.0234\,C}{S+E+C+J+H} + \frac{0.0234\,S\,C}{(S+E+C+J+H)^2} - 0.016,\right.\right.$$
$$\frac{0.0234\,S\,C}{(S+E+C+J+H)^2}, -\frac{0.0234\,S}{S+E+C+J+H} + \frac{0.0234\,S\,C}{(S+E+C+J+H)^2}, 0.11750$$
$$\left. + \frac{0.0234\,S\,C}{(S+E+C+J+H)^2}, 0.0021 + \frac{0.0234\,S\,C}{(S+E+C+J+H)^2}\right],$$
$$\left[\frac{0.0234\,C}{S+E+C+J+H} - \frac{0.0234\,S\,C}{(S+E+C+J+H)^2}, -\frac{0.0234\,S\,C}{(S+E+C+J+H)^2} - 0.216,\right.$$
$$\frac{0.0234\,S}{S+E+C+J+H} - \frac{0.0234\,S\,C}{(S+E+C+J+H)^2}, -\frac{0.0234\,S\,C}{(S+E+C+J+H)^2},$$
$$\left. -\frac{0.0234\,S\,C}{(S+E+C+J+H)^2}\right],$$
$$[0, 0.2, -0.016, 0, 0],$$
$$[0, 0, 0, -0.14100, 0],$$
$$\left.[0, 0, 0, 0.00750, -0.0181]\right]$$

```
> jac1 := subs(fix1, evalm(jb)); eigenvalues(jac1);
```

$$jac1 := \begin{bmatrix} -0.016 & 0. & -0.02340000000 & 0.11750 & 0.0021 \\ 0. & -0.216 & 0.02340000000 & 0 & -0. \\ 0 & 0.2 & -0.016 & 0 & 0 \\ 0 & 0 & 0 & -0.14100 & 0 \\ 0 & 0 & 0 & 0.00750 & -0.0181 \end{bmatrix}$$

$$-0.0160000000000000,\ -0.237161049846888,\ 0.00516104984688768,$$
$$-0.0181000000000000,\ -0.141000000000000$$

```
> fix2 := fixpoint[2];
```

$$fix2 := \{C = 1.816239316\,10^5, E = 14529.91453, H = 0., J = 0., S = 5.538461538\,10^5\}$$

```
> jac2 := subs(fix2, evalm(jb)); eigenvalues(jac2);
```

```
jac2 :=
[[-0.01748205128, 0.004184615387, -0.01309538461, 0.1216846154,
0.006284615387],
[0.001482051280, -0.2201846154, 0.01309538461, -0.004184615387, -0.004184615387
],
[0, 0.2, -0.016, 0, 0],
[0, 0, 0, -0.14100, 0],
[0, 0, 0, 0.00750, -0.0181]]
```

$$-0.0160000000000000,\ -0.00526678407571977,\ -0.232399882604280,$$
$$-0.0181000000000000,\ -0.141000000000000$$

Lampiran 3. Titik Kesetimbangan Bebas Korupsi

>

$\Lambda := 12000 : \omega := 0.0021 : \alpha := 0.95 : \mu := 0.016 : \rho := 0.95 : \eta := 0.95 :$
$\beta := 0.0234 :$ **local** $\gamma := 0.125 : \tau := 0.06 : \theta := 0.2 : u_1 := 0.95 : u_2 := 0.95 : u_3 := 0.95 :$

> $P1 := \Lambda + \omega \cdot H + (1 - \tau) \cdot \gamma \cdot J - \dfrac{\beta \cdot (1 - \alpha \cdot u_1) \cdot S \cdot C}{S + E + C + J + H} - \rho \cdot u_2 \cdot S - \mu \cdot S$

$$P1 := 12000 + 0.0021\,H + 0.11750\,J - \frac{0.00228150\,S\,C}{S + E + C + J + H} - 0.9185\,S$$

> $P2 := \dfrac{\beta \cdot (1 - \alpha \cdot u_1) \cdot S \cdot C}{S + E + C + J + H} - \theta \cdot (1 - \rho \cdot u_2) \cdot E - \rho \cdot u_2 \cdot E - \mu \cdot E$

$$P2 := \frac{0.00228150\,S\,C}{S + E + C + J + H} - 0.93800\,E$$

> $P3 := \theta \cdot (1 - \rho \cdot u_2) \cdot E - \eta \cdot u_3 \cdot C - \mu \cdot C$

$$P3 := 0.01950\,E - 0.9185\,C$$

> $P4 := \eta \cdot u_3 \cdot C - \tau \cdot \gamma \cdot J - (1 - \tau) \cdot \gamma \cdot J - \mu \cdot J$

$$P4 := 0.9025\,C - 0.14100\,J$$

> $P5 := \rho \cdot u_2 \cdot S + \tau \cdot \gamma \cdot J + \rho \cdot u_2 \cdot E - \omega \cdot H - \mu \cdot H$

$$P5 := 0.9025\,S + 0.00750\,J + 0.9025\,E - 0.0181\,H$$

> $fixpoint := solve(\{P1, P2, P3, P4, P5\}, \{S, E, C, J, H\})$

$$fixpoint := \{C = 0., E = 0., H = 7.352541821\,10^5, J = 0., S = 14745.81794\}, \{C = -3.070609681\,10^8, E = -1.446335893\,10^{10}, H = 2.212513069\,10^9, J = -1.965407970\,10^9, S = 1.452406480\,10^{10}\}$$

> $fix1 := fixpoint[1];$

$$fix1 := \{C = 0., E = 0., H = 7.352541821\,10^5, J = 0., S = 14745.81794\}$$

> $jb := Jacobian([P1, P2, P3, P4, P5], [S, E, C, J, H]);$

$$jb := \left[\left[-\frac{0.00228150\,C}{S+E+C+J+H} + \frac{0.00228150\,S\,C}{(S+E+C+J+H)^2} - 0.9185,\right.\right.$$
$$\frac{0.00228150\,S\,C}{(S+E+C+J+H)^2}, -\frac{0.00228150\,S}{S+E+C+J+H} + \frac{0.00228150\,S\,C}{(S+E+C+J+H)^2}, 0.11750$$
$$\left.+ \frac{0.00228150\,S\,C}{(S+E+C+J+H)^2}, 0.0021 + \frac{0.00228150\,S\,C}{(S+E+C+J+H)^2}\right],$$
$$\left[\frac{0.00228150\,C}{S+E+C+J+H} - \frac{0.00228150\,S\,C}{(S+E+C+J+H)^2}, -\frac{0.00228150\,S\,C}{(S+E+C+J+H)^2}\right.$$
$$-0.93800, \frac{0.00228150\,S}{S+E+C+J+H} - \frac{0.00228150\,S\,C}{(S+E+C+J+H)^2},$$
$$\left.-\frac{0.00228150\,S\,C}{(S+E+C+J+H)^2}, -\frac{0.00228150\,S\,C}{(S+E+C+J+H)^2}\right],$$
$$[0, 0.01950, -0.9185, 0, 0],$$
$$[0, 0, 0.9025, -0.14100, 0],$$
$$\left.[0.9025, 0.9025, 0, 0.00750, -0.0181]\right]$$

> $jac1 := subs(fix1, evalm(jb)); eigenvalues(jac1);$

$$jac1 := \begin{bmatrix} -0.9185 & 0. & -0.00004485677818 & 0.11750 & 0.0021 \\ 0. & -0.93800 & 0.00004485677818 & -0. & 0 \\ 0 & 0.01950 & -0.9185 & 0 & 0 \\ 0 & 0 & 0.9025 & -0.14100 & 0 \\ 0.9025 & 0.9025 & 0 & 0.00750 & -0.0181 \end{bmatrix}$$

$$-0.920600000000000,\ -0.0160000000000000,\ -0.918455245935987,\ -0.938044754064014,$$
$$-0.141000000000000$$

> $fix2 := fixpoint[2];$

$$fix2 := \{C = -3.070609681\,10^{8}, E = -1.446335893\,10^{10}, H = 2.212513069\,10^{9}, J =$$
$$-1.965407970\,10^{9}, S = 1.452406480\,10^{10}\}$$

> $jac2 := subs(fix2, evalm(jb)); eigenvalues(jac2);$

$$jac2 := \begin{bmatrix} -18088.77708 & -18088.79266 & -18132.97481 & -18088.67516 & -18088.79056 \\ 18087.85858 & 18087.85466 & 18132.97481 & 18088.79266 & 18088.79266 \\ 0 & 0.01950 & -0.9185 & 0 & 0 \\ 0 & 0 & 0.9025 & -0.14100 & 0 \\ 0.9025 & 0.9025 & 0 & 0.00750 & -0.0181 \end{bmatrix}$$

$$0.581446176780561,\ -1.50355976652574,\ -0.0160017203243943,\ -0.138534512101512,$$
$$-0.923370177814130$$

Lampiran 4. Koefisien Polinomial Adanya Korupsi

```
> restart :
> with(linalg) :
>
```

$$A := matrix\left(5, 5, \left[p_{11}, 0, -p_{13}, p_{14}, p_{15}, -p_{21}, -p_{22}, p_{23}, 0, 0, 0, p_{32}, -p_{33}, 0, 0, 0, 0, p_{43}, -p_{44}, 0, p_{51}, p_{52}, 0, p_{54}, p_{55}\right]\right)$$

$$A := \begin{bmatrix} p_{11} & 0 & -p_{13} & p_{14} & p_{15} \\ -p_{21} & -p_{22} & p_{23} & 0 & 0 \\ 0 & p_{32} & -p_{33} & 0 & 0 \\ 0 & 0 & p_{43} & -p_{44} & 0 \\ p_{51} & p_{52} & 0 & p_{54} & p_{55} \end{bmatrix}$$

```
> A1 := linalg['charpoly']( A, λ )
```

$$\begin{aligned} A1 := & -\lambda^2 p_{11} p_{22} p_{33} - \lambda^2 p_{11} p_{22} p_{44} + \lambda^2 p_{11} p_{22} p_{55} + \lambda^2 p_{11} p_{23} p_{32} - \lambda^2 p_{11} p_{33} p_{44} \\ & + \lambda^2 p_{11} p_{33} p_{55} + \lambda^2 p_{11} p_{44} p_{55} + \lambda^2 p_{22} p_{33} p_{44} - \lambda^2 p_{22} p_{33} p_{55} - \lambda^2 p_{22} p_{44} p_{55} \\ & - \lambda^2 p_{23} p_{32} p_{44} + \lambda^2 p_{23} p_{32} p_{55} - \lambda^2 p_{33} p_{44} p_{55} - \lambda^2 p_{13} p_{21} p_{32} + \lambda^2 p_{15} p_{21} p_{52} \\ & - \lambda^2 p_{15} p_{22} p_{51} - \lambda^2 p_{15} p_{33} p_{51} - \lambda^2 p_{15} p_{44} p_{51} - \lambda^4 p_{11} + \lambda^4 p_{22} + \lambda^4 p_{33} + \lambda^4 p_{44} \\ & - \lambda^4 p_{55} + \lambda^5 - \lambda^3 p_{11} p_{22} - \lambda^3 p_{11} p_{33} - \lambda^3 p_{11} p_{44} + \lambda^3 p_{11} p_{55} + \lambda^3 p_{22} p_{33} \\ & + \lambda^3 p_{22} p_{44} - \lambda^3 p_{22} p_{55} - \lambda^3 p_{23} p_{32} + \lambda^3 p_{33} p_{44} - \lambda^3 p_{33} p_{55} - \lambda^3 p_{44} p_{55} - \lambda^3 p_{15} p_{51} \\ & + p_{15} p_{23} p_{32} p_{44} p_{51} - \lambda p_{11} p_{22} p_{33} p_{44} + \lambda p_{11} p_{22} p_{33} p_{55} + \lambda p_{11} p_{22} p_{44} p_{55} \\ & + \lambda p_{11} p_{23} p_{32} p_{44} - \lambda p_{11} p_{23} p_{32} p_{55} + \lambda p_{11} p_{33} p_{44} p_{55} - \lambda p_{22} p_{33} p_{44} p_{55} \\ & + \lambda p_{23} p_{32} p_{44} p_{55} + p_{11} p_{22} p_{33} p_{44} p_{55} - p_{11} p_{23} p_{32} p_{44} p_{55} - \lambda p_{13} p_{21} p_{32} p_{44} \\ & + \lambda p_{13} p_{21} p_{32} p_{55} + \lambda p_{14} p_{21} p_{32} p_{43} + \lambda p_{15} p_{21} p_{33} p_{52} + \lambda p_{15} p_{21} p_{44} p_{52} \\ & + p_{13} p_{21} p_{32} p_{44} p_{55} - p_{14} p_{21} p_{32} p_{43} p_{55} + p_{15} p_{21} p_{32} p_{43} p_{54} + p_{15} p_{21} p_{33} p_{44} p_{52} \\ & - \lambda p_{15} p_{22} p_{33} p_{51} - \lambda p_{15} p_{22} p_{44} p_{51} + \lambda p_{15} p_{23} p_{32} p_{51} - \lambda p_{15} p_{33} p_{44} p_{51} \\ & - p_{15} p_{22} p_{33} p_{44} p_{51} \end{aligned}$$

```
> factor(%)
```

$$
\begin{aligned}
&-\lambda^2 p_{11}p_{22}p_{33} - \lambda^2 p_{11}p_{22}p_{44} + \lambda^2 p_{11}p_{22}p_{55} + \lambda^2 p_{11}p_{23}p_{32} - \lambda^2 p_{11}p_{33}p_{44} \\
&\quad + \lambda^2 p_{11}p_{33}p_{55} + \lambda^2 p_{11}p_{44}p_{55} + \lambda^2 p_{22}p_{33}p_{44} - \lambda^2 p_{22}p_{33}p_{55} - \lambda^2 p_{22}p_{44}p_{55} \\
&\quad - \lambda^2 p_{23}p_{32}p_{44} + \lambda^2 p_{23}p_{32}p_{55} - \lambda^2 p_{33}p_{44}p_{55} - \lambda^2 p_{13}p_{21}p_{32} + \lambda^2 p_{15}p_{21}p_{52} \\
&\quad - \lambda^2 p_{15}p_{22}p_{51} - \lambda^2 p_{15}p_{33}p_{51} - \lambda^2 p_{15}p_{44}p_{51} - \lambda^4 p_{11} + \lambda^4 p_{22} + \lambda^4 p_{33} + \lambda^4 p_{44} \\
&\quad - \lambda^4 p_{55} + \lambda^5 - \lambda^3 p_{11}p_{22} - \lambda^3 p_{11}p_{33} - \lambda^3 p_{11}p_{44} + \lambda^3 p_{11}p_{55} + \lambda^3 p_{22}p_{33} \\
&\quad + \lambda^3 p_{22}p_{44} - \lambda^3 p_{22}p_{55} - \lambda^3 p_{23}p_{32} + \lambda^3 p_{33}p_{44} - \lambda^3 p_{33}p_{55} - \lambda^3 p_{44}p_{55} - \lambda^3 p_{15}p_{51} \\
&\quad + p_{15}p_{23}p_{32}p_{44}p_{51} - \lambda p_{11}p_{22}p_{33}p_{44} + \lambda p_{11}p_{22}p_{33}p_{55} + \lambda p_{11}p_{22}p_{44}p_{55} \\
&\quad + \lambda p_{11}p_{23}p_{32}p_{44} - \lambda p_{11}p_{23}p_{32}p_{55} + \lambda p_{11}p_{33}p_{44}p_{55} - \lambda p_{22}p_{33}p_{44}p_{55} \\
&\quad + \lambda p_{23}p_{32}p_{44}p_{55} + p_{11}p_{22}p_{33}p_{44}p_{55} - p_{11}p_{23}p_{32}p_{44}p_{55} - \lambda p_{13}p_{21}p_{32}p_{44} \\
&\quad + \lambda p_{13}p_{21}p_{32}p_{55} + \lambda p_{14}p_{21}p_{32}p_{43} + \lambda p_{15}p_{21}p_{33}p_{52} + \lambda p_{15}p_{21}p_{44}p_{52} \\
&\quad + p_{13}p_{21}p_{32}p_{44}p_{55} - p_{14}p_{21}p_{32}p_{43}p_{55} + p_{15}p_{21}p_{32}p_{43}p_{54} + p_{15}p_{21}p_{33}p_{44}p_{52} \\
&\quad - \lambda p_{15}p_{22}p_{33}p_{51} - \lambda p_{15}p_{22}p_{44}p_{51} + \lambda p_{15}p_{23}p_{32}p_{51} - \lambda p_{15}p_{33}p_{44}p_{51} \\
&\quad - p_{15}p_{22}p_{33}p_{44}p_{51}
\end{aligned}
$$

>

$$
\begin{aligned}
&lambda1 := collect\Big(-\lambda^2 p_{11}p_{22}p_{33} - \lambda^2 p_{11}p_{22}p_{44} + \lambda^2 p_{11}p_{22}p_{55} + \lambda^2 p_{11}p_{23}p_{32} \\
&\quad - \lambda^2 p_{11}p_{33}p_{44} + \lambda^2 p_{11}p_{33}p_{55} + \lambda^2 p_{11}p_{44}p_{55} + \lambda^2 p_{22}p_{33}p_{44} - \lambda^2 p_{22}p_{33}p_{55} \\
&\quad - \lambda^2 p_{22}p_{44}p_{55} - \lambda^2 p_{23}p_{32}p_{44} + \lambda^2 p_{23}p_{32}p_{55} - \lambda^2 p_{33}p_{44}p_{55} - \lambda^2 p_{13}p_{21}p_{32} \\
&\quad + \lambda^2 p_{15}p_{21}p_{52} - \lambda^2 p_{15}p_{22}p_{51} - \lambda^2 p_{15}p_{33}p_{51} - \lambda^2 p_{15}p_{44}p_{51} - \lambda^4 p_{11} + \lambda^4 p_{22} \\
&\quad + \lambda^4 p_{33} + \lambda^4 p_{44} - \lambda^4 p_{55} + \lambda^5 - \lambda^3 p_{11}p_{22} - \lambda^3 p_{11}p_{33} - \lambda^3 p_{11}p_{44} + \lambda^3 p_{11}p_{55} \\
&\quad + \lambda^3 p_{22}p_{33} + \lambda^3 p_{22}p_{44} - \lambda^3 p_{22}p_{55} - \lambda^3 p_{23}p_{32} + \lambda^3 p_{33}p_{44} - \lambda^3 p_{33}p_{55} - \lambda^3 p_{44}p_{55} \\
&\quad - \lambda^3 p_{15}p_{51} + p_{15}p_{23}p_{32}p_{44}p_{51} - \lambda p_{11}p_{22}p_{33}p_{44} + \lambda p_{11}p_{22}p_{33}p_{55} \\
&\quad + \lambda p_{11}p_{22}p_{44}p_{55} + \lambda p_{11}p_{23}p_{32}p_{44} - \lambda p_{11}p_{23}p_{32}p_{55} + \lambda p_{11}p_{33}p_{44}p_{55} \\
&\quad - \lambda p_{22}p_{33}p_{44}p_{55} + \lambda p_{23}p_{32}p_{44}p_{55} + p_{11}p_{22}p_{33}p_{44}p_{55} - p_{11}p_{23}p_{32}p_{44}p_{55} \\
&\quad - \lambda p_{13}p_{21}p_{32}p_{44} + \lambda p_{13}p_{21}p_{32}p_{55} + \lambda p_{14}p_{21}p_{32}p_{43} + \lambda p_{15}p_{21}p_{33}p_{52} \\
&\quad + \lambda p_{15}p_{21}p_{44}p_{52} + p_{13}p_{21}p_{32}p_{44}p_{55} - p_{14}p_{21}p_{32}p_{43}p_{55} + p_{15}p_{21}p_{32}p_{43}p_{54} \\
&\quad + p_{15}p_{21}p_{33}p_{44}p_{52} - \lambda p_{15}p_{22}p_{33}p_{51} - \lambda p_{15}p_{22}p_{44}p_{51} + \lambda p_{15}p_{23}p_{32}p_{51} \\
&\quad - \lambda p_{15}p_{33}p_{44}p_{51} - p_{15}p_{22}p_{33}p_{44}p_{51}, \text{lambda}\Big)
\end{aligned}
$$

$$\lambda 1 := \lambda^5 + \left(-p_{11} + p_{22} + p_{33} + p_{44} - p_{55}\right)\lambda^4 + \left(-p_{11}p_{22} - p_{11}p_{33} - p_{11}p_{44} + p_{11}p_{55} - p_{15}p_{51} + p_{22}p_{33} + p_{22}p_{44} - p_{22}p_{55} - p_{23}p_{32} + p_{33}p_{44} - p_{33}p_{55} - p_{44}p_{55}\right)\lambda^3 + \left(-p_{11}p_{22}p_{33} - p_{11}p_{22}p_{44} + p_{11}p_{22}p_{55} + p_{11}p_{23}p_{32} - p_{11}p_{33}p_{44} + p_{11}p_{33}p_{55} + p_{11}p_{44}p_{55} - p_{13}p_{21}p_{32} + p_{15}p_{21}p_{52} - p_{15}p_{22}p_{51} - p_{15}p_{33}p_{51} - p_{15}p_{44}p_{51} + p_{22}p_{33}p_{44} - p_{22}p_{33}p_{55} - p_{22}p_{44}p_{55} - p_{23}p_{32}p_{44} + p_{23}p_{32}p_{55} - p_{33}p_{44}p_{55}\right)\lambda^2 + \left(-p_{11}p_{22}p_{33}p_{44} + p_{11}p_{22}p_{33}p_{55} + p_{11}p_{22}p_{44}p_{55} + p_{11}p_{23}p_{32}p_{44} - p_{11}p_{23}p_{32}p_{55} + p_{11}p_{33}p_{44}p_{55} - p_{13}p_{21}p_{32}p_{44} + p_{13}p_{21}p_{32}p_{55} + p_{14}p_{21}p_{32}p_{43} + p_{15}p_{21}p_{33}p_{52} + p_{15}p_{21}p_{44}p_{52} - p_{15}p_{22}p_{33}p_{51} - p_{15}p_{22}p_{44}p_{51} + p_{15}p_{23}p_{32}p_{51} - p_{15}p_{33}p_{44}p_{51} - p_{22}p_{33}p_{44}p_{55} + p_{23}p_{32}p_{44}p_{55}\right)\lambda + p_{15}p_{23}p_{32}p_{44}p_{51} + p_{11}p_{22}p_{33}p_{44}p_{55} - p_{11}p_{23}p_{32}p_{44}p_{55} + p_{13}p_{21}p_{32}p_{44}p_{55} - p_{14}p_{21}p_{32}p_{43}p_{55} + p_{15}p_{21}p_{32}p_{43}p_{54} + p_{15}p_{21}p_{33}p_{44}p_{52} - p_{15}p_{22}p_{33}p_{44}p_{51}$$