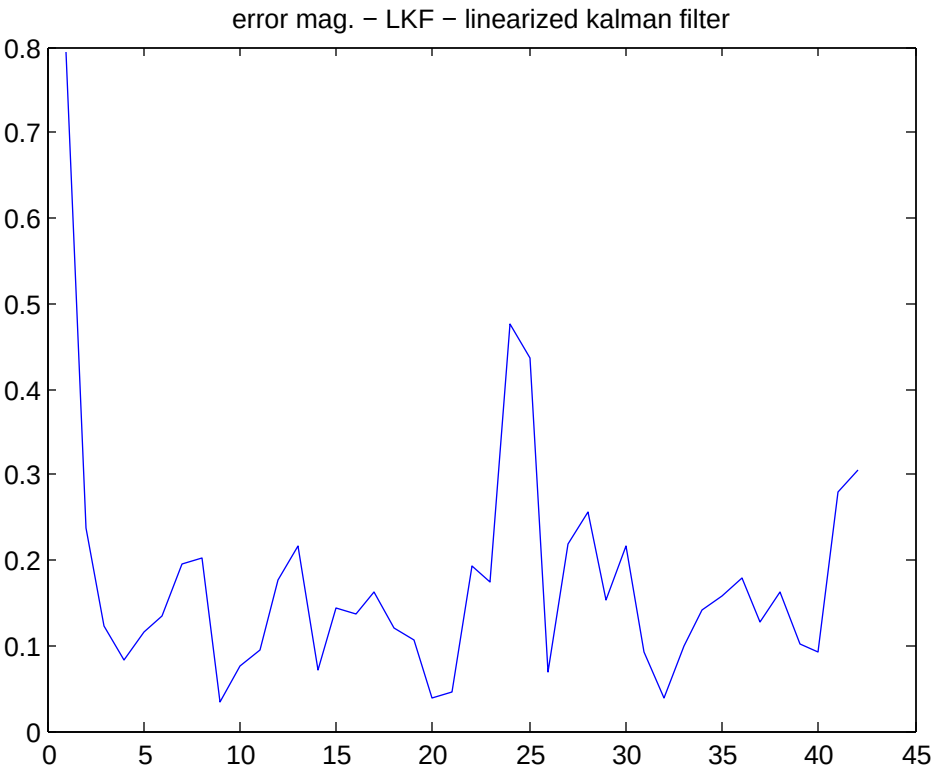
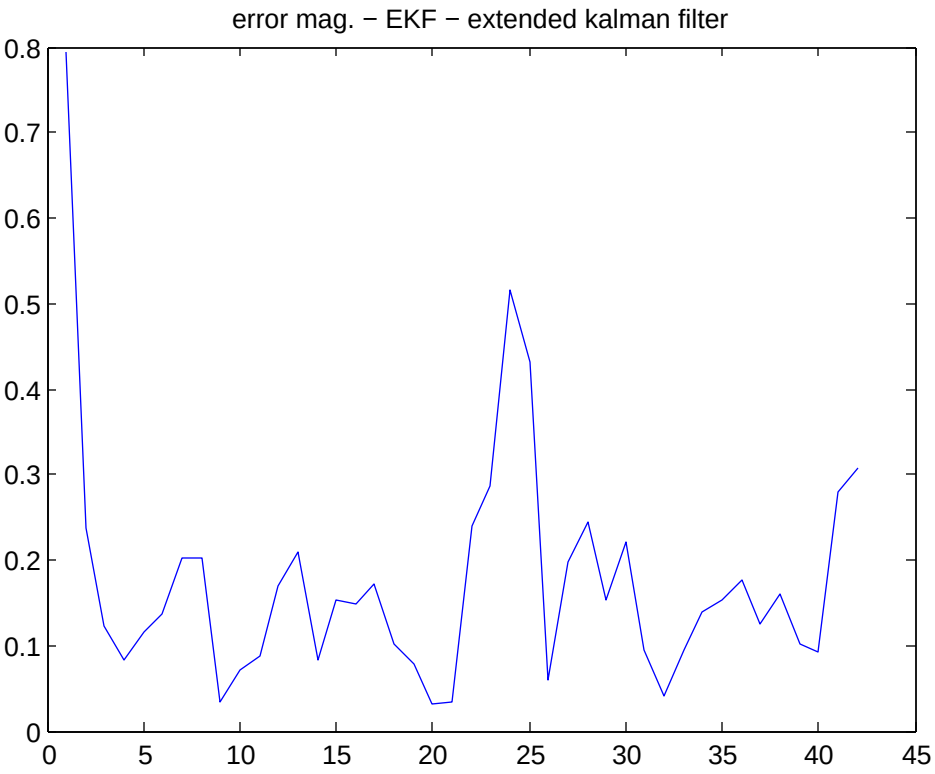

error mag. − LKF − linearized kalman filter
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
45


error mag. − EKF − extended kalman filter
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
45

```
% simkal5.m  12-apr-09
% very weak geometry with dist obs from only 1 cp so
% now alternate dist obs from 2 cp's for better geometric strength
% simulate data for a nonlinear kalman filter exercise
% try to (1) linearize about a reference trajectory and
%        (2) let the filter provide the linearization points
% (1) is called linearized kalman filter
% (2) is called extended kalman filter
% we do a 2-dimensional exercise with range observations
% ok - let's use upper case letters for the actual coordinates
% and lower case letters for the deviation coordinates

% ok, some new ideas about (1) from tekalp, appendix c.

linstrat=2;
% array for formatted printing of data
dspd=zeros(9,1);

% make some variables so it's easy to experiment with uncertainty
coord_sig=2.0;
velo_sig=0.5;
stm_pos_sig=2.0;
stm_vel_sig=1.0;
obs_sig=0.1;

Xc1=200;
Yc1=100;
Xc2=300;
Yc2=400;
X=zeros(42,1);
Y=zeros(42,1);
Xdot=zeros(42,1);
Ydot=zeros(42,1);
pfX=zeros(42,1);
pfY=zeros(42,1);
range1=zeros(42,1);
range2=zeros(42,1);
plerr=zeros(42,1);
prederr=zeros(42,1);

pfX(1)=0;
pfY(1)=200;
range1(1)=sqrt((pfX(1)-Xc1)^2 + (pfY(1)-Yc1)^2);
range1(2)=sqrt((pfX(1)-Xc1)^2 + (pfY(1)-Yc1)^2);
theta=atan(0.4);
dx=13.4*cos(theta);
% let's use randn since it is more flexible about seeding
%e=random('norm',0,1,42,1);
randn('state',0);
e1=randn(42,1);
e2=randn(42,1);
e1=e1*obs_sig;
e2=e2*obs_sig;
for i=2:42
  pfX(i)=pfX(i-1) + dx;
  pfY(i)=0.4*pfX(i) + 200;
  range1(i)=sqrt((pfX(i)-Xc1)^2 + (pfY(i)-Yc1)^2) + e1(i);
  range2(i)=sqrt((pfX(i)-Xc2)^2 + (pfY(i)-Yc2)^2) + e2(i);
  end
range1(1)=range1(1) + e1(1);
range2(1)=range2(1) + e2(1);

% actual trajectory:     y = 0.400*x + 200
% reference trajectory:  y = 0.402*x + 198

refX=zeros(42,1);
refY=zeros(42,1);

refX(1)=1.25;
refY(1)=0.402*refX(1) + 198;
for i=2:42
  refX(i)=refX(i-1) + dx;
  refY(i)=0.402*refX(i) + 198;
  end

Xa=refX(1) - dx;
Ya=0.402*Xa + 198;
Xadot=13.4*cos(atan(201/500));
Yadot=13.4*sin(atan(201/500));
disp('first state vector');
svXa1=[Xa;Ya;Xadot;Yadot];
svXa1'
%fid=fopen('hwdat.txt','wt');
```

```
%dspd=[0;Xa;Ya;Xadot;Yadot;0;0;0;0];
%fprintf(fid,'%4.1f %9.4f %9.4f %9.6f %9.6f %9.4f %9.4f %9.4f %4.1f\n',dspd);

coord_var=coord_sig^2;
velo_var=velo_sig^2;
stm_pos_var=stm_pos_sig^2;
stm_vel_var=stm_vel_sig^2;
obs_var=obs_sig^2;


% ok let's do the KF
x=[0;0;0;0];
P=[coord_var 0 0 0; 0 coord_var 0 0; 0 0 velo_var 0; 0 0 0 velo_var];
PHI=[1 0 1 0; 0 1 0 1; 0 0 1 0; 0 0 0 1];
Q=[stm_pos_var 0 0 0;0 stm_pos_var 0 0;0 0 stm_vel_var 0; 0 0 0 stm_vel_var];
R=obs_var;
I4=eye(4);
disp('initial P & Q');
P
Q
X1m=PHI*svXa1;

sumsqr=0;
for i=1:42

  isodd=0;
  if(mod(i,2) == 1)
    isodd=1;
    end

  % reference trajectory Xa,Ya: prior point
  % reference trajectory Xb,Yb: current point
  % already initialized Xa,Ya

  % prediction step
  if(i == 1)
    Xim1=[Xa;Ya;Xadot;Yadot];
  else
    Xim1=[X(i-1);Y(i-1);Xdot(i-1);Ydot(i-1)];
    end

  Xim=PHI*Xim1;
  Xim

  % linstrat=1 fixed reference trajectory
  % linstrat=2 reference from prior point
  if((linstrat == 1) | (i < 6))
    Xb=refX(i);
    Yb=refY(i);
    Xbdot=Xadot;
    Ybdot=Yadot;
  else
    Xb=Xim(1);
    Yb=Xim(2);
    Xbdot=Xim(3);
    Ybdot=Xim(4);
    end

  Pm=PHI*P*PHI' + Q;
  [Xb;Yb;Xbdot;Ybdot]
  % linearize the observation at the reference trajectory point: Xb,Yb
  % F = D - sqrt((Xb-Xc)^2 + (Yb-Yc)^2);
  if(isodd == 1)
    dist=sqrt((Xb-Xc1)^2 + (Yb-Yc1)^2);
    dFdX = -(Xb-Xc1)/dist;
    dFdY = -(Yb-Yc1)/dist;
    H=[dFdX dFdY 0 0];
    D=range1(i);
    z=-(D - dist);
    [i z]
    %dspd=[i;refX(i);refY(i);Xadot;Yadot;pfX(i);pfY(i);D;1];
  else
    dist=sqrt((Xb-Xc2)^2 + (Yb-Yc2)^2);
    dFdX = -(Xb-Xc2)/dist;
    dFdY = -(Yb-Yc2)/dist;
    H=[dFdX dFdY 0 0];
    D=range2(i);
    z=-(D - dist);
    [i z]
    %dspd=[i;refX(i);refY(i);Xadot;Yadot;pfX(i);pfY(i);D;2];
    end
  %fprintf(fid,'%4.1f %9.4f %9.4f %9.6f %9.6f %9.4f %9.4f %9.4f %4.1f\n',dspd);
```

```
  % now the kalman gain matrix
  K=Pm*H'*inv(H*Pm*H' + R);

  % blend prior and current
  dxm=Xim - [Xb;Yb;Xbdot;Ybdot];
  dx=dxm + K*(z - H*dxm);

  % covariance
  P=(I4 - K*H)*Pm;
  disp('std dev for x,y at each step');
  [sqrt(P(1,1)) sqrt(P(2,2))]
  prederr(i)=sqrt(P(1,1) + P(2,2));
  % keep a list of the point estimates
  X(i)=Xb + dx(1);
  Y(i)=Yb + dx(2);
  Xdot(i)=Xbdot + dx(3);
  Ydot(i)=Ybdot + dx(4);
  [X(i);Y(i);Xdot(i);Ydot(i)]
  errdist=sqrt((X(i)-pfX(i))^2 + (Y(i)-pfY(i))^2)
  %z
  %D
  %H
  %dist
  %dx

  %keyboard

  Xa=Xb;
  Ya=Yb;
  Xadot=Xbdot;
  Yadot=Ybdot;
  dx'
  ex=X(i)-pfX(i);
  ey=Y(i)-pfY(i);
  er=sqrt(ex^2 + ey^2);
  plerr(i)=er;
  sumsqr=sumsqr + er^2;
  end

rmse=sqrt(sumsqr/42)
%fclose(fid);
```

```
simkal5
first state vector
ans =
      -11.192        193.5       12.433       4.9981
initial P & Q
P =
            4            0            0            0
            0            4            0            0
            0            0         0.25            0
            0            0            0         0.25
Q =
     4     0     0     0
     0     4     0     0
     0     0     1     0
     0     0     0     1
Xim =
       1.2414
        198.5
       12.433
       4.9981
ans =
         1.25
        198.5
       12.433
       4.9981
ans =
            1      -1.7431
std dev for x,y at each step
ans =
       1.2786       2.5739
ans =
       -0.313
       199.27
       12.386
       5.0214
errdist =
       0.7948
ans =
       -1.563      0.76693    -0.047103     0.023345
Xim =
       12.073
       204.29
       12.386
       5.0214
ans =
       13.692
        203.5
       12.433
       4.9981
ans =
            2     -0.34416
std dev for x,y at each step
ans =
       1.4069       2.0495
ans =
       12.426
       204.74
       12.437
       5.0627
errdist =
      0.23779
ans =
      -1.2658       1.2354    0.0042776     0.064677
Xim =
       24.863
        209.8
       12.437
       5.0627
ans =
       26.133
       208.51
       12.433
       4.9981
ans =
            3      -1.8402
std dev for x,y at each step
ans =
       1.3613       2.1793
ans =
       24.807
       209.86
       12.422
       5.0738
```

```
errdist =
      0.12294
ans =
       -1.326       1.3511    -0.011049     0.075771
Xim =
       37.229
       214.93
       12.422
       5.0738
ans =
       38.575
       213.51
       12.433
       4.9981
ans =
           4     -0.24969
std dev for x,y at each step
ans =
       1.5386       2.1562
ans =
       37.242
       214.95
       12.426
       5.0779
errdist =
     0.084147
ans =
      -1.3327       1.4382   -0.0070064      0.07988
Xim =
       49.668
       220.02
       12.426
       5.0779
ans =
       51.016
       218.51
       12.433
       4.9981
ans =
           5      -1.7341
std dev for x,y at each step
ans =
        1.634       2.0538
ans =
       49.845
       219.82
       12.483
       5.0187
errdist =
      0.11546
ans =
       -1.171       1.3138     0.050064     0.020661
Xim =
       62.328
       224.84
       12.483
       5.0187
ans =
       63.458
       223.51
       12.433
       4.9981
ans =
           6    -0.094334
std dev for x,y at each step
ans =
       1.5714       2.1053
ans =
       62.339
       224.85
       12.486
       5.0221
errdist =
      0.13467
ans =
       -1.119        1.342     0.053502     0.024007
Xim =
       74.825
       229.87
       12.486
       5.0221
ans =
         75.9
```

```
       228.51
       12.433
       4.9981
ans =
           7      -1.9571
std dev for x,y at each step
ans =
       1.8619       1.7986
ans =
       74.678
       230.05
       12.439
       5.0777
errdist =
       0.1951
ans =
      -1.2212       1.5412    0.0055374     0.079653
Xim =
       87.117
       235.13
       12.439
       5.0777
ans =
       88.341
       233.51
       12.433
       4.9981
ans =
           8     -0.16453
std dev for x,y at each step
ans =
         1.6        2.033
ans =
       86.966
          235
        12.39
       5.0351
errdist =
      0.20201
ans =
       -1.375        1.482    -0.043127     0.037008
Xim =
       99.356
       240.03
        12.39
       5.0351
ans =
       100.78
       238.51
       12.433
       4.9981
ans =
           9      -1.8164
std dev for x,y at each step
ans =
       2.0971       1.5036
ans =
       99.506
       239.83
       12.438
       4.9724
errdist =
     0.034365
ans =
      -1.2769       1.3198    0.0048218    -0.025626
Xim =
       111.94
       244.81
       12.438
       4.9724
ans =
       113.22
       243.52
       12.433
       4.9981
ans =
          10     -0.20821
std dev for x,y at each step
ans =
       1.6598       1.9797
ans =
        111.9
       244.77
```

```
       12.424
       4.9615
errdist =
     0.076629
ans =
      -1.3249       1.2572   -0.0092012    -0.036547
Xim =
       124.32
       249.73
       12.424
       4.9615
ans =
       125.67
       248.52
       12.433
       4.9981
ans =
          11      -1.6583
std dev for x,y at each step
ans =
       2.3452       1.1763
ans =
       124.34
       249.71
       12.429
       4.9532
errdist =
      0.09395
ans =
      -1.3246       1.1915   -0.0036076    -0.044908
Xim =
       136.77
       254.66
       12.429
       4.9532
ans =
       138.11
       253.52
       12.433
       4.9981
ans =
          12     -0.28205
std dev for x,y at each step
ans =
       1.7701       1.9548
ans =
       136.72
       254.63
       12.414
       4.9426
errdist =
      0.17639
ans =
      -1.3863       1.1118    -0.019044    -0.055503
Xim =
       149.14
       259.57
       12.414
       4.9426
ans =
       150.55
       258.52
       12.433
       4.9981
ans =
          13        -1.46
std dev for x,y at each step
ans =
       2.6103      0.81873
ans =
       149.12
        259.6
       12.408
       4.9523
errdist =
      0.21705
ans =
      -1.4331       1.0823    -0.024663    -0.045771
Xim =
       161.52
       264.56
       12.408
       4.9523
```

```
ans =
       162.99
       263.52
       12.433
       4.9981
ans =
           14  -0.00029169
std dev for x,y at each step
ans =
       1.9578       1.9638
ans =
       161.81
        264.7
       12.496
       5.0055
errdist =
     0.072249
ans =
      -1.1782       1.1821     0.063312    0.0074737
Xim =
       174.31
       269.71
       12.496
       5.0055
ans =
       175.43
       268.52
       12.433
       4.9981
ans =
           15      -1.3071
std dev for x,y at each step
ans =
       2.9084      0.43395
ans =
       174.32
       269.68
       12.501
       4.9967
errdist =
      0.14302
ans =
      -1.1074       1.1595     0.067702   -0.0013862
Xim =
       186.83
       274.68
       12.501
       4.9967
ans =
       187.87
       273.53
       12.433
       4.9981
ans =
           16      0.10457
std dev for x,y at each step
ans =
         2.27       2.0109
ans =
       186.76
       274.65
       12.481
       4.9861
errdist =
      0.13631
ans =
      -1.1137       1.1272     0.048188       -0.012
Xim =
       199.24
       279.64
       12.481
       4.9861
ans =
       200.32
       278.53
       12.433
       4.9981
ans =
           17      -1.2082
std dev for x,y at each step
ans =
       3.2863      0.10024
ans =
```

```
       199.18
       279.74
       12.467
       5.0188
errdist =
      0.16232
ans =
      -1.1313       1.2101     0.034183     0.020755
Xim =
       211.65
       284.76
       12.467
       5.0188
ans =
       212.76
       283.53
       12.433
       4.9981
ans =
           18      0.10611
std dev for x,y at each step
ans =
       2.8064       2.1008
ans =
       211.41
       284.67
       12.397
       4.9827
errdist =
      0.11983
ans =
      -1.3484       1.1428     -0.03585    -0.015399
Xim =
       223.81
       289.65
       12.397
       4.9827
ans =
        225.2
       288.53
       12.433
       4.9981
ans =
           19     -0.87016
std dev for x,y at each step
ans =
       3.8707      0.52871
ans =
       223.84
       289.59
       12.405
       4.9612
errdist =
      0.10554
ans =
      -1.3551       1.0591    -0.027839    -0.036877
Xim =
       236.25
       294.55
       12.405
       4.9612
ans =
       237.64
       293.53
       12.433
       4.9981
ans =
           20       0.2739
std dev for x,y at each step
ans =
       3.8332       2.2443
ans =
       236.37
       294.59
        12.44
       4.9805
errdist =
     0.038286
ans =
      -1.2666       1.0592    0.0065477    -0.017579
Xim =
       248.81
       299.57
```

```
        12.44
       4.9805
ans =
       250.08
       298.53
       12.433
       4.9981
ans =
          21     -0.69833
std dev for x,y at each step
ans =
       5.0586       1.2817
ans =
       248.81
       299.57
       12.439
       4.9813
errdist =
     0.045447
ans =
      -1.2701       1.0406    0.0063044    -0.016779
Xim =
       261.25
       304.55
       12.439
       4.9813
ans =
       262.52
       303.53
       12.433
       4.9981
ans =
          22      0.63233
std dev for x,y at each step
ans =
       6.2192       2.4166
ans =
       261.41
       304.64
       12.481
        5.023
errdist =
      0.19303
ans =
      -1.1124       1.1103     0.048397     0.024953
Xim =
       273.89
       309.67
       12.481
        5.023
ans =
       274.96
       308.54
       12.433
       4.9981
ans =
          23     -0.54768
std dev for x,y at each step
ans =
        8.122       2.9216
ans =
       273.89
       309.51
        12.47
        4.963
errdist =
      0.17447
ans =
      -1.0766      0.96925     0.037338    -0.035036
Xim =
       286.36
       314.47
        12.47
        4.963
ans =
       287.41
       313.54
       12.433
       4.9981
ans =
          24      0.63496
std dev for x,y at each step
ans =
```

```
       8.3006       1.2154
ans =
        286.6
        314.3
       12.512
       4.9154
errdist =
       0.4749
ans =
     -0.80511      0.75905     0.078549     -0.08271
Xim =
       299.11
       319.21
       12.512
       4.9154
ans =
       299.85
       318.54
       12.433
       4.9981
ans =
           25     -0.23499
std dev for x,y at each step
ans =
       6.0218       2.7497
ans =
       298.96
        319.2
       12.483
       4.9041
errdist =
      0.43666
ans =
     -0.88393      0.66226     0.050437    -0.093952
Xim =
       311.45
       324.11
       12.483
       4.9041
ans =
       312.29
       323.54
       12.433
       4.9981
ans =
           26      0.99706
std dev for x,y at each step
ans =
       4.0284      0.65233
ans =
       311.07
       324.35
        12.42
       4.9721
errdist =
     0.070044
ans =
      -1.2157      0.81434    -0.013179    -0.025971
Xim =
       323.49
       329.33
        12.42
       4.9721
ans =
       324.73
       328.54
       12.433
       4.9981
ans =
           27      -0.2775
std dev for x,y at each step
ans =
        3.121       1.7031
ans =
        323.7
       329.42
       12.467
         5.01
errdist =
      0.21837
ans =
      -1.0337      0.88016     0.034431      0.01189
Xim =
```

```
       336.17
       334.43
       12.467
         5.01
ans =
       337.17
       333.54
       12.433
       4.9981
ans =
          28       1.2599
std dev for x,y at each step
ans =
       2.5209       1.4109
ans =
       336.17
       334.43
       12.469
       5.0083
errdist =
      0.25535
ans =
      -1.0013      0.88356     0.036191     0.010236
Xim =
       348.64
       339.44
       12.469
       5.0083
ans =
       349.61
       338.55
       12.433
       4.9981
ans =
          29      0.12597
std dev for x,y at each step
ans =
       2.4012       1.5066
ans =
       348.34
       339.19
       12.381
       4.9272
errdist =
       0.1529
ans =
      -1.2723      0.64951    -0.052254    -0.070898
Xim =
       360.72
       344.12
       12.381
       4.9272
ans =
       362.06
       343.55
       12.433
       4.9981
ans =
          30       1.4719
std dev for x,y at each step
ans =
       1.7542        1.927
ans =
       360.64
       344.18
       12.355
       4.9464
errdist =
      0.21749
ans =
      -1.4139      0.63297    -0.077506    -0.051681
Xim =
          373
       349.13
       12.355
       4.9464
ans =
        374.5
       348.55
       12.433
       4.9981
ans =
          31       0.1401
```

```
std dev for x,y at each step
ans =
       2.1296       1.4964
ans =
       373.16
       349.32
       12.406
       5.0081
errdist =
     0.091719
ans =
      -1.3399      0.76934    -0.026761     0.010057
Xim =
       385.56
       354.33
       12.406
       5.0081
ans =
       386.94
       353.55
       12.433
       4.9981
ans =
           32       1.4743
std dev for x,y at each step
ans =
       1.2236       2.2853
ans =
       385.65
       354.27
       12.435
       4.9901
errdist =
     0.037854
ans =
      -1.2872       0.7193    0.0017287   -0.0079681
Xim =
       398.09
       359.26
       12.435
       4.9901
ans =
       399.38
       358.55
       12.433
       4.9981
ans =
           33      0.12338
std dev for x,y at each step
ans =
       2.0598       1.5902
ans =
       398.14
       359.35
       12.453
       5.0187
errdist =
     0.098278
ans =
       -1.238      0.79878     0.020459     0.020663
Xim =
        410.6
       364.37
       12.453
       5.0187
ans =
       411.82
       363.55
       12.433
       4.9981
ans =
           34       1.4212
std dev for x,y at each step
ans =
      0.83312       2.5422
ans =
       410.59
       364.37
       12.453
       5.0191
errdist =
      0.14262
ans =
```

```
      -1.2284      0.81732     0.019714     0.021063
Xim =
       423.05
       369.39
       12.453
       5.0191
ans =
       424.26
       368.55
       12.433
       4.9981
ans =
           35      0.16944
std dev for x,y at each step
ans =
       2.0689       1.7298
ans =
       423.03
       369.36
       12.448
       5.0105
errdist =
      0.15682
ans =
      -1.2308      0.80712     0.014923     0.012455
Xim =
       435.48
       374.37
       12.448
       5.0105
ans =
       436.71
       373.56
       12.433
       4.9981
ans =
           36       1.3143
std dev for x,y at each step
ans =
      0.53833       2.7426
ans =
       435.52
       374.35
       12.461
       5.0043
errdist =
      0.17963
ans =
       -1.185      0.79406      0.02793    0.0062703
Xim =
       447.98
       379.35
       12.461
       5.0043
ans =
       449.15
       378.56
       12.433
       4.9981
ans =
           37      0.26338
std dev for x,y at each step
ans =
       2.1069       1.8867
ans =
       447.95
       379.28
       12.449
       4.9803
errdist =
      0.12748
ans =
      -1.1977      0.71798     0.015964    -0.017764
Xim =
        460.4
       384.26
       12.449
       4.9803
ans =
       461.59
       383.56
       12.433
       4.9981
```

```
ans =
          38       1.3364
std dev for x,y at each step
ans =
      0.31132       2.9136
ans =
       460.32
        384.3
       12.423
       4.9915
errdist =
      0.16336
ans =
      -1.2681      0.73918   -0.0096038   -0.0065837
Xim =
       472.74
       389.29
       12.423
       4.9915
ans =
       474.03
       388.56
       12.433
       4.9981
ans =
          39      0.46044
std dev for x,y at each step
ans =
       2.1547       2.0486
ans =
       472.71
       389.18
       12.409
       4.9594
errdist =
      0.10183
ans =
      -1.3237      0.62218    -0.024413    -0.038692
Xim =
       485.12
       394.14
       12.409
       4.9594
ans =
       486.47
       393.56
       12.433
       4.9981
ans =
          40       1.1869
std dev for x,y at each step
ans =
      0.14444       3.0687
ans =
        485.3
       394.04
       12.469
       4.9343
errdist =
     0.092148
ans =
      -1.1712      0.47932     0.036375      -0.0638
Xim =
       497.77
       398.98
       12.469
       4.9343
ans =
       498.91
       398.56
       12.433
       4.9981
ans =
          41      0.68811
std dev for x,y at each step
ans =
       2.2054       2.2103
ans =
       497.71
       398.79
       12.446
       4.8798
errdist =
```

```
      0.27847
ans =
      -1.2003      0.22817     0.012564     -0.11822
Xim =
       510.16
       403.67
       12.446
       4.8798
ans =
       511.36
       403.56
       12.433
       4.9981
ans =
           42       1.3404
std dev for x,y at each step
ans =
      0.11455       3.2146
ans =
       510.01
       403.75
       12.398
       4.8989
errdist =
      0.30512
ans =
      -1.3436       0.1869    -0.035443    -0.099145
rmse =
      0.21909
diary off
```

```
simkal5
first state vector
ans =
      -11.192        193.5       12.433       4.9981
initial P & Q
P =
            4            0            0            0
            0            4            0            0
            0            0         0.25            0
            0            0            0         0.25
Q =
     4     0     0     0
     0     4     0     0
     0     0     1     0
     0     0     0     1
Xim =
       1.2414
        198.5
       12.433
       4.9981
ans =
         1.25
        198.5
       12.433
       4.9981
ans =
            1      -1.7431
std dev for x,y at each step
ans =
       1.2786       2.5739
ans =
       -0.313
       199.27
       12.386
       5.0214
errdist =
       0.7948
ans =
       -1.563      0.76693    -0.047103     0.023345
Xim =
       12.073
       204.29
       12.386
       5.0214
ans =
       13.692
        203.5
       12.433
       4.9981
ans =
            2     -0.34416
std dev for x,y at each step
ans =
       1.4069       2.0495
ans =
       12.426
       204.74
       12.437
       5.0627
errdist =
      0.23779
ans =
      -1.2658       1.2354    0.0042776     0.064677
Xim =
       24.863
        209.8
       12.437
       5.0627
ans =
       26.133
       208.51
       12.433
       4.9981
ans =
            3      -1.8402
std dev for x,y at each step
ans =
       1.3613       2.1793
ans =
       24.807
       209.86
       12.422
       5.0738
```

```
errdist =
      0.12294
ans =
       -1.326       1.3511    -0.011049     0.075771
Xim =
       37.229
       214.93
       12.422
       5.0738
ans =
       38.575
       213.51
       12.433
       4.9981
ans =
           4     -0.24969
std dev for x,y at each step
ans =
       1.5386       2.1562
ans =
       37.242
       214.95
       12.426
       5.0779
errdist =
     0.084147
ans =
      -1.3327       1.4382   -0.0070064      0.07988
Xim =
       49.668
       220.02
       12.426
       5.0779
ans =
       51.016
       218.51
       12.433
       4.9981
ans =
           5      -1.7341
std dev for x,y at each step
ans =
        1.634       2.0538
ans =
       49.845
       219.82
       12.483
       5.0187
errdist =
      0.11546
ans =
       -1.171       1.3138     0.050064     0.020661
Xim =
       62.328
       224.84
       12.483
       5.0187
ans =
       62.328
       224.84
       12.483
       5.0187
ans =
           6     0.020145
std dev for x,y at each step
ans =
       1.5605       2.1166
ans =
       62.343
       224.86
       12.488
       5.0232
errdist =
      0.13743
ans =
     0.014179     0.014698    0.0046322    0.0044848
Xim =
        74.83
       229.88
       12.488
       5.0232
ans =
        74.83
```

```
       229.88
       12.488
       5.0232
ans =
           7     -0.23061
std dev for x,y at each step
ans =
       1.8643       1.7974
ans =
       74.684
       230.06
        12.44
        5.079
errdist =
      0.20127
ans =
     -0.14629      0.17912    -0.047733     0.055746
Xim =
       87.124
       235.14
        12.44
        5.079
ans =
       87.124
       235.14
        12.44
        5.079
ans =
           8     -0.20421
std dev for x,y at each step
ans =
       1.5853       2.0458
ans =
       86.971
          235
       12.391
       5.0361
errdist =
      0.20347
ans =
     -0.15269     -0.13618    -0.049337     -0.04287
Xim =
       99.362
       240.04
       12.391
       5.0361
ans =
       99.362
       240.04
       12.391
       5.0361
ans =
           9      0.24876
std dev for x,y at each step
ans =
       2.0942       1.5065
ans =
       99.512
       239.84
       12.439
       4.9727
errdist =
     0.032899
ans =
      0.15028     -0.19818     0.048174    -0.063339
Xim =
       111.95
       244.81
       12.439
       4.9727
ans =
       111.95
       244.81
       12.439
       4.9727
ans =
          10    -0.057347
std dev for x,y at each step
ans =
       1.6444       1.9912
ans =
       111.91
       244.78
```

```
      12.424
      4.9615
errdist =
     0.070234
ans =
   -0.045731    -0.034638    -0.014528    -0.011244
Xim =
      124.33
      249.74
      12.424
      4.9615
ans =
      124.33
      249.74
      12.424
      4.9615
ans =
          11     0.032658
std dev for x,y at each step
ans =
      2.3368       1.1835
ans =
      124.35
      249.71
       12.43
      4.9527
errdist =
     0.087012
ans =
     0.01892    -0.027011     0.005866   -0.0088019
Xim =
      136.78
      254.66
       12.43
      4.9527
ans =
      136.78
      254.66
       12.43
      4.9527
ans =
          12    -0.057842
std dev for x,y at each step
ans =
      1.7511        1.965
ans =
      136.73
      254.63
      12.415
      4.9421
errdist =
      0.16924
ans =
    -0.04955    -0.031288    -0.015458    -0.010563
Xim =
      149.14
      259.57
      12.415
      4.9421
ans =
      149.14
      259.57
      12.415
      4.9421
ans =
          13    -0.031949
std dev for x,y at each step
ans =
      2.5953      0.83148
ans =
      149.13
       259.6
      12.409
      4.9513
errdist =
      0.20907
ans =
   -0.017959      0.02779   -0.0052915    0.0091774
Xim =
      161.54
      264.55
      12.409
      4.9513
```

```
ans =
       161.54
       264.55
       12.409
       4.9513
ans =
           14      0.31073
std dev for x,y at each step
ans =
       1.9309       1.9722
ans =
       161.82
        264.7
       12.498
       5.0045
errdist =
     0.083081
ans =
      0.28831      0.14938     0.088198       0.0532
Xim =
       174.32
       269.71
       12.498
       5.0045
ans =
       174.32
       269.71
       12.498
       5.0045
ans =
           15     0.027475
std dev for x,y at each step
ans =
       2.8881      0.44665
ans =
       174.34
       269.68
       12.502
        4.996
errdist =
      0.15437
ans =
     0.015304    -0.025455     0.004184   -0.0084654
Xim =
       186.84
       274.68
       12.502
        4.996
ans =
       186.84
       274.68
       12.502
        4.996
ans =
           16     -0.06426
std dev for x,y at each step
ans =
       2.2353       2.0167
ans =
       186.77
       274.65
       12.482
       4.9855
errdist =
      0.14889
ans =
    -0.065364    -0.027506    -0.019531    -0.010569
Xim =
       199.25
       279.64
       12.482
       4.9855
ans =
       199.25
       279.64
       12.482
       4.9855
ans =
           17    -0.097216
std dev for x,y at each step
ans =
        3.255      0.10064
ans =
```

```
       199.2
      279.73
      12.468
      5.0177
errdist =
     0.17133
ans =
   -0.055936     0.096918    -0.013774     0.032238
Xim =
      211.67
      284.75
      12.468
      5.0177
ans =
      211.67
      284.75
      12.468
      5.0177
ans =
          18     -0.21054
std dev for x,y at each step
ans =
      2.7473       2.1043
ans =
      211.43
      284.67
        12.4
      4.9825
errdist =
     0.10145
ans =
    -0.23786     -0.08277    -0.068868    -0.035212
Xim =
      223.83
      289.65
        12.4
      4.9825
ans =
      223.83
      289.65
        12.4
      4.9825
ans =
          19      0.06553
std dev for x,y at each step
ans =
      3.8062      0.49037
ans =
      223.87
      289.58
      12.408
       4.959
errdist =
     0.078223
ans =
    0.041173    -0.071166     0.008829    -0.023536
Xim =
      236.28
      294.54
      12.408
       4.959
ans =
      236.28
      294.54
      12.408
       4.959
ans =
          20      0.10424
std dev for x,y at each step
ans =
      3.7074       2.2391
ans =
      236.41
      294.58
      12.445
       4.979
errdist =
     0.031993
ans =
     0.13169     0.042113     0.036433     0.020001
Xim =
      248.86
      299.56
```

```
       12.445
        4.979
ans =
       248.86
       299.56
       12.445
        4.979
ans =
          21    0.0024521
std dev for x,y at each step
ans =
       4.9065       1.2071
ans =
       248.86
       299.56
       12.445
        4.978
errdist =
     0.034949
ans =
    0.0017283   -0.0029451   0.00030202  -0.00096964
Xim =
        261.3
       304.53
       12.445
        4.978
ans =
        261.3
       304.53
       12.445
        4.978
ans =
          22      0.15293
std dev for x,y at each step
ans =
       5.9392       2.4078
ans =
       261.48
       304.63
       12.493
       5.0212
errdist =
      0.23965
ans =
      0.18014     0.091787     0.047445      0.04319
Xim =
       273.97
       309.65
       12.493
       5.0212
ans =
       273.97
       309.65
       12.493
       5.0212
ans =
          23      0.16761
std dev for x,y at each step
ans =
       7.8023       2.7553
ans =
         274
       309.46
       12.487
       4.9543
errdist =
      0.28609
ans =
     0.025033     -0.18631   -0.0058133    -0.066891
Xim =
       286.49
       314.42
       12.487
       4.9543
ans =
       286.49
       314.42
       12.487
       4.9543
ans =
          24    -0.095469
std dev for x,y at each step
ans =
```

```
       8.4114       1.3339
ans =
       286.64
       314.29
       12.514
       4.9194
errdist =
      0.51544
ans =
        0.157     -0.12134     0.026762    -0.034888
Xim =
       299.16
       319.21
       12.514
       4.9194
ans =
       299.16
       319.21
       12.514
       4.9194
ans =
          25     0.093539
std dev for x,y at each step
ans =
       6.2719       2.8354
ans =
       298.96
        319.2
       12.476
       4.9048
errdist =
      0.43157
ans =
     -0.19913    -0.012524    -0.037933    -0.014567
Xim =
       311.43
       324.11
       12.476
       4.9048
ans =
       311.43
       324.11
       12.476
       4.9048
ans =
          26      0.30639
std dev for x,y at each step
ans =
       4.1216      0.62607
ans =
       311.05
       324.36
       12.411
       4.9726
errdist =
     0.058666
ans =
     -0.38495      0.25174    -0.064874     0.067705
Xim =
       323.46
       329.33
       12.411
       4.9726
ans =
       323.46
       329.33
       12.411
       4.9726
ans =
          27     -0.19031
std dev for x,y at each step
ans =
       3.1724       1.7076
ans =
       323.68
       329.43
       12.461
       5.0124
errdist =
      0.19878
ans =
      0.21697     0.099206     0.049926     0.039839
Xim =
```

```
       336.14
       334.44
       12.461
       5.0124
ans =
       336.14
       334.44
       12.461
       5.0124
ans =
           28    -0.028432
std dev for x,y at each step
ans =
       2.5429       1.4025
ans =
       336.16
       334.42
       12.467
       5.0062
errdist =
      0.24499
ans =
     0.024605    -0.018889    0.0065749   -0.0061932
Xim =
       348.63
       339.43
       12.467
       5.0062
ans =
       348.63
       339.43
       12.467
       5.0062
ans =
           29      0.35463
std dev for x,y at each step
ans =
       2.4179       1.5015
ans =
       348.34
       339.19
       12.381
       4.9268
errdist =
      0.15429
ans =
     -0.29308     -0.23525    -0.086417    -0.079381
Xim =
       360.72
       344.12
       12.381
       4.9268
ans =
       360.72
       344.12
       12.381
       4.9268
ans =
           30     0.096076
std dev for x,y at each step
ans =
       1.7675       1.9193
ans =
       360.64
       344.18
       12.356
       4.9455
errdist =
      0.22211
ans =
    -0.078793     0.056197    -0.024598     0.018703
Xim =
       372.99
       349.12
       12.356
       4.9455
ans =
       372.99
       349.12
       12.356
       4.9455
ans =
           31     -0.24943
```

```
std dev for x,y at each step
ans =
       2.1396       1.4871
ans =
       373.16
       349.31
       12.407
       5.0074
errdist =
     0.093659
ans =
      0.16098      0.19173      0.05092      0.06186
Xim =
       385.56
       354.32
       12.407
       5.0074
ans =
       385.56
       354.32
       12.407
       5.0074
ans =
           32     -0.10401
std dev for x,y at each step
ans =
       1.2224       2.2849
ans =
       385.65
       354.27
       12.436
       4.9895
errdist =
     0.040255
ans =
     0.087859    -0.056158     0.028431    -0.017895
Xim =
       398.09
       359.26
       12.436
       4.9895
ans =
       398.09
       359.26
       12.436
       4.9895
ans =
           33     -0.10667
std dev for x,y at each step
ans =
       2.0661       1.5804
ans =
       398.14
       359.35
       12.454
       5.0182
errdist =
     0.094712
ans =
     0.056142     0.091274     0.018725     0.028762
Xim =
        410.6
       364.36
       12.454
       5.0182
ans =
        410.6
       364.36
       12.454
       5.0182
ans =
           34     0.004438
std dev for x,y at each step
ans =
      0.82443       2.5444
ans =
       410.59
       364.37
       12.453
       5.0189
errdist =
      0.13939
ans =
```

```
   -0.0039223    0.0022899   -0.0012882   0.00068528
Xim =
       423.05
       369.39
       12.453
       5.0189
ans =
       423.05
       369.39
       12.453
       5.0189
ans =
          35     0.029814
std dev for x,y at each step
ans =
       2.0757       1.7207
ans =
       423.03
       369.36
       12.448
       5.0104
errdist =
      0.15369
ans =
    -0.013365     -0.02762   -0.0047175   -0.0085505
Xim =
       435.48
       374.37
       12.448
       5.0104
ans =
       435.48
       374.37
       12.448
       5.0104
ans =
          36     -0.04196
std dev for x,y at each step
ans =
      0.52726       2.7446
ans =
       435.52
       374.35
       12.461
       5.0044
errdist =
      0.17674
ans =
     0.038634    -0.021385      0.01273   -0.0059885
Xim =
       447.98
       379.35
       12.461
       5.0044
ans =
       447.98
       379.35
       12.461
       5.0044
ans =
          37     0.080028
std dev for x,y at each step
ans =
       2.1142        1.879
ans =
       447.95
       379.27
       12.449
       4.9804
errdist =
      0.12486
ans =
    -0.031658    -0.078847    -0.011846     -0.02403
Xim =
        460.4
       384.25
       12.449
       4.9804
ans =
        460.4
       384.25
       12.449
       4.9804
```

```
ans =
          38     0.082013
std dev for x,y at each step
ans =
      0.30155       2.9143
ans =
       460.32
        384.3
       12.423
       4.9915
errdist =
      0.16112
ans =
    -0.078204     0.042313    -0.025716     0.011134
Xim =
       472.74
       389.29
       12.423
       4.9915
ans =
       472.74
       389.29
       12.423
       4.9915
ans =
          39      0.10335
std dev for x,y at each step
ans =
       2.162       2.0407
ans =
       472.71
       389.18
       12.409
       4.9594
errdist =
      0.10081
ans =
    -0.037042     -0.10704    -0.014687    -0.032145
Xim =
       485.11
       394.14
       12.409
       4.9594
ans =
       485.11
       394.14
       12.409
       4.9594
ans =
          40      -0.1889
std dev for x,y at each step
ans =
      0.13821       3.0679
ans =
        485.3
       394.04
        12.47
       4.9345
errdist =
     0.092622
ans =
      0.18571     -0.10001      0.06081    -0.024891
Xim =
       497.77
       398.97
        12.47
       4.9345
ans =
       497.77
       398.97
        12.47
       4.9345
ans =
          41       0.1704
std dev for x,y at each step
ans =
       2.2113       2.2048
ans =
       497.71
       398.79
       12.446
       4.8799
errdist =
```

```
      0.28029
ans =
    -0.056456     -0.18412    -0.023681    -0.054512
Xim =
       510.16
       403.67
       12.446
       4.8799
ans =
       510.16
       403.67
       12.446
       4.8799
ans =
           42      0.14649
std dev for x,y at each step
ans =
      0.11546       3.2109
ans =
       510.01
       403.75
       12.398
        4.899
errdist =
      0.30677
ans =
     -0.14783     0.080396    -0.048154      0.01906
rmse =
      0.22389
diary off
```