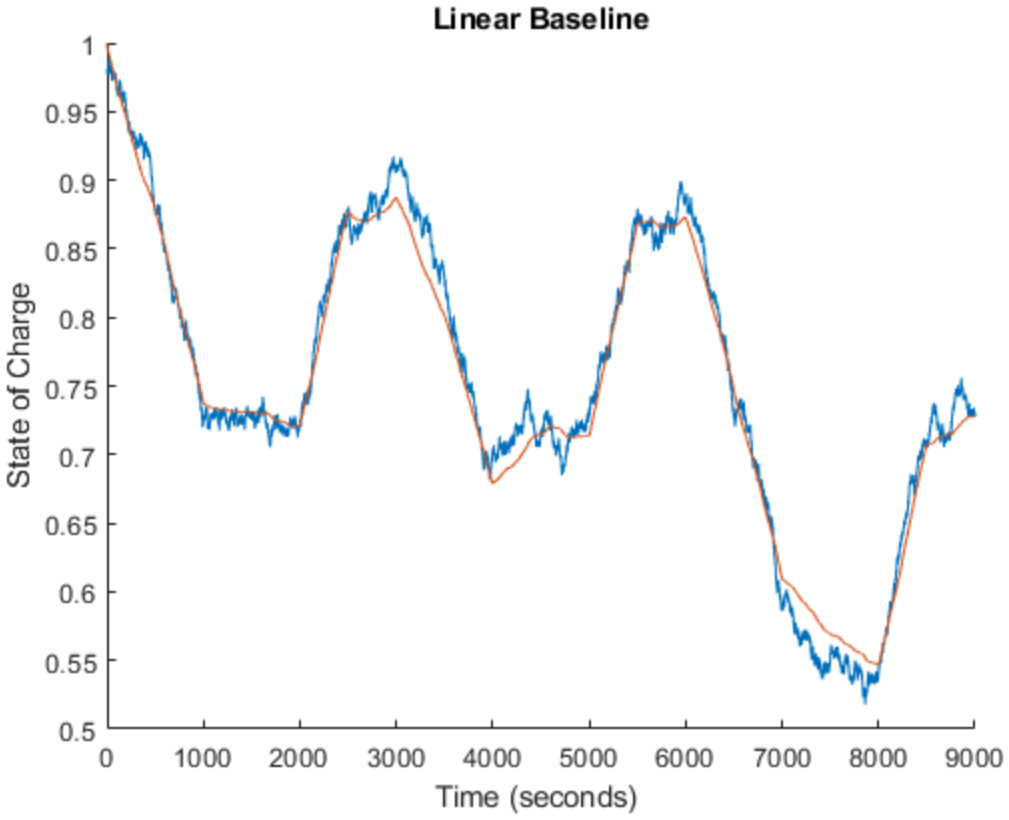
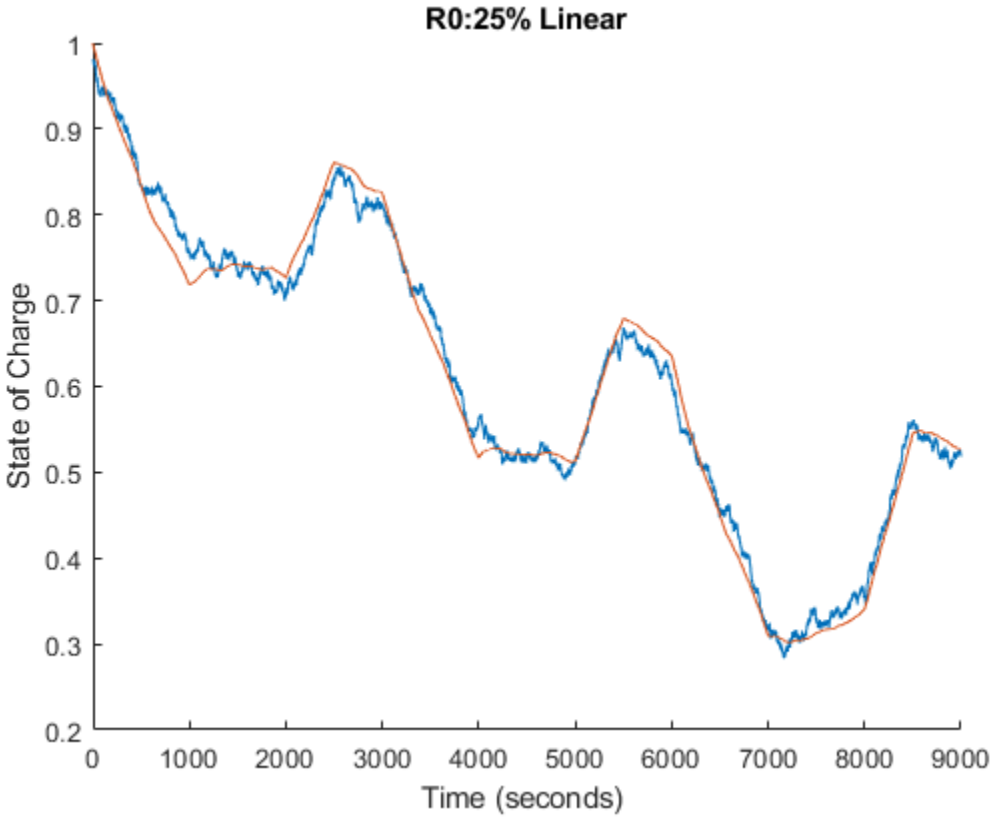
Table of Contents

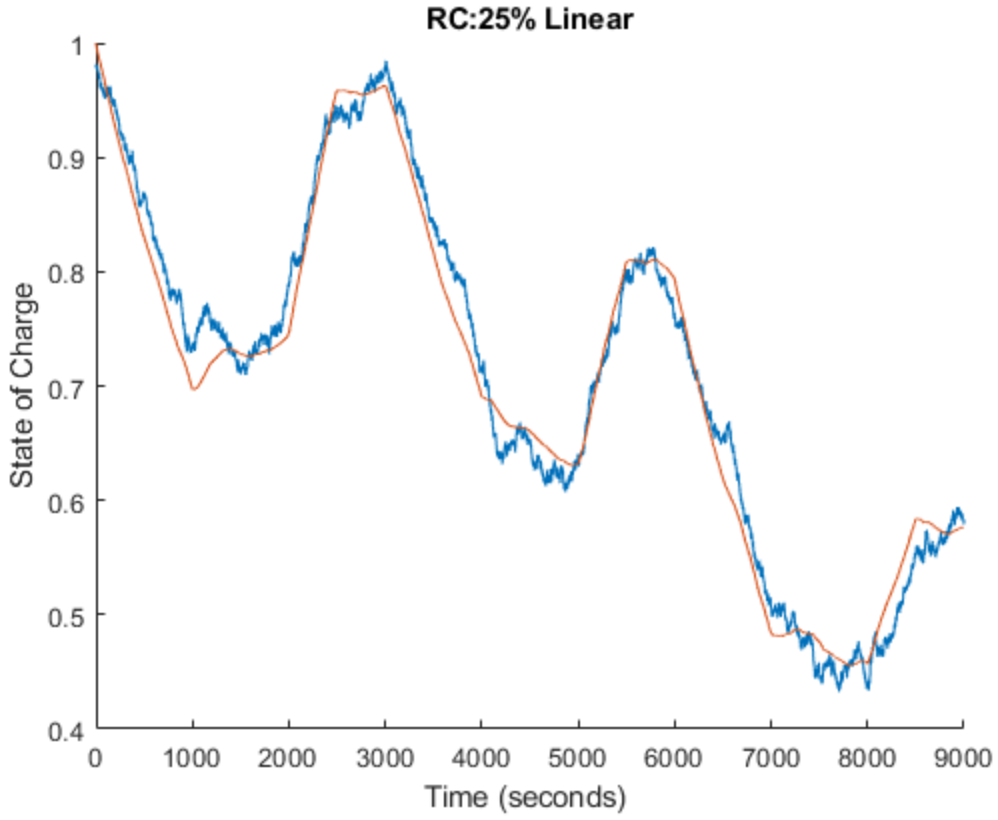
MAE 273A Project Script

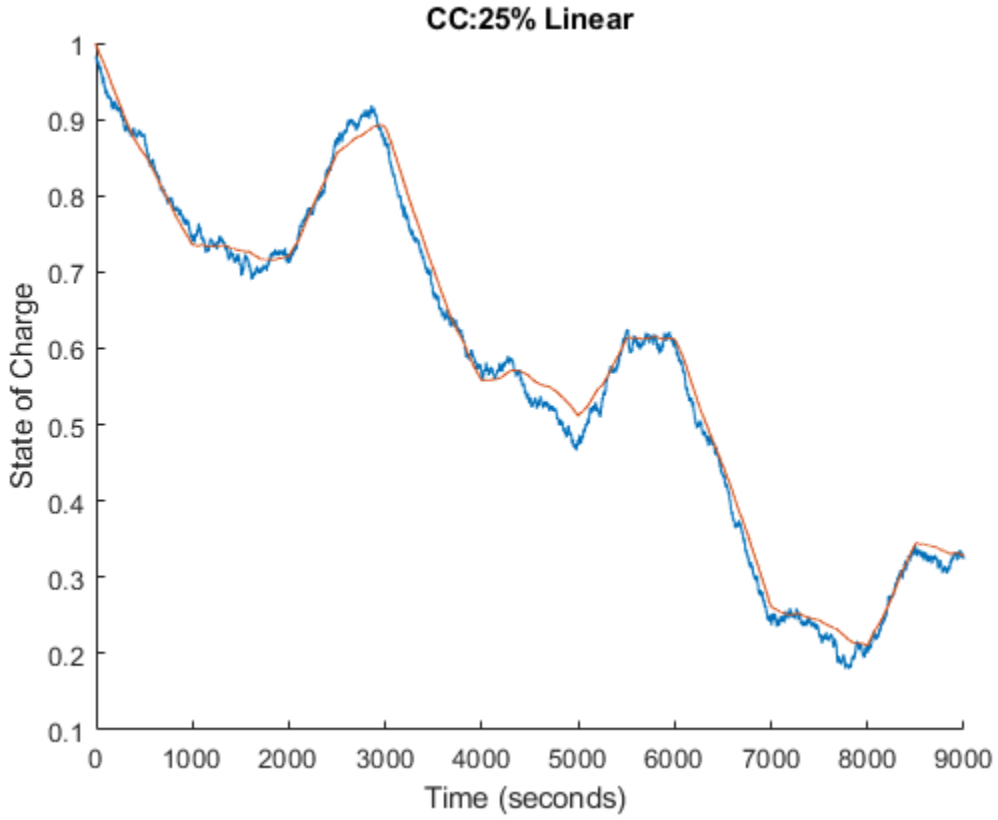
```
clear all

List =
 ["FirstOrderTruth_BASELINE_linear.mat","FirstOrderTruth_R0_25_linear.mat","FirstO
NameList = ["Linear Baseline", "R0:25% Linear", "RC:25%
 Linear","CC:25% Linear","R0:50% Linear","RC:50% Linear","CC:50%
 Linear","R0:20% RC: 20%Linear","Nonlinear Baseline ","R0:25%
 Nonlinear","RC:25% Nonlinear","CC:25% Nonlinear","R0:50%
 Nonlinear","RC:50% Nonlinear","CC:50% Nonlinear", "R0:20% RC:20%
 Nonlinear" ];


for k = 1:length(List)
    load(List(k))

s = tf('s');

%battery model parameters
Rc = 0.015;    %Ohms
Cc = 2400;     %F
Cbat = 5*3600;
alpha =0.65;
R0 = 0.01;     %Ohms
Vocv0 = 3.435; %V

%tunning parameters
K = 1;         %gain
% zeta = 0.707;  %damping ratio
zeta = 0.5;  %damping ratio

wn = 75;      %natural frequency

%continuous time ss model
A = [-1/(Rc*Cc) 0; 0 0];
B = [1/Cc; -1/Cbat];
C = [-1 alpha];
D = -R0;

A1 = A(1,1);
B1 = B(1,1);
A2 = A(2,2);
B2 = B(2,1);
```

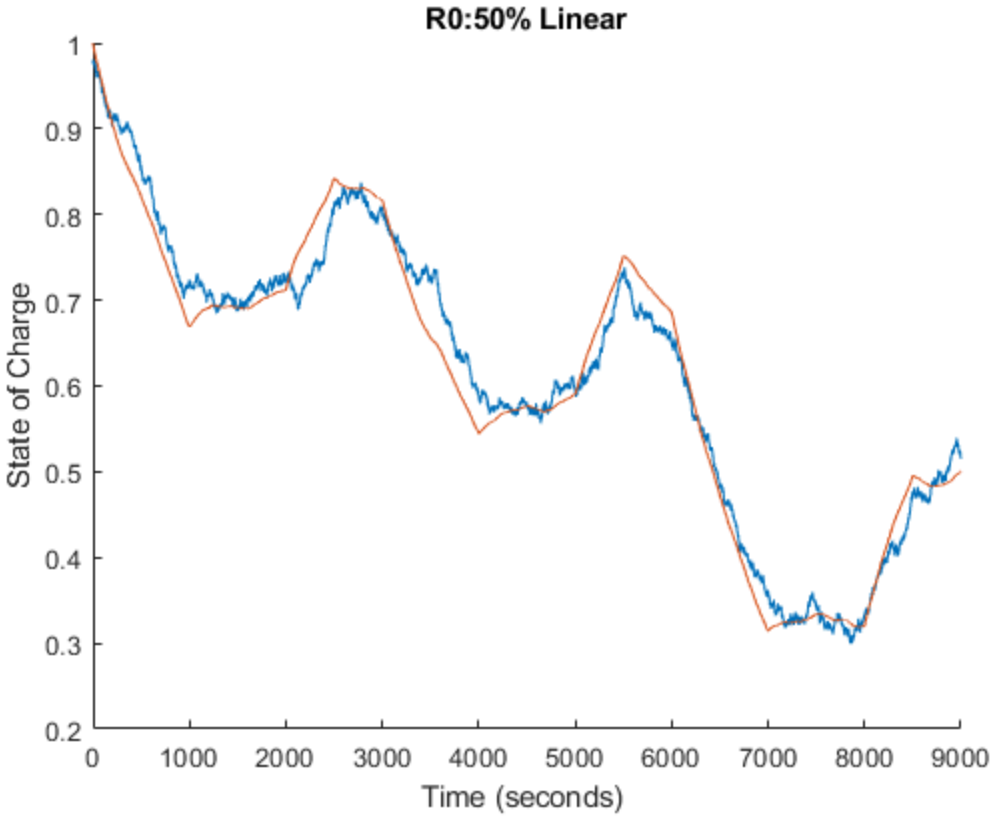
```
C2 = alpha;

SI = [s 0;0 s];
Gp = C*(inv(SI-A))*B+D;       %plant
T = minreal(K*wn^2/(s^2+2*zeta*wn*s+wn^2)); %complimentary
Y = minreal(T/Gp);            %youla
S = minreal(1-T);             %sensitivity
Gc = minreal(Y/S);            %controller
L = minreal(Gc*Gp);                   %open loop TF
sysTF = minreal(Gc*Gp/(1+Gc*Gp));     %actual sys TF
[num, den] = tfdata(Gc, 'v'); %get numerator and denominator of Gc tf

out = sim('Estimator_Simulink_trial1') ;   %run simulink model

est_soc = out.SOC_est;
tout = out.tout;

YOULA_ACTUAL (:,k) = SOC_act;
YOULA_ESTIMATED(:,k) = est_soc;

figure()
hold on
plot(t,SOC_act);
plot(tout,est_soc);

title(NameList(k))
xlabel('Time (seconds) ')
ylabel('State of Charge')

end
```

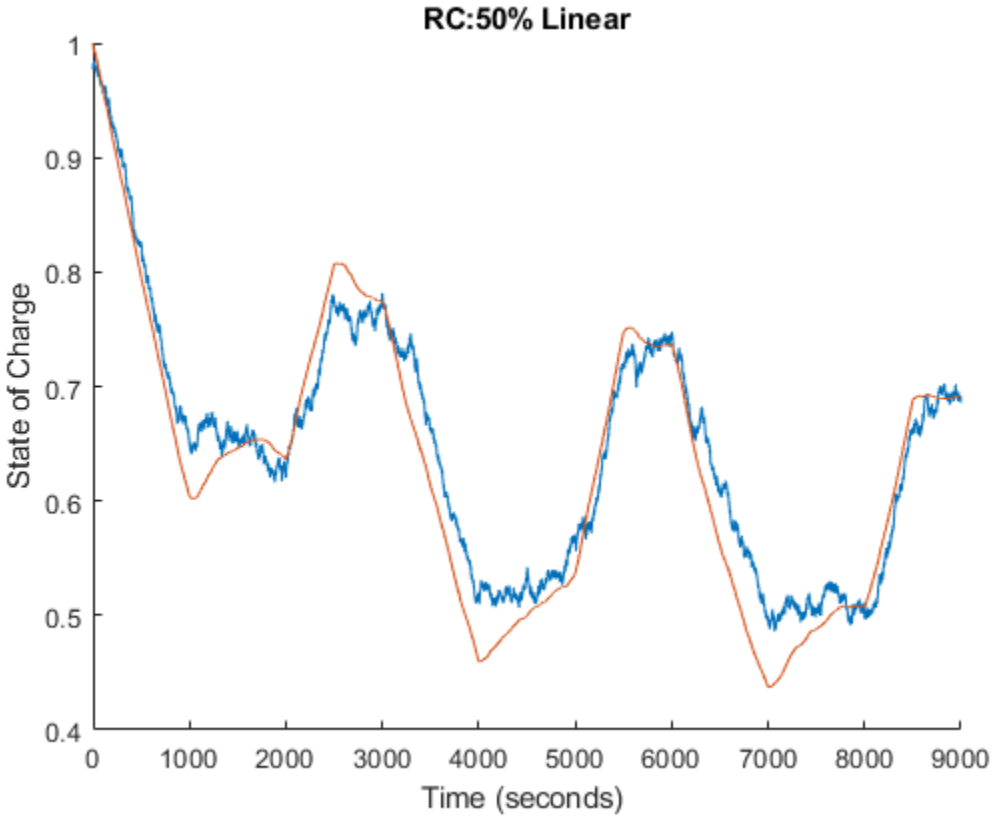

Linear Baseline
State of Charge
Time (seconds)
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

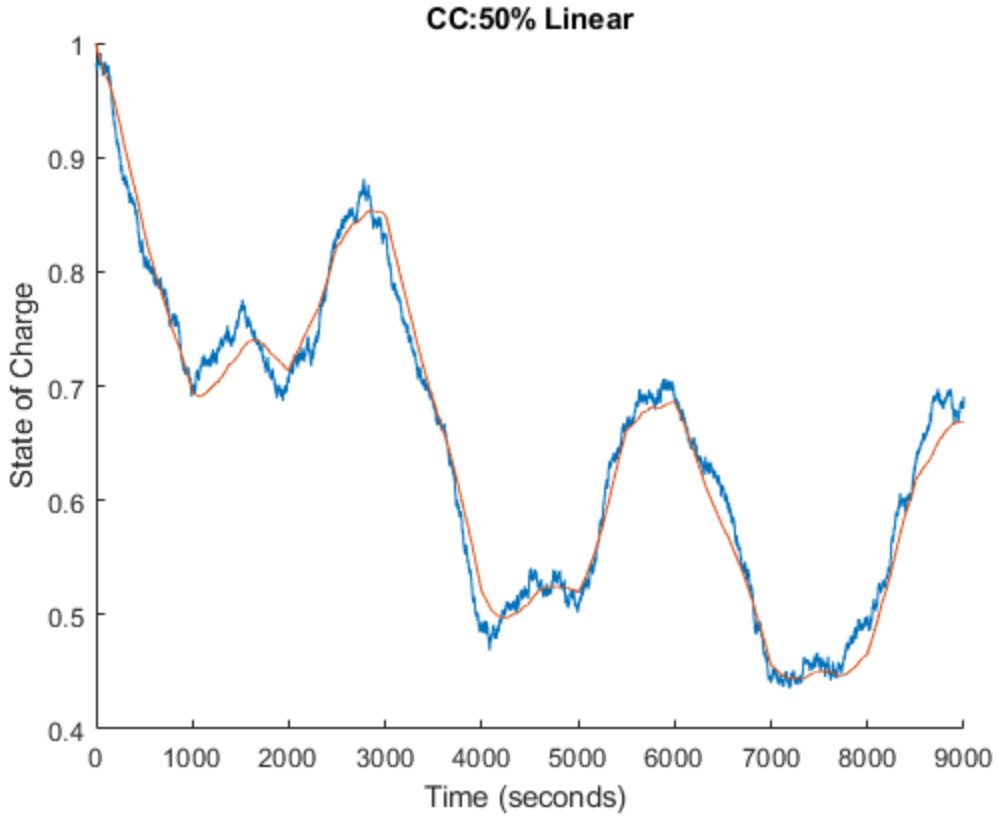

R0:25% Linear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

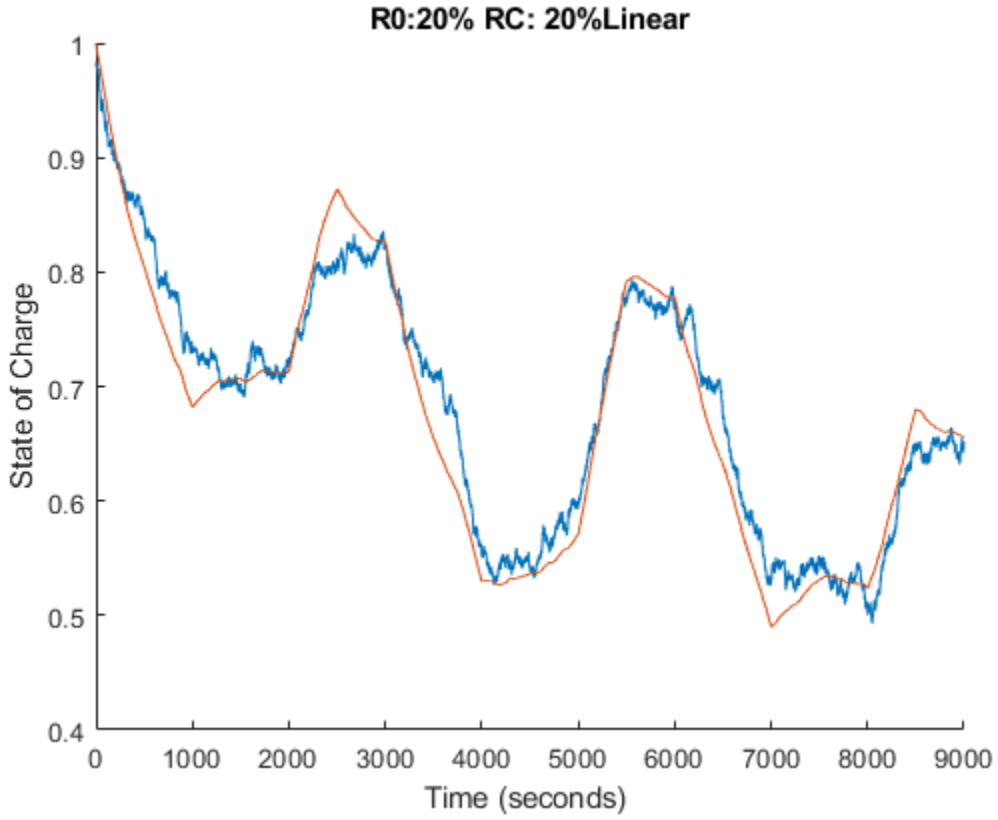

RC:25% Linear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

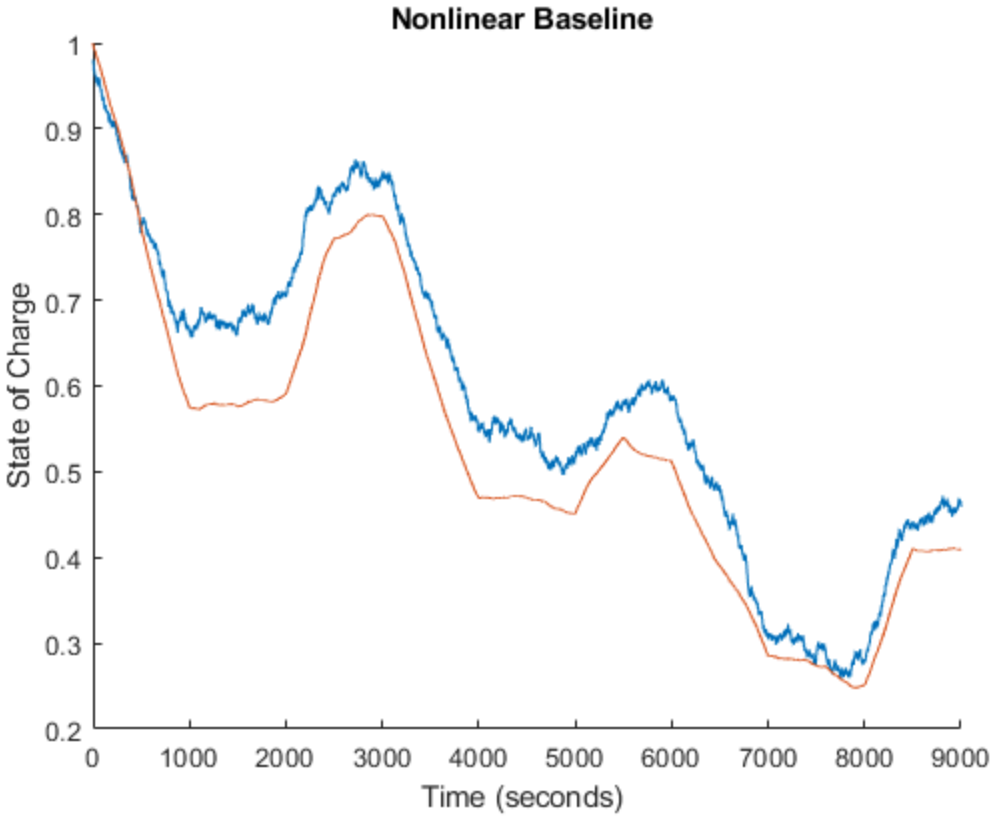

CC:25% Linear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

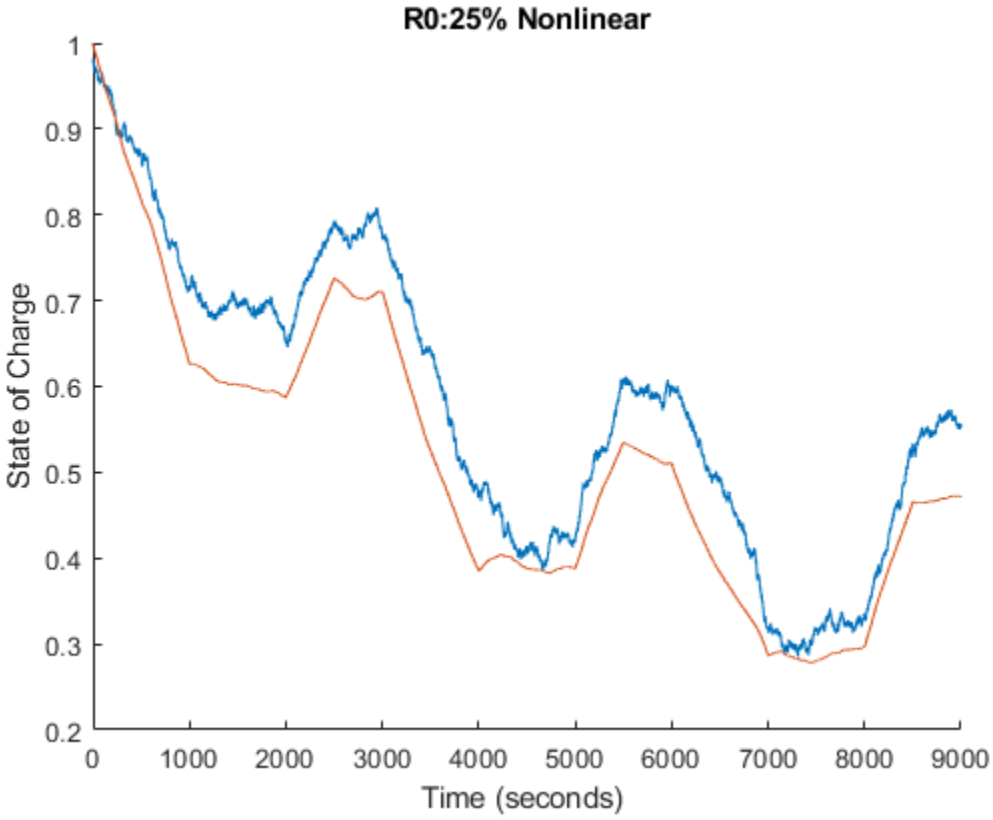

R0:50% Linear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

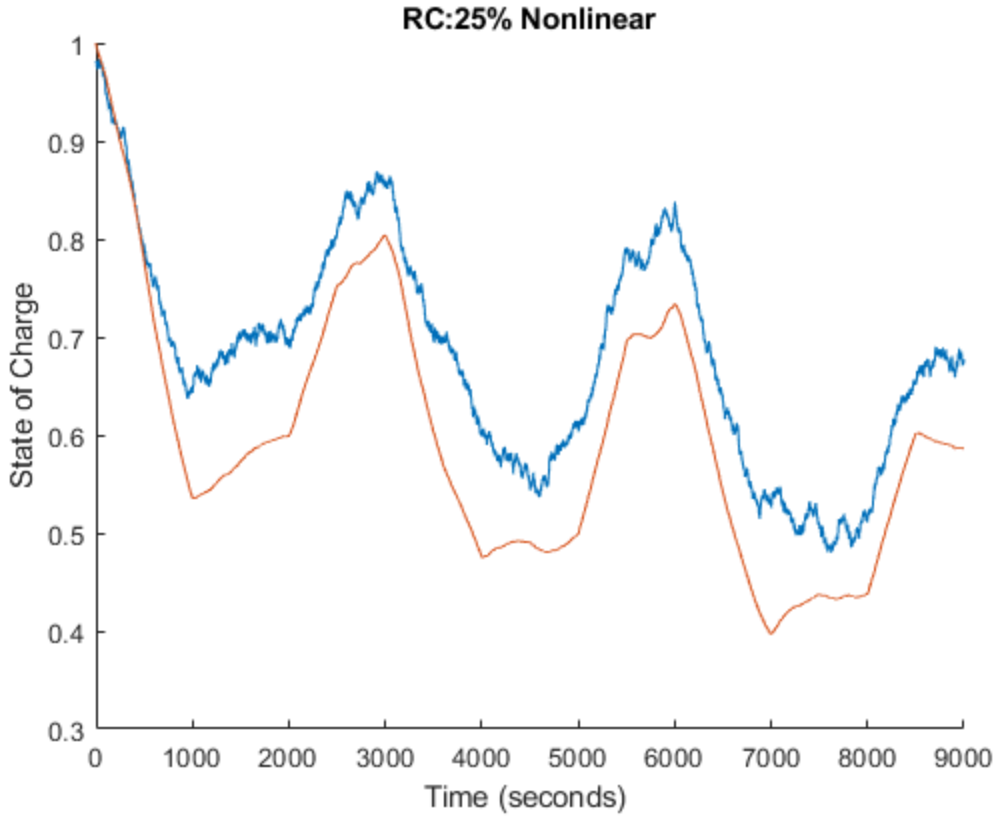

RC:50% Linear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

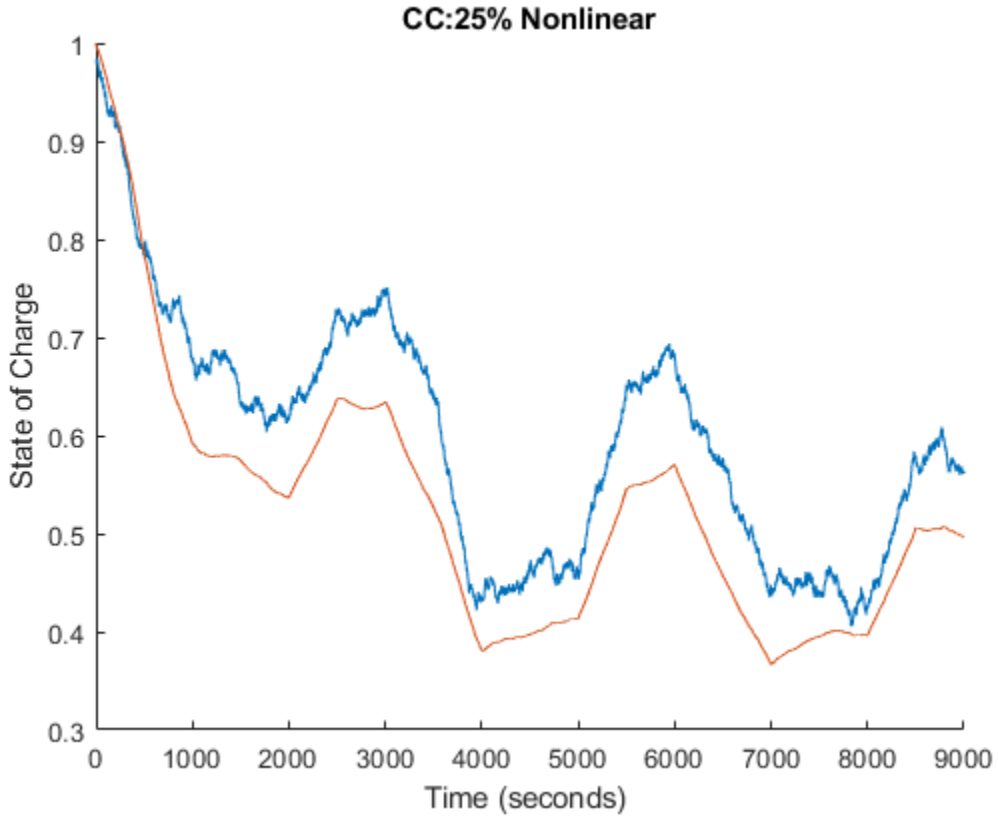

CC:50% Linear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

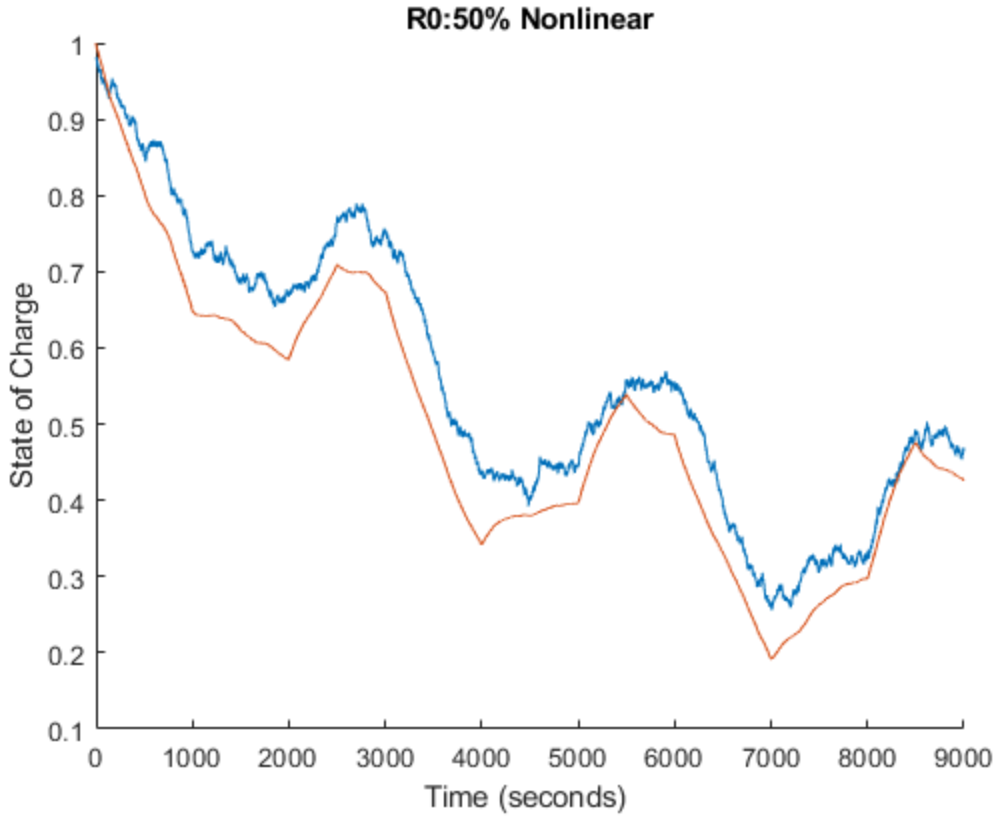

R0:20% RC: 20%Linear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

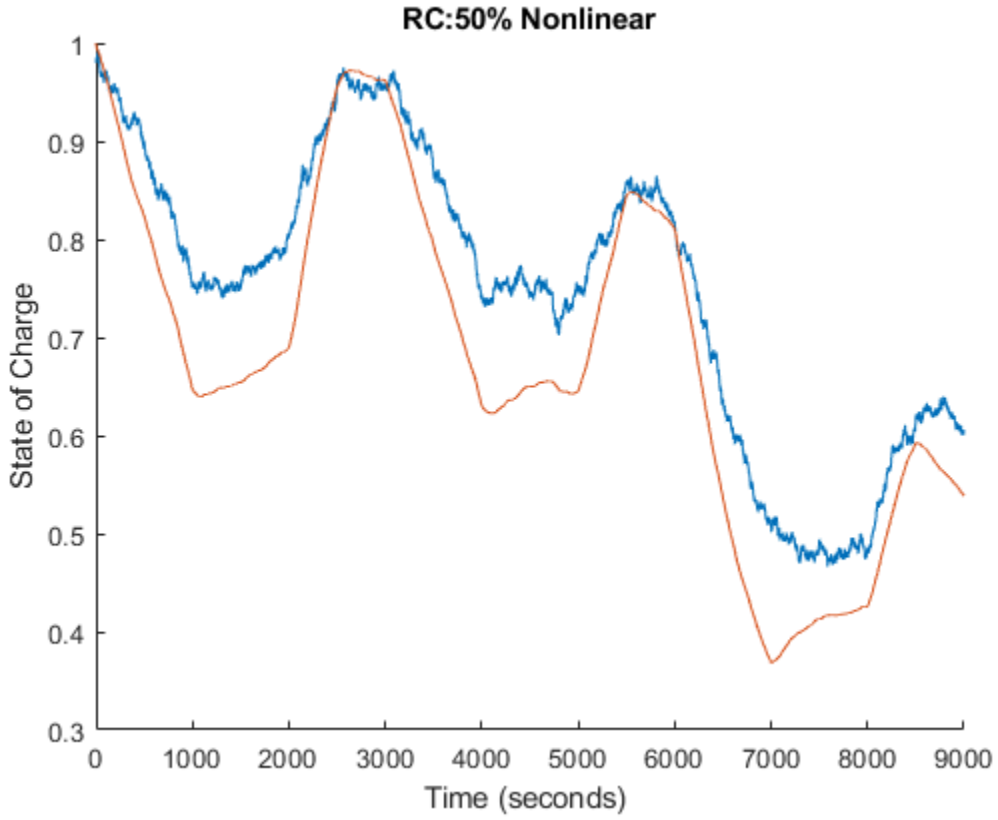

Nonlinear Baseline
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

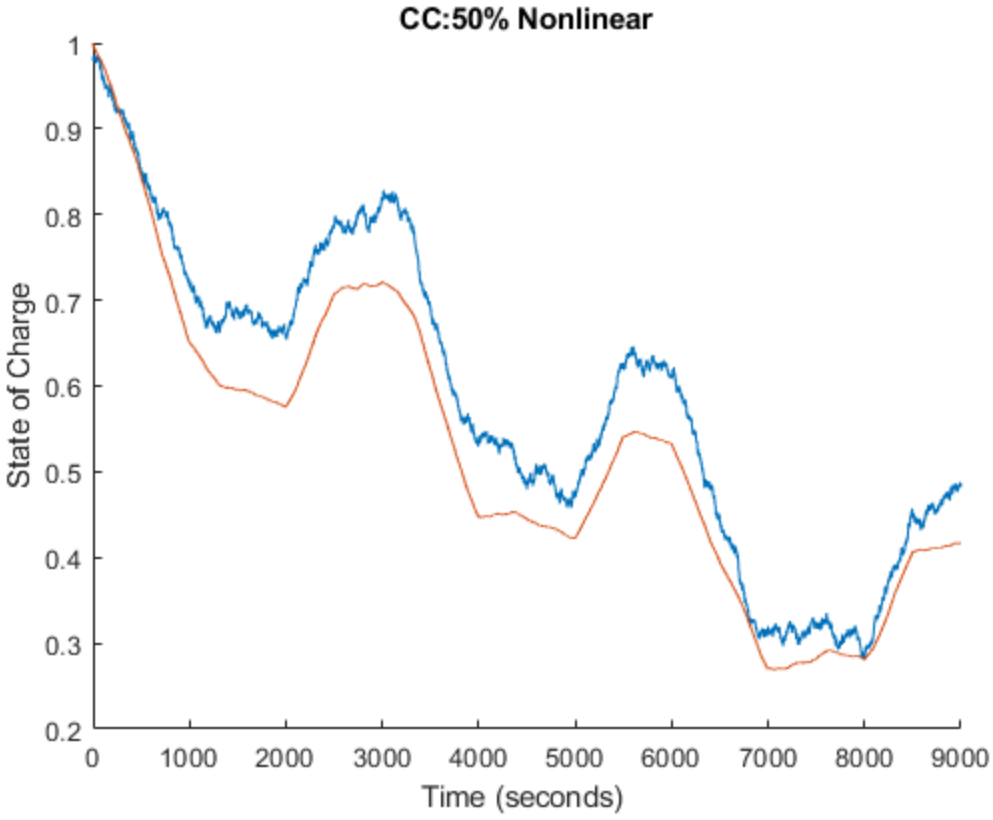

R0:25% Nonlinear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

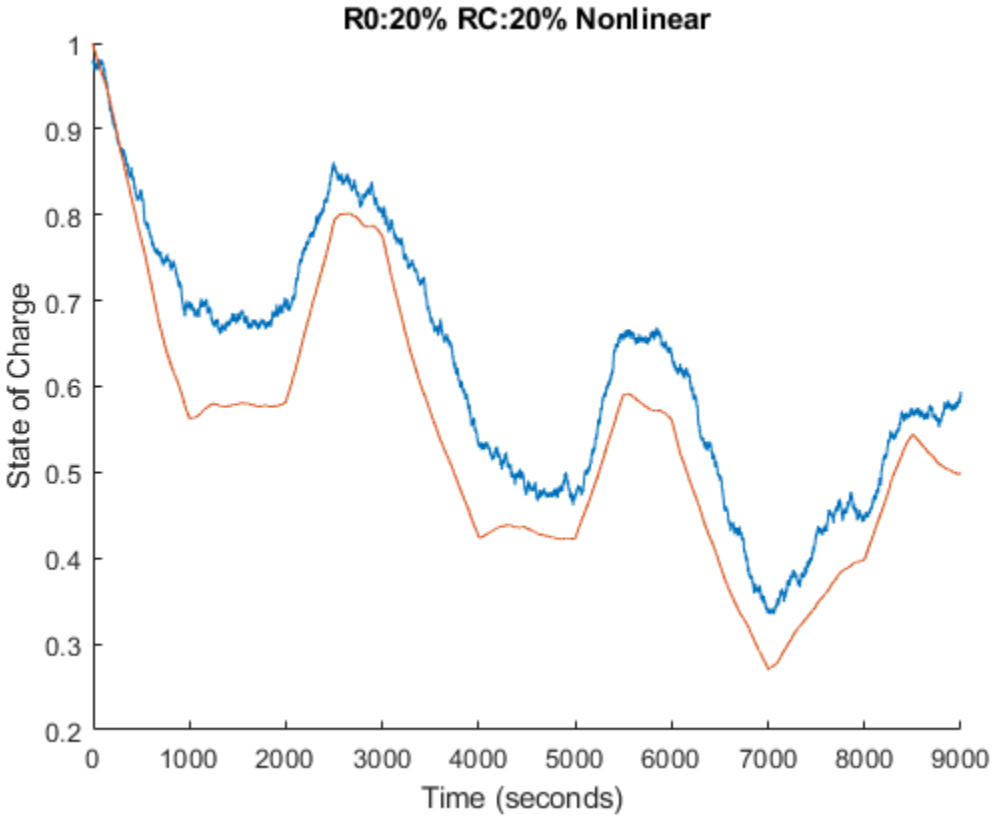

RC:25% Nonlinear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


CC:25% Nonlinear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


R0:50% Nonlinear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


RC:50% Nonlinear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

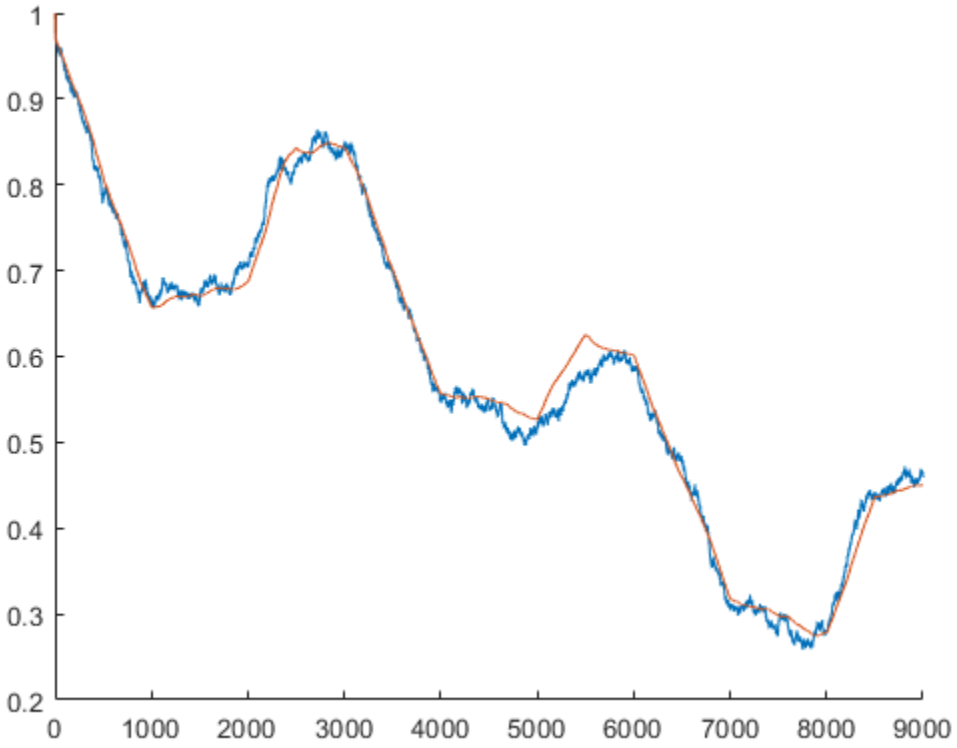

CC:50% Nonlinear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


R0:20% RC:20% Nonlinear
State of Charge
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

Nonlinear Estimator Plant with Nonlinear BASELINE data

```
List =
 ["FirstOrderTruth_BASELINE_linear.mat","FirstOrderTruth_R0_25_linear.mat","FirstO


load('OCV_table.mat')
load('OCV_slope_table.mat')
load(List(9));

s = tf('s');

%battery model parameters
Rc = 0.015;    %Ohms
Cc = 2400;     %F
Cbat = 5*3600;
alpha =0.65;
R0 = 0.01;     %Ohms
Vocv0 = 3.435; %V

%tunning parameters
K = 1;         %gain
% zeta = 0.707;  %damping ratio
zeta = 0.5;  %damping ratio

wn = 75;      %natural frequency

%continuous time ss model
A = [-1/(Rc*Cc) 0; 0 0];
B = [1/Cc; -1/Cbat];
C = [-1 alpha];
D = -R0;

A1 = A(1,1);
B1 = B(1,1);
A2 = A(2,2);
B2 = B(2,1);
C2 = alpha;

SI = [s 0;0 s];
Gp = C*(inv(SI-A))*B+D;       %plant
T = minreal(K*wn^2/(s^2+2*zeta*wn*s+wn^2)); %complimentary
Y = minreal(T/Gp);            %youla
S = minreal(1-T);             %sensitivity
Gc = minreal(Y/S);            %controller
L = minreal(Gc*Gp);                    %open loop TF
sysTF = minreal(Gc*Gp/(1+Gc*Gp));      %actual sys TF
[num, den] = tfdata(Gc, 'v'); %get numerator and denominator of Gc tf

out = sim('Estimator_Simulink_trial2') ;   %run simulink model
```

```
est_soc = out.SOC_est;
tout = out.tout;

figure()
hold on
plot(t,SOC_act);
plot(tout,est_soc);
```

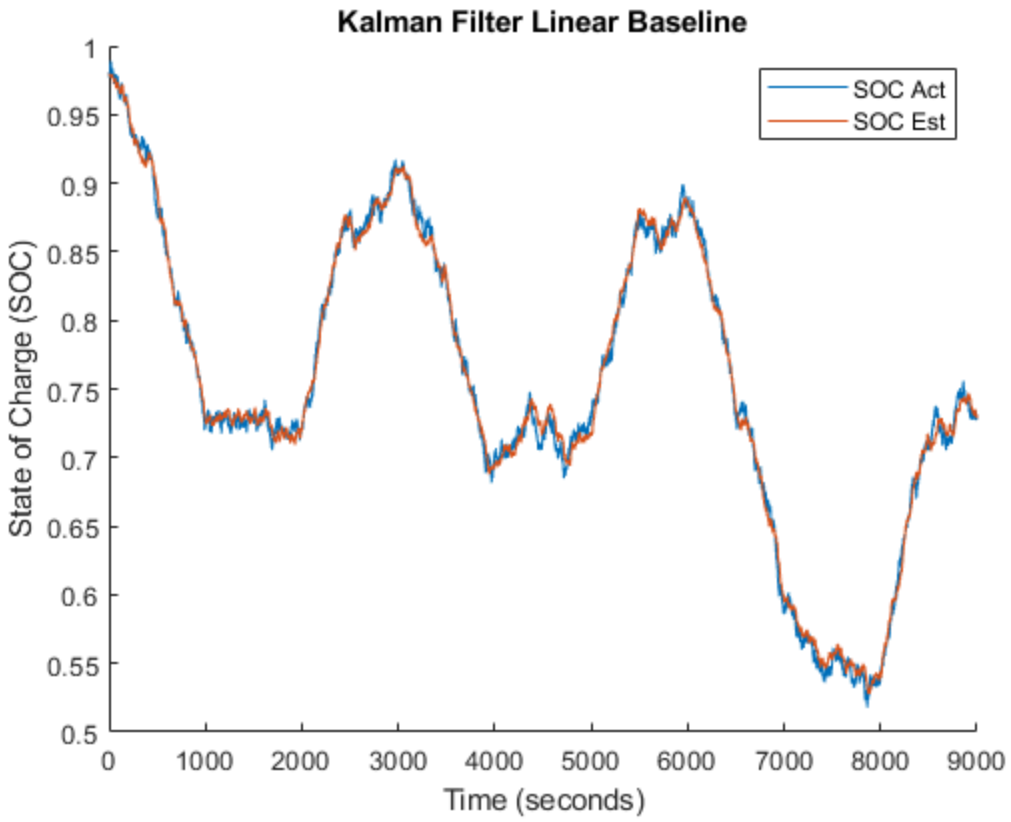


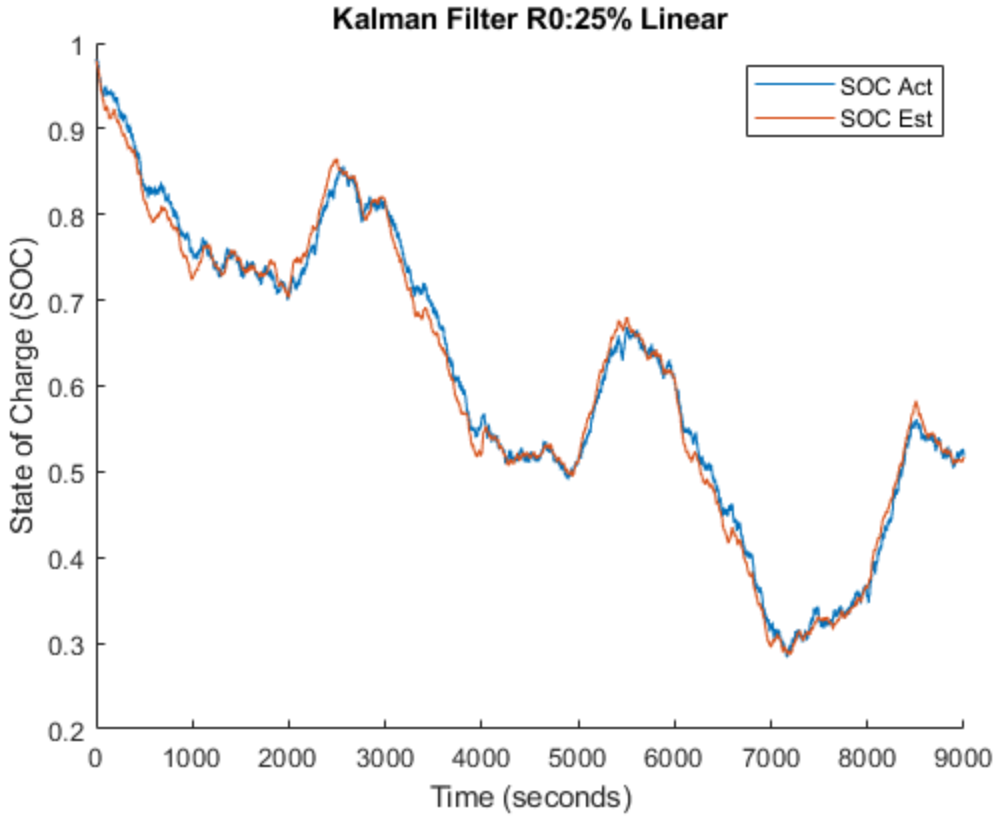
Kalman Filter

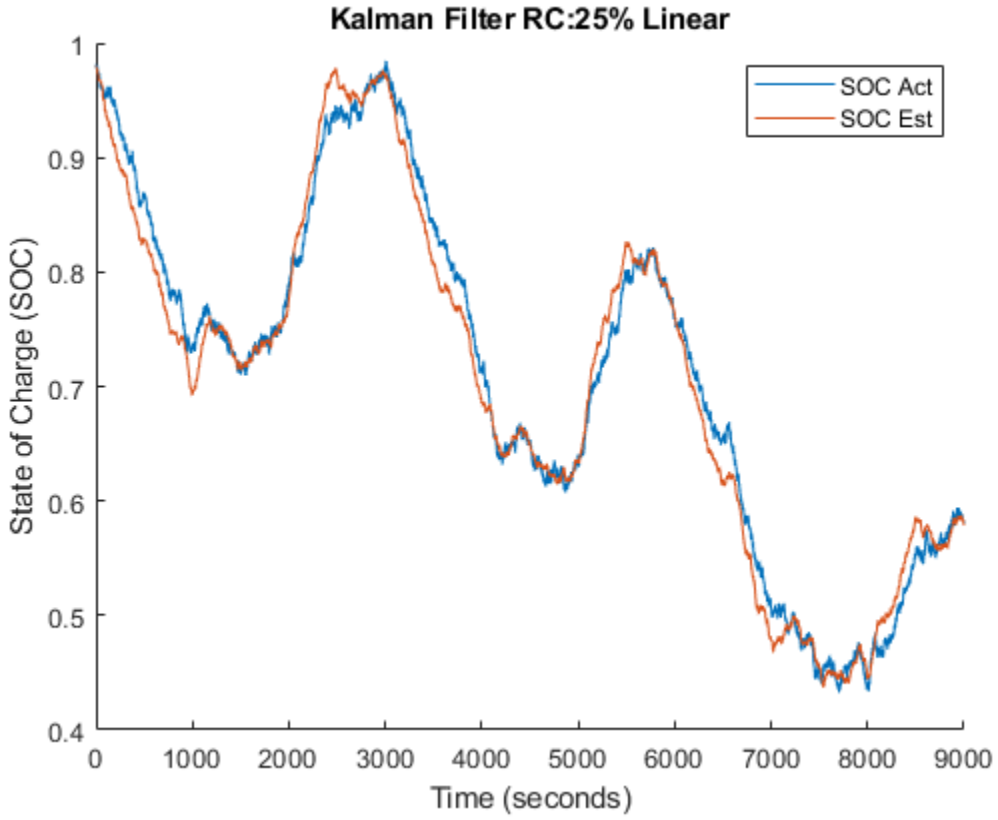
```
List =
 ["FirstOrderTruth_BASELINE_linear.mat","FirstOrderTruth_R0_25_linear.mat","FirstO
NameList = ["Linear Baseline", "R0:25% Linear", "RC:25%
 Linear","CC:25% Linear","R0:50% Linear","RC:50% Linear","CC:50%
 Linear","R0:20% RC: 20%Linear","Nonlinear Baseline ","R0:25%
 Nonlinear","RC:25% Nonlinear","CC:25% Nonlinear","R0:50%
 Nonlinear","RC:50% Nonlinear","CC:50% Nonlinear", "R0:20% RC:20%
 Nonlinear" ];


for i = 1:length(List)

    load(List(i));

R0 = 0.01;
Rc = 0.015;
```

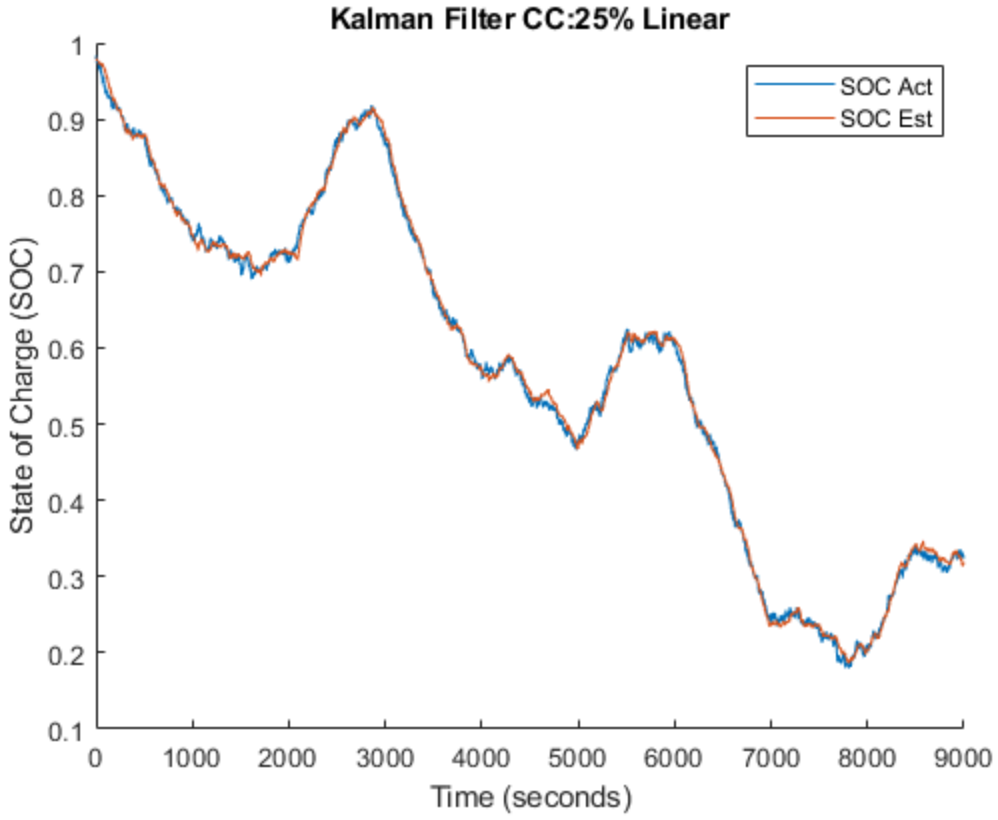
```
Cc = 2400;
Cbat = (5*3600);
alpha = .65;
Voc_0 = 3.435;
SOC0 = 1;

dt = .1;

%System Dynamics
%Linear Model
A = [1 0 ; 0 (1-(dt/(Rc*Cc)))];
B = [-(dt/Cbat) ; (dt/Cc)];
C = [alpha -1];
D = [-R0];

%Kalman Model
Ak = [1];
Bk = [-(dt/Cbat)];
Ck=[alpha];
Dk=[R0];

% Kalman Filter

wk_mean = 0;
Q = 2.5*10^-7;
vk_mean = 0;
R = 1*10^-4;
P0 = 0;

Q = 2.5*10^-9;


% Set Initial Conditions
P(1) = P0;
x1(1) = .98; % SOC
x2(1) = 0;  % Vc
x1_hat(1) = .98;

for k = 2:1:length(t)
    %State Equations:
    x1(k) = x1(k-1)-(dt/Cbat)*I(k-1); %+normrnd(0,Q);  % SOC
    x2(k) = (1-(dt/(Rc*Cc)))*x2(k-1)+(dt/Cc)*I(k-1);  % Vc

    % Open Loop:
    x1_ol(k) = Ak*x1(k-1)+Bk*I(k-1);

    % Model Prediction:
    x1_hat_prev(k) = Ak*x1_hat(k-1)+ Bk*I(k-1);
    P_prev = Ak*P(k-1)*Ak' + Q;

    %Estimated Output:
    V_hat = alpha*x1_hat_prev(k)-x2(k)- R0*I(k)+ Voc_0;

    % Measurement Update:
```

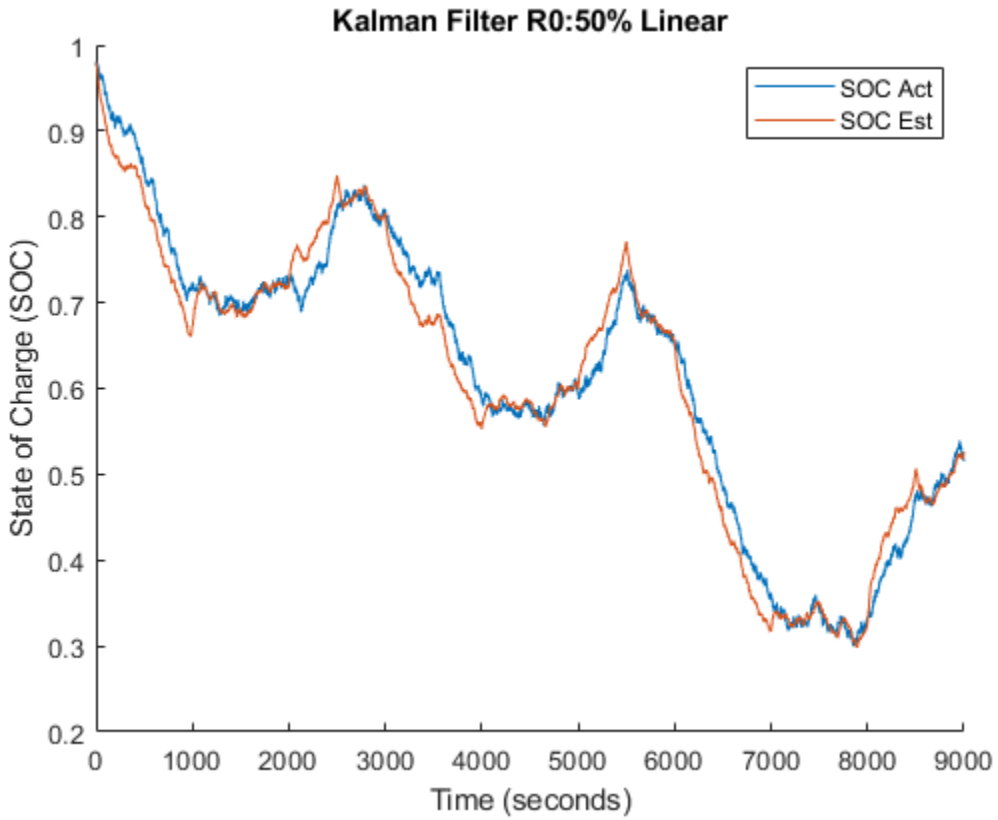
```
    x1_hat(k) = x1_hat_prev(k) +
 P_prev*Ck'*inv(Ck*P_prev*Ck'+R)*(V(k)-V_hat);
    P(k) = P_prev -P_prev*Ck'*inv(Ck*P_prev*Ck'+R)*Ck*P_prev;


end

KALMAN_ACTUAL(:,i)= SOC_act;
KALMAN_ESTIMATED(:,i)=x1_hat;

figure();
hold on
plot(t,SOC_act)
plot(t,x1_hat)
title('Kalman Filter '+ NameList(i));
xlabel('Time (seconds)');
ylabel('State of Charge (SOC)');
legend('SOC Act','SOC Est');

end
```

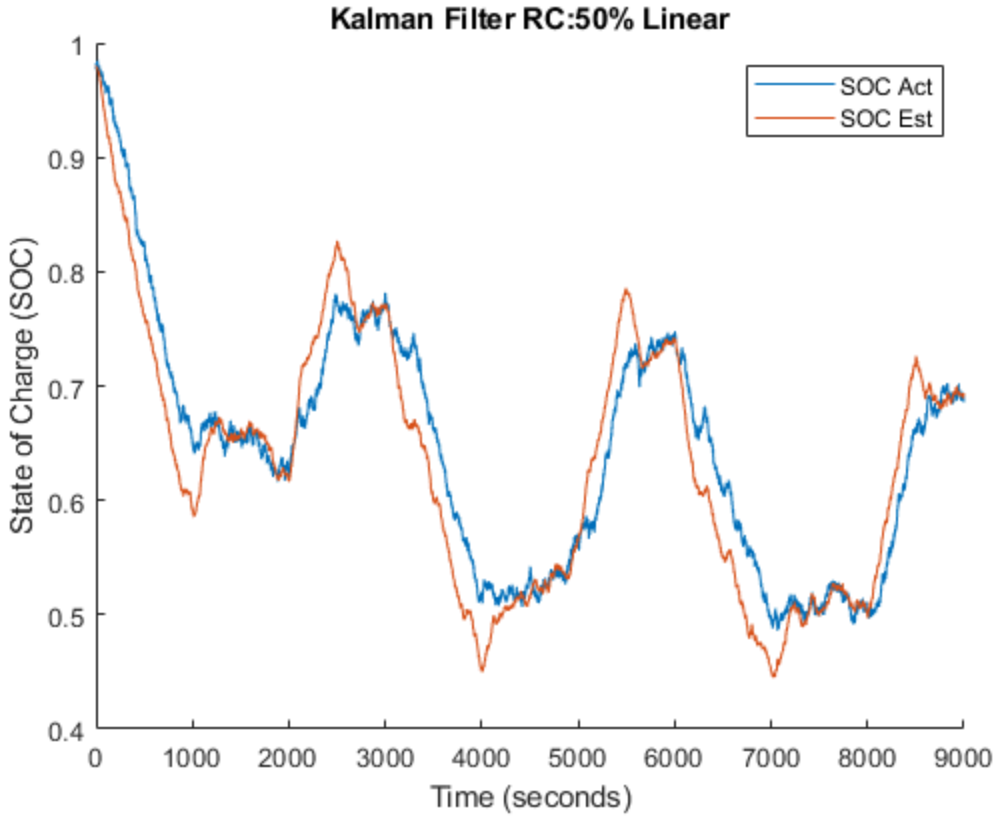


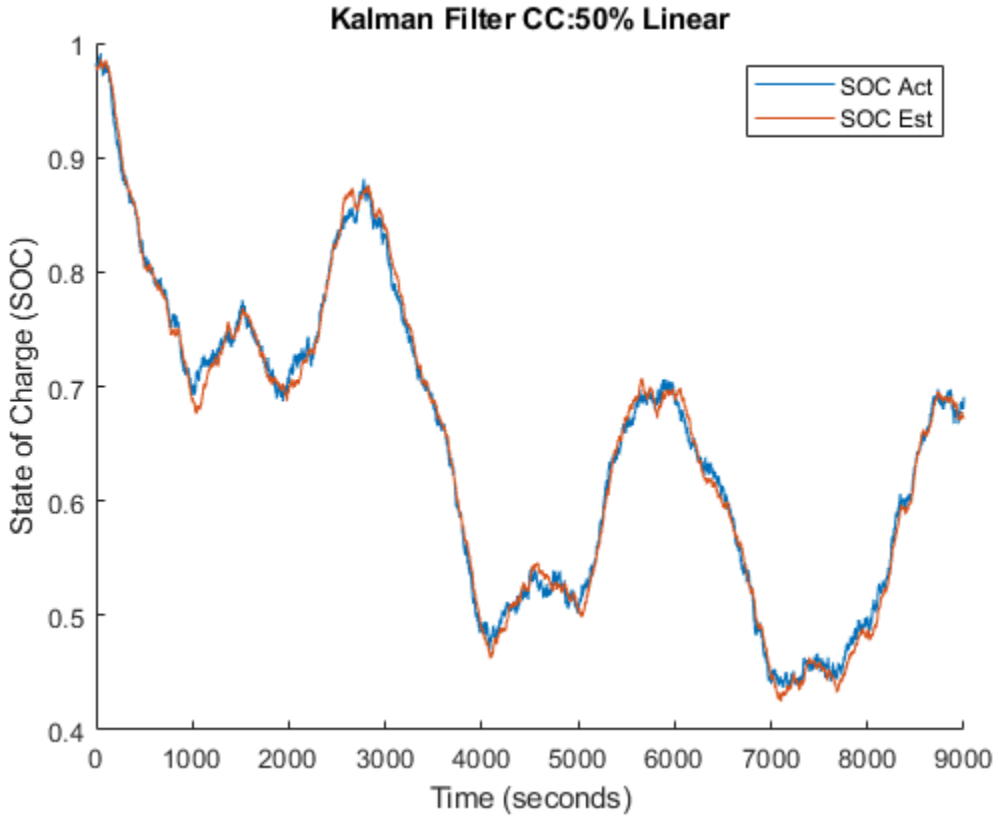

Kalman Filter R0:25% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

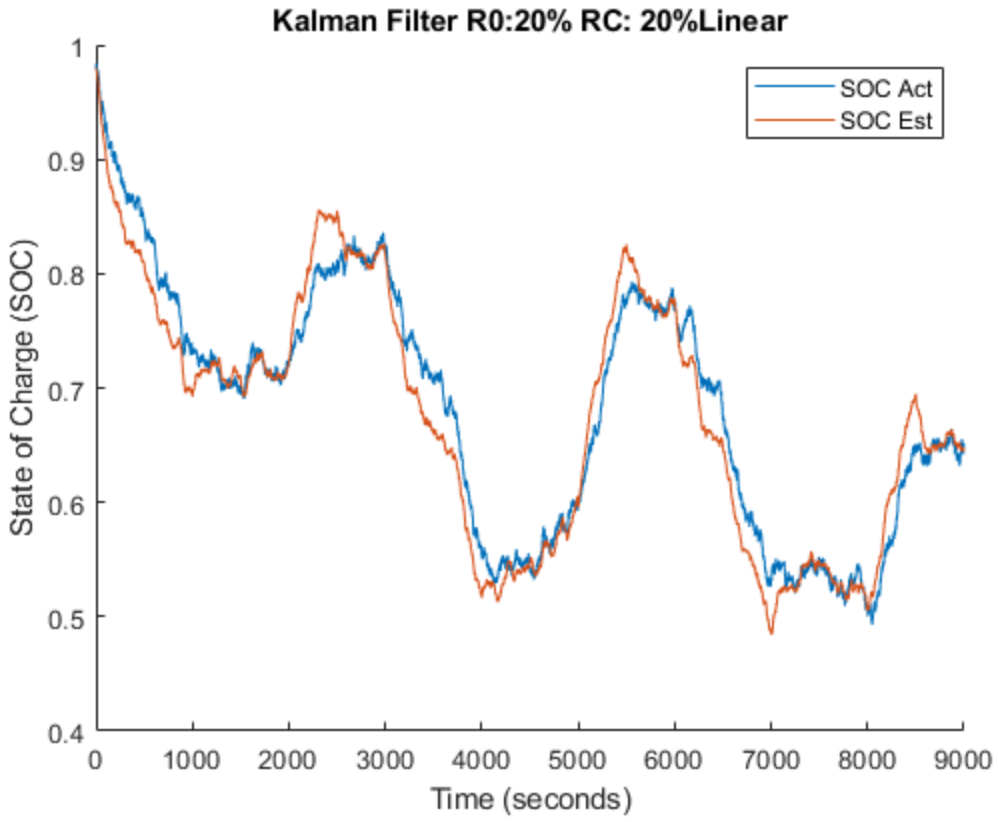

Kalman Filter RC:25% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

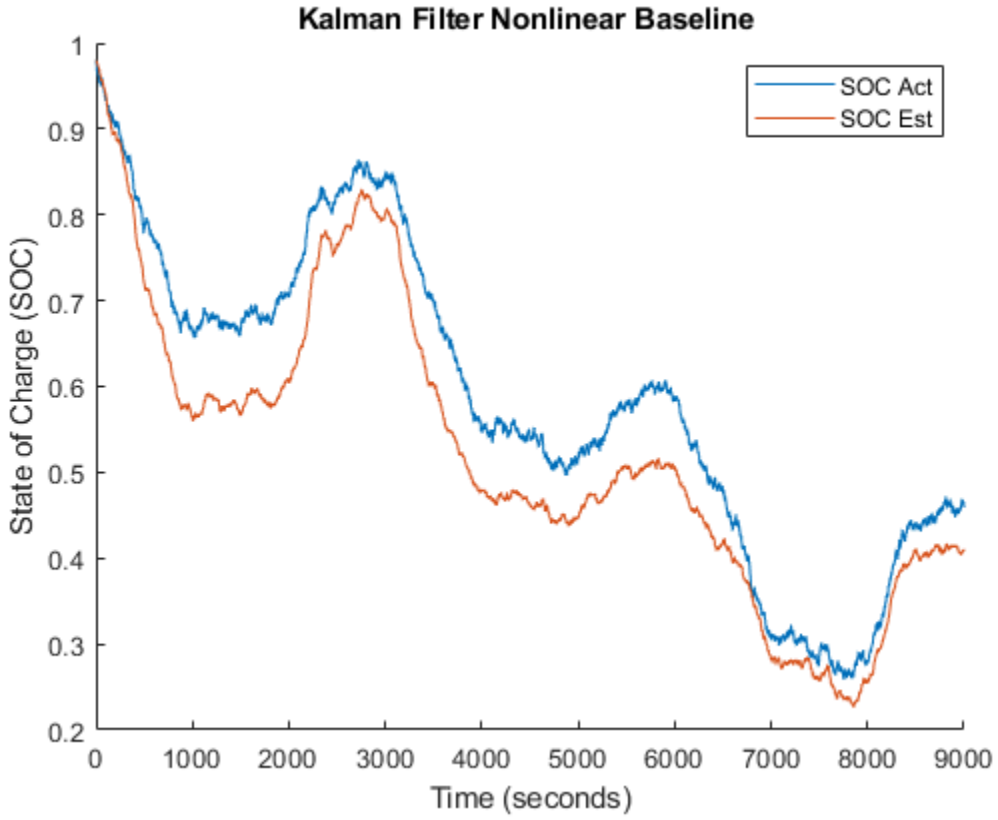

Kalman Filter CC:25% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

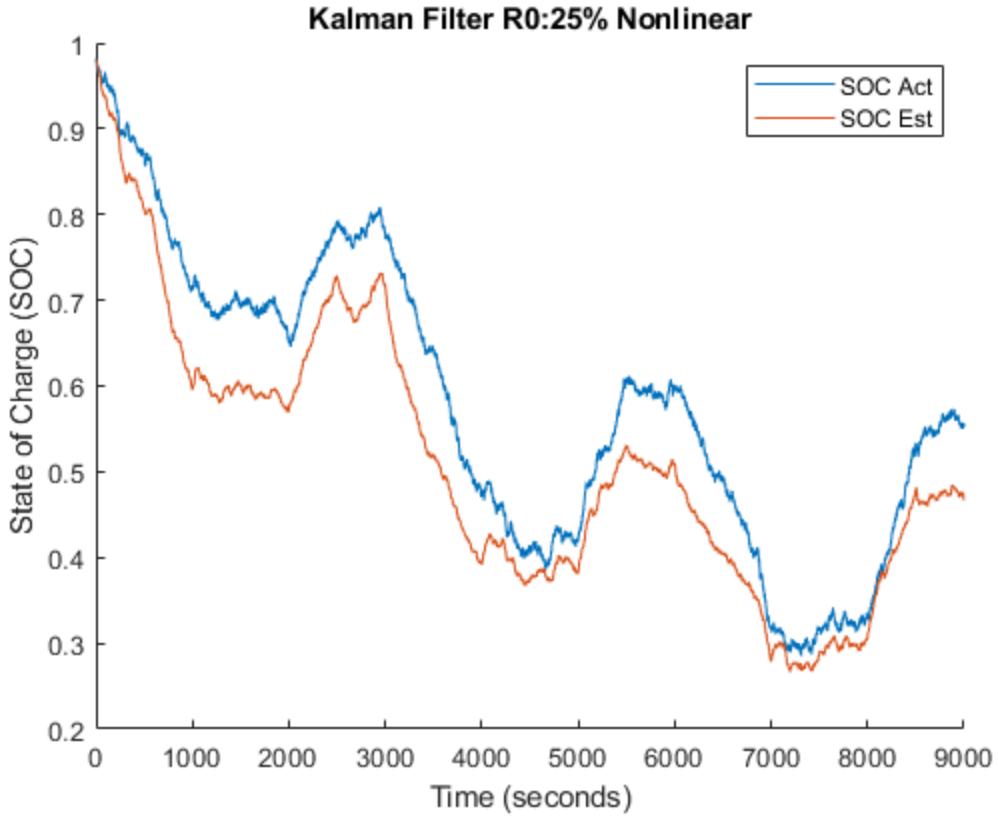

Kalman Filter R0:50% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

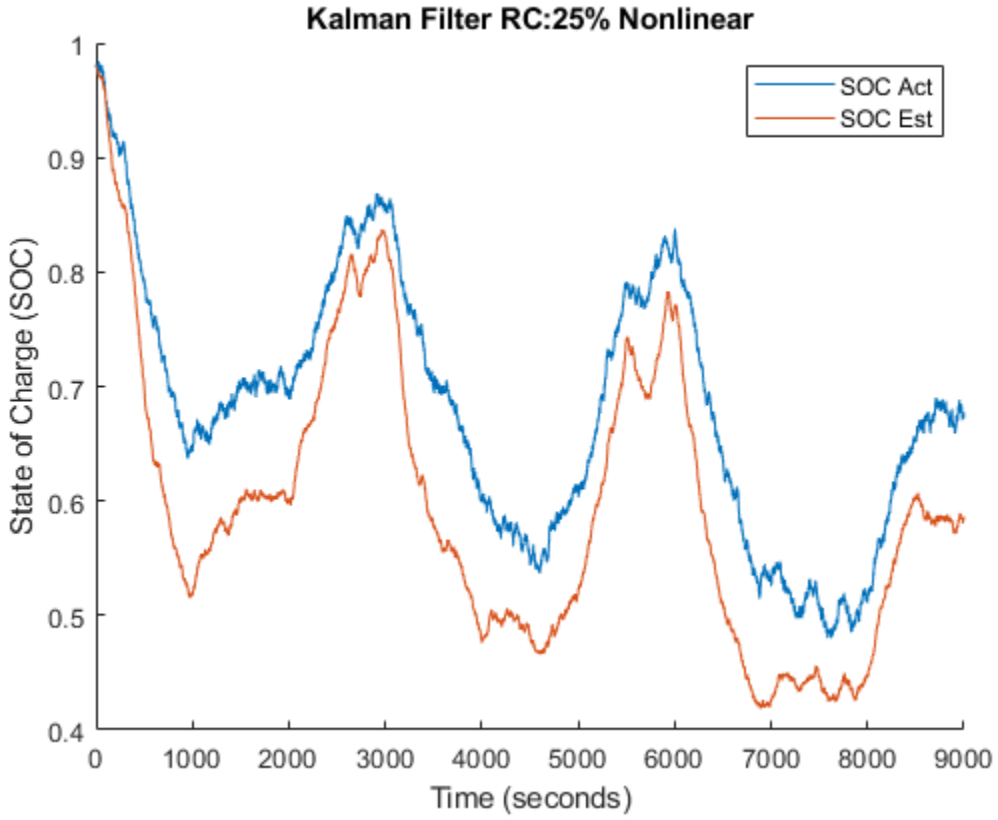

Kalman Filter RC:50% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

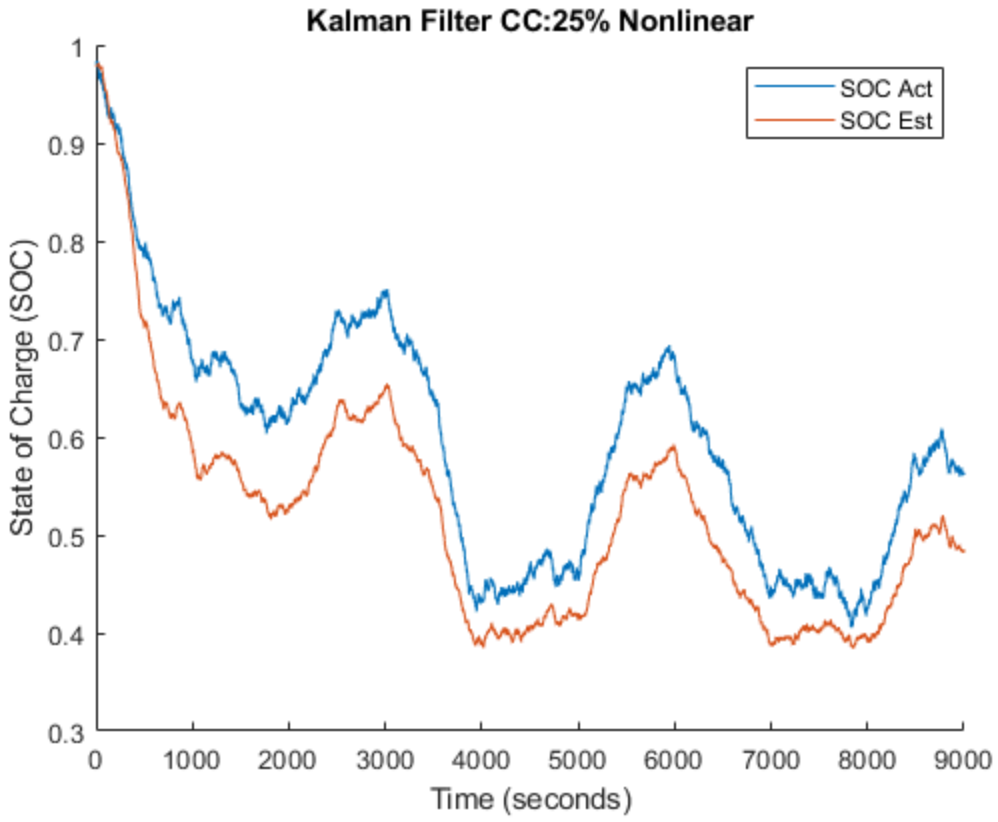

Kalman Filter CC:50% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

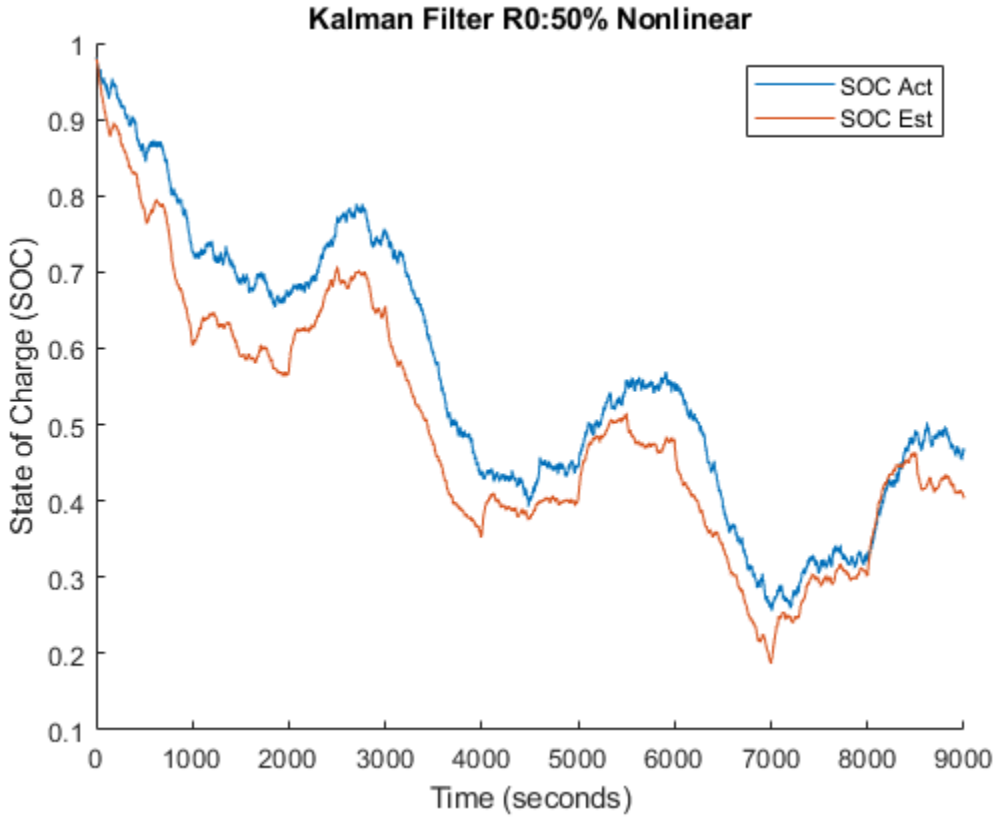

Kalman Filter R0:20% RC: 20%Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

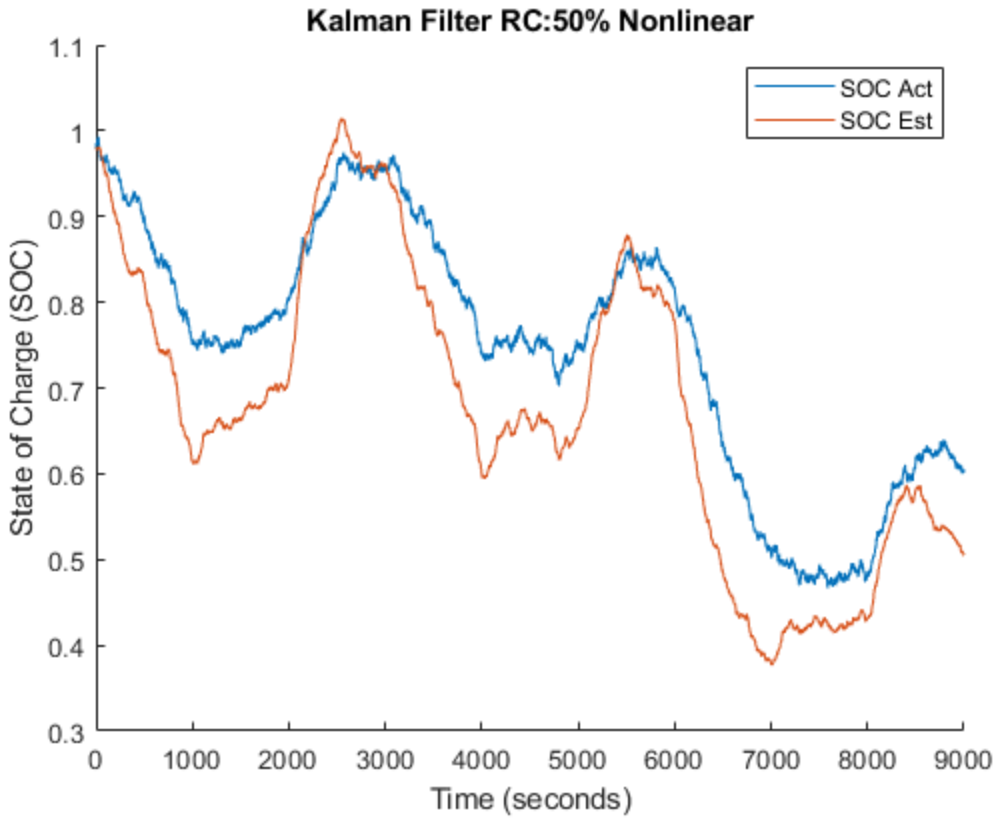

Kalman Filter Nonlinear Baseline
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

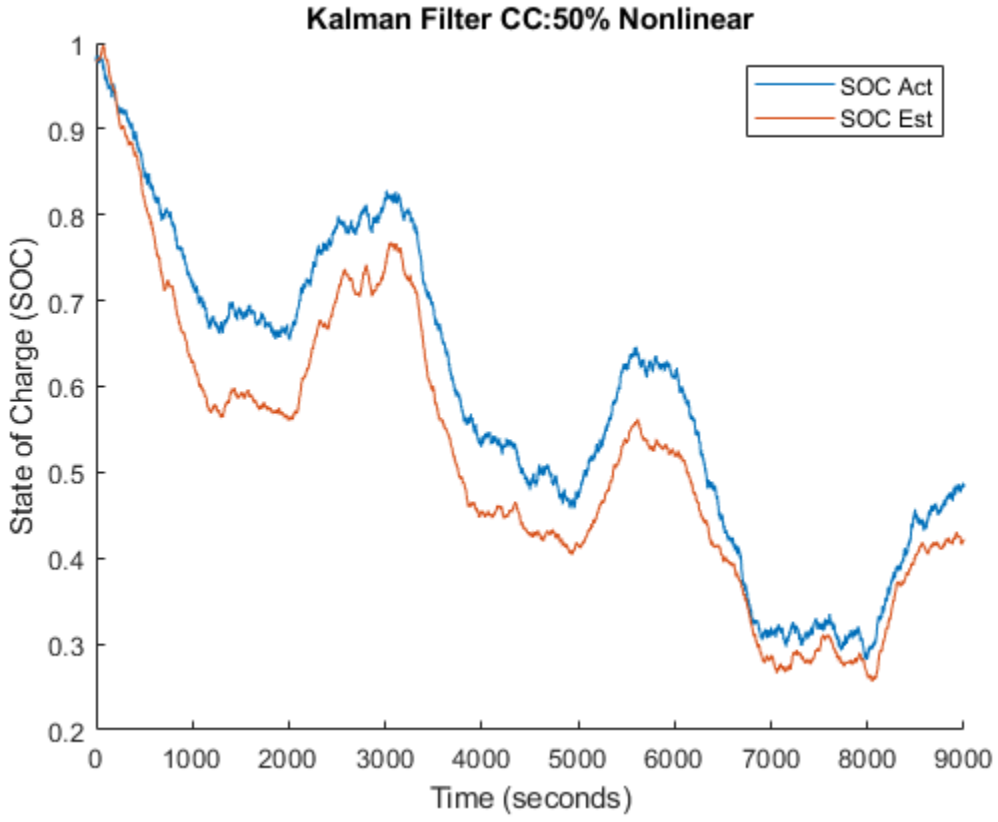

Kalman Filter R0:25% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

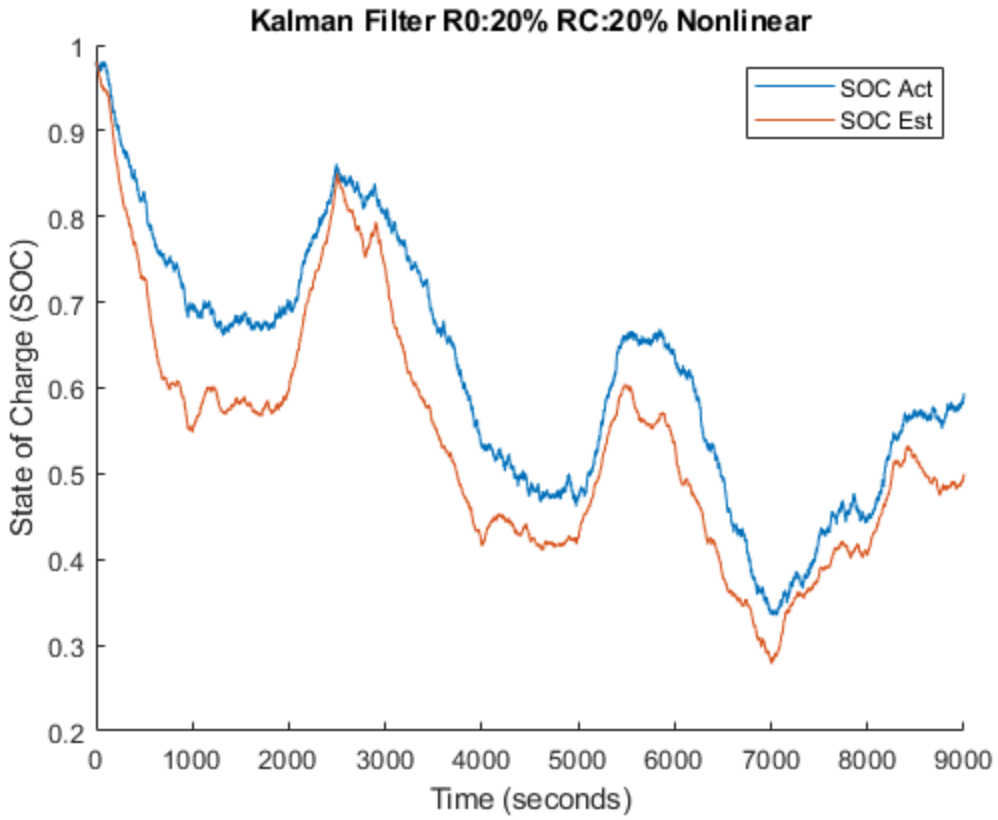

Kalman Filter RC:25% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Kalman Filter CC:25% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Kalman Filter R0:50% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Kalman Filter RC:50% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Kalman Filter CC:50% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

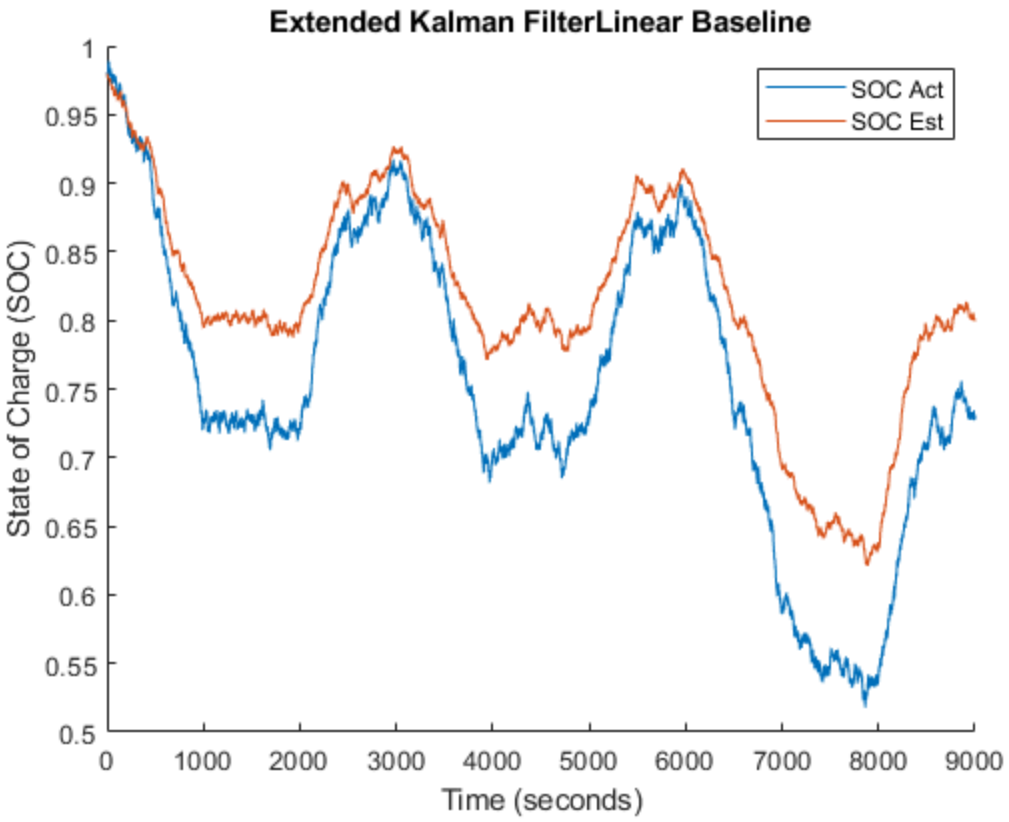


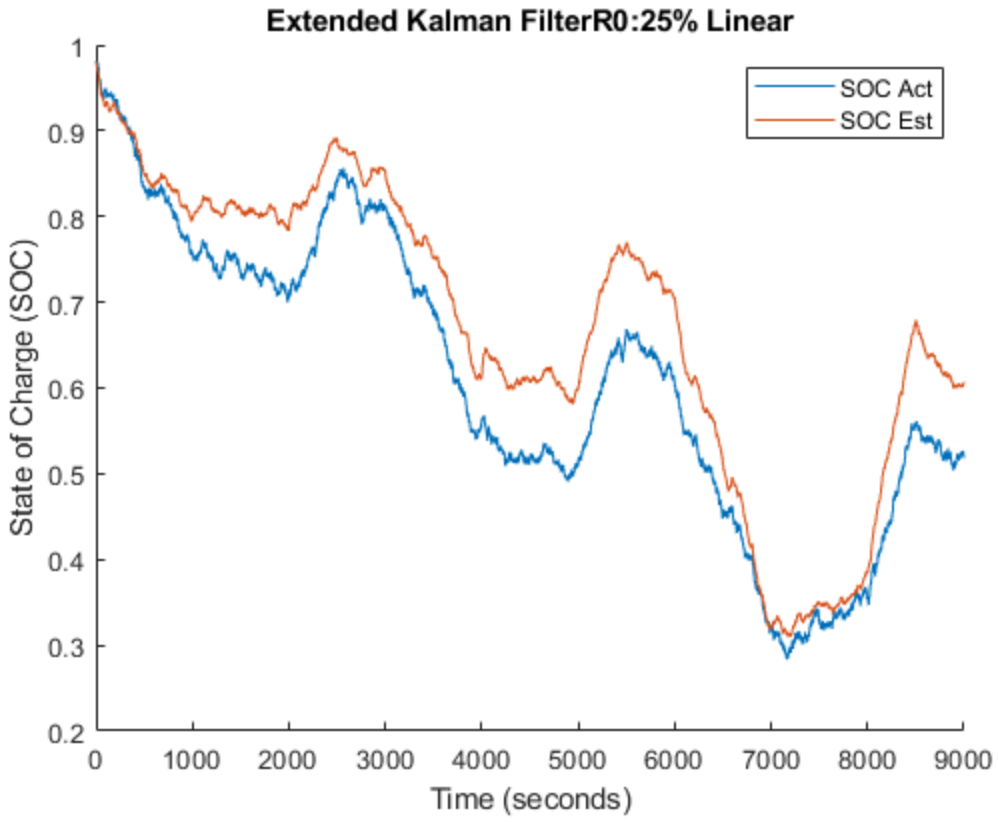
Extended Kalman Filter

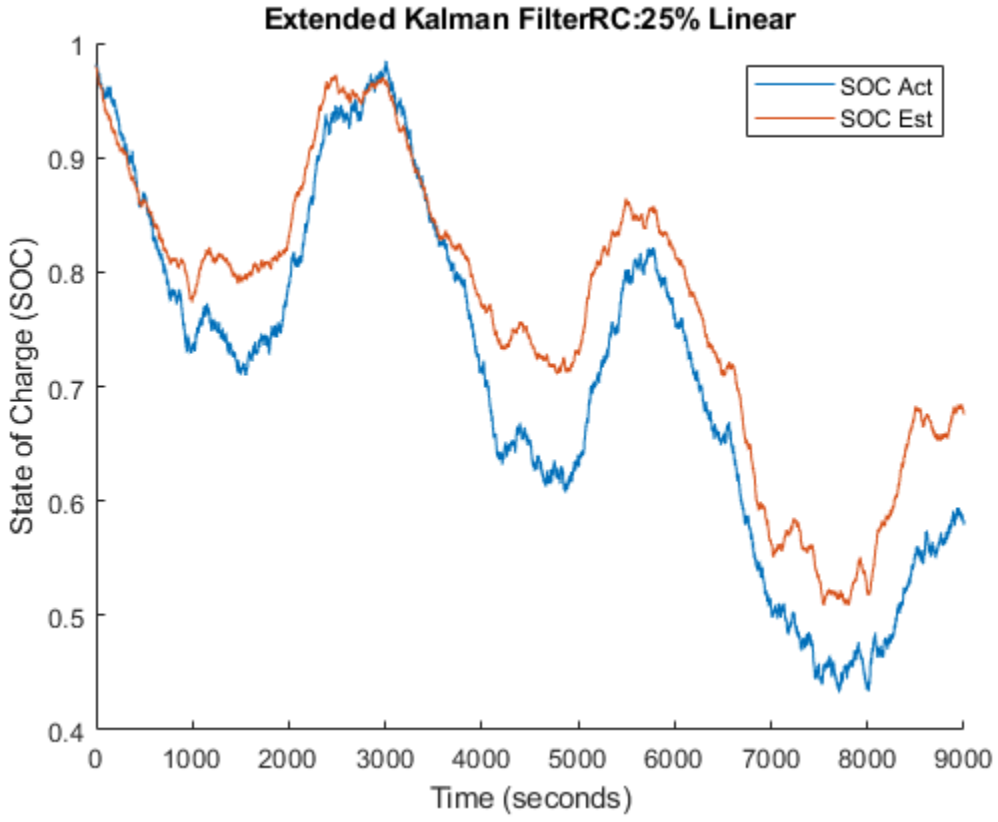
```
List =
 ["FirstOrderTruth_BASELINE_linear.mat","FirstOrderTruth_R0_25_linear.mat","FirstO
NameList = ["Linear Baseline", "R0:25% Linear", "RC:25%
 Linear","CC:25% Linear","R0:50% Linear","RC:50% Linear","CC:50%
 Linear","R0:20% RC: 20%Linear","Nonlinear Baseline ","R0:25%
 Nonlinear","RC:25% Nonlinear","CC:25% Nonlinear","R0:50%
 Nonlinear","RC:50% Nonlinear","CC:50% Nonlinear", "R0:20% RC:20%
 Nonlinear" ];


for i = 1:length(List)

    load(List(i));

R0 = 0.01;
Rc = 0.015;
Cc = 2400;
Cbat = (5*3600);
alpha = .65;
Voc_0 = 3.435;
SOC0 = 1;

dt = .1;
```

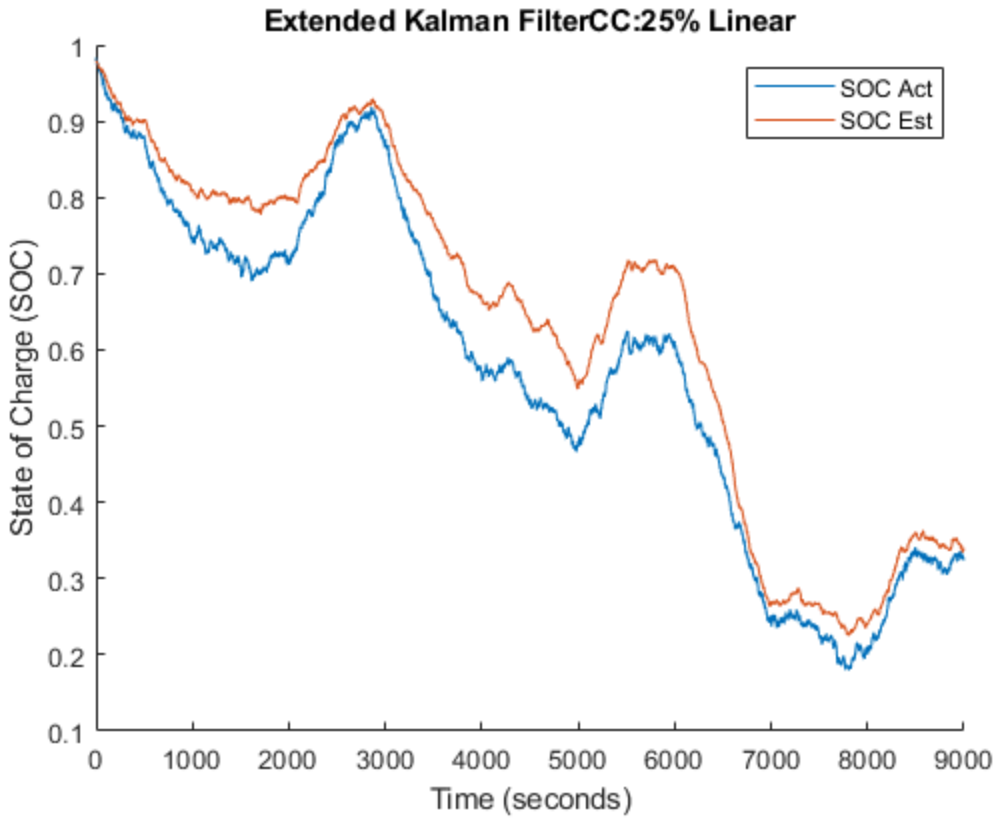
```
wk_mean = 0;
Q = 2.5*10^-7;
vk_mean = 0;
R = 1*10^-4;
P0 = 0;

A_ek = 1 ;

% function val = C_ek(SOC_hat)
%  val = intep1(soc_intpts_OCV_slope,OCV_slope_intpts,SOC_hat);
% end
E_ek = 1;
F_ek = 1;

Ak = 1;
Bk = -dt/Cbat;

load('OCV_table.mat')
load('OCV_slope_table.mat')
% load('IV_data_nonlinear')

R = 1*10^-4;
Q = 2.5*10^-9;

% Set Initial Conditions
P(1) = P0;
x1(1) = .98; % SOC
x2(1) = 0;  % Vc
x1_hat(1) = .98;

for k = 2:length(t)
    x1(k) = x1(k-1)-(dt/Cbat)*I(k-1); %+normrnd(0,Q);  % SOC - Coulomb
 Counting
    x2(k) = (1-(dt/(Rc*Cc)))*x2(k-1)+(dt/Cc)*I(k-1);  % Vc


    C_ek =
 interp1(soc_intpts_OCV_slope' ,OCV_slope_intpts,x1_hat(k-1));

    % Model Prediction:
    x1_hat_prev = Ak*x1_hat(k-1)+Bk*I(k-1);
    P_prev = A_ek*P(k-1)*A_ek'+E_ek*Q*E_ek';

    % Measurement Update:
    V_hat = interp1(soc_intpts_OCV' ,OCV_intpts,x1_hat(k-1)) -I(k)*R0-
x2(k);
    L = P_prev*C_ek'*inv(C_ek*P_prev*C_ek'+F_ek*R*F_ek');

    x1_hat(k) = x1_hat_prev + L*(V(k)-V_hat);
    P(k) = P_prev -L*C_ek*P_prev;

end
```

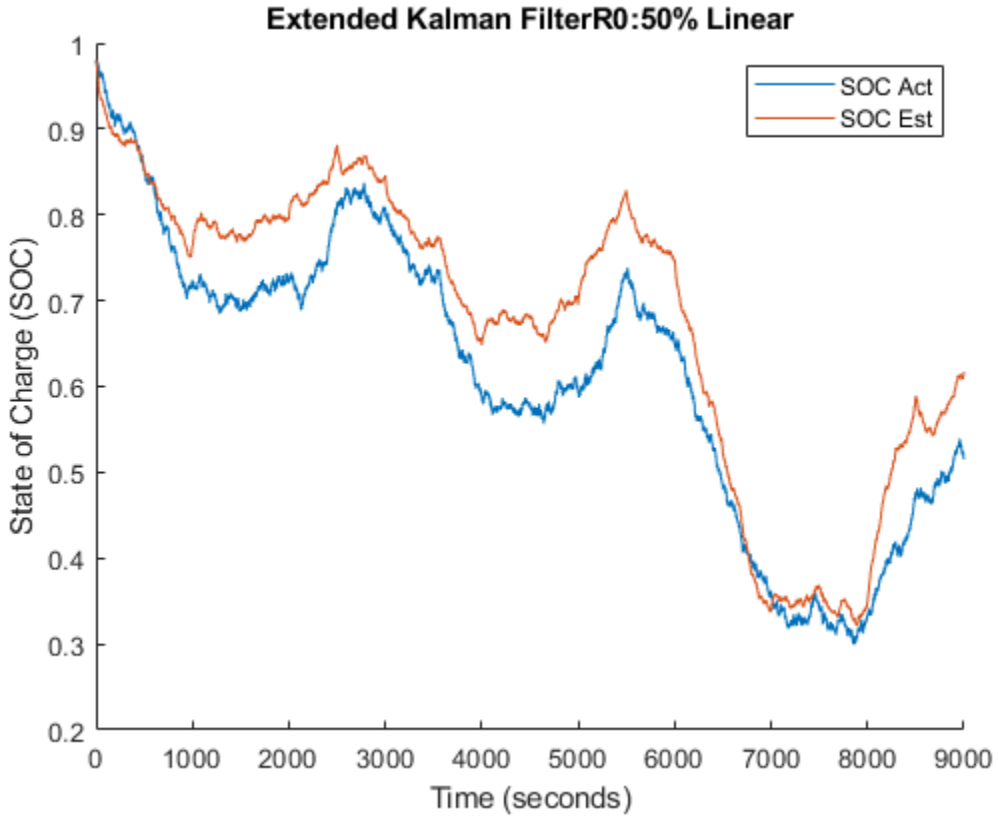
```
EXTENDED_KALMAN_ACTUAL(:,i)= SOC_act;
EXTENDED_KALMAN_ESTIMATED(:,i)=x1_hat;

figure();
hold on
plot(t,SOC_act)
plot(t,x1_hat)
title('Extended Kalman Filter' + NameList(i));
xlabel('Time (seconds)');
ylabel('State of Charge (SOC)');

legend('SOC Act','SOC Est');


end
```

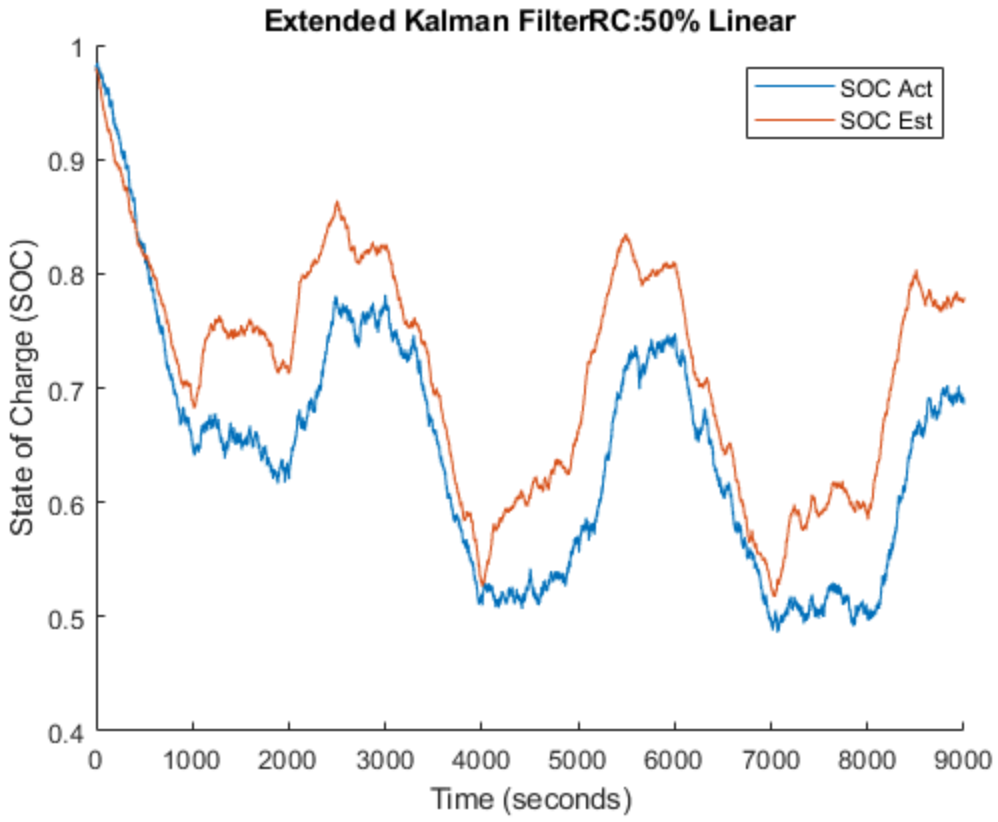


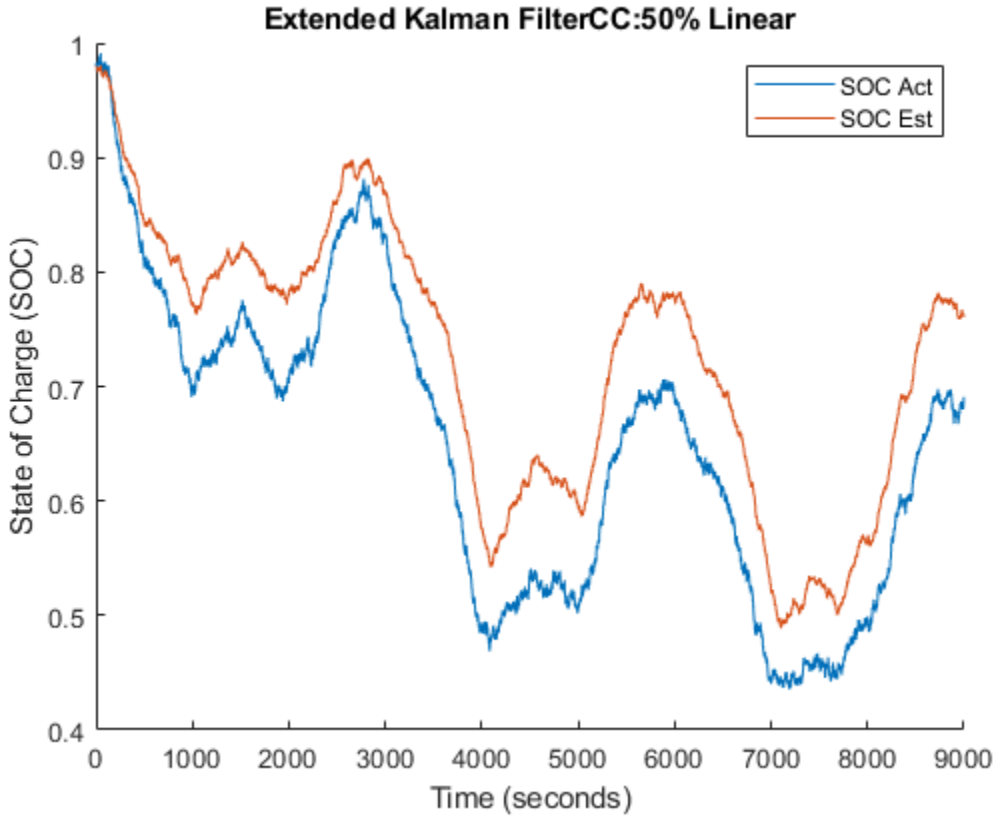

Extended Kalman FilterR0:25% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

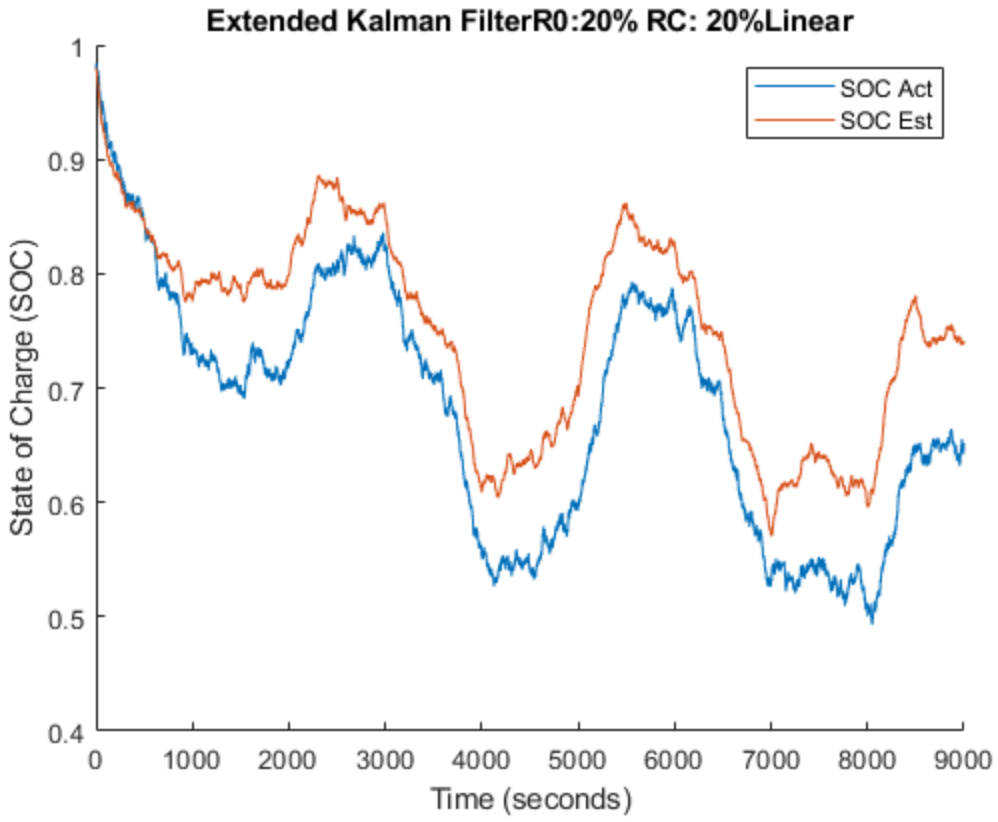

Extended Kalman FilterRC:25% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

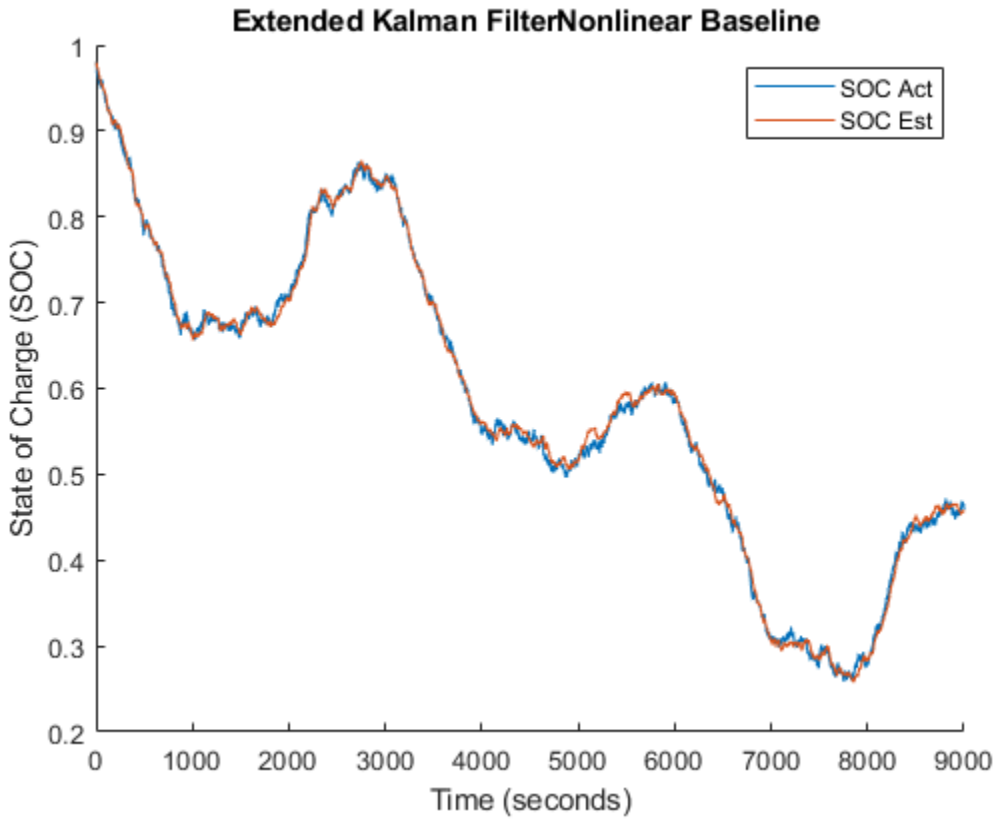

Extended Kalman FilterCC:25% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

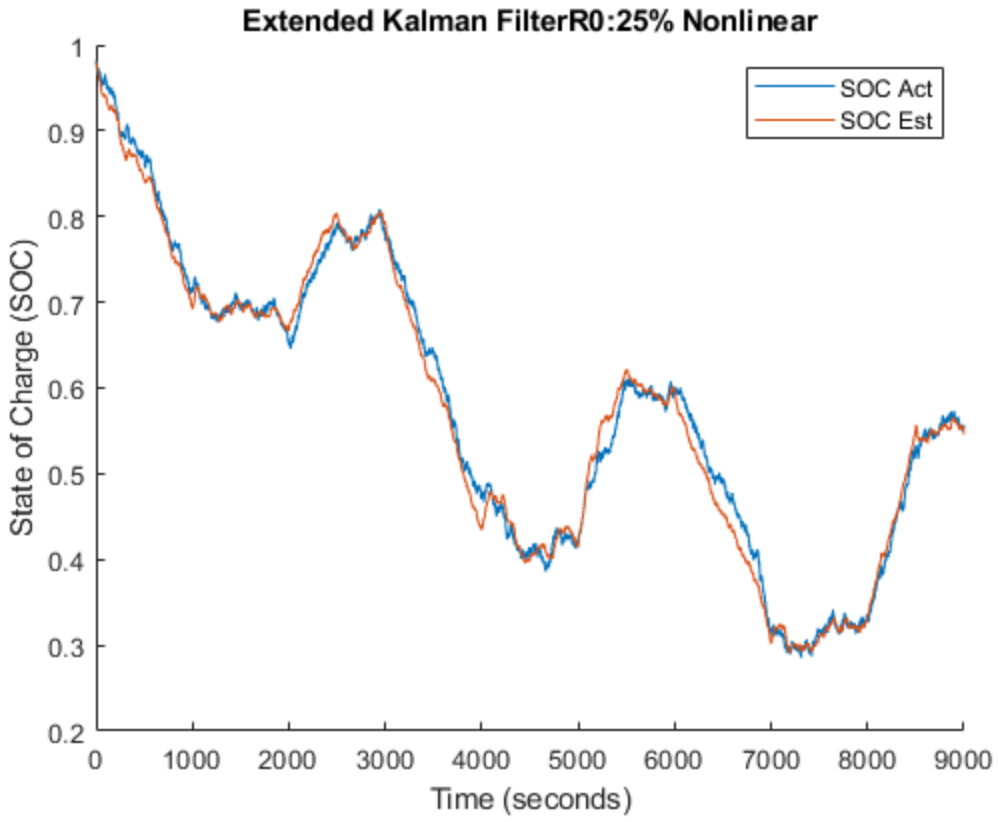

Extended Kalman FilterR0:50% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

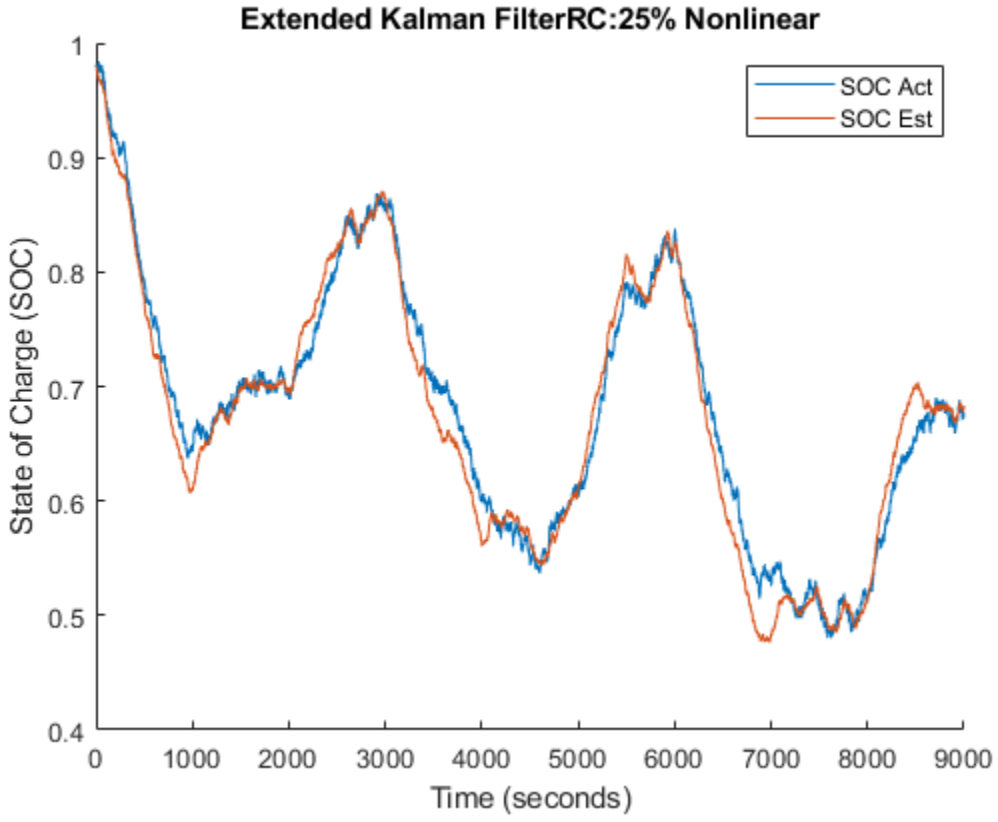

Extended Kalman FilterRC:50% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

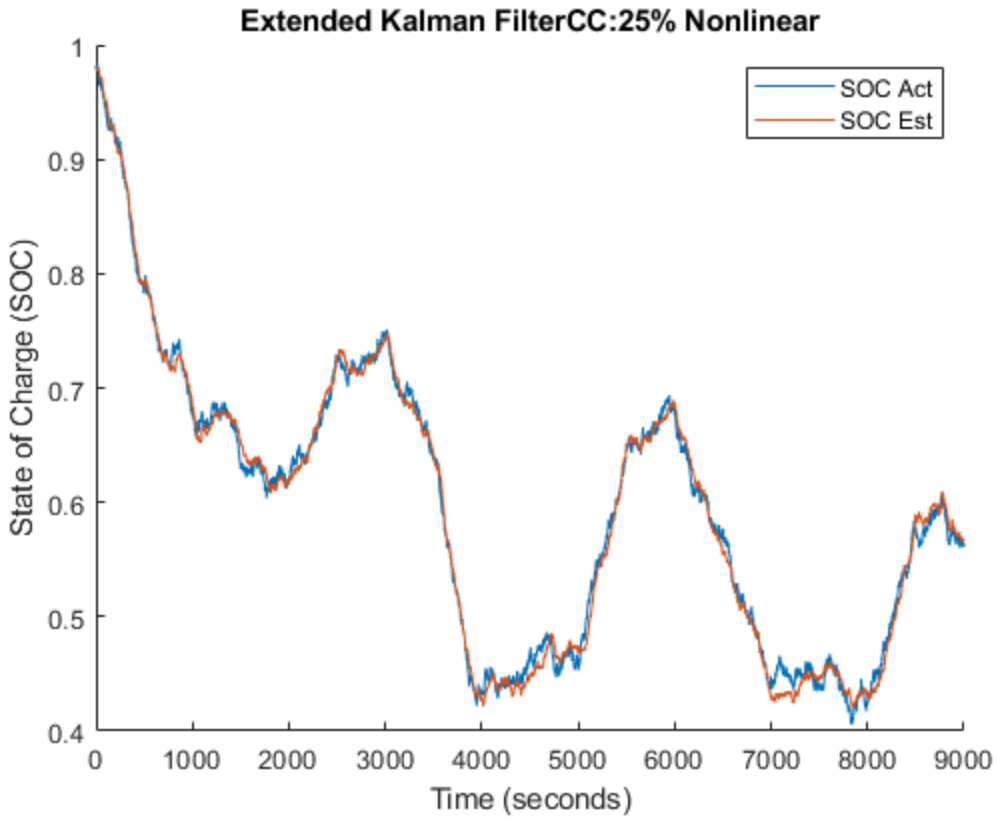

Extended Kalman FilterCC:50% Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

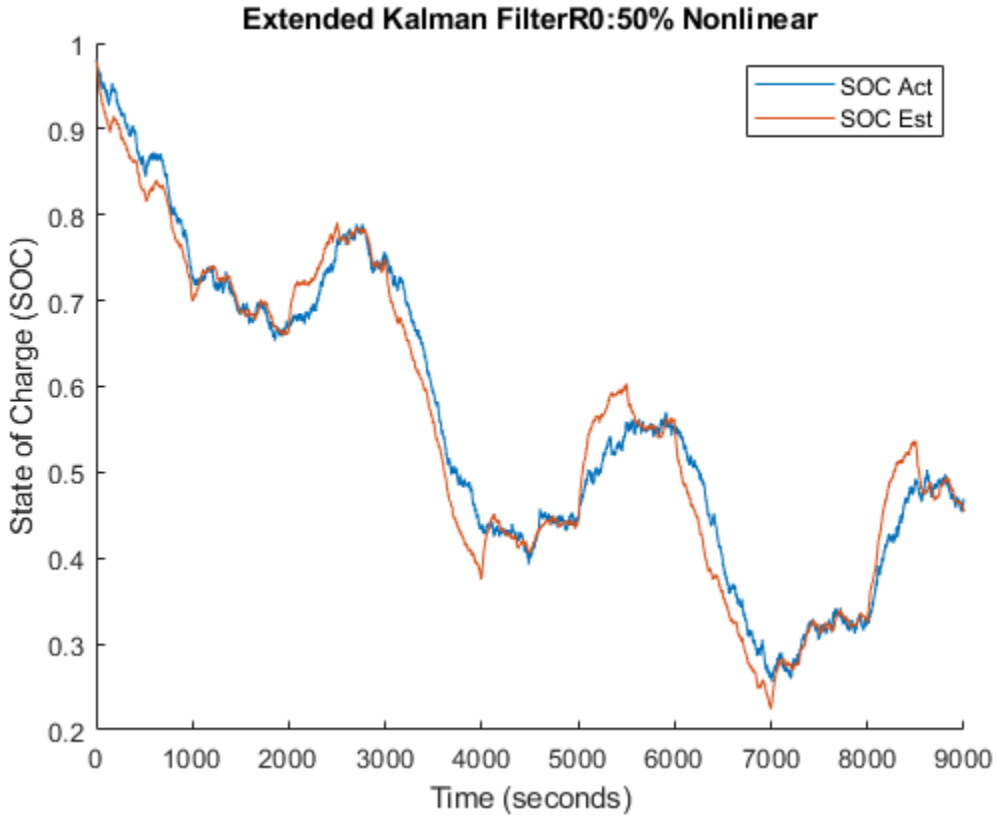

Extended Kalman FilterR0:20% RC: 20%Linear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

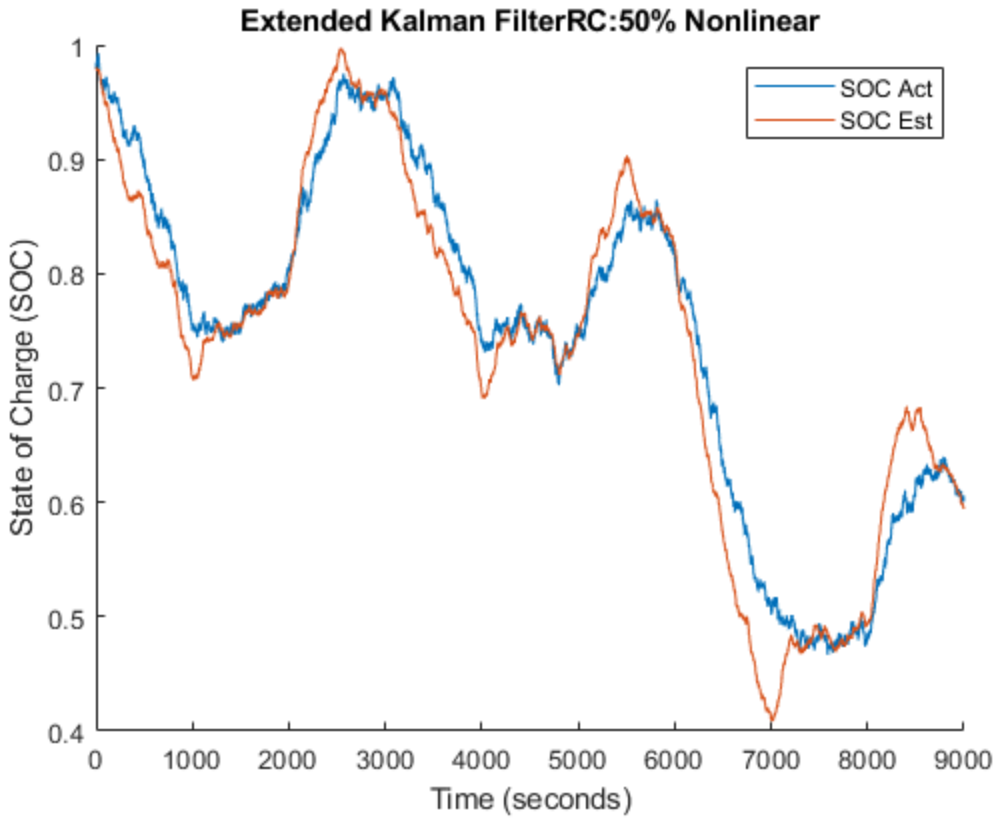

Extended Kalman FilterNonlinear Baseline
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

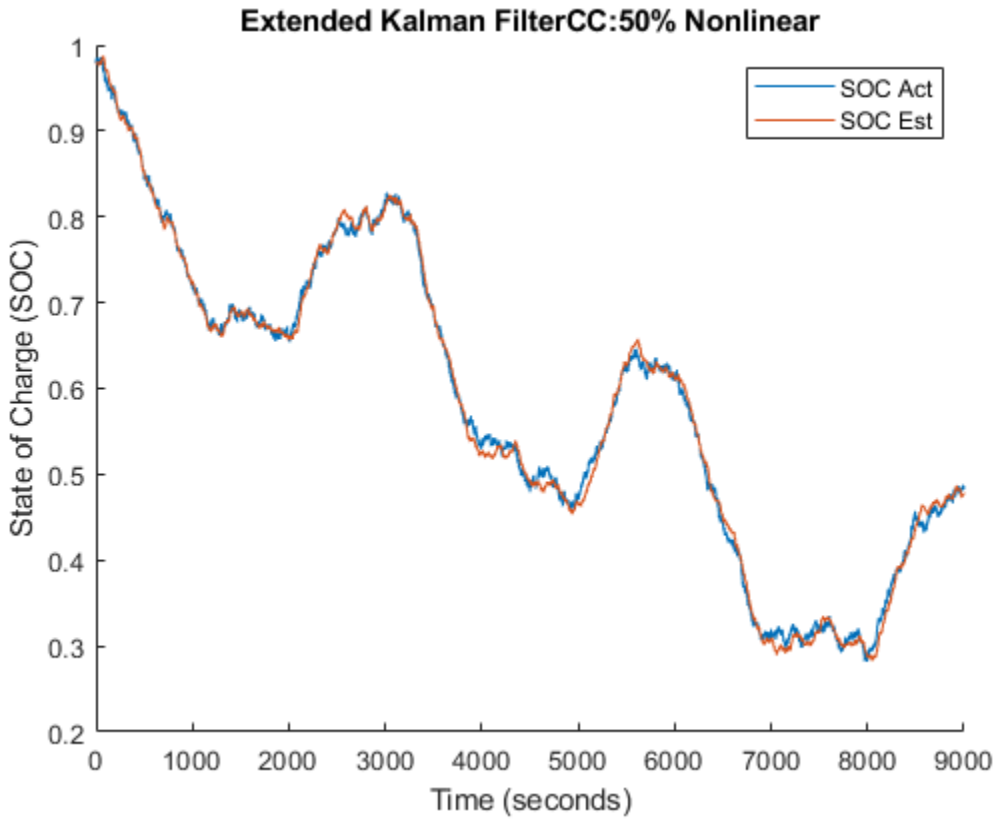

Extended Kalman FilterR0:25% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Extended Kalman FilterRC:25% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Extended Kalman FilterCC:25% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Extended Kalman FilterR0:50% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Extended Kalman FilterRC:50% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Extended Kalman FilterCC:50% Nonlinear
SOC Act
SOC Est
State of Charge (SOC)
Time (seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
1000
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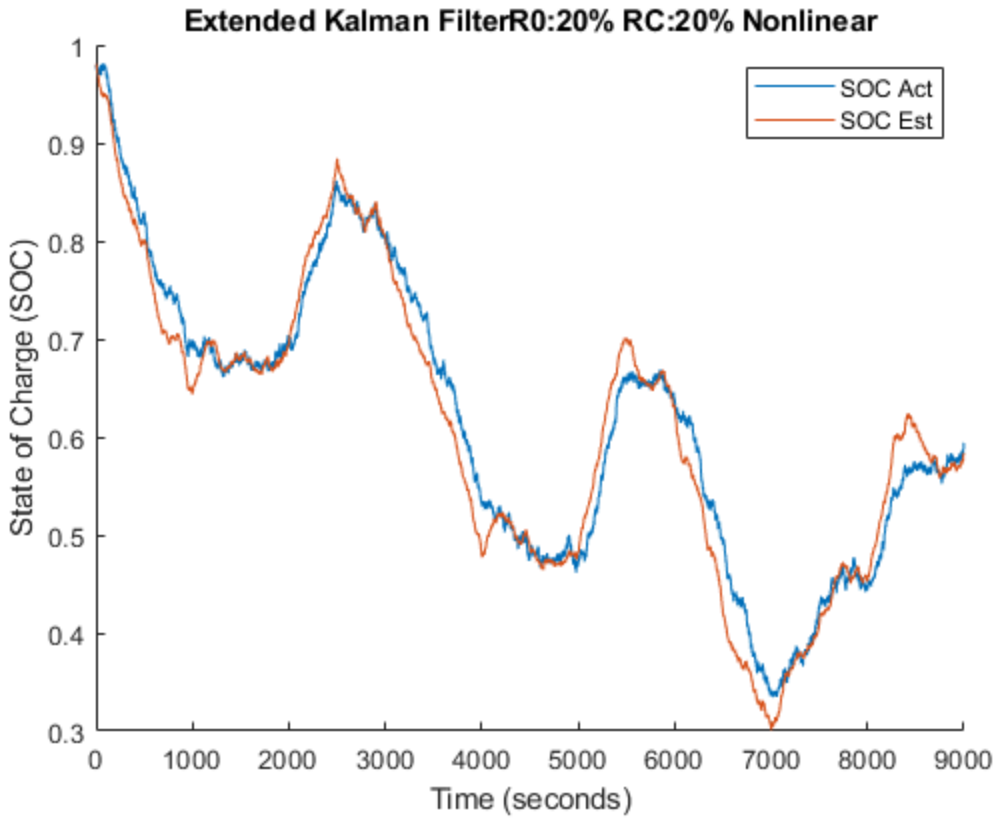
4000
5000
6000
7000
8000
9000



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