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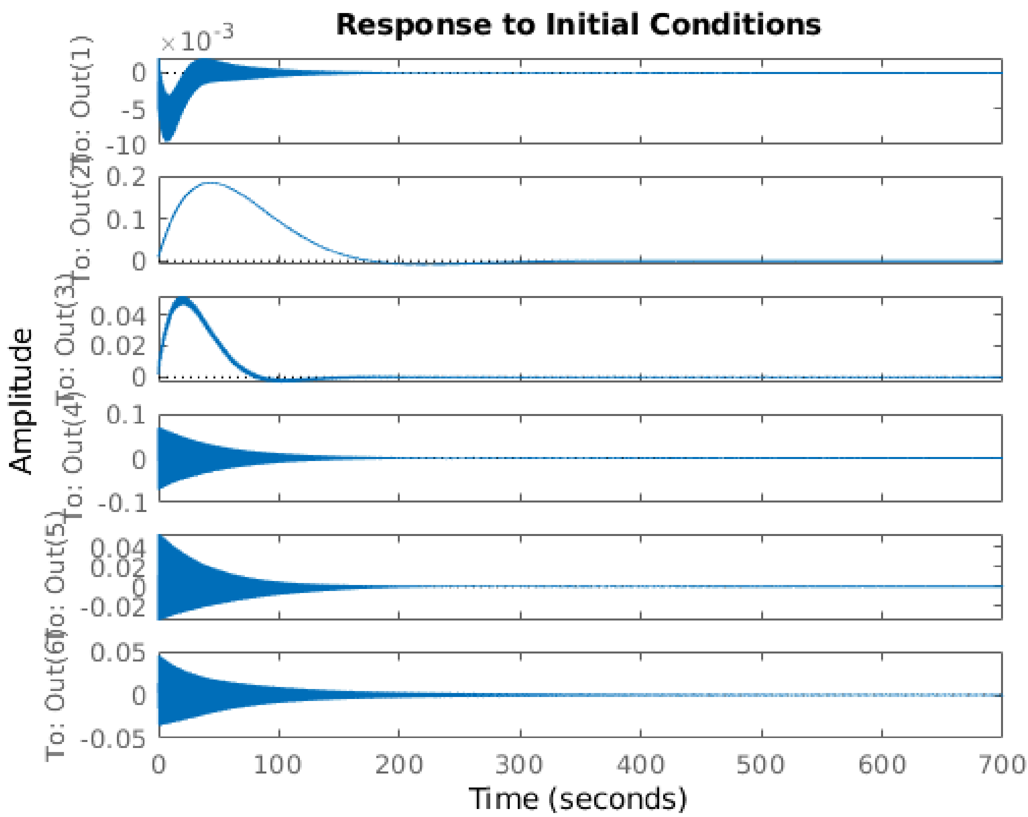
```
close all;
clear all;

load('sat.mat')
```

a)

```
% First ensure that the system is controllable and observable.
cont_r = rank(ctrb(A,B));  % The rank of this is 10. So not
 controllable.
obsv_r = rank(obsv(A,C));  % The rank of this is 12. So not
 observable.

% Since the system is not controllable or observable. I need to ensure
 that
% it is stabilizable and detectable.

% Detectability: The system is detectable iff every eigen value vector
 of A
% corresponding to an eigenvalue with a positive or zero real part is
 not
% in the kernal of C.
eig_A = eig(A);
detectable = 1;
for ii=1:length(eig_A)
   if real(eig_A(ii)) >= 0
       PHB = [A-eig_A(ii)*eye(18); C];
       if rank(PHB) < 18
           detectable = 0;
       end
   end
end
% The value of detectable is still 1. So the system is detectable.

% Stabilizability: The system is stabilizable iff every eigenvector of
 A'
% corresponding to and eigenvalue with a positive or zero real part is
 not
% in the kernal of B'.
eig_A = eig(A);
stabilizable = 1;
for ii=1:length(eig_A)
   if real(eig_A(ii)) >= 0
       PHB = [A-eig_A(ii)*eye(18) B];
```

```
        if rank(PHB) < 18
            stabilizable = 0;
        end
    end
end
% The value of stabilizable is still 1. So the system is stabilizable.

%%%% Now that I know that the system is both stabilizable and
 detectable, I
%%%% can start to create an LQR and LQG controller.

%%%% LQR
% I will use Bryson's rule to create my Q1 and R1 matrices as a
 starting point for
% the LQR controller.
max_x = 2;                      % Desired maximum state deviation from
 equilibrium.
Q1 = diag(ones(18,1)/max_x^2);
q = 1;                          % Used to tune performance
Q = q*Q1;

max_u = 1;                      % Desired maximum input deviation from
 equilibrium.
R1 = diag(ones(3,1)/max_u^2);
r = diag([5,2000,120]);        % Used to tune performance to meet
 input constraints.
R=r*R1;

[K,S,E] = lqr(A,B,Q,R);
K
eig(A-B*K); % Ensure that the eigen values are all less than zero.

%%%% LQG
% I will use the known noise covariance to and model disturbance
 covariance
% To construct my D and N covariance matrices.
Dk = eye(3,3)*10^-3;
Nk = diag([ones(3,1)*10^-5;ones(3,1)*10^-10]);

[Kest,L,P] = kalman(ss(A,B,C,D),Dk,Nk);
L
eig(A-L*C);   % Ensure that the eigen values are all less than zero.

%%%% Plot the results of the controller.
figure(1),clf;
initial(ss(A-B*K,B*0,C,D),ones(18,1));


K =

  Columns 1 through 7

   -0.1941    0.0942    0.0588    0.0000   -0.0000    0.0000    0.0001
    0.0053    0.0095    0.0024   -0.0000   -0.0000   -0.0000    0.0000
```

```
    0.0062   -0.0141    0.0430   -0.0000   -0.0001   -0.0000   -0.0000

  Columns 8 through 14

    0.0000   -0.0040   -2.1812    1.0505    0.6543    0.0000   -0.0002
   -0.0000   -0.0000    0.3020    0.5384    0.1328   -0.0000   -0.0000
   -0.0000   -0.0000    0.1656   -0.3794    1.1516   -0.0000   -0.0014

  Columns 15 through 18

    0.0000    0.0004    0.0001   -0.0221
   -0.0000    0.0000   -0.0000   -0.0000
   -0.0000   -0.0000   -0.0004   -0.0000


L =

   -0.3430    0.2387    0.0616 -108.2513   75.2563   19.4366
    0.1584    0.4254   -0.1431   50.0020  134.1480  -45.1310
    0.0992    0.1048    0.4312   31.3024   33.0538  135.9677
   -0.0000   -0.0000   -0.0000    0.0019   -0.0043   -0.0063
   -0.0000   -0.0000   -0.0000   -0.0397   -0.0152   -0.2099
    0.0000    0.0000   -0.0000    0.0000   -0.0001   -0.0007
    0.0000    0.0000   -0.0000   -0.0003    0.0433   -0.0002
    0.0000    0.0000   -0.0000    0.0000   -0.0004   -0.0711
   -0.0000    0.0000   -0.0000   -0.0491    0.0004   -0.0026
   -0.0011    0.0008    0.0002 -196.6251   81.7363   25.3544
    0.0005    0.0013   -0.0005   95.5744  152.5872  -59.0762
    0.0003    0.0003    0.0014   59.8239   38.9626  182.0306
   -0.0000    0.0000    0.0000    0.0226    0.0040   -1.4165
    0.0000    0.0000    0.0000    0.5664    0.2701  -47.2445
    0.0000    0.0000    0.0000    0.0014   -0.0651   -0.3312
    0.0000   -0.0000    0.0000    1.6415   53.3897    0.0375
    0.0000    0.0000    0.0000   -0.0964   -0.6793  -31.9242
    0.0000    0.0000   -0.0000  -96.4643   -2.9768   -0.7414
```

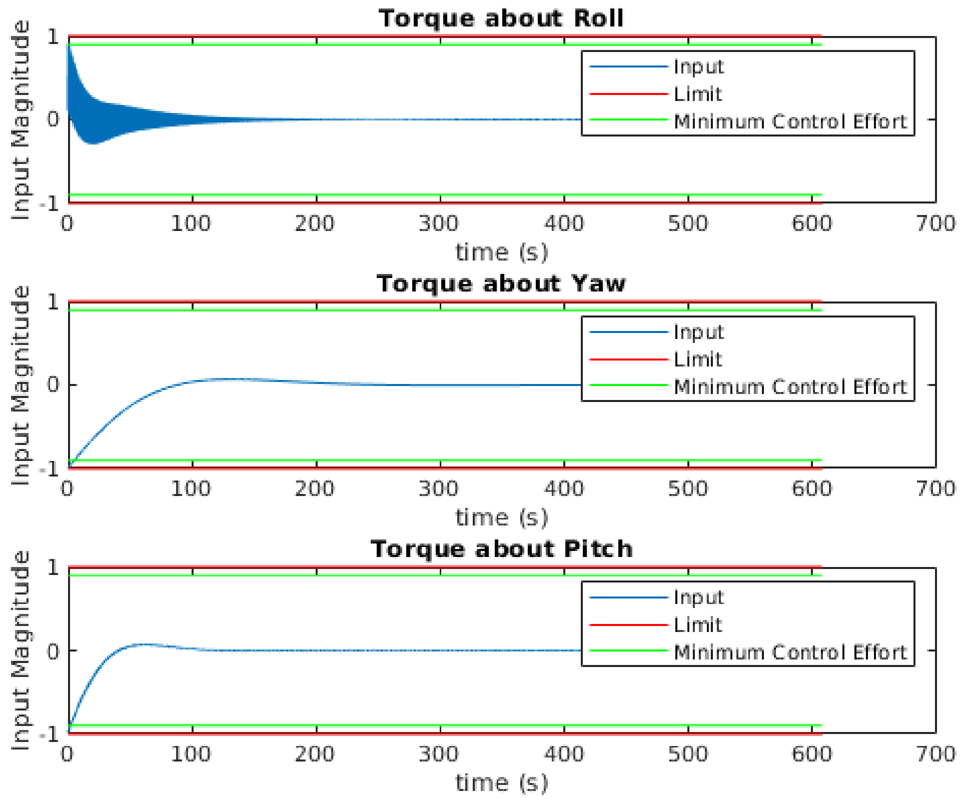


b)

Run the simulation again to get the state values

```
[Y,T,X] =initial(ss(A-B*K,B*0,C,D),ones(18,1));

% Get the input values since u = -Kx;
u =-K*X';

% Plot the input
figure(2),clf;
subplot(3,1,1)
plot(T,u(1,:));
hold on
plot(T,ones(1,length(T))*1,'r')
plot(T,ones(1,length(T))*0.9,'g')
plot(T,-ones(1,length(T))*1,'r')
plot(T,-ones(1,length(T))*0.9,'g')
title('Torque about Roll');
xlabel('time (s)')
ylabel('Input Magnitude');
legend('Input','Limit','Minimum Control Effort');

subplot(3,1,2)
```

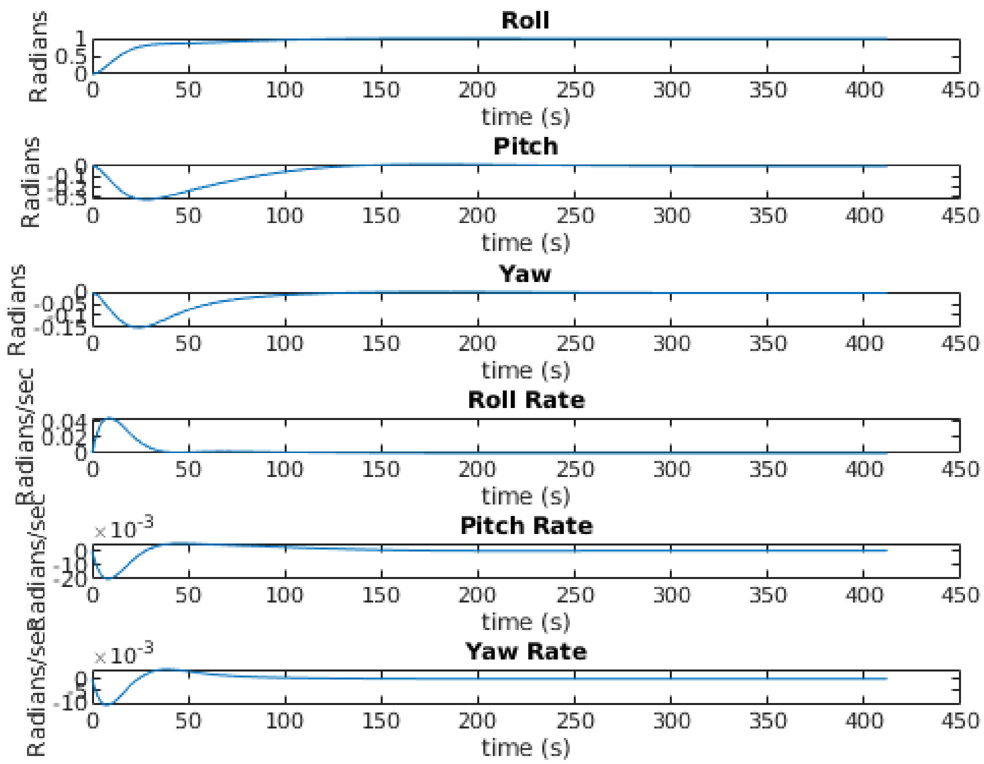
```
plot(T,u(2,:));
hold on
plot(T,ones(1,length(T))*1,'r')
plot(T,ones(1,length(T))*0.9,'g')
plot(T,-ones(1,length(T))*1,'r')
plot(T,-ones(1,length(T))*0.9,'g')
title('Torque about Yaw');
xlabel('time (s)')
ylabel('Input Magnitude');
legend('Input','Limit','Minimum Control Effort');

subplot(3,1,3)
plot(T,u(3,:));
hold on
plot(T,ones(1,length(T))*1,'r')
plot(T,ones(1,length(T))*0.9,'g')
plot(T,-ones(1,length(T))*1,'r')
plot(T,-ones(1,length(T))*0.9,'g')
title('Torque about Pitch');
xlabel('time (s)')
ylabel('Input Magnitude');
legend('Input','Limit','Minimum Control Effort');

% Verify that the maximum input value is between 0.9 and 1.
max(abs(u),[],2);
% The maximum values are [0.91;0.9905;0.9813]. Thus the system
 constraints
% are satisfied.
```



c)

```
% I want to controll yaw to 1 radian. I need to find an equilibrium
 input
% for this state such that Ax_d +Bu_eq = 0.
x_d = zeros(18,1);
x_d(1) = 1;             % Desired x_state.
A*x_d;                  % Since this value is zero, u_eq is also zero.
 This
                        % Simplifies the problem.

% Using section 23.6.1 in the book. I need my input to be
% u = -K(x-x_d) + u_eq =>  -K(x-x_d)


temp = zeros(18,1);
temp(1) = 1;
% Set it up such that x_dot = Ax -B*K(x-x_d) with a step input.
[Y,T,X] = step(ss(A-B*K,+B*K*temp,C,0));

% Plot the results. I am plotting X instead of Y because Y is not even
% close to being the pointing angles and angular velocities.
figure(3),clf;
subplot(6,1,1);
```

```
plot(T,X(:,1))
title("Roll");
xlabel('time (s)')
ylabel('Radians');

subplot(6,1,2);
plot(T,X(:,2))
title("Pitch");
xlabel('time (s)')
ylabel('Radians');

subplot(6,1,3);
plot(T,X(:,3))
title("Yaw");
xlabel('time (s)')
ylabel('Radians');

subplot(6,1,4);
plot(T,X(:,10))
title("Roll Rate");
xlabel('time (s)')
ylabel('Radians/sec');

subplot(6,1,5);
plot(T,X(:,11))
title("Pitch Rate");
xlabel('time (s)')
ylabel('Radians/sec');

subplot(6,1,6);
plot(T,X(:,12))
title("Yaw Rate");
xlabel('time (s)')
ylabel('Radians/sec');
```



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