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Kalman Filter Implementation for AAUSHIP1:

Rasmus Christensen 26/11/2012 - 12gr730 - AAUSHIP Kalaman Filter (c)

```
clc; clear all; clf;
load inputD.mat; % Loads system input file from contsimu.m
inputD = inputD';

% To reduce the amount of noise on the measurements which are fed to the
% system, and to enhance the precision of these, the data is run through a
% Kalman filter which is then estiamtes the position, given the noisy
% inputs. The HLI interface, which computes if the waypoint is reached,
% needs the X and Y position for the vessel to verify wether the ship has
% reached the desired waypoints. These two, can be measured by several
% devices, first of, the GPS spits out the position of the vessel, as well
% as the velocity. The velocity can be converted to a Y position, using the
% inverse of the rotation matrix. Using the IMU on board the ship, we're
% able to measure the acceleration in the X and Y direction. The IMU also
% meausres the rotational acceleration around the center of the ship.
%
% Later, this can also be used to estimate the roll of the ship, to give
% the precise position of the measurement taken, using simple geometry!
%
% First of, the state vector Y is defined as:
% Y(n) = A(n) * Y(n-1) + Z(n), where W(n) is driving noise/input to the
% system.
%
% Then the measuremen vector X can be defined as:
% X(n) = H(n) * Y(n) + W(n), where Z(n) expresses the noisy measurements.
%
```

```
% The desired measurements can be described as (the definition of the A
% matrix):
```

Number of Samples:

```
N = 1000;
```

System Parameters:

```
m = 12; % The ships mass
I = (1/12)*m*(0.25*0.25+1.05*1.05); % The ships inertia
ts = 0.1; % Sampling time
betaX = 0.4462;
betaY = 0.0784;
betaW = 1.3;
```

System Definition:

```
Hn = [1 ts ts^2/2 0 0 0 0 0 0;... % The X position
     0 1 ts 0 0 0 0 0 0;... % The X velocity
     0 -betaX 0 0 0 0 0 0 0;... % The X acceleration is a sum of forward motion (F
     0 0 0 1 ts ts^2/2 0 0 0;... % The Y Position
     0 0 0 0 1 ts 0 0 0;... % The Y Velocity
     0 0 0 0 -betaY 0 0 0 0;... % The Y acceleration is a sum of the sideways moti
     0 0 0 0 0 0 1 ts ts^2/2;... % The angle
     0 0 0 0 0 0 0 1 ts;... % The angular velocity
     0 0 0 0 0 0 0 -betaW 0]; % The angular acceleration is a sum of the drag an i

An = eye(9); % An eye matrix, as all the outputs scales equally - everything is in
```

Noise Terms (Input and Measurement Noise):

The Z(n) is the "driving noise" - as the system input is a forward force and a torque, these are input here as well. The "input" matrix for the driving noise Z(n) is then equal to:

```
Bn = [0 0;...
     0 0;...
     1/m 0;... % From force to input acceleration
     0 0;...
     0 0;...
     0 0;...
     0 0;...
     0 0;...
     0 1/I]; % From torque to angular acceleration

 for ii = 1:N
    Z(:,ii) = Bn*inputD(:,ii);
end

% W is the measurement noise on the system, this can be estimated to be
% white gaussian noise, with zero mean (for most cases) and with a
```

```
% variance, that are estimated in Appendix #XX.
varXpos = 15;
varXvel = .2;
varXacc = 4.9451e-5; %  m/s^2 or 5.045*10^-6 G

varYpos = 16;
varYvel = .2;
varYacc = 4.8815e-5; % m/s^2; or 4.9801*10^-6 G

varWpos = .2;
varWvel = .2;
varWacc = 2.3559e-5; % m/s^2 or 2.4035*10^-6 G

varYWacc = 2.4496*10^-6; % rad/s^2
SqM = sqrt([varXpos varXvel varXacc varYpos varYvel varYacc varWpos varWvel varWac

 % Random number at each iteration with a given variance.
```

Covariance Matrices:

As the vector Kalman filter have several system inputs, the noise added to the system generates a covariance matrix. These are computed below. The covariance of a vector is given as: cov(Z_i(n),Z_j(n)) = E[(Zi-mu_i)(Zj - mu_j)]. If the process is zero mean, this becomes a matrix with the diagonal entires given as: cov(Z(n) = E[Z(n)*Z(n)'], but as the inputs to the system, cannot be considered to be zero mean, the latter is not used. Qz = cov(Z(n-1)*Z(n)'); The measuremnets, are considered to be white gaussian zero mean noise, and this can then be considered to be a diagonal matrix with the elements squared, hence there is no need for the square root, as this just gives the variance it self.

System initiation:

The system is initialized, the parameters are:

```
Qz = zeros(9,9,N);
Qw = zeros(9,9,N);
Y = zeros(9,N);
X = zeros(9,N);
Ypred = zeros(9,N);
Xpred = zeros(9,N);
Rpred = zeros(9,9,N);
B = zeros(9,9,N);
Yupdate = zeros(9,N);
Rupdate = zeros(9,9,N);
k_newpos = zeros(2,N);
y_newpos = zeros(2,N);
x_newpos = zeros(2,N);
k_rot = zeros(2,N);
```

Running Computation of the Monorate Kalman filter:

```
for n = 2:N;
```

```
        Wn(:,n) = randn(9,1).*SqM';
      Qz(:,:,n) = cov(Z(:,n-1)*Z(:,n)');
      Qw(:,:,n) = diag([varXpos varXvel varXacc varYpos varYvel varYacc varWpos var
         Y(:,n) = Hn*Y(:,n-1)+Z(:,n);
         X(:,n) = An*Y(:,n)+Wn(:,n);
     Ypred(:,n) = Hn*Yupdate(:,n-1);
     Xpred(:,n) = An*Ypred(:,n);
   Rpred(:,:,n) = Hn*Rupdate(:,:,n-1)*Hn'+Qz(:,:,n);
       B(:,:,n) = (Rpred(:,:,n)*An')/(An*Rpred(:,:,n)*An'+Qw(:,:,n));
   Yupdate(:,n) = Ypred(:,n)+B(:,:,n)*(X(:,n)-Xpred(:,n));
 Rupdate(:,:,n) = (eye(9)-B(:,:,n)*An)*Rpred(:,:,n);
 % Below - rotation udpate, so the route can be plotted:
     k_rot(:,n) = [cos(Yupdate(7,n-1));sin(Yupdate(7,n-1))];%;sin(Yupdate(7,n)) cos
  k_newpos(:,n) = k_newpos(:,n-1) + k_rot(:,n-1).*Yupdate(2,n-1).*ts;%.*(Yupdate(2,
     y_rot(:,n) = [cos(Y(7,n-1));sin(Y(7,n-1))];
  y_newpos(:,n) = y_newpos(:,n-1) + (y_rot(:,n).*Y(2,n-1).*ts);
     x_rot(:,n) = [cos(X(7,n-1));sin(X(7,n-1))];
  x_newpos(:,n) = x_newpos(:,n-1) + (x_rot(:,n).*X(2,n-1).*ts);
end
```

Output definitions:

Filtered:

```
Y_kal_pos_X = Yupdate(1,:)'; % Updated Y - x position
Y_kal_vel_X = Yupdate(2,:)';
Y_kal_acc_X = Yupdate(3,:)';

Y_kal_pos_Y = Yupdate(4,:)'; % Updated Y - y position
Y_kal_vel_Y = Yupdate(5,:)';
Y_kal_acc_Y = Yupdate(6,:)';

Y_kal_pos_W = Yupdate(7,:)'; % Updated Y - angle
Y_kal_vel_W = Yupdate(8,:)';
Y_kal_acc_W = Yupdate(9,:)';

% Measured:
X_pos_X = X(1,:)'; % Observation X - x position
X_vel_X = X(2,:)';
X_acc_X = X(3,:)';

X_pos_Y = X(4,:)'; % Observation X - y position
X_vel_Y = X(5,:)';
X_acc_Y = X(6,:)';

X_pos_W = X(7,:)'; % Observation X - angle
X_vel_W = X(8,:)';
X_acc_W = X(9,:)';

% Actual:
Y_pos_X = Y(1,:)'; % True Y - x position
Y_vel_X = Y(2,:)';
Y_acc_X = Y(3,:)';
```

```
Y_pos_Y = Y(4,:)'; % True Y - x position
Y_vel_Y = Y(5,:)';
Y_acc_Y = Y(6,:)';

Y_pos_W = Y(7,:)'; % True Y - x position
Y_vel_W = Y(8,:)';
Y_acc_W = Y(9,:)';
```

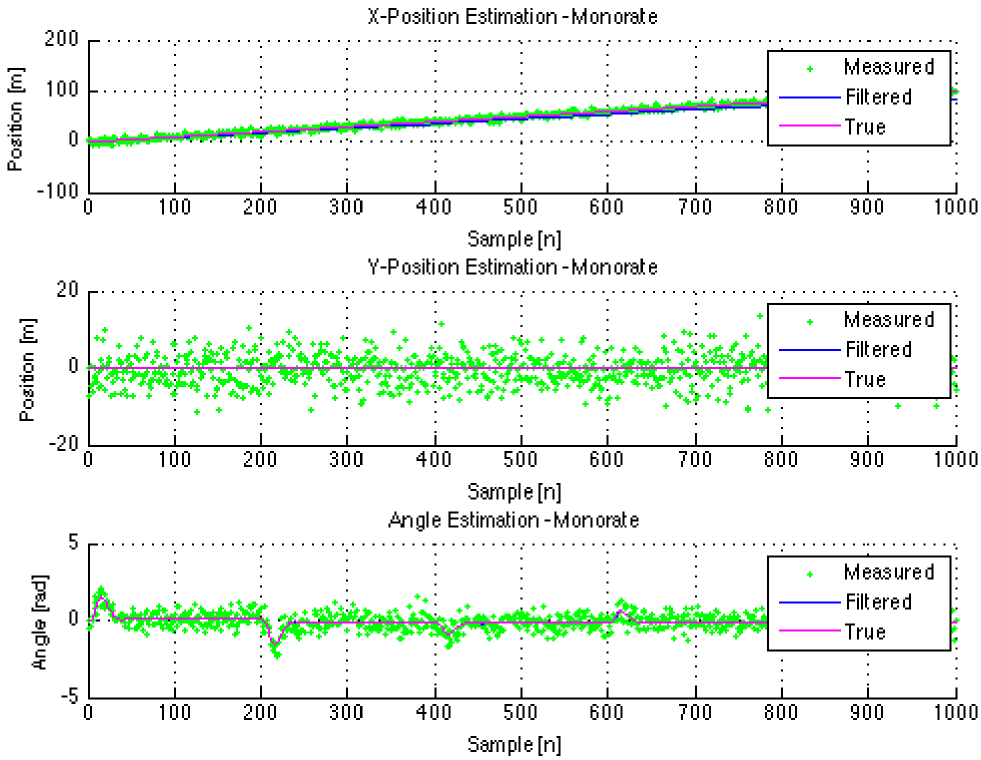
Plot of figures for same Monorate sampling:

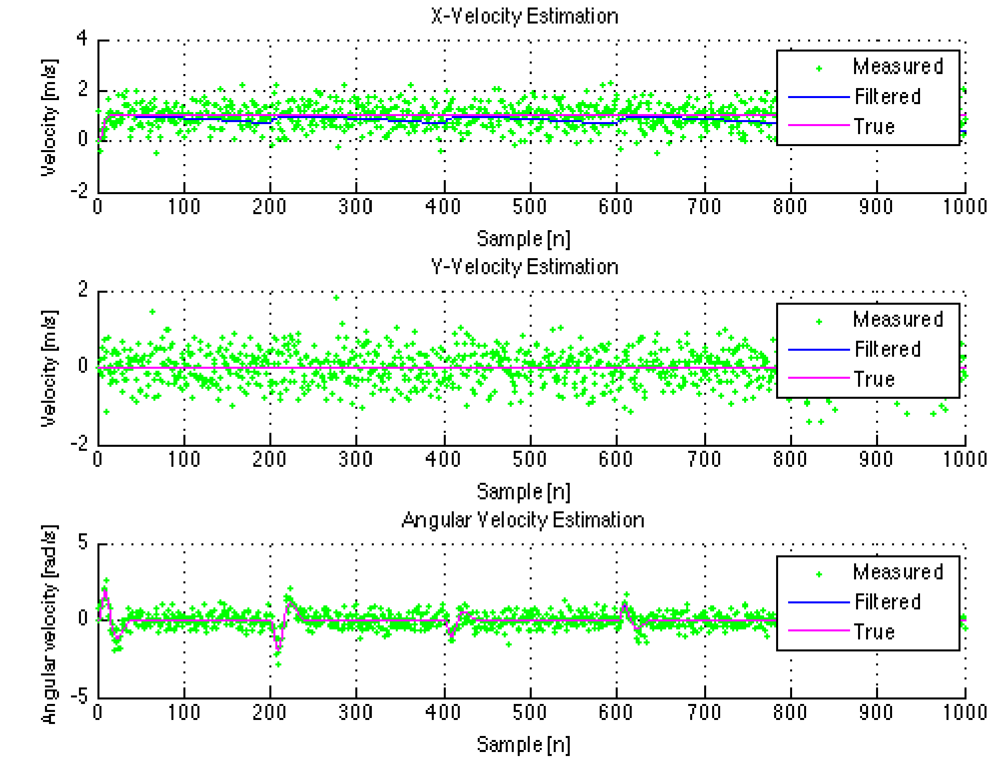
Plot of position (x,y,w)

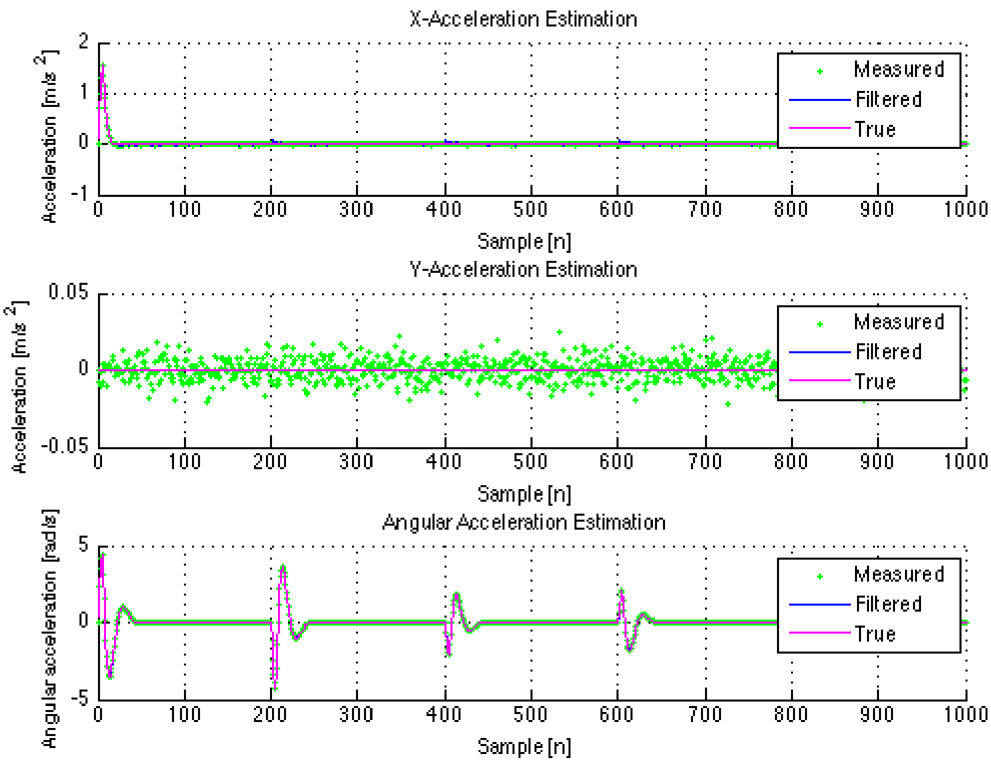
```
h1 = figure(1);
subplot(3,1,1)
hold on
plot(X_pos_X,'g+','MarkerSize',2);
plot(Y_kal_pos_X,'b','LineWidth',1);
plot(Y_pos_X,'m','LineWidth',1);
hold off
title('X-Position Estimation - Monorate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Position [m]');
grid on

subplot(3,1,2)
hold on
plot(X_pos_Y,'g+','MarkerSize',2);
plot(Y_kal_pos_Y,'b','LineWidth',1);
plot(Y_pos_Y,'m','LineWidth',1);
hold off
title('Y-Position Estimation - Monorate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Position [m]');
grid on

subplot(3,1,3)
hold on
plot(X_pos_W,'g+','MarkerSize',2);
plot(Y_kal_pos_W,'b','LineWidth',1);
plot(Y_pos_W,'m','LineWidth',1);
hold off
title('Angle Estimation - Monorate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Angle [rad]');
grid on

% Plot of velocity (x,y,w)
h2 = figure(2);
subplot(3,1,1)
hold on
plot(X_vel_X,'g+','MarkerSize',2);
plot(Y_kal_vel_X,'b','LineWidth',1);
```

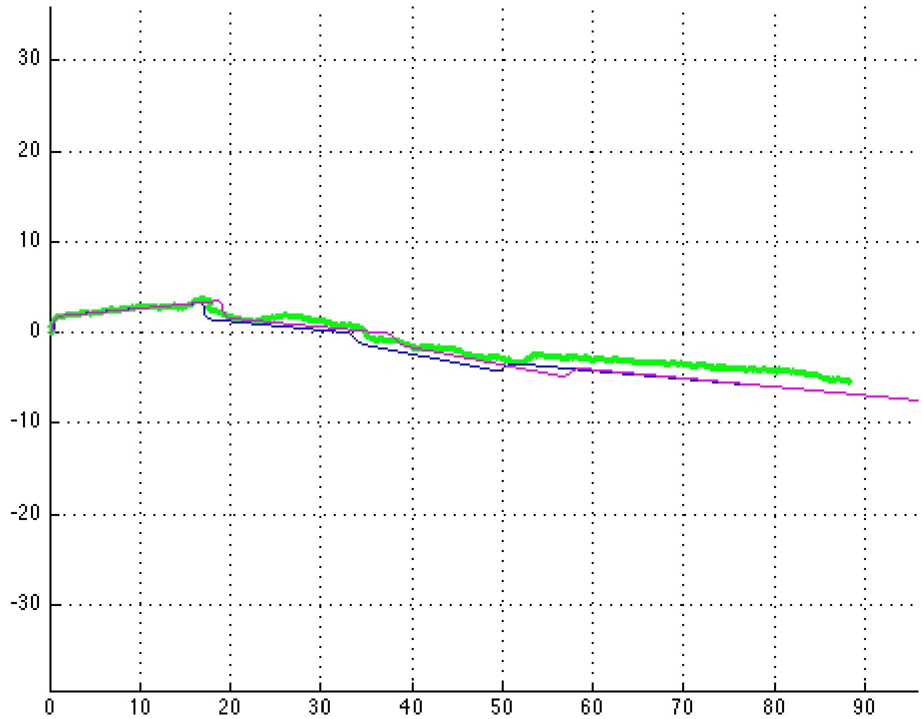
```
plot(Y_vel_X,'m','LineWidth',1);
hold off
title('X-Velocity Estimation')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Velocity [m/s]');
grid on

subplot(3,1,2)
hold on
plot(X_vel_Y,'g+','MarkerSize',2);
plot(Y_kal_vel_Y,'b','LineWidth',1);
plot(Y_vel_Y,'m','LineWidth',1);
hold off
title('Y-Velocity Estimation')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Velocity [m/s]');
grid on

subplot(3,1,3)
hold on
plot(X_vel_W,'g+','MarkerSize',2);
plot(Y_kal_vel_W,'b','LineWidth',1);
plot(Y_vel_W,'m','LineWidth',1);
hold off
title('Angular Velocity Estimation')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Angular velocity [rad/s]');
grid on

% Plot of acceleration (x,y,w)
h3 = figure(3);
subplot(3,1,1)
hold on
plot(X_acc_X,'g+','MarkerSize',2);
plot(Y_kal_acc_X,'b','LineWidth',1);
plot(Y_acc_X,'m','LineWidth',1);
hold off
title('X-Acceleration Estimation')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Acceleration [m/s^2]');
grid on

subplot(3,1,2)
hold on
plot(X_acc_Y,'g+','MarkerSize',2);
plot(Y_kal_acc_Y,'b','LineWidth',1);
plot(Y_acc_Y,'m','LineWidth',1);
hold off
title('Y-Acceleration Estimation')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Acceleration [m/s^2]');
grid on

subplot(3,1,3)
```

```
hold on
plot(X_acc_W,'g+','MarkerSize',2);
plot(Y_kal_acc_W,'b','LineWidth',1);
plot(Y_acc_W,'m','LineWidth',1);
hold off
title('Angular Acceleration Estimation')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Angular acceleration [rad/s]');
grid on

% Plot of actual X-Y position
h4 = figure(4);
hold on
plot(x_newpos(1,:),x_newpos(2,:),'g+','MarkerSize',2);
plot(k_newpos(1,:),k_newpos(2,:),'b','LineWidth',1);
plot(y_newpos(1,:),y_newpos(2,:),'m','LineWidth',1);
hold off
grid on
axis equal
```




X-Velocity Estimation
Velocity [m/s]
Sample [n]
Measured
Filtered
True
Y-Velocity Estimation
Velocity [m/s]
Sample [n]
Measured
Filtered
True
Angular Velocity Estimation
Angular velocity [rad/s]
Sample [n]
Measured
Filtered
True


X-Acceleration Estimation
Acceleration [m/s 2]
Sample [n]
Measured
Filtered
True
Y-Acceleration Estimation
Acceleration [m/s 2]
Sample [n]
Measured
Filtered
True
Angular Acceleration Estimation
Angular acceleration [rad/s]
Sample [n]
Measured
Filtered
True



Running Computation of the Multirate Kalman filter::

As not all of the measurements are sampled at the same time (some are slower, as the GPS for instance) - the samples where no GPS reading is available will have to increase the level of the noise. Below is a list of the sampling speeds of the sensors mounted on the ship: GPS = 1Hz; IMU = 20Hz; This calls for attention to the GPS measurements, as these are not sampled as often as the IMU! When this is done, the computation of the Kalman filter becomes:

```
% Resetting the parameters:
YD = zeros(9,N);
XD = zeros(9,N);
YpredD = zeros(9,N);
XpredD = zeros(9,N);
RpredD = zeros(9,9,N);
BD = zeros(9,9,N);
YupdateD = zeros(9,N);
RupdateD = zeros(9,9,N);
k_newposD = zeros(2,N);
y_newposD = zeros(2,N);
x_newposD = zeros(2,N);
k_rotD = zeros(2,N);
y_rotD = zeros(2,N);
x_rotD = zeros(2,N);
```

```
sC = 0; % Sample counter - used to only include the 10th GPS sample.

for n = 2:N;
            %sC = isinteger(n/10) % Sensor Count, used to zero out unsampled syste
       Wn(:,n) = randn(9,1).*SqM';
     Qz(:,:,n) = cov(Z(:,n-1)*Z(:,n)');
     Qw(:,:,n) = diag([varXpos varXvel varXacc varYpos varYvel varYacc varWpos var
       YD(:,n) = Hn*YD(:,n-1)+Z(:,n);
       XD(:,n) = An*YD(:,n)+Wn(:,n);
   YpredD(:,n) = Hn*YupdateD(:,n-1);
   XpredD(:,n) = An*YpredD(:,n);
 RpredD(:,:,n) = Hn*RupdateD(:,:,n-1)*Hn'+Qz(:,:,n);
     BD(:,:,n) = (RpredD(:,:,n)*An')/(An*RpredD(:,:,n)*An'+Qw(:,:,n));
             if sC ~= 10;
                   BD(:,1,n) = zeros(9,1);
                   BD(:,4,n) = zeros(9,1);
             else
                   BD(:,:,n) = B(:,:,n);
                    sC = 0;
             end
 YupdateD(:,n) = YpredD(:,n)+BD(:,:,n)*(XD(:,n)-XpredD(:,n));
RupdateD(:,:,n) = (eye(9)-BD(:,:,n)*An)*RpredD(:,:,n);
            sC = sC + 1;
% Below - rotation udpate, so the route can be plotted:
    k_rotD(:,n) = [cos(YupdateD(7,n-1));sin(YupdateD(7,n-1))]; %;sin(Yupdate(7,n))
 k_newposD(:,n) = k_newposD(:,n-1) + k_rotD(:,n-1).*YupdateD(2,n-1).*ts;
    y_rotD(:,n) = [cos(YD(7,n-1));sin(YD(7,n-1))];
 y_newposD(:,n) = y_newposD(:,n-1) + (y_rotD(:,n).*YD(2,n-1).*ts);
    x_rotD(:,n) = [cos(XD(7,n-1));sin(XD(7,n-1))];
 x_newposD(:,n) = x_newposD(:,n-1) + (x_rotD(:,n).*XD(2,n-1).*ts);
end
```

Output definitions - Multirate sampling:

Filtered:

```
Y_kal_pos_XD = YupdateD(1,:)'; % Updated Y - x position
Y_kal_vel_XD = YupdateD(2,:)';
Y_kal_acc_XD = YupdateD(3,:)';

Y_kal_pos_YD = YupdateD(4,:)'; % Updated Y - y position
Y_kal_vel_YD = YupdateD(5,:)';
Y_kal_acc_YD = YupdateD(6,:)';

Y_kal_pos_WD = YupdateD(7,:)'; % Updated Y - angle
Y_kal_vel_WD = YupdateD(8,:)';
Y_kal_acc_WD = YupdateD(9,:)';

% Measured:
X_pos_XD = XD(1,:)'; % Observation X - x position
X_vel_XD = XD(2,:)';
X_acc_XD = XD(3,:)';
```

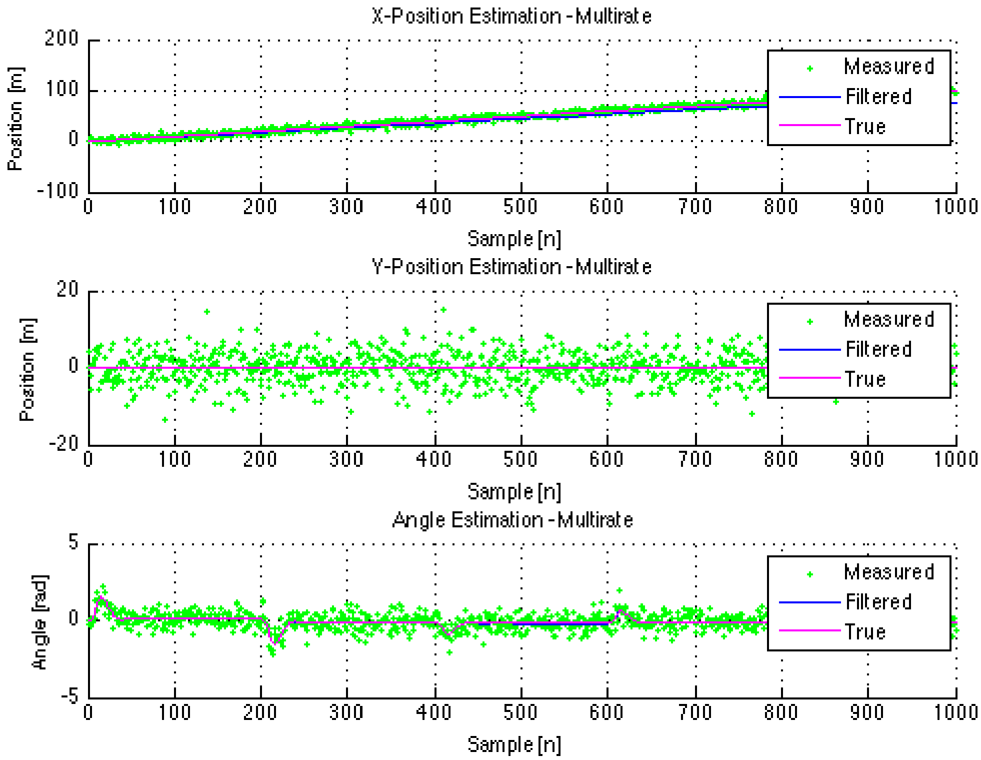
```
X_pos_YD = XD(4,:)'; % Observation X - y position
X_vel_YD = XD(5,:)';
X_acc_YD = XD(6,:)';

X_pos_WD = XD(7,:)'; % Observation X - angle
X_vel_WD = XD(8,:)';
X_acc_WD = XD(9,:)';

% Actual:
Y_pos_XD = YD(1,:)'; % True Y - x position
Y_vel_XD = YD(2,:)';
Y_acc_XD = YD(3,:)';

Y_pos_YD = YD(4,:)'; % True Y - x position
Y_vel_YD = YD(5,:)';
Y_acc_YD = YD(6,:)';

Y_pos_WD = YD(7,:)'; % True Y - x position
Y_vel_WD = YD(8,:)';
Y_acc_WD = YD(9,:)';
```

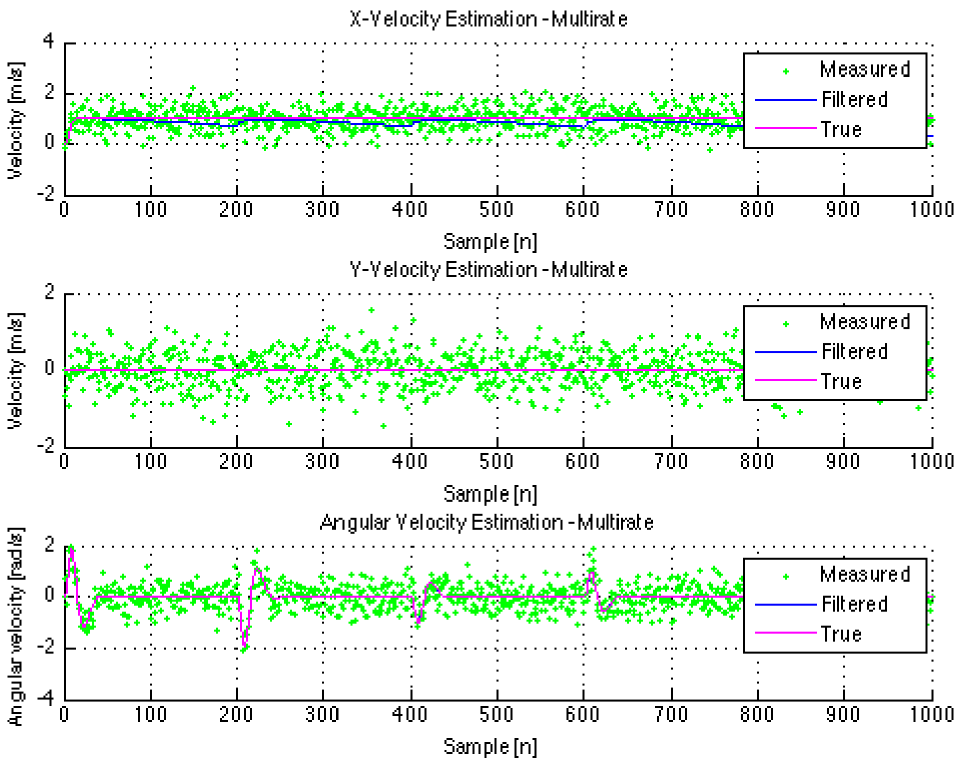
Plot - Multirate Sampling (x,y,w)

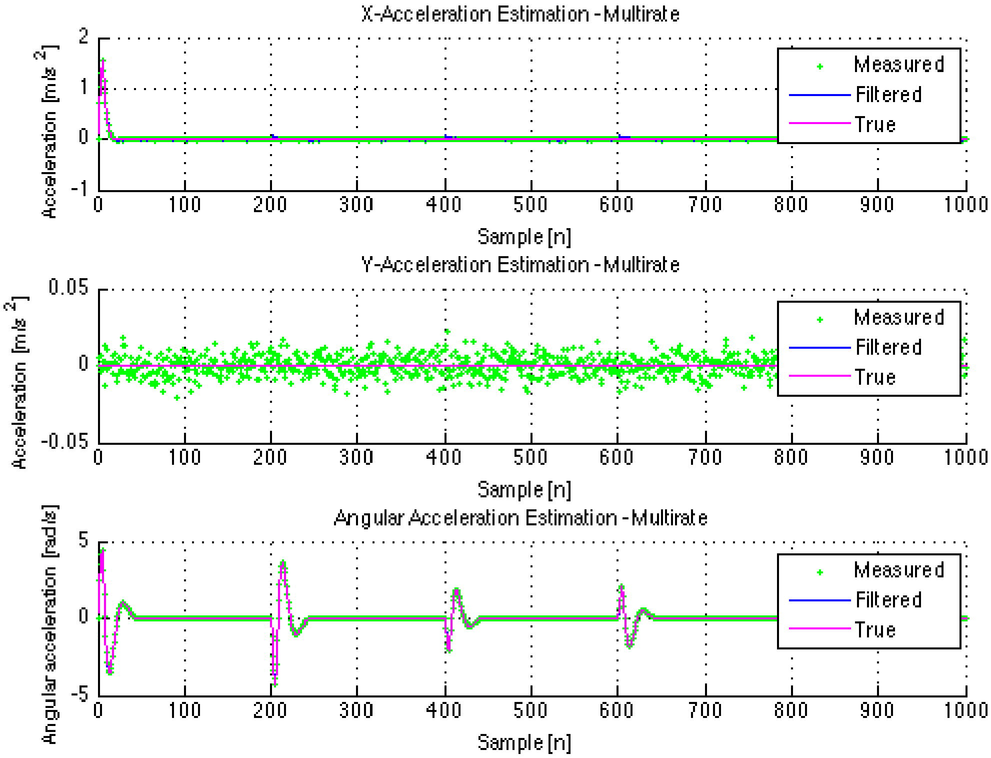
```
h5 = figure(5);
subplot(3,1,1)
hold on
plot(X_pos_XD,'g+','MarkerSize',2);
plot(Y_kal_pos_XD,'b','LineWidth',1);
plot(Y_pos_XD,'m','LineWidth',1);
hold off
title('X-Position Estimation - Multirate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Position [m]');
grid on

subplot(3,1,2)
hold on
plot(X_pos_YD,'g+','MarkerSize',2);
plot(Y_kal_pos_YD,'b','LineWidth',1);
plot(Y_pos_YD,'m','LineWidth',1);
hold off
title('Y-Position Estimation - Multirate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Position [m]');
grid on

subplot(3,1,3)
hold on
plot(X_pos_WD,'g+','MarkerSize',2);
plot(Y_kal_pos_WD,'b','LineWidth',1);
plot(Y_pos_WD,'m','LineWidth',1);
hold off
title('Angle Estimation - Multirate')
```

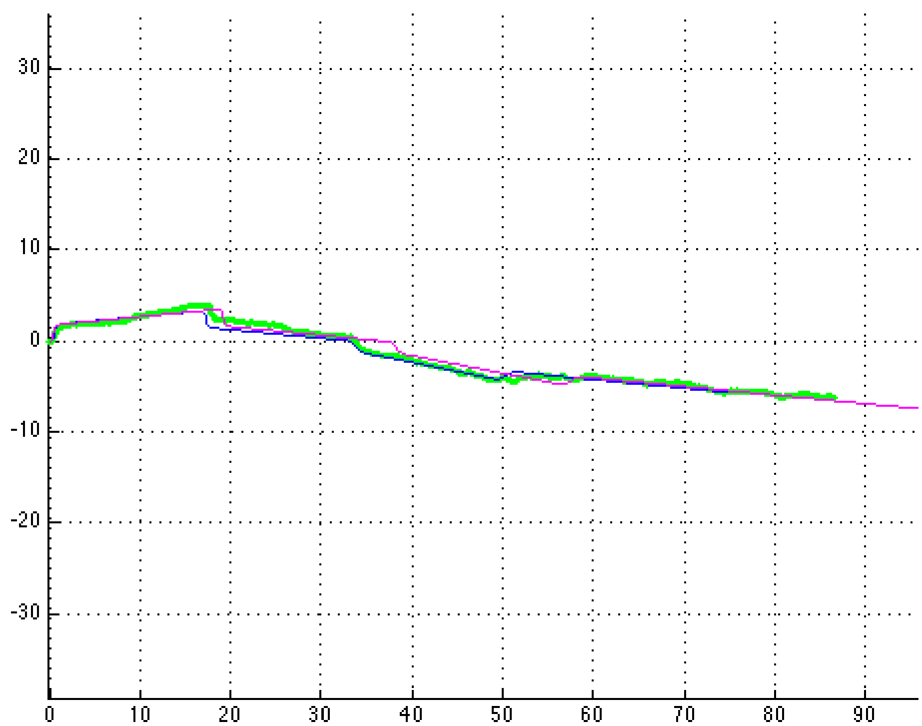
```
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Angle [rad]');
grid on

% Plot of velocity (x,y,w)
h6 = figure(6);
subplot(3,1,1)
hold on
plot(X_vel_XD,'g+','MarkerSize',2);
plot(Y_kal_vel_XD,'b','LineWidth',1);
plot(Y_vel_XD,'m','LineWidth',1);
hold off
title('X-Velocity Estimation - Multirate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Velocity [m/s]');
grid on

subplot(3,1,2)
hold on
plot(X_vel_YD,'g+','MarkerSize',2);
plot(Y_kal_vel_YD,'b','LineWidth',1);
plot(Y_vel_YD,'m','LineWidth',1);
hold off
title('Y-Velocity Estimation - Multirate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Velocity [m/s]');
grid on

subplot(3,1,3)
hold on
plot(X_vel_WD,'g+','MarkerSize',2);
plot(Y_kal_vel_WD,'b','LineWidth',1);
plot(Y_vel_WD,'m','LineWidth',1);
hold off
title('Angular Velocity Estimation - Multirate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Angular velocity [rad/s]');
grid on

% Plot of acceleration (x,y,w)
h7 = figure(7);
subplot(3,1,1)
hold on
plot(X_acc_XD,'g+','MarkerSize',2);
plot(Y_kal_acc_XD,'b','LineWidth',1);
plot(Y_acc_XD,'m','LineWidth',1);
hold off
title('X-Acceleration Estimation - Multirate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Acceleration [m/s^2]');
grid on

subplot(3,1,2)
hold on
```

```
plot(X_acc_YD,'g+','MarkerSize',2);
plot(Y_kal_acc_YD,'b','LineWidth',1);
plot(Y_acc_YD,'m','LineWidth',1);
hold off
title('Y-Acceleration Estimation - Multirate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Acceleration [m/s^2]');
grid on

subplot(3,1,3)
hold on
plot(X_acc_WD,'g+','MarkerSize',2);
plot(Y_kal_acc_WD,'b','LineWidth',1);
plot(Y_acc_WD,'m','LineWidth',1);
hold off
title('Angular Acceleration Estimation - Multirate')
legend('Measured','Filtered','True')
xlabel('Sample [n]') ;ylabel('Angular acceleration [rad/s]');
grid on

% Plot of actual X-Y position
h8 = figure(8);
hold on
plot(x_newposD(1,:),x_newposD(2,:),'g+','MarkerSize',2);
plot(k_newposD(1,:),k_newposD(2,:),'b','LineWidth',1);
plot(y_newposD(1,:),y_newposD(2,:),'m','LineWidth',1);
hold off
grid on
axis equal
```


X-Position Estimation - Multirate
Position [m]
Sample [n]
Measured
Filtered
True
Y-Position Estimation - Multirate
Position [m]
Sample [n]
Measured
Filtered
True
Angle Estimation - Multirate
Angle [rad]
Sample [n]
Measured
Filtered
True


X-Velocity Estimation - Multirate
Velocity [m/s]
Sample [n]
Measured
Filtered
True
Y-Velocity Estimation - Multirate
Velocity [m/s]
Sample [n]
Measured
Filtered
True
Angular Velocity Estimation - Multirate
Angular velocity [rad/s]
Sample [n]
Measured
Filtered
True


X-Acceleration Estimation - Multirate
Acceleration [m/s 2]
Sample [n]
Measured
Filtered
True
Y-Acceleration Estimation - Multirate
Acceleration [m/s 2]
Sample [n]
Angular Acceleration Estimation - Multirate
Angular acceleration [rad/s]
Sample [n]



Calculation differente between Monorate and Multirate

The difference in X-position:

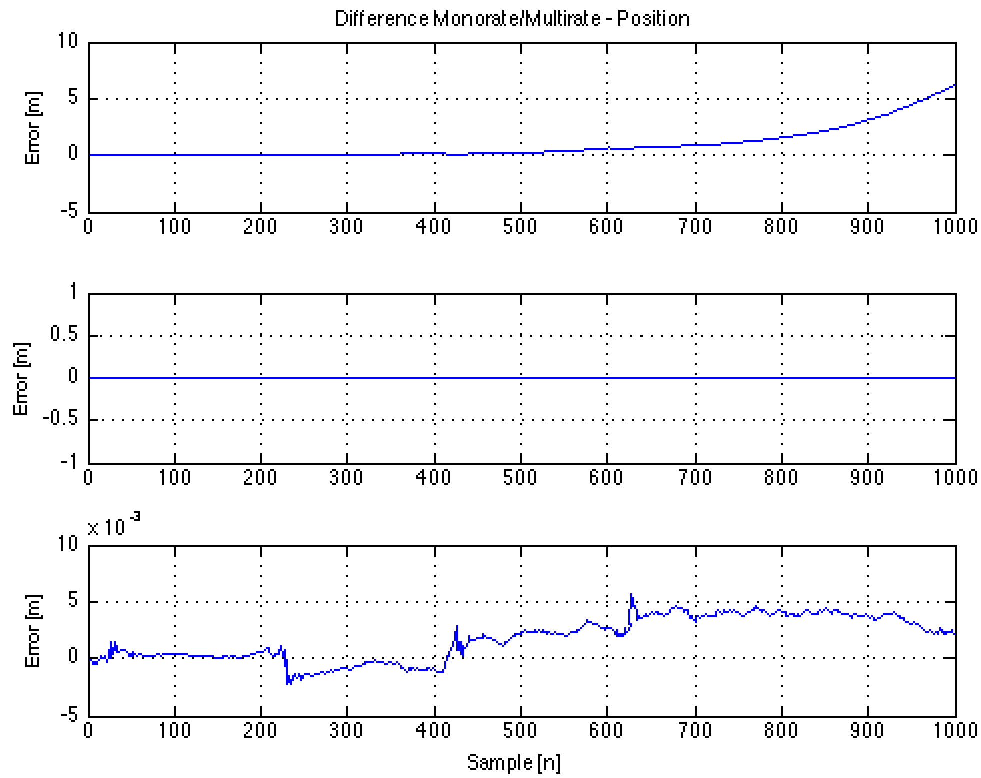
```
diffX_pos = Y_kal_pos_X - Y_kal_pos_XD;

% The difference in Y-position:
diffY_pos = Y_kal_pos_Y - Y_kal_pos_YD;

% The difference in W-position:
diffW_pos = Y_kal_pos_W - Y_kal_pos_WD;

% The difference in X-velocity:
diffX_vel = Y_kal_vel_X - Y_kal_vel_XD;

% The difference in Y-velocity:
diffY_vel = Y_kal_vel_Y - Y_kal_vel_YD;

% The difference in W-velocity:
diffW_vel = Y_kal_vel_W - Y_kal_vel_WD;

% The difference in X-acceleration:
diffX_acc = Y_kal_acc_X - Y_kal_acc_XD;

% The difference in Y-acceleration:
diffY_acc = Y_kal_acc_Y - Y_kal_acc_YD;

% The difference in W-acceleration:
diffW_acc = Y_kal_acc_W - Y_kal_acc_WD;
```

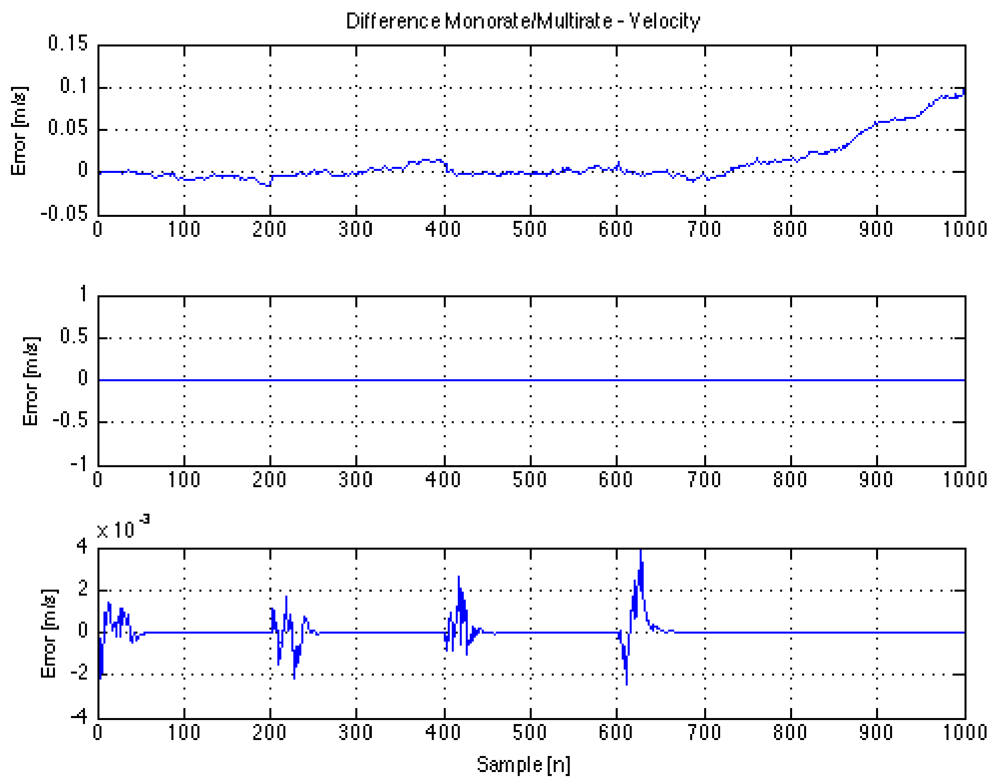
Plot of the error between monorate and multi-rate:

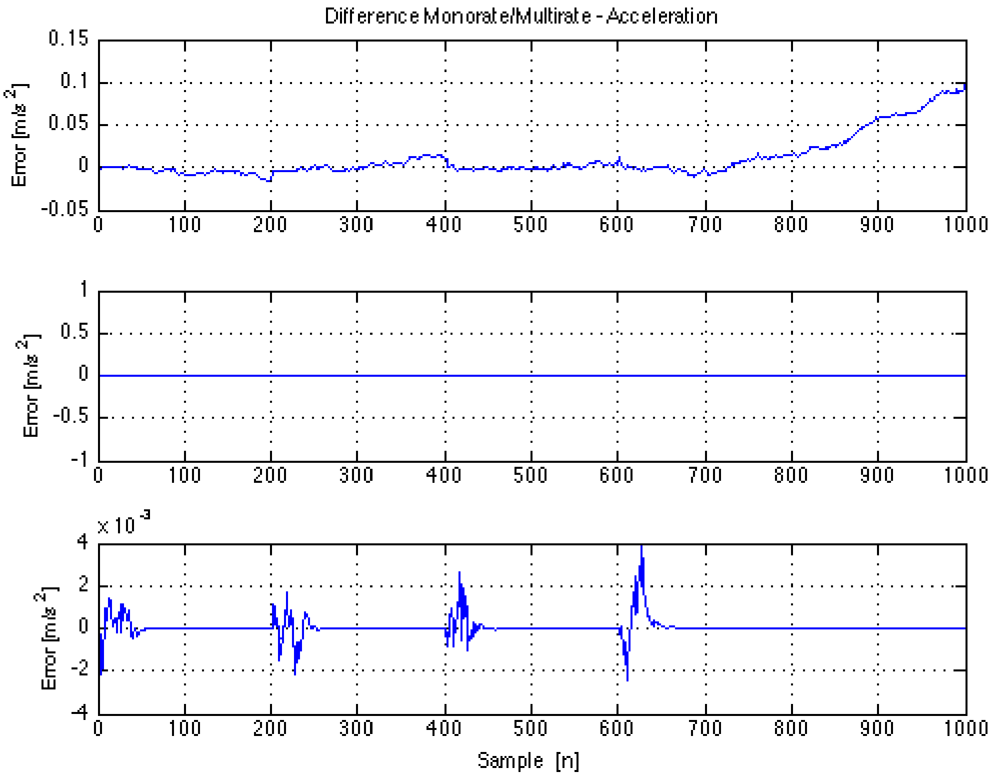
Position

```
h9 = figure(9);
subplot(3,1,1)
plot(diffX_pos,'b');
title('Difference Monorate/Multirate - Position')
grid on
ylabel('Error [m]');
subplot(3,1,2)
plot(diffY_pos,'b');
grid on
ylabel('Error [m]');
subplot(3,1,3)
plot(diffW_pos,'b');
grid on
ylabel('Error [m]');
xlabel('Sample [n]');
```

```
hold off
grid on

% Velocity
h10 = figure(10);
subplot(3,1,1)
plot(diffX_vel,'b');
title('Difference Monorate/Multirate - Velocity')
grid on
ylabel('Error [m/s]');
subplot(3,1,2)
plot(diffY_vel,'b');
grid on
ylabel('Error [m/s]');
subplot(3,1,3)
plot(diffW_vel,'b');
ylabel('Error [m/s]');
xlabel('Sample [n]');
hold off
grid on

% Acceleration
h11 = figure(11);
subplot(3,1,1)
plot(diffX_vel,'b');
title('Difference Monorate/Multirate - Acceleration')
grid on
ylabel('Error [m/s^2]');
subplot(3,1,2)
plot(diffY_vel,'b');
grid on
ylabel('Error [m/s^2]');
subplot(3,1,3)
plot(diffW_vel,'b');
ylabel('Error [m/s^2]');
xlabel('Sample [n]');
hold off
grid on
```


Difference Monorate/Multirate - Position
Error [m]
Sample [n]
x 10^-3


Difference Monorate/Multirate - Velocity
Error [m/s]
Sample [n]
x 10^-3



Estiamting a Wind Bias:

As Wind might push the ship out of course (constantly in the same direction) this can be considered a bias to the system. This is then to be subtracted, so the system only computes on the actual data, rather than the wind-biased data.

Combined Kalman filter with test inputs:

Below is a simulation of a walk around the parking lot, with the IMU and the GPS used as reference for the ship (no bias, as the ship doesn't drift when running on wheels!).

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