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```
%   This MATLAB code simulates the YildizNav system, which integrates an
%   inertial navigation system (INS) with a VOR/DME system.
%   INS data is collected from inertial measurement unit (IMU)
%   sensors, Very high frequency omni-directional range / distance measuring
%   equipment (VOR/DME) data is simulated based on GNSS measurements.

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%
%   This project is inspired by the "NaveGo" INS/GNSS project.
%
%   Specially thanks to our academic advisor, Dr. "BAHADIR ÇATALBAŞ".
%
%
%
%   Copyright (C) 2014, Rodrigo Gonzalez, all rights reserved.
%
%   This file is part of YildizNav, an open-source MATLAB toolbox for
%   simulation of integrated navigation systems.
%
%   YildizNav is free software: you can redistribute it and/or modify
%   it under the terms of the GNU Lesser General Public License (LGPL)
%   version 3 as published by the Free Software Foundation.
%
%   This program is distributed in the hope that it will be useful,
%   but WITHOUT ANY WARRANTY; without even the implied warranty of
%   MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
%   GNU Lesser General Public License for more details.
```

```
%
%   You should have received a copy of the GNU Lesser General Public
%   License along with this program. If not, see
%   <http://www.gnu.org/licenses/>.
%
%
%   Modifications by Yavuz Hanege <hanegeyavuz@gmail.com>
%   Modifications by Mehmet Emre Eyvaz <mehmetemre.eyvaz@gmail.com>
%   Modifications by Kerem Vatansever <keremvatansver@gmail.com>
%   Date: 05.2024


clc; % Clear command window
clear; % Clear workspace
close all; % Close all figure windows
matlabrc; % Reload MATLAB startup options
format long; % Set double-precision format

% Paths to YildizNav functions
addpath C:\Users\yhane\Desktop\Yildiz_Localization_INS_GNSS\ins
addpath C:\Users\yhane\Desktop\Yildiz_Localization_INS_GNSS\ins-gnss
addpath C:\Users\yhane\Desktop\Yildiz_Localization_INS_GNSS\conversions
addpath C:\Users\yhane\Desktop\Yildiz_Localization_INS_GNSS\performance-
analysis
addpath C:\Users\yhane\Desktop\Yildiz_Localization_INS_GNSS\plot
addpath C:\Users\yhane\Desktop\Yildiz_Localization_INS_GNSS\allan-variance
addpath C:\Users\yhane\Desktop\Yildiz_Localization_INS_GNSS\Radio-Navigation
```

CODE EXECUTION PARAMETERS

```
INS_VOR_DME    = 'ON';
PLOT        = 'ON';

% Check if variables exist, otherwise set default values
if (~exist('INS_VOR_DME', 'var'))
    INS_VOR_DME = 'OFF';
end
if (~exist('PLOT', 'var'))
    PLOT = 'OFF';
end
```

CONSTANTS

```
G =  9.80665;       % Gravity constant, m/s^2
D2R = (pi/180);     % Degrees to radians
R2D = (180/pi);     % Radians to degrees
G2T = 1E-4;         % Gauss to Tesla
normalize_angle = @(angle) mod(angle + 360, 720) - 360; % Normalize Function
```

TIME INTERVAL

```
tmin = 0;      % VOR/DME first time
tmax = 400 ;    % VOR/DME last time
```

REFERENCE

```
load ref_zedf9p.mat
ref_data = struct2table(ref_data);

% ref data structure
ref.lat = ref_data.Latitude;
ref.lon = ref_data.Longitude;
ref.t = double(ref_data.Time);
ref.h = ref_data.Altitude;
% Serveral fields are missing: roll, pitch, yaw,vel etc.
```

IMU DATA

```
load imu_xsense_delivers.mat
imu_data = struct2table(imu_data);

% IMU data structure
imu.t = double(imu_data.Time);
imu.fb = [imu_data.Ax imu_data.Ay imu_data.Az ] ;
imu.wb = [imu_data.Gx imu_data.Gy imu_data.Gz ] ;


% IMU frequency
imu.freq = get_freq(imu.t);
```

IMU RAW ORIENTATION

```
fs = 100;
decim = 1;
% IMU frequency
% imu.freq = get_freq(imu.t);

fuse = imufilter('SampleRate',fs,'DecimationFactor',decim);
q = fuse(imu.fb,imu.wb);
[yaw_gyro, pitch_gyro, roll_gyro] = quat2angle(q);

time = (0:decim:size(imu.fb,1)-1)/fs;
```

GNSS DATA

```
load zedf9p_gnss_delivers.mat
load gnss_vel_data_delivers.mat

gnss_data = struct2table(gnss_data);
```

```
gnss_vel_data = struct2table(gnss_vel_data);


% GNSS data structure
gnss.t = double(gnss_data.Time);
gnss.lat = gnss_data.Latitude;
gnss.lon = gnss_data.Longitude;
gnss.h = double(gnss_data.Altitude);
gnss.vel = [ gnss_vel_data.Velx gnss_vel_data.Vely gnss_vel_data.Velz] ;

% GNSS frequency
gnss.freq = get_freq(gnss.t);
```

VOR-DME INIT

```
stat.lat = 41.126954;
stat.lon = 29.142890;
vor_dme.h = double(gnss_data.Altitude);
% VOR/DME Velocity Calculation is not effective when using simulated data
vor_dme.vel = [ gnss_vel_data.Velx gnss_vel_data.Vely gnss_vel_data.Velz] ;
vor_dme.t = gnss.t;
```

DISTANCE CALCULATION(m)

Distance data from DME station

```
vor_dme.distance = dme_dist(gnss,stat);
```

BEARING CALCULATION(Deg)

Bearing data from VOR Station

```
vor_dme.bearing = vor_bearing(gnss,stat);
```

VEHICLE POSITION CALCULATE

Combining VOR and DME systems

```
[vor_dme.lat, vor_dme.lon] = radio_navigation_position(vor_dme,stat);
```

DEG TO RAD CONVERSIONS

```
ref.lat = ref.lat * D2R;
ref.lon = ref.lon * D2R;

gnss.lat = gnss.lat * D2R;
gnss.lon = gnss.lon * D2R;

vor_dme.lat = vor_dme.lat * D2R;
vor_dme.lon = vor_dme.lon * D2R;
```

IMU ERROR PROFILE

Error profile from Allan variance

```
% Apply to system just one time for taking error profile

% imu_allan = allan_imu(imu);
%
imu.ini_align = [ -9.9864e-05 0.0103 0.2256 ];
imu.ini_align_err = [0.5 0.5 1.5] * D2R;
imu.vrw = [0.357052112936883,0.961774519858292,0.097937677583613];
imu.arw = [0.042121868141229,0.009525679451282,0.215964553168146];
imu.vrrw = [4.690958161815616,0.025017042332123,8.151900100864590];
imu.arrw = [0.365296716563698,0.652790283467330,0.332242479057422];
imu.ab_dyn = [0.317843621047626,0.269877573663284,0.043008085334205];
imu.gb_dyn = [0.119085569975979,0.183160823036258,0.119983749586203];
imu.ab_corr = [8.658268346330733,1.489702059588082,14.137172565486901];
imu.gb_corr = [0.209958008398320,0.129974005198960,4.809038192361528];
imu.ab_psd = [0.935252807786899,0.329394623420481,0.161707956271642];
imu.gb_psd = [0.054566407491244,0.066032970944379,0.263118595909555];
imu.ab_sta = [70e-06 70e-06 70e-06];
imu.gb_sta = [0.00166667 0.00166667 0.00166667];
```

VOR/DME ERROR PROFILE

```
vor_dme.stdm = [0.01 0.001 0.01]; % Standart Deviation Position Error
vor_dme.stdv = ones(1,3) .* 0.1 ; % Standart Deviation Velocity Error
vor_dme.zupt_th  = 0.1;        % ZUPT threshold (m/s).
vor_dme.zupt_win = 2;          % ZUPT time window (seconds)
vor_dme.eps = mean(diff(imu.t)) / 2;  % Time Interval
vor_dme = gnss_m2r(vor_dme.lat(1), vor_dme.h(1), vor_dme);
vor_dme.larm = [0 0.03974 0.00851]'; % Same Larm with GNSS
```

NAVIGATION TIME

```
to = (gnss.t(end) - gnss.t(1));

fprintf('YildizNav: navigation time is %.2f minutes or %.2f seconds. \n',
(to/60), to)
```

YildizNav: navigation time is 6.67 minutes or 400.00 seconds.

TRAVELED DISTANCE

```
distance = gnss_distance (gnss.lat, gnss.lon);

fprintf('YildizNav: distance traveled by the vehicle is %.2f meters or %.2f
km. \n', distance, distance/1000)
```

YildizNav: distance traveled by the vehicle is 645.97 meters or 0.65 km.

INS/VOR/DME INTEGRATION

```
if strcmp(INS_VOR_DME, 'ON')

    % Execute INS/VOR/DME integration
    %
-----------------------------------------------------------------------
    fprintf('YildizNav: INS/VOR/DME integration... \n')
    yildiz_nav = ins_vor_dme(imu, vor_dme, 'quaternion');
    % -----------------------------------------------------------------------

    save yildiz_nav yildiz_nav
else

    load yildiz_nav
end


% Referance Orientation is not provided by RTK. Equations for init
% orientation of ref structure.

ref.yaw = yildiz_nav.yaw;
ref.roll = yildiz_nav.roll;
ref.pitch = yildiz_nav.pitch;
```

```
YildizNav: INS/VOR/DME integration...
. . . .
```

INTERPOLATION OF INS/VOR/DME DATASET

```
% INS/VOR/DME estimates and GNSS data are interpolated according to the
% reference dataset.

[nav_i,  ref_n] = interpolation (yildiz_nav, ref);
[gnss_i, ref_g] = interpolation (gnss, ref);
```

```
Yildiz_NAV_interpolation: nearest method to interpolate INS/VOR/DME solution
Yildiz_NAV_interpolation: spline method to interpolate GNSS-only solution
```

NAVIGATION RMSE

RMS Calculation

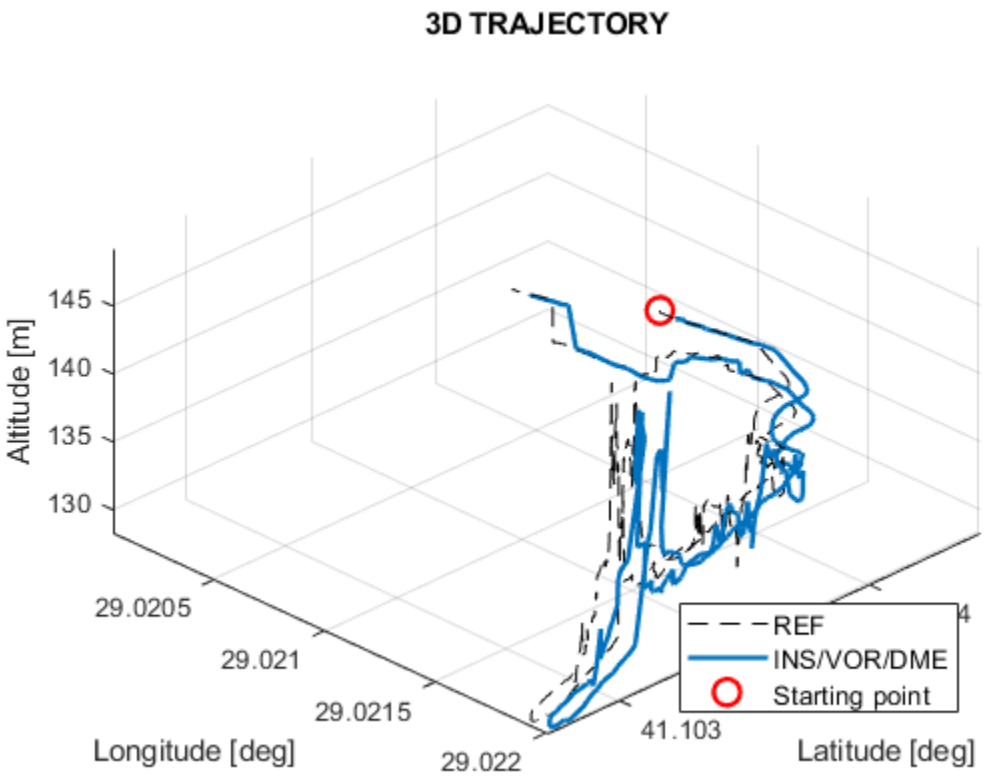
```
rmse_v = print_rmse (nav_i, gnss_i, ref_n, ref_g, 'Inertial Sense INS/VOR/
DME');
```

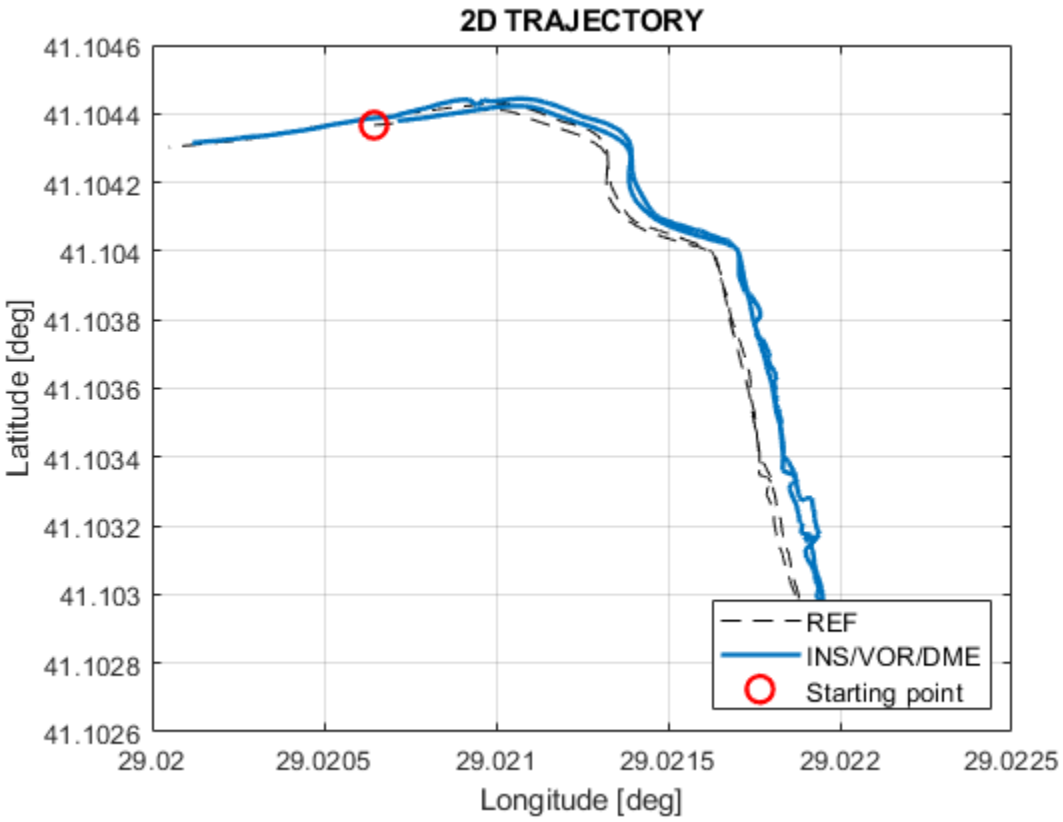
```
print_rmse: RMSE for Inertial Sense INS/VOR/DME

 Latitude,  Inertial Sense INS/VOR/DME = 1.7812e+00 m, GNSS = 8.3875e-01 m
 Longitude, Inertial Sense INS/VOR/DME = 5.8375e+00 m, GNSS = 6.6422e-01 m
 Altitude,  Inertial Sense INS/VOR/DME = 6.5690e-01 m, GNSS = 6.5608e-01 m
```

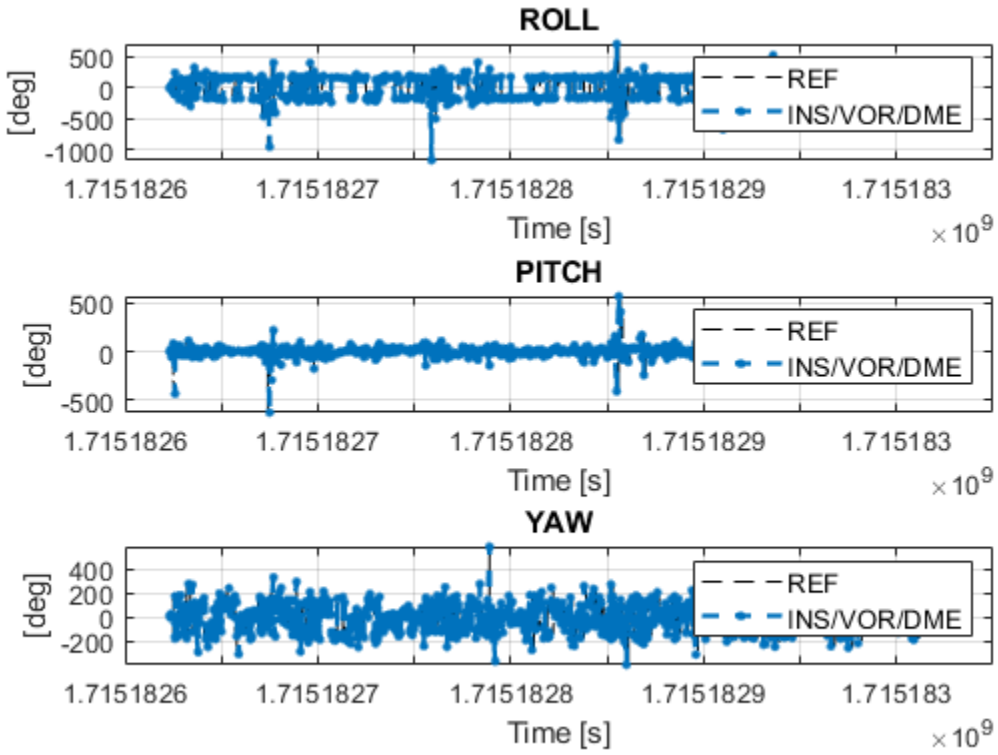
PLOTS

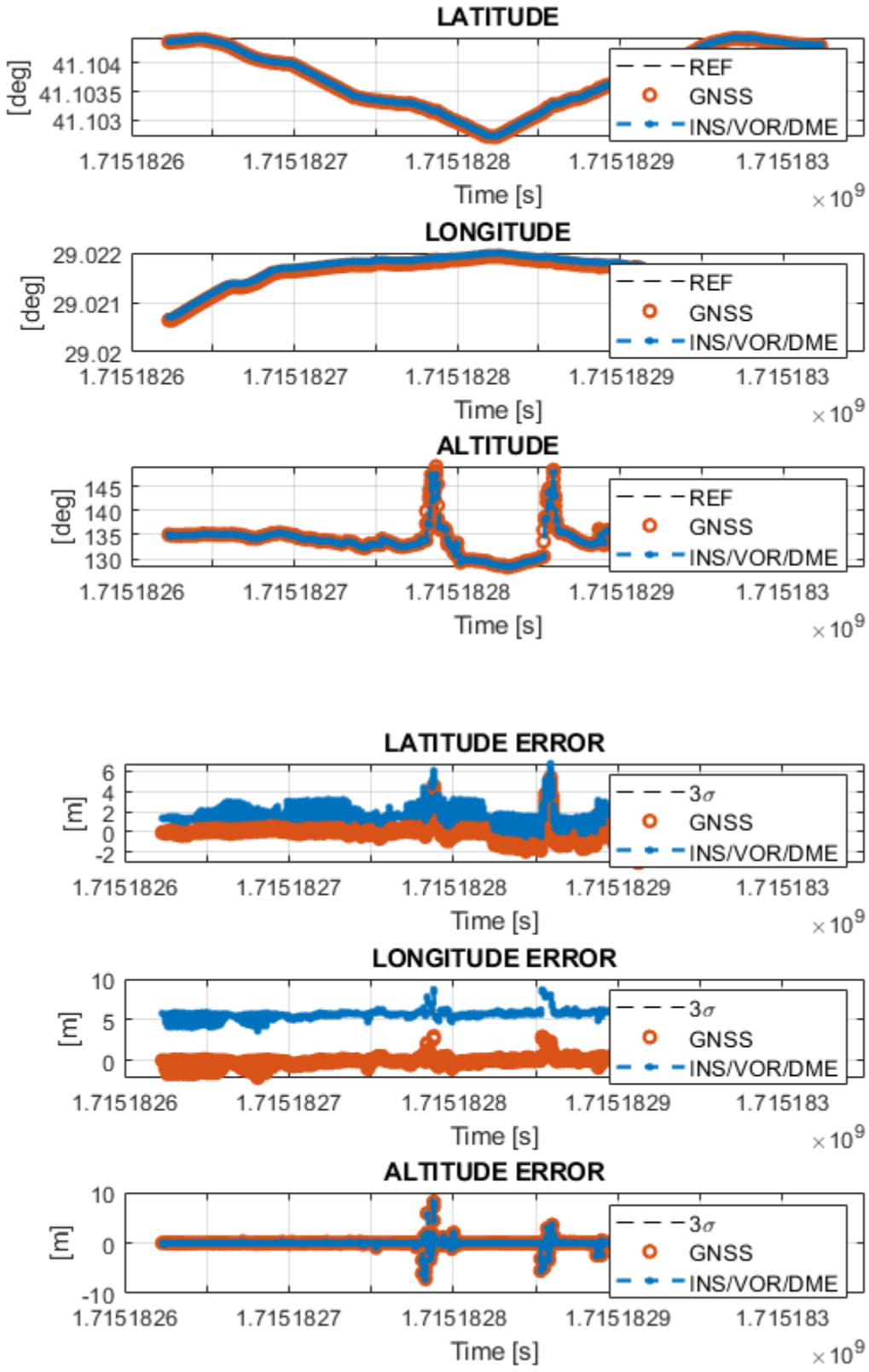
```
if (strcmp(PLOT,'ON'))

    % Main Plot Sequence
    plot_main (ref, gnss, yildiz_nav, gnss_i, nav_i, ref_g, ref_n);

    % Plot for compare gyro and INS/VOR/DME Outputs
    roll_nav = normalize_angle(yildiz_nav.roll * R2D);
    pitch_nav = normalize_angle(yildiz_nav.pitch * R2D);
    yaw_nav = normalize_angle(yildiz_nav.yaw * R2D);

    roll_gyro = (roll_gyro * R2D);
    pitch_gyro = (pitch_gyro * R2D);
    yaw_gyro = (yaw_gyro * R2D);


    % Raw imu sensor orientation
    figure;
    plot(time,[yaw_gyro,pitch_gyro,roll_gyro])
    title('Raw IMU Orientation Estimate')
    legend('Z-axis', 'Y-axis', 'X-axis')
    xlabel('Time (s)')
    ylabel('Rotation (degrees)')
    ylim([-360 360]);


    % Comparison Sequence
    figure;
    subplot(3,1,1);
    plot(time, roll_nav, 'b', time, roll_gyro, 'r');
    xlabel('Time (s)');
    ylabel('Roll (Deg)');
    legend('INS/GNSS', 'Gyro');
    title('Roll');
    ylim([-360 360]);

    subplot(3,1,2);
    plot(time, pitch_nav, 'b', time, pitch_gyro, 'r');
    xlabel('Time (s)');
    ylabel('Pitch (Deg)');
    legend('INS/GNSS', 'Gyro');
    title('Pitch');
    ylim([-360 360]);

    subplot(3,1,3);
    plot(time, yaw_nav, 'b', time, yaw_gyro, 'r');
    xlabel('Time (s)');
    ylabel('Yaw (Deg)');
    legend('INS/GNSS', 'Gyro');
    title('Yaw');
    ylim([-360 360]);
```

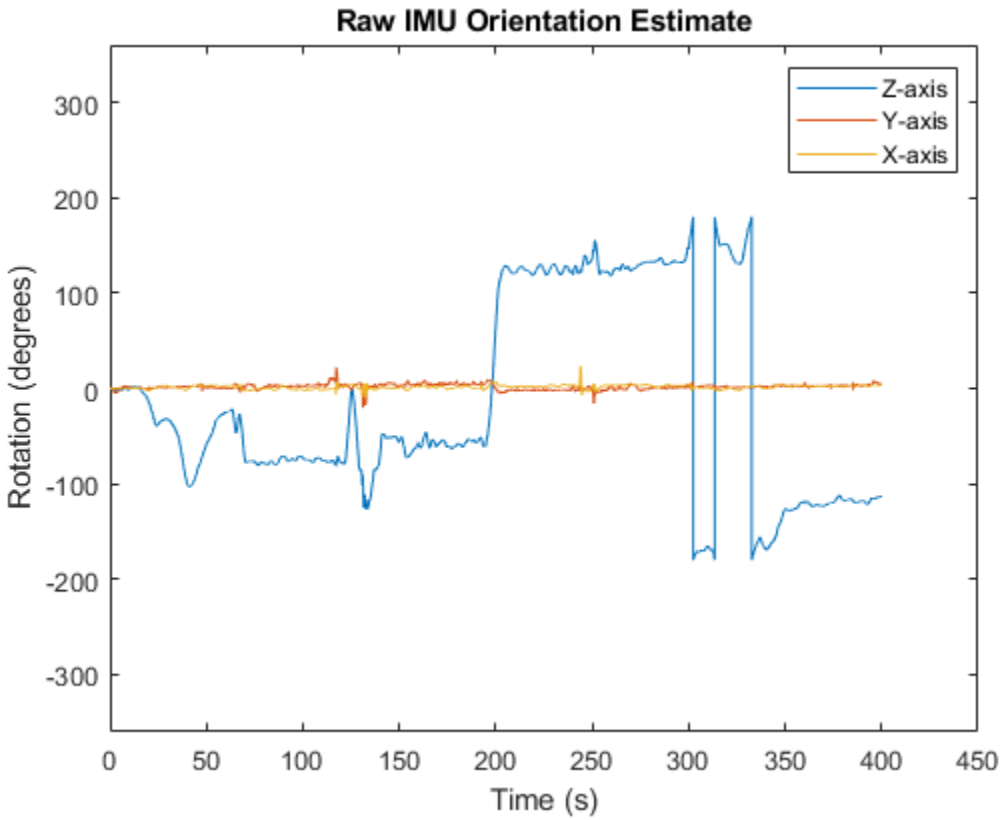
```
end
```

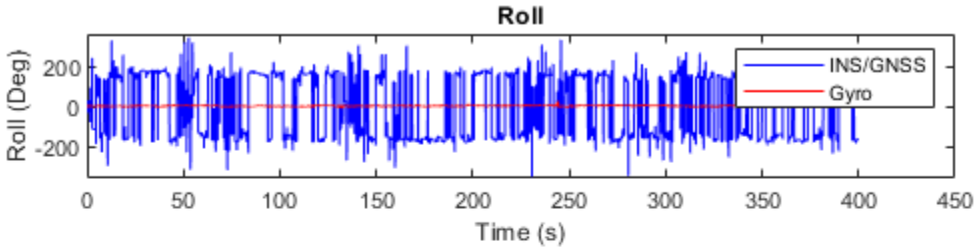

3D TRAJECTORY
Altitude [m]
145
140
135
130
29.0205
29.021
29.0215
29.022
Longitude [deg]
41.103
Latitude [deg]
REF
INS/VOR/DME
Starting point

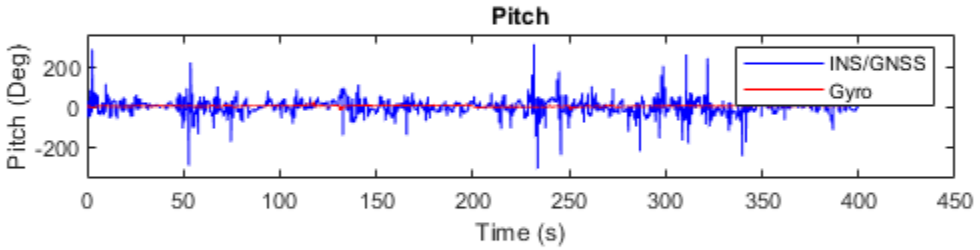

2D TRAJECTORY
41.1046
41.1044
41.1042
41.104
41.1038
41.1036
41.1034
41.1032
41.103
41.1028
41.1026
Latitude [deg]
29.02
29.0205
29.021
29.0215
29.022
29.0225
Longitude [deg]
REF
INS/VOR/DME
Starting point

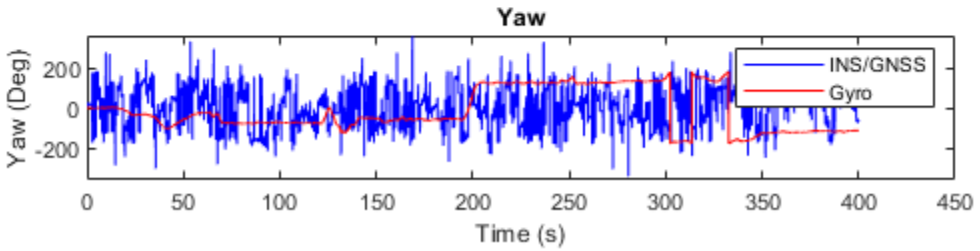

ROLL
500
0
-500
-1000
[deg]
1.7151826
1.7151827
1.7151828
1.7151829
1.715183
Time [s]
×10^9
REF
INS/VOR/DME
PITCH
500
0
-500
[deg]
1.7151826
1.7151827
1.7151828
1.7151829
1.715183
Time [s]
×10^9
REF
INS/VOR/DME
YAW
400
200
0
-200
[deg]
1.7151826
1.7151827
1.7151828
1.7151829
1.715183
Time [s]
×10^9
REF
INS/VOR/DME


LATITUDE
[deg]
41.104
41.1035
41.103
REF
GNSS
INS/VOR/DME
1.7151826
1.7151827
1.7151828
1.7151829
1.715183
Time [s]
×10^9
LONGITUDE
[deg]
29.022
29.021
29.02
REF
GNSS
INS/VOR/DME
1.7151826
1.7151827
1.7151828
1.7151829
1.715183
Time [s]
×10^9
ALTITUDE
[deg]
145
140
135
130
REF
GNSS
INS/VOR/DME
1.7151826
1.7151827
1.7151828
1.7151829
1.715183
Time [s]
×10^9
LATITUDE ERROR
[m]
6
4
2
0
-2
3σ
GNSS
INS/VOR/DME
1.7151826
1.7151827
1.7151828
1.7151829
1.715183
Time [s]
×10^9
LONGITUDE ERROR
[m]
10
5
0
3σ
GNSS
INS/VOR/DME
1.7151826
1.7151827
1.7151828
1.7151829
1.715183
Time [s]
×10^9
ALTITUDE ERROR
[m]
10
0
-10
3σ
GNSS
INS/VOR/DME
1.7151826
1.7151827
1.7151828
1.7151829
1.715183
Time [s]
×10^9


Raw IMU Orientation Estimate
Z-axis
Y-axis
X-axis
Rotation (degrees)
300
200
100
0
-100
-200
-300
0
50
100
150
200
250
300
350
400
450
Time (s)


Roll
INS/GNSS
Gyro
Roll (Deg)
200
0
-200
0
50
100
150
200
250
300
350
400
450
Time (s)


Pitch
INS/GNSS
Gyro
Pitch (Deg)
200
0
-200
0
50
100
150
200
250
300
350
400
450
Time (s)


Yaw
INS/GNSS
Gyro
Yaw (Deg)
200
0
-200
0
50
100
150
200
250
300
350
400
450
Time (s)

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