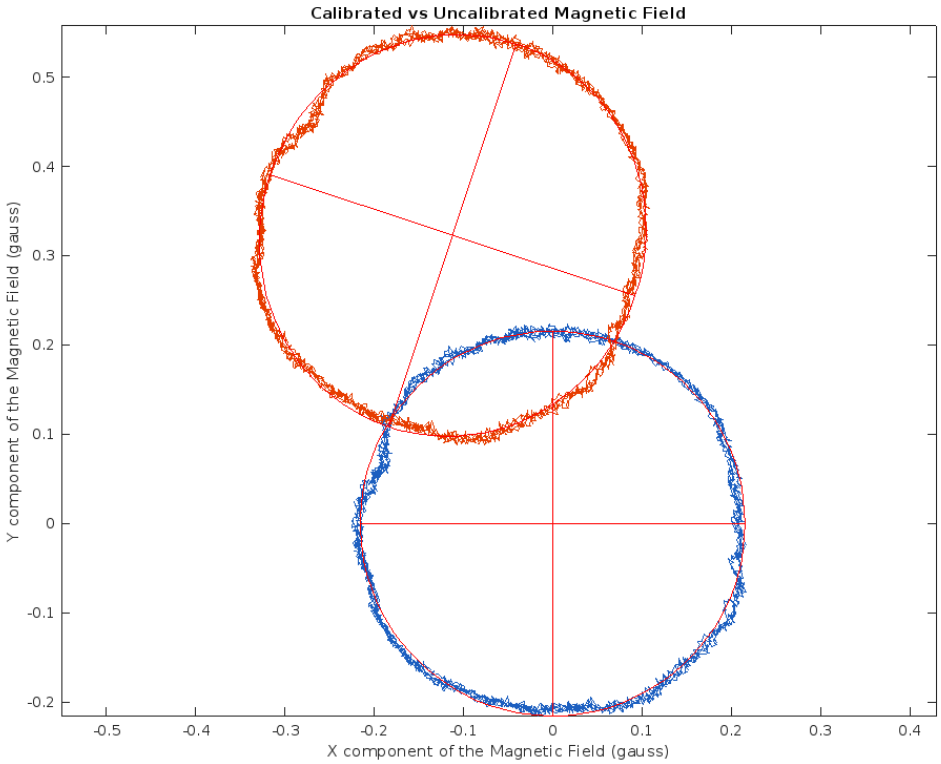
LAB4 NAVIGATION WITH IMU AND MAGNETOMETER

KAUSHAL SORTE **NUID : 002769107**

HEADING ESTIMATION

<u>Magnetic Calibration</u>

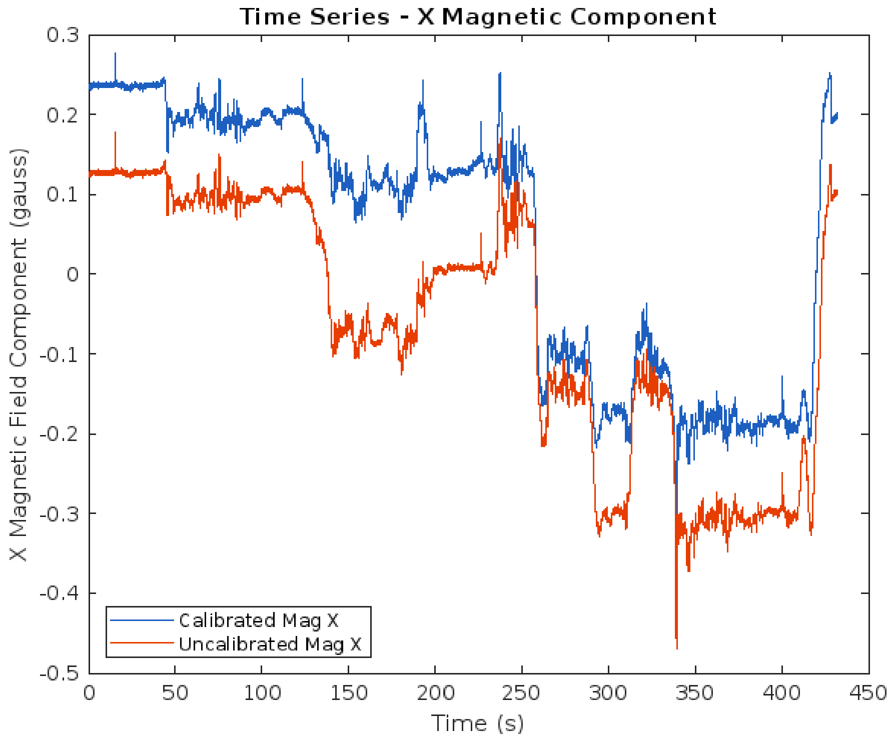


Red : Uncalibrated Magnetic Field

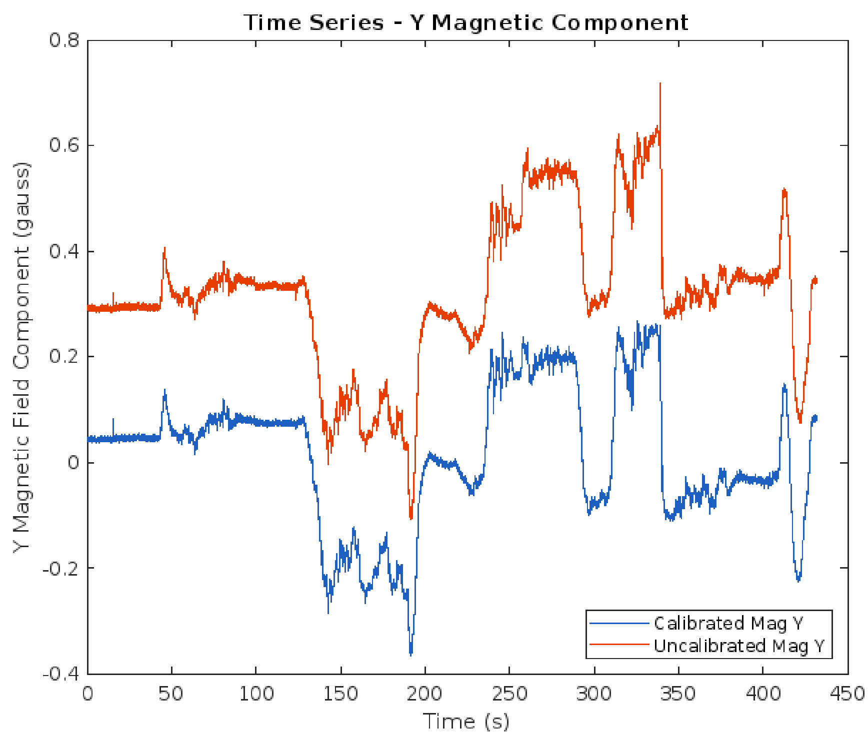
Blue : Calibrated Magnetic Field

Firstly, an ellipse was fit to the magnetometer readings, the center of which was not observed to be the origin. This offset is reflective of the hard iron distortion caused my magnetic materials around the module. After visual inspection, the shape of the magnetic data is found to be nearly circular, which indicates only a meager effect of the soft iron distortion.

The offset was first nullified by bringing the ellipse to the origin. Then the inclination of the ellipse was used to rotate it so that the diameters of the ellipse conform to the x and the y axis. Then the major axis of the ellipse (which was along y) was squished by the ratio (minor axis/major axis) to turn it into a circle. The combined transformation matrix for the rotation followed by the squishing along with the bias was stored and used for calibrating the driving magnetometer data. The below plots show the calibrated and uncalibrated magnetometer data from the driving.



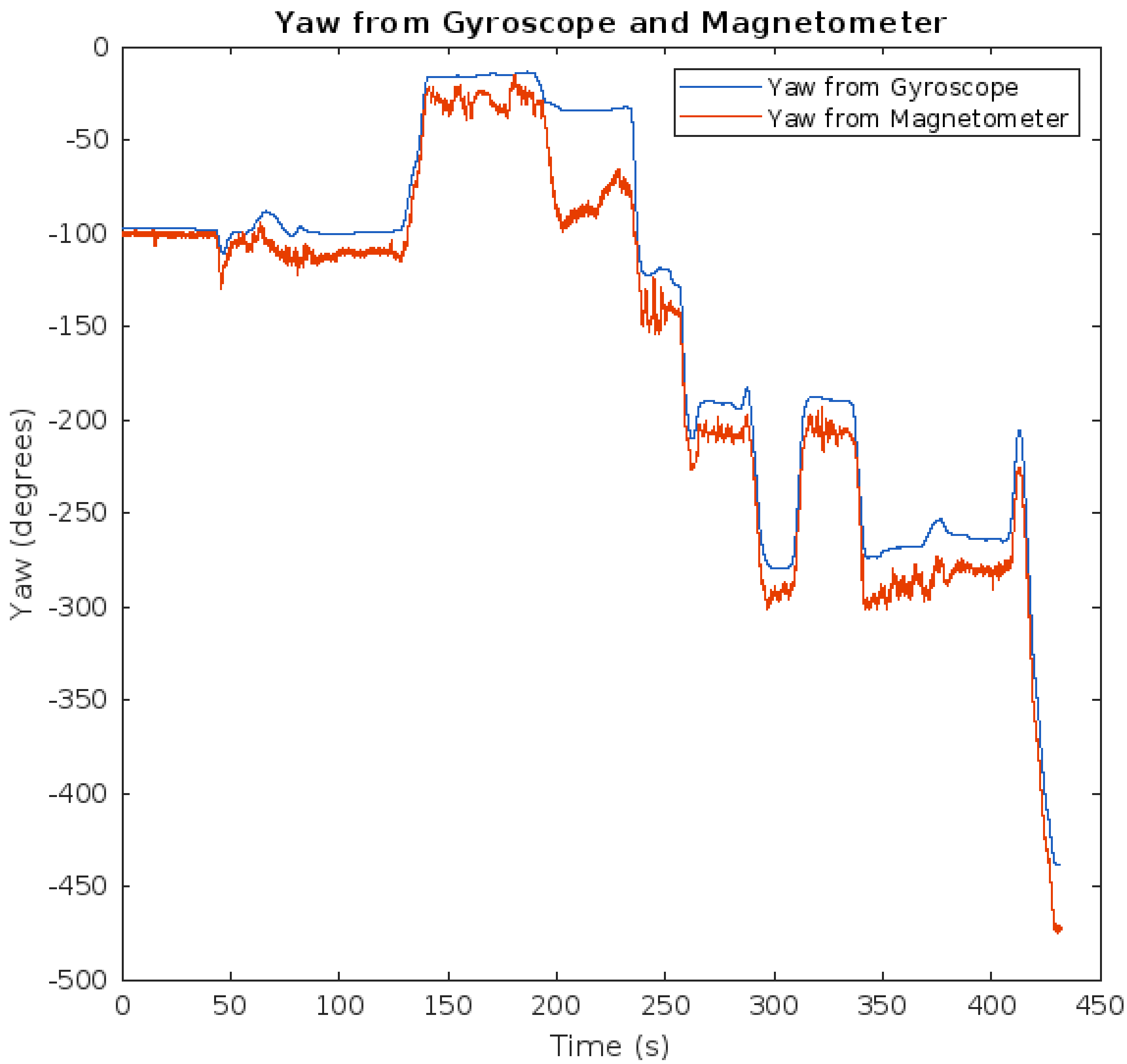
Time Series - X Magnetic Component
X Magnetic Field Component (gauss)
Time (s)
Calibrated Mag X
Uncalibrated Mag X
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
50
100
150
200
250
300
350
400
450

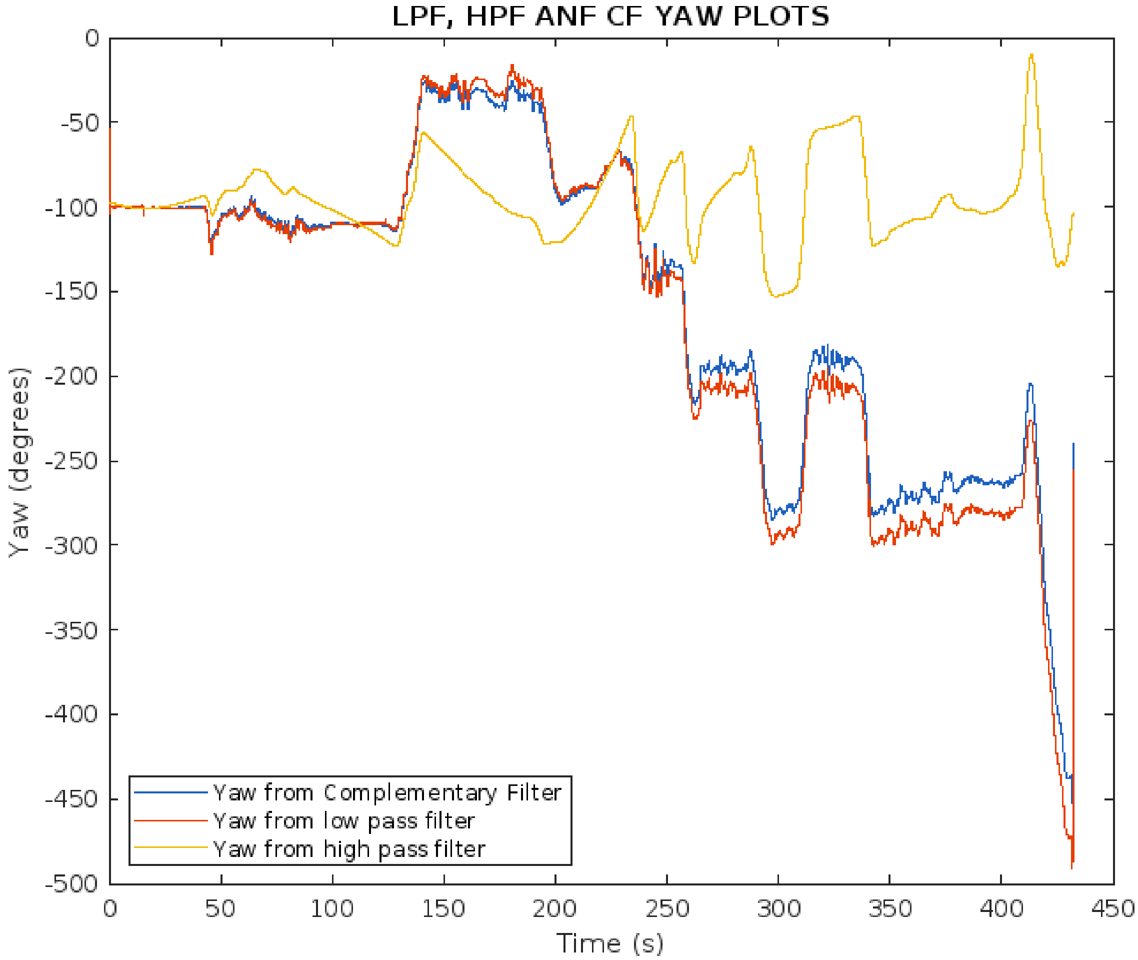


Time Series - Y Magnetic Component
Y Magnetic Field Component (gauss)
Time (s)
Calibrated Mag Y
Uncalibrated Mag Y
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
50
100
150
200
250
300
350
400
450

Sensor Fusion

A complementary filter is the weighted average of the high pass filtered gyroscope yaw and the low pass filtered magnetometer yaw.



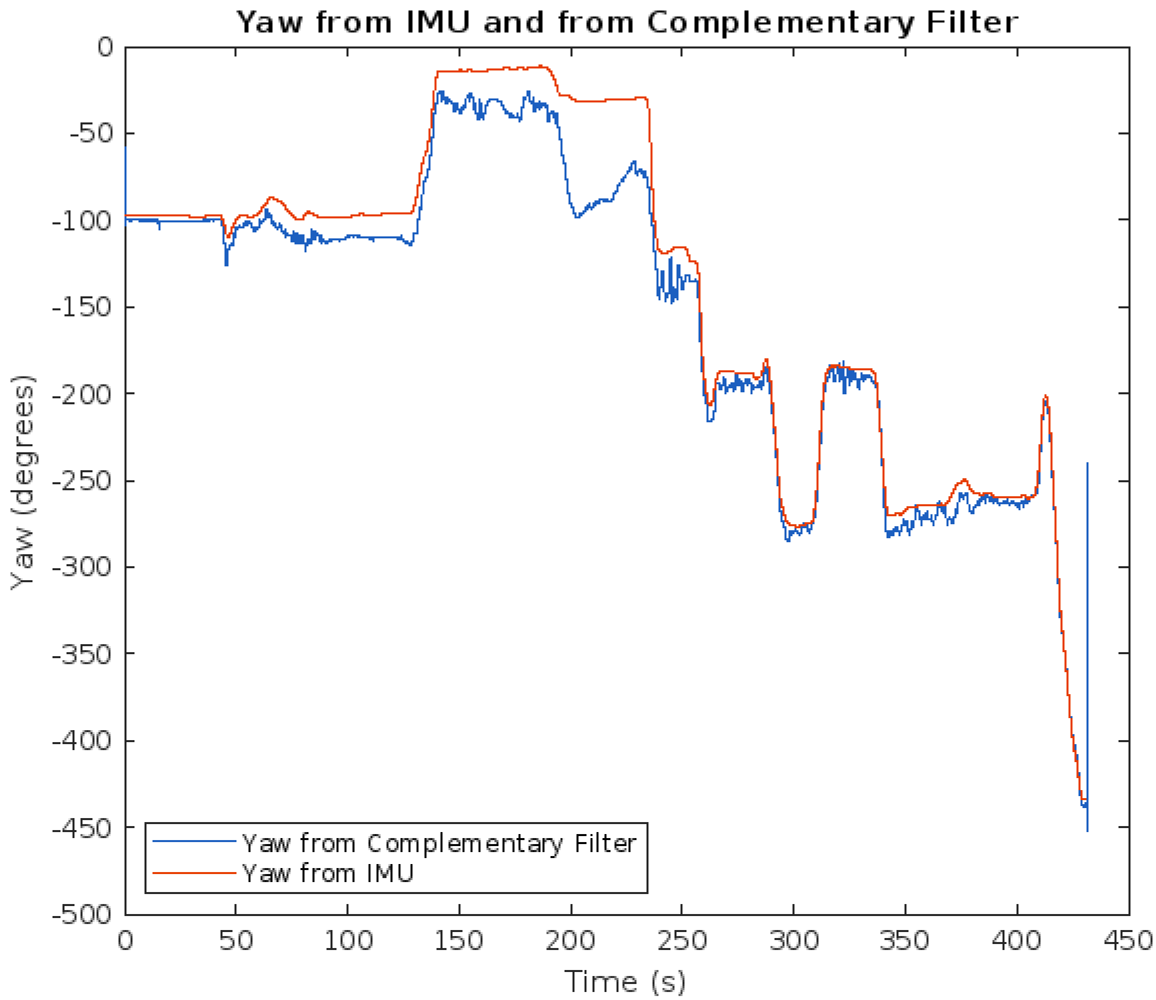


Cut-off frequency for high pass filter = 0.01 Hz
This cut-off frequency duly removed the low frequency undulations of the plot leaving only the short term changes.

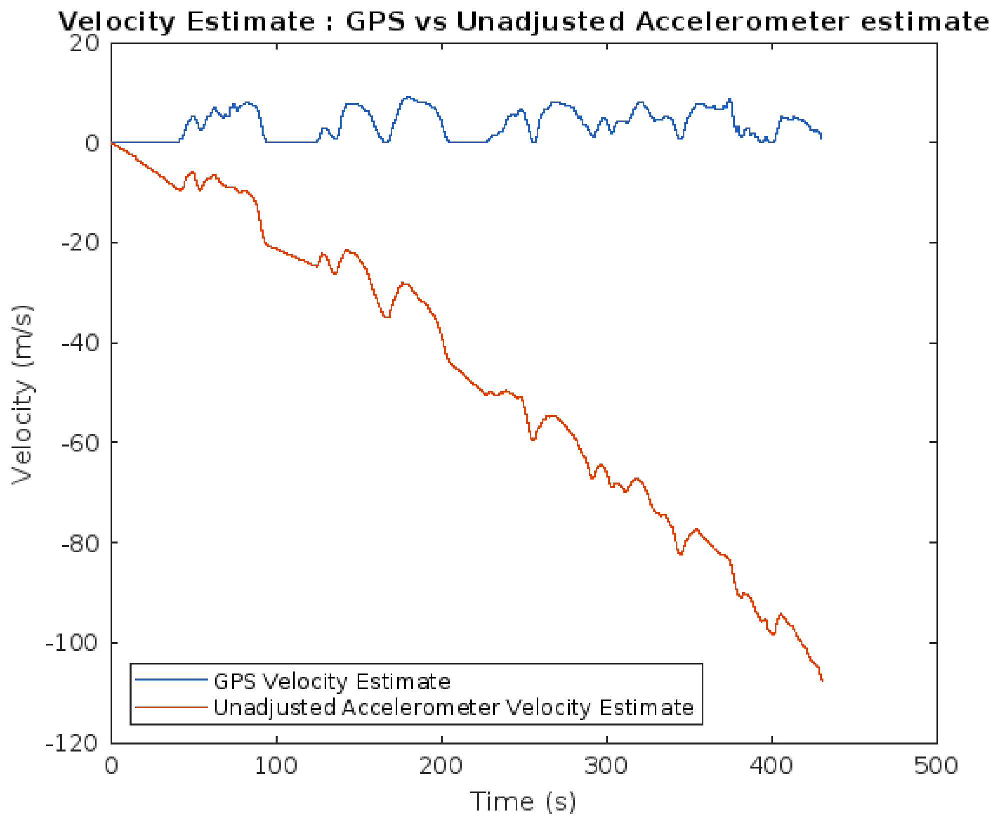
Cut-off frequency for low pass filter = 0.00001 Hz
This cut-off frequency smoothed out the noise that the magnetometer is susceptible to, especially during situations such as sharp turns.

Thus, with these filters, the long term issues with the gyroscope data and the short term noise in the magnetometer data were mitigated. They were combined in the complementary with a weighing factor of 0.1 for gyroscope yaw and 0.9 for magnetometer yaw.

The yaw estimated by the complementary filter is trusted by me for navigation. It closely follows the magnetometer yaw estimate, but is augmented by the relatively noise-free readings from the gyroscope.


Yaw from IMU and from Complementary Filter
Yaw (degrees)
Time (s)
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
-500
0
50
100
150
200
250
300
350
400
450
Yaw from Complementary Filter
Yaw from IMU

FORWARD VELOCITY ESTIMATE



The blue plot is the GPS forward velocity estimate which is found by central difference approximation of the UTM Easting and UTM Northing and then taking the norm of those velocities.

The red plot is found by cumulative addition of the x component of acceleration (since the x direction is the forward direction and the driving was done on fairly even roads with minimal slopes).

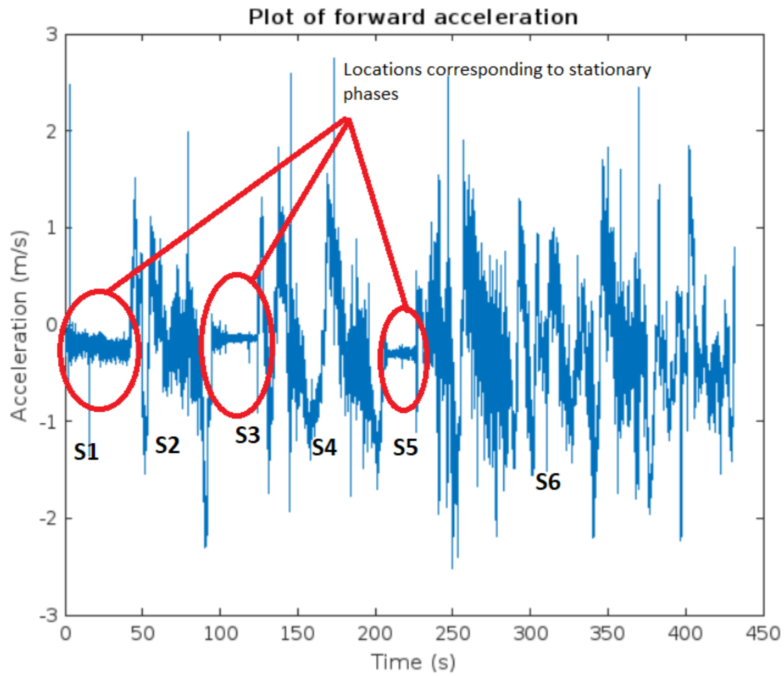
<u>Adjustments for the forward velocity estimate :</u>

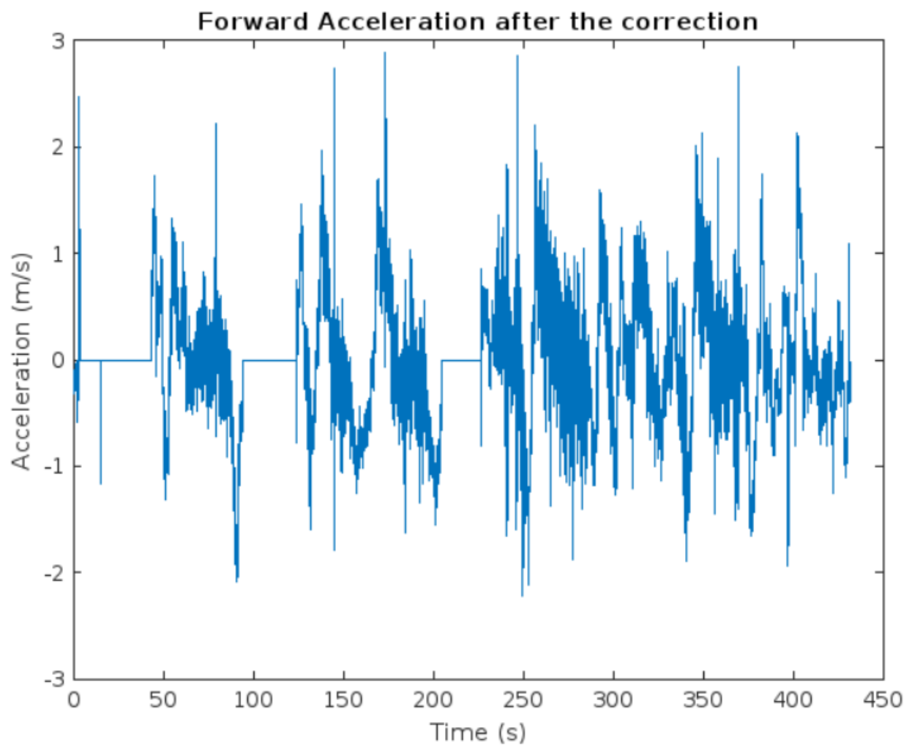
The accelerometer has a bias that shifts with time and conditions. Integration of that bias led to the red plot above to drift so far away from the GPS estimate. The car had various stationary phases during the ride, which could be used to get an approximation of the accelerometer bias at those points.

Procedure adopted for adjusting velocity forward estimate :

1) From the acceleration plot, sections were identified that correspond to the car being stationary.
2) The mean acceleration in these sections was found out since the acceleration distribution is a Gaussian as found out from the IMU Noise Characterisation.
3) These mean values were then subtracted from the succeeding non-stationary sections. This method takes into the account the bias instability of the accelerometer. Refer figure below. The mean from S1 is subtracted from S2, the mean from S3 is subtracted from

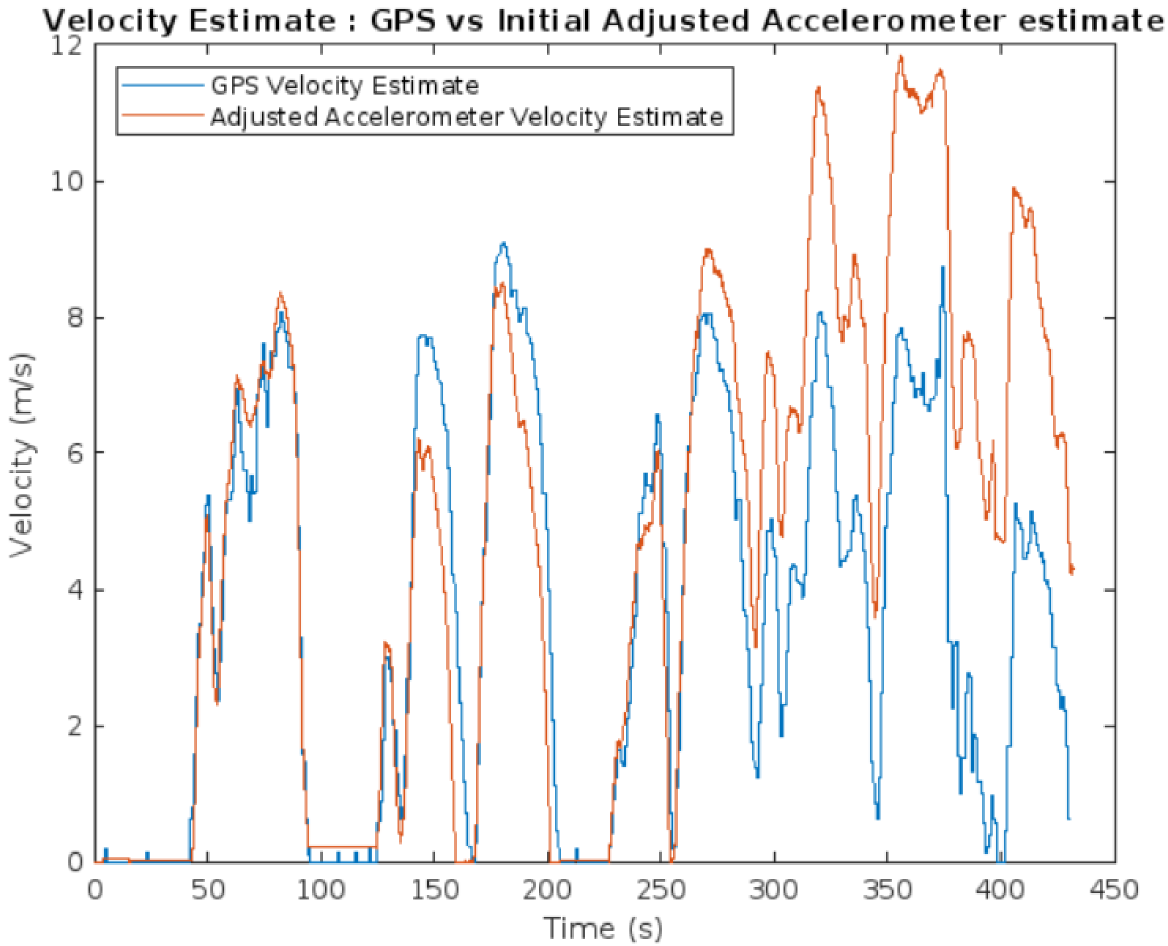
S4 and so on. The acceleration in the stationary zones is made zero to simulate stationary conditions better and to remove all bias.





4) The above acceleration was integrated to get a forward velocity estimate. The integration is a cumulative sum of the forward acceleration. A special condition is put such that if this sum falls below zero, only a zero is added, because the sum falling below zero corresponds to negative forward velocity. This small adjustment mitigates the effect of

any remaining biases or noises present in the accelerometer.

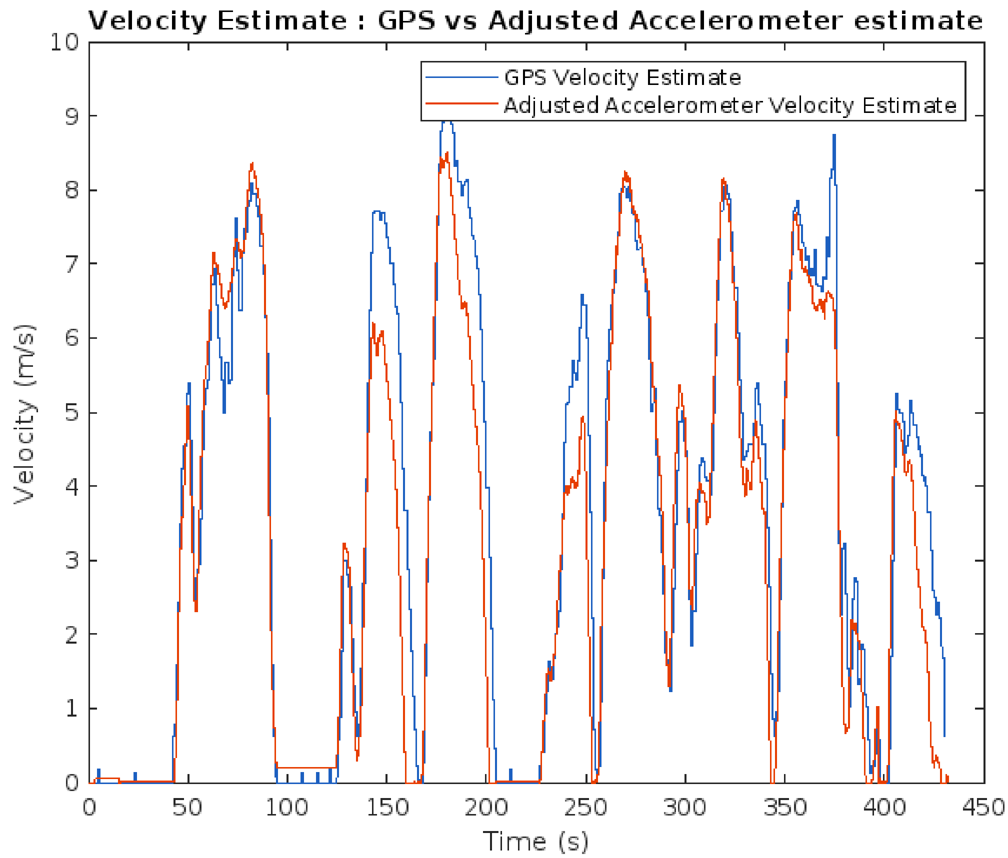


The plot follows the GPS estimate closely initially before deviating significantly in the end. The procedure detailed above has its limitations and does not remove the biases in the accelerometer as thoroughly as one would desire.

Limitations of the procedure detailed above:

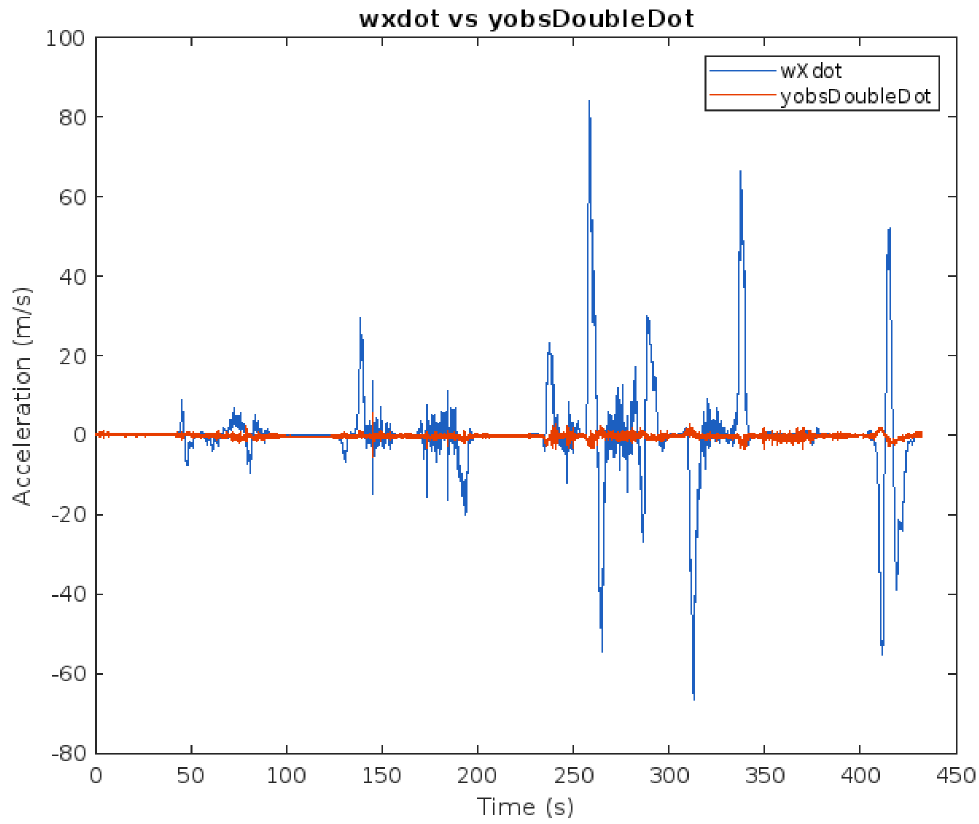
1) It does not take into account the slope of the road. The slope would result into the leaking of the gravitational acceleration into the forward direction. Even a 0.1 radian slope would result into an acceleration equivalent to ~ 1m/s2 extra in the forward direction. The magnitude of the net acceleration would be a better tool for estimating sections of stationary phases.
2) A long enough stationary reading in the beginning of the driving would have resulted in a better estimate of the bias that could be subtracted from the entire dataset. However, the car was not allowed to stand still enough in the beginning.

To take into account these factors, a bias of 0.05 m/s was manually subtracted in the last section of the forward acceleration to get the velocity plot shown below. After the adjustment, now the forward velocity estimate from the accelerometer agrees with that of the GPS estimate fairly closely. There are still places where there are differences and they would contribute to the eventual drift in the dead reckoning.

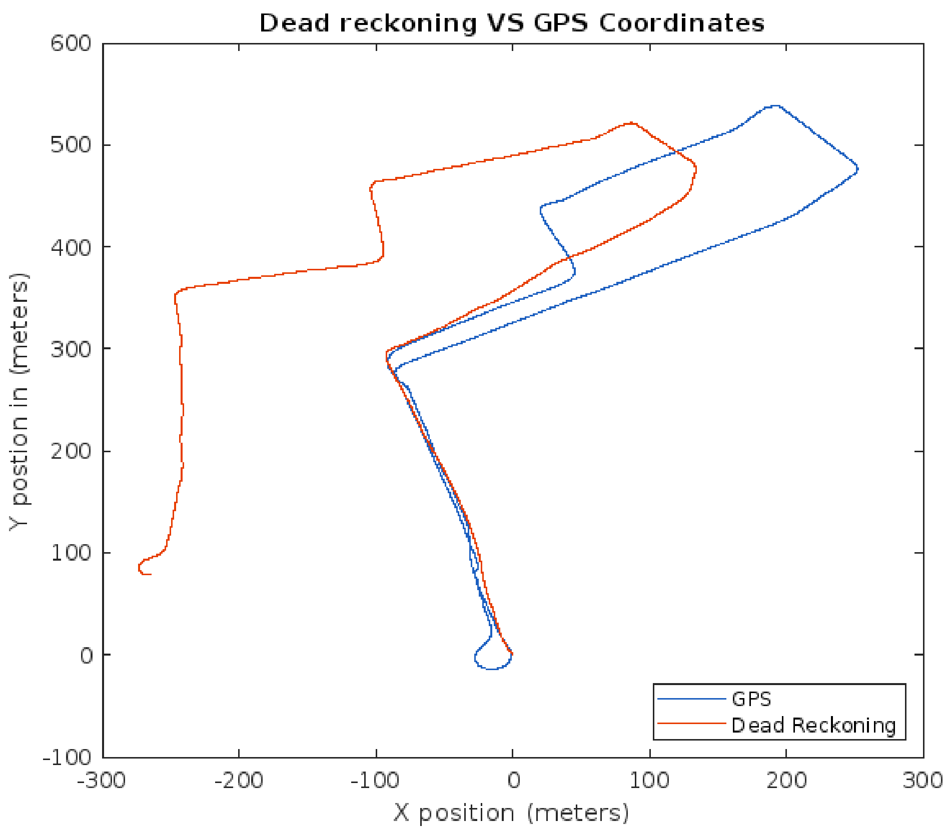


Possible reason for the discrepancy between the GPS and IMU acceleration :
It is impossible to keep the module exactly at the center of mass of the car. This offset results in the module being affected by the roll and the pitch of the car during turns and accelerations/decelerations respectively. The pitch especially would contribute to the g acceleration leaking in the forward direction, which again contributes to the bias. Also, offset between the GPS and the IMU module contributes to errors.

DEAD RECKONING



For all the analysis till now, it was assumed that the car COM acceleration is the same as the one we get from the IMU. However, that is not the case because the IMU is not exactly located at the center of mass of the car and that offset adds extra terms in the equation detailing the acceleration of the IMU.



The IMU is subject to the centrifugal term when seen from the COM frame of reference and that term is directly proportional to the displacement of the IMU module from the COM. Hence, with our current set of assumptions, one cannot get an accurate dead reckoning.

The heading is adjusted to make sure the trajectories match. The IMU position estimate matches closely (within 2 meters) with that of the GPS estimate for ~48 seconds. The accumulated error of the dead-reckoning after 10 seconds is 19.529m. The same value for the industrial grade Vectornav module is just 0.7 m.

CONCLUSIONS :

1) The heading obtained from the complementary agrees appreciably with the IMU heading. The calibration of the magnetic field was a success.
2) Acceleration from the IMU needed bias removal before it could be integrated to get velocity.
3) Dead-reckoning from IMU matches closely with GPS for nearly 48 seconds before the deviation exceeds 2m.
4) The reasons for this enormous deviations are :
    a) IMU and GPS are not coincident in position.
    b) Forward velocity estimation does not take into account the gradient of the terrain.

NOTE :
The driver for this lab is pushed through the account whose username is : shirgaonkar.a