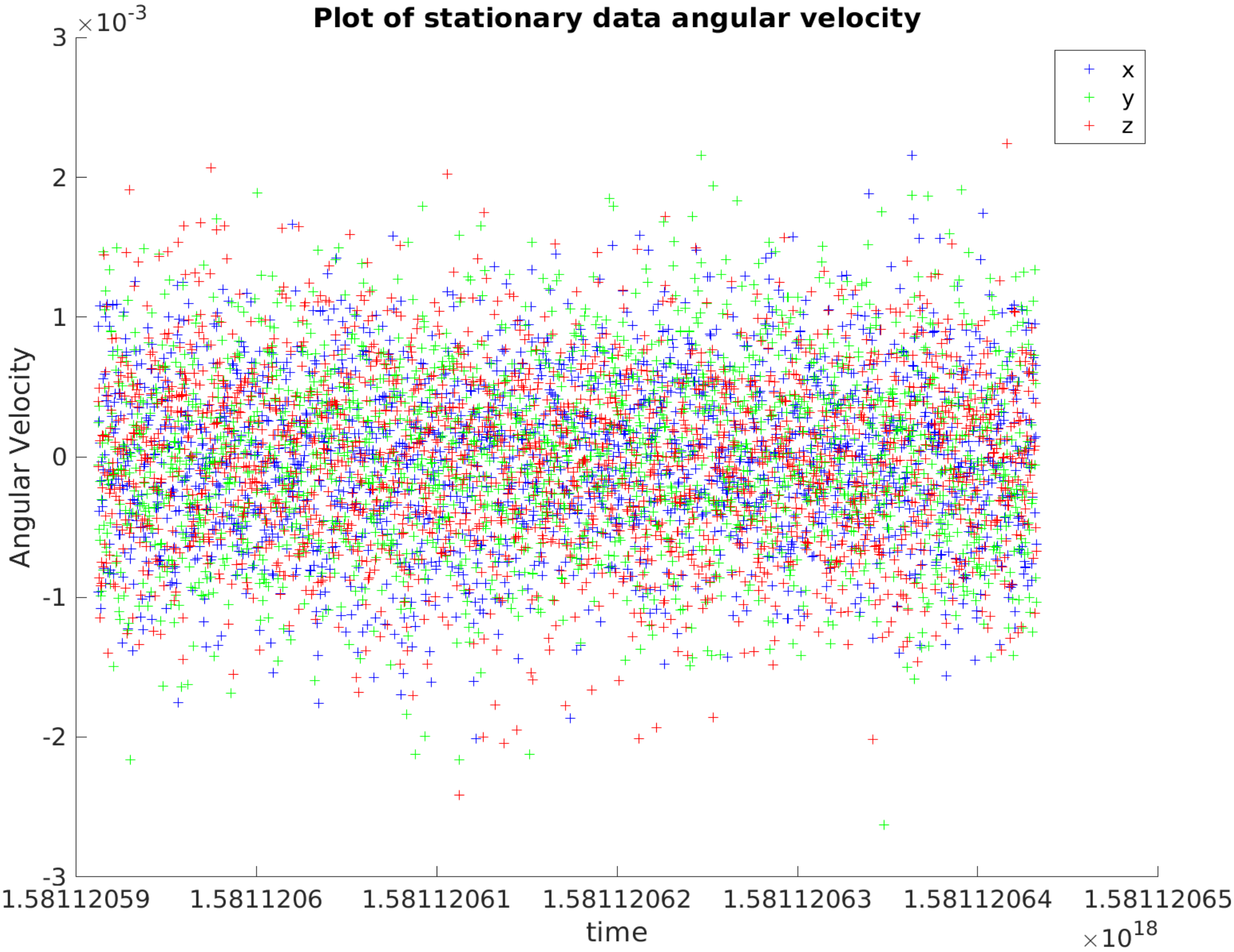
LAB 2: EECE 5554 - Robotics Sensing and Navigation

PART 1: Write a device driver for IMU

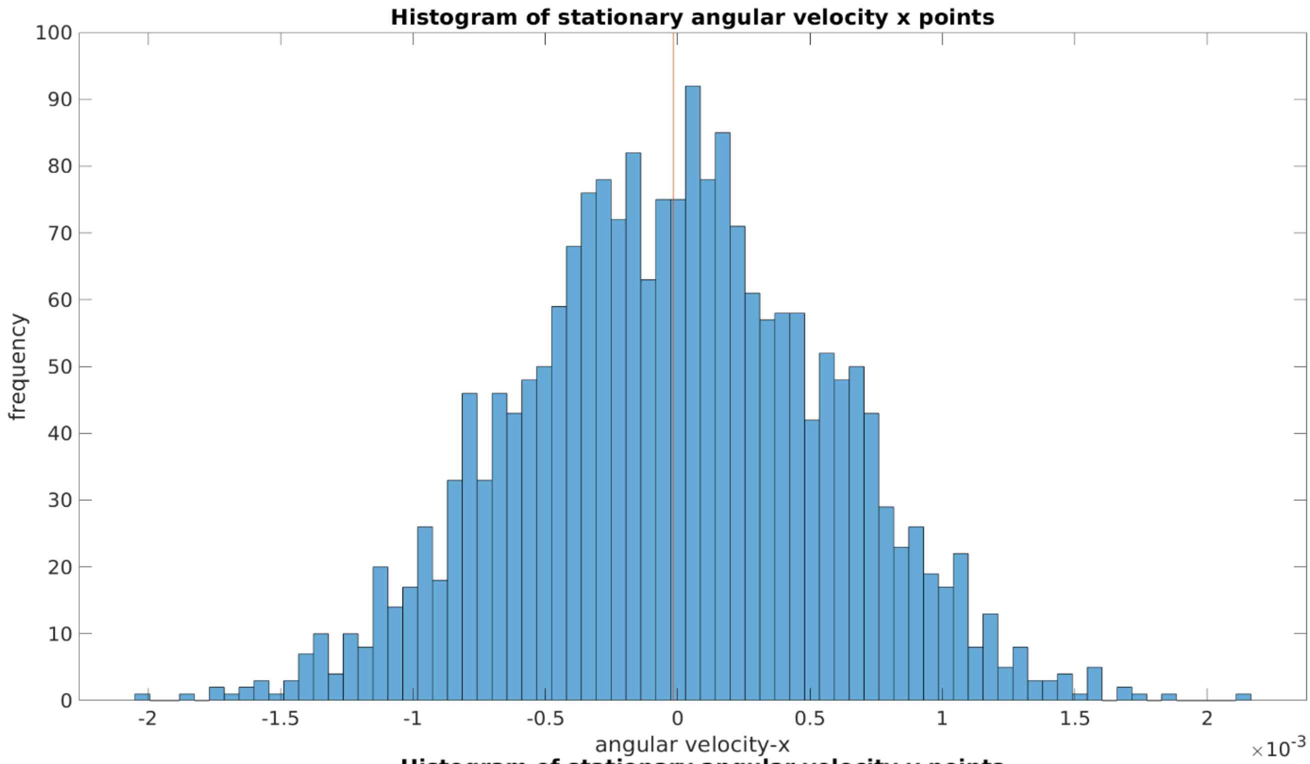
The stationary data was collected from the IMU using the device driver. A total of around 2000 points were collected. The plots of each of the parameters are shown in the figures below.

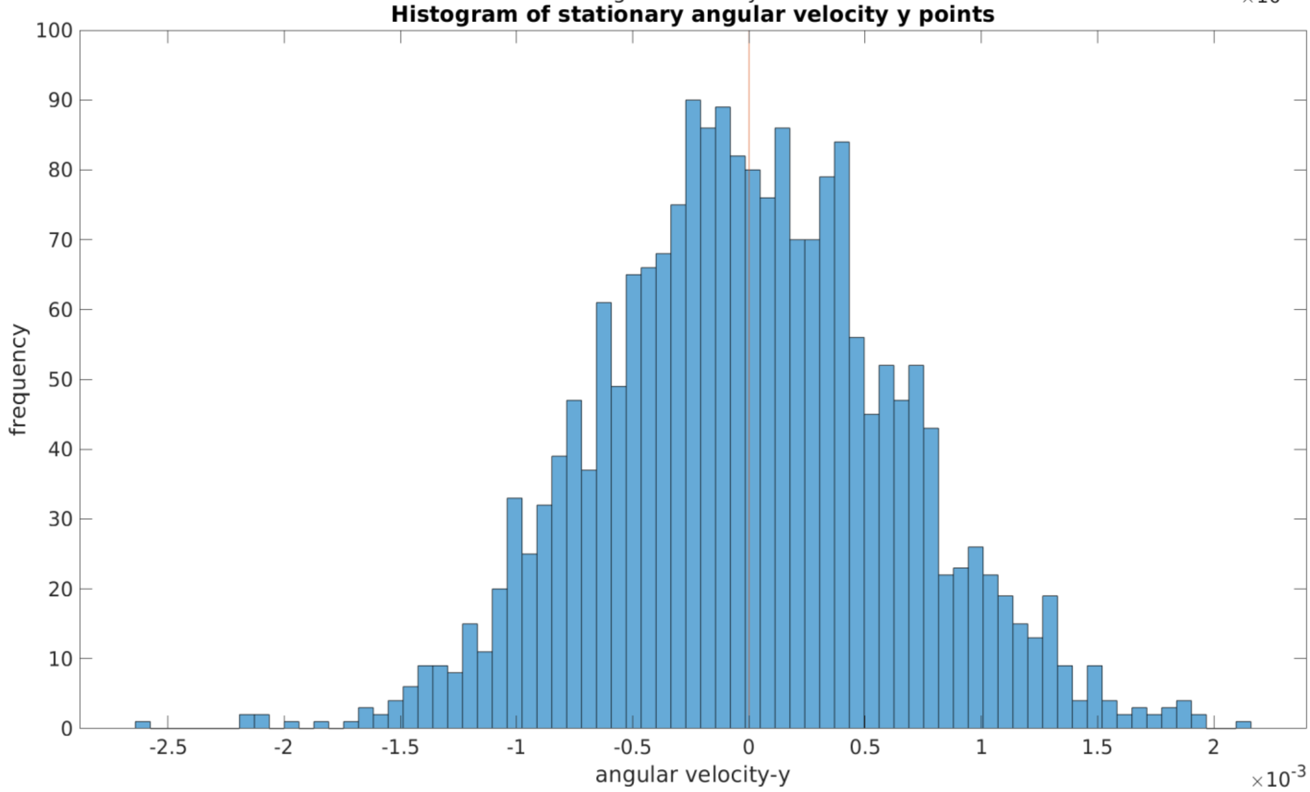
1) Angular rate gyros:



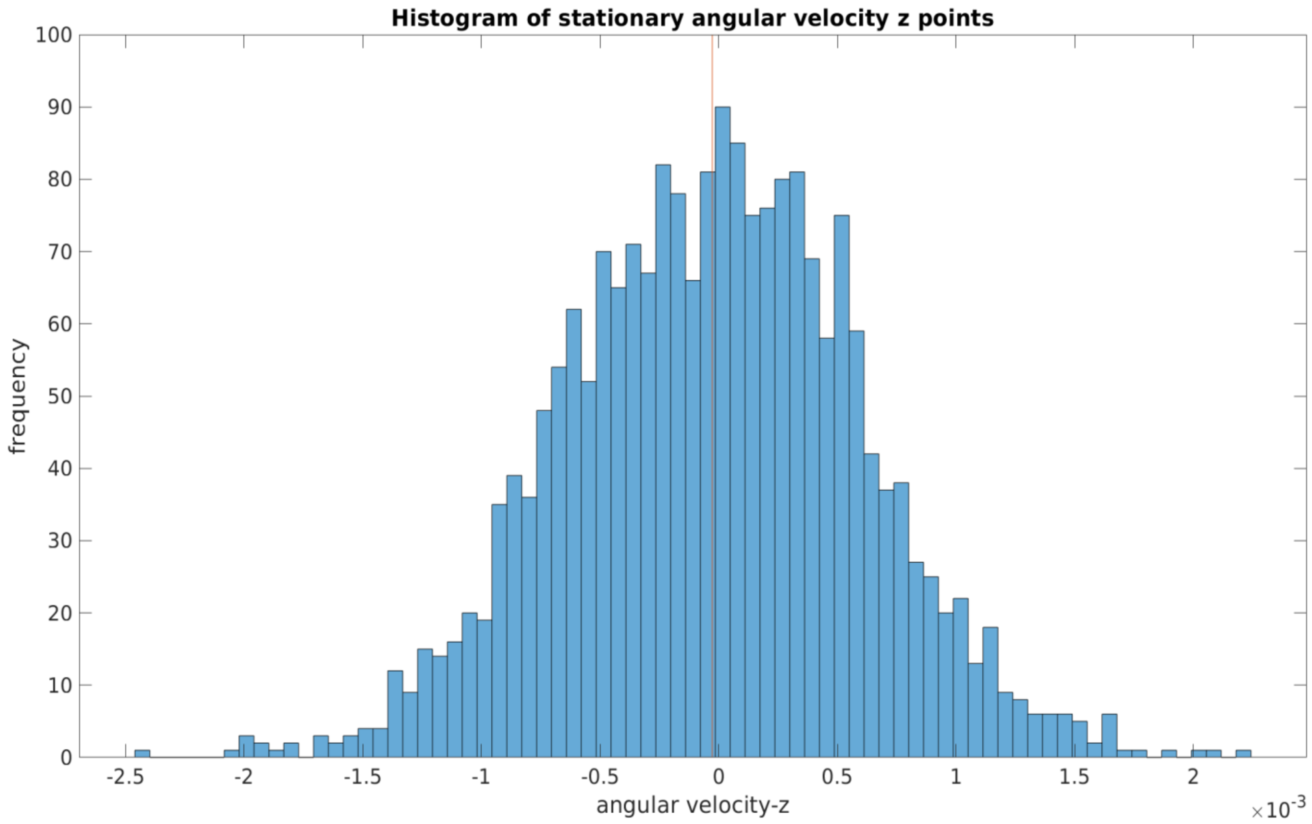
The angular velocity can be seen to be lying majorly in a range of -0.002 to +0.002 rad./sec. This is quite a small value and even though the sensor is stationary, these readings are observed due to the high sensitivity of the IMU.

The histograms of the x, y, and z parameters of angular velocity are plotted individually as below. As can be observed here, all the graphs signify a Gaussian distribution. This implies that the data is distributed about its mean in a gaussian distribution. This distribution is the noise and hence can be concluded that the noise is distributed in a gaussian manner.

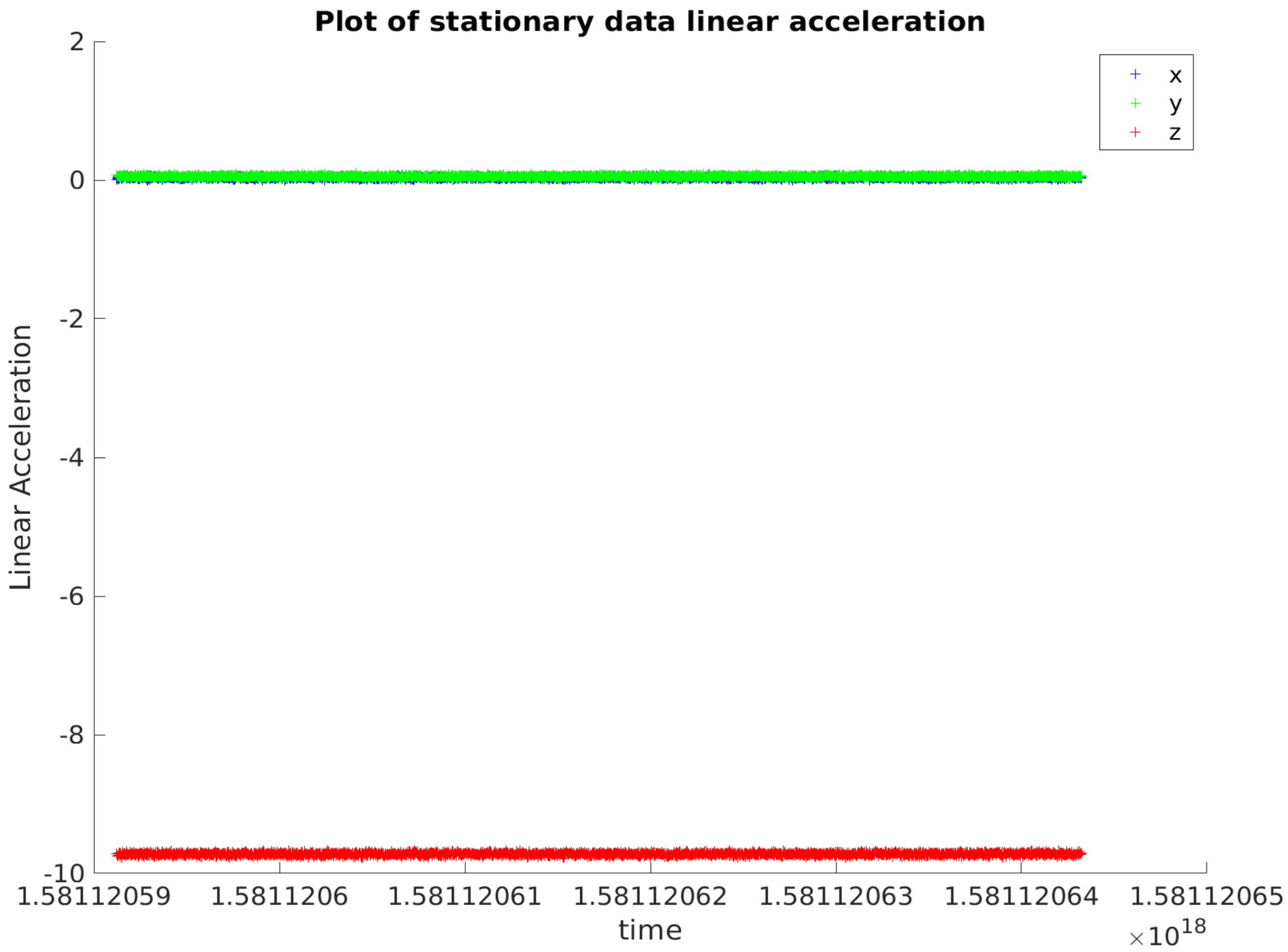




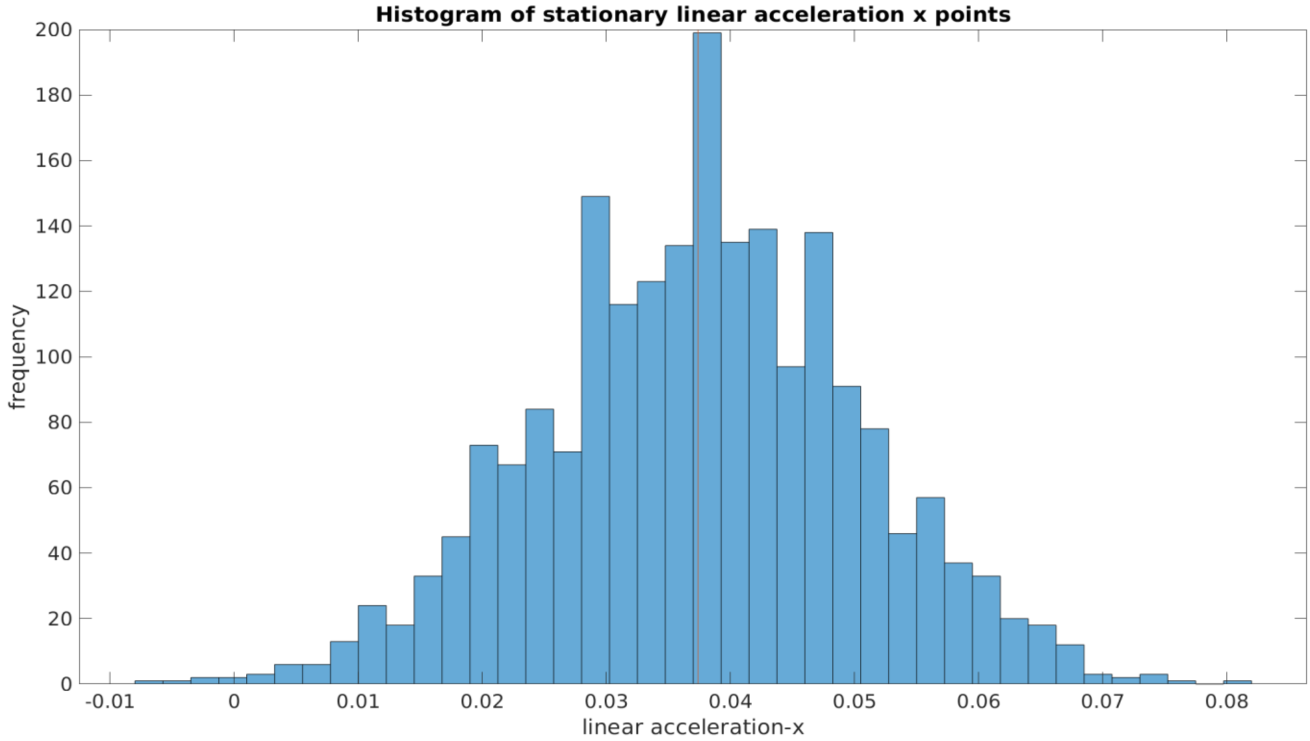
Another observation is that the mean lies very near zero. This goes to show that the device is stationary and the non-zero values are the noise that creeps in into the readings.

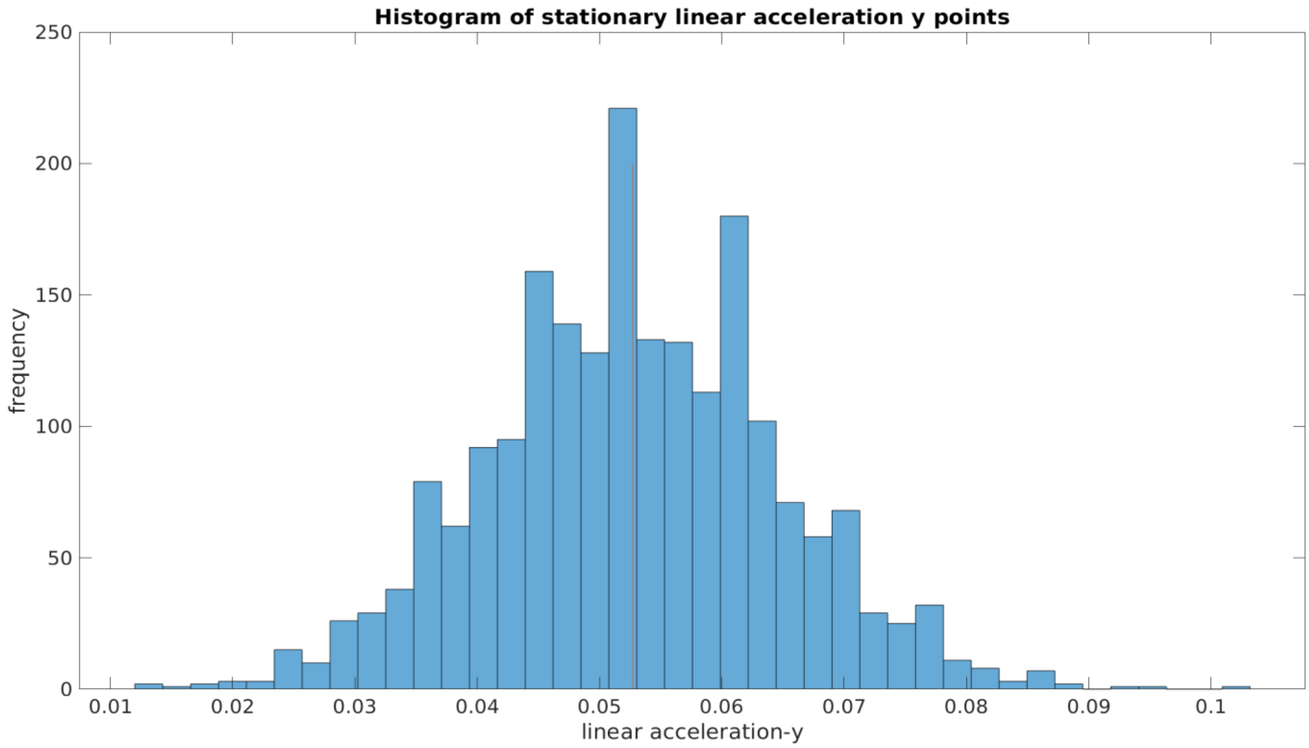


2) Linear acceleration:

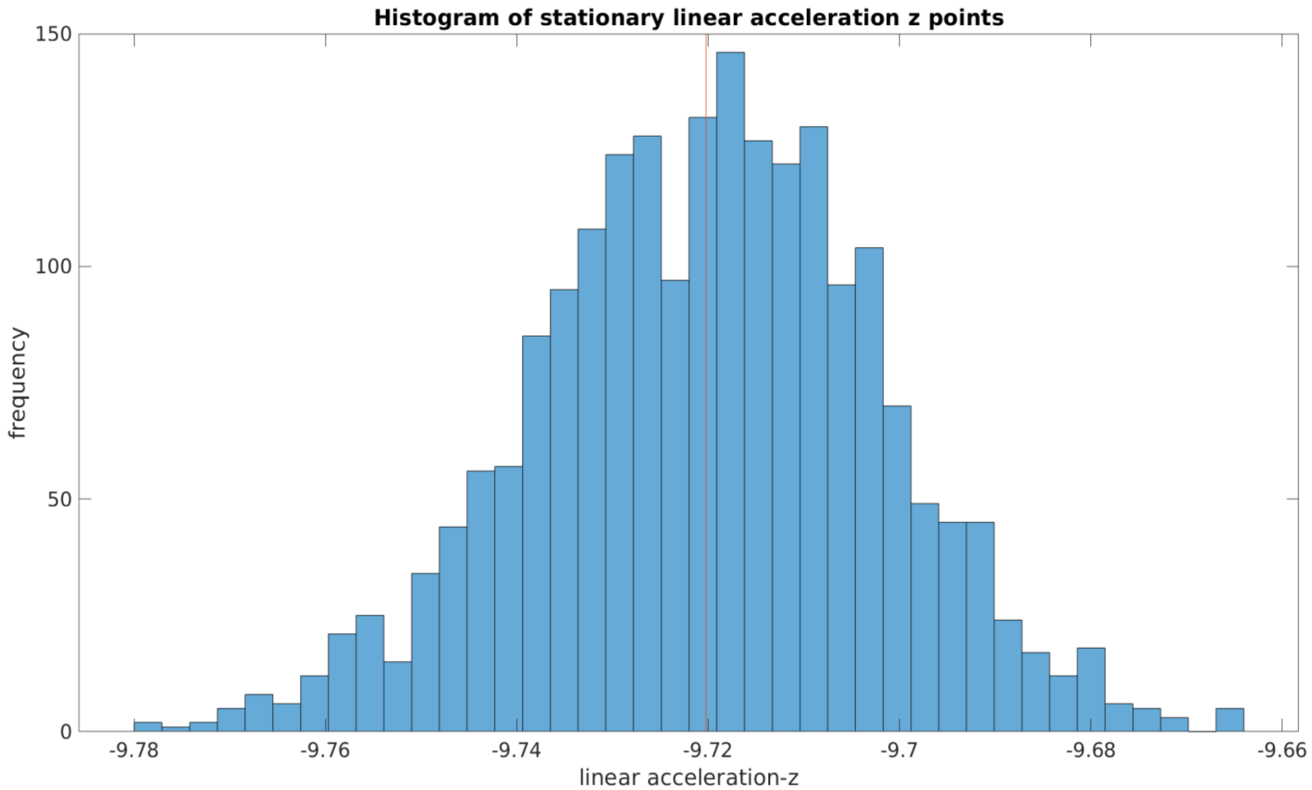


In this plot, the accelerations in the direction of x (hidden under the plot of y) and y axes are almost near zero since the IMU is stationary. The acceleration in the z direction is near -10. This is because of an acceleration due to gravity acting on the IMU in the negative z direction. In the histogram graphs, it can be again seen that the data is distributed in a Gaussian





manner. This implies a gaussian distributed noise just as that in angular velocity. Two major observations in these graphs are the slight offsets in the mean values of accelerations in the x and y directions and the mean of the acceleration in the z direction. The offsets in the x and y directions could be either attributed to some constant offset in the device which needs to

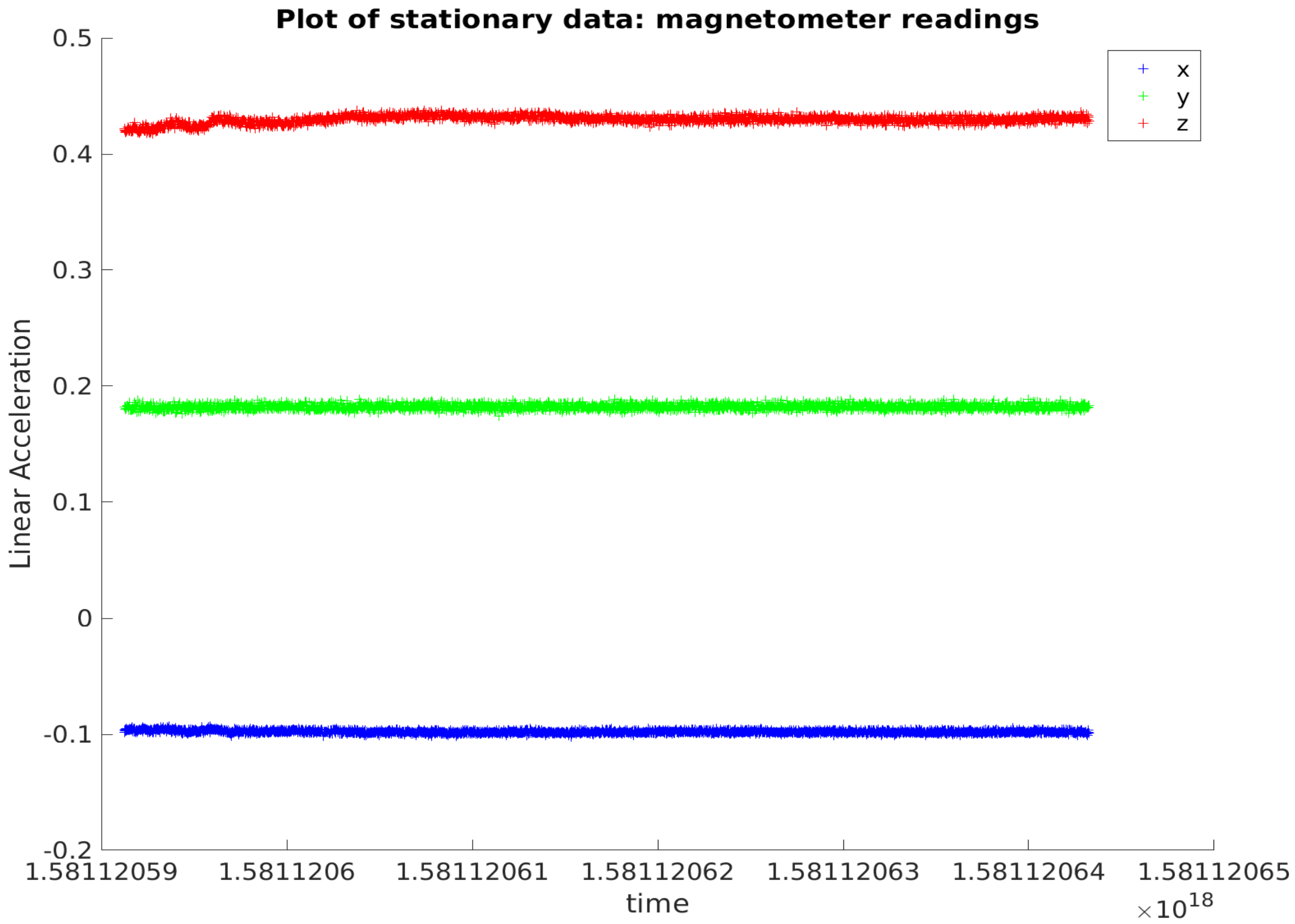


be subtracted, or a constant noise due to a slight tilt in the IMU. The second reasoning would also explain the slight offset in the z direction from the expected 9.8 value.

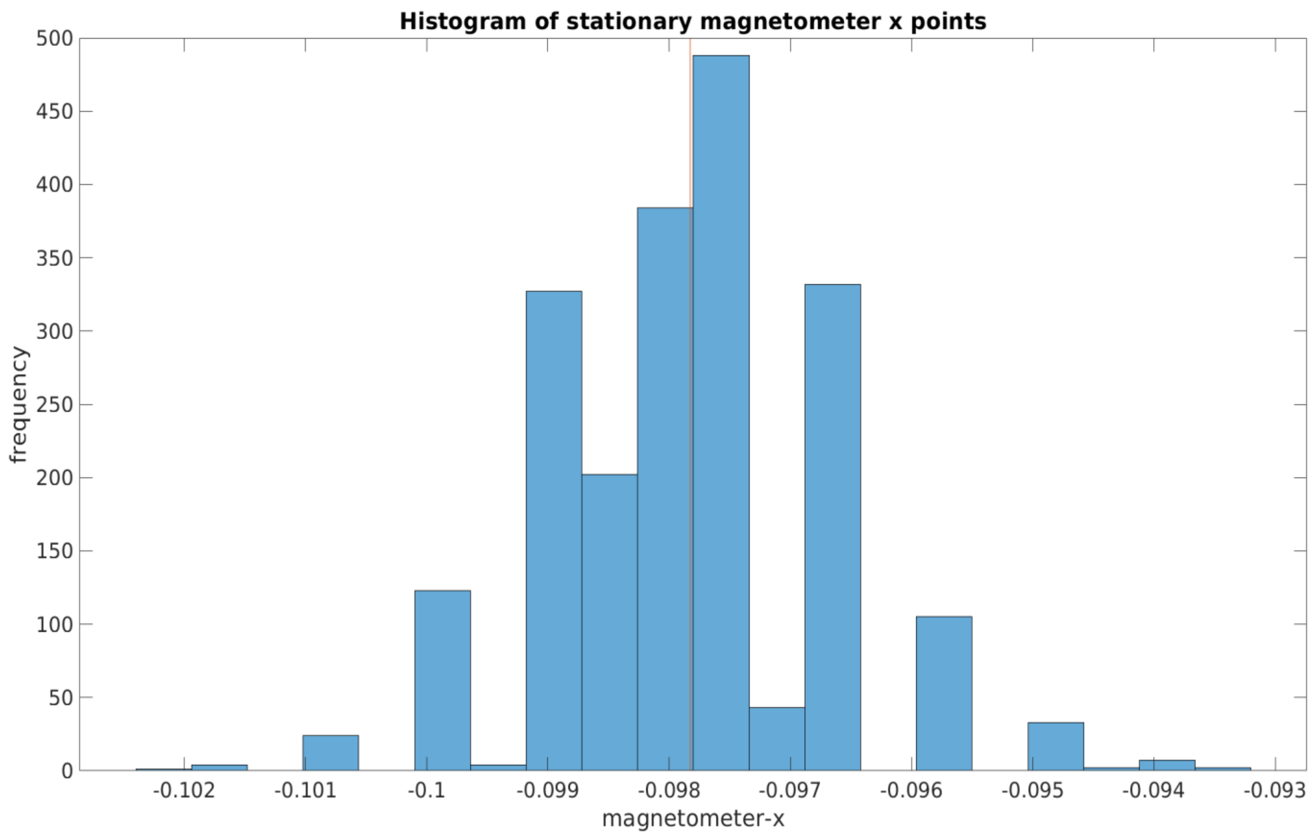
3) Magnetometer:

The magnetometer readings are mainly based on the magnetic field strengths of the earth in particular directions. Hence, these values are at particular values based on the direction of the IMU at that point of time. The values seem to be more or less constant. This shows the stationary state of the IMU.

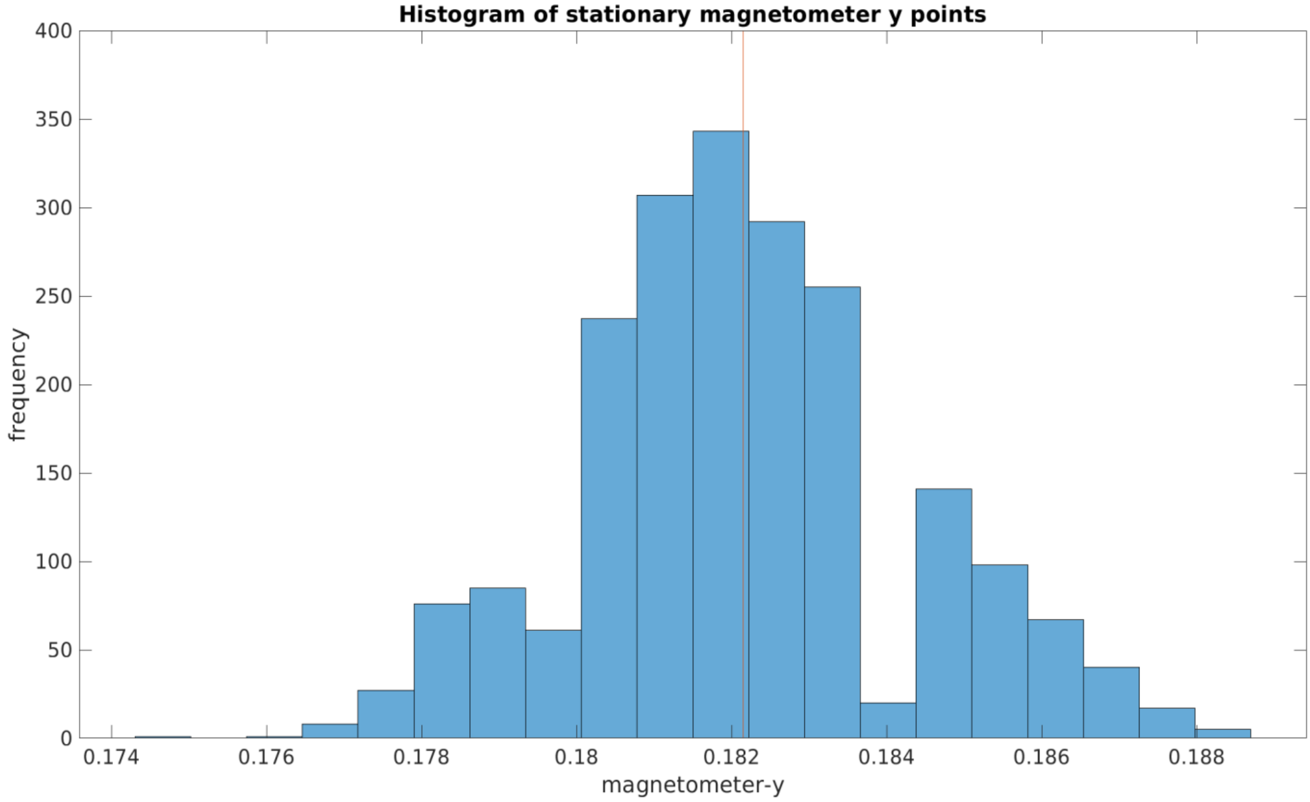
In the histograms, it can again be seen that the data is distributed in a Gaussian manner signifying a gaussian noise.



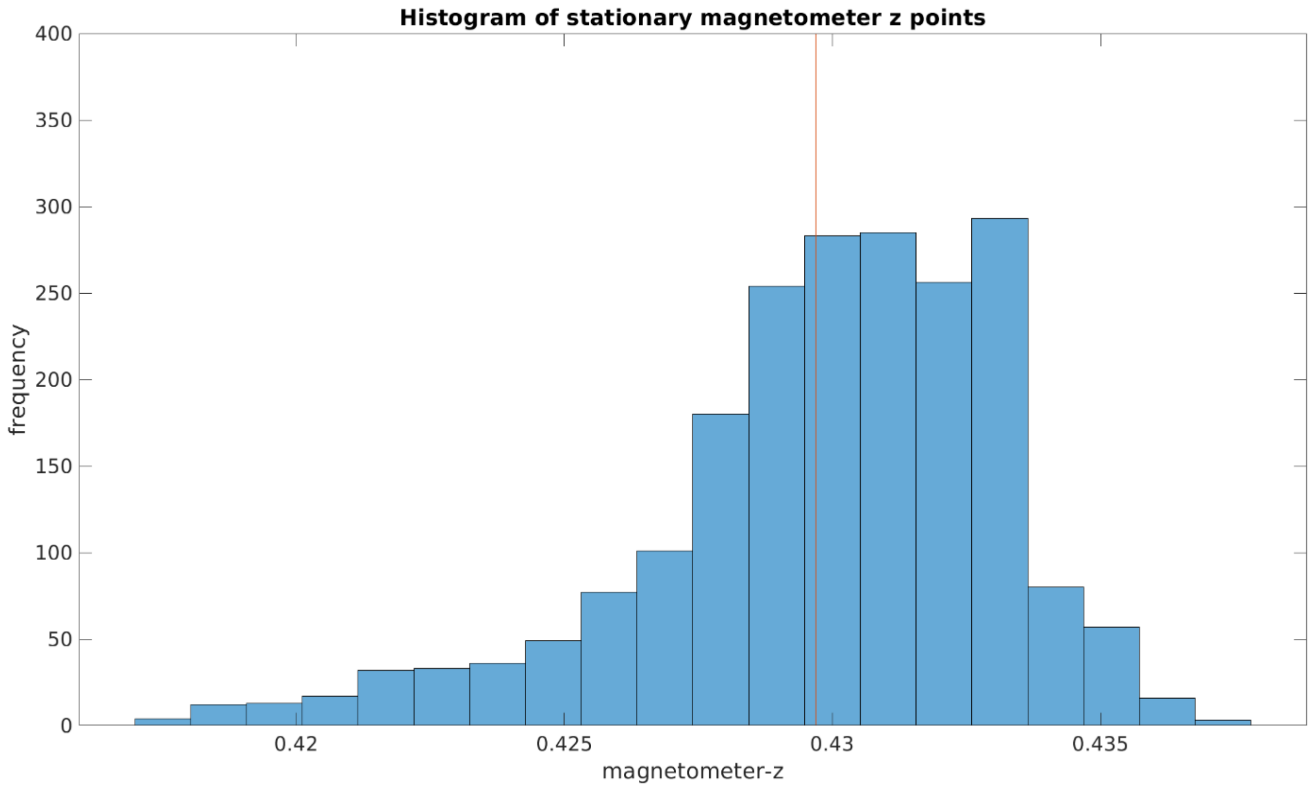
Plot of stationary data: magnetometer readings
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Linear Acceleration
x
y
z
1.58112059
1.5811206
1.58112061
1.58112062
1.58112063
1.58112064
1.58112065
time
$\times 10^{18}$



Histogram of stationary magnetometer x points
500
450
400
350
300
250
200
150
100
50
0
frequency
-0.102
-0.101
-0.1
-0.099
-0.098
-0.097
-0.096
-0.095
-0.094
-0.093
magnetometer-x



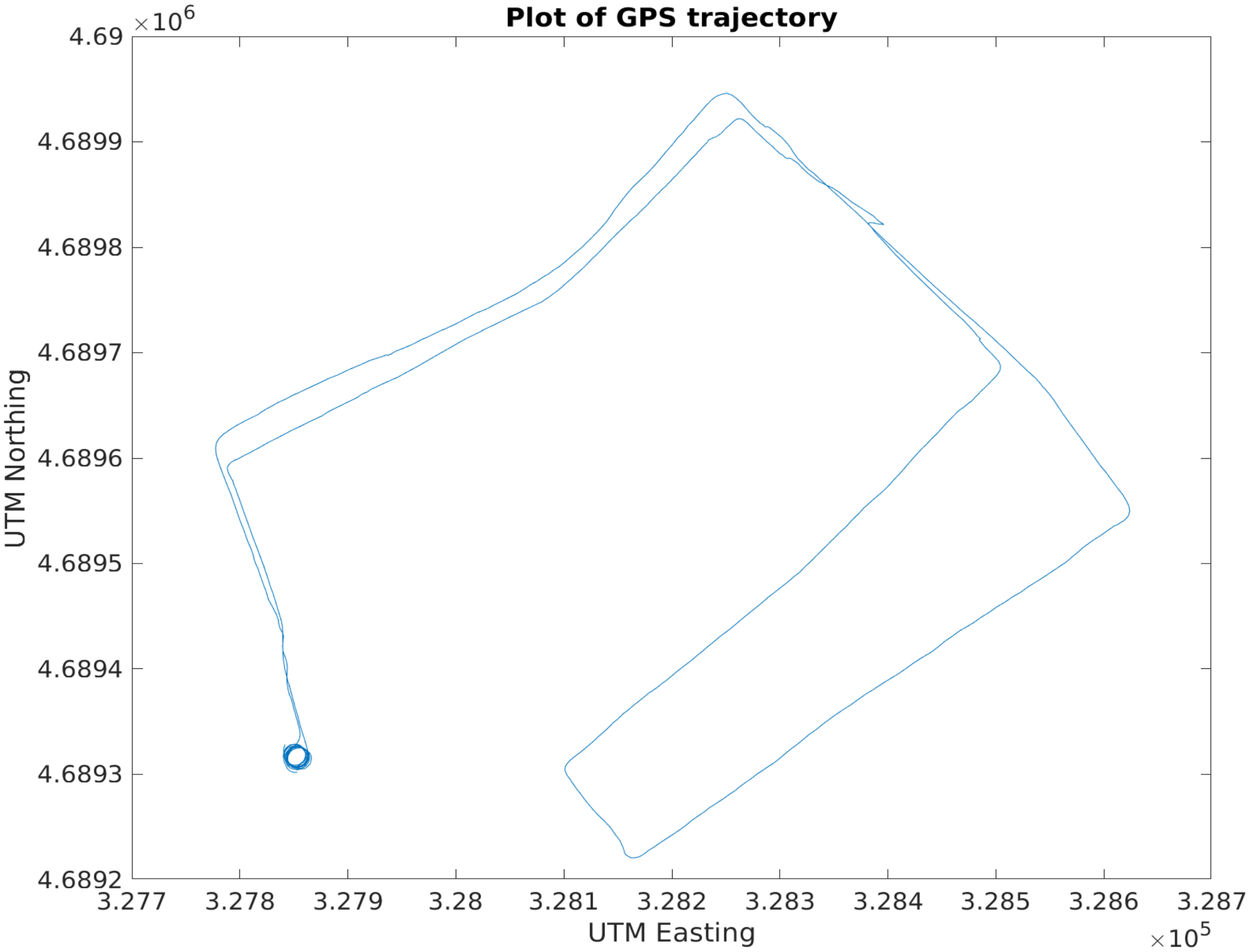
Histogram of stationary magnetometer y points
frequency
400
350
300
250
200
150
100
50
0
0.174
0.176
0.178
0.18
0.182
0.184
0.186
0.188
magnetometer-y

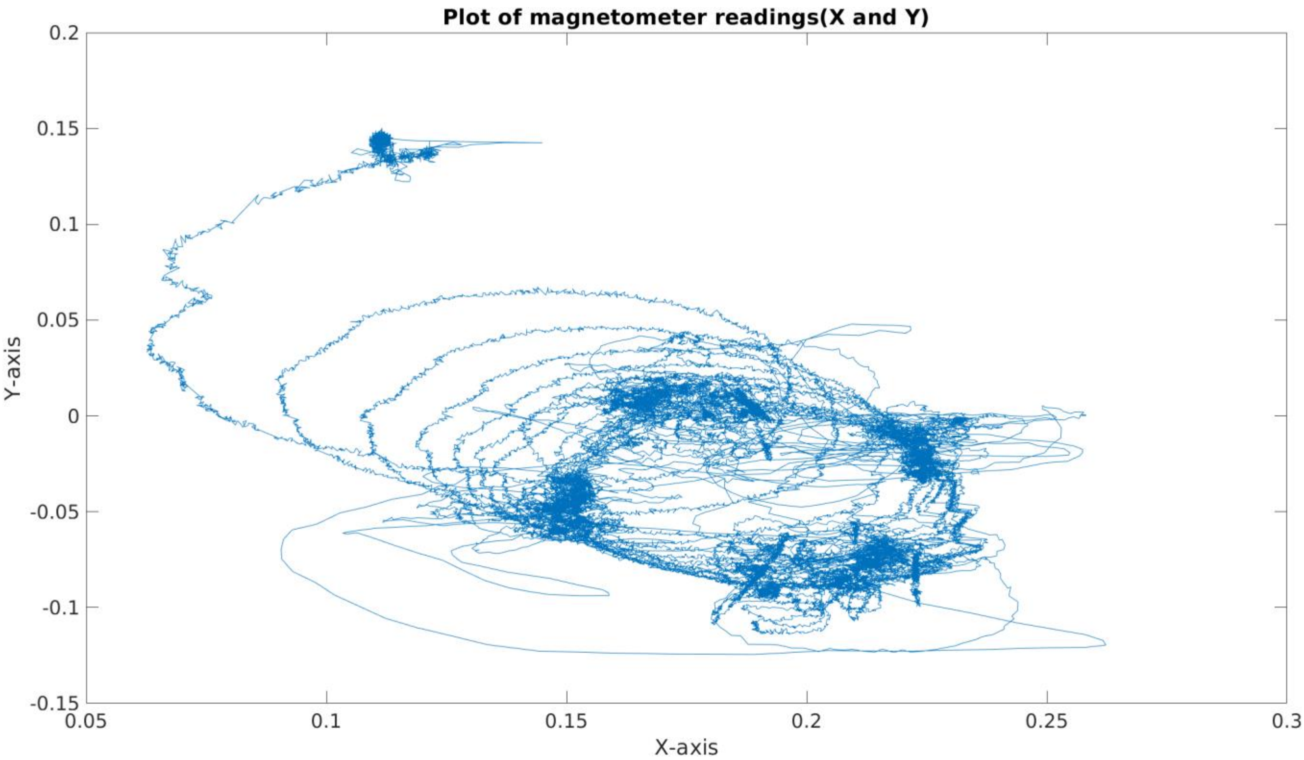


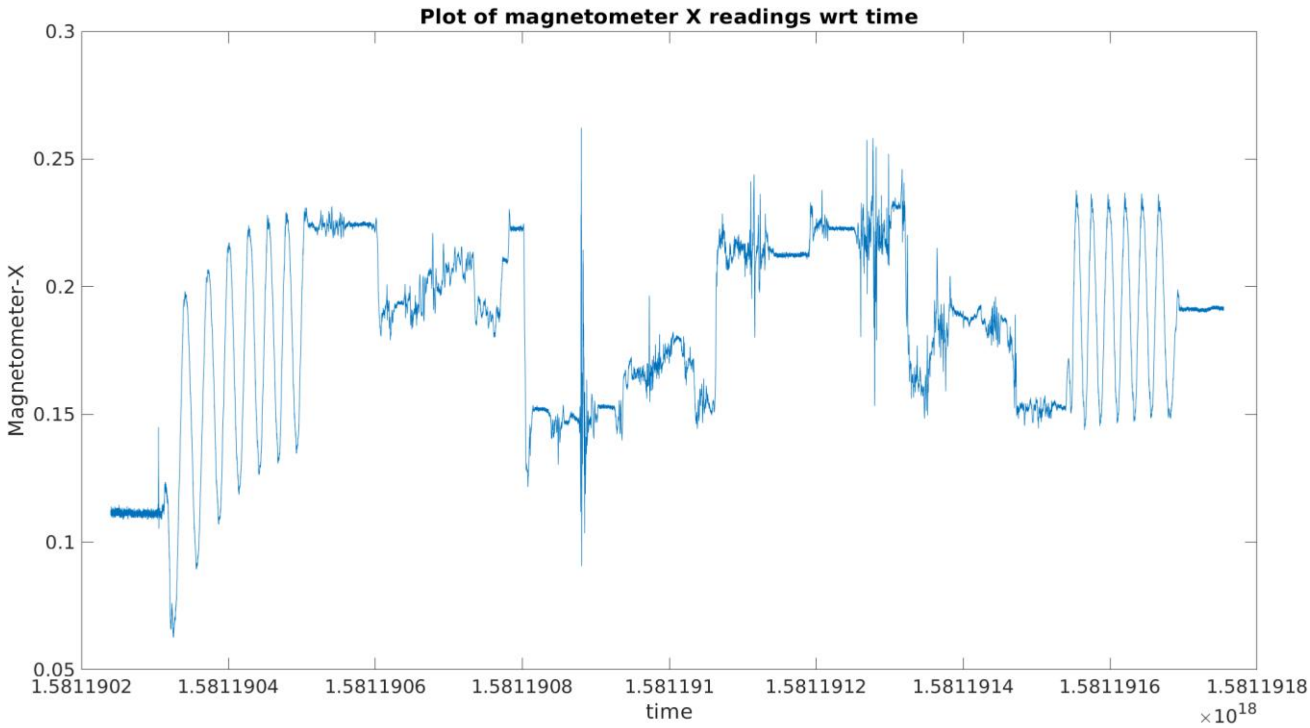
Histogram of stationary magnetometer z points
frequency
400
350
300
250
200
150
100
50
0
0.42
0.425
0.43
0.435
magnetometer-z

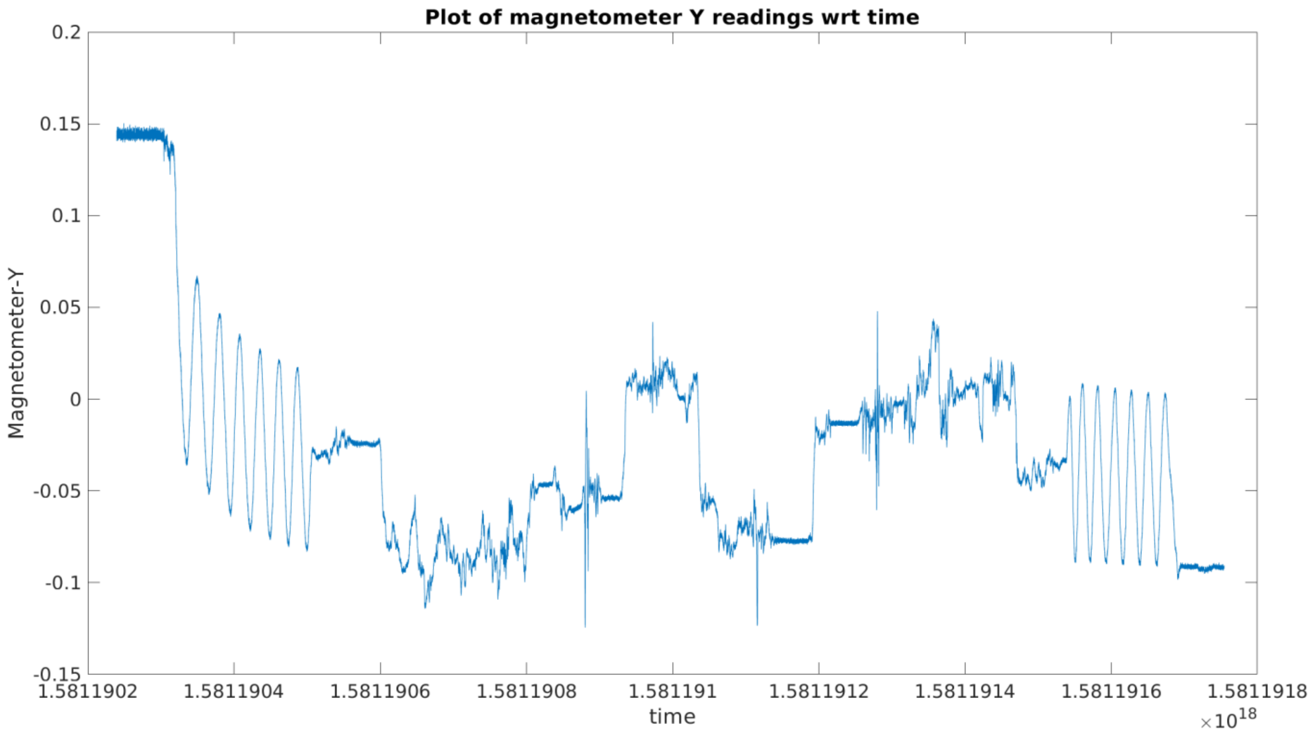
PART 2: Collect data in a car for dead-reckoning:

The data was collected successfully in the first try and used for the dead-reckoning section.

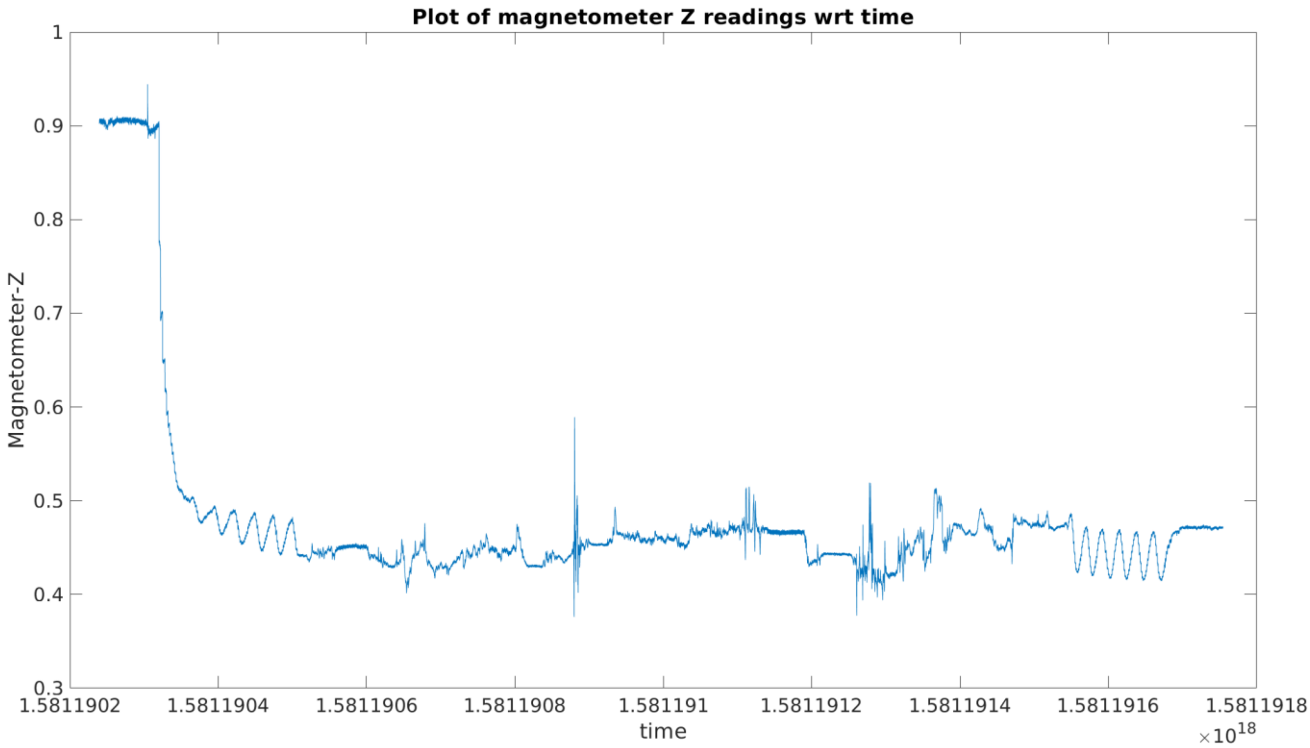








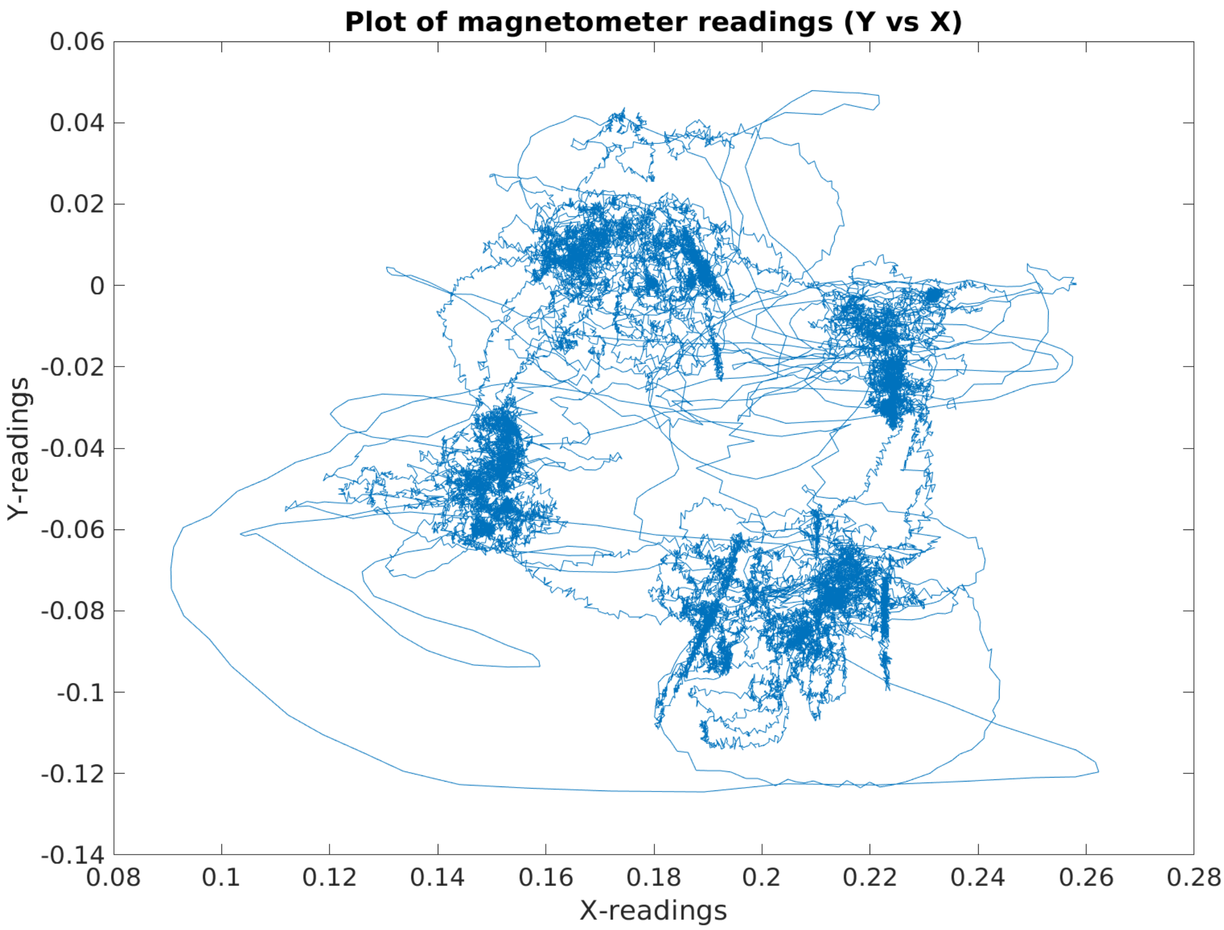
In the above plots, we can see the magnetometer readings plotted in the x and y directions, and in the x, y, and z directions individually. We can see the initial and ending circles taken for calibration in the form of sinusoidal waves which signify the changing and repetitive magnetometer readings while moving in circles. The calibration can be observed in the slowly shifting values at the beginning and ending of the plots.

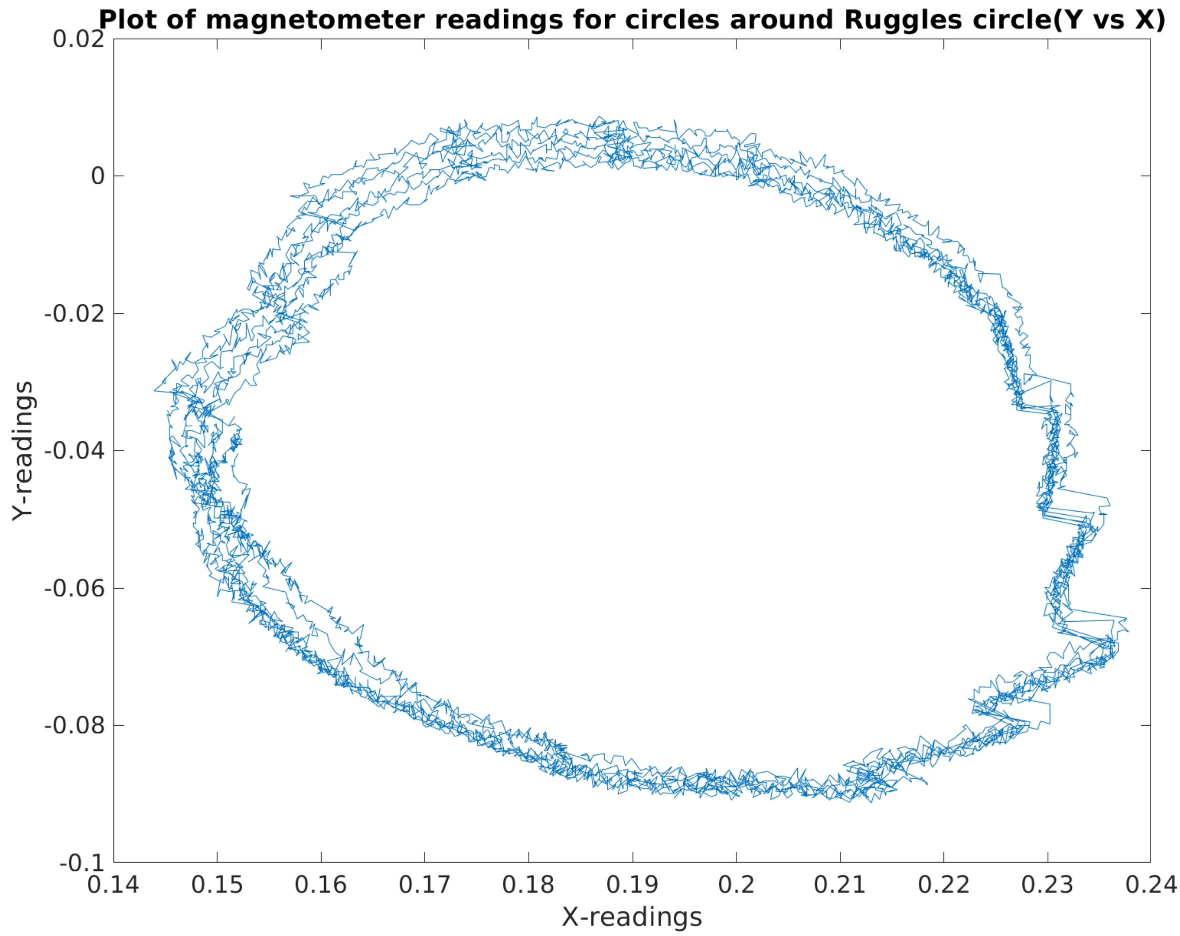


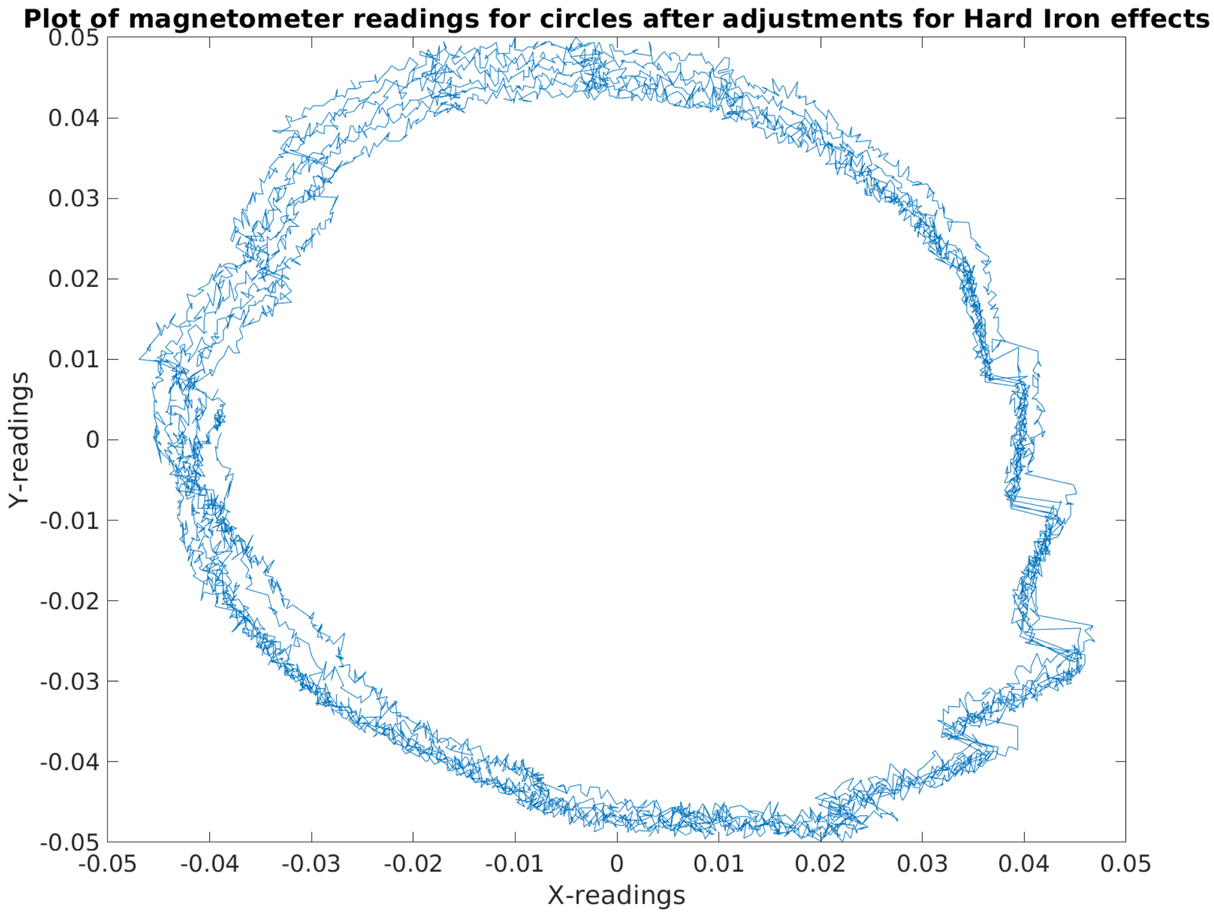
<u>PART 3: Analysis on the data collected in Part 2:</u>

1) Estimate the headings (yaw):

Magnetometer calibration:



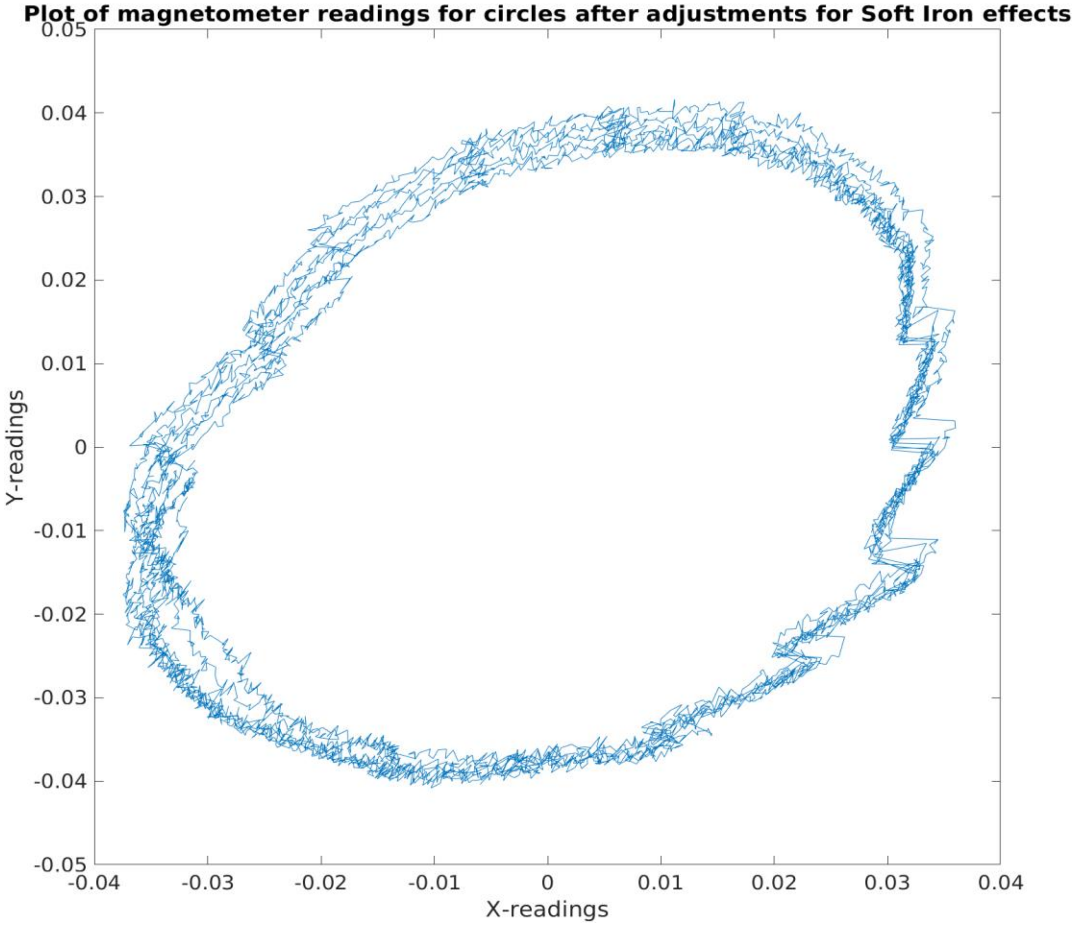




The first two figures show the x-y plot of magnetometer after removing the initial calibration circles from it followed by the circles themselves to adjust for the hard and soft iron effects.

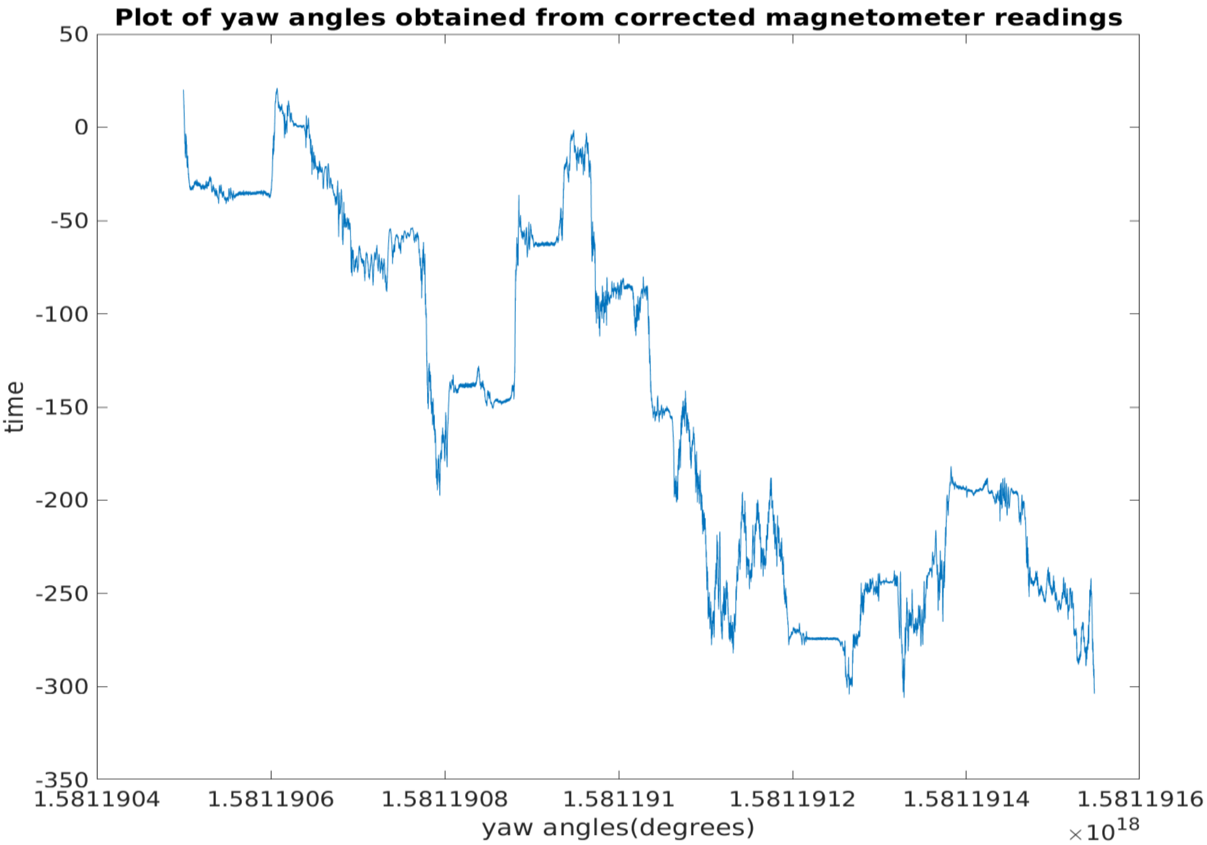
After adjusting for the hard-iron effects, the circles shift to (0,0) as shown.

After removing the soft-iron effects, the circle and the final adjustments reflecting on the entire magnetometer readings are shown below:



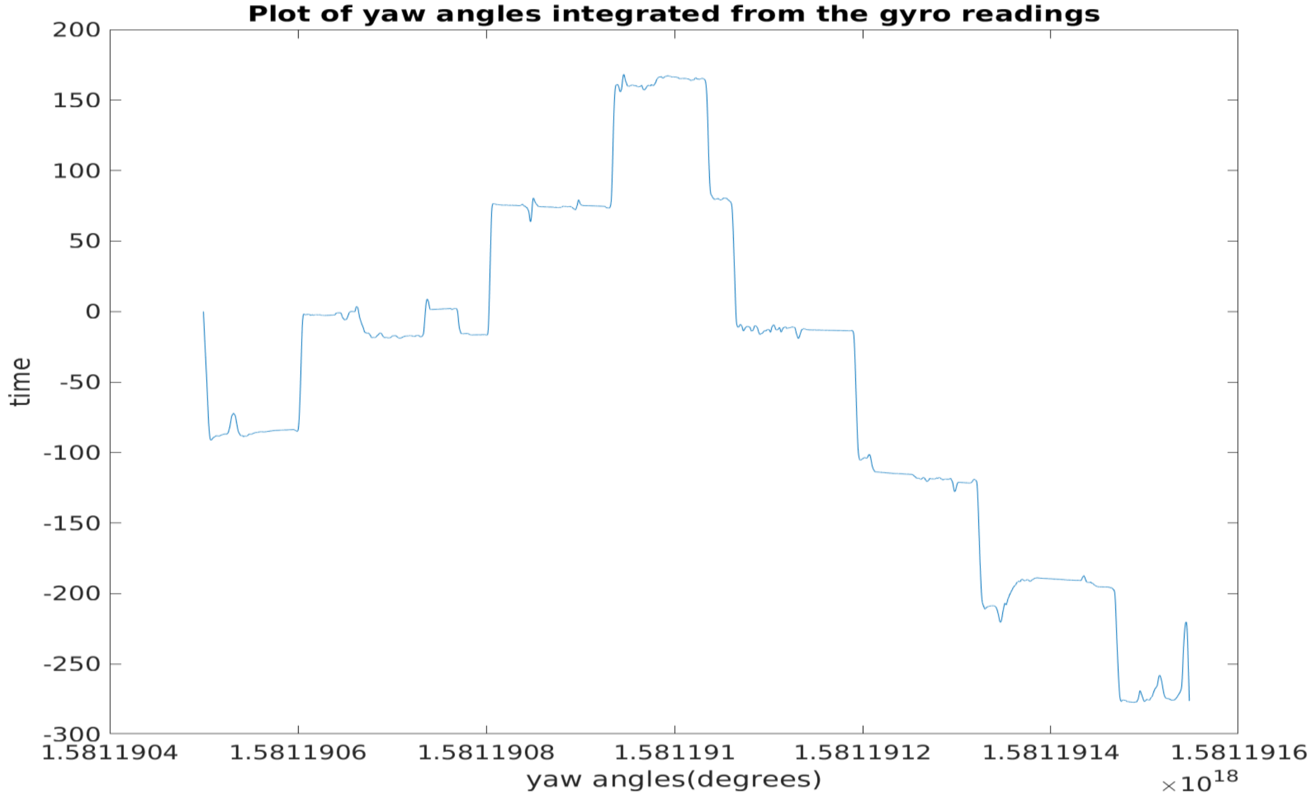
Plot of magnetometer readings after adjustments for Soft and Hard Iron effects
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
Y-readings
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
X-readings

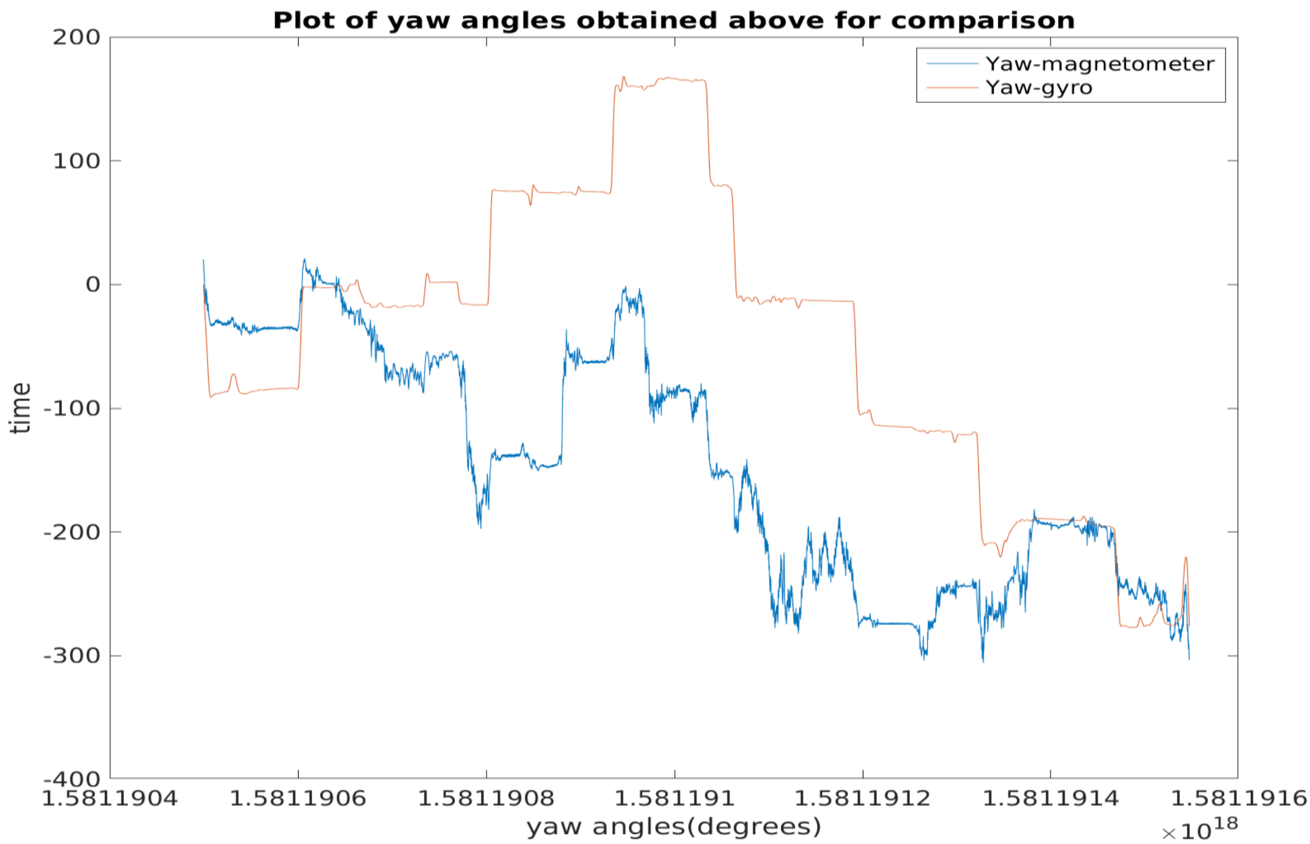
Yaw angles:



Plot of yaw angles obtained from corrected magnetometer readings
50
0
-50
-100
-150
-200
-250
-300
-350
time
1.5811904
1.5811906
1.5811908
1.581191
1.5811912
1.5811914
1.5811916
yaw angles(degrees)
×10^18

1) The yaw angles from the corrected magnetometer readings were obtained and have been plotted along time in the figure shwon.
2) The yaw angles obtained by integrating the yaw rate sensor readings have been plotted along time in the below figure.

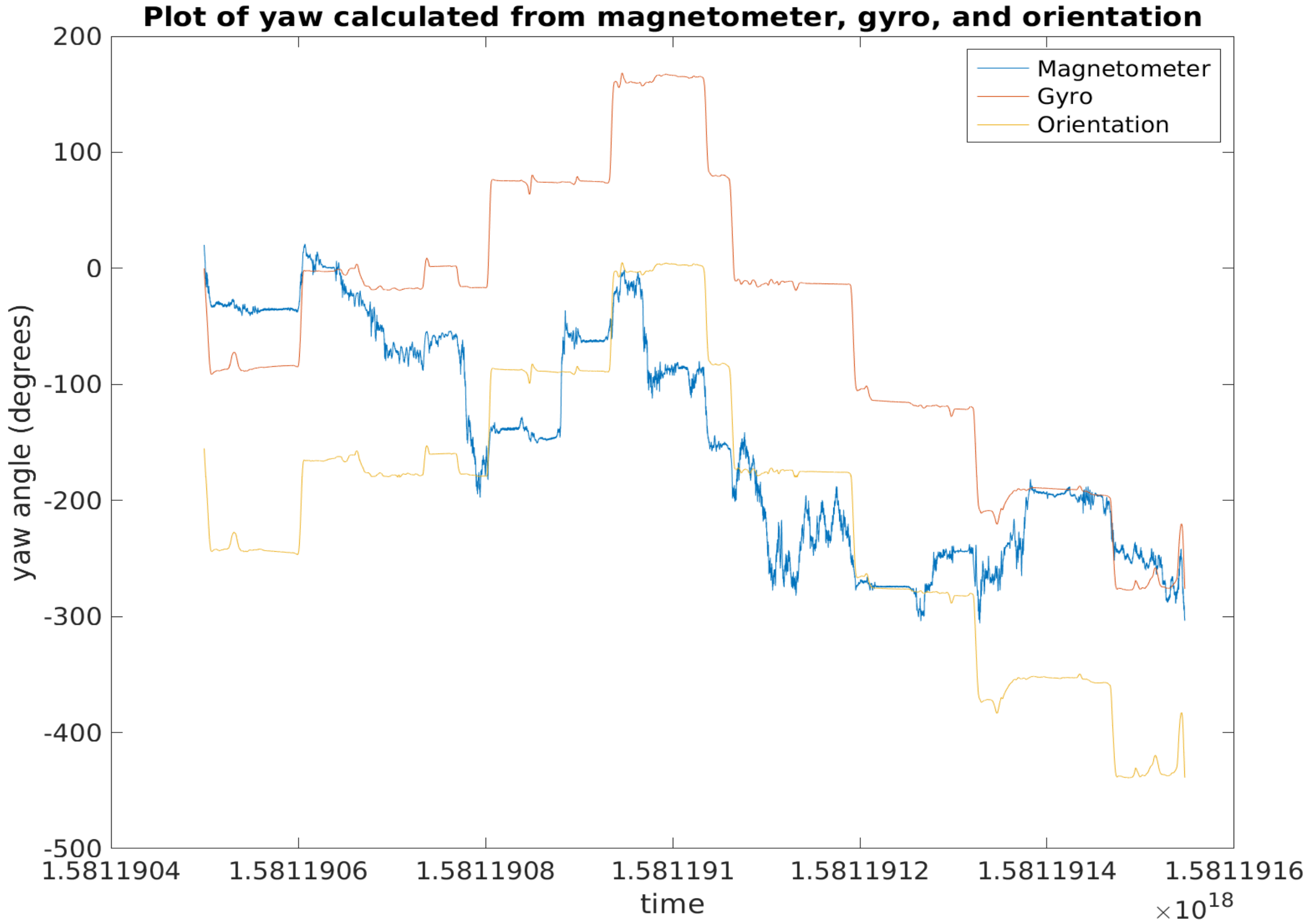




These two plots were again plotted together as shown.

The observations from this plot are summarized below in the next subsection along with observations of the figures plotted therein.

3) These angles have been further plotted again to compare them with the yaw angles obtained using the IMU below.

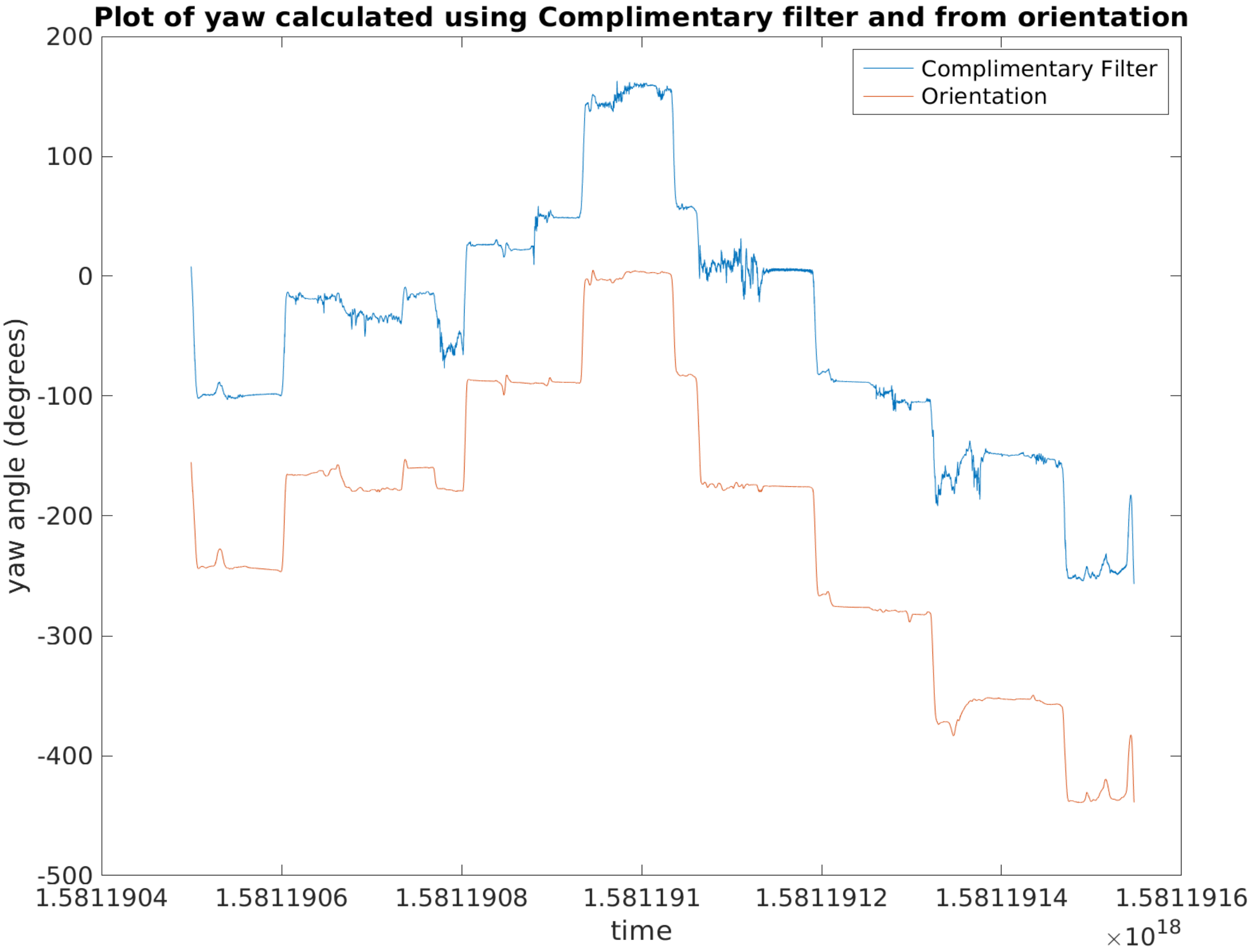


Here, by comparing all the three angle values over time, we can observe that the yaw angles obtained from the magnetometer readings seem disturbed and changing at almost every small point of time. This is since the magnetometer is sensitive to lower frequencies and hence susceptible to change and sensitivity to the slightest of changes/disturbances. This phenomenon is not observed in the yaw angle readings calculated from the gyro and the IMU's orientation. This is because they are more sensitive and calibrated towards sensitivity to higher frequencies. Hence these give more steadier values.

At this point of the lab, a complementary filter was implemented on the yaw angles from the magnetometer and the gyro to obtain a better time-series which would encapsulate the best of both the errors. The scaling factor used here was 0.4.

It was required to use a low-pass and a high-pass filter. But the filters were imposing some extreme undesired effects to the yaw angles and hence it was deemed better not to use them.

Hence, the complementary filter has been implemented without incorporating any low-pass and high-pass filters.



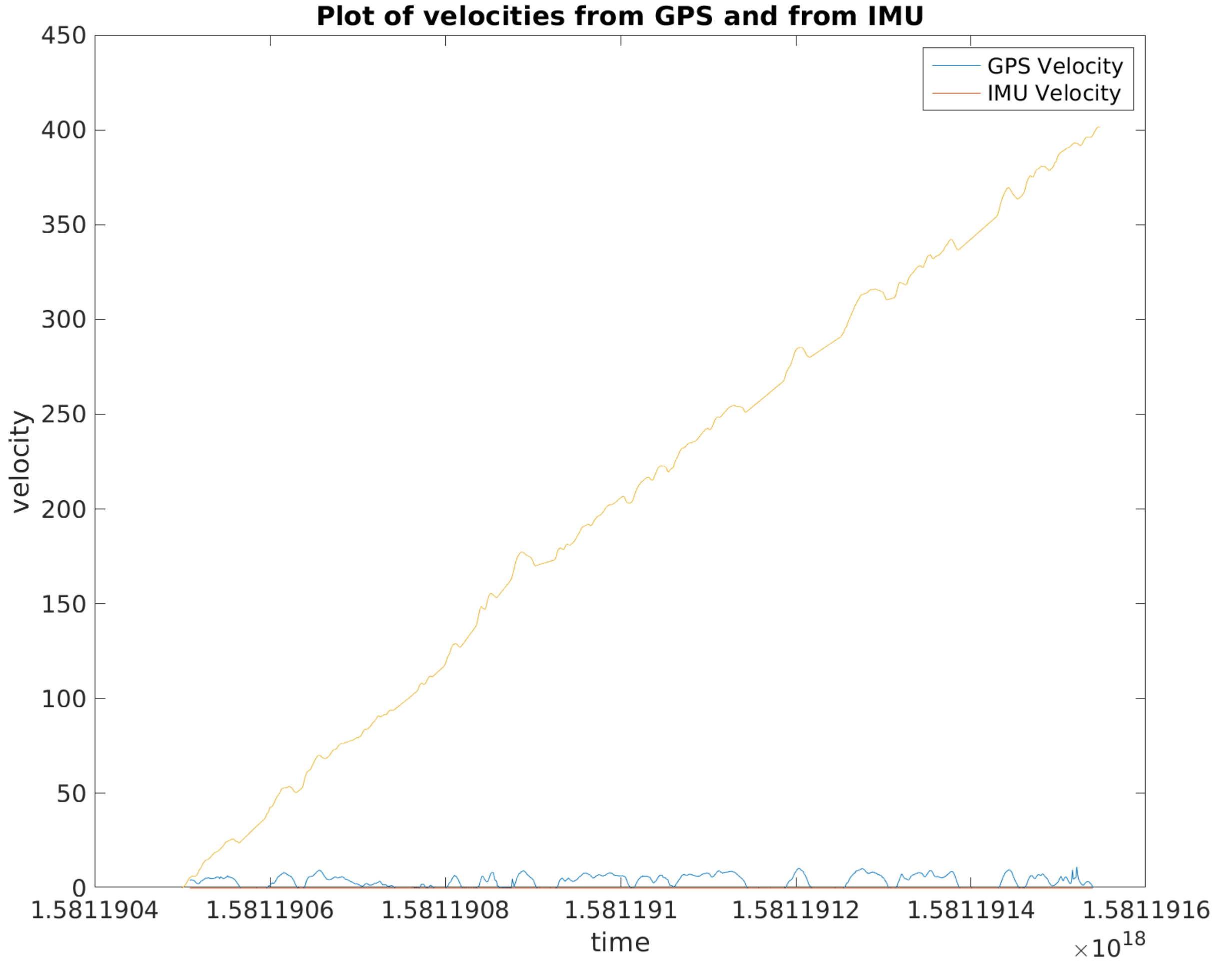
In this figure,we see that the yaw angle values from the complementary filter are a mix of the values from both its components. The magnetometer adds some degree of variation in the constant-seeming lines of the gyro readings. This might be an undesired effect in many real life applications, especially to the extent seen here with a scaling factor of 0.4. But it has been incorporated here to observe the effects of both sensors in our readings. Also, if the scaling factor was lowered by a significant value to negate the variations from the magnetometer, then it would become very much similar to having only the gyro readings and would thus nullify the very purpose of having a complementary filter.

A major observation here is that there seems to be a sizable offset between the two yaw angle values. This is something that I could not ascertain conclusively. It was first thought of to be due to some calculation errors while formatting the yaw angle vectors through radians, degrees, wrapping, etc. But after cross-checking, these were found to have not been the reasons for the above observed effects.

NOTE: The angles plotted above can be observed to be exceeding the -180 to 180 degrees barrier. This is since the readings were unwrapped before plotting for the purpose of better visualization of the plots. The wrapped figures had abrupt changes in their values when values reached the threshold of (+/-) 180 degrees. The offset between the two plots further contributed to mismatch between the data plots when the data was wrapped.

2) Estimate the forward velocity:

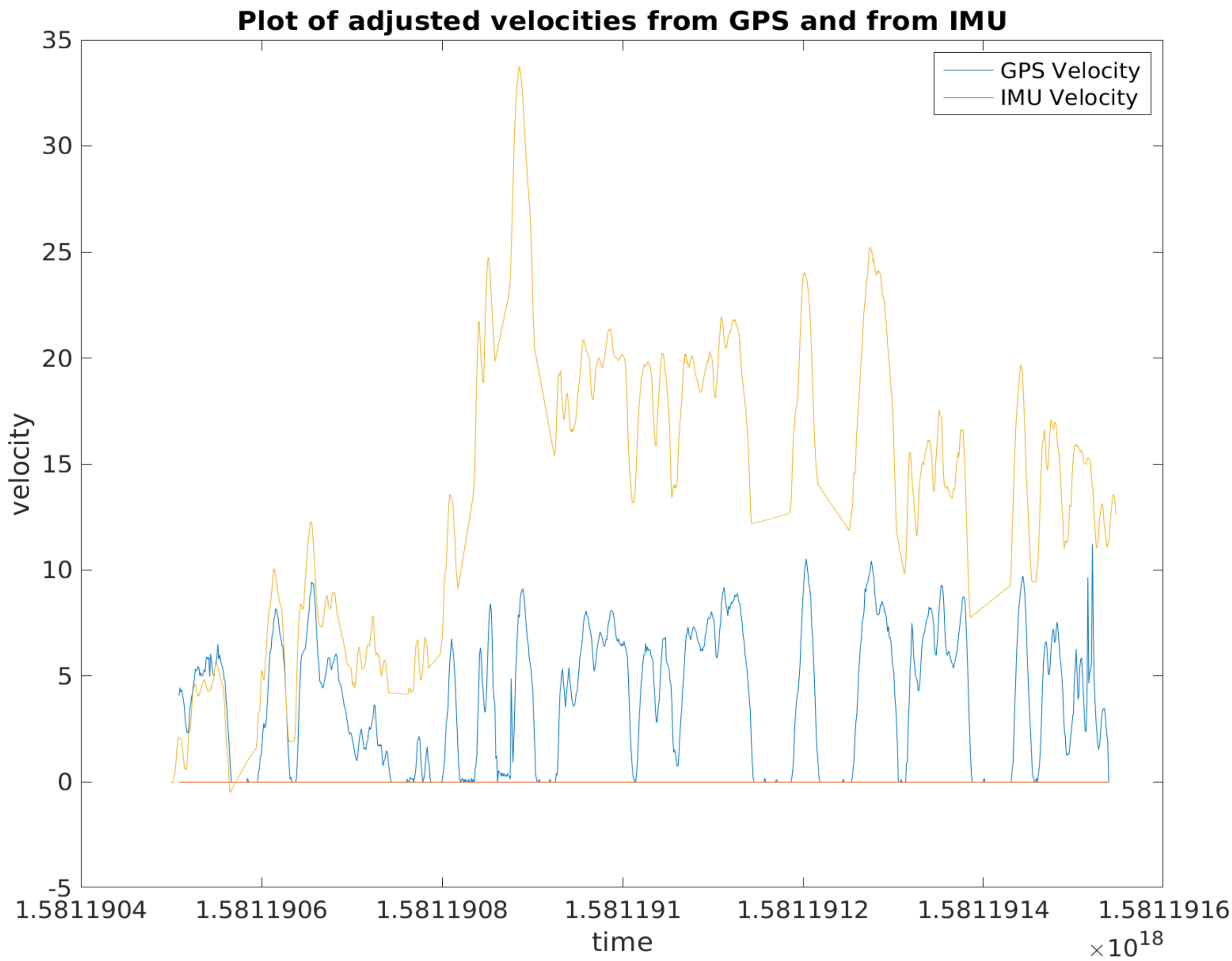
On integrating the forward acceleration from the IMU and estimating the velocity from the GPS, the following graph was obtained.



Here, it can be observed that the integrated velocity continuously increases and doesn’t match the velocity of the GPS at all. This was ascertained to be due to some initial noise in the acceleration values when the IMU was stationary even before the vehicle ignition was turned on. This starting error was then integrated continuously over all the values and eventually summed up repeatedly to give an increasing velocity plot. To overcome this, the initial offset values were subtracted from all values of the acceleration readings. Once this was done, the forward acceleration was integrated again, and the following graph was plotted.

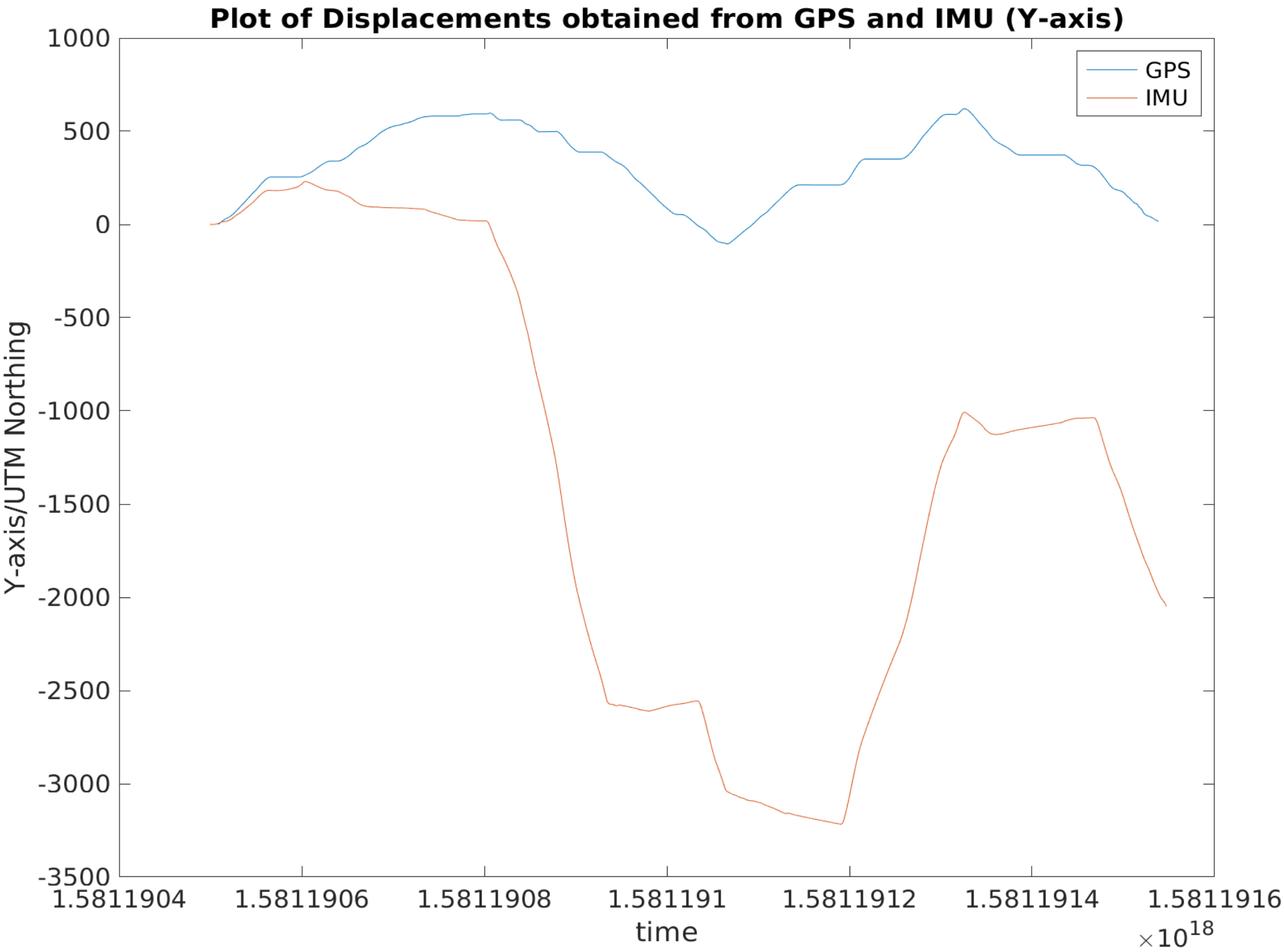
This plot is much better than the previous one and actually matches to a great extent with the velocity calculated from the GPS.

An issue with this plot is its sudden spike in between that later goes upto a velocity of 35 m/sec. This seems like an unrealistic value considering the speeds travelled by the group in reality while collecting the data. This uncalled for spike in the data that further gets propagated into the following readings on the velocity is thought of to be due to addition of some noise at some point of time during the data collection process. I strongly feel that this might have been added at some point where the car was stationary for a substantial amount of time to have allowed for a slow build up of the error. This reasoning could not be ascertained with confidence since a successful method to counter such an effect was not found for implementation in the duration of the lab. Yet, it is believed that this undesired effect could potentially be adjusted for by trying to determine when the vehicle might have been stationary and subtracting any noise at that point of time from all subsequent readings. This would help prevent a build up of noise over time while the vehicle was stationary.



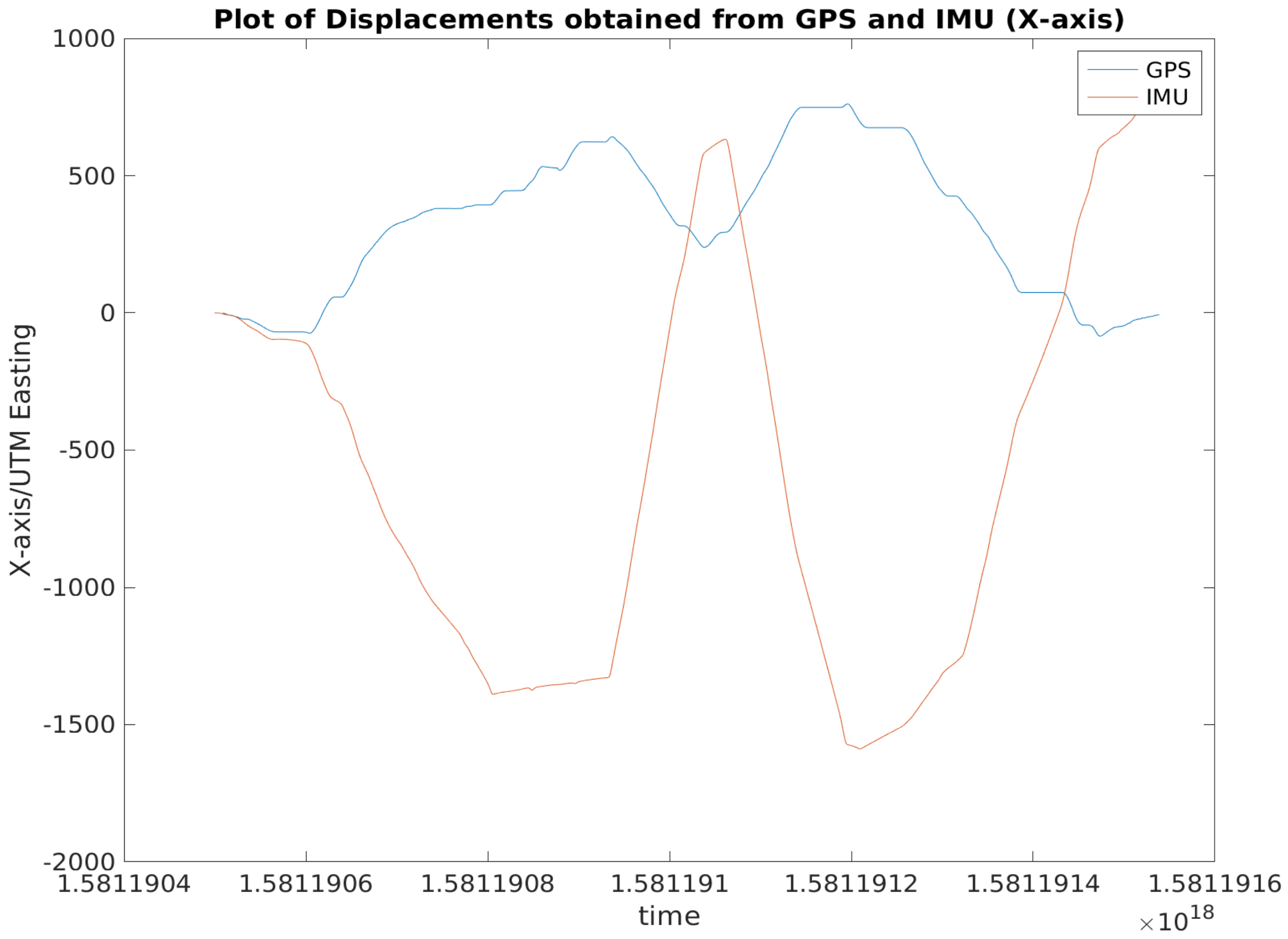
3) Dead Reckoning with IMU:

Upon integration of the IMU data to obtain displacement, the following graphs were obtained for the time-series plots of the x and y displacements from the IMU and the GPS.

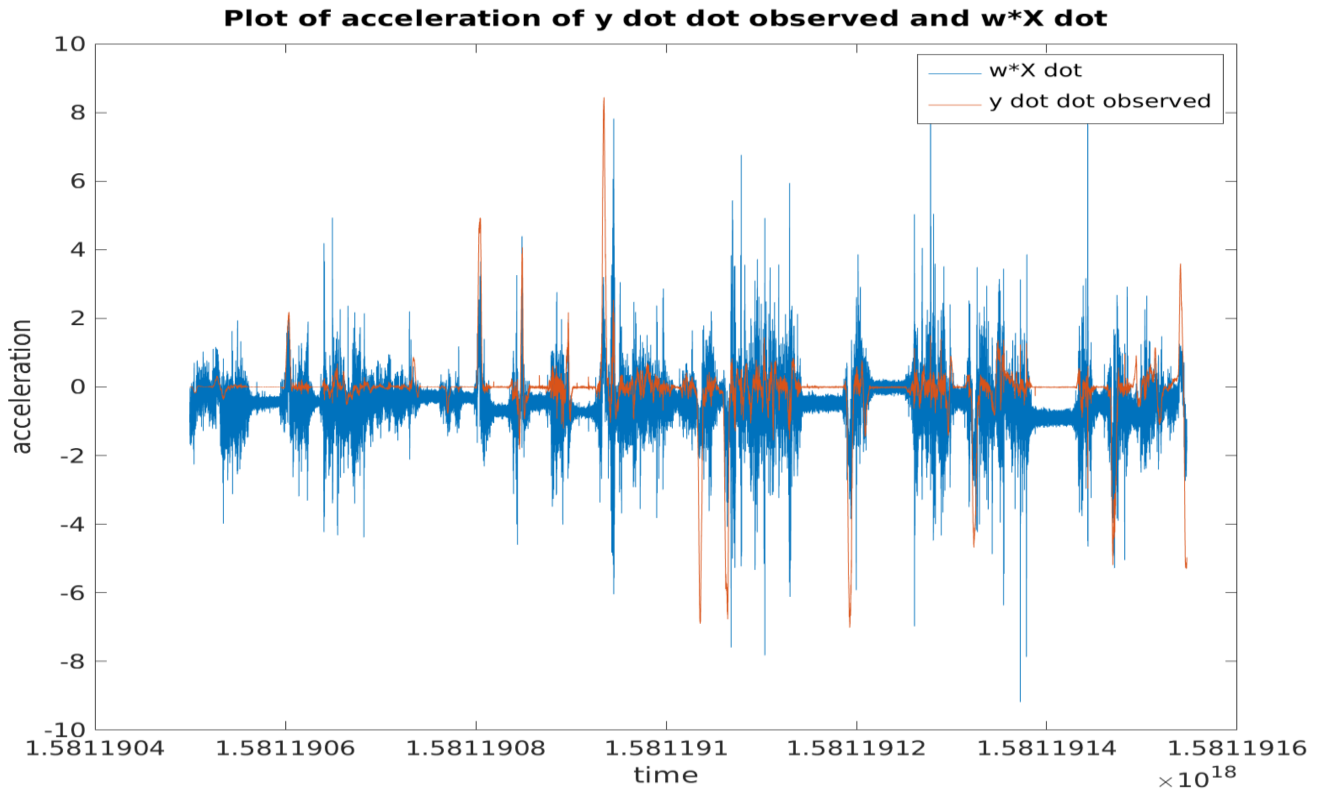


The IMU displacement of each axis was calculated using the velocity from the IMU that was calculated in the previous section, and the yaw angles from the IMU.

In the plots, it can be noticed that the plots of the displacements calculated from the IMU and the GPS seem to be of similar designs. One major difference that is observed across both the plots is that the initial time plots seem to be identical to each other. But then the IMU values seem to suddenly scale up by a huge factor. The x-axis values seem to be oppositely identical to the GPS values while the y-axis values seem to match pretty well in the scale of magnitude shift is negated while observing them. These observations will be used in the following section when aligning and scaling the displacement values to match the GPS trajectory.

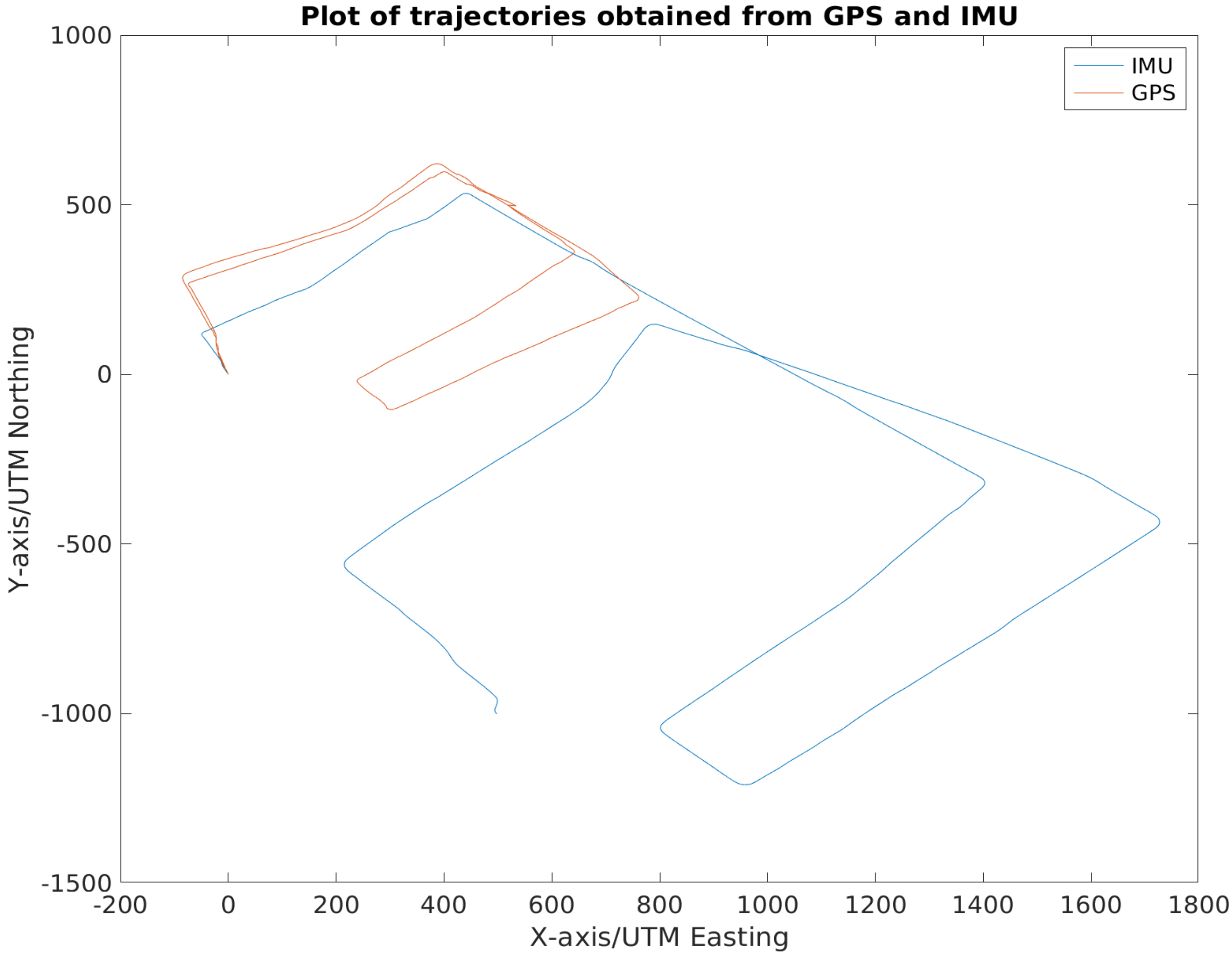


1) Computing the accelerations in the y-direction (sliding of the car), we get the following figure.



Here, we notice that there is a slight offset in the calculated (w*X_dot) values compared to the actual observed readings. This can be easily noticed at instances where the vehicle was stationary while collecting the data. This offset is slowly increasing from one stationary point to the next as time passes. Another observation is the higher magnitude and variation noticed in the calculated values. The reasoning for this could not be ascertained with strong reasoning, but the primary reason is thought to be due to the offset x_c between the center-of-mass and the IMU device in the vehicle.

2) The integrated and subsequently oriented and scaled figure of the trajectory obtained from the IMU and that from the GPS is plotted below.



Here, the scaling factor used is 0.5. The scaling factor is limited to 0.5 since further scaling of the IMU plot could scale it down in an undesirable way wherein one axis would be too small when compared to both the other axis, as well as the GPS trajectory.

Conclusion:

Finally, we can conclude that the IMU is an amazing sensor capable of reading numerous parameters of data that can be then applied to a variety of applications. Yet, there are some shortcomings that can be observed in its usage. The sensor, though really useful, can at time be very sensitive and thus be part to recording of very noisy data that might require a lot of analysis and cleaning for its final use. A good knowledge and experience in signal processing and cleaning of the data can thus be the key to unlocking the full potential an IMU.