LAB 3

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Preamble –

The following analysis was performed using the VN-100 (accel-gyro-mag) sensor. The data set has been collected for (a) Short interval (5 mins) and a (b) Long interval (5 hrs) for the purpose of calculating the Allan Variance and the error analysis of the sensor data collected from the sensor. The short version of the data was collected on the 3rd floor of Snell Library, while the longer version of the data was collected on a 14th floor of a build on a desk (next to where I sleep).

Analysis –

A. Short Interval (5 mins)

Below are the Time and Frequency plots of the sensor data collected over a period of 5 mins. From the plots we can infer that the error of the data has a **gaussian distribution**. The QQ plots in the end helps us access if the set of data comes from a theoretical distribution (like a gaussian). The following table illustrates the standard deviation, mean and the variance of the collected data.

	Ang. Vel. X	**Ang. Vel. Y**	**Ang. Vel. Z**	**Lin Acc. X**	**Lin Acc. Y**	**Lin Acc. Z**	**Mag Fld. X**	**Mag Fld. Y**	**Mag Fld. Z**
SD	0.0024	0.0040	0.0007	0.0142	0.0131	0.0221	0.0021	0.0020	0.0064
Mean	-0.0021	0.0022	-0.0003	0.24137	-0.414	-9.497	-0.330	-0.187	0.050
Var	5.93e-06	1.62e-05	5.60e-07	0.0002020	0.00017	0.000490	4.35e-06	3.86e-06	4.15e-05

Table 1. SD, Mean and Variance of the collected data.

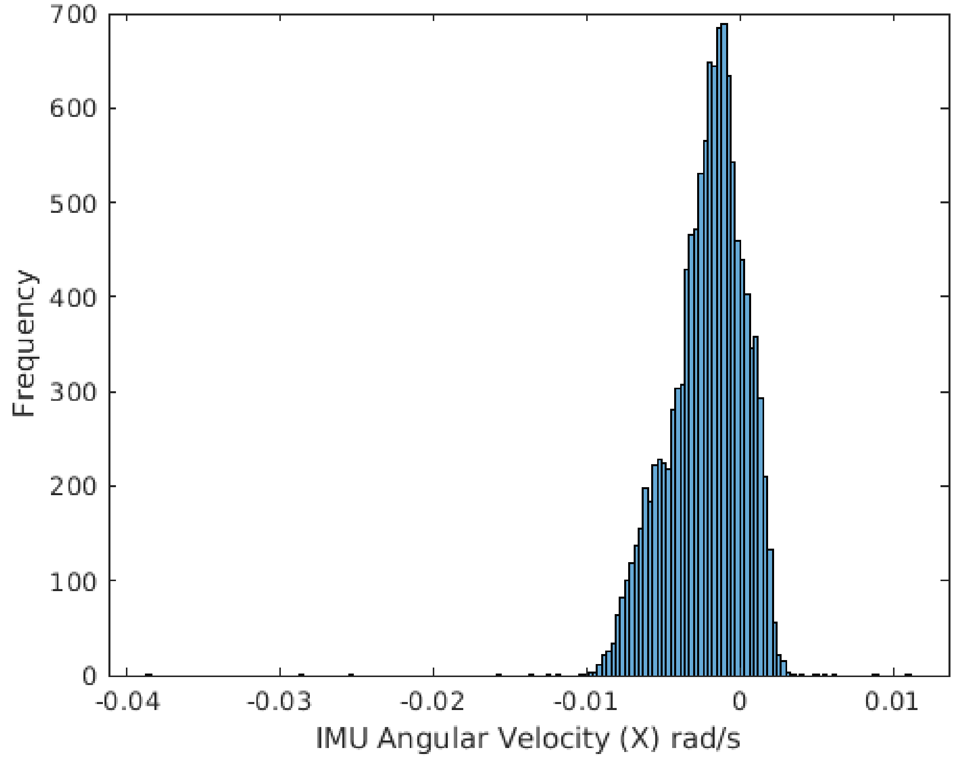
Note: I have not added the orientation data into this table as **Orientations are not vectors!!** One cannot approximate noise in the orientation of a robot by analysis of Gaussian Distribution. The orientation of a robot in a plane is just a **unit circle**. We must use the topological and geometrical information of the object to approximate the correct orientation, this requires the use of the concepts of Lie Algebra!

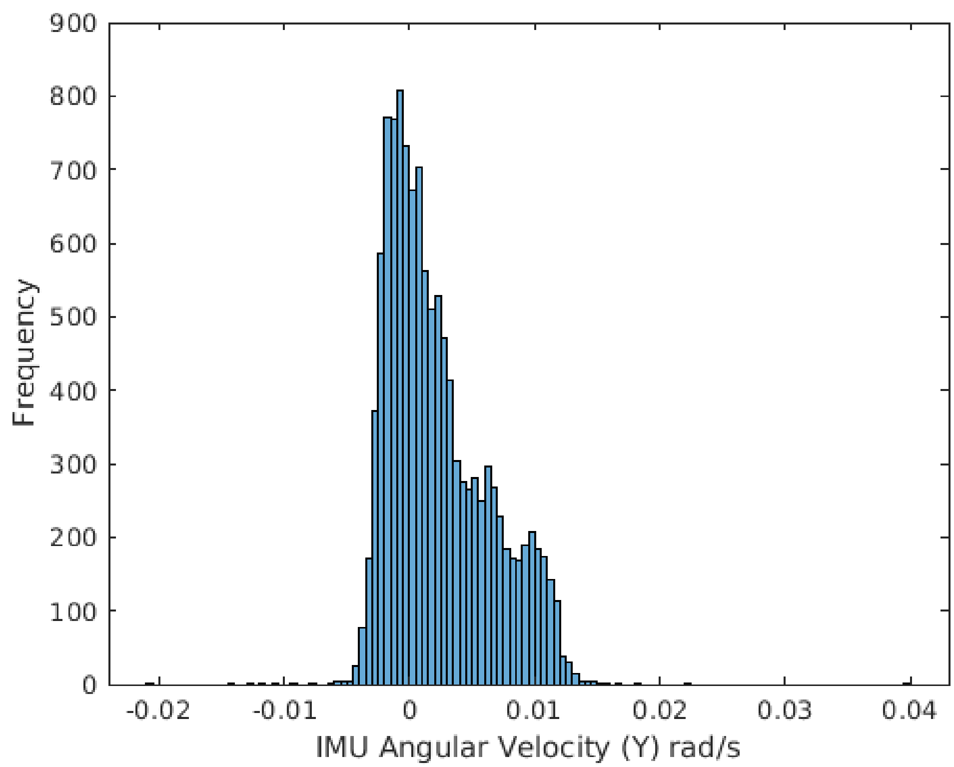
Further, we can observer obvious spikes in our data between different intervals of time. This noise in the data is due to the vibrations, contributed by the passers-by at the library. The accelerometer data in the 'Z' axis shows values around -9.497 m/s^2, this is due to the presence of the Gravitational forces.

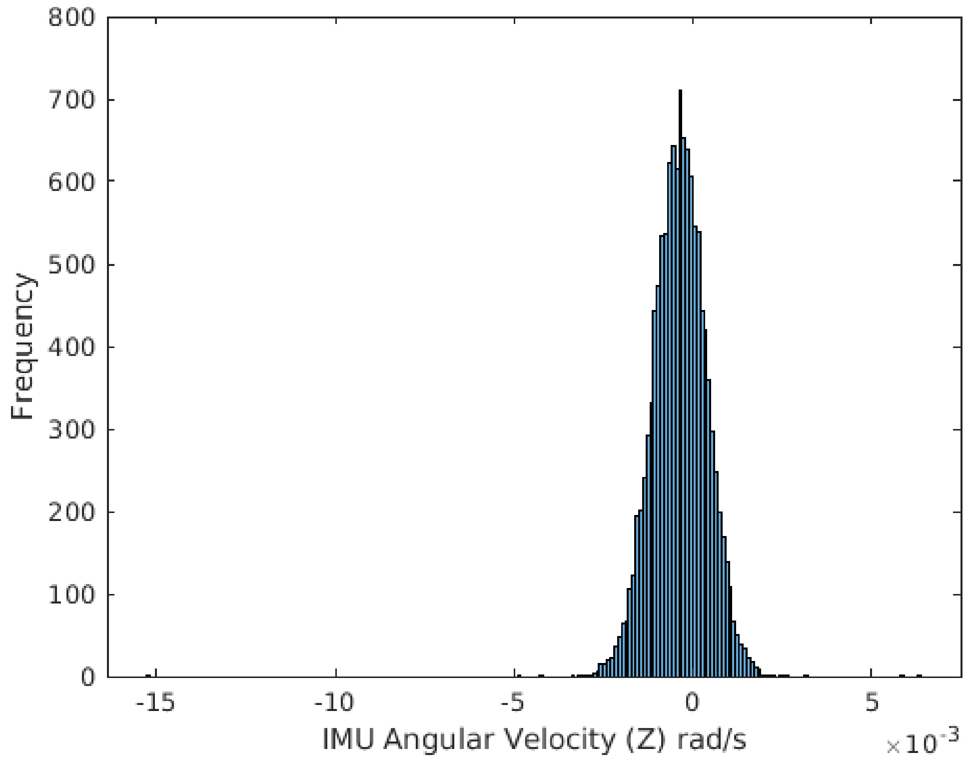
We also observed spikes in out Magnetic Field data due to the presence of electronic devices and absence of any magnetic field calibrations.

In order to remove this noise in the system we can employ filters like Low-Pass, High-Pass, Band-Pass filters that can attenuate a range of different frequencies.

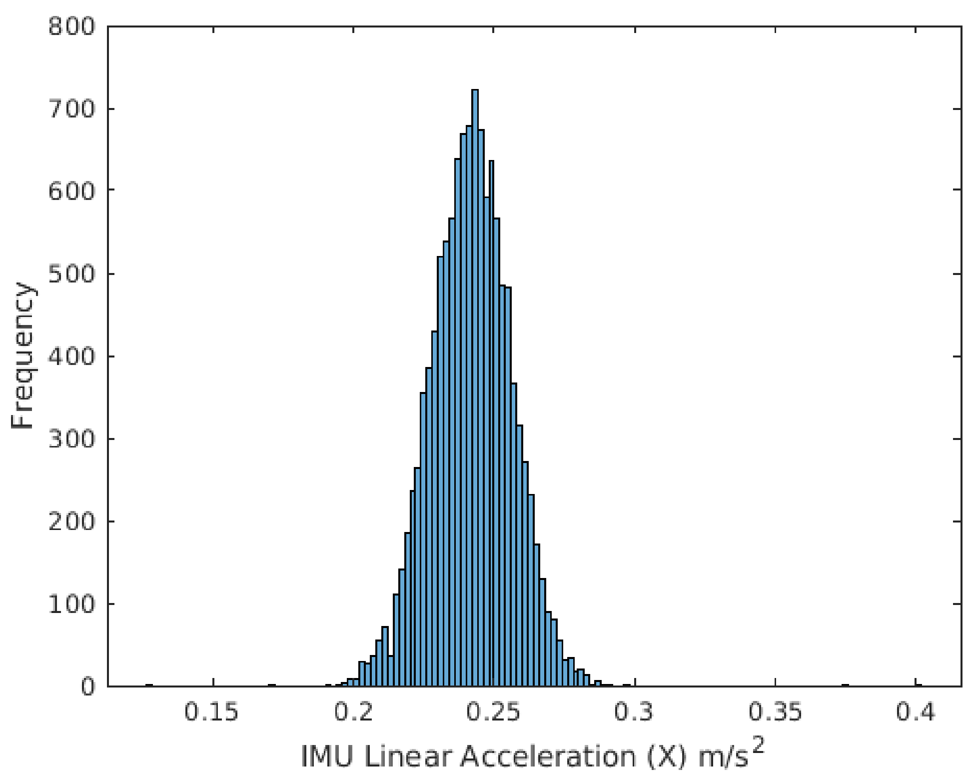
Frequency plots for Short Period Data collected



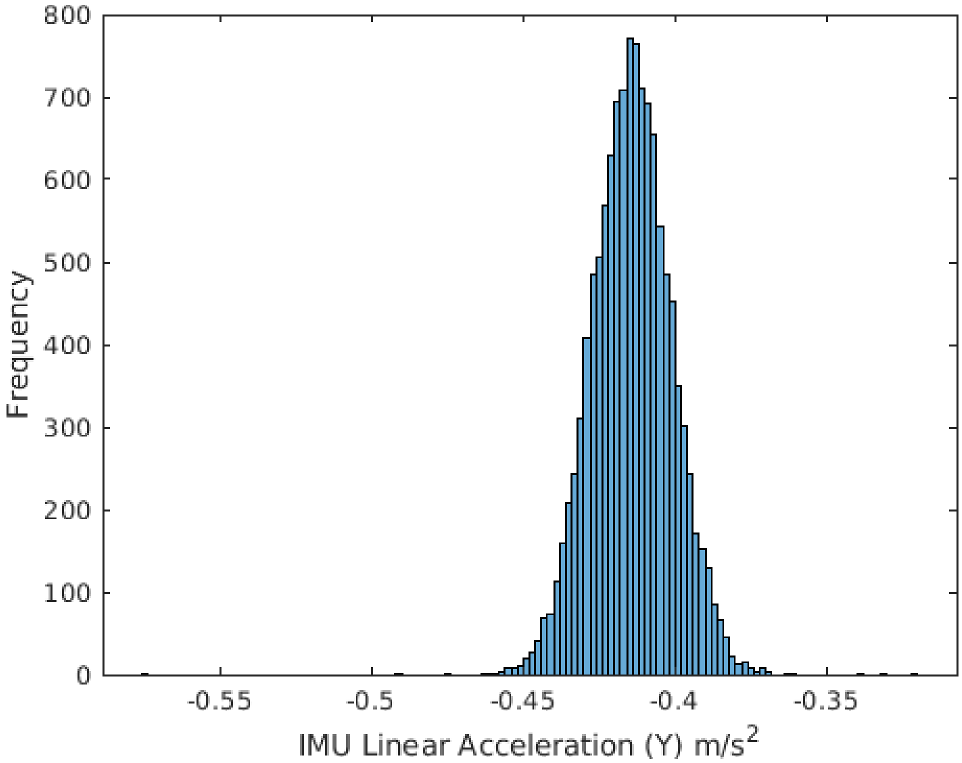




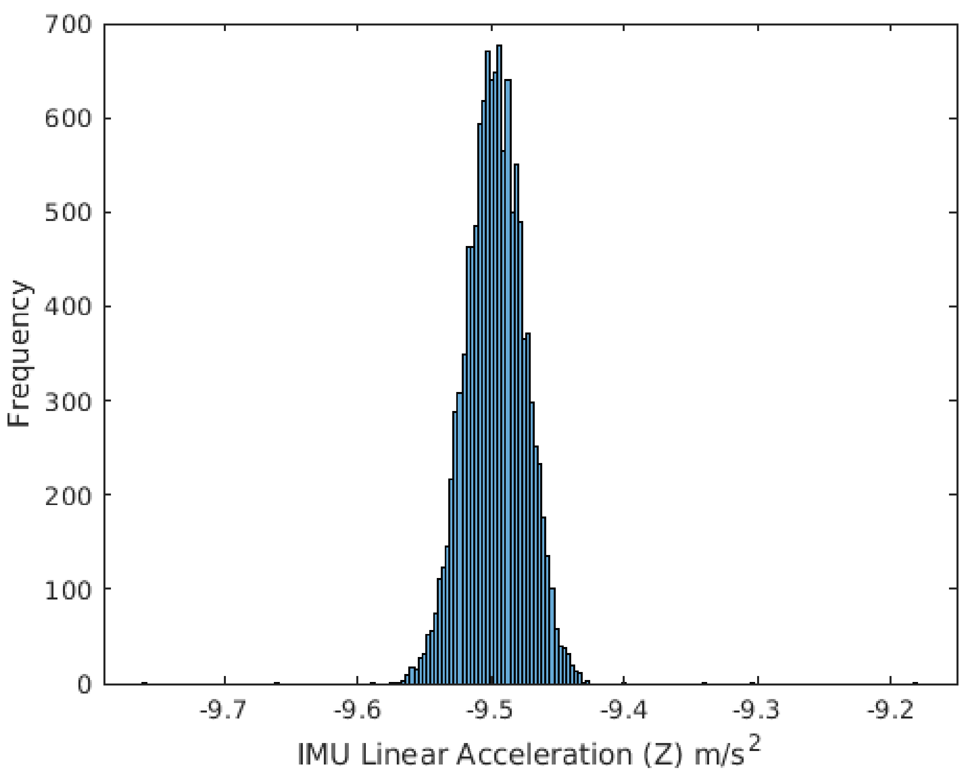
800
700
600
500
400
300
200
100
0
Frequency
-15
-10
-5
0
5
IMU Angular Velocity (Z) rad/s
×10^-3



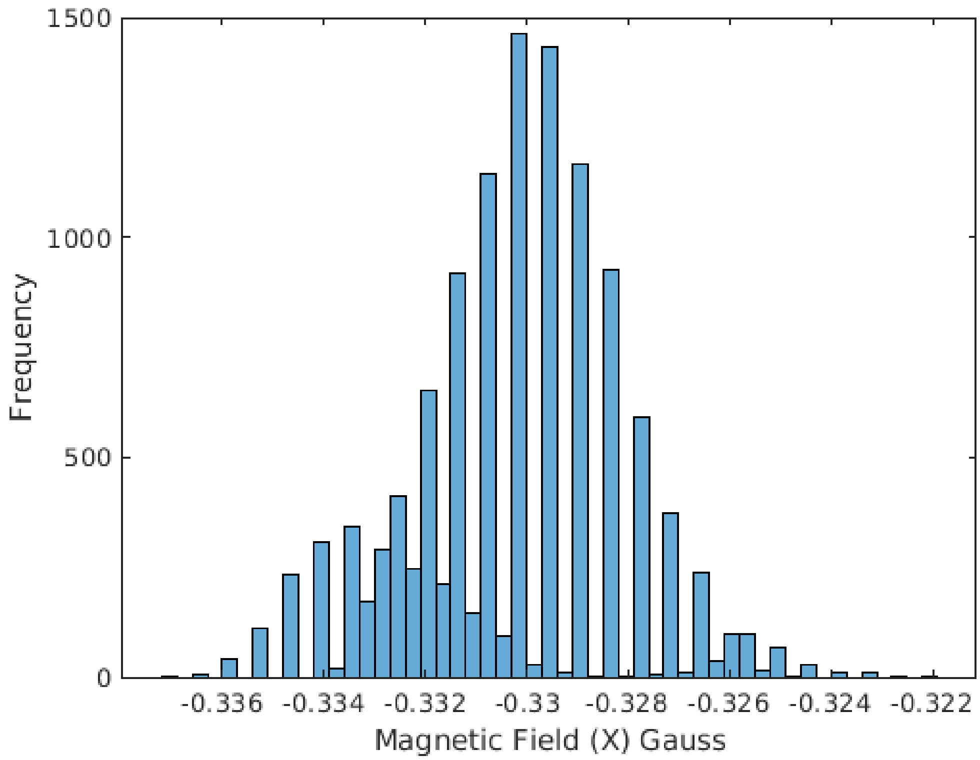
800
700
600
500
400
300
200
100
0
Frequency
0.15
0.2
0.25
0.3
0.35
0.4
IMU Linear Acceleration (X) m/s^2

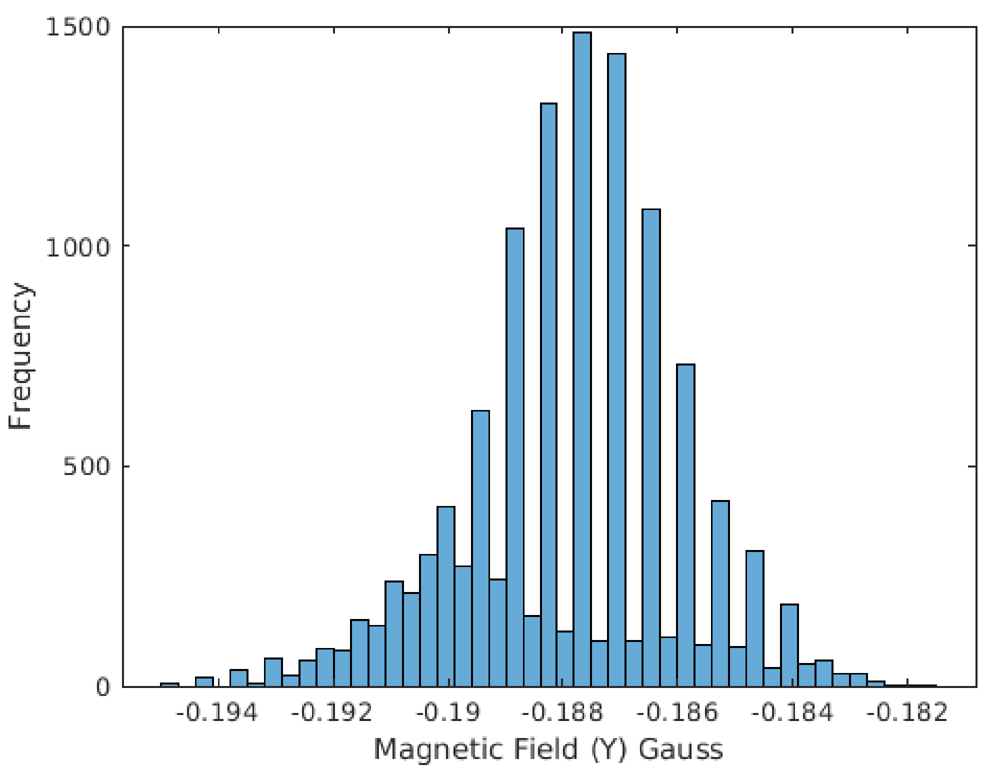


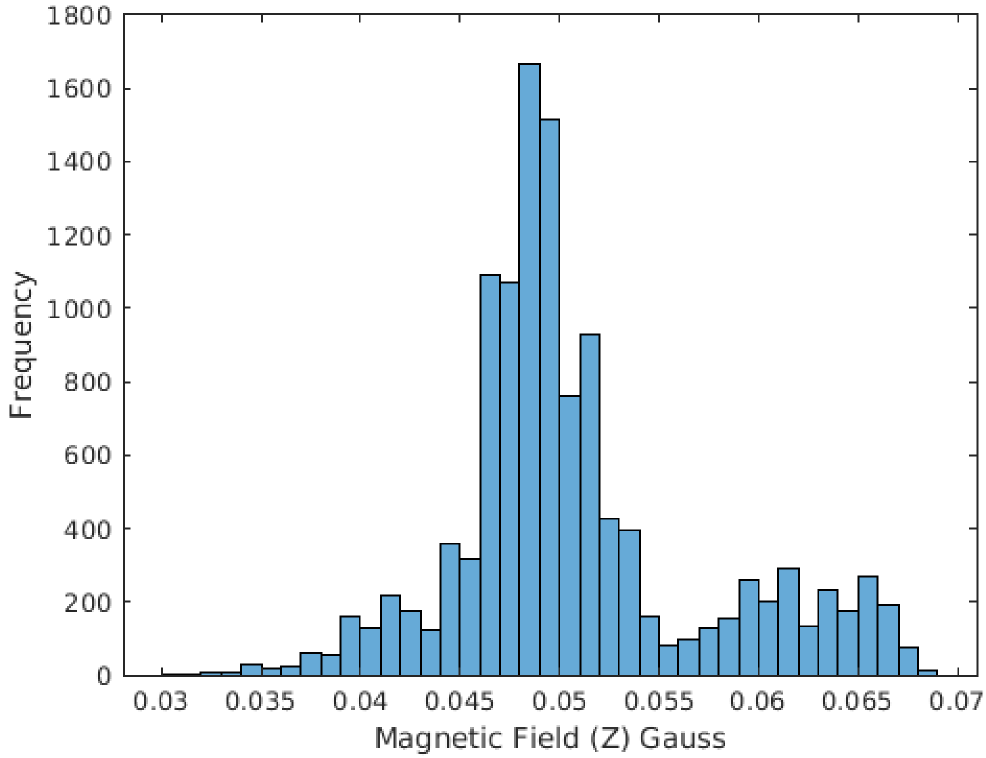
Frequency
IMU Linear Acceleration (Y) m/s^2



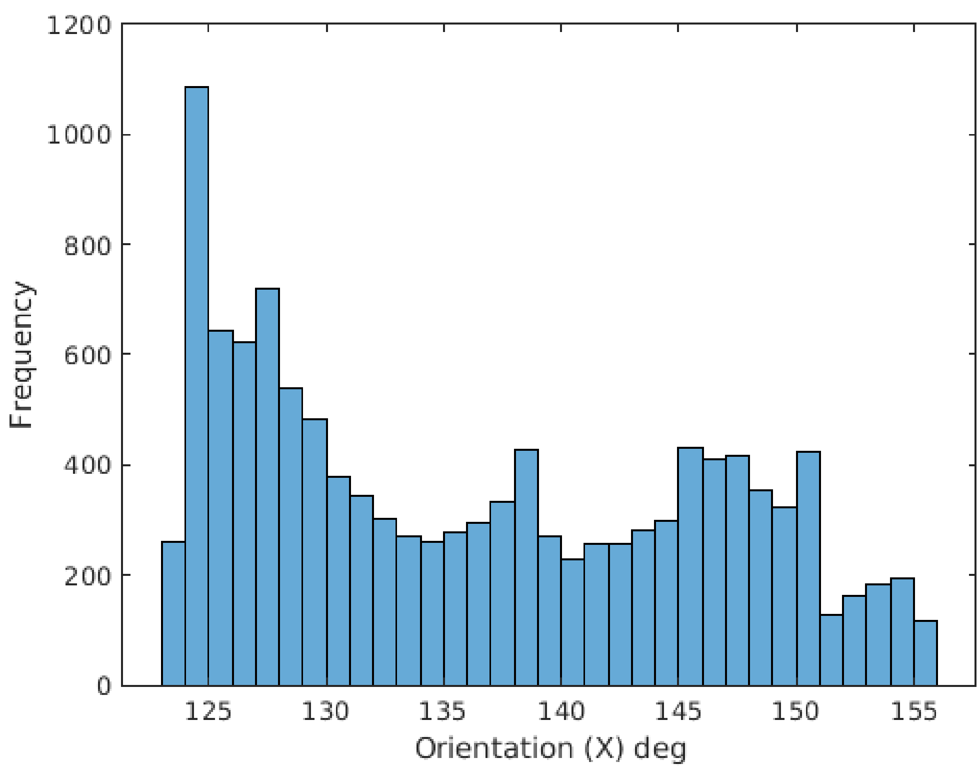
Frequency
IMU Linear Acceleration (Z) m/s^2


1500
1000
500
0
Frequency
-0.336
-0.334
-0.332
-0.33
-0.328
-0.326
-0.324
-0.322
Magnetic Field (X) Gauss

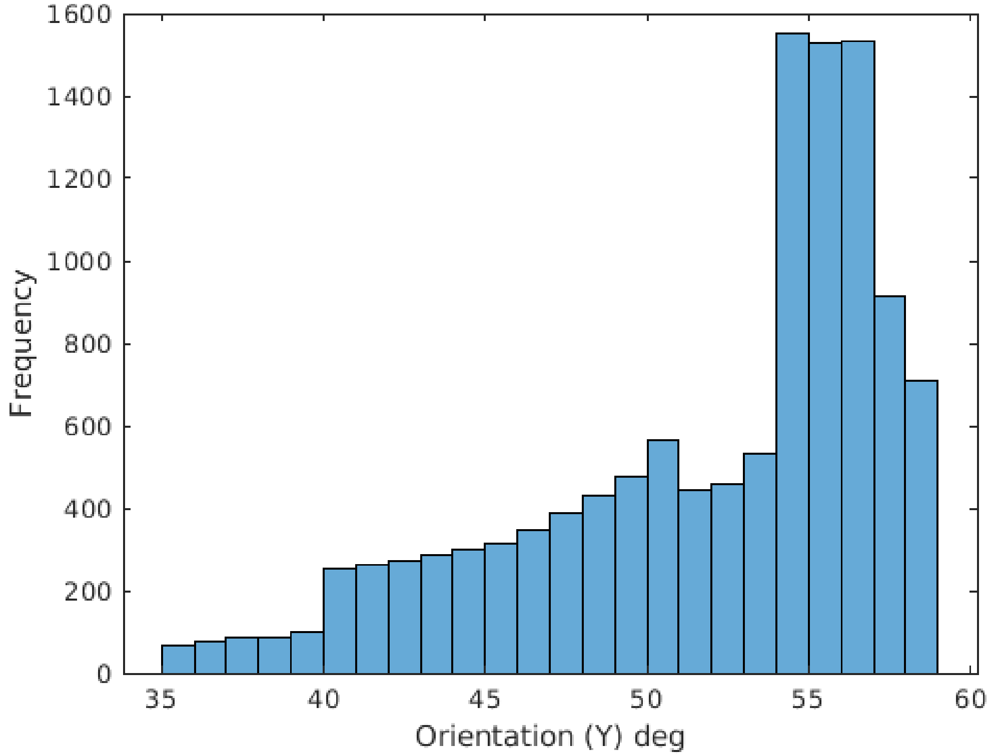

1500
1000
500
0
Frequency
-0.194
-0.192
-0.19
-0.188
-0.186
-0.184
-0.182
Magnetic Field (Y) Gauss



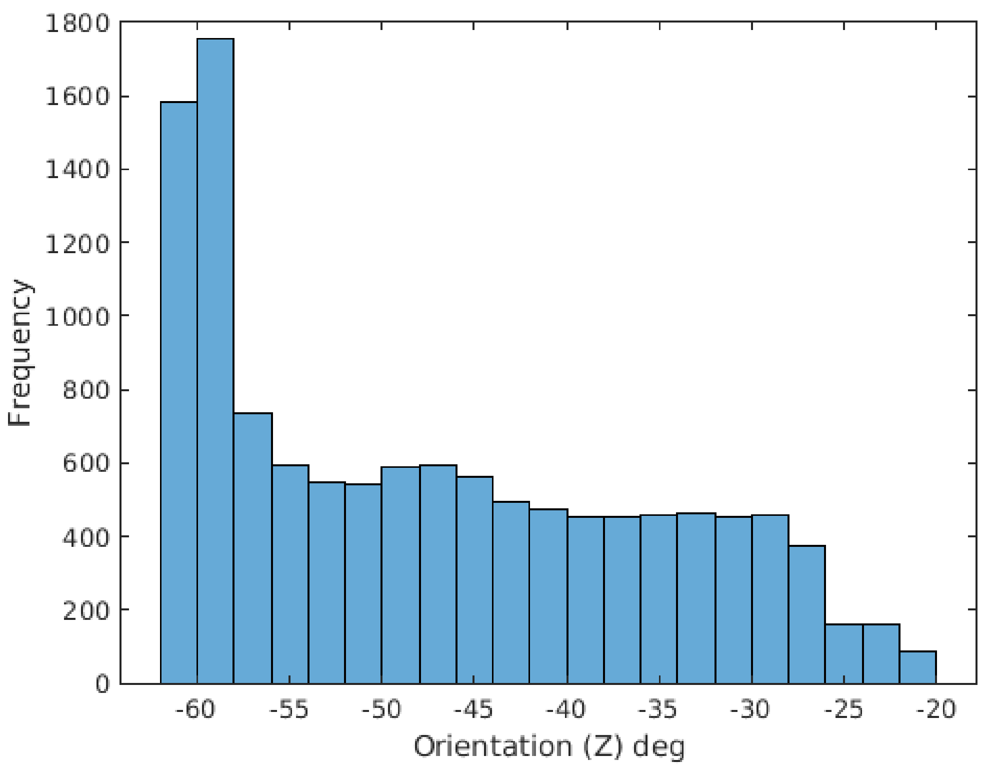
1800
1600
1400
1200
1000
800
600
400
200
0
Frequency
0.03
0.035
0.04
0.045
0.05
0.055
0.06
0.065
0.07
Magnetic Field (Z) Gauss



1200
1000
800
600
400
200
0
Frequency
125
130
135
140
145
150
155
Orientation (X) deg

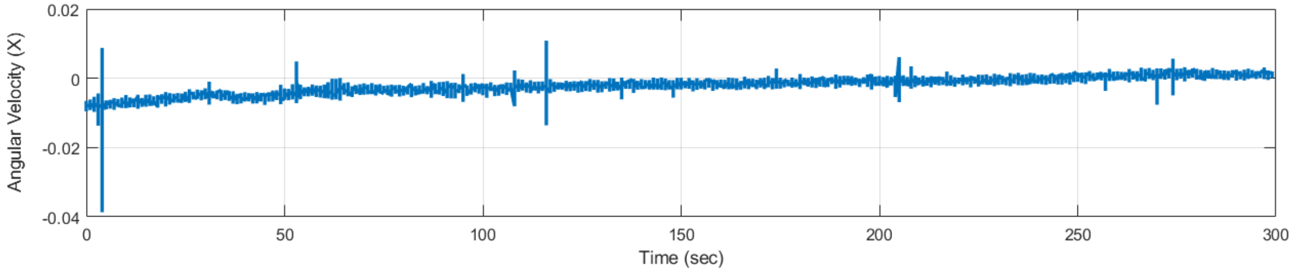


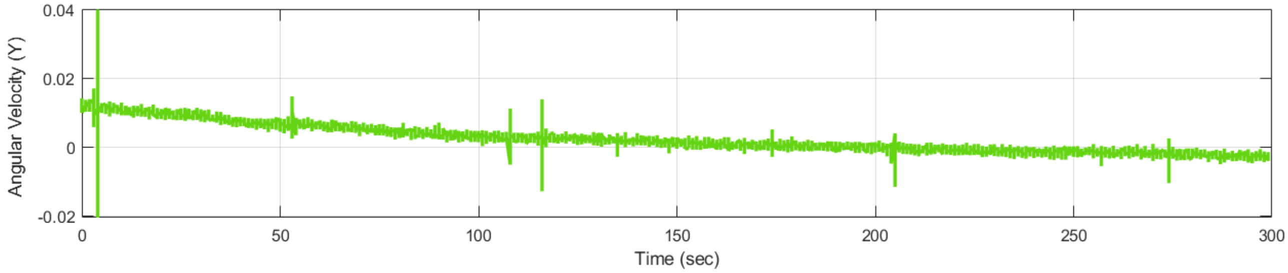
Frequency
Orientation (Y) deg

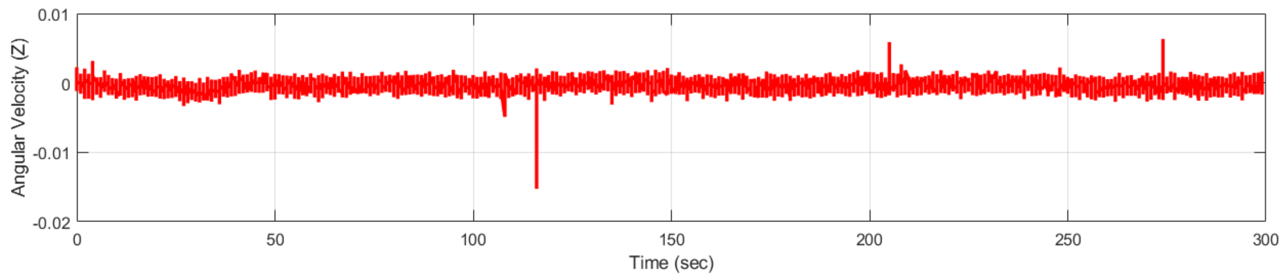


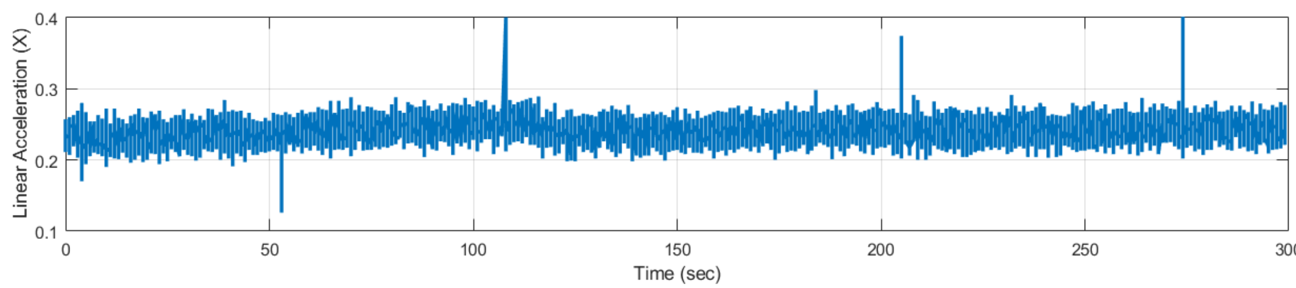
Frequency
Orientation (Z) deg

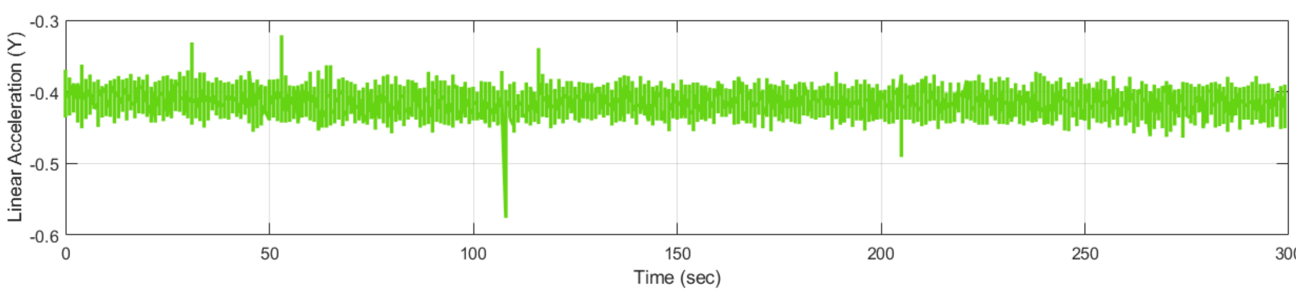
Time plots for Short Period Data collected

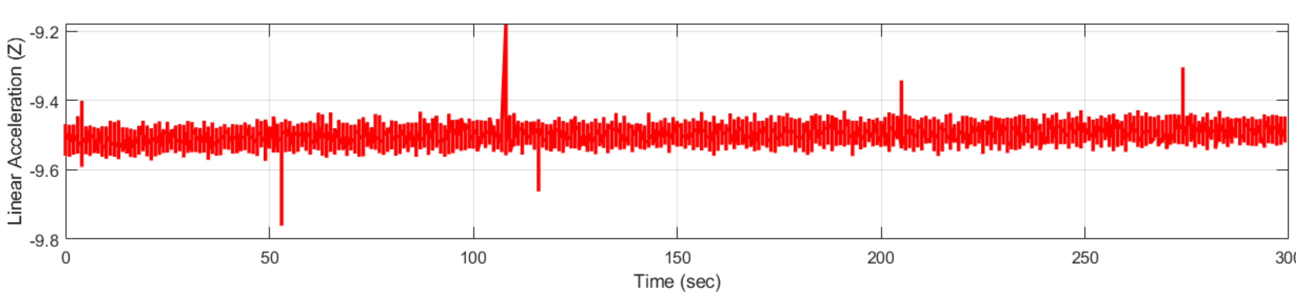


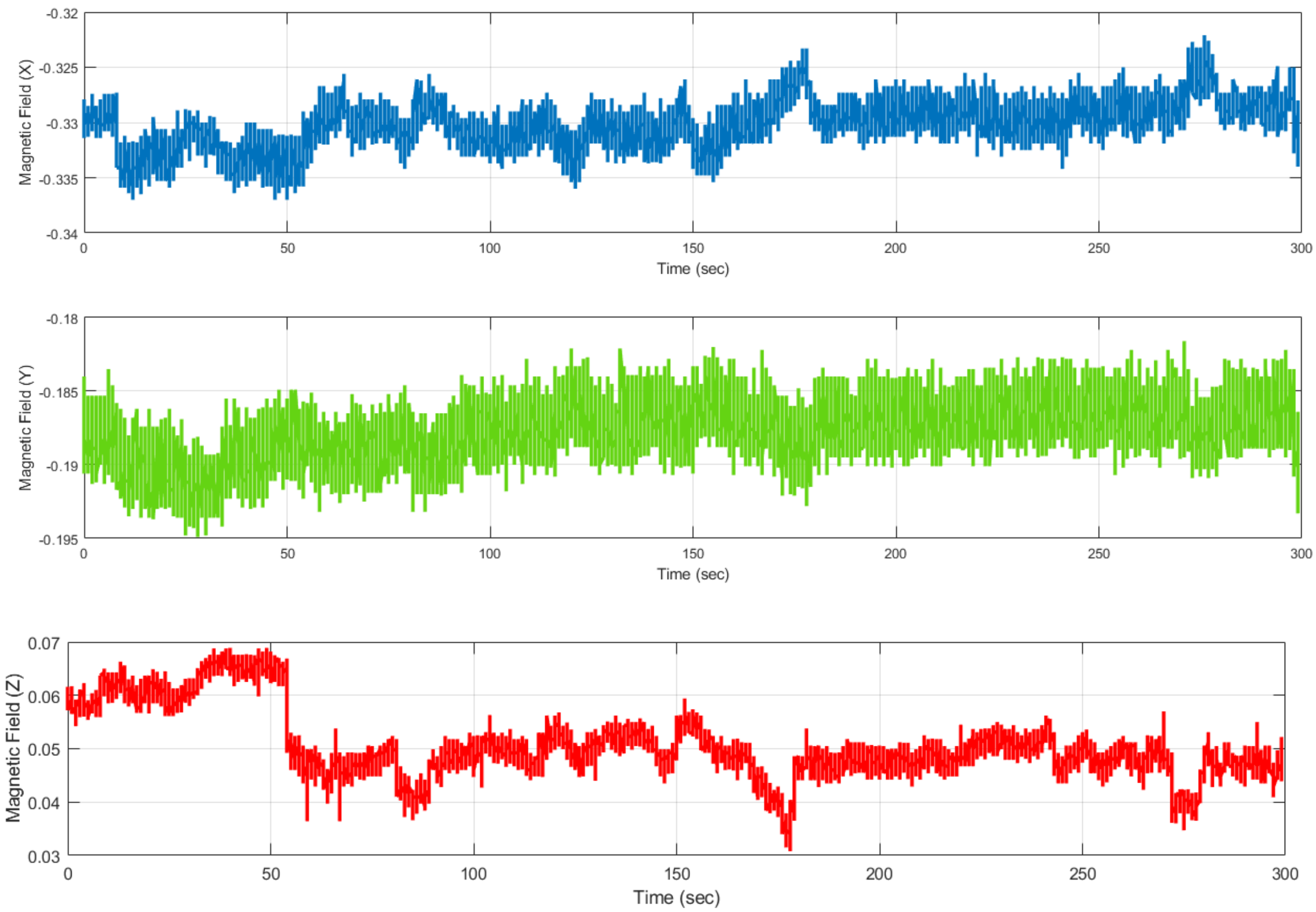




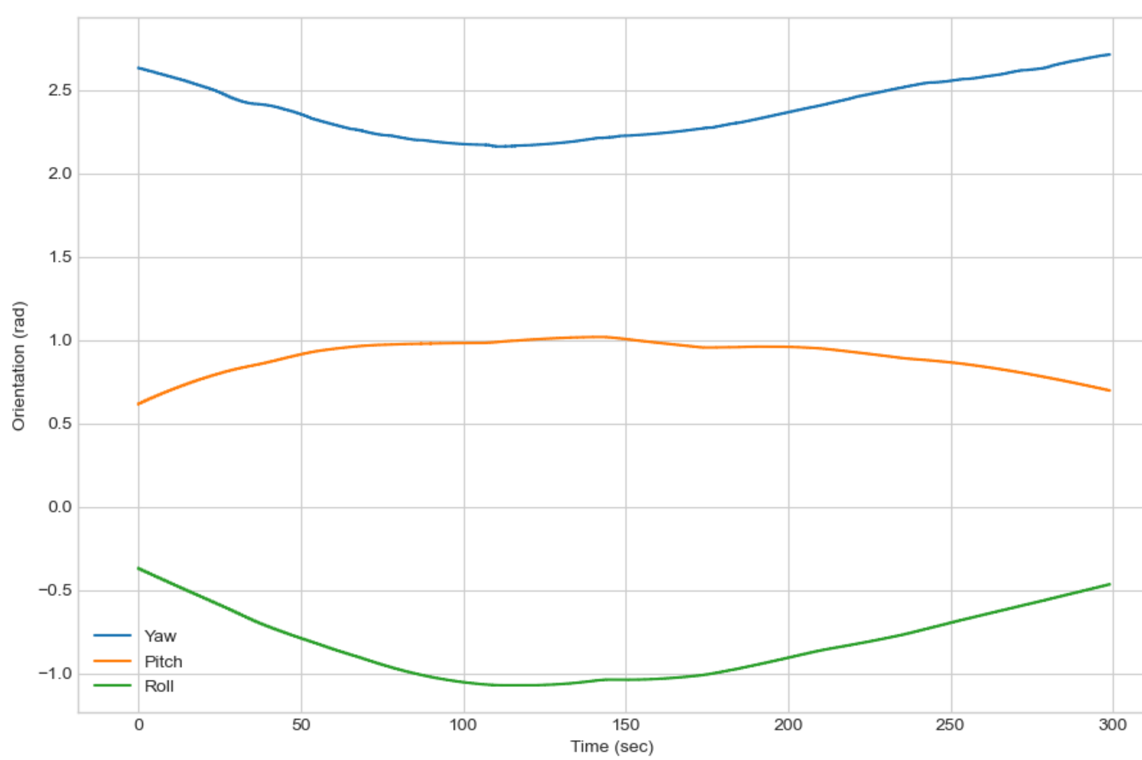








Magnetic Field (X)
Time (sec)
Magnetic Field (Y)
Time (sec)
Magnetic Field (Z)
Time (sec)



Yaw
Pitch
Roll
Orientation (rad)
Time (sec)

B. Long Interval (5 hrs)

Below are the Allan Variance along with the noise parameters of the Gyroscope and Acceleration data. The Angle Random Walk and the Bias Instability of the gyroscope data collected have been illustrated in the table below.

	Bias Instability [deg/hr]	**Angle Random Walk [deg/sec sqrt(Hz)]**	**Noise Density**
X	1.3719598625528957	6.103764200211175e-06	0.0055
Y	3.0972722966746793	4.23935487295135e-06	0.0061
Z	0.5289221093787566	1.5832399530845806e-06	0.0061

Table 2. Bias Instability and Angle Random Walk of Gyroscope

The Velocity Random Walk and the Bias Instability of the accelerometer data collected have been illustrated in the table below.

	Bias Instability [mg]	**Velocity Random Walk [m/sec sqrt(Hr)]**	**Noise Density**
X	0.058597401778397326	0.011600266742164527	0.2053
Y	0.061909472907145456	0.01368191651558229	0.1969
Z	0.05629284071201202	0.00463041028566747	0.3069

Table 3. Bias Instability and Velocity Random Walk of Accelerometer

The specifications of the sensor note the following values

	Bias Instability	**Random Walk**	**Noise Density**
Accel	<0.04 mg		0.14 mg/sqrt(Hz)
Gyro	5-7 deg/hr		0.0035 deg/sec sqrt(Hz)

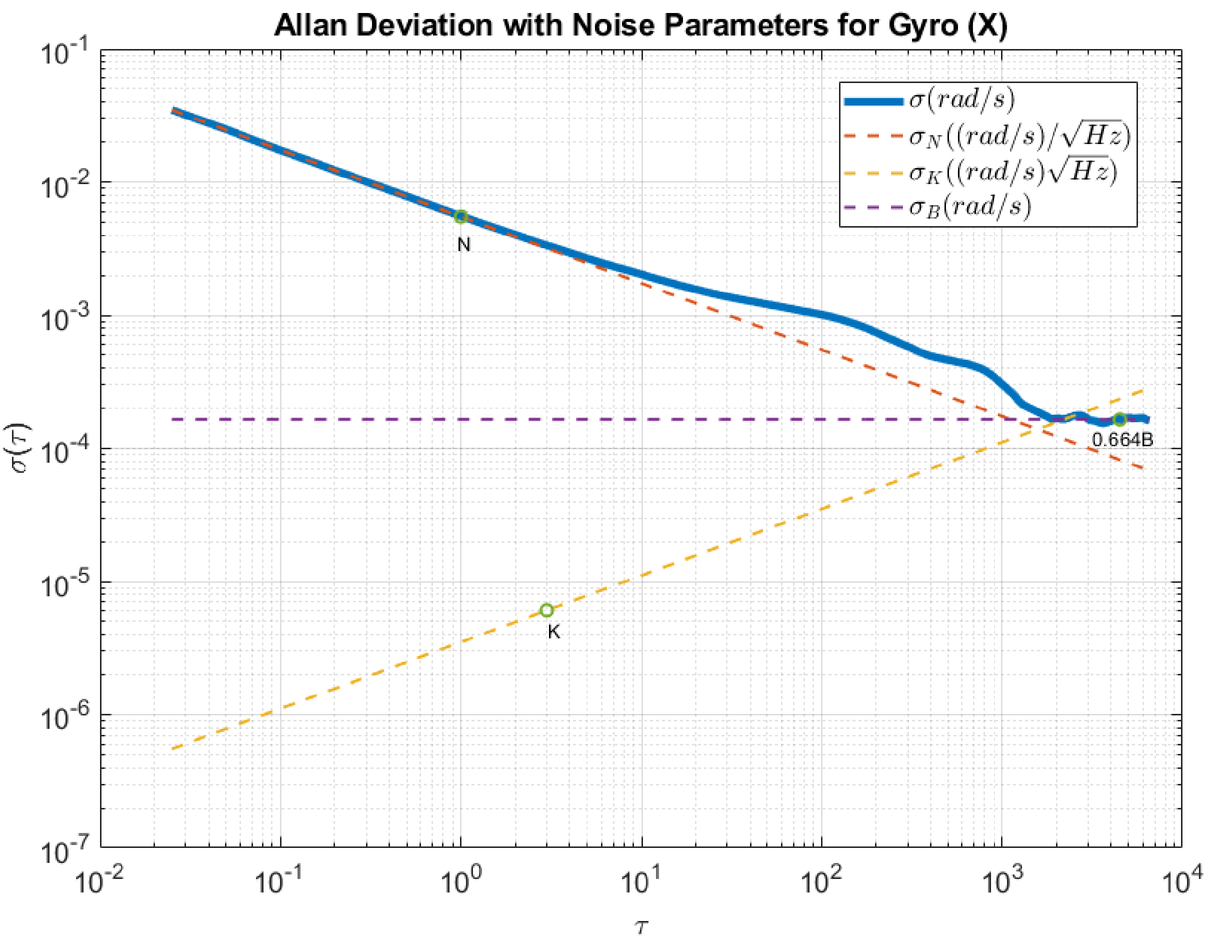
Table 4. Specifications of the sensor VN-100

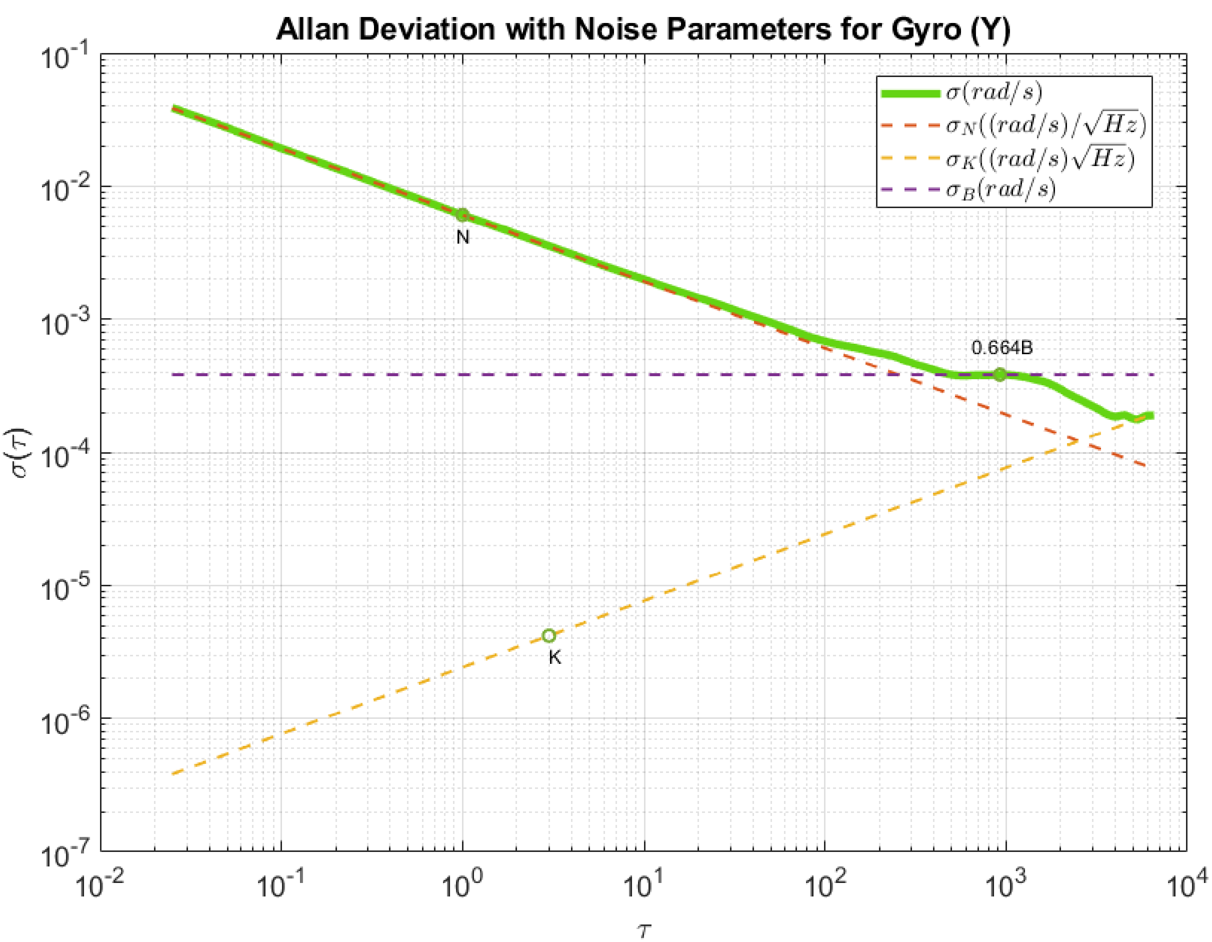
From the sensor specifications, the Inrun bias stability of the accelerometer is **<0.04 mg**. We can observer that the Bias Instability observer is slightly higher. This could be due to the change in temperature at which the sensor measurements were performed. The Bias is the constant offset of the output value from the input. It is measured over constant temperature. Th bias of a sensor changes for different ranges of temperatures.

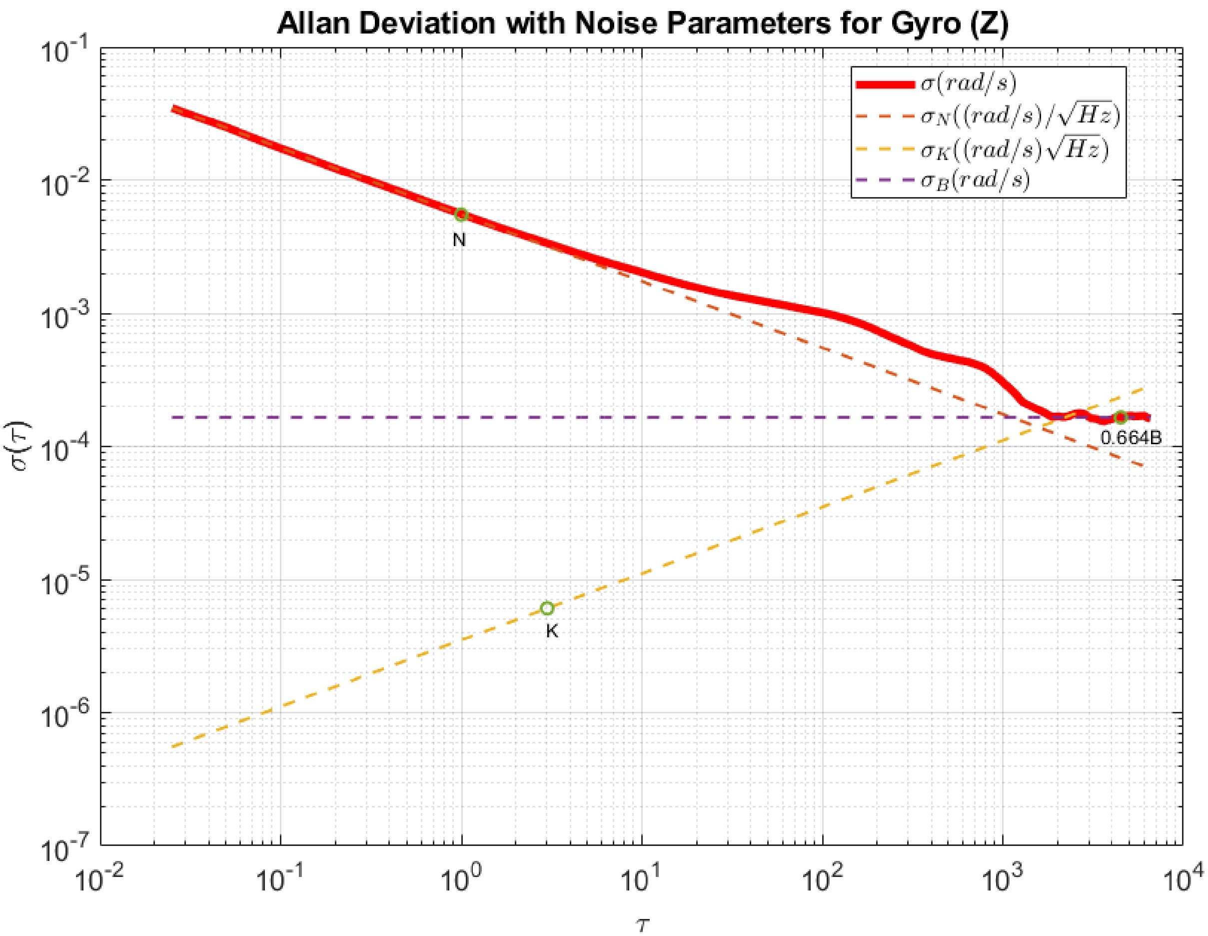
Our sensor has a Noise density of **0.0035 deg/sec sqrt(Hz)**, from our measurements 0.0055 deg/sec sqrt(Hz). This is higher compared to the data sheet due to the presence of higher white Gaussian Noise in the system. This noise could be due to random disturbances in the system. In this case, the system was placed next to my bed, hence, once can infer that the vibrations caused due to the sleeping pattern could have affected a higher White Gaussian Noise in the system.

The Random walk of a noisy signal is the calculated by integrating the output signal to look at the drift of the values over due to the noise. The inertial sensor has 2 two types of random walk called the Angle Random Walk (gyro data) and the Velocity Random Walk (accelerometer data).

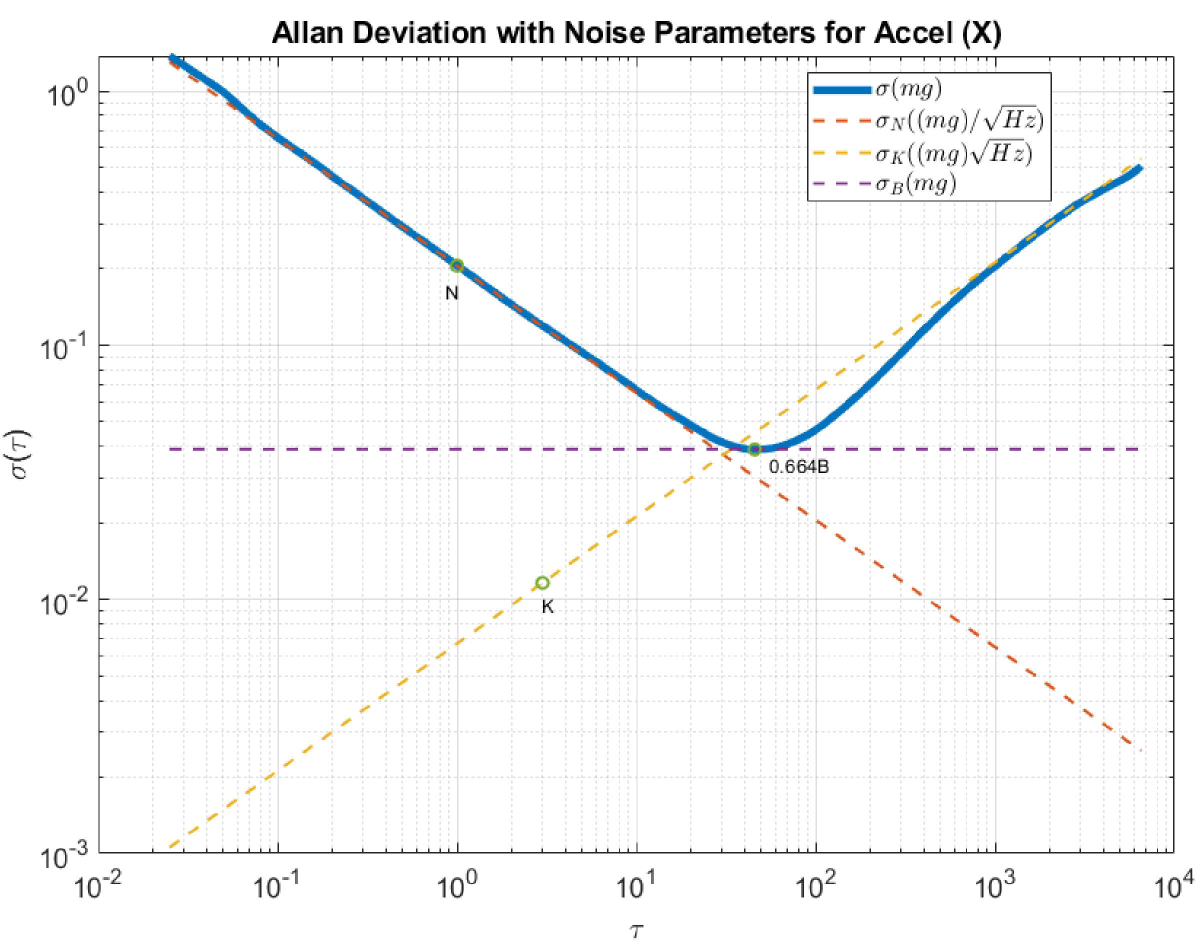
Allan Variance Plots



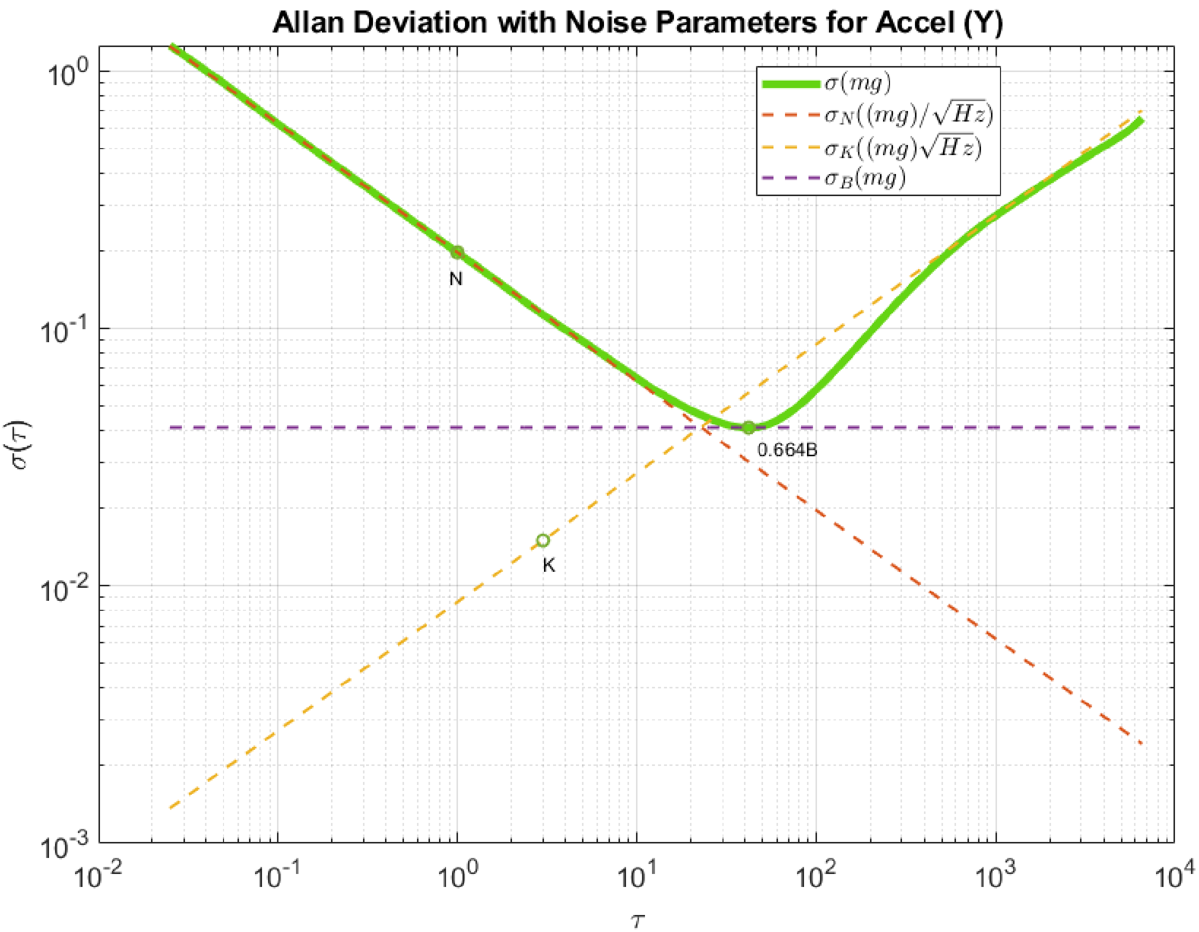


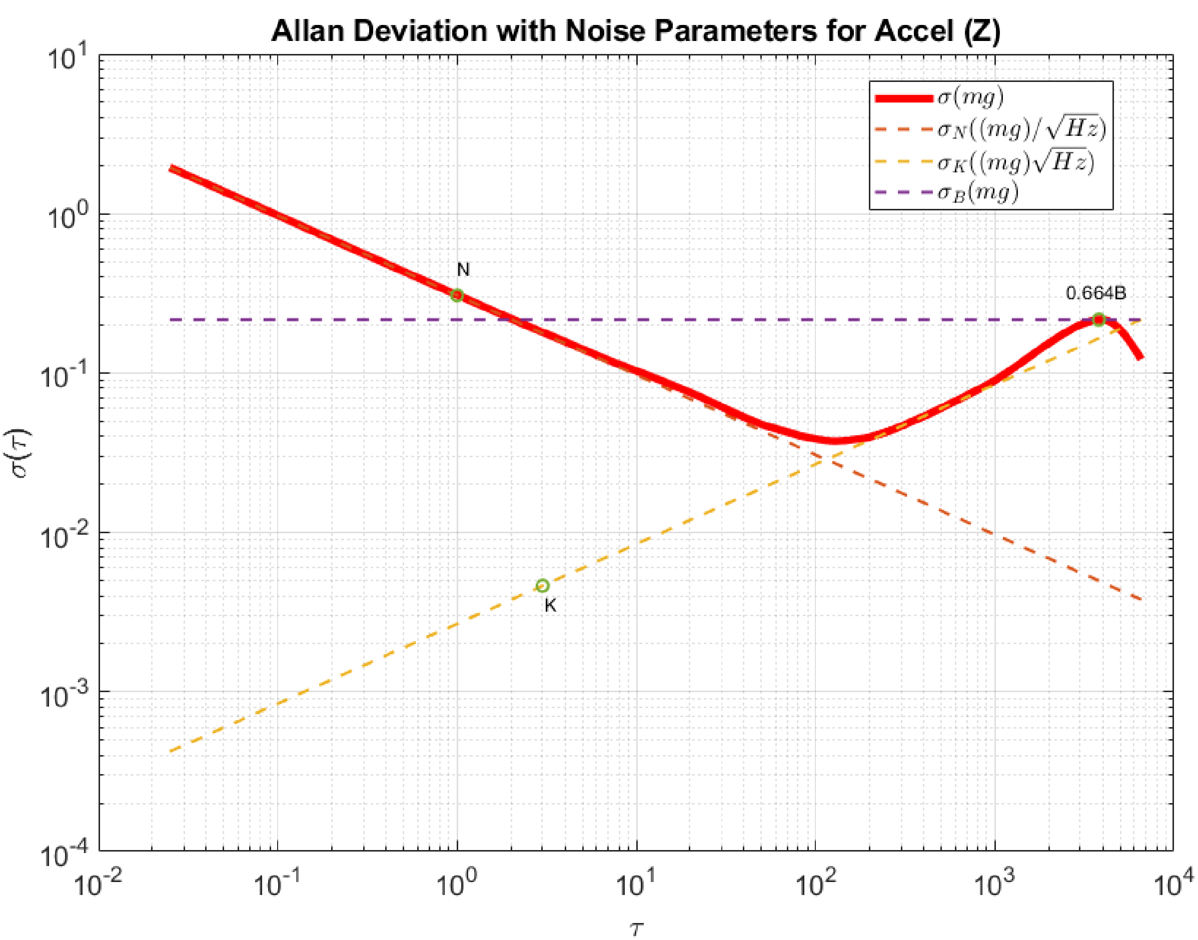


Allan Deviation with Noise Parameters for Gyro (Z)
$\sigma(rad/s)$
$\sigma_N((rad/s)/\sqrt{Hz})$
$\sigma_K((rad/s)\sqrt{Hz})$
$\sigma_B(rad/s)$
N
K
0.664B
$\sigma(\tau)$
τ



Allan Deviation with Noise Parameters for Accel (X)
$\sigma(mg)$
$\sigma_N((mg)/\sqrt{Hz})$
$\sigma_K((mg)\sqrt{Hz})$
$\sigma_B(mg)$
N
K
0.664B
$\sigma(\tau)$
τ

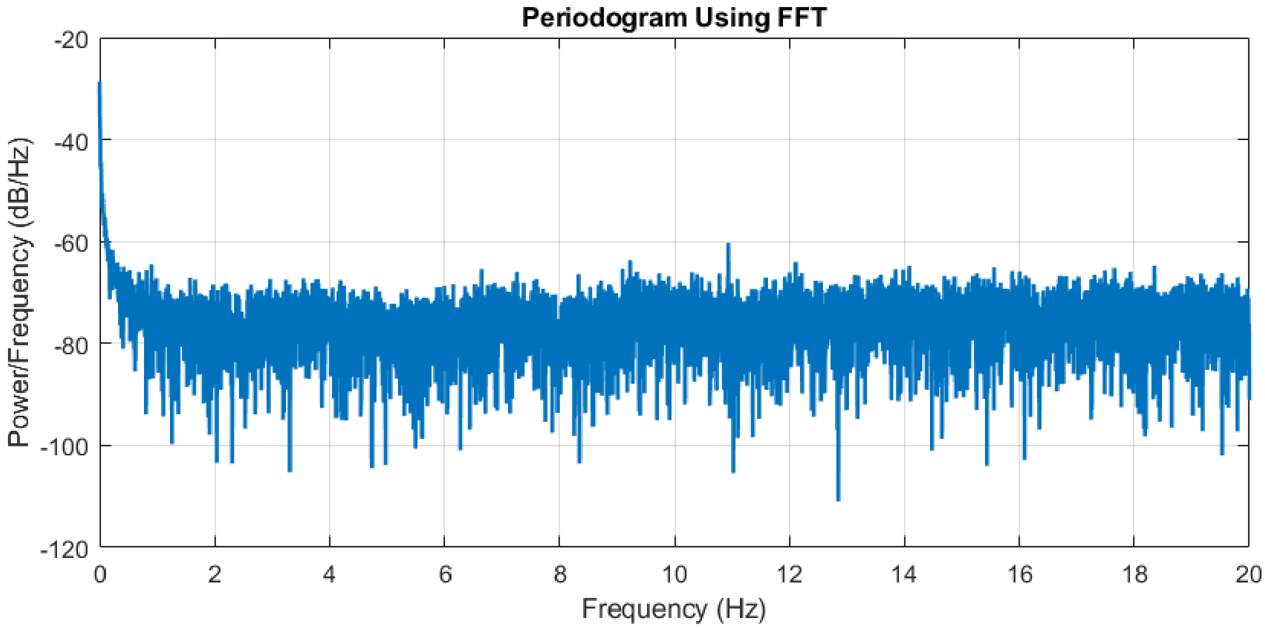

Allan Deviation with Noise Parameters for Accel (Y)
$\sigma(mg)$
$\sigma_N((mg)/\sqrt{Hz})$
$\sigma_K((mg)\sqrt{Hz})$
$\sigma_B(mg)$
N
K
0.664B
$\sigma(\tau)$
τ
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4

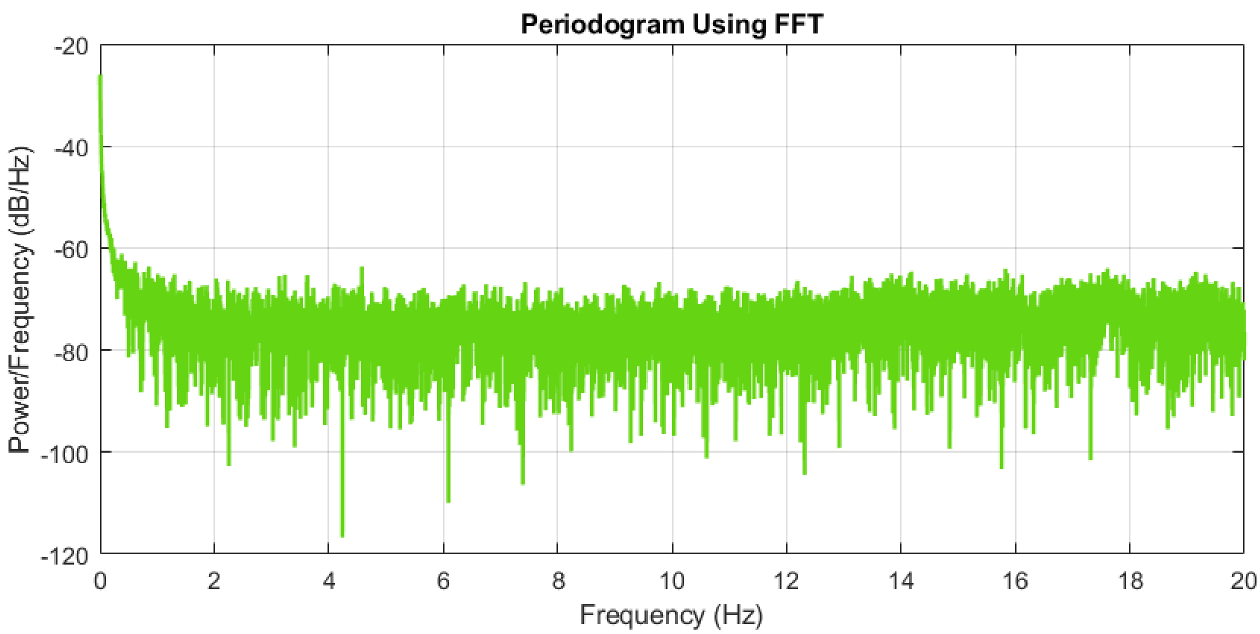

Allan Deviation with Noise Parameters for Accel (Z)
$\sigma(mg)$
$\sigma_N((mg)/\sqrt{Hz})$
$\sigma_K((mg)\sqrt{Hz})$
$\sigma_B(mg)$
N
0.664B
K
$\sigma(\tau)$
τ
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4

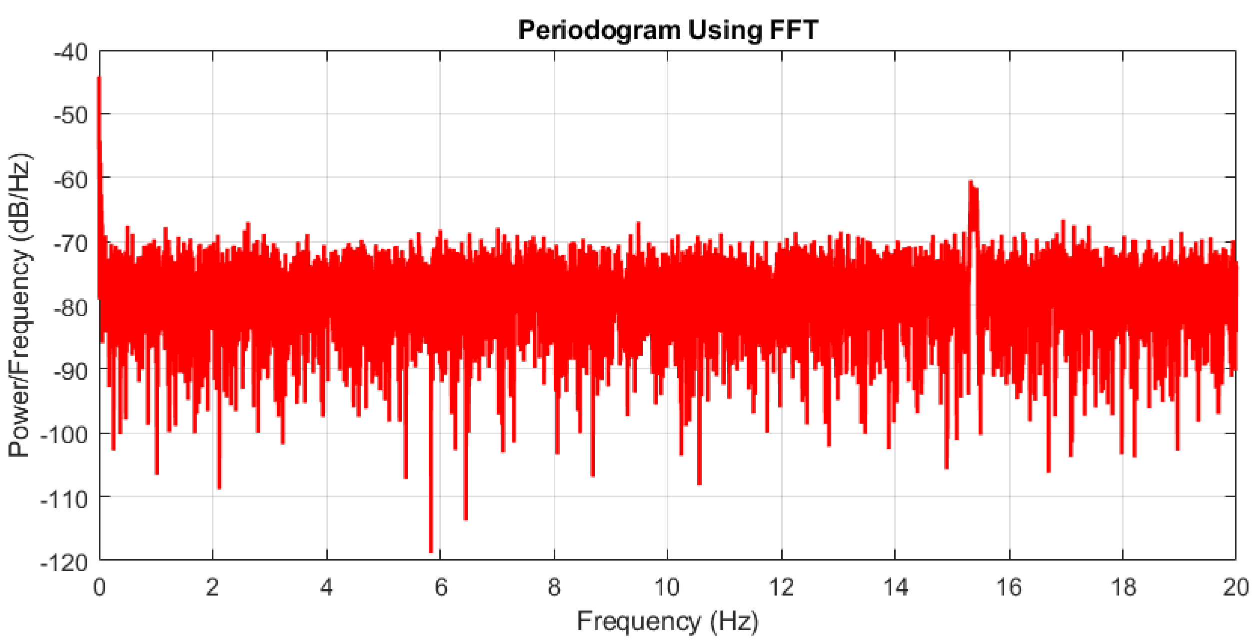
C. Colours of Noise.

We can understand much more about the sources of noise in the system by modelling the different colours of noise. This can be done using Power Spectral Density. Using `periodogram`, a function in MATLAB we can obtain an equivalent nonparametric PSD estimate of the `fft` functions. From the below plots one can separate the different colours of noise by plotting the S(f), Spectral Density (1/f). We can see a combination of White, Pink and Brown noise in Gyroscope data.

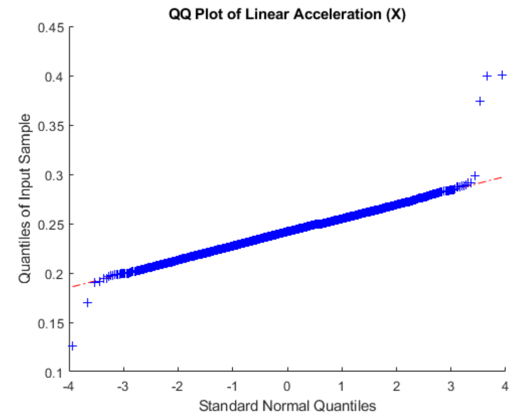
Plots for PSD of the collected data

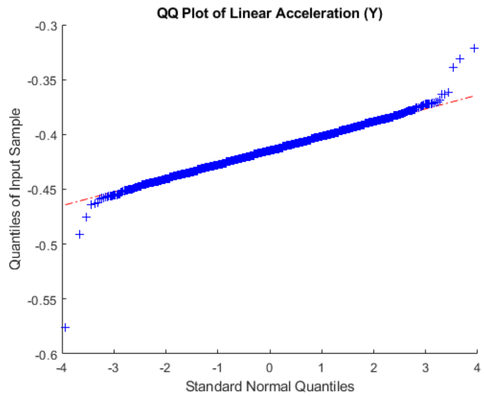


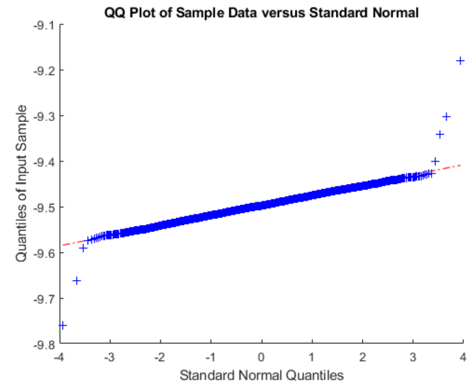


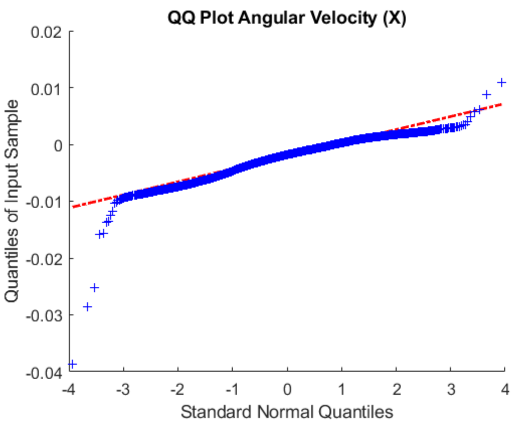


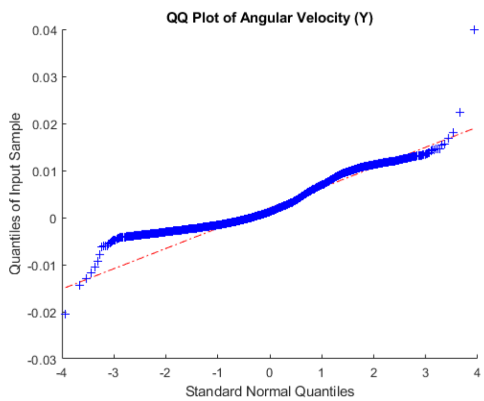
QQ plots

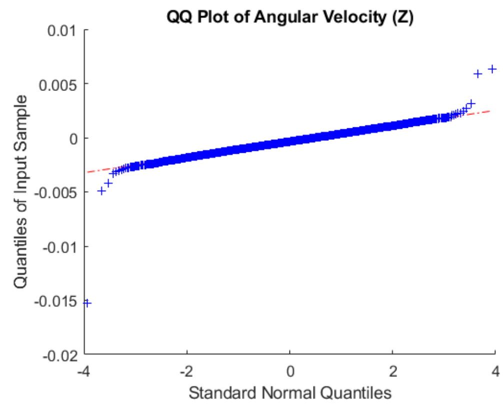

QQ Plot of Linear Acceleration (X)
Quantiles of Input Sample
Standard Normal Quantiles


QQ Plot of Linear Acceleration (Y)
Quantiles of Input Sample
Standard Normal Quantiles


QQ Plot of Sample Data versus Standard Normal
Quantiles of Input Sample
Standard Normal Quantiles


QQ Plot Angular Velocity (X)
Quantiles of Input Sample
Standard Normal Quantiles


QQ Plot of Angular Velocity (Y)
Quantiles of Input Sample
Standard Normal Quantiles


QQ Plot of Angular Velocity (Z)
Quantiles of Input Sample
Standard Normal Quantiles