ROBOTIC SENSING AND NAVIGATION

LAB 3 ANALYSIS REPORT

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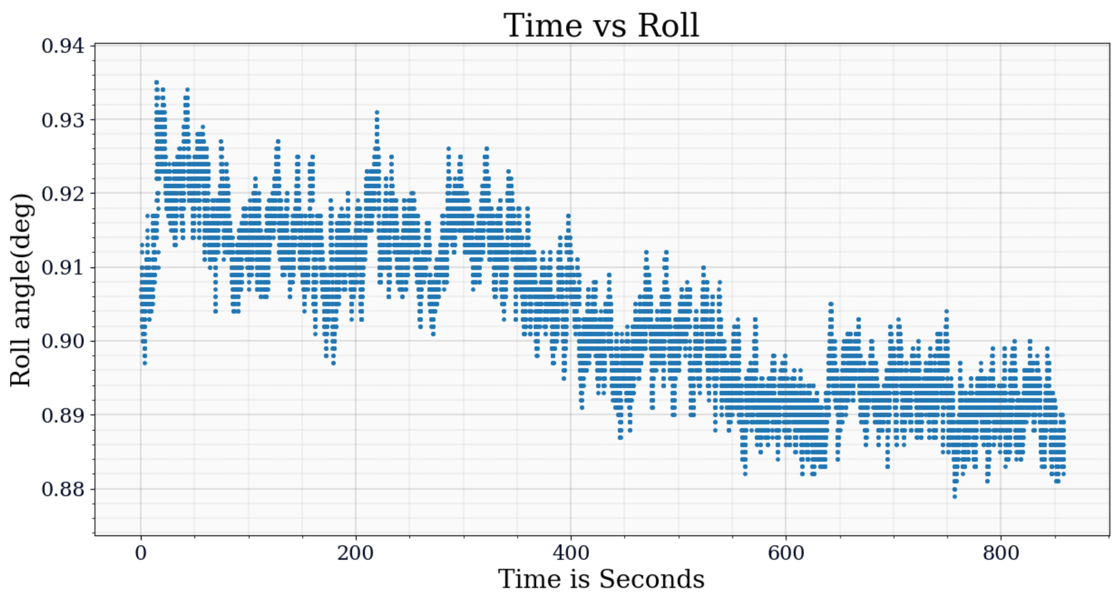
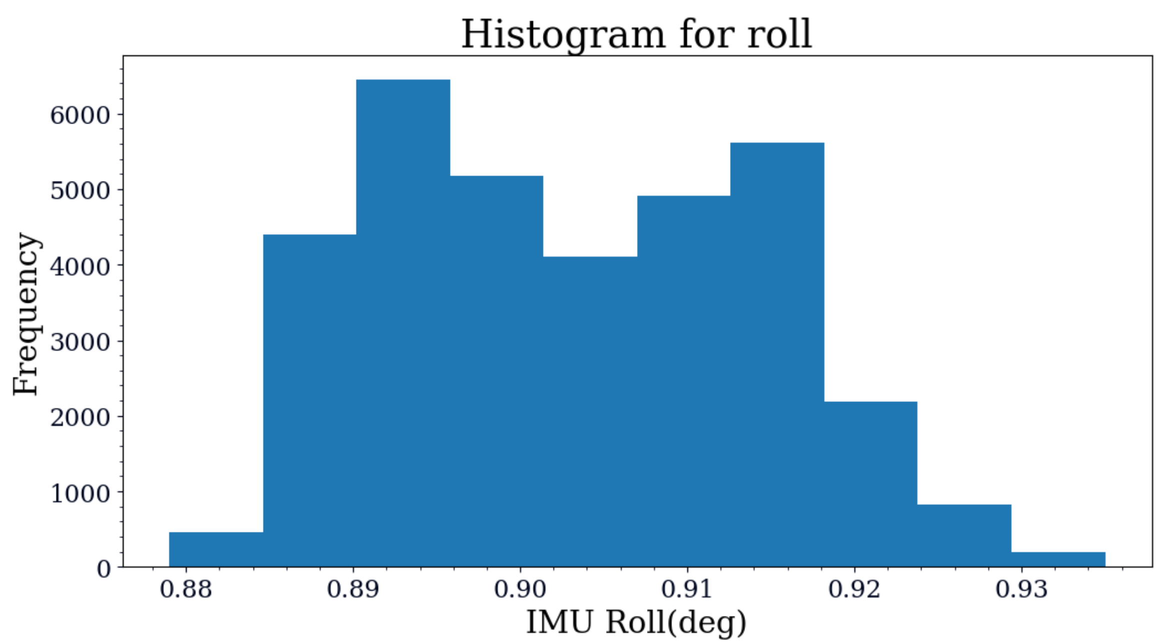
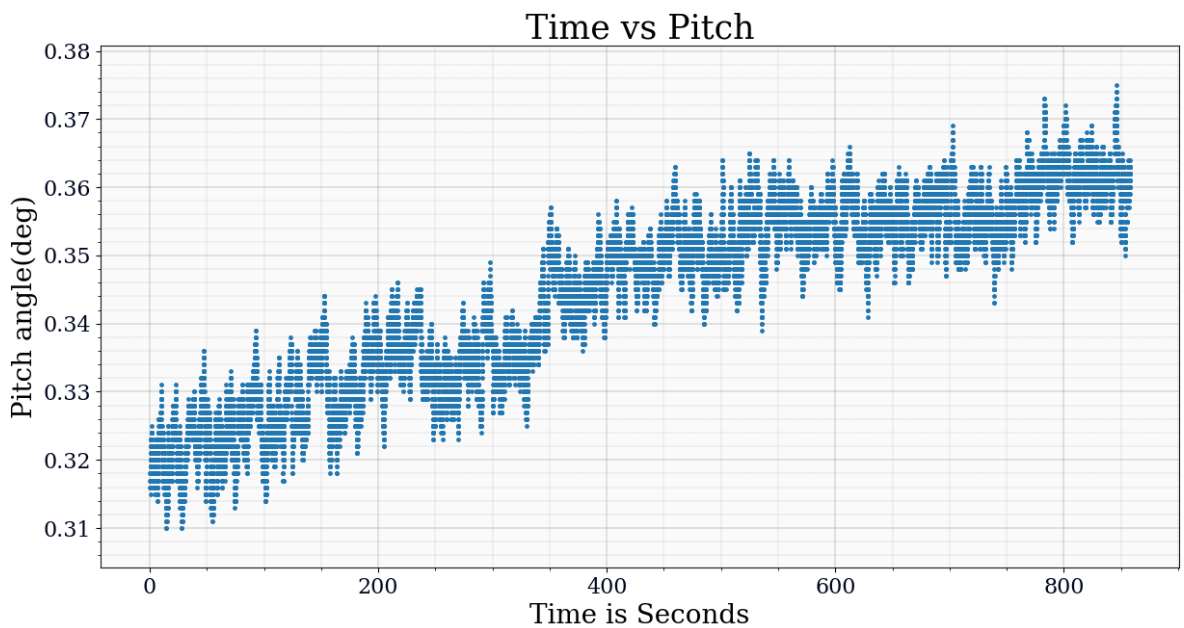
Stationary data for 10 mins



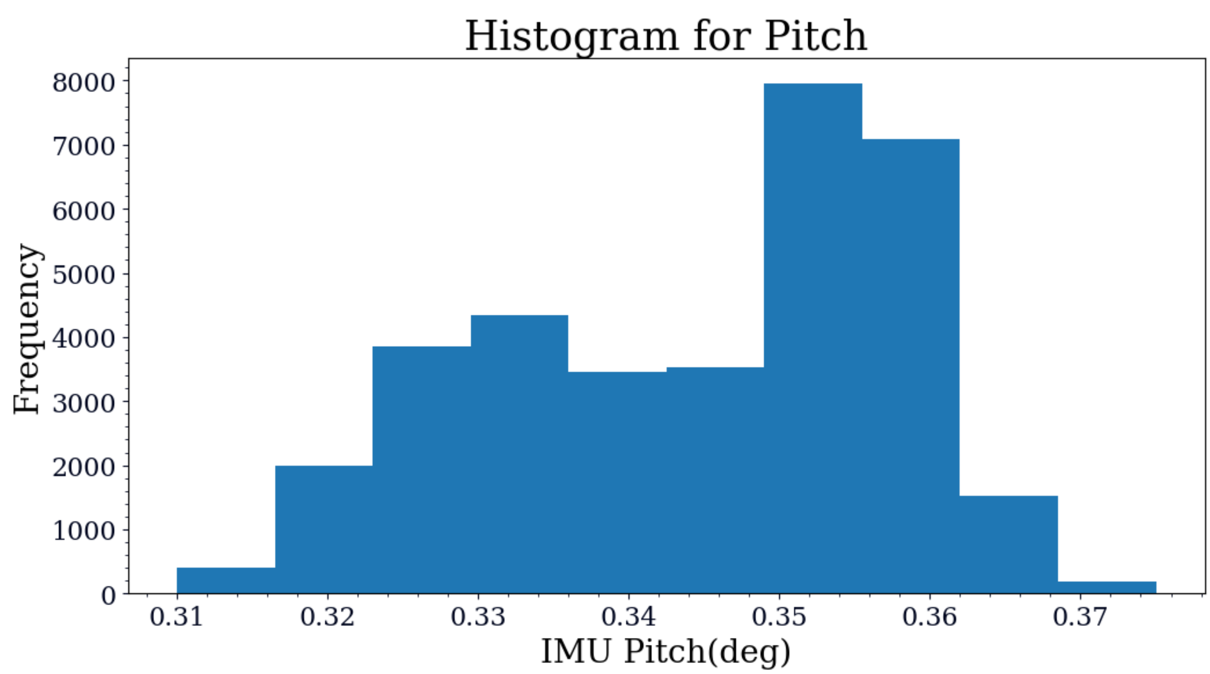
The Roll angle time series plot shows data with high intensity of noise.



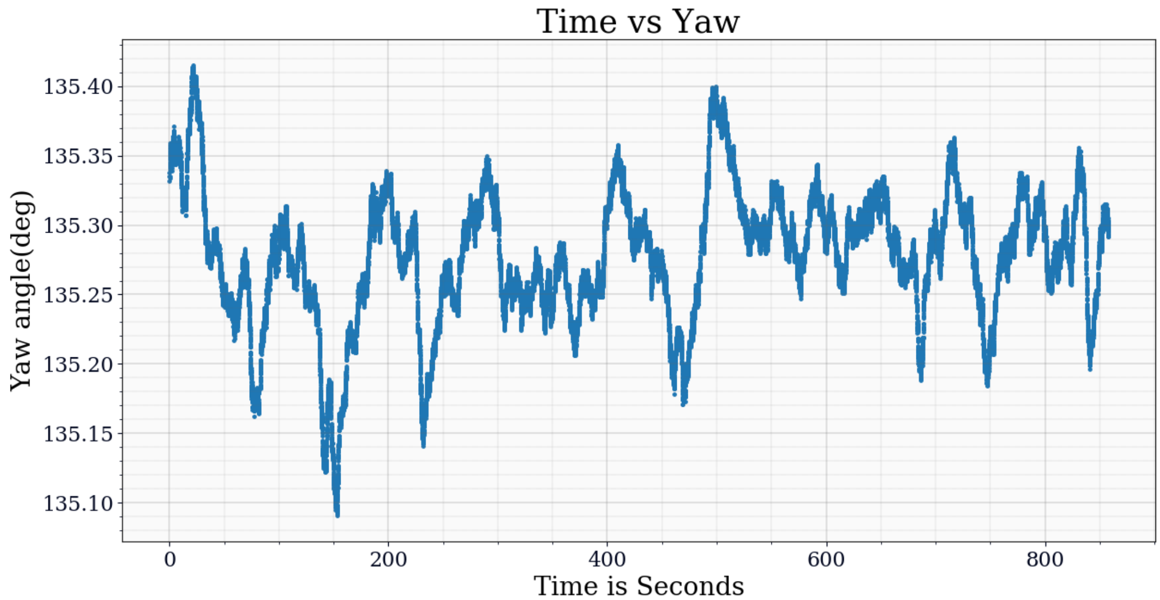
The Histogram plot of the Roll angle does not appear to be a Gaussian distribution. The graph looks like a skewed distribution.



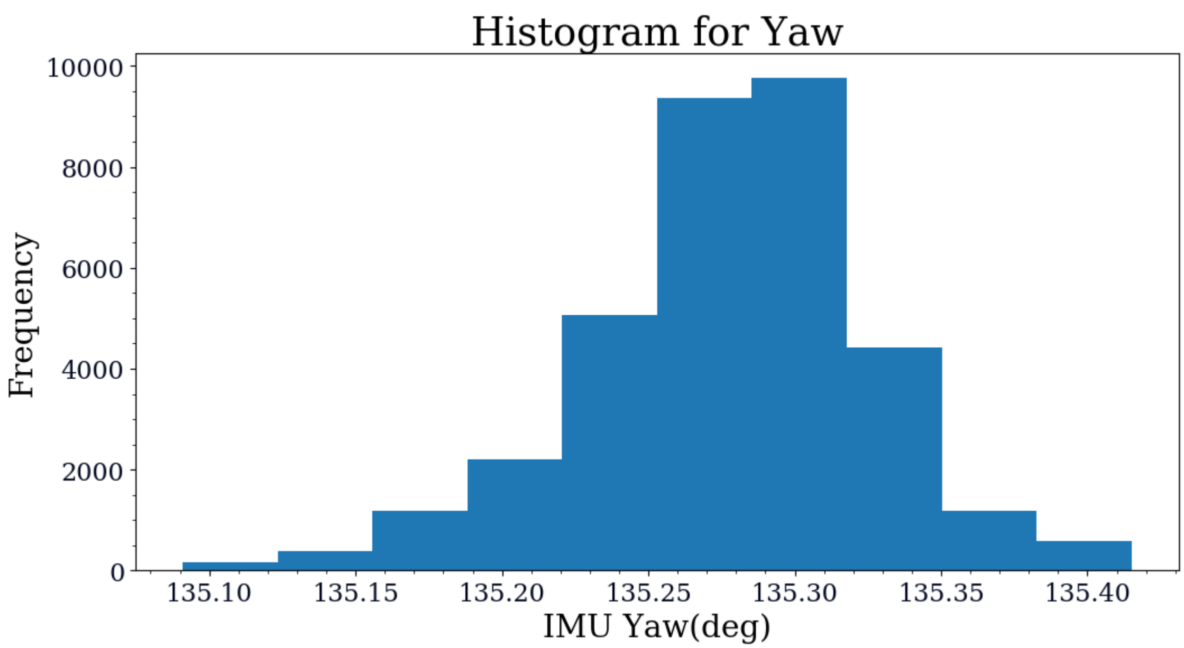
The PItch angle time series plot shows data with high intensity of noise.



The Histogram plot of the PItch angle resembles a skewed distribution



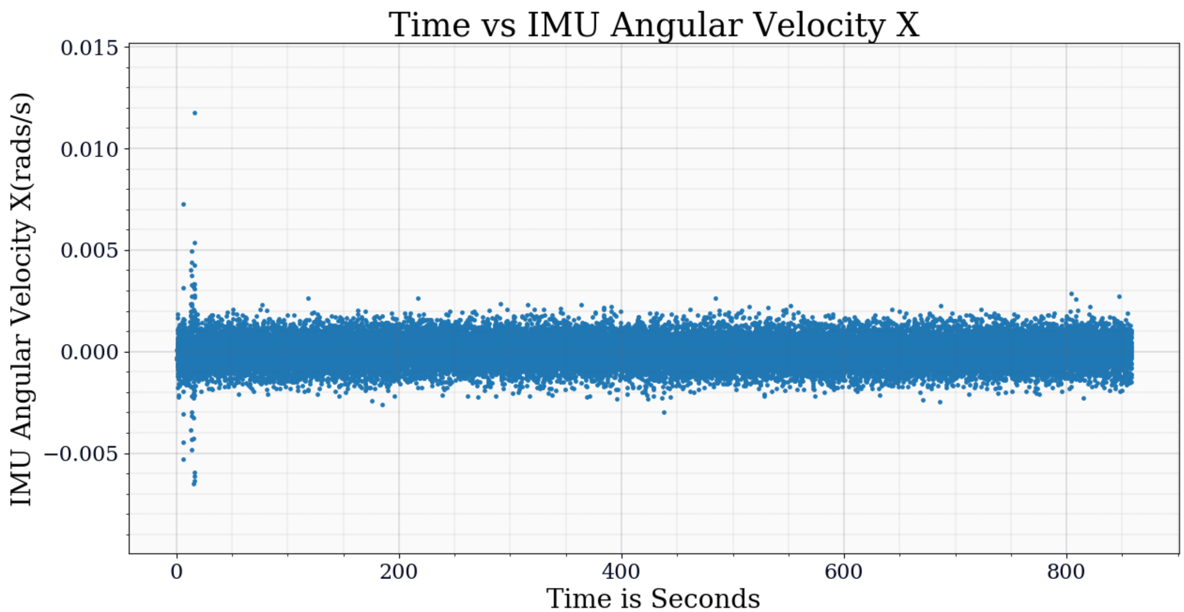
The Yaw angle time series plot shows data has a lot of noise.



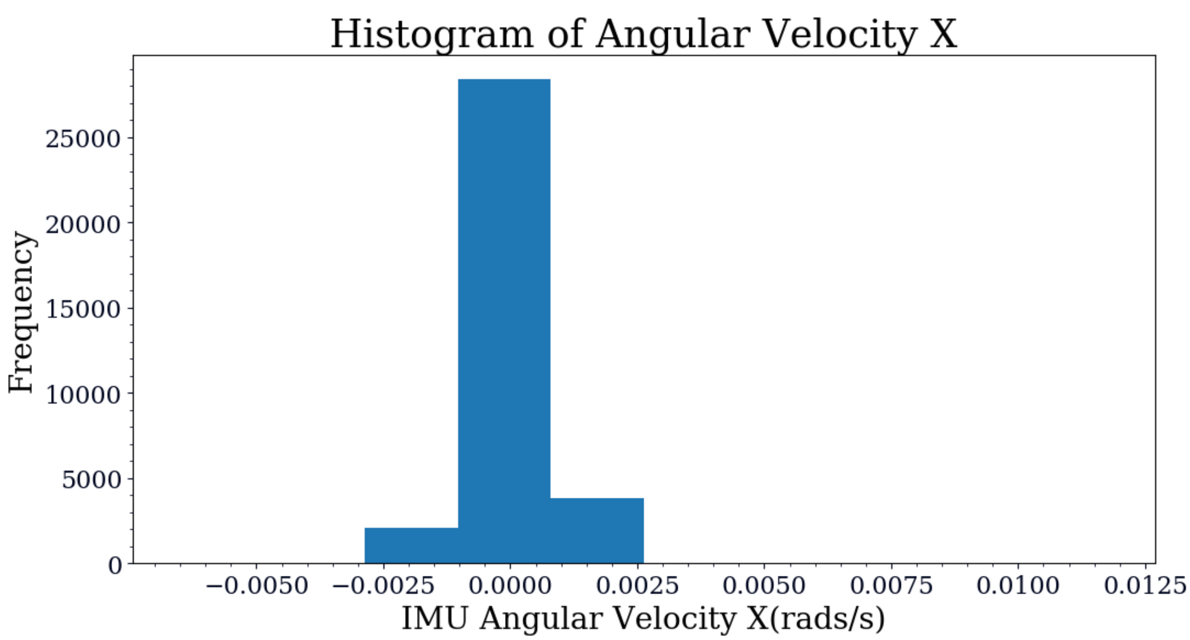
The Histogram plot of the Yaw angle appears to be a Gaussian distribution

Comparing all the graphs between the time series and histograms of the Roll, Pitch the graph is skewed and for yaw the graph is Gaussian distribution in nature and the time series shows huge variation in the collected values.

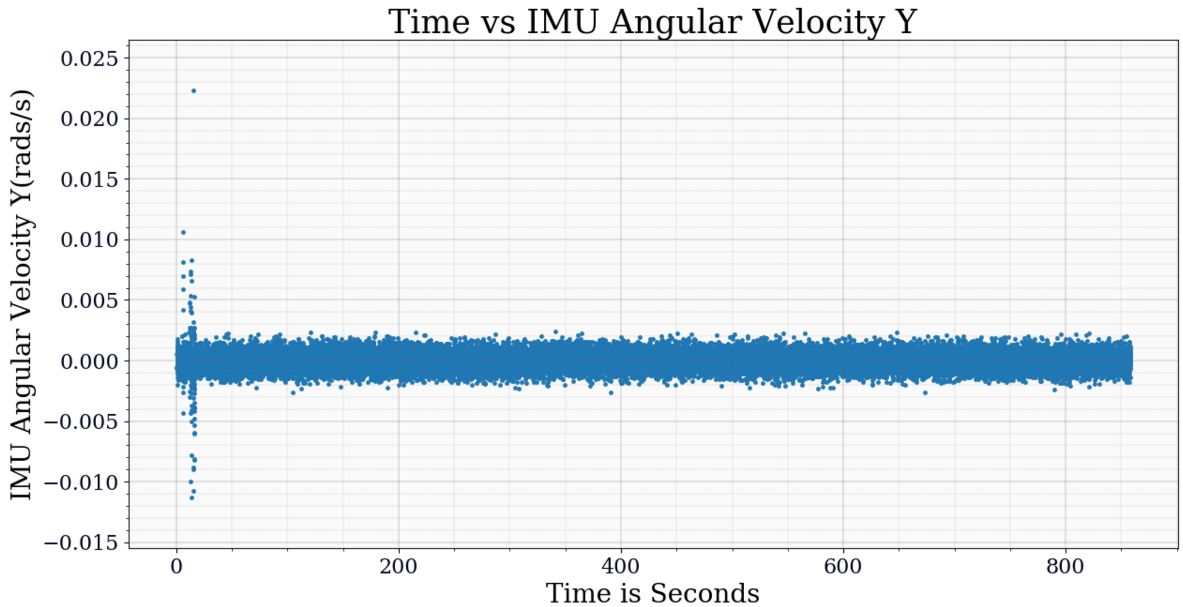
Angular Velocity Analysis



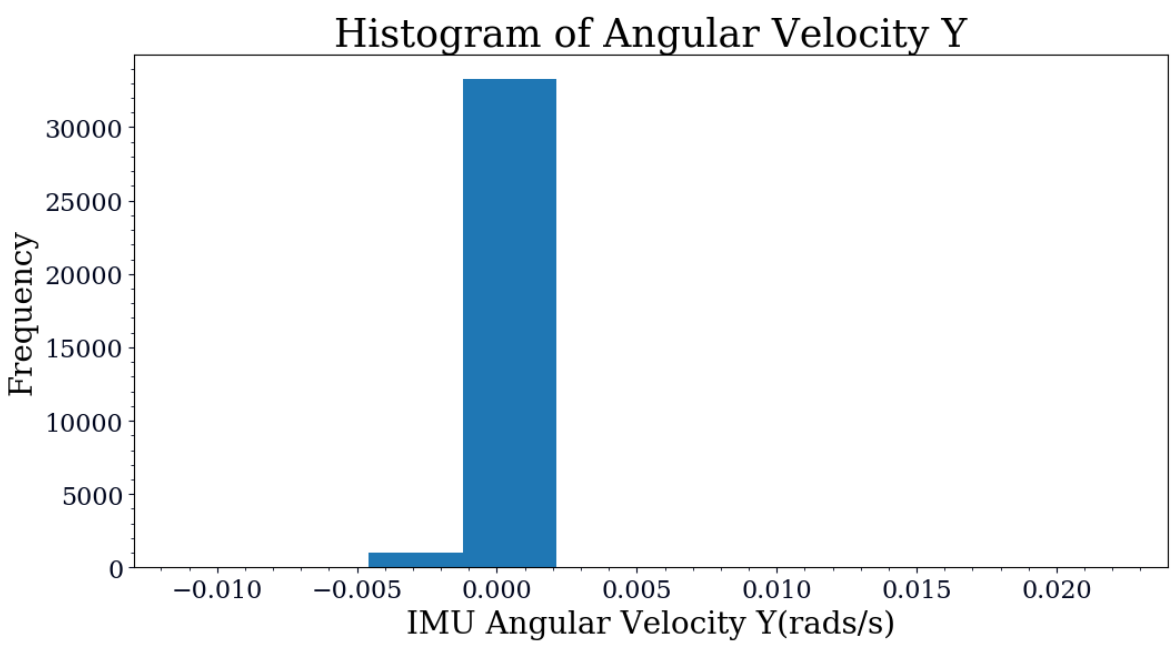
The time series plot of the Angular Velocity of X axis versus time graph shows that there is a high value of noise in the initial part of the graph, but the noise stabilizes as time passes.



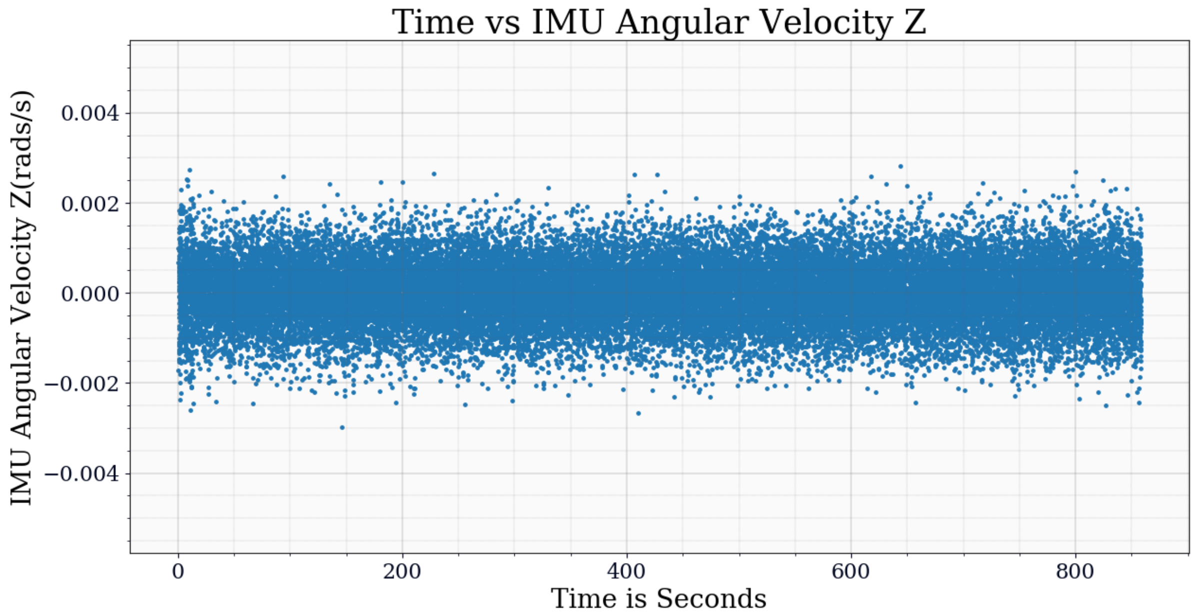
The Histogram plot of the Angular Velocity of X appears to be a Gaussian distribution.
Mean:8.45003933910307e-07 (rads/s)
Standard Deviation:0.0006750315591992023 (rads/s)



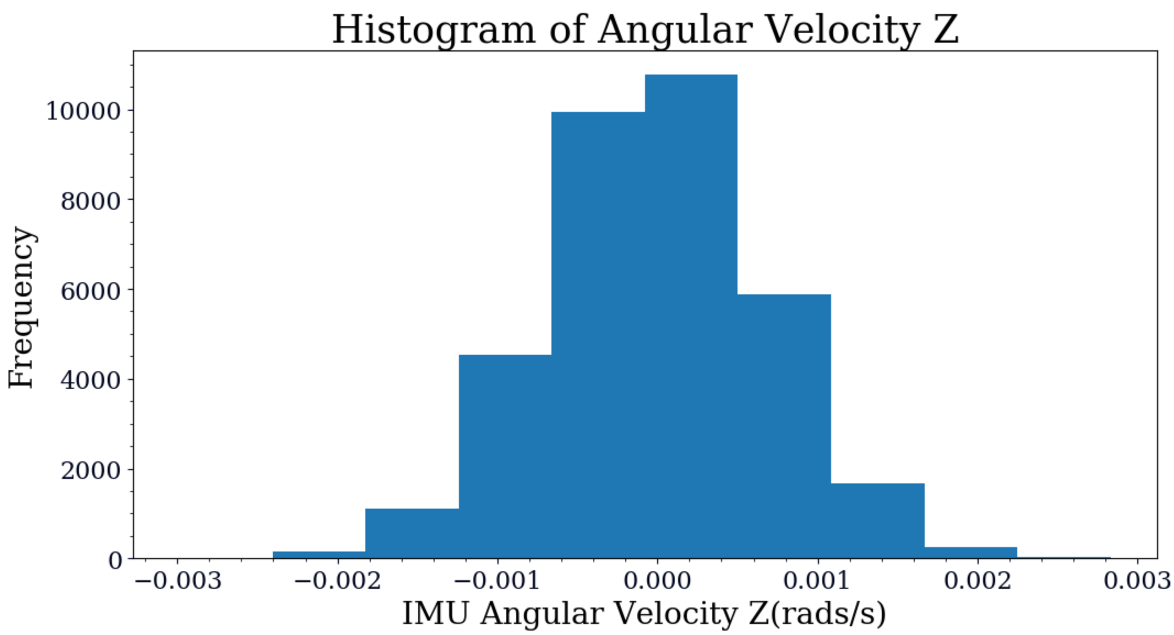
The time series plot of the Angular Velocity of the Y axis versus the time graph shows that there is a high frequency of noise.



The Histogram plot of the Angular Velocity of Y appears to be a Gaussian distribution
Mean:7.040038464900777e-06 (rads/s)
Standard Deviation:0.0006973010061896531 (rads/s)



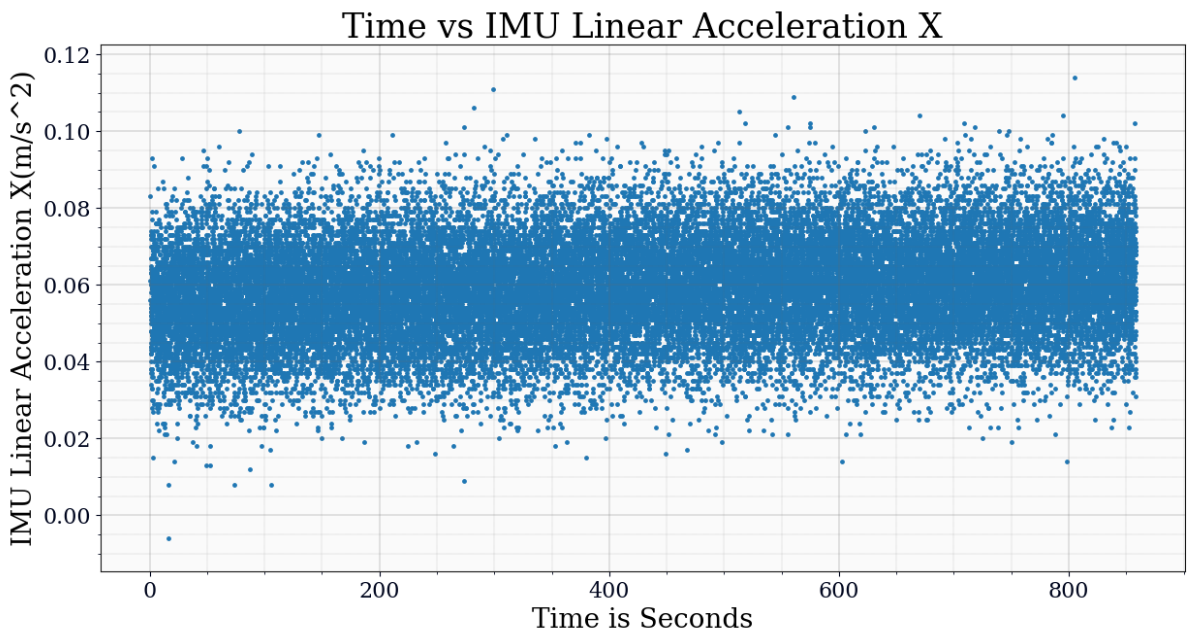
The time series plot of the Angular Velocity of the Z axis versus the time graph shows that there is a high magnitude of noise as time passes.



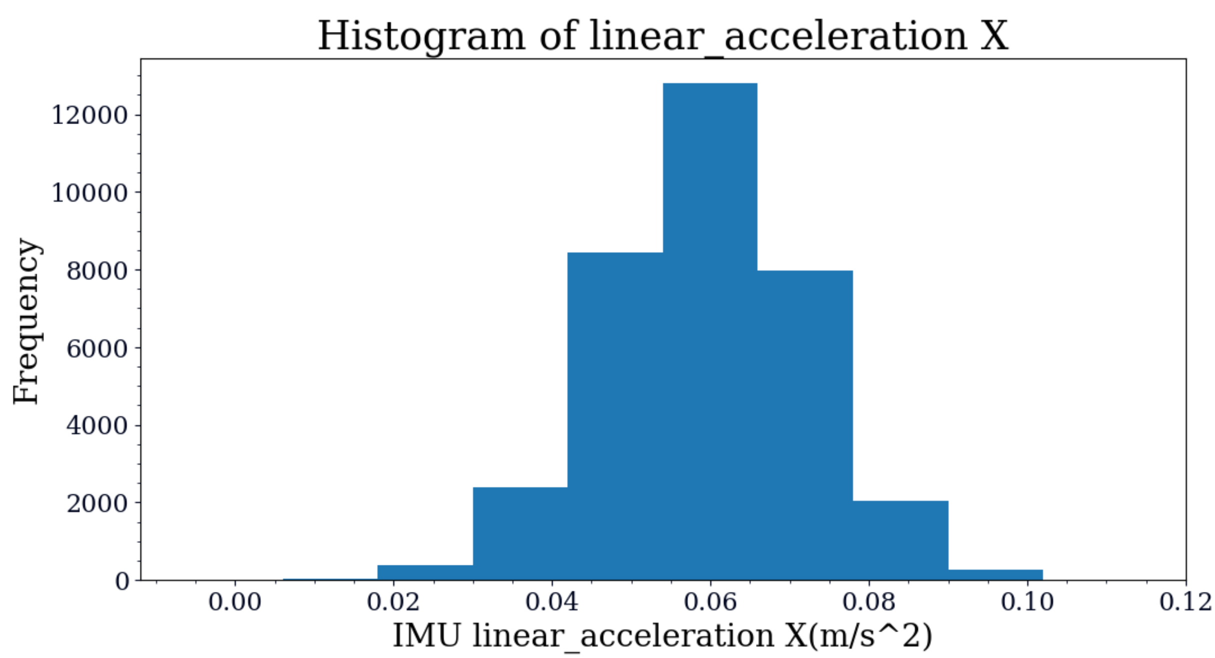
The Histogram plot of the Angular Velocity of Z appears to be a Gaussian distribution.
Mean:-5.699886353702247e-06 rads/s
Standard Deviation:0.0006883359121079397 rads/s

Comparing all the three axis X, Y and Z axis Angular Velocities it can be observed that the histograms are fairly Gaussian in nature and the time series plots have a lot of Noise and Error in them, hence the graphs are having scattered distribution of points the Angular velocities vs time graph

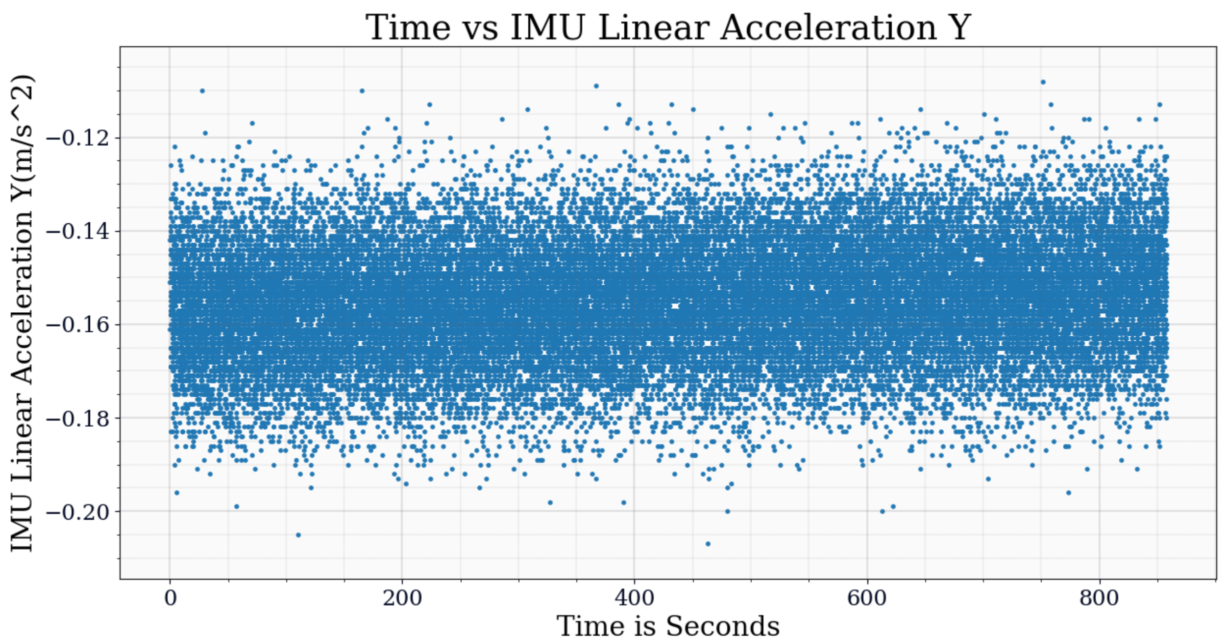
Linear Acceleration Graphs



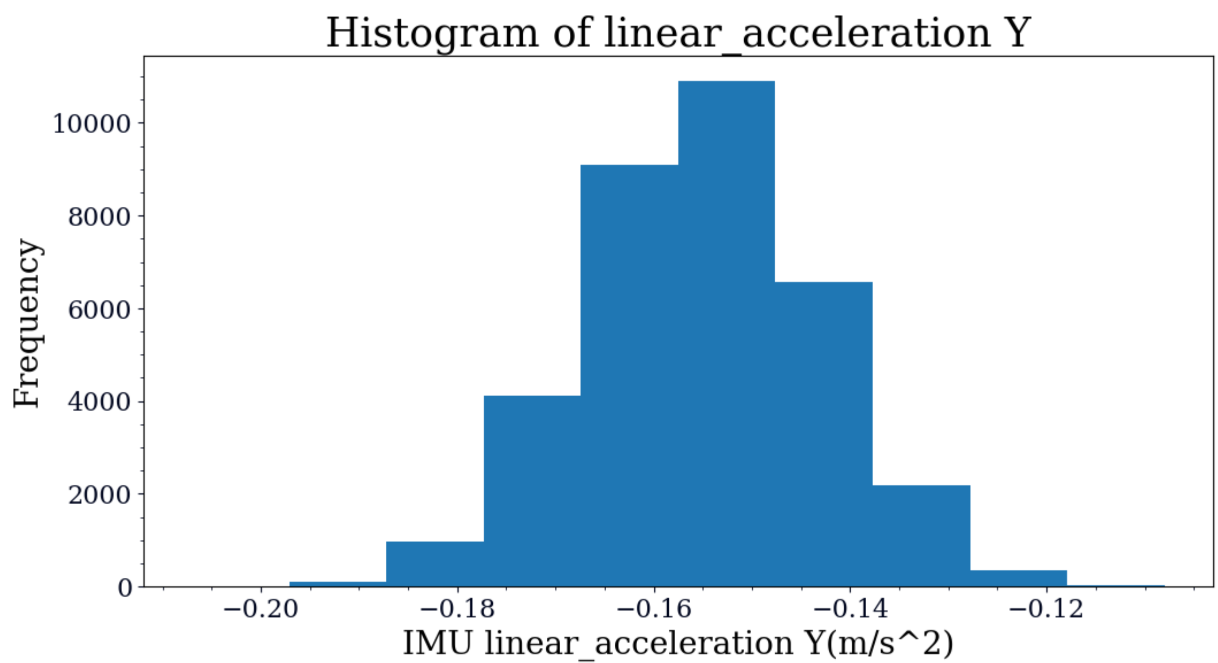
The time series plot of the LInear Acceleration of the X axis shows large amounts of noise in the plot through the duration.



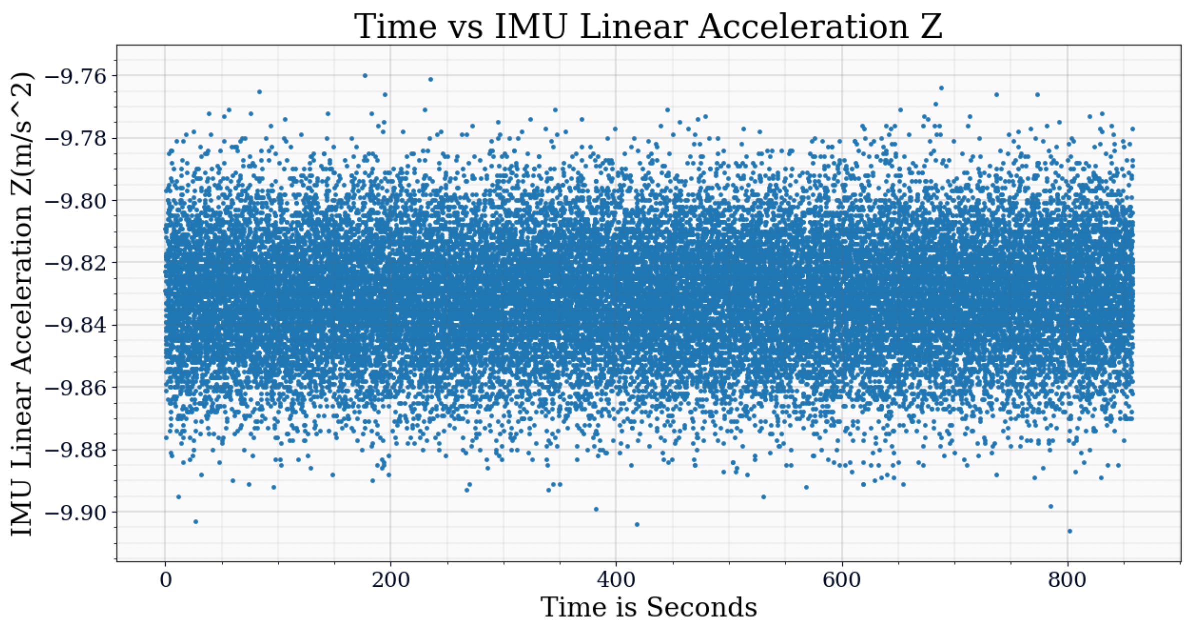
The Histogram plot of the LInear Acceleration of X appears to be a Gaussian distribution
Mean:0.05899358918320366 rads/s
Standard Deviation:0.012487625988210621 rads/s



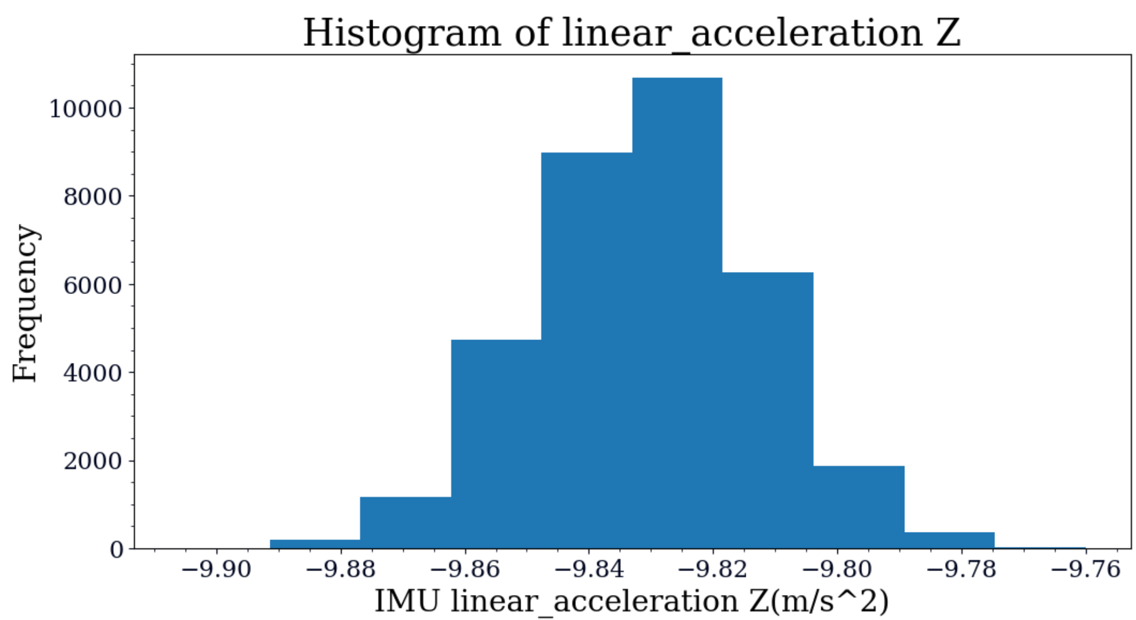
The time series plot of the LInear Acceleration of the Y axis shows large amounts of noise in the plot through the duration



The Histogram plot of LInear Acceleration appears to be a Gaussian distribution
Mean:-0.15500713931870502 (rads/s)
Standard Deviation:0.01207508377035805 (rads/s)



The time series plot of the LInear Acceleration of the Z axis shows large amounts of noise in the plot through the duration

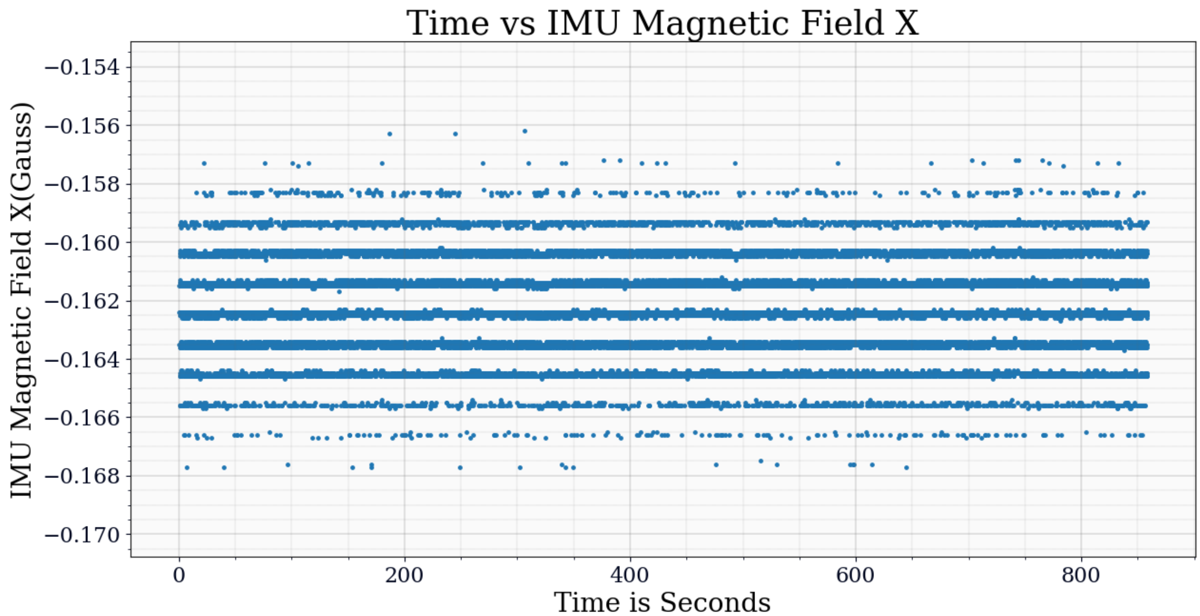


The Histogram plot of the LInear Acceleration of Z appears to be a Gaussian distribution.
Mean:-9.830795611504502 (rads/s)
Standard Deviation:0.018124926228365045 (rads/s)

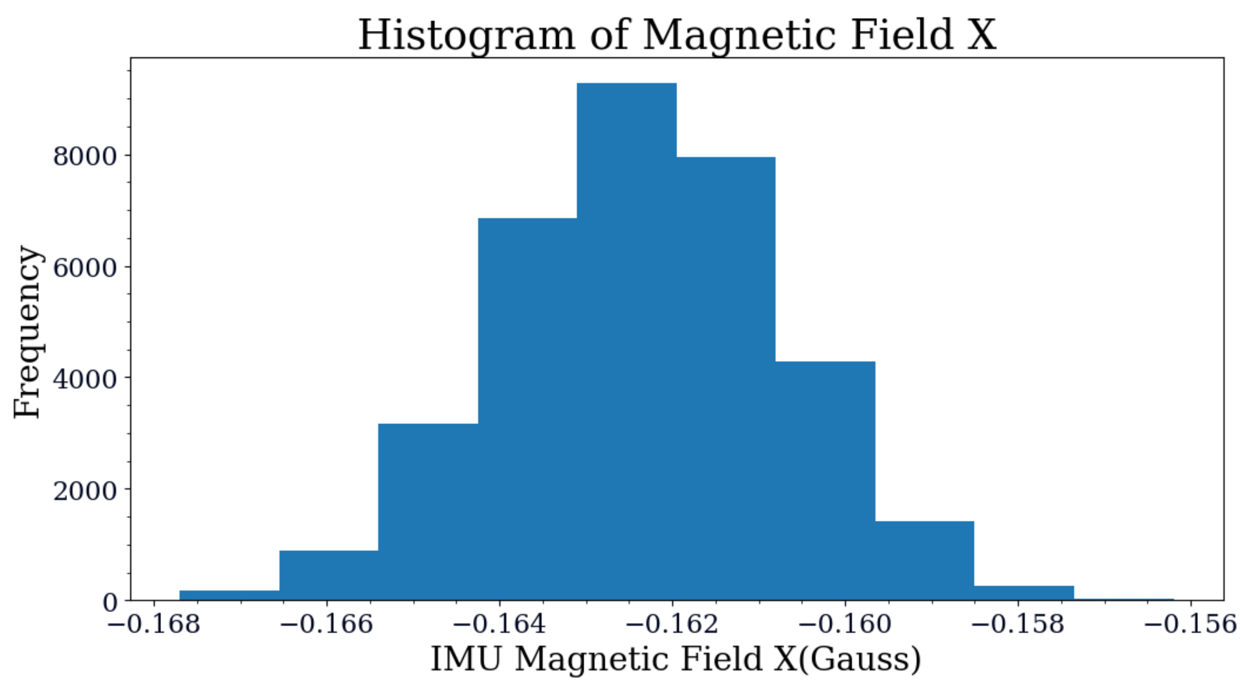
Ideally, only the Linear Acceleration of the Z axis is supposed to influence because of the presence of Gravity, but unfortunately, it can be observed that there is an influence on the X and Y axis also. This is because of the misalignment of the IMU while collecting data. Comparing all the graphs of the LInear Acceleration graphs of the X, Y and Z axis, the Histogram shows that all of them have Gaussian distribution.

According to the ISO 80000 Or IEC 80000 Standard the linear acceleration due to gravity is 9.80665 m/s^2. **The Root Mean Square Error(RMS**) of linear acceleration data in the Z axis is **0.13886 m/s^2** taking the ISO 80000 standard as ideal.

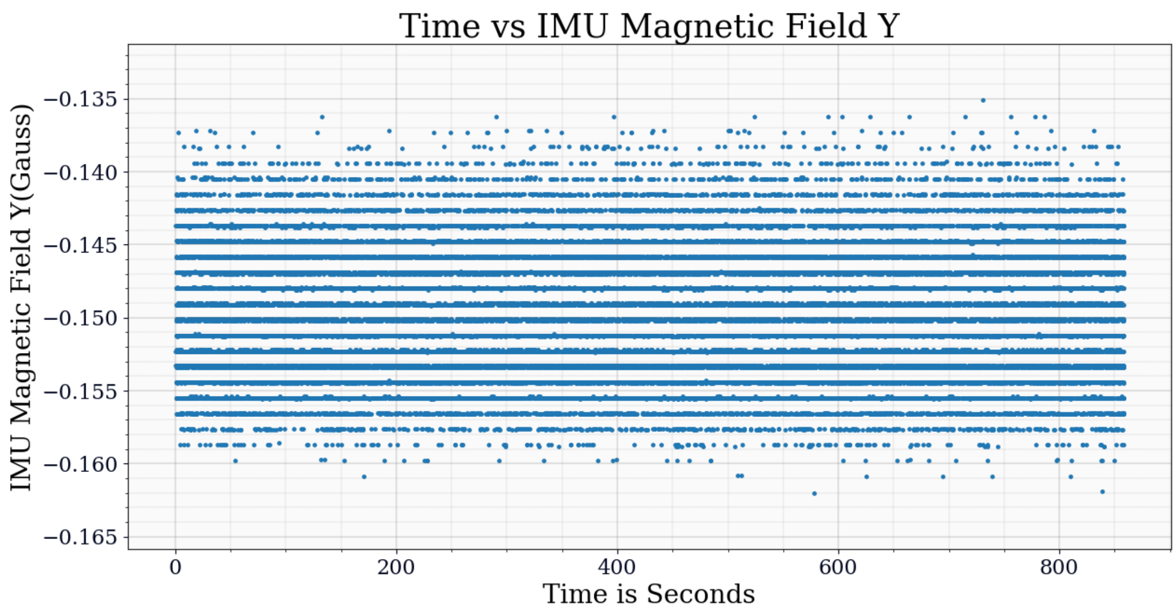
Magnetic Field Graphs



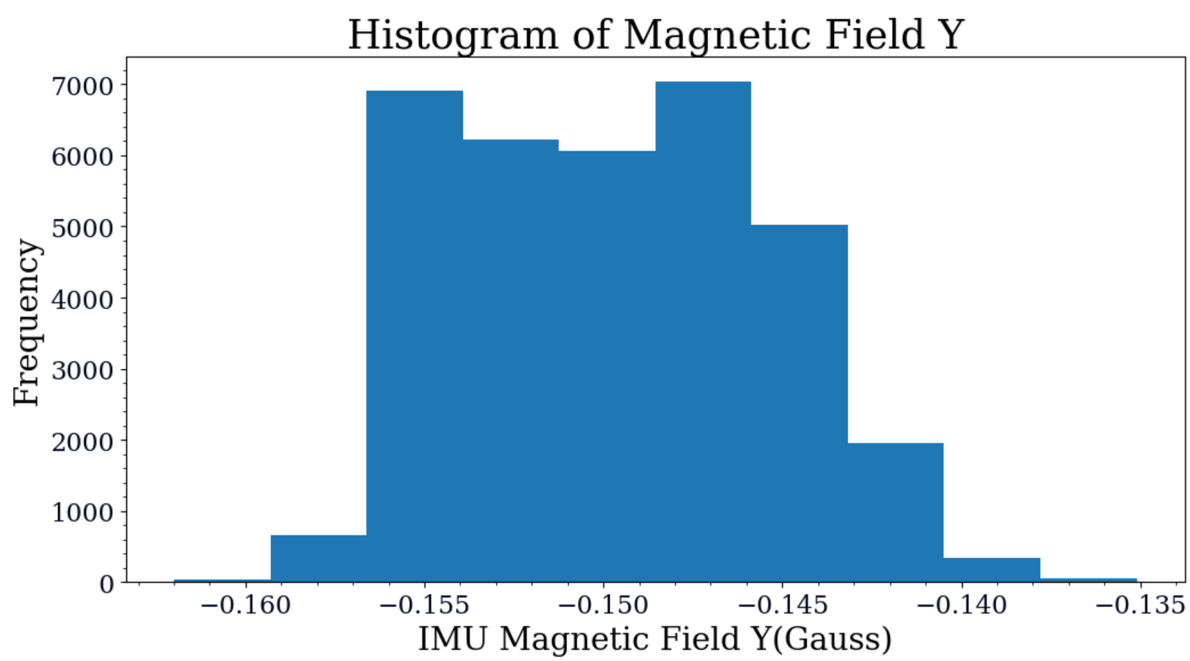
The time series plot of the Magnetic field of X axis shows large amounts of noise in the plot through the duration



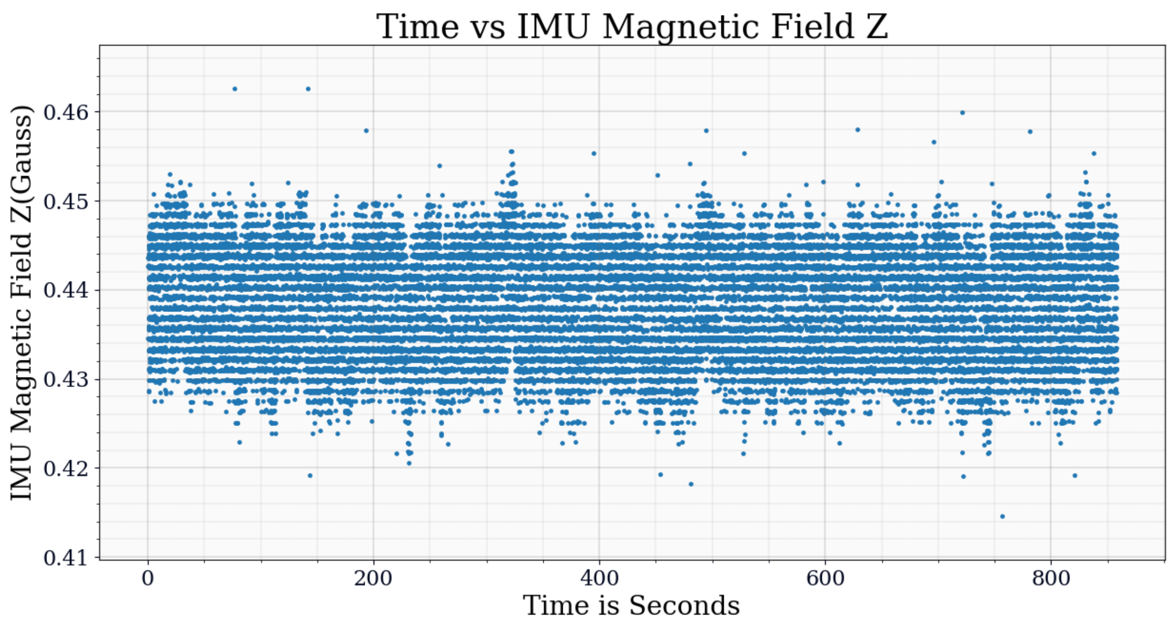
The Histogram plot of the Magnetic Field of X appears to be a Gaussian distribution
Mean:-0.16230202232129848 (rads/s)
Standard Deviation:0.0015139251413373524 (rads/s)



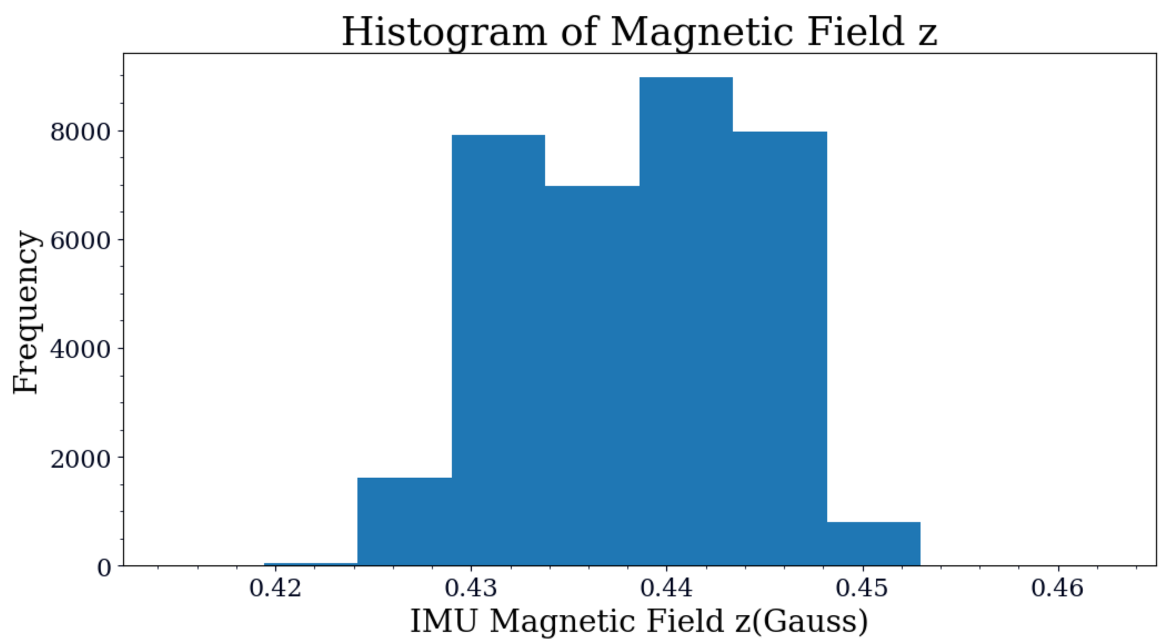
The time series plot of the Magnetic field of X axis shows large amounts of noise in the plot through the duration



The Histogram plot of the Magnetic Field of Y appears to be a Gaussian distribution
Mean:-0.1497981262930909 (rads/s)
Standard Deviation:0.004431024685355393 (rads/s)



The time series plot of the Magnetic field of X axis shows large amounts of noise in the plot through the duration



The Histogram plot of Magnetic Field of Z appears to be a Gaussian distribution
Mean:0.4383804353527406 (rads/s)
Standard Deviation:0.005803616226928835 (rads/s)

The Histogram for all the Magnetic field axes X,Y and Z appear to a gaussian distribution.The time series plot of the Magnetic field axis displayed large amounts of noise in it.

Stationary data for 5 hours data

IMU Accuracy Error combines the rotation magnitude from a gyroscope and linear acceleration from an accelerometer to provide the parameters to navigate and determine position. These parameters have errors and they are:

Errors for Gyroscope:

Calibration Errors

When there are errors in scale factors, alignments, and linearities of the gyros, they in turn produce errors when the devices turn. This error results in additional drift.

Bias Stability

The drift a measurement has from its average value of output rate is known as bias stability (or bias instability). You can determine how steady the gyro output is over time using the bias stability measurement. Bias can be classified as either Bias Repeatability (variance over various IMU cycles) or Bias Stability (variation during a single operation of the IMU).

Angle Random Walk

Thermoelectric reactions will cause high-frequency white noise in MEMS gyros.
This random noise is a second signal error source that calibration cannot eliminate.
The error grows in this random walk in a square-root-dependent manner.

Accelerometer errors

Constant Bias

An error in position is produced by a bias error that is constant and accumulates over time.
By observing the accelerometer's output over time when it is not accelerating, it is feasible to calculate the bias. However, gravity is operating on the accelerometer and will cause a bias to be visible. To quantify the bias, one needs to be aware of the exact orientation of the apparatus with regard to the gravitational field. In real life, calibration and orthogonality measurement can help with this.

Velocity Random Walk

Sensor noise from the electronics has an impact on an accelerometer's output. This white noise mistake increases in direct proportion to the square root of time

Scale Factor

The scale factor is the difference between the measurement's real sensor output and the accelerometer's input. The scale factor is hence the linear progression of input variance to actual measurement, given in ppm. The reasons are the change in temperature and the change in resonance frequency of the oscillating mass of the MEMS Gyroscope. Changes in the spring constant and damping coefficient of the MEMS Gyroscope. This error is also caused because of the g-dependant forces.

Noise Parameter Identification

To obtain the noise parameters for the gyroscope, use the following relationship between the Allan variance and the two-sided power spectral density (PSD) of the noise parameters in the original data set Ω. The relationship is:

$$\sigma^2(\tau) = 4\int_0^\infty S_\Omega(f)\frac{sin^4(\pi f\tau)}{(\pi f\tau)^2}df$$

From the above equation, the Allan variance is proportional to the total noise power of the gyroscope when passed through a filter with a transfer function of $sin^4(x)/(x)^2$. This transfer function arises from the operations done to create and operate on the clusters.

Using this transfer function interpretation, the filter bandpass depends on τ. This means that different noise parameters can be identified by changing the filter bandpass, or varying τ.

Angle Random Walk

The angle random walk is characterised by the white noise spectrum of the gyroscope output. The PSD is represented by:

$$S_\Omega(f) = N^2$$

where

N = angle random walk coefficient

Substituting into the original PSD equation and performing integration yields:

$$\sigma^2(\tau) = \frac{N^2}{\tau}$$

The above equation is a line with a slope of -1/2 when plotted on a log-log plot of $\sigma(\tau)$ versus τ. The value of *N* can be read directly off of this line at $\tau = 1$. The units of *N* are $(rad/s)/\sqrt{Hz}$.

Rate Random Walk

The rate random walk is characterised by the red noise (Brownian noise) spectrum of the gyroscope output. The PSD is represented by:

$$S_\Omega(f) = (\frac{K}{2\pi})^2\frac{1}{f^2}$$

where

K = rate random walk coefficient

Substituting into the original PSD equation and performing integration yields:

$$\sigma^2(\tau) = \frac{K^2\tau}{3}$$

The above equation is a line with a slope of 1/2 when plotted on a log-log plot of $\sigma(\tau)$ versus τ. The value of *K* can be read directly off of this line at $\tau = 3$. The units of *K* are $(rad/s)\sqrt{Hz}$.

Bias Instability

The bias instability is characterised by the gyroscope output's pink (flicker noise) spectrum. The PSD is represented by:

$$S_\Omega(f) = \begin{cases} (\frac{B^2}{2\pi})\frac{1}{f} & : f \leq f_0 \\ 0 & : f > f_0 \end{cases}$$

where

B = bias instability coefficient

f_0 = cut-off frequency

Substituting into the original PSD equation and performing integration yields:

$$\sigma^2(\tau) = \frac{2B^2}{\pi}[\ln 2 + -\frac{sin^3x}{2x^2}(sinx + 4xcosx) + Ci(2x) - Ci(4x)]$$

where

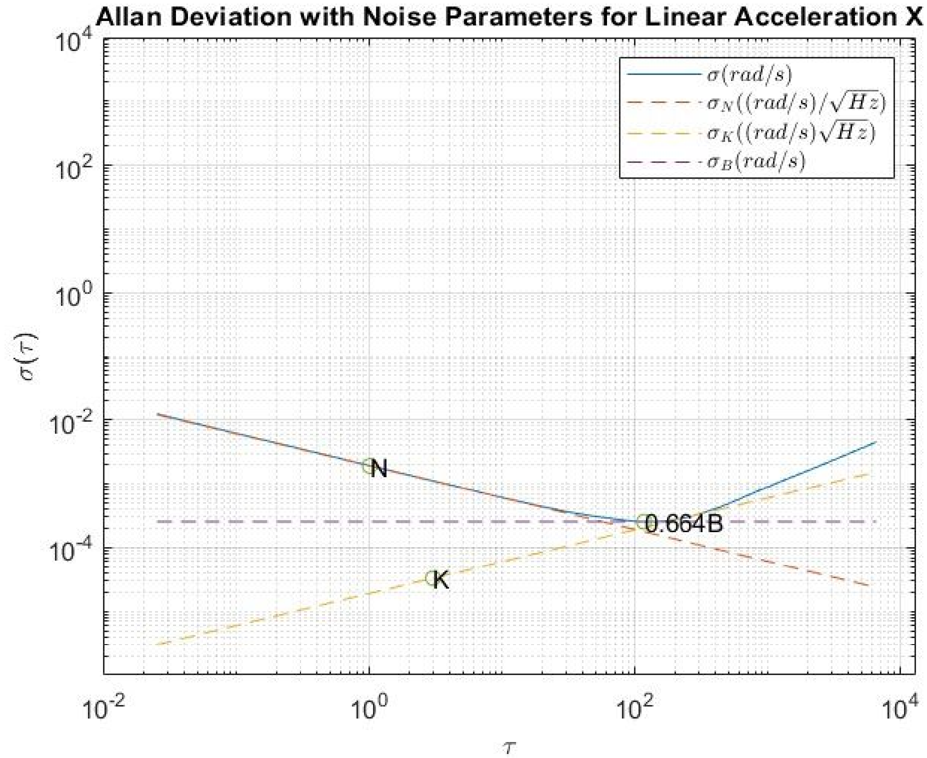
$$x = \pi f_0 \tau$$

Ci = cosine-integral function

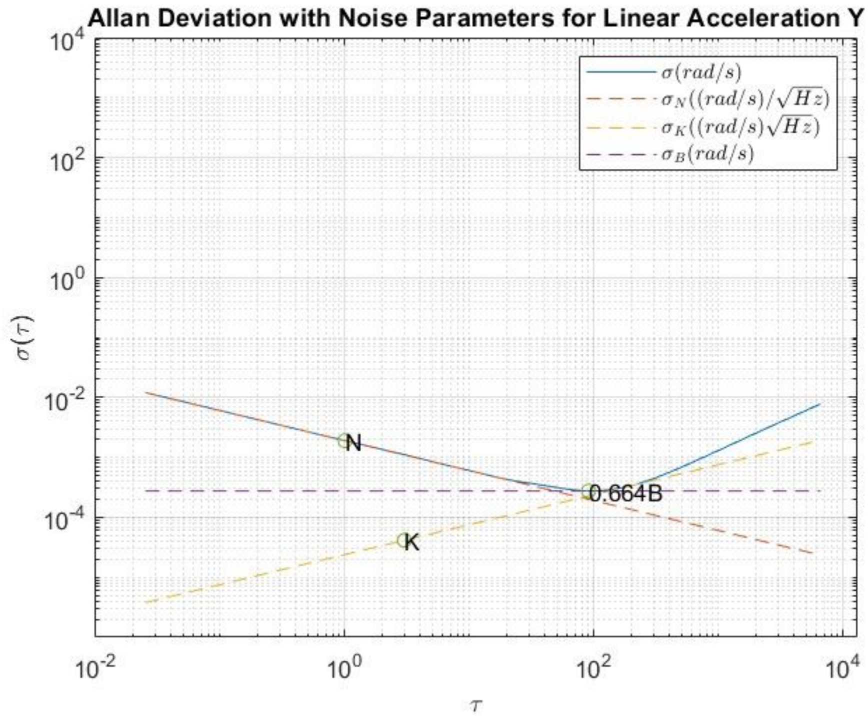
When τ is much longer than the inverse of the cutoff frequency, the PSD equation is:

$$\sigma^2(\tau) = \frac{2B^2}{\pi}\ln 2$$

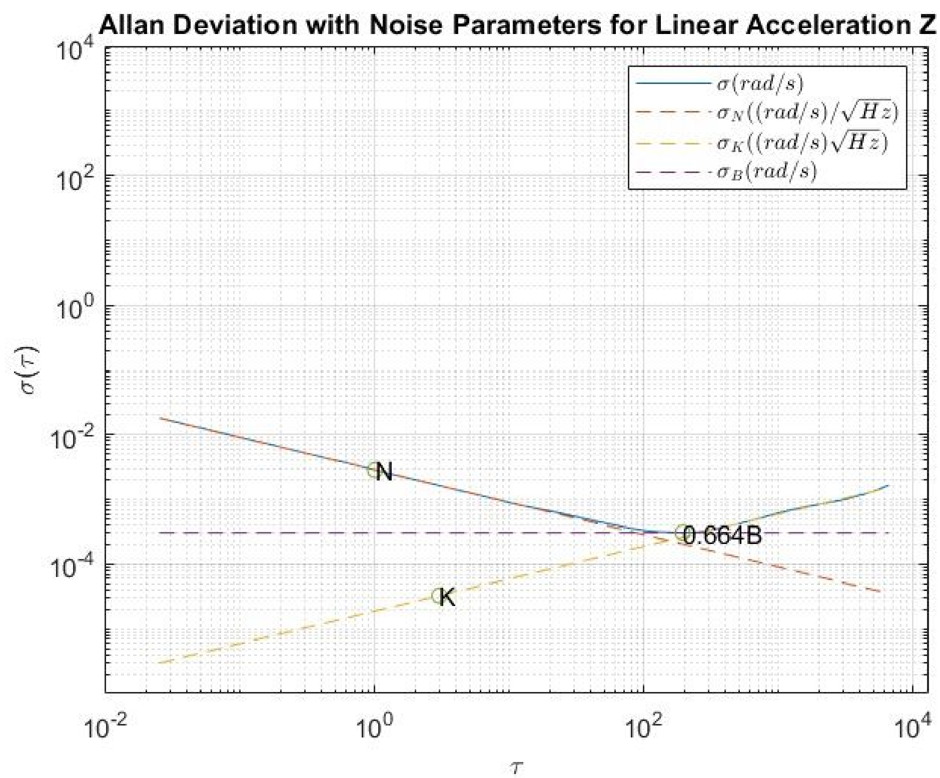
The above equation is a line with a slope of 0 when plotted on a log-log plot of $\sigma(\tau)$ versus τ. The value of *B* can be read directly off of this line with a scaling of $\sqrt{\frac{2\ln 2}{\pi}} \approx 0.664$. The units of *B* are rad/s. [1]



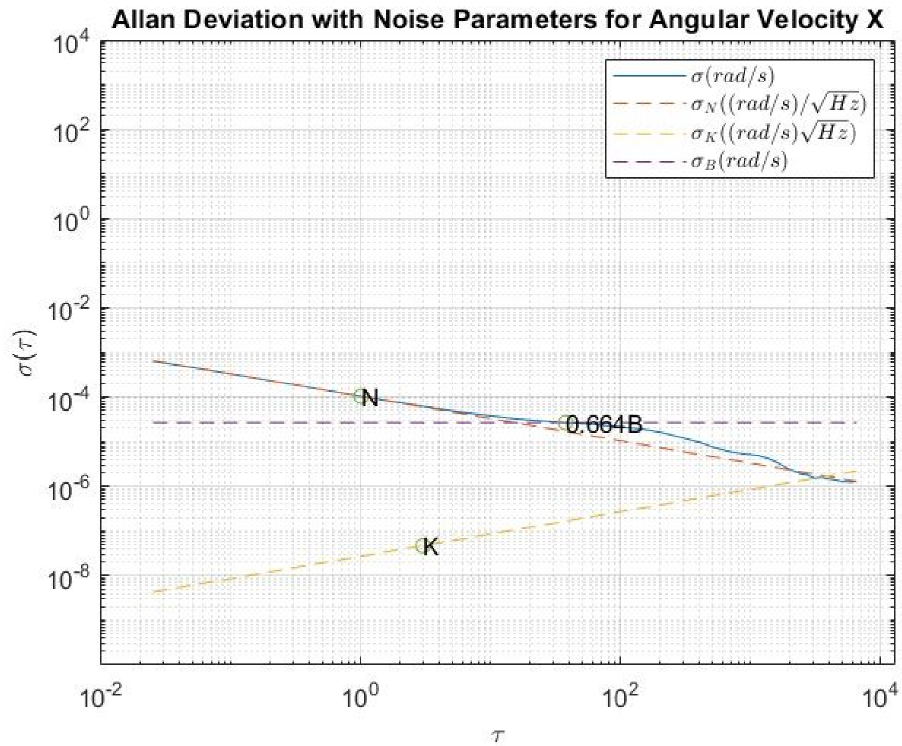
This is the Allan Deviation plot for linear acceleration X with Noise parameters



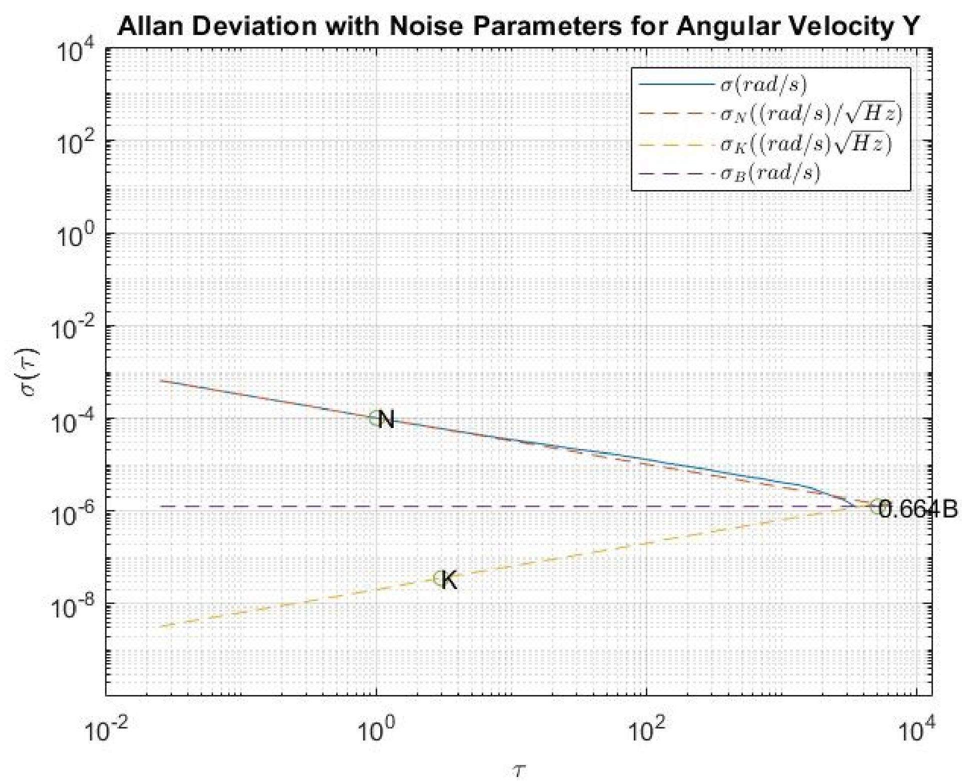
This is the Allan Deviation plot for linear acceleration Y with Noise parameters



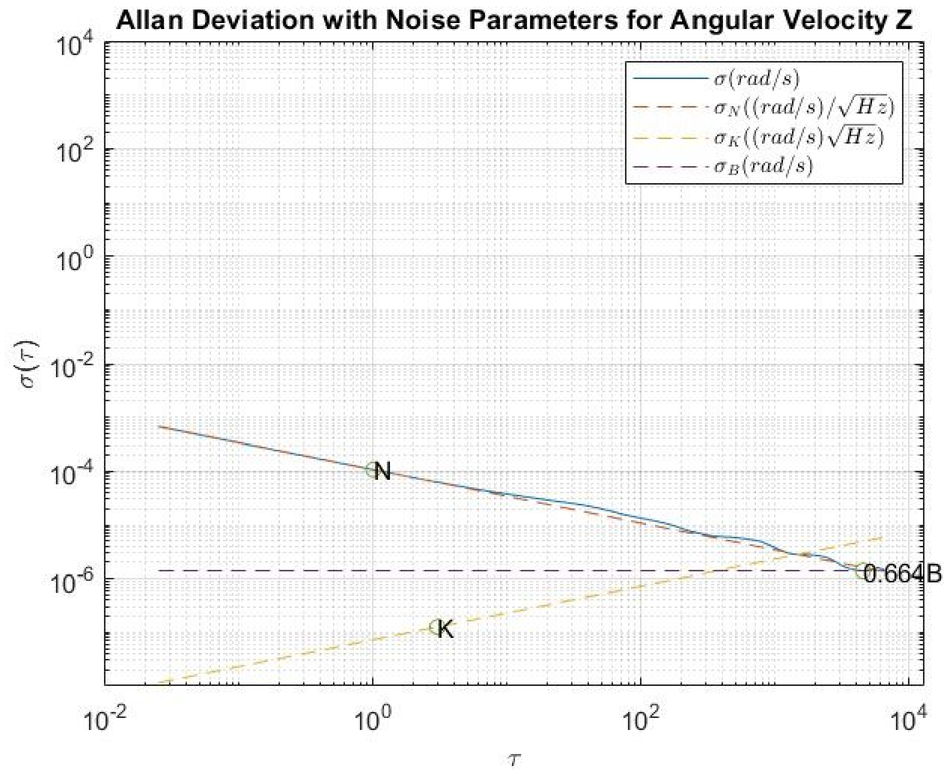
This is the Allan Deviation plot for linear acceleration Z with Noise parameters



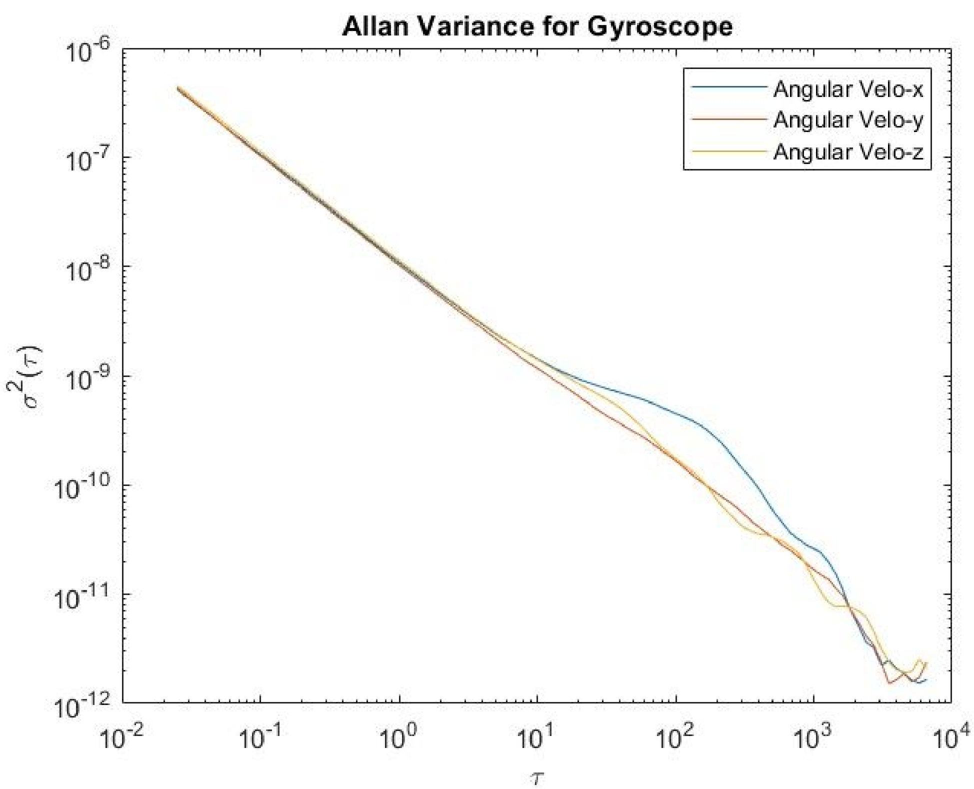
This is the Allan Deviation plot for Angular Velocity X with Noise parameters



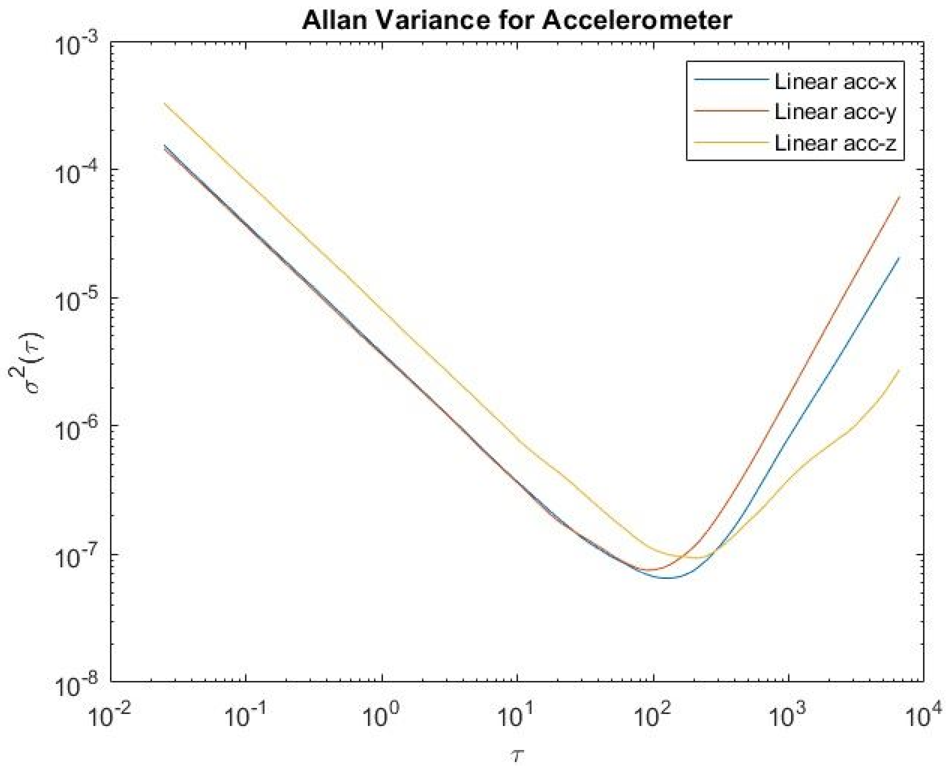
This is the Allan Deviation plot for Angular Velocity Y with Noise parameters



This is the Allan Deviation plot for Angular Velocity Z with Noise parameters



This is the Allan Variance plot for the Gyroscope including all the Angular Velocity slope comparison



This is the Allan Variance plot for the Gyroscope including all the Linear Acceleration slope comparison

B	C	D	E	F	G	H	I
	Data sheet	Our value	Data sheet	Our value			
	In Run Bias Stability		Noise Density				
	(B) in °/hr		(N) in °/s /√Hz			deg/hour	rad to deg
Angular Velocity X	< 10°/hr	8.31103565	0.0035 °/s /√Hz	0.00594558517		206265	57.2958
Angular Velocity Y	< 10°/hr	0.39058340	0.0035 °/s /√Hz	0.00005824118			
Angular Velocity Z	< 10°/hr	0.43274397	0.0035 °/s /√Hz	0.00615757963			
	(B) in mg		(N) in mg/√Hz				0.01
Linear Acceleration X	< 0.04 mg	0.03835900	0.14 mg/√Hz	0.00010555556			
Linear Acceleration Y	< 0.04 mg	0.04132000	0.14 mg/√Hz	0.19000000000			
Linear Acceleration Z	< 0.04 mg	0.04617000	0.14 mg/√Hz	0.28000000000			

Due to the Noises and the Error that was present while collecting the data there is a substantial difference from the Ideal Data Sheet Run Bias Stability and Noise Density values.

The reasons for the error in the data collected can be attributed to the following factors-

- The temperature of the place where the data is collected
- The surrounding disturbances like the interference by other electronic devices, the physical disturbances by wind and vibration of the building
- The age of the IMU is also a factor that affects the data that is generated by the IMU

REFERENCES:

[1]
https://www.mathworks.com/help/nav/ug/inertial-sensor-noise-analysis-using-allan-variance.html

[2]
VECTORNAV, “VN-100 IMU/AHRS Miniature, lightweight and high-performance IMU & AHRS”, https://www.vectornav.com/docs/default-source/datasheets/vn-100-datasheet-rev2.pdf?sfvrsn=8e35fd12_10[accessed October 23rd,2022].