EECE5554 – Robotics Sensing and Navigation

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Lab3 Report

IMU Data - Stationary Noise Analysis

I have taken the data for orientation, angular velocity, linear acceleration and magnetic field for this experiment using the Vectornav VN-100 IMU Sensor (Inertial Measurement Unit). The data was collected for 15 minutes in a classroom in the basement of Snell Library at Northeastern University. The Sensor was secured to the ground using a double-sided tape. The sensor was completely stationary during the entire process.

Orientation Data (Roll, Pitch & Yaw):

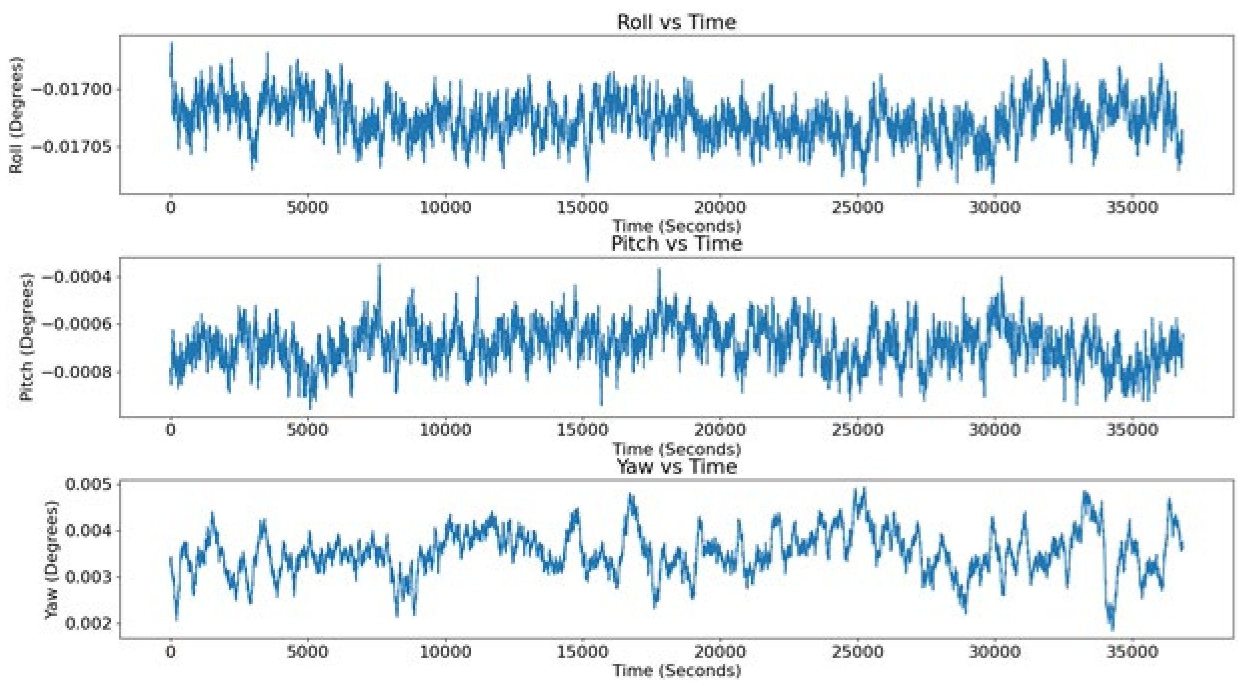

Figure 1: Roll, Pitch & Yaw vs Time Line Plots

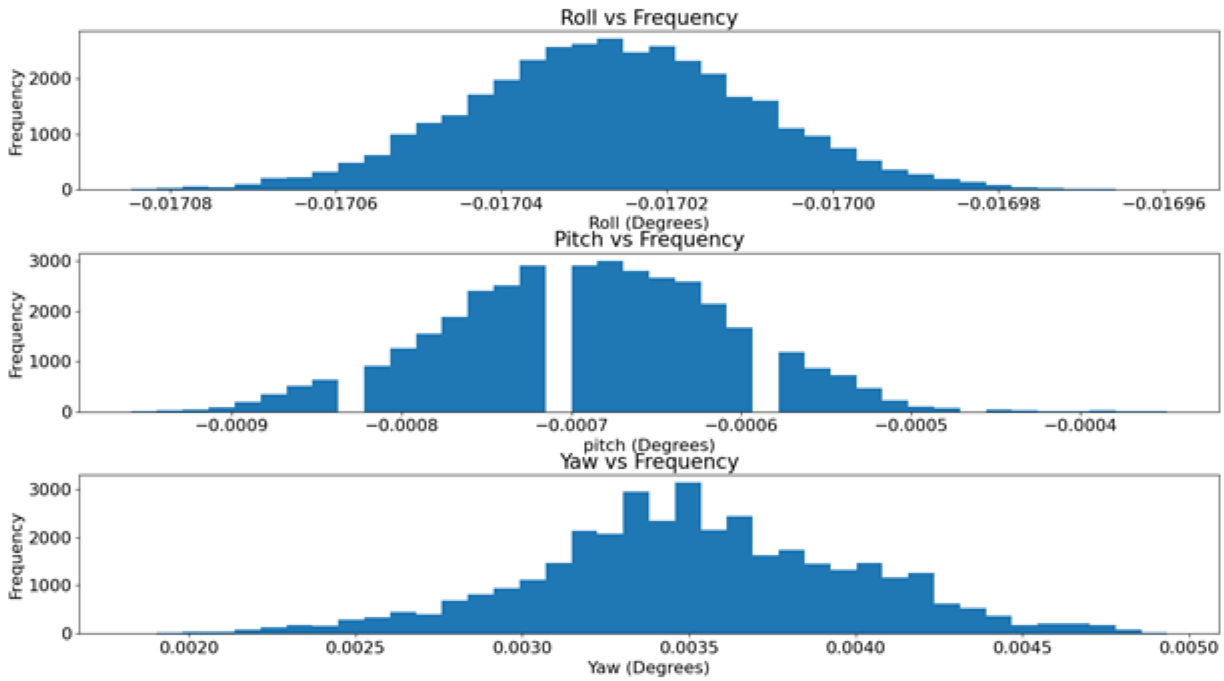

Figure 2: Roll, Pitch & Yaw Histograms

	Roll	**Pitch**	**Yaw**
Mean	- 0.017026	- 0.000688	0.003520
Standard Deviation	1.727712×10^{-5}	8.370338×10^{-5}	0.000482

From the line plots, we can see that the Roll & Pitch are densely populated, whereas, Yaw has less number of data points. This distribution is further confirmed from the histogram. The peak value of the histogram is almost equal to the mean of the respective parameter readings. The values of the Standard Deviation for Roll & Pitch are also very low as compared to Yaw.

Magnetometer Data (Magnetic Field):

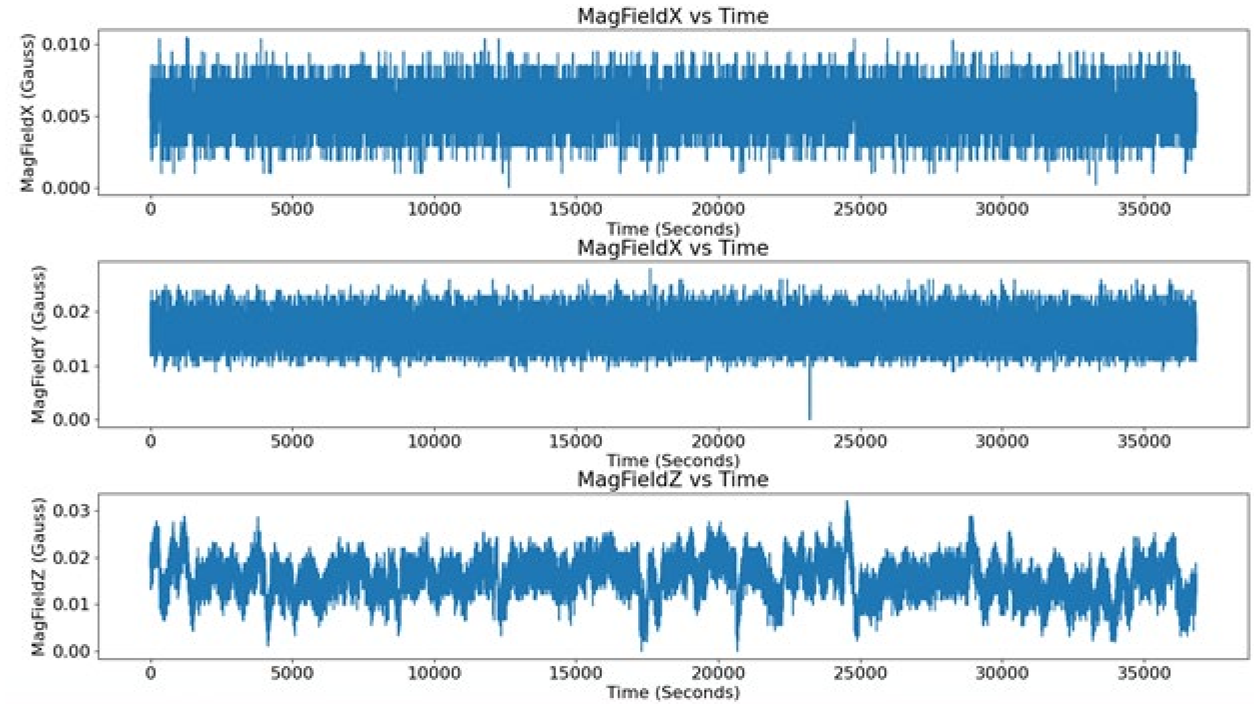

Figure 3: Magnetic Field vs Time Line Plots

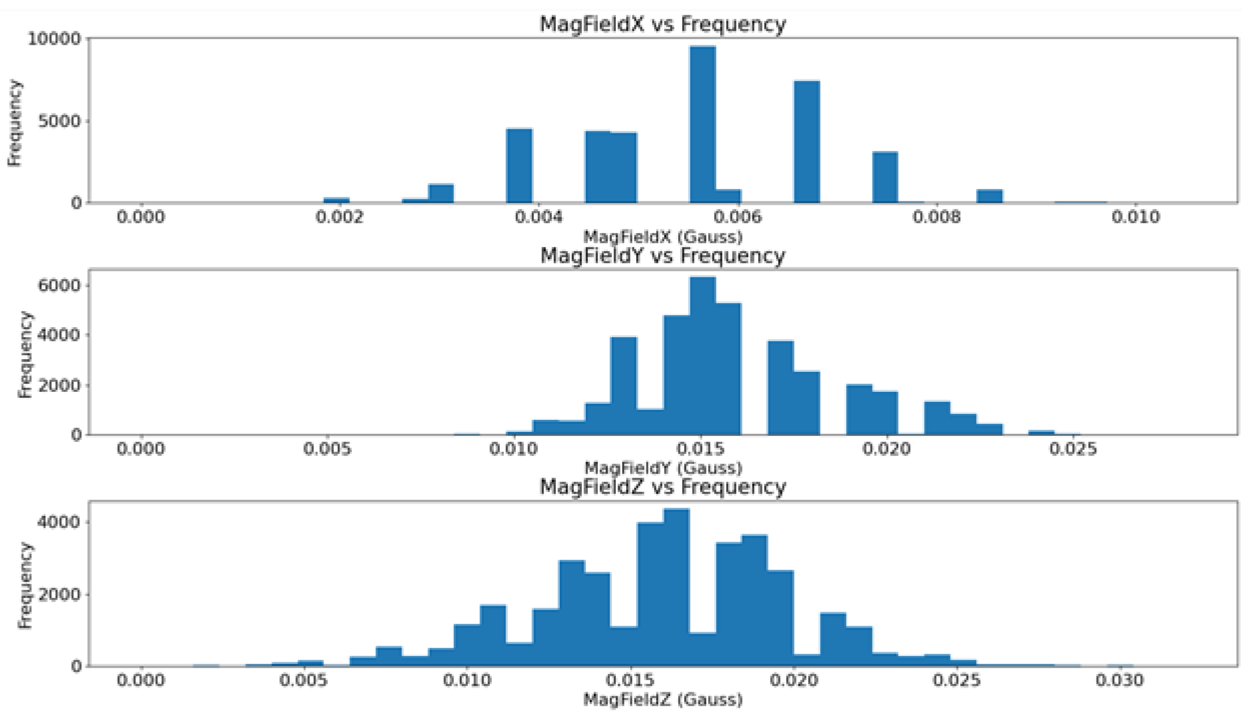

Figure 4: Magnetic Field Histograms

	MagX	MagY	MagZ
Mean	0.005530	0.015923	0.015949
Standard Deviation	0.001328	0.002747	0.003876

From the line plots, we can see that the Magnetic Field in X & Y axis is densely populated, whereas, Magnetic Field in Z- axis has less number of data points. The histogram distribution of MagX & MagY is discontinuous and has multiple peaks. Whereas, the histogram of MagZ shows a continuous distribution. The peak value of the histogram is almost equal to the mean of the respective parameter readings.

Accelerometer Data (Linear Acceleration):

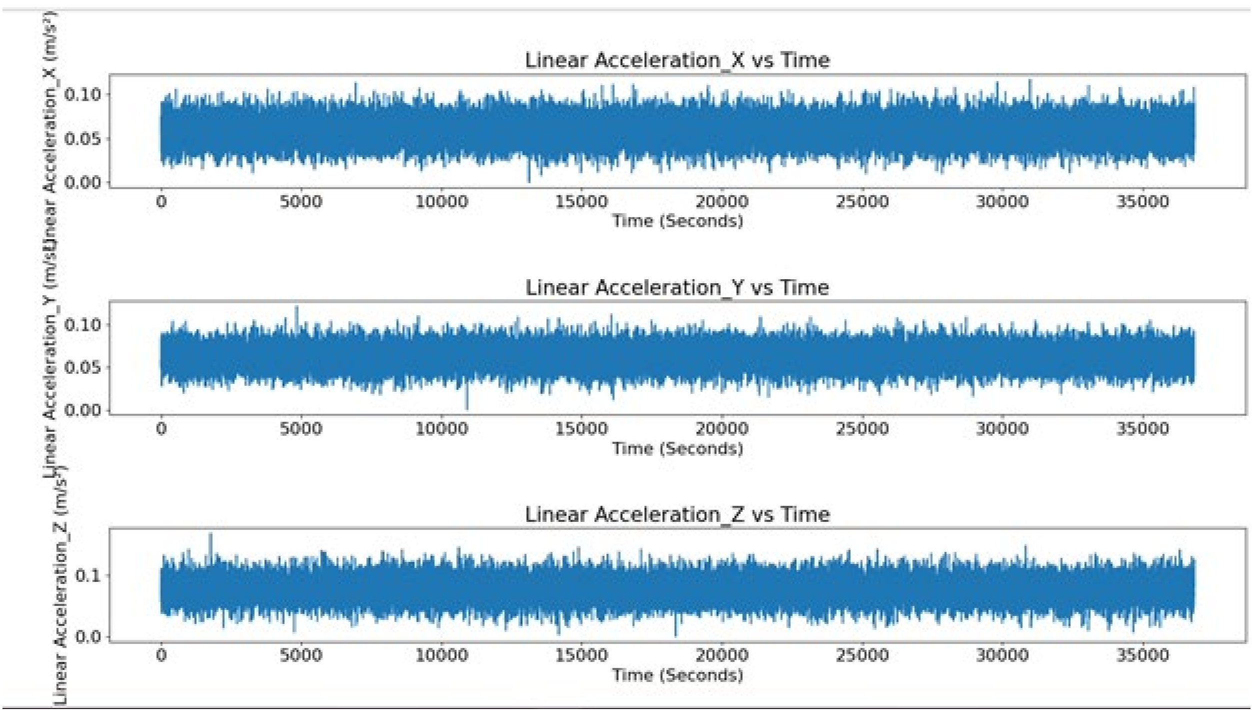

Figure 5: Linear Acceleration vs Time Line Plots

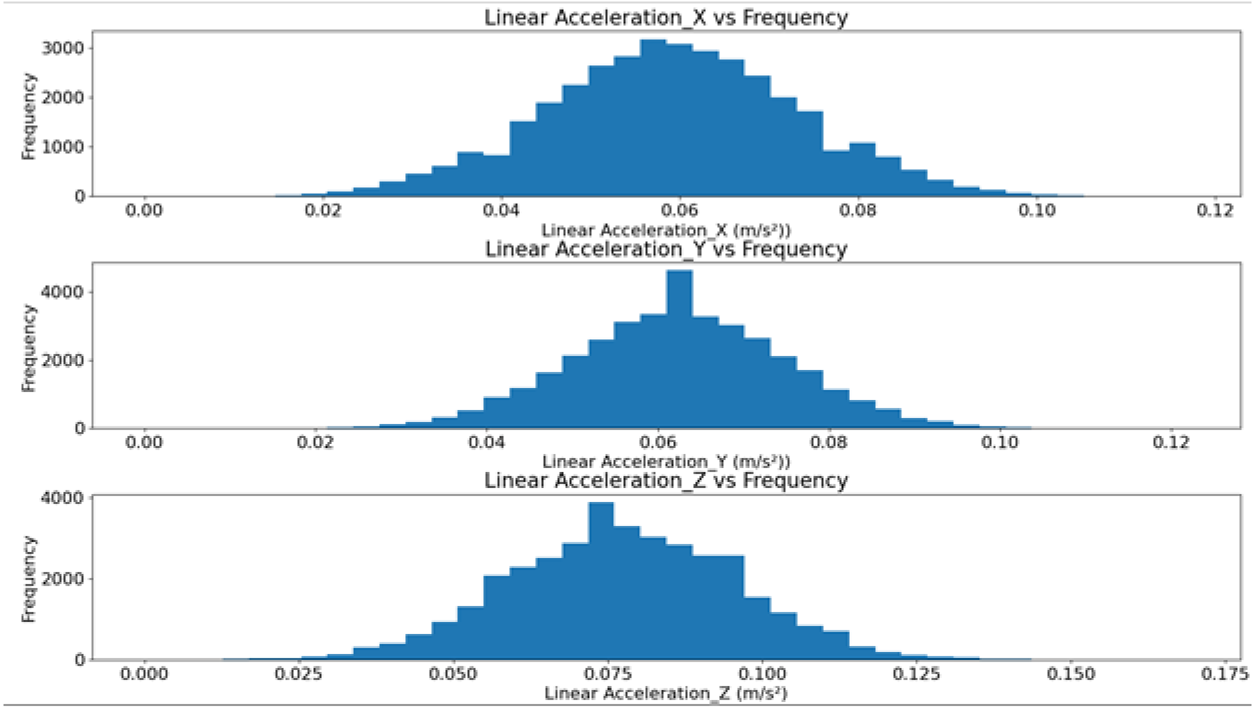

Figure 6: Linear Acceleration Histograms

	AccX	**AccY**	**AccZ**
Mean	0.059200	0.062455	0.077534
Standard Deviation	0.014189	0.012691	0.018306

From the line plots, we can see that the Linear Acceleration in all the three axes is densely populated. The histogram distribution of all three is consistent with this. The histogram of X is almost symmetrical, whereas, for Y & Z, it has a sharp peak. The peak value of the histogram is almost equal to the mean of the respective parameter readings.

Gyroscope Data (Angular Velocity):

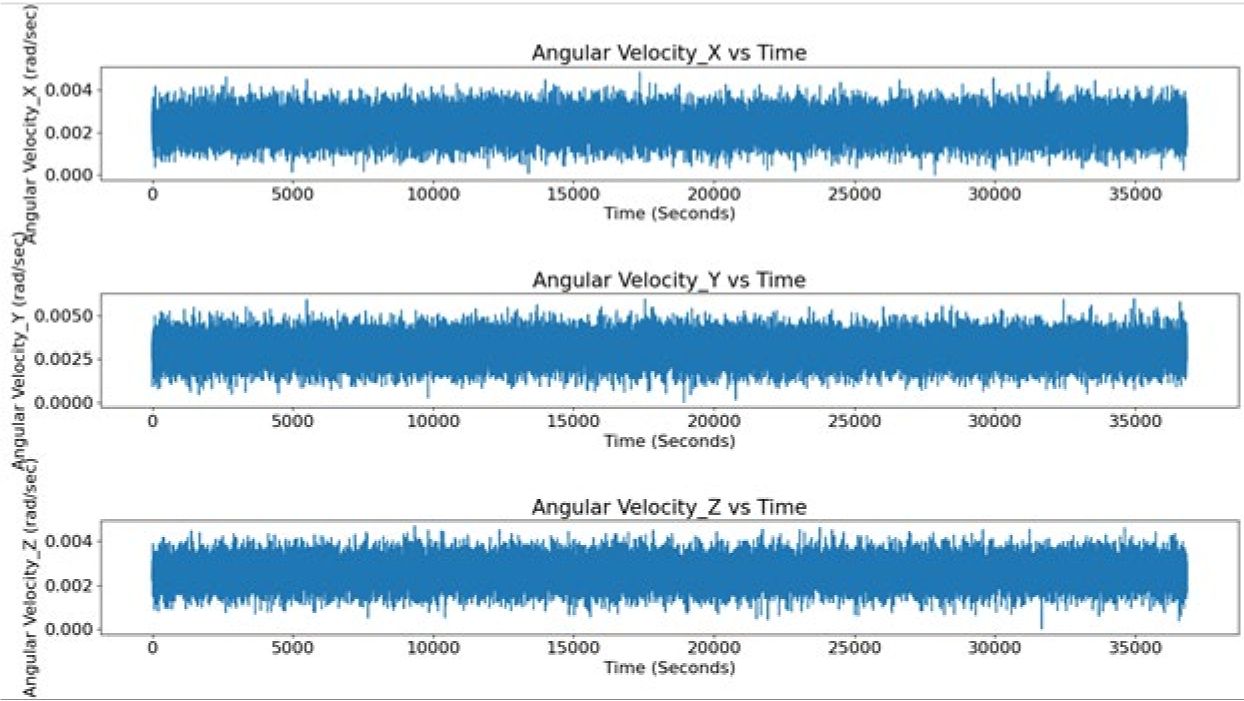

Figure 7: Angular Velocity vs Time Line Plots

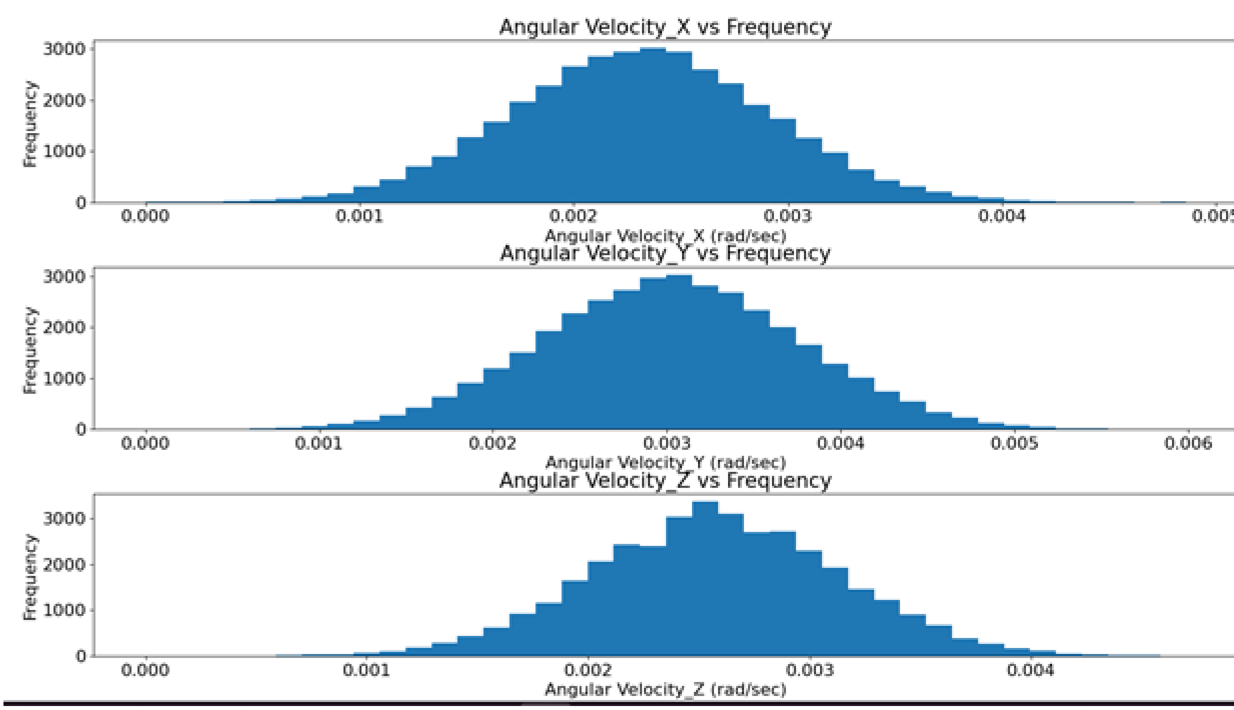

Figure 8: Angular Velocity Histograms

	GyroX	GyroY	GyroZ
Mean	0.002311	0.003024	0.002576
Standard Deviation	0.000594	0.000738	0.000561

From the line plots, we can see that the Angular Velocity in all the three axes is densely populated. The histogram distribution of all three is consistent with this. The histogram of X & Y is symmetrical, as compared to Z. The peak value of the histogram is almost equal to the mean of the respective parameter readings.

IMU Data - Allan Variance Noise Analysis:

Allan variance was originally derived to measure the noise characteristics and stability of clock oscillators. More specifically, the frequency stability of oscillators. Allan variance analysis is used to estimate the stability of a time-domain signal due to noise processes, not systematic errors such as temperature effects. Allan deviation is simply the square root of Allan variance.

Allan deviation can also be applied to analyze the stability and noise characteristics of IMU sensors. We will compute the Allan deviation for Gyroscope. The result of an Allan deviation analysis is a plot, typically plotted on a log scale. The x-axis will be time in seconds, and the y-axis will be Allan deviation of the angular velocity in degrees per sec. The data collection for Allan variance was done in similar physical conditions as the stationary noise analysis. The only difference being that the data was collected for 5 hours.

Noise Parameters/Characteristics:

The following are the sources of noise present in the IMU sensor readings which can be characterized using Allan deviation:

1. Random Walk: If a noisy output signal from a sensor is integrated, for example integrating an angular rate signal to determine an angle, the integration will drift over time due to the noise. This drift is called random walk, as it will appear that the integration is taking random steps from one sample to the next. The two main types of random walk for inertial sensors are referred to as angle random walk (ARW), which is applicable to gyroscopes, and velocity random walk (VRW), which is applicable to accelerometers.

2. Bias Instability: The in-run bias stability, or often called the bias instability, is a measure of how the bias will drift during operation over time at a constant temperature. This parameter also represents the best possible accuracy with which a sensor's bias can be estimated. Due to this, in-run bias stability is generally the most critical specification as it gives a floor to how accurate a bias can be measured.

Calculation of Noise Characteristics:

Angle Random Walk is roughly equal to the standard deviation at an averaging time constant of one second, while the minimum standard deviation value on the plot is the bias instability. If we drop a perpendicular line from $\tau = 10$, the point at which it intersects the Allan Deviation Graph is the Angle Random Walk, and the point at which the slope of Allan Deviation Graph is zero is the bias instability.

Allan Deviation Plots for Gyroscope Data (Angular Velocity):

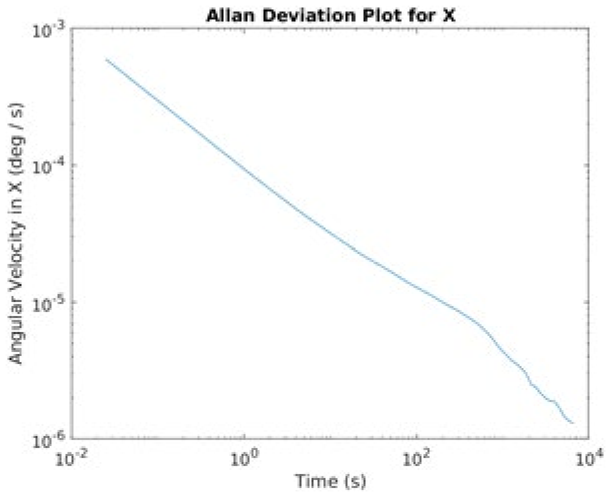

Figure 9 - Allan Deviation for GyroX

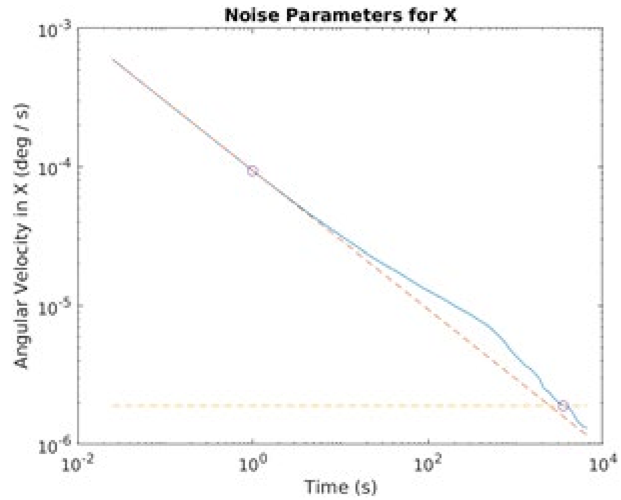

Figure 10 - Noise Parameters for GyroX

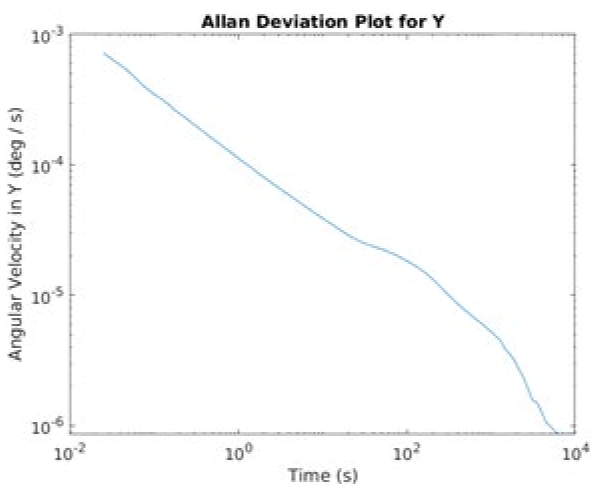

Figure 11 - Allan Deviation for GyroY

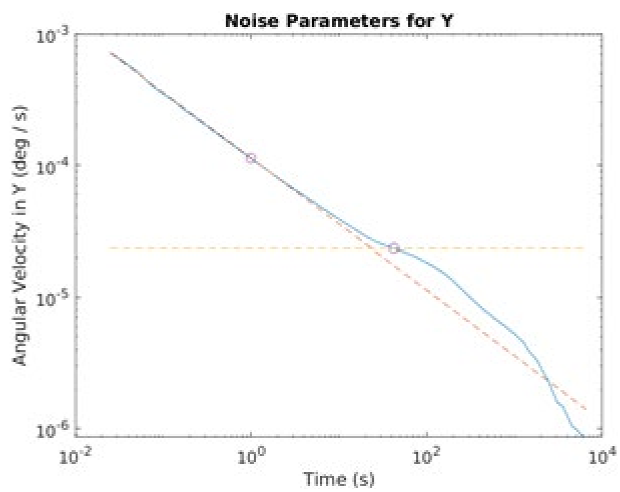

Figure 12 - Noise Parameters for GyroY

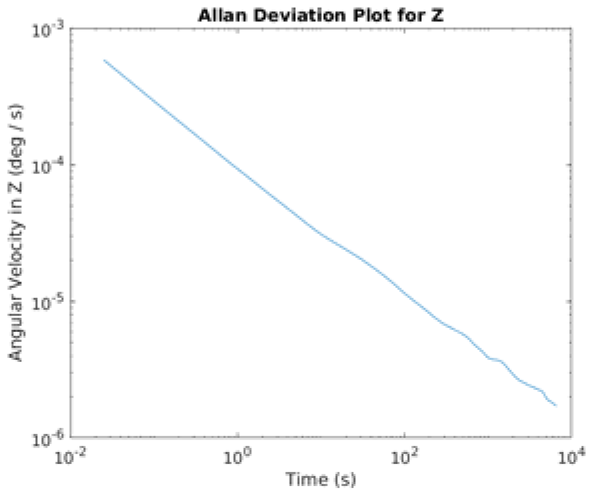

Figure 13 - Allan Deviation for GyroZ

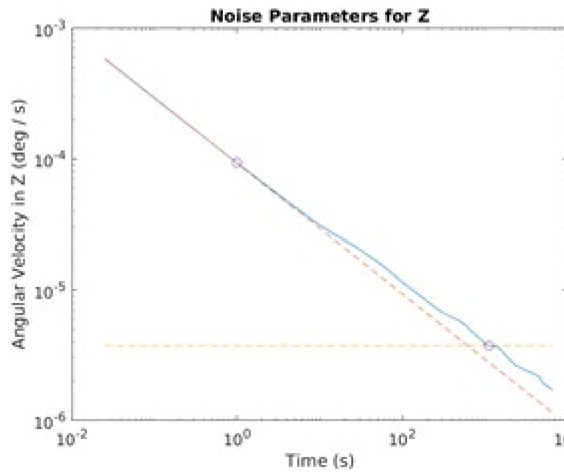

Figure 14 - Noise Parameters for GyroZ

From the above plots, we can conclude that there is very less drift in the Gyroscope output over a long time period since there are no sudden fluctuations in the curves.

We can compare the MATLAB computed noise parameters for the gyroscope with those listed on the VN100 IMU sensor datasheet from the following table:

	GyroX	**GyroY**	**GyroZ**	**Datasheet Value**
Angle Random Walk	9.410866e-05	1.133137e-04	9.297690e-05	0.0035 °/s /√Hz
Bias Instability	2.862280e-06	3.516400e-05	5.653537e-06	< 10°/hr (5-7°/hr typ.)

Allan Deviation Plots for Accelerometer Data (Linear Acceleration):

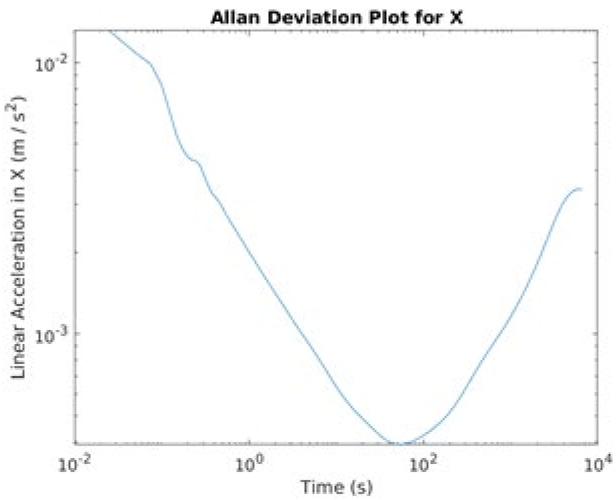

Figure 15 - Allan Deviation for AccelX

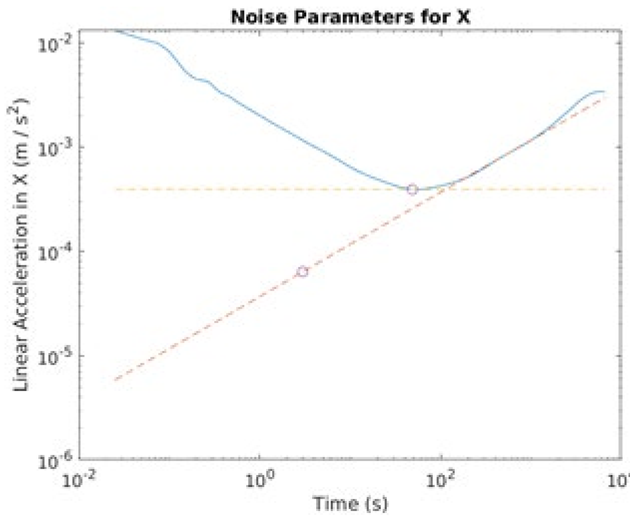

Figure 16 - Noise Parameters for AccelX

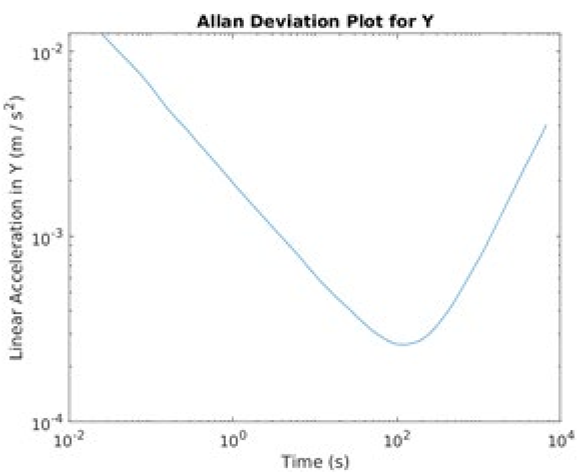

Figure 17 - Allan Deviation for AccelY

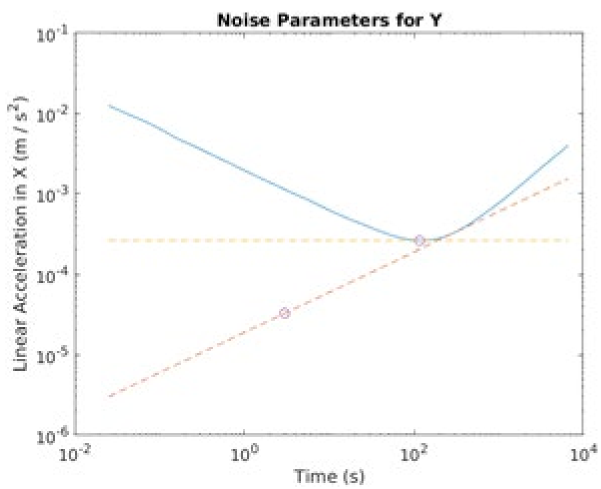

Figure 18 - Noise Parameters for AccelY

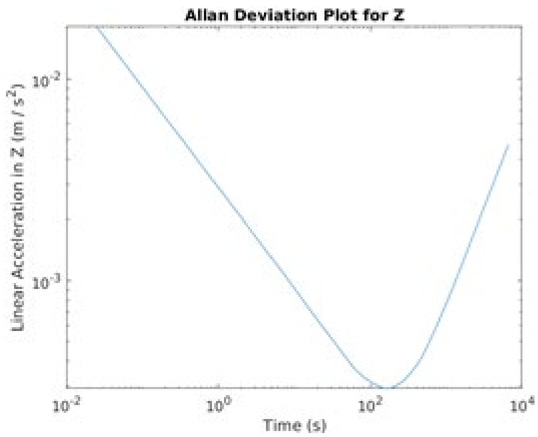

Figure 19 - Allan Deviation for AccelZ

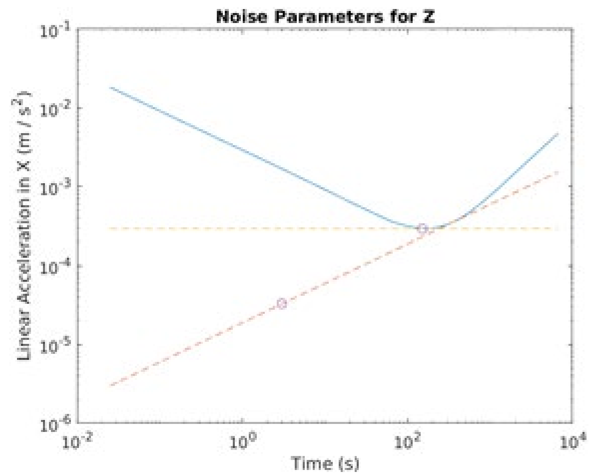

Figure 20 - Noise Parameters for AccelZ

From the above plots, we can conclude that drift builds in the accelerometer readings over time since there is a clear inflection point visible in the curve.

We can compare the MATLAB computed noise parameters for the accelerometer with those listed on the VN100 IMU sensor datasheet from the following table:

	AccelX	**AccelY**	**AccelZ**	**Datasheet Value**
Rate Random Walk	6.384141e-05	3.292780e-05	3.268102e-05	0.14 mg/√Hz
Bias Instability	5.902487e-04	3.939513e-04	4.402778e-04	< 0.04 mg