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EECE 5554 - Robotics Sensing and Navigation

Lab 3 - IMU Report

Overview

In this lab, we collected two datasets: a short 15-minute IMU reading and a long 5-hour IMU reading. In both scenarios, the VectorNav was placed in an environment that would not introduce external forces, like vibrations of people walking, cars, and any other type of noise. For this lab, the 5-hour long IMU reading was used to calculate the Allan variances, while the 15-minute dataset was used to observe behaviors in sensor readings and noise.

Analysis

1.1 Stationary 15-minute IMU Data

Data Type	**Units**	**Mean**	**Standard Deviation**
Linear Acceleration X	m/s^2	-0.532788	0.042392
Linear Acceleration Y	m/s^2	-0.960436	0.062734
Linear Acceleration Z	m/s^2	-9.622933	0.026804
Angular Velocity X	rad/s	-0.000046	0.005719
Angular Velocity Y	rad/s	0.000022	0.002371
Angular Velocity Z	rad/s	-0.000010	0.002557
Magnetic Field X	Gauss	-0.005890	0.003197
Magnetic Field Y	Gauss	0.110874	0.005025
Magnetic Field Z	Gauss	0.490503	0.002888
Roll	rad	-0.050137	0.002979
Pitch	rad	-0.543724	0.003562
Yaw	rad	0.837323	0.002449

Table 1: Mean and Standard Deviation for 15-minute dataset.

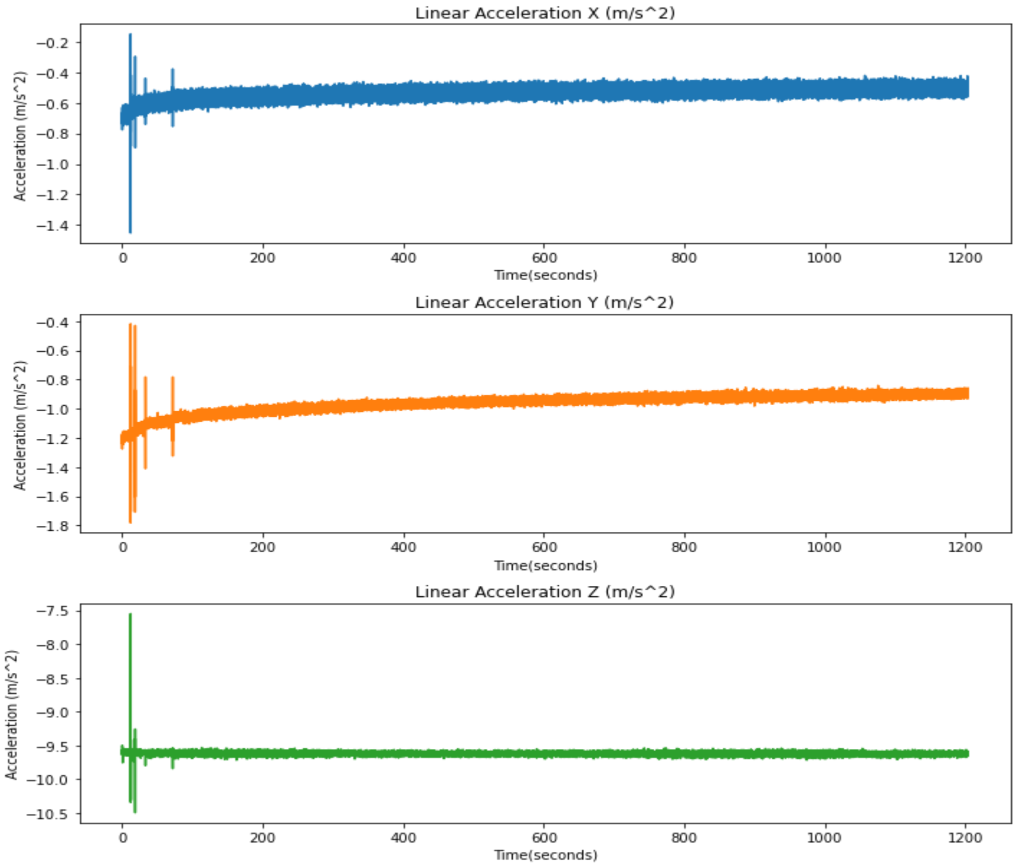

Figure 1: Linear Acceleration for 15-minute dataset.

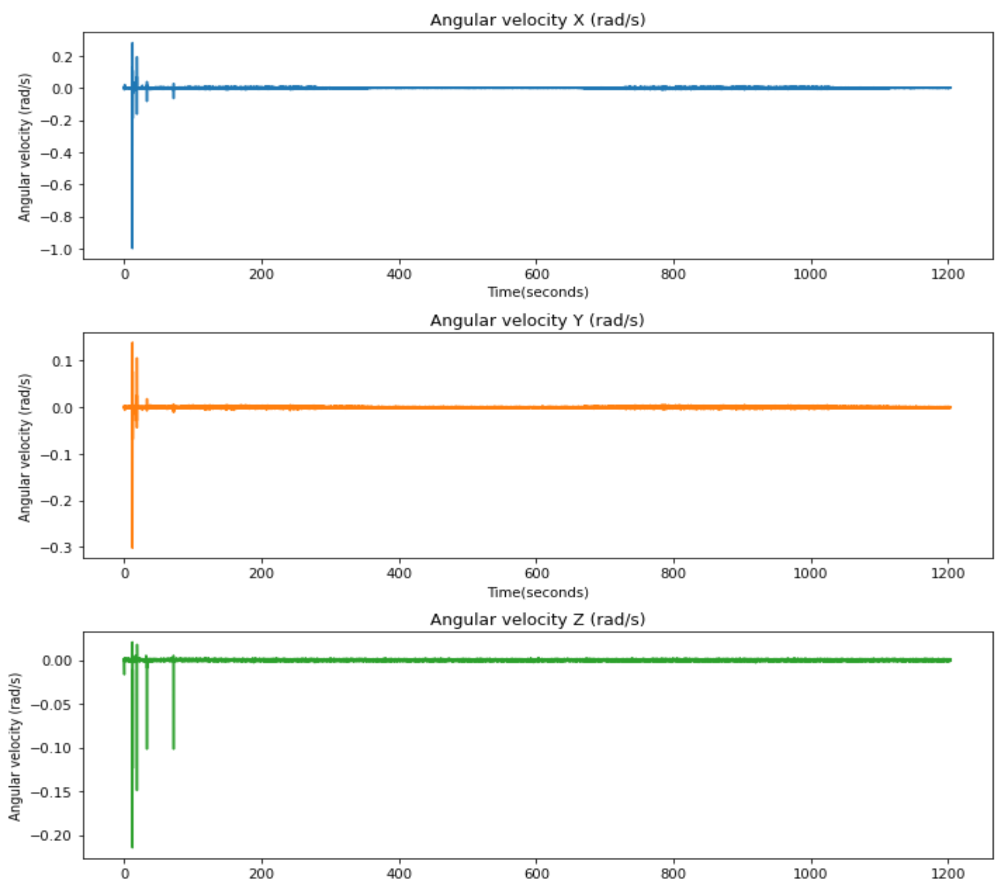

Figure 2: Angular Velocity for 15-minute dataset.

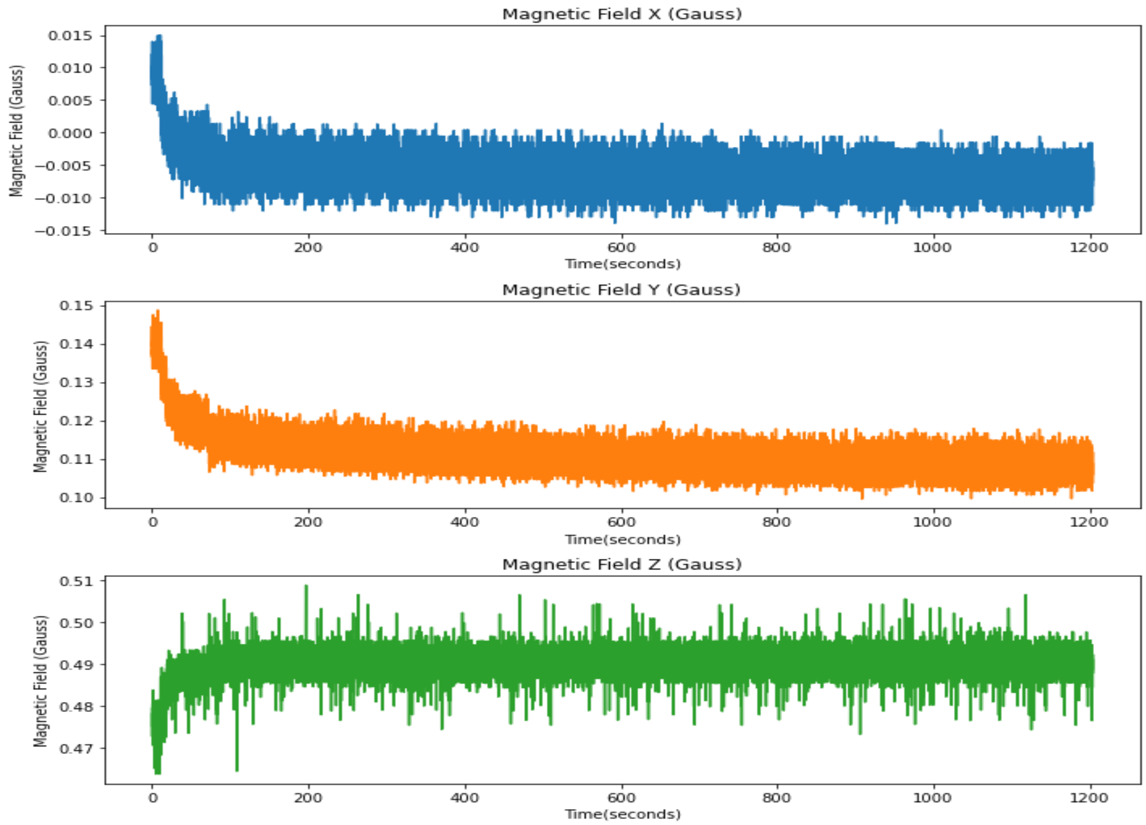

Figure 3: Magnetic Field vs time for 15-minute dataset.

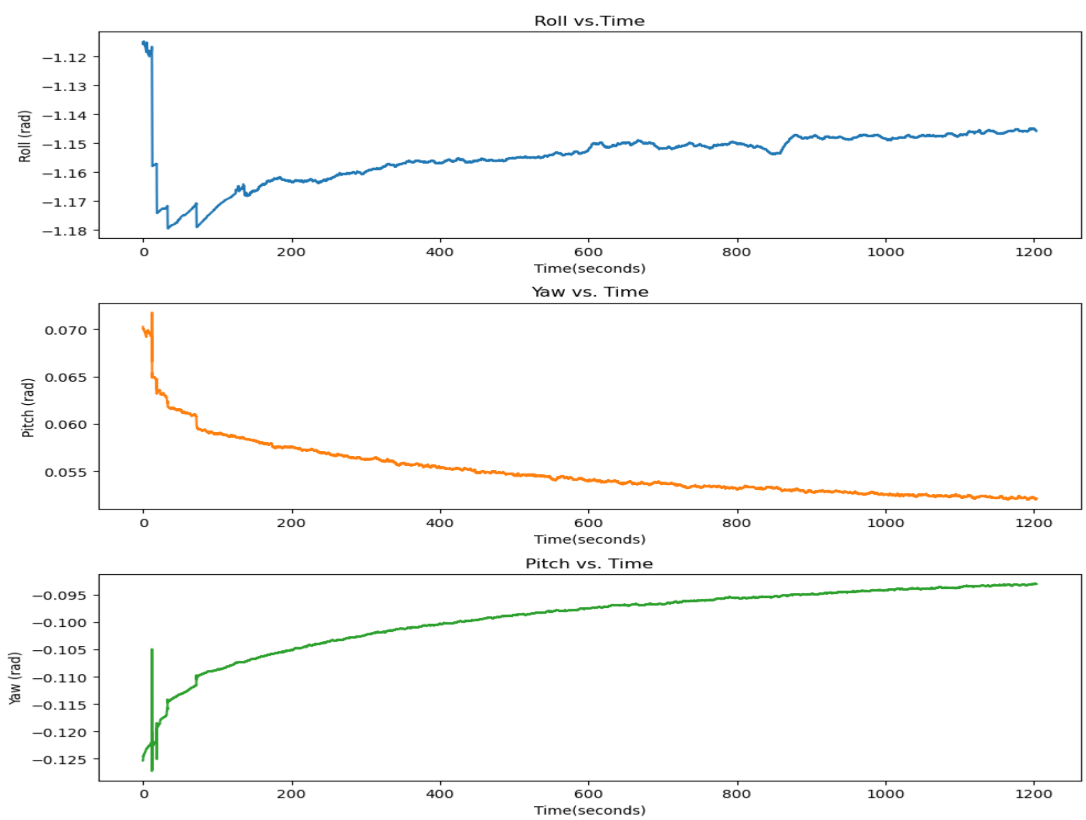

Figure 4: Roll, Pitch, and Yaw as a function of time for 15-minute dataset(converted to Euler).

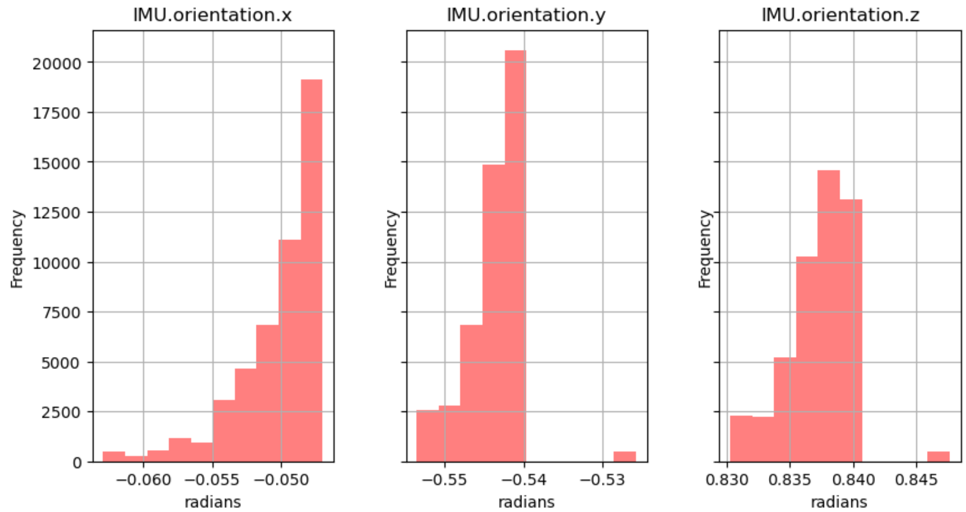

Figure 5: Frequency Domain Plot of Orientation

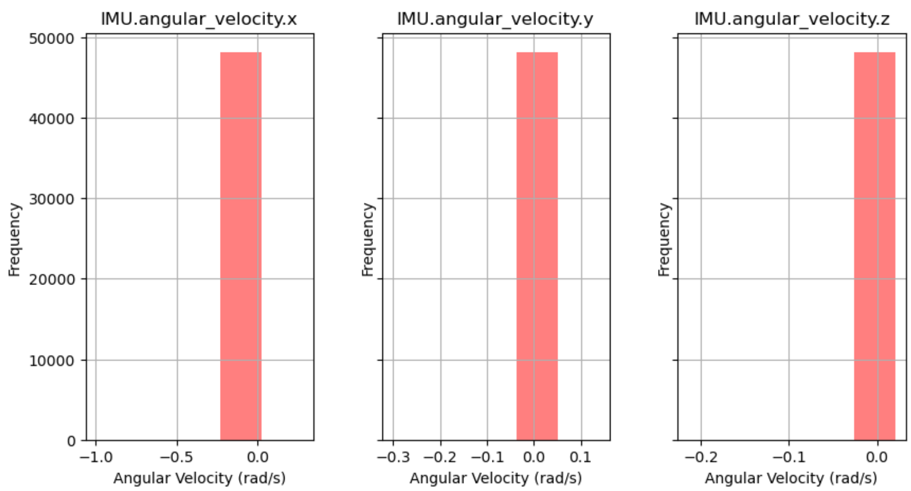

Figure 6: Frequency Domain Plot of Angular Velocity

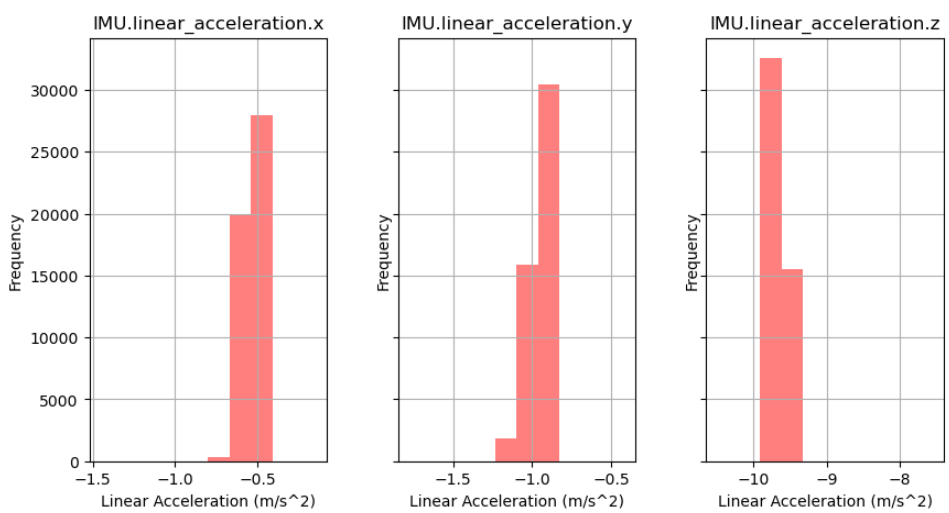

Figure 7: Frequency Domain Plot of Linear Acceleration

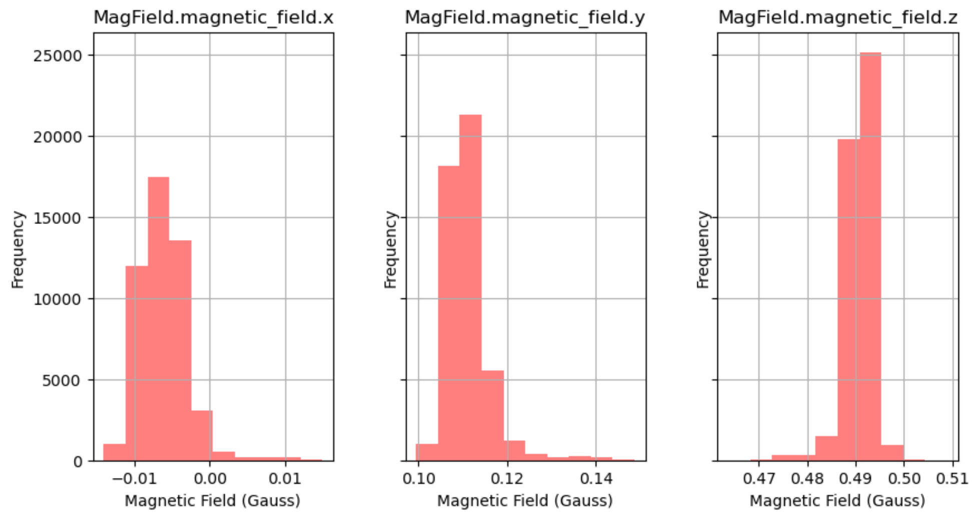

Figure 8: Frequency Domain plot of Magnetic Fields

The data that was collected from the IMU for 15-minutes has been plotted in Figures 1-8 for linear acceleration, angular velocity, magnetic field, and for roll, pitch, and yaw for every axis. From Table 1, the average value and the standard deviation for each axis can be noted. By observing the different plots and the table various patterns can be determined.

Firstly, by analyzing Table 1, the data shows a relatively accurate description of what would happen when the IMU is set in a stationary position. Theoretically, a standstill IMU would show a zero in nearly every category except for linear acceleration in the Z-direction and the magnetic fields. This is because the acceleration in the Z-direction is due to gravity, and we observe in Figure 3, that the magnetometer reading drifts over time. This may be partially caused by nearby electrical circuits and magnetic materials that were near the sensor during the data collection. These nearby objects can have their own magnetic fields that become superimposed with the Earth's field, affecting the sensor readings. Given that the IMU was in a stationary position, the standard deviation should not vary much. In this case, we see that the standard deviation for every data type is below 0.07, showing that there is very little dispersion of data points. This demonstrates that the data taken was fairly good data as there was not a lot of interference in the gathering of the data.

In Figures 1 and 2, the linear acceleration and angular velocity shows that very early on, there is some type of a noise which can be seen as several jumps within the data. Given that these were very early on in the data collection, these can be attributed to some noise that could be of the sensor itself, or some external force, such as a shake of the wire of the IMU. In Figures 1, 3 and 4, it can be noted that after the initial start of the data, the points tend to drift towards a certain value and then settle.For an example, in Figure 1, the linear acceleration in the x-direction drifts from -0.8 m/s^2 to between -0.45 and -0.6 m/s^2. This is most likely due to the accelerometer and gyroscope taking time to accurately settle on a position. The angular velocities, in Figure 2, show very little bias, and standard deviation, which is expected due to the IMU being calibrated by factory settings to mitigate the effects of scale factor, misalignment, and bias. From the frequency domain plots, we can see how often certain values were repeated, and contribute values far from the majority as noise. The most distinguishable plots can be seen in Figure 5 and 8, where there are more outliers within the magnetic field and orientation. The roll, pitch, and yaw readings can be seen in Figure 4. Since the IMU was stationary on the ground there is likely a bias in all three directions. This can be attributed to the fact that when integrating the gyroscope readings to get a heading value, the angular random walk can appear as a drift in the euler angle readings. Additionally, the bias instability in the gyroscopes will result in an angular error. The noise on all linear acceleration, angular velocity, and magnetometer signals are Gaussian.

1.2 Stationary 5-hour Dataset (Allan Variance)

Data Type	Units	Mean	Standard Deviation
Linear Acceleration X	m/s^2	-0.011431	0.013016
Linear Acceleration Y	m/s^2	0.169037	0.011644
Linear Acceleration Z	m/s^2	-9.609361	0.016704
Angular Velocity X	rad/s	2.074393e-06	0.000605
Angular Velocity Y	rad/s	6.352467e-07	0.001967
Angular Velocity Z	rad/s	1.126691e-06	0.000603
Magnetic Field X	Gauss	0.175397	0.001496
Magnetic Field Y	Gauss	0.131415	0.004935
Magnetic Field Z	Gauss	0.445144	0.005746
Roll	rad	-0.007423	0.000066
Pitch	rad	0.004746	0.000154
Yaw	rad	-0.594253	0.000436

Table 2: Mean and Standard Deviation for Allan Variance dataset.

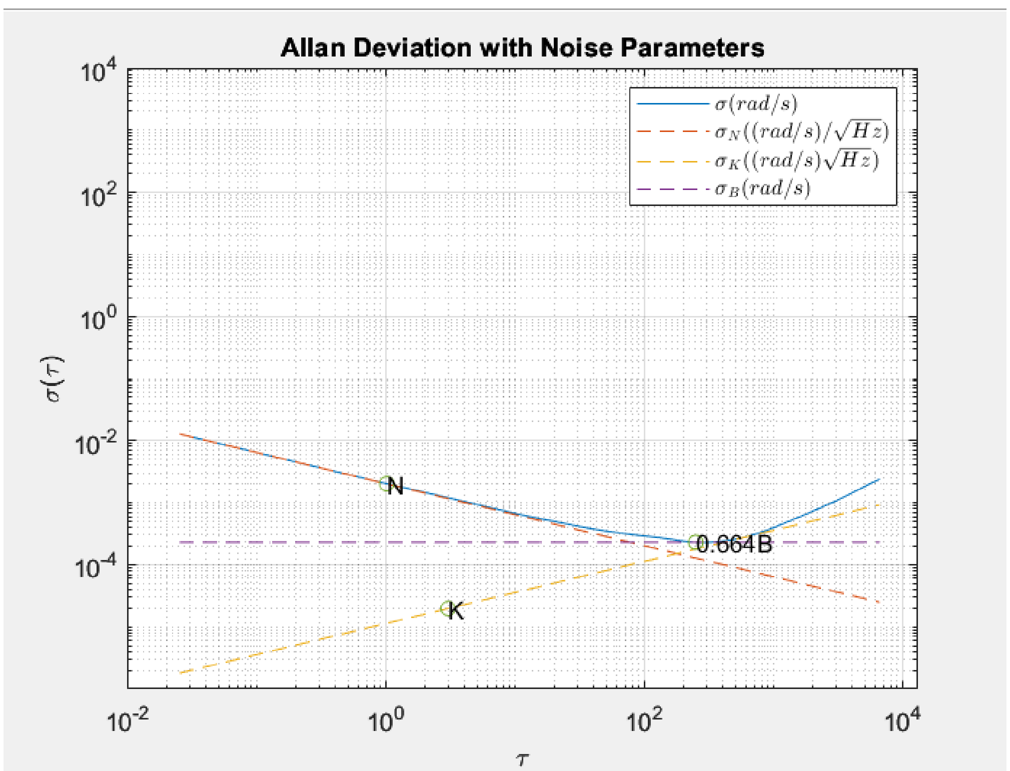

Figure 9: Allan Variation and Noise characteristics for x linear acceleration. N is the velocity random walk coefficient and is 0.0020 (m/s^2) / √(Hz). K is the acceleration random walk and is 0.000 (m/s^2) / √(Hz). B is bias instability coefficient and is 0.000346 m/s^2.

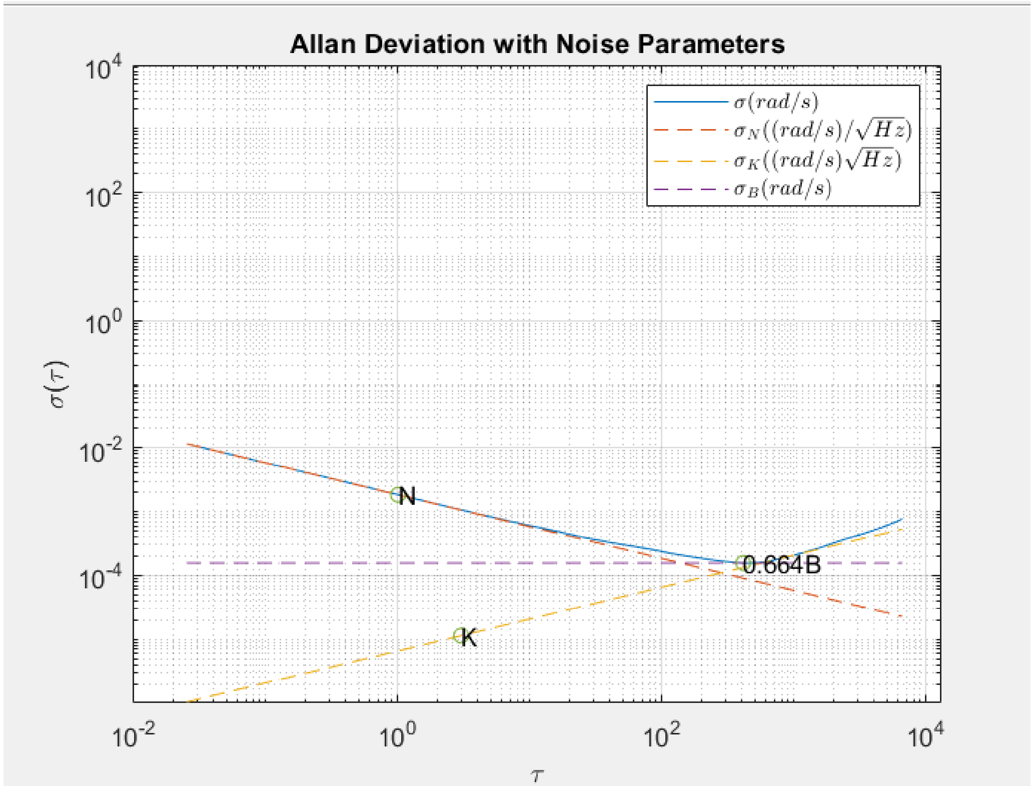

Figure 10: Allan Variation and Noise characteristics for y linear acceleration. N is the velocity random walk coefficient and is 0. 0018 (m/s^2) / √(Hz). K is the acceleration random walk and is 0.00001 (m/s^2) / √(Hz). B is bias instability coefficient and is 0. 00023 m/s^2.

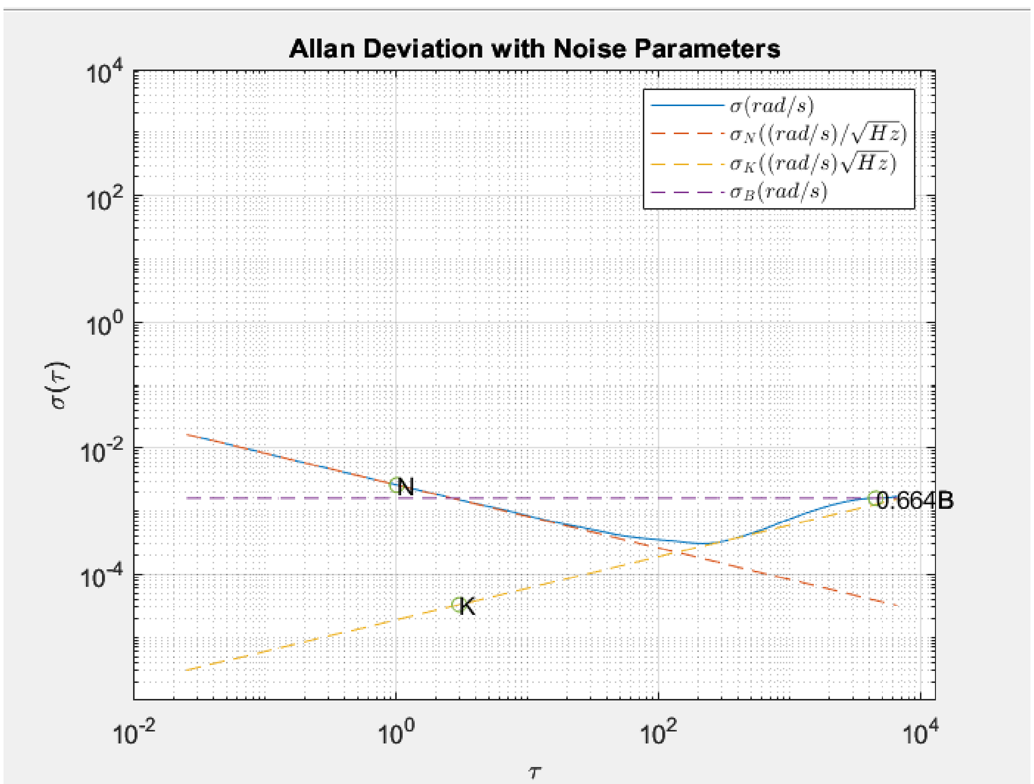

Figure 11: Allan Variation and Noise characteristics for z linear acceleration. N is the velocity random walk coefficient and is 0. 0025 (m/s^2) / √(Hz). K is the acceleration random walk and is 0.00003 (m/s^2) / √(Hz). B is bias instability coefficient and is 0. 00239 m/s^2.

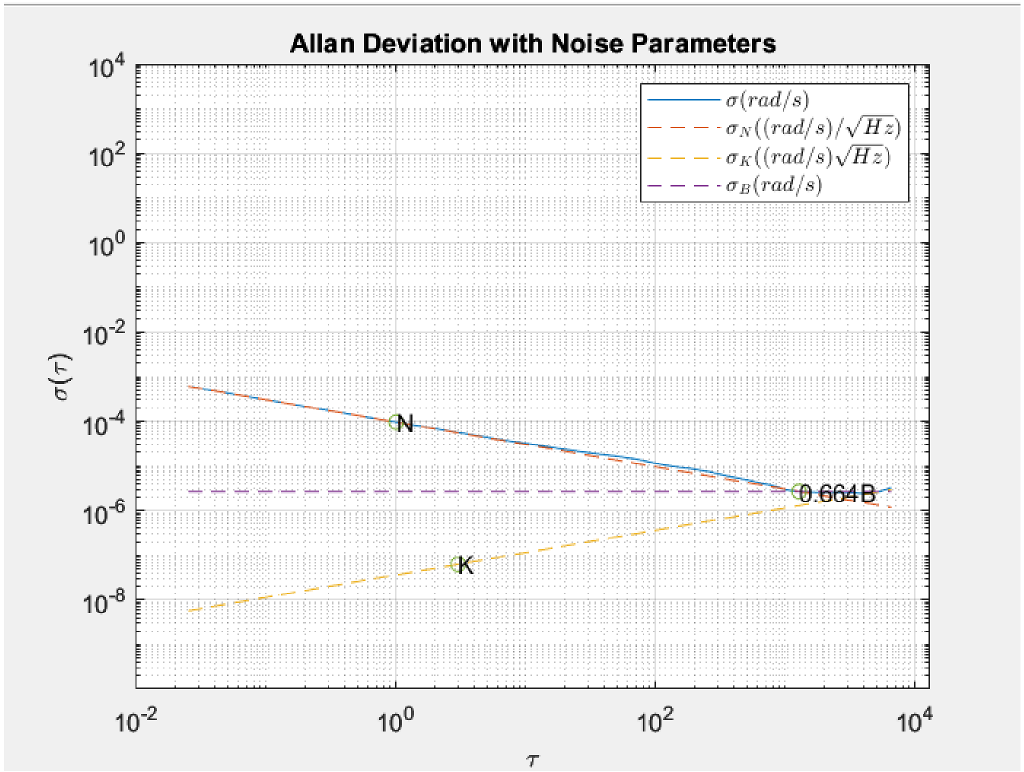

Figure 12: Allan Variation and Noise characteristics for x angular velocity. N is the angle random walk coefficient and is 0. 0000953 (rad/s) / √(Hz). K is the rate random walk and is 0.00 (rad/s) / √(Hz). B is bias instability coefficient and is 0. 000004 rad/s.

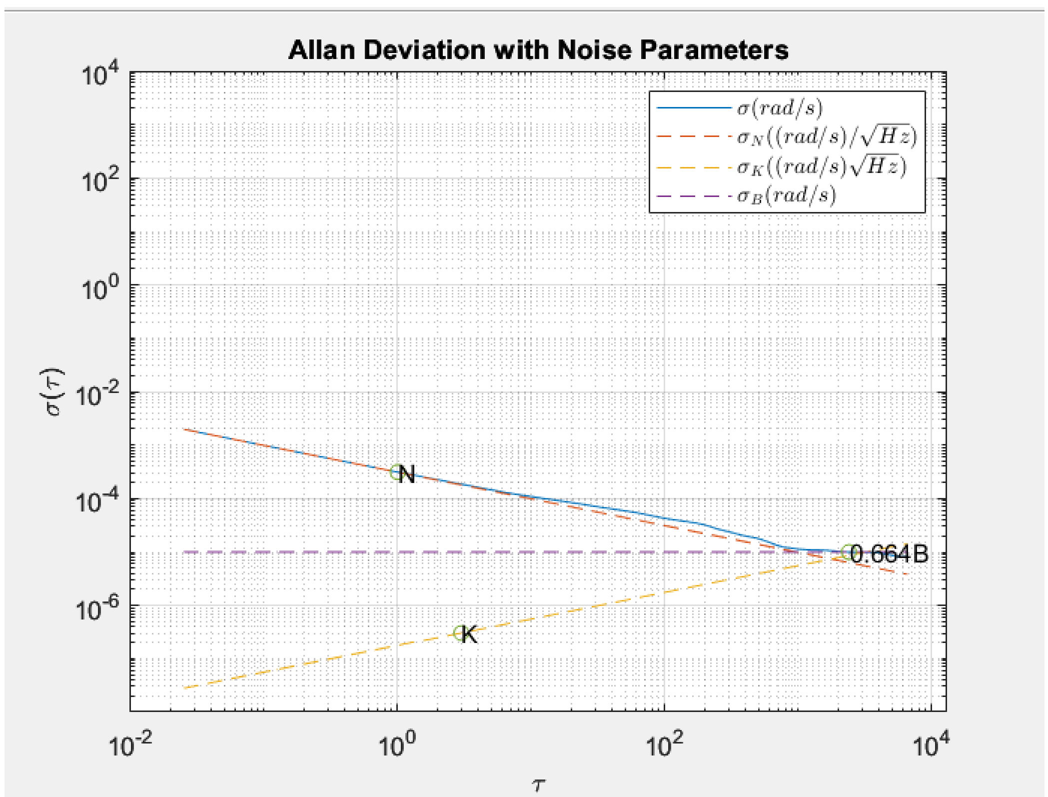

Figure 13: Allan Variation and Noise characteristics for y angular velocity. N is the angle random walk coefficient and is 0. 00031 (rad/s) / √(Hz). K is the rate random walk and is 0.00 (rad/s) / √(Hz). B is bias instability coefficient and is 0. 000015 rad/s.

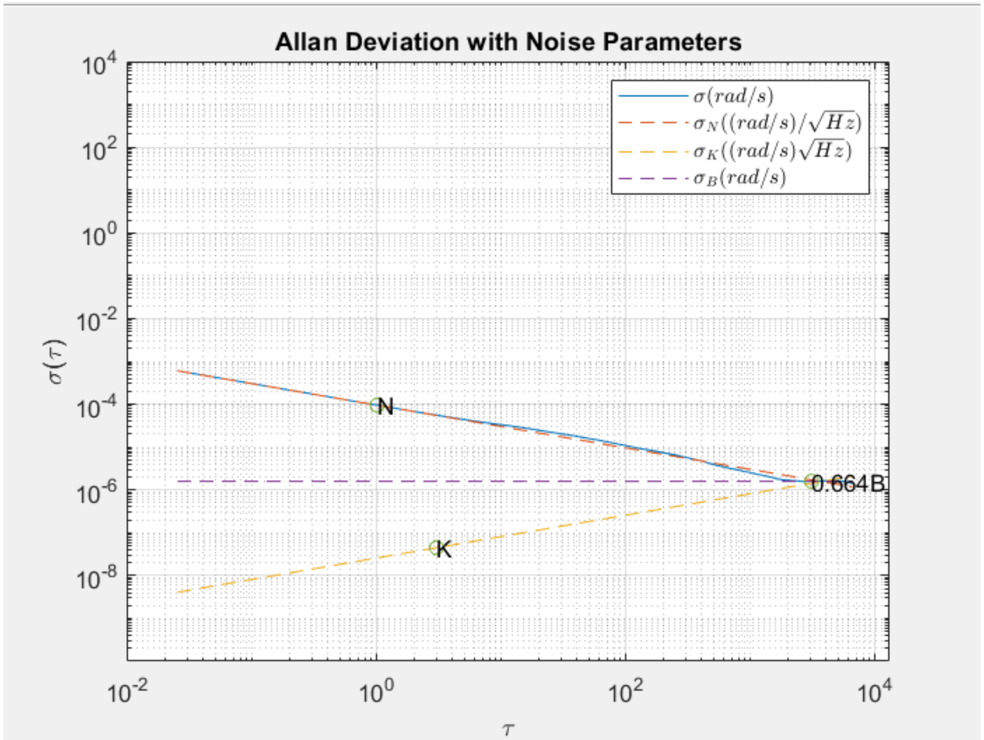

Figure 14: Allan Variation and Noise characteristics for z angular velocity. N is the angle random walk coefficient and is 0.00009 (rad/s) / √(Hz). K is the rate random walk and is 0.00 (rad/s) / √(Hz). B is bias instability coefficient and is 0.0000023 rad/s.

*NOTE: K values are so tiny, that rounded to 0.00

Allan variance is used to estimate the frequency stability due to noise processes. The Allan variance plots take a period of time, Tau, that is optimal for which data can be averaged and not lose its accuracy. By averaging the sensor readings, this will help to mitigate noise on the dataset.

Noise is characterized by computing the root Allan variance and analyzing specific regions where the slopes of the deviation curves identify the types of noise present, and their degree of influence. Angular random walk/velocity random walk appears when the slope of the curve is -0.5. Bias instability appears on the plot where the slope is 0, while rate/acceleration random walk appears when the slope of the curve is 0.5.

Within the Allan Variance plots, we can see that there is an uptick of the sigma value towards the end of the time period. It is a more drastic curvature seen in the linear acceleration plots compared to that of the angular velocity. The angle random walk is characterized by the white noise spectrum of the gyroscope output. The N value in each of the plots represents the angle random walk coefficient, or the degree to which white noise contributes to the signal. The bias instability measures how the bias of the gyroscope changes over a specified period of time. The bias instability is represented by B in the Allan Variance figures above. Finally, the rate random walk is characterized by the Brownian noise in the output, where K represents the rate random walk coefficient. For accelerometers, the N coefficient represents velocity random walk and the K coefficient represents acceleration random walk.

For all the plots from Figure 9-11 we see that the Allan Variance plots come to a point where the rate of random walk, angle random walk, and bias instability can be confidently characterized. We can see using the slopes of each line that the sigma plot(blue line) follows, at different times in Tau, the slopes for each characteristic.

Some sources of noise and errors can be due to scale factor and misalignment in IMUs, which are a byproduct of the manufacturing process. In gyroscopes, misalignment describes the angular difference between each gyroscope's axis of rotation and the system defined as the inertial reference frame. Scale factor describes how well the output of a sensor corresponds to a force input. Both of these issues will directly affect the random walk and bias observed in the Allan Variance plots. Additional error sources include unintentional vibrations due to the surroundings of the sensor. While attempts were made to place the sensor in the basement of a house (mitigating the effects of building sway and vibrations due to nearby train stations), it is not impossible to eliminate vibrations.

According to the VN100 datasheet, the in-run bias instability is less than 0.04 mg for the accelerometer, and less than 10 degrees/hr for the gyroscope. In this case, looking at the bias instability values that were calculated for each axis of the accelerometer and gyroscope, they were very minimal. For example, the bias instability for x-direction linear acceleration is 0.000346 m/s^2, and the bias instability for the x-direction angular velocity 0.000004 rad/s. Based on these very small numbers, we do not even need to convert to mg and degrees/hr to tell that our measurements are excellent compared to the performance specifications listed in the datasheet. However, the conversion 0.000004 rad/s to degree/hour is 0.825. The conversion from 0.000346 m/s^2 to mg is 0.03mg. So this performance of the Vectornav is within specification.

In conclusion, Allan Variance plots are useful to help us characterize the noise and bias stability over time. However, in order for the plots to accurately characterize the noise present, a sufficiently long data sample must be acquired such that the deviation curve reaches a minimum before transitioning to a positive slope.