Lab 3: Analysis of IMU Data

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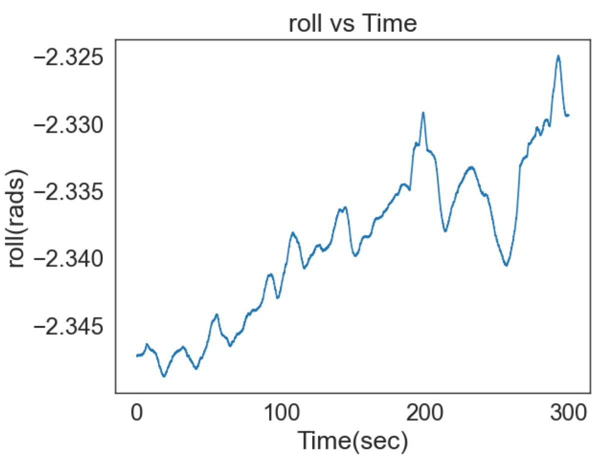
Setting up the hardware for the collection of the IMU data involved the configuration of the VectorNav IMU for two objectives. (1) To set the sensor to send the data in the $VNYMR format. (2) To set the data collection rate of the sensor at 40Hz.

Analysis of 5-minute Stationary Data

Here, a rosbag was created, which recorded the data from the IMU sensor at the rate of 40Hz. 11989 messages were created. These points help in analyzing the accuracy of the data collected and it can be compared to the datasheet specifications.

Time Series Plot – Roll, Pitch, Yaw

Roll with respect to the sensor is defined as the rotation of the sensor along the x-axis. Likewise, pitch is the rotation of the sensor with respect to the y-axis. Yaw is the rotation of the sensor with respect to the z-axis.



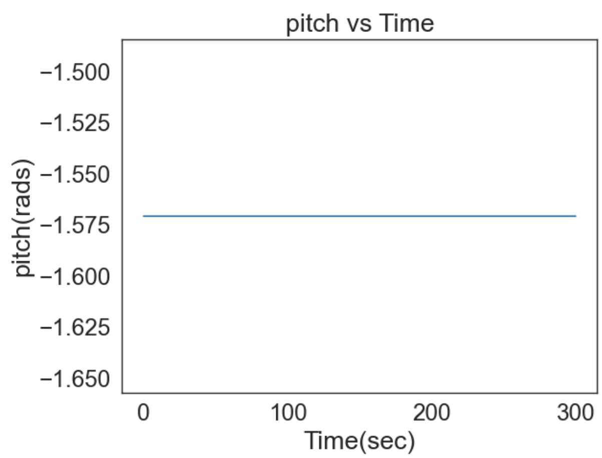


Figure 1 – (a) Roll vs Time (b) Pitch vs Time (c) Yaw vs Time

In Figure 1, the three time series plots for Roll, Pitch and Yaw can be observed. In 1(a) there is an upward trend in the roll value with respect to time. In 1(b), it is observed that the pitch maintains a constant value, over the time frame of 300 seconds. In 1(c), there is a downward trend in the plot of yaw with time.

Time Series Plot – Linear Acceleration

When plotting Linear Acceleration, scatter plots are plotted for each of the x,y and z axes. It can be observed that the data is dense at the middle, which indicates that the data can be modeled as a normal distribution. There is no distinct trend in the readings collected for each of the axes.

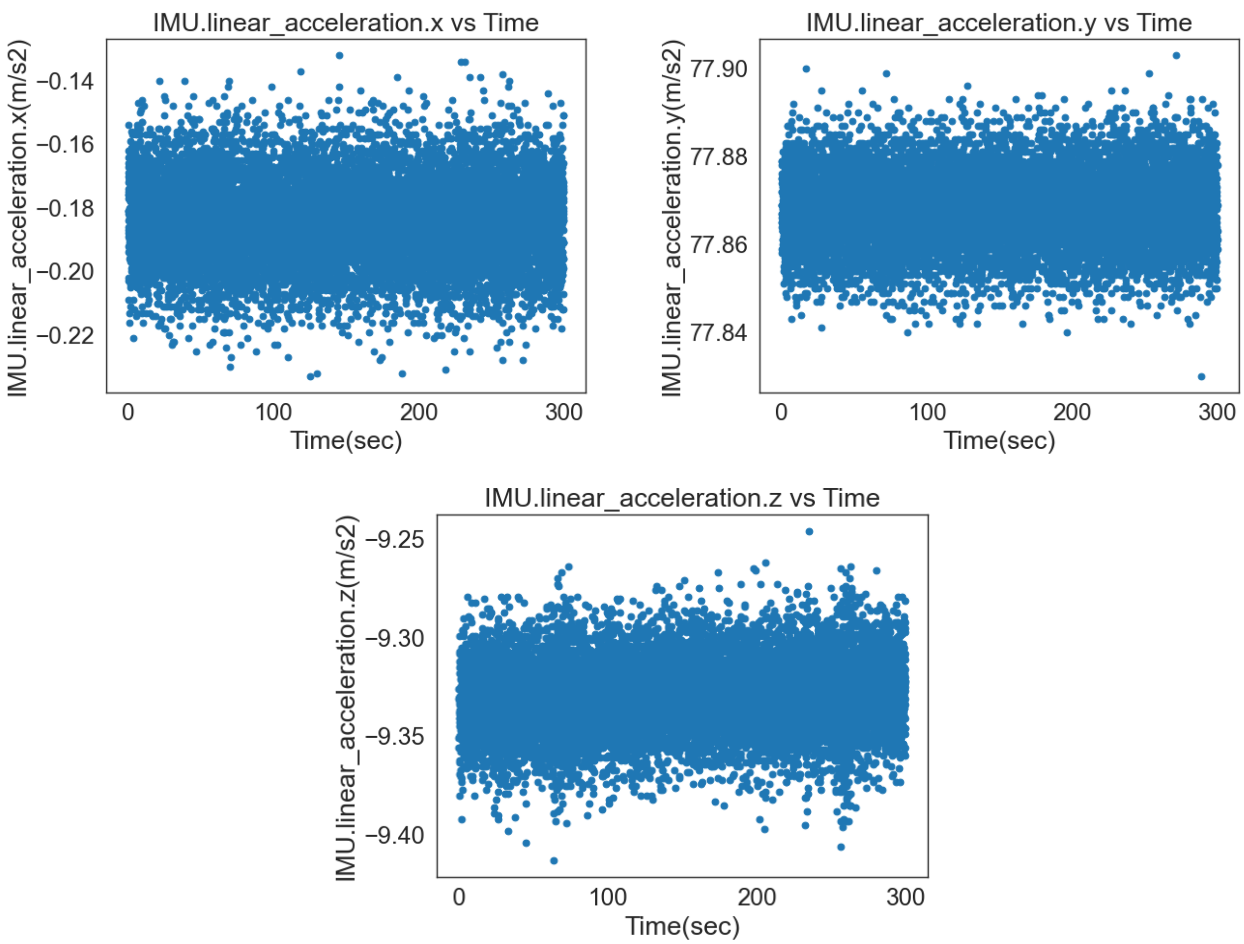


Figure 2 – (a) Linear Acceleration X vs Time (b) Linear Acceleration X vs Time (c) Linear Acceleration X vs Time

Time Series Plot – Angular Velocity

When plotting the Angular velocity, there is no distinct pattern that can be analyzed in any of the three axes. However, there are some spikes that can be seen in Figure 3(a) and (b). This might be due to inherent sensor errors, or the effect of microvibrations durong data collection. However, these spikes are well within the permissible range for this sensor.

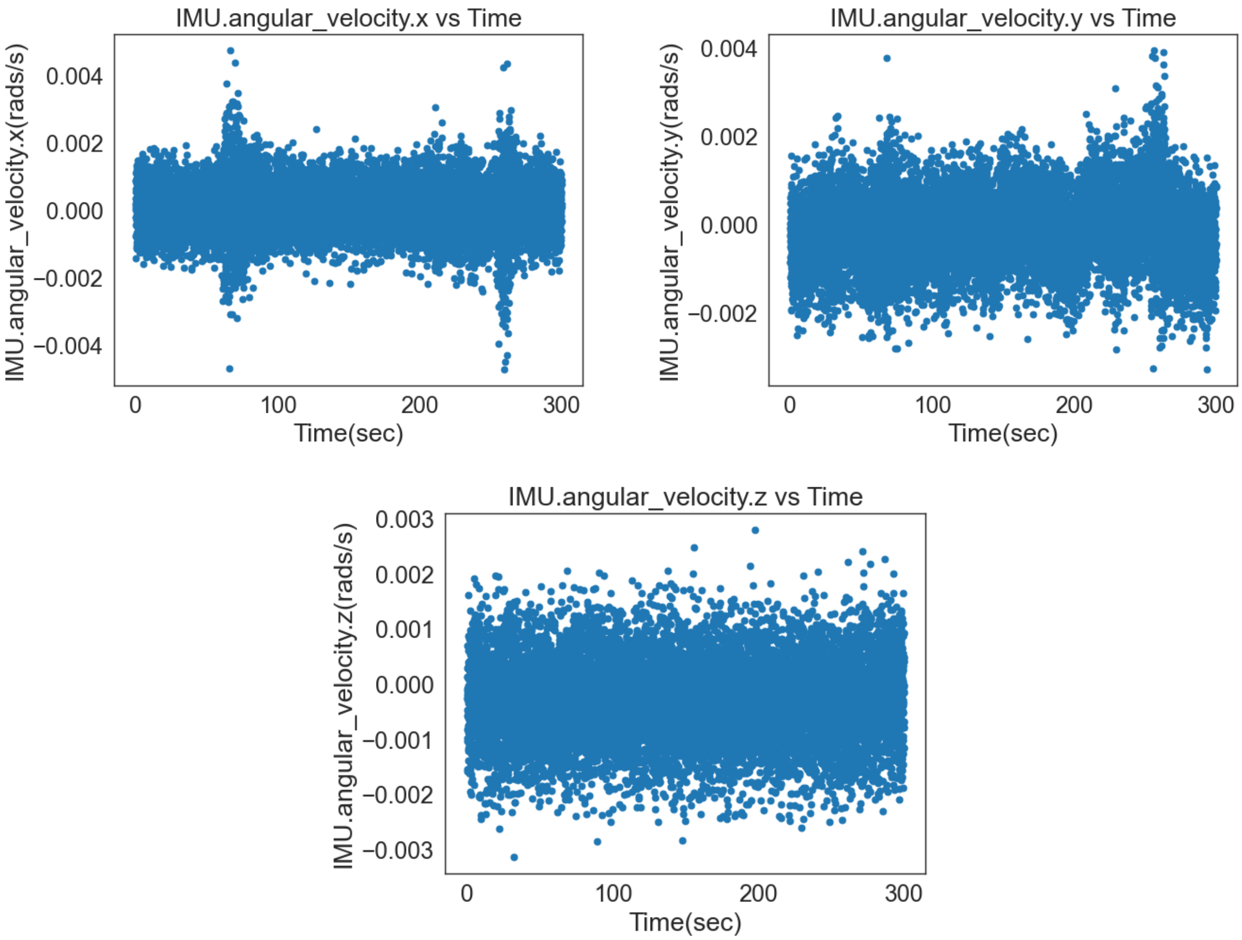
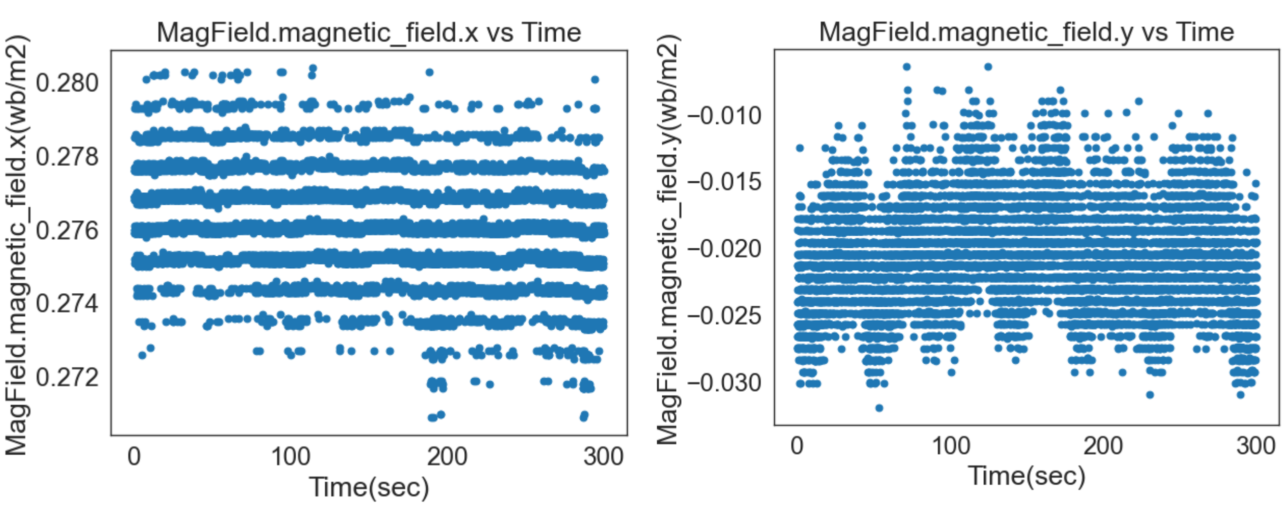


Figure 3 – (a) Angular Velocity X vs Time (b) Angular Velocity X vs Time (c) Angular Velocity X vs Time

Time Series Plot – Magnetic Field

In Figure 4, the time series plot is shown in all 3 axes. One key observation that can be made in 4(a) and 4(b) are the white spaced out bands that can be seen in the plot. These are due to the resolution of the sensor, where the data is being quantized into specific intervals, which is why these bands appear. Again, like in the previous case, there are spikes in the plots, which might indicate some external influences, or inherent chip errors.



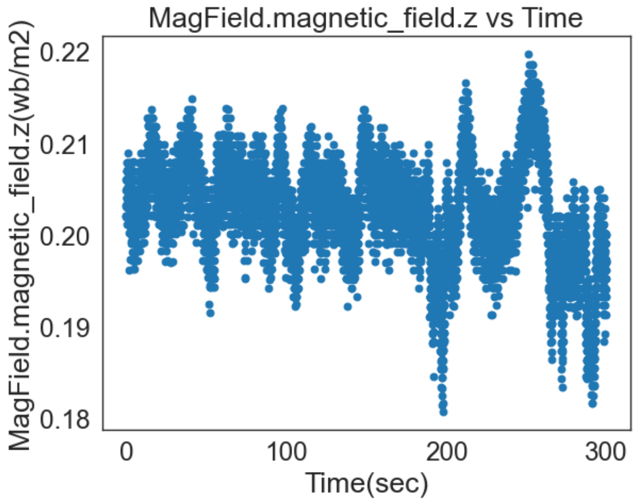


Figure 4 – (a) Magnetic Field X vs Time (b) Magnetic Field X vs Time (c) Magnetic Field X vs Time

Noise Characteristics – Mean and Standard Deviation

Table 1 – 4 shows the Noise Characteristics, namely, Mean and Standard Deviation for Orientation, Linear Acceleration, Angular Velocity, Magnetic Field in the three axes respectively.

Table 1 – Mean and Standard Deviation of Orientation in all axes

	Mean	Standard Deviation
Roll	-2.33894367781616	0.005801928971189676
Pitch	-1.5707963267948966	0.0
Yaw	1.3608930243763553	0.008898526800637983

Table 2 – Mean and Standard Deviation of Linear Acceleration in all axes

	Mean	Standard Deviation
Linear Acceleration X	-0.18418416882141964	0.013186077970942733
Linear Acceleration Y	77.86815522562348	0.008307919833399164
Linear Acceleration Z	-9.330048044040371	0.01865538485093958

Table 3 – Mean and Standard Deviation of Angular Velocity in all axes

	Mean	Standard Deviation
Angular Velocity X	6.121694886979731 x 10^{-5}	0.0007484973903782624
Angular Velocity Y	-0.00010587988989907416	0.0008171842523909833
Angular Velocity Z	-0.0002904017015597631	0.0007182679631009989

Table 4 – Mean and Standard Deviation of Magnetic Field in all axes

	Mean	Standard Deviation
Magnetic Field X	0.27620812411377094	0.0013539148710639021
Magnetic Field Y	-0.020926182333805988	0.0035017705060624194
Magnetic Field Z	0.20304308949870714	0.005242705340728552

Error Distribution Histogram Plot – Roll, Pitch, Yaw

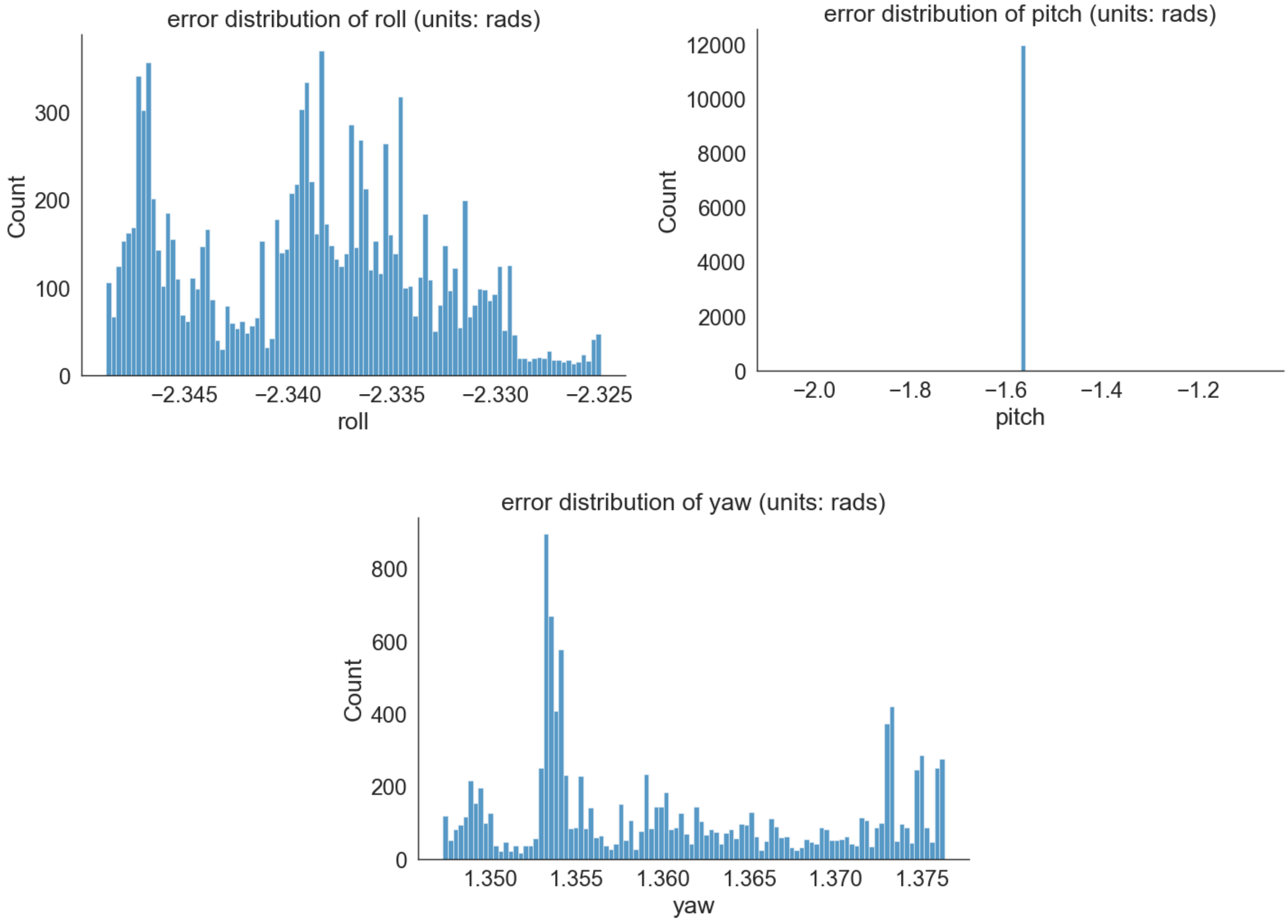
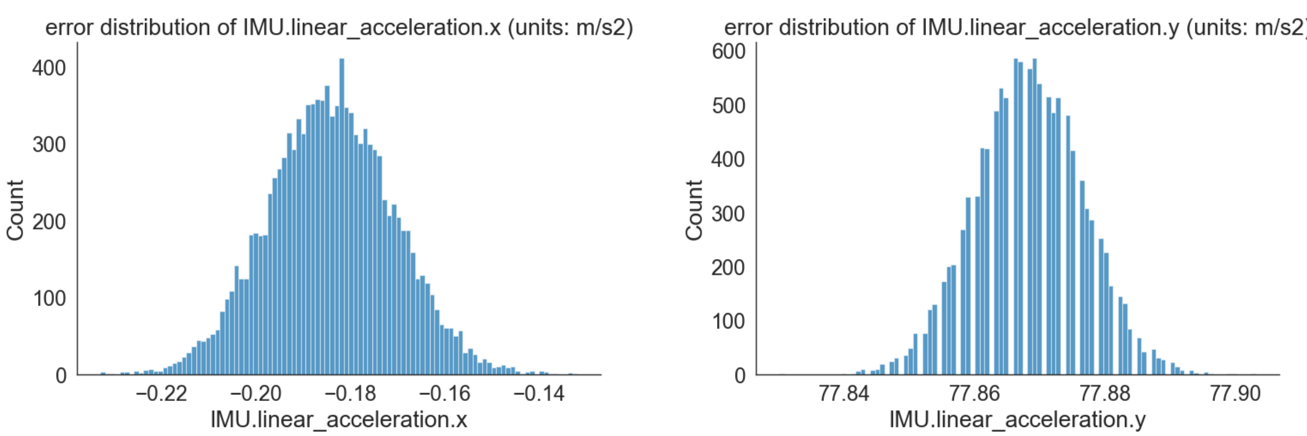


Figure 5 – Error Distributions of (a) Roll (b) Pitch (c) Yaw

In Figure 5, the error distributions of Roll, Pitch, and Yaw are plotted. In the Error distribution of Roll 5(a), it can be observed that the values are distributed as a bimodal distribution. These are attributed to environmental errors, or microvibrations that may cause multiple peaks. One unintuitive observation is in 5(b) where the pitch shows just one value. This means that the data is incredibly accurate, and there is minimal to no deviation from the recorded value. Noise factors are minimal or negligible in this case, that might give rise to this phenomenon.

Error Distribution Histogram Plot – Linear Acceleration



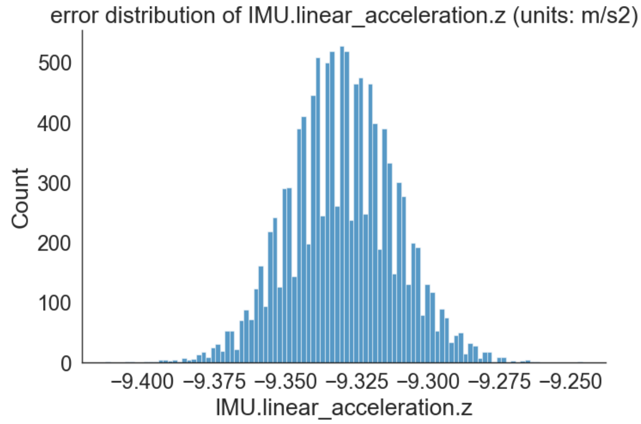
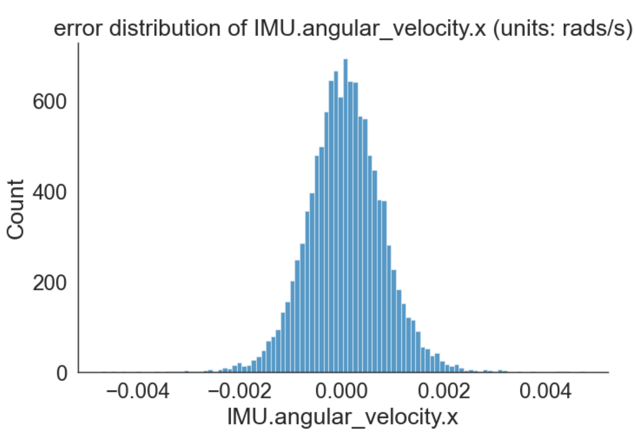


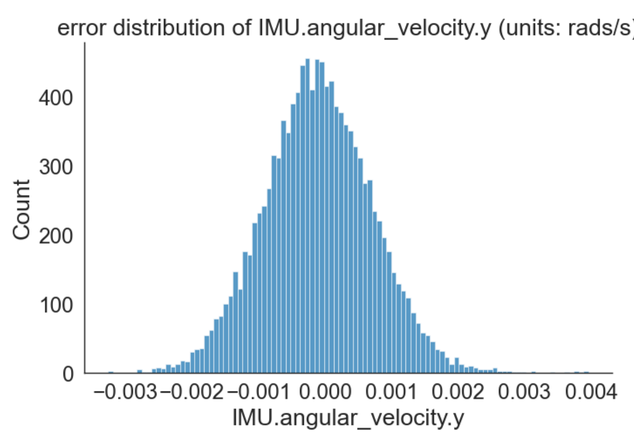
Figure 6 – Error Distributions of (a) Linear Acceleration X Axis (b) Linear Acceleration Y Axis (c) Linear Acceleration Z Axis

In Figure 6, The error distributions of Linear Accelerations for the three axes are plotted. These three plots are very ideal and can be easily inferred that the data is distributed in the pattern of a normal distribution. From this data, it can be observed that the device was truly stationary. All the bell curves indicate the errors of the device that are recorded because of noise and sensor calibration/sensitivity. The mean, which is the peak of the bell curves, indicate probabilistically to be the true value for each of the linear accelerations in their respective axes.

Error Distribution Histogram Plot – Angular Velocity

In Figure 7, The error distributions of Angular Velocity for the three axes are plotted. These three plots are also very ideal just like linear acceleration and it can be easily inferred that the data is distributed in the pattern of a normal distribution. From this data, it can be observed that the device was truly stationary. All the bell curves indicate the errors of the device that are recorded because of noise and sensor calibration/sensitivity. The mean, which is the peak of the bell curves, indicate probabilistically to be the true value for each of the linear accelerations in their respective axes. The effects of errors are constant which leads to a uniform bell curve – the data is distributed normally.





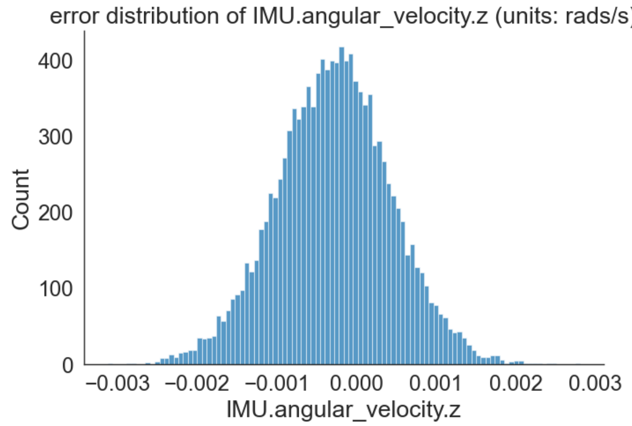


Figure 7 – Error Distributions of (a) Angular Velocity X Axis (b) Angular Velocity Y Axis (c) Angular Velocity Z Axis

Error Distribution Histogram Plot – Magnetic Field

Just how it was seen in the time series plot for magnetic field, there are discrete bands. This is the way the sensor performs quantization, for magnetic fields. In all the three axes, as seen in Figure 8, there are discretized bands that were talked about. It is also crucial to note that the data is distributed normally - follows normal distribution.

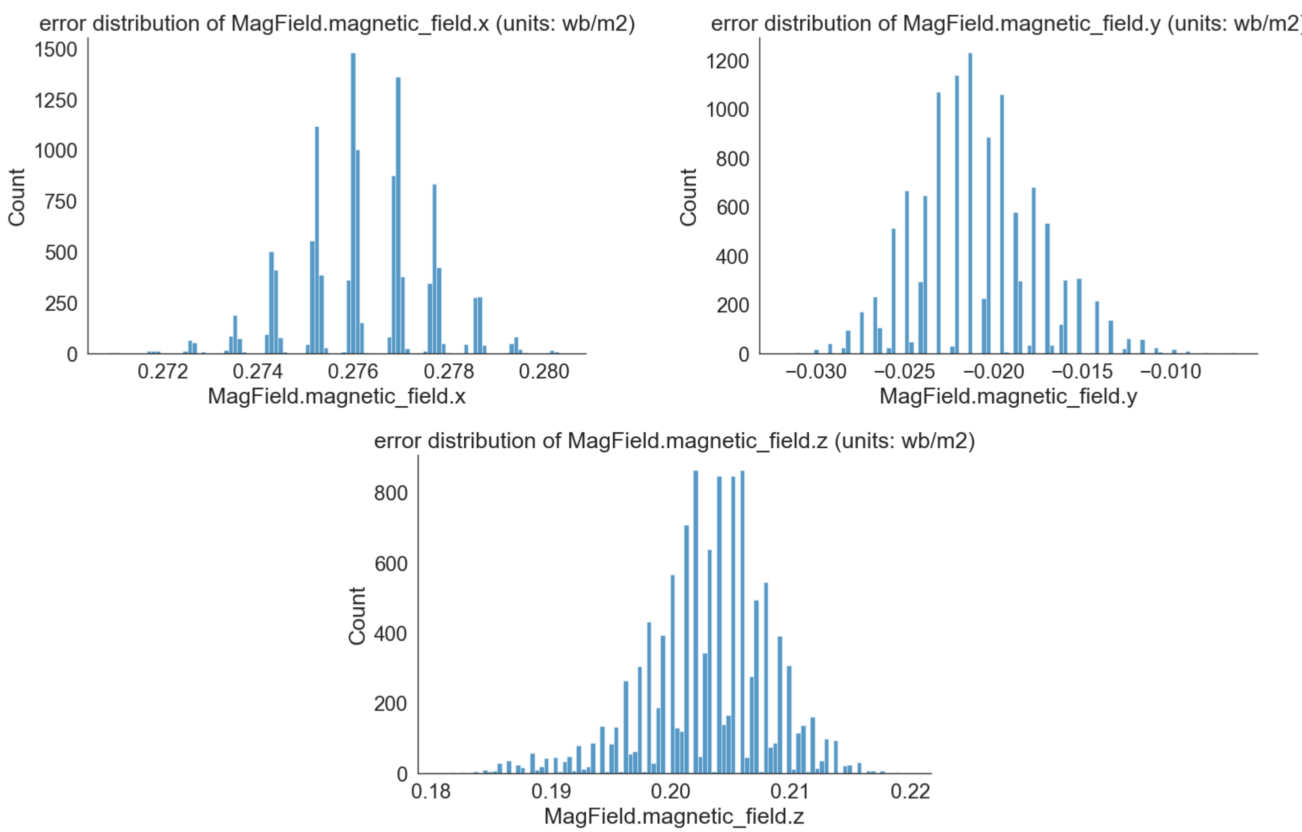


Figure 8 – Error Distributions of (a) Magnetic Field X Axis (b) Magnetic Field Y Axis (c) Magnetic Field Z Axis

Analysis of 5-hour Stationary Data

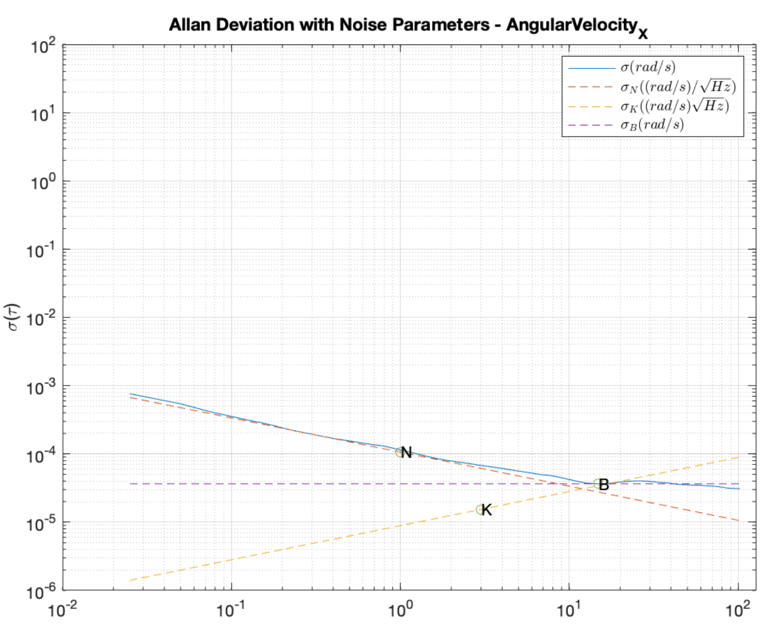
The analysis of the 5-hour stationary data comprises of 719987 messages, taken over a time period of 5 hours. This data is collected at 40Hz. With the help of long-term data, the Allan deviation and the effects of the drift of the data readings can be observed. The plots are shown in Figure 9. The plots of Alan Variance are shown in Figure 10.
When performing analysis of this data, there are 3 data points that are used when calculating the Allan Deviation and performance characteristics of the sensor.

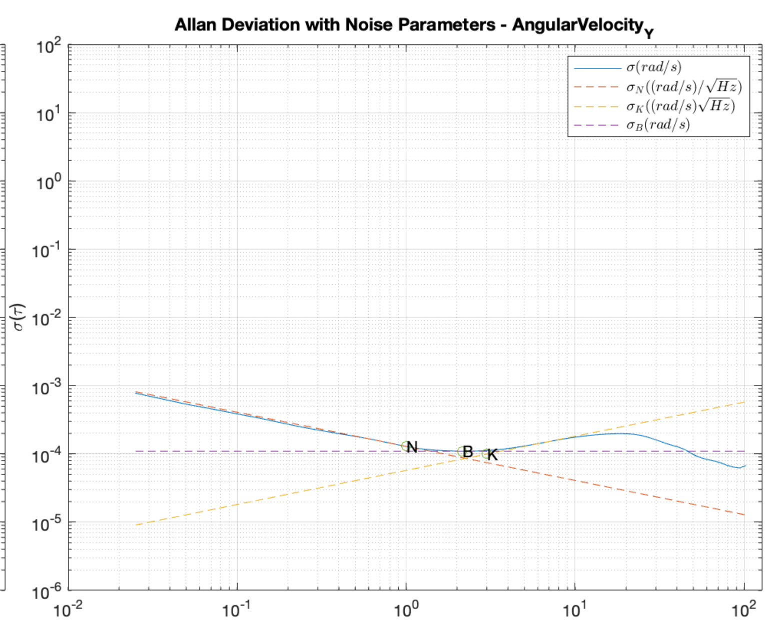
N – Angle Random Walk Coefficient
K – Rate Random Walk Coefficient
B - Bias Instability Coefficient

These parameters are calculated in MATLAB, for each of the three axes for Angular Velocity, as follows, in Table 1.

Table 5 – N, K, B Values for Angular Velocity X, Y, Z

	Angular Velocity X	**Angular Velocity Y**	**Angular Velocity Z**
Angle Random Walk Coefficient (N)	1.0639×10^{-4}	1.2908×10^{-4}	1.1167×10^{-4}
Rate Random Walk Coefficient (K)	1.5401×10^{-5}	9.9495×10^{-5}	3.6413×10^{-6}
Bias Instability Coefficient (B)	5.4868×10^{-5}	1.6467×10^{-4}	2.6565×10^{-5}





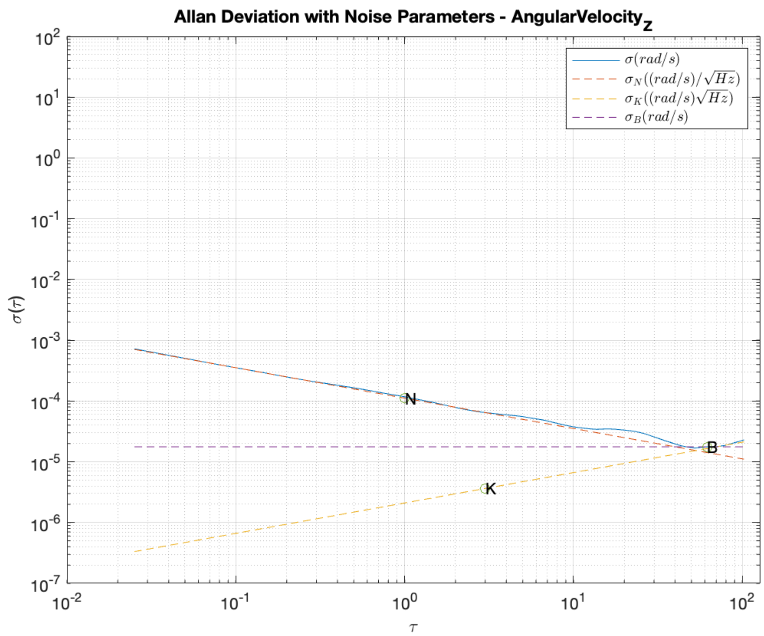


Figure 9 – Allan Deviation of (a) Angular Velocity X Axis (b) Angular Velocity Y Axis (c) Angular Velocity Z Axis

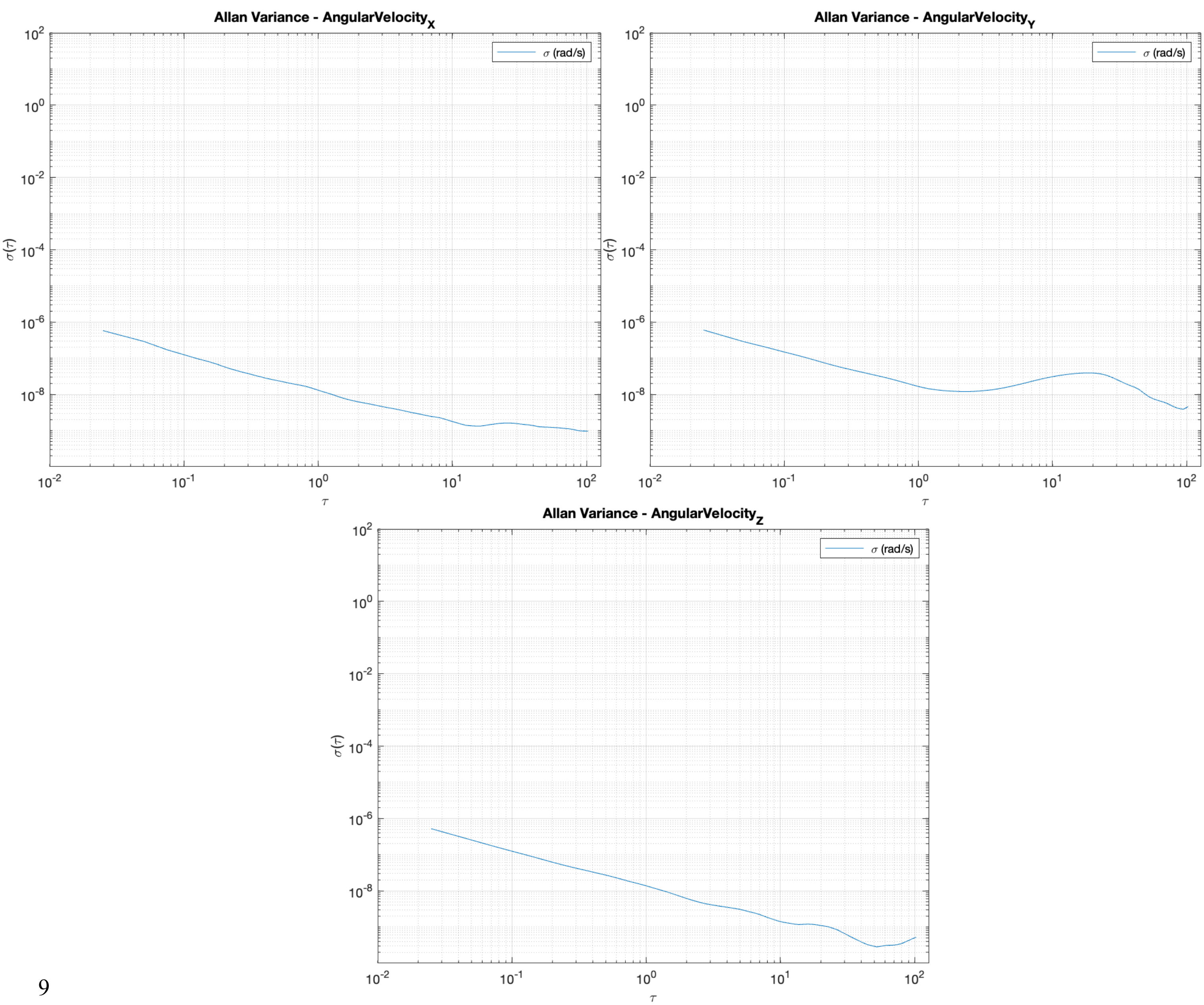


Figure 10 – Allan Variance of (a) Angular Velocity X Axis (b) Angular Velocity Y Axis (c) Angular Velocity Z Axis

Errors and Sources of Noise

Here we use the VN-100 IMU Sensor to take the readings.
The VN-100 EKF (Extended Kalman Filter) integrates measurements from the three-axis gyroscopes to provide faster and smoother attitude estimates as well as angular rate measurements. Gyroscopes of all kinds are subject to bias instabilities, in which the zero readings of the gyro will drift over time to due to inherent noise properties of the gyro itself. Just how EKF was used by the GPS in Lab1 to estimate the true position, the VN-100 EKF uses the accelerometer and magnetometer measurements to continuously estimate the gyro bias, such that the reported angular rates are compensated for this drift. [1]

The VN-100 is a MEMS Intertial Sensor, and these sensors are subject to several common sources of error: **bias, scale factor, axis misalignments, temperature dependencies, and gyro g-sensitivity**. To overcome this error to a certain degree, the sensor can undergo a thermal calibration process over multiple temperatures to ensure performance specifications are met over the full operating temperature range of -40 C to +85 C. [1]

Another method to reduce the errors would be to perform calibration for all the parameters of the sensor. For example, the experiment must be made on the proper magnetic declination, suitable magnetic environment and valid hard/soft iron calibration.

These errors can be modeled in the form of Probability Density Functions that can be distributed normally or in any modal form. The effects of Noise can be observed in the error of the data by evaluating the Mean and Standard Deviations as how it was measured in Table 1 – 4.

They are measured when dealing with sensitive apparatus and very delicate instruments. These noises can give rise to errors that although are very minute, they pose a great risk to the quality of analysis, and eventually the inference / result of the experiment or project.

Evaluated Performance vs Datasheet Performance

Table 6 – Datasheet Specification vs Evaluated Specification

	Datasheet Specification	Evaluated Specification
Orientation	**± 0.05°**	**± 0.166°**
Linear Acceleration	**< 0.04 mg**	**< 0.008 mg**
Angular Velocity	**< 0.05°**	**< 0.0411°**
Magnetic Field	**± 0.05°**	**< 0.0775°**
In – Run Bias Stability	**<10°/hr (5° - 7°/hr)**	**1.8°/hr ; 9.434° for 5 hours**

References

[1] "VN-100 User Manual" Available : https://www.vectornav.com/resources/user-manuals/vn-100-user-manual