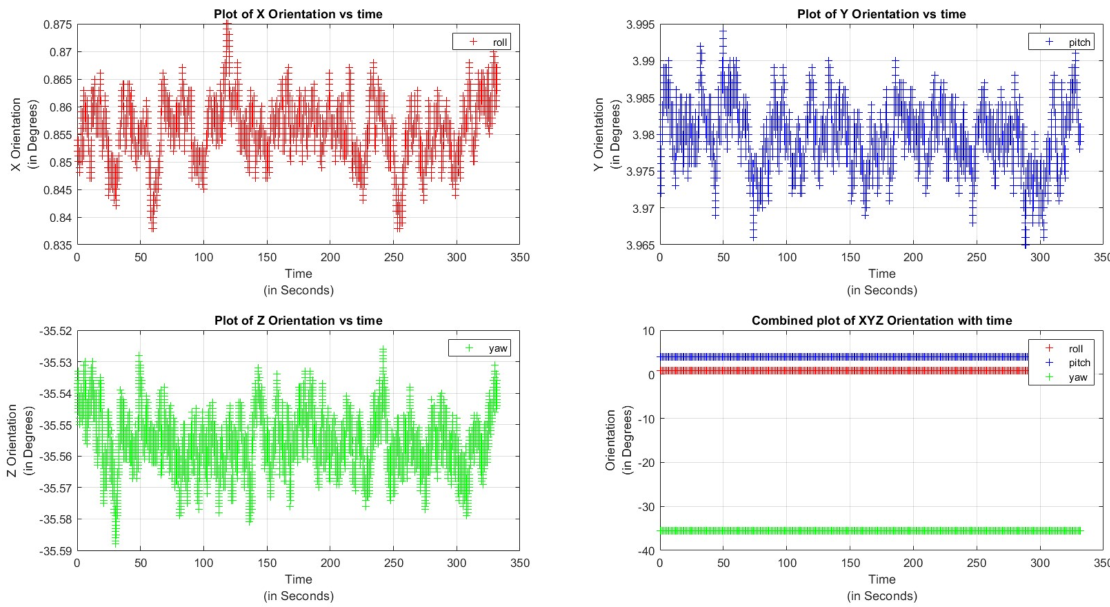
ANALYSIS OF IMU DATA

The following document aims to analysis the data collected from a IMU using a custom driver written in Python and ran using ROS.

The stationary data was collected from the IMU for a little more than 5 minutes. The plots of each of the parameters are shown in the figures below.

Orientation:

Figure 1.



The driver was coded to record orientation data in Quaternions instead of Euler angles so as to avoid issues like gimble lock and ambiguity. Quaternions are also easy to perform computations. Every Quaternion is plotted in 4D space, which is out of the perception of humans. On the other hand, Euler angles are easy to be imagined and viewed by humans as it is in the 3D space. Hence, in order to plot the angles in 3D space, the values were converted from Quaternions to Euler angles.

Figure 1 is divided into 4 subplots. The subplots show the plot of X orientation vs time, Y orientation vs time, Z orientation vs time and XYZ Orientation vs time with respect to each other. Figure 2 shows the orientation points in 3D space.

Figure 2.

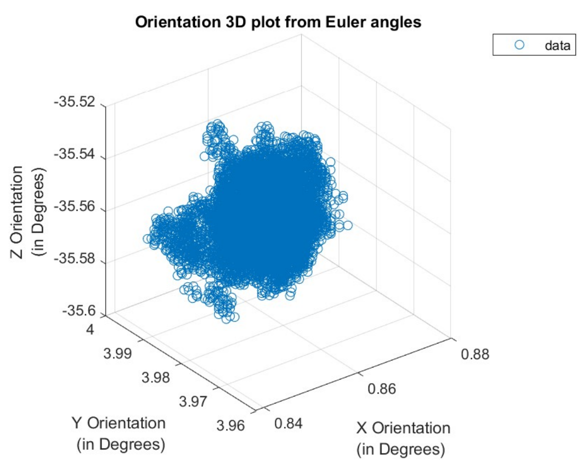


Figure 3, Figure 4 and Figure 5 show the histograms for Orientation in X, Y and Z respectively. Each graph has a mean line drawn to indicate the mean value of the particular Orientation. We can clearly see that the Orientation in X has a gaussain curve and Orientation in Y and Z some what resemble a gaussain curve.

Figure 3.

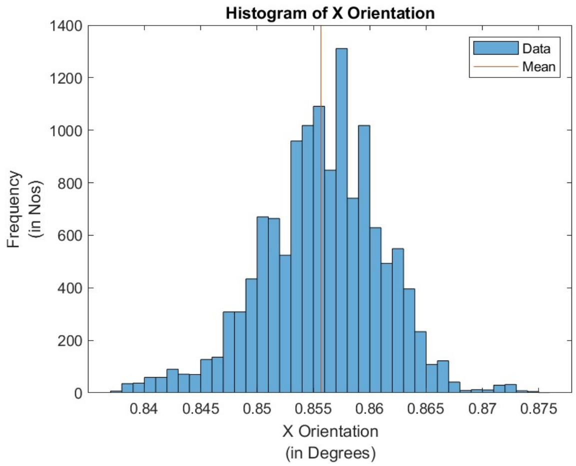
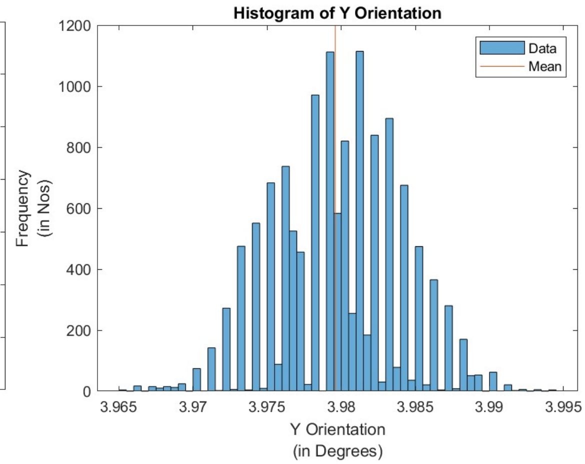


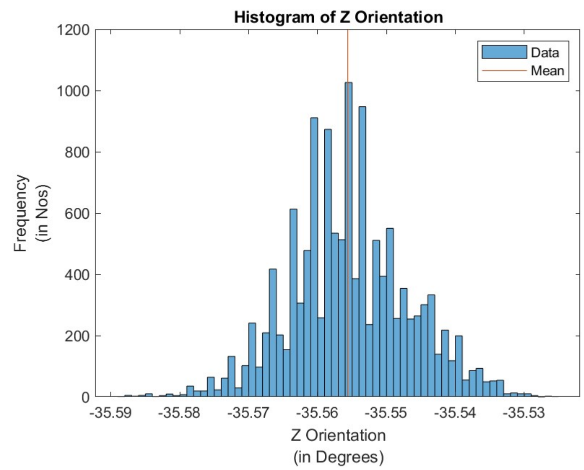
Figure 4.



Orientation in X is called roll, Orientation in Y is called pitch and Orientation in Z is called yaw. In Figure 1 we can see that there is some variation in the data in each of the first 3 subplots. In the last plot, we can see that the data is pretty constant if looked from far.

Sr. No	Orientation	Variation
1.	X (roll)	0.035^{O}
2.	Y (pitch)	0.03^{O}
3.	Z (yaw)	0.06^{O}

Figure 5.



Angular Velocity:

The Figure 7 shows the plot of angular velocity vs time. The first 3 subplots show the plot of angular velocity in X, Y and Z respectively and the 4th subplot shows the combination of all 3.

The angular velocity can be seen to be lying majorly in a range of -0.002 to +0.002 rad./sec. This is quite a small value and even though the sensor is stationary, these readings are observed due to the high sensitivity of the IMU. Figure 6, Figure 8 and Figure 9 show the histogram plots for the Angular velocity in X, Y and Z respectively.

Figure 6.

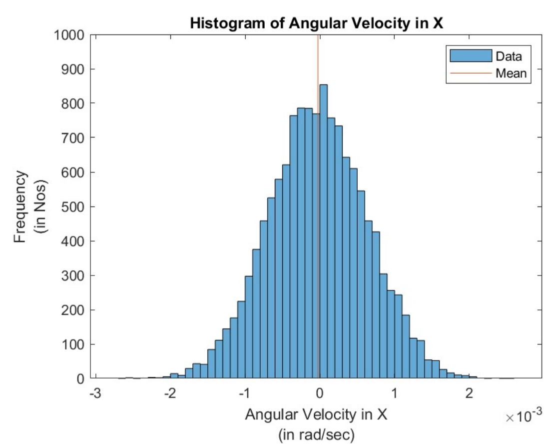
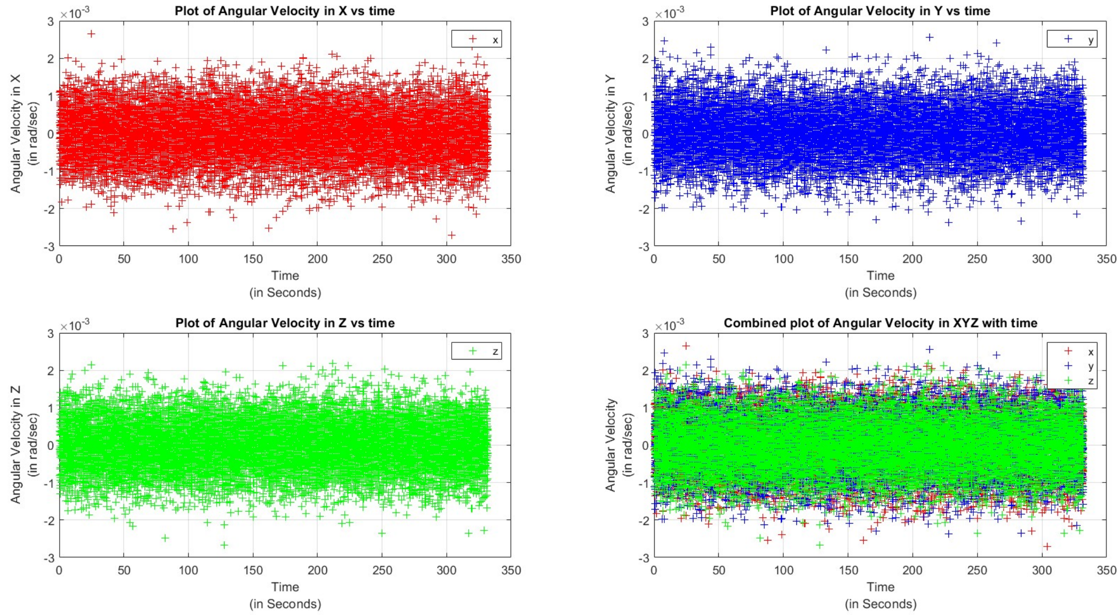


Figure 7.



It can clearly be seen that all the histograms signify a Gaussian distribution and implies that the data is distributed about its mean normally. This distribution is the noise and hence can be concluded that the noise is distributed in a gaussian manner. It can also be seen that the mean lies very close to zero. This shows that the device is stationary and the non-zero values are the noise that creeps in into the readings.

Figure 8.

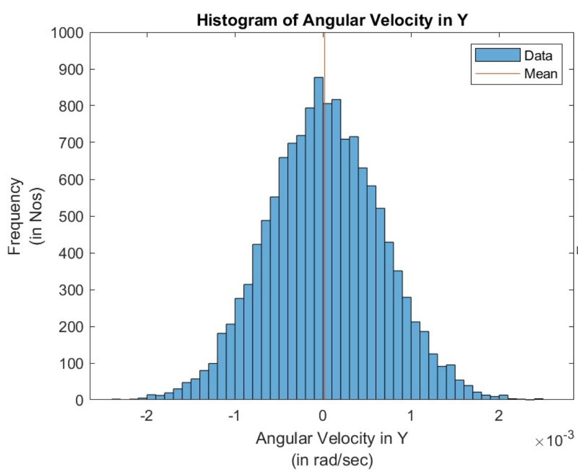
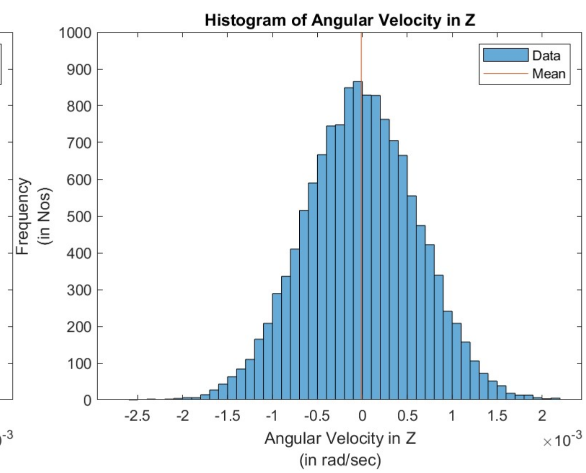
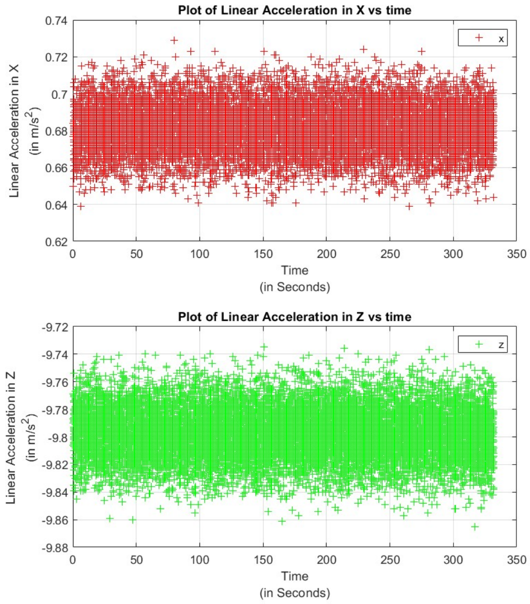


Figure 9.



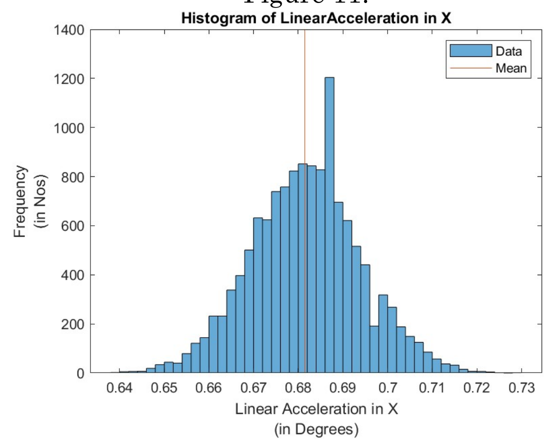
Linear Acceleration:

Figure 10.



In Figure 10 the first 3 subplots show the plots for Linear acceleration in X, Y and Z against time respectively. The 4th subplot shows the combined plot for XYZ against time. As the IMU is stationary, the acceleration in X and Y direction is very close to 0. The acceleration in the Z direction is close to -10. This is because of an acceleration due to gravity acting on the IMU in the negative z direction.

Figure 11.



Figures 11, 12 and 13 show the histogram plots for Linear Acceleration in X, Y and Z respectively. It can be seen that the data is distributed in a Gaussian manner. This implies a gaussian distributed noise. The mean values of accelerations in the X and Y directions seem to have slight offsets which can be due to some constant offset in the device which needs to be subtracted of due to some constant noise from the device being slightly tilted. After looking at the histogram in the Z direction, we can see that the mean of the data is near -9.8 due to the constant gravitational force acting on it. The slight offset can be due to the device being a little tilted.

Figure 12.

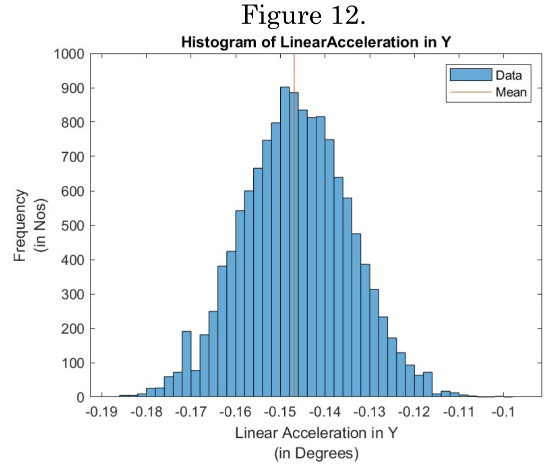
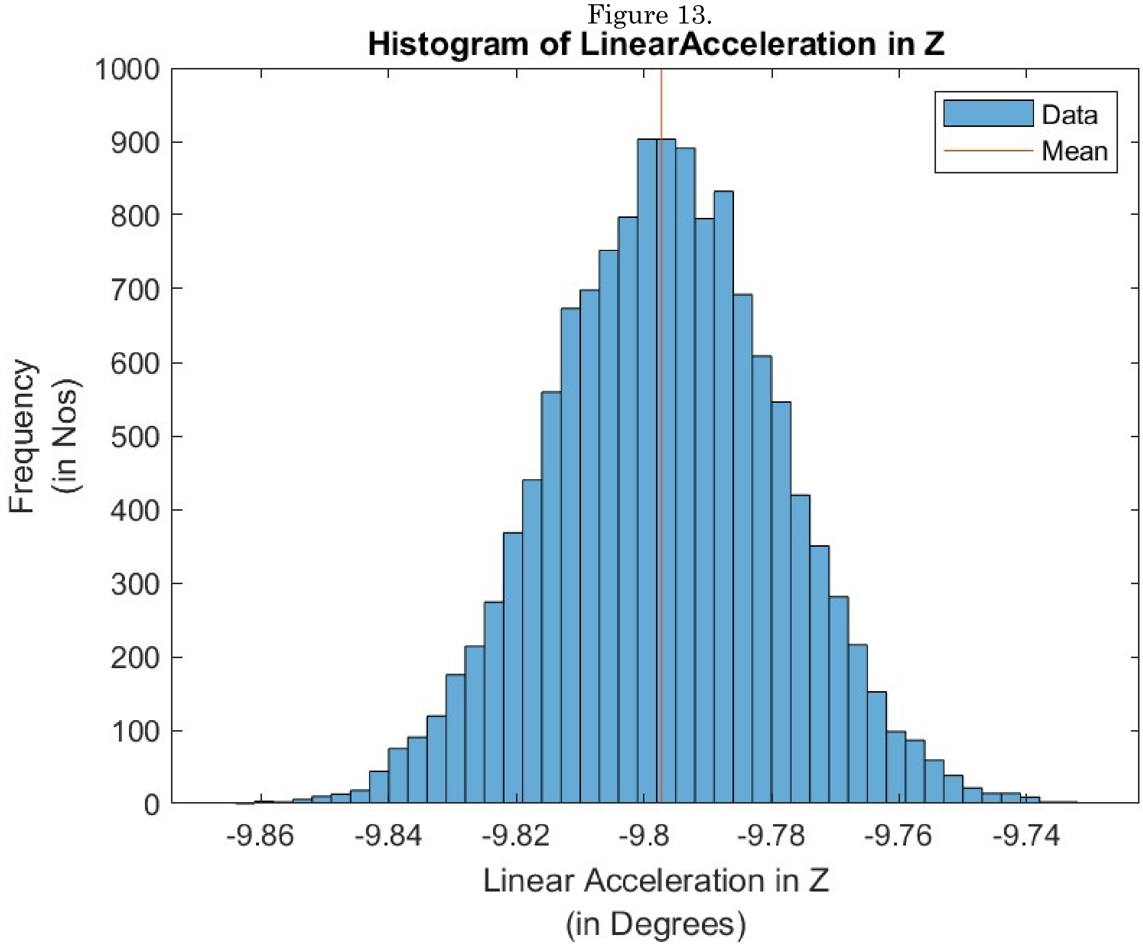


Figure 13.



Magnetic Field:

Figure 14.

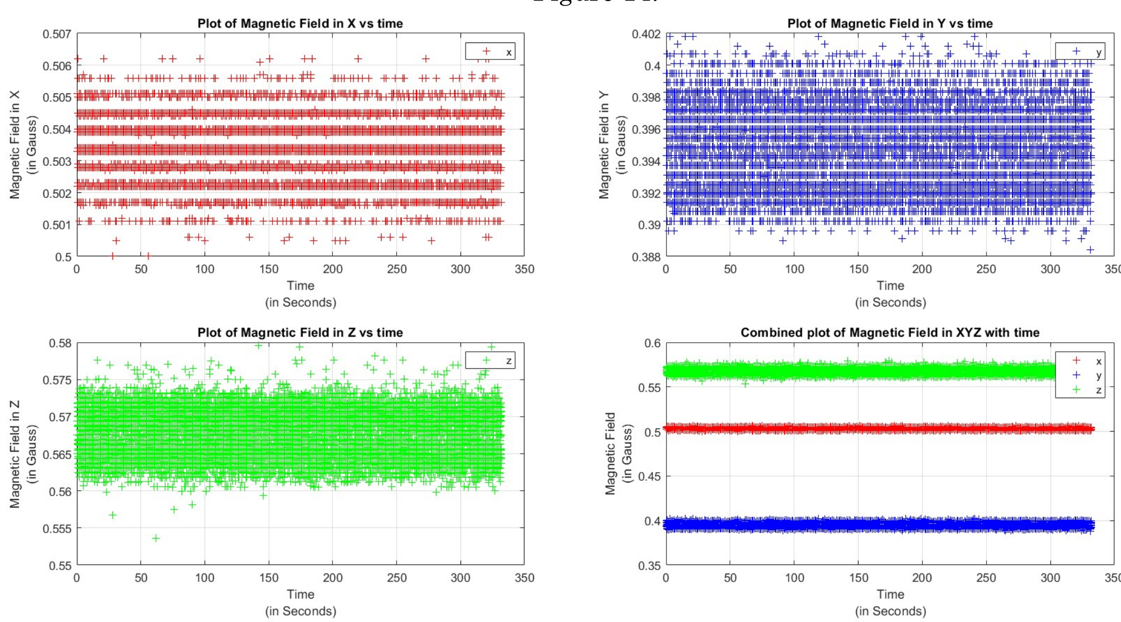


Figure 14 shows the plots for change in magnetic fields vs time. The first 3 subplots show the plots for magnetic field in X, Y and Z respectively. The 4th subplot shows the plot for magnetic field in X,Y and Z combained against time. Figure 15, Figure 16, and Figure 17 show the histogram plots for the magnetic fields in X, Y and Z respectively.

The Earth's magnetic field strengths in specific directions serve as the primary basis for the magnetometer readings. As a result, these values are exactly what they are based on the direction of the IMU at that precise moment. The numbers appear to be quite steady and this displays that the IMU is in its stationary condition. Once more, the data's gaussian distribution in X direction—which denotes gaussian noise—can be seen in the histograms. The magnetic field in Y and Z direction seem to have a different distribution. This could be due to slight changes in the magnetic field around the IMU.

Figure 15.

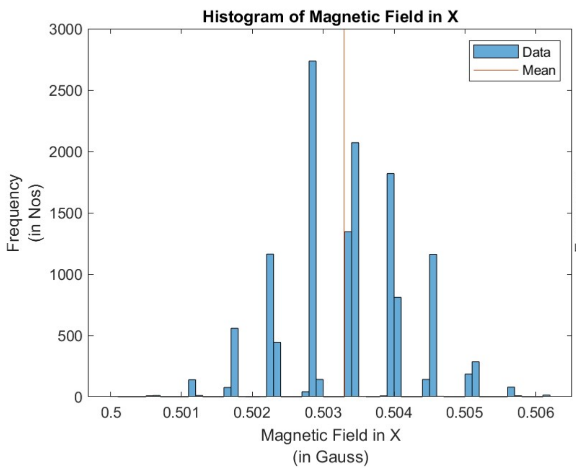


Figure 16.

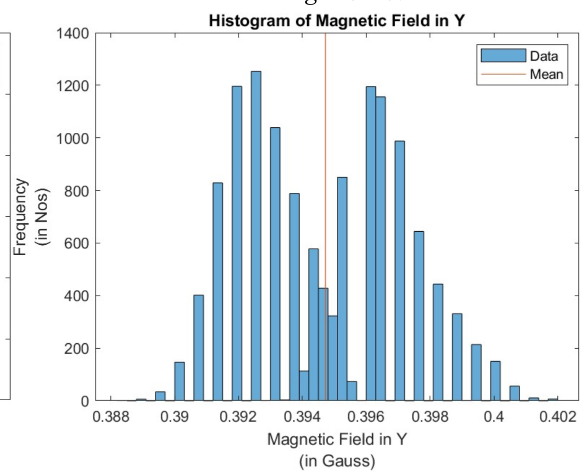
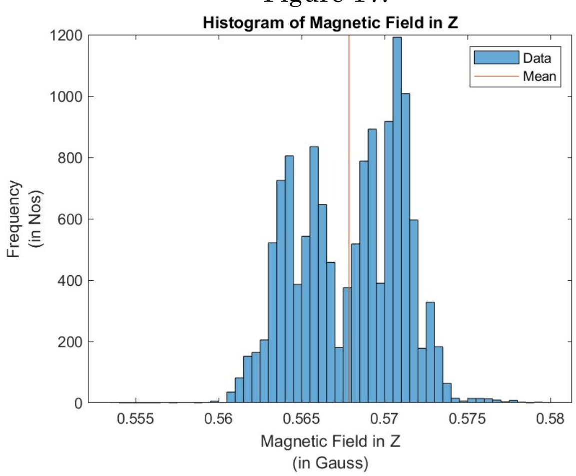


Figure 17.



Allan Variance Analysis:

Allan variance is a method of analyzing a sequence of data in the time domain, to measure frequency stability of the sensor.

Figure 18, Figure 19 and Figure 20 show the Allan Deviations in X, Y and Z respectively. The graphs show that the deviation calculated manually and calculated using the 'allanvar' function to be same and thus the two lines overlap each other. All the graphs are drawn on a Log scale on both X and Y axis.

Figure 18.

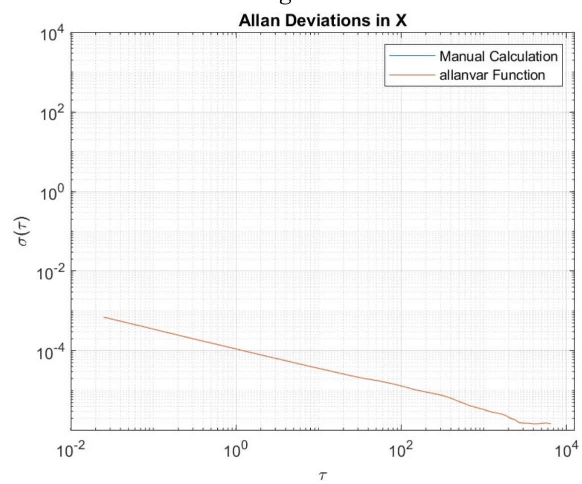


Figure 19.

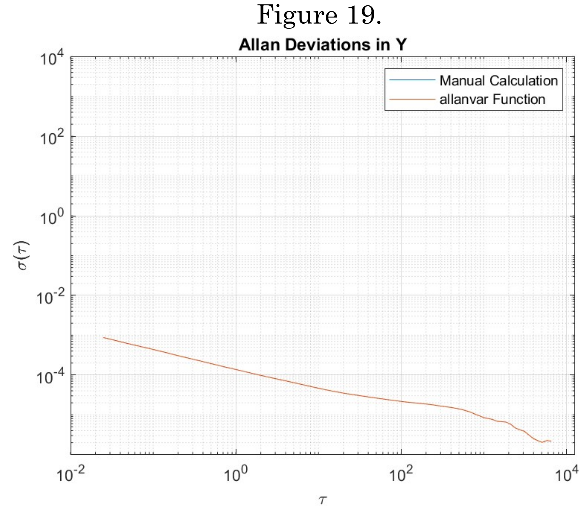
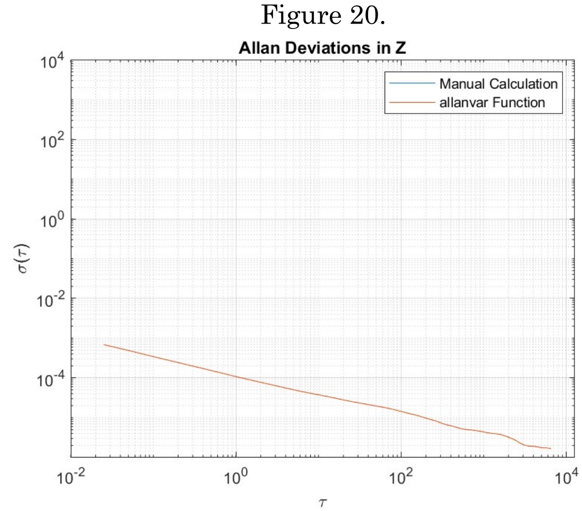


Figure 20.



Allan Deviation with Angle Random Walk:

Angle Random Walk (ARW) is derived from the Allan Variance of the bias data, at an integration time of 1 second and is characterized by the white noise spectrum of the gyroscope output.

Figure 21, Figure 22 and Figure 23 show the Allan Deviation with Angle Random Walk in X, Y and Z respectively.

Angle random walk can be calculated by the formula:

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

Where, N is the Angle Random Walk constant. Using the data from Figure 23, the Allan Deviation with Angle Random Walk in Z direction, we get

$N = 1.0847 \times 10^{-4}$

The fact that the linear part of the graph intersects with the line with a slope of -0.5, indicates that there is white gaussian noise present in the data.

To calculate the angle random walk, we take the value of allan deviation at Time = 1 second and multiply it by 60. It has the unit

$$(rad/s)/\sqrt{Hz}.$$

Figure 21.

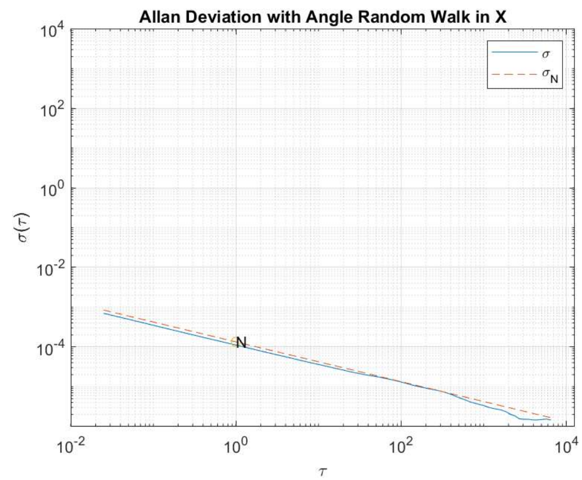


Figure 22.

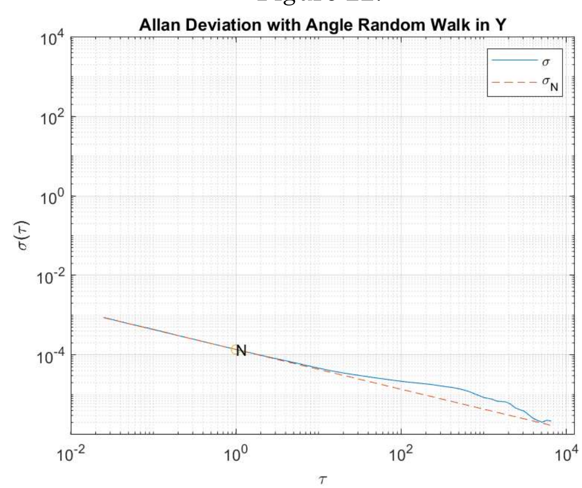
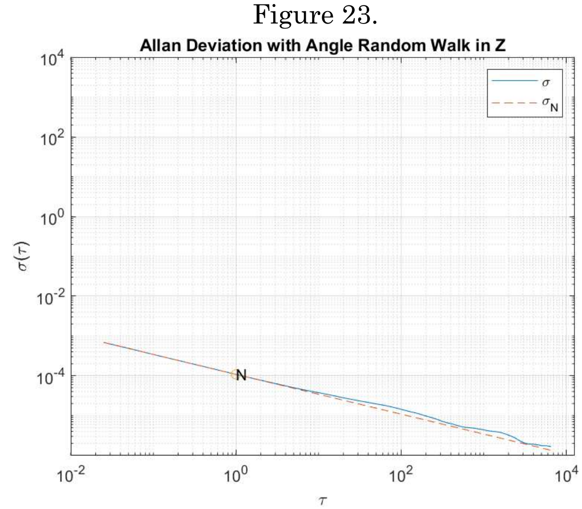


Figure 23.



Allan Deviation with Rate Random Walk:

The rate random walk is characterized by the red noise (Brownian noise) spectrum of the gyroscope output.

Figure 24, Figure 25 and Figure 26 show the Allan Deviation with Rate Random Walk in X, Y and Z respectively.

Rate random walk can be calculated by the formula:

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

Where K is the rate random walk coefficient. We can use the data from Figure 25, Allan Deviation with Rate Random Walk in Y, to calculate the value of K

$K=4.9190 \times 10^{-8}$

The unit of K is

$$(rad/s)\sqrt{Hz}.$$

Figure 24.

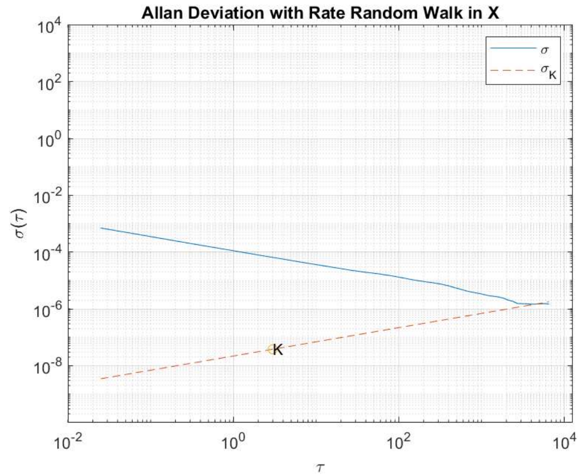


Figure 25.

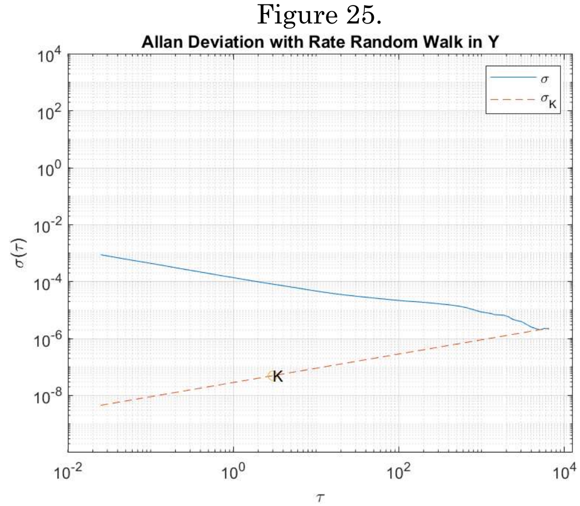
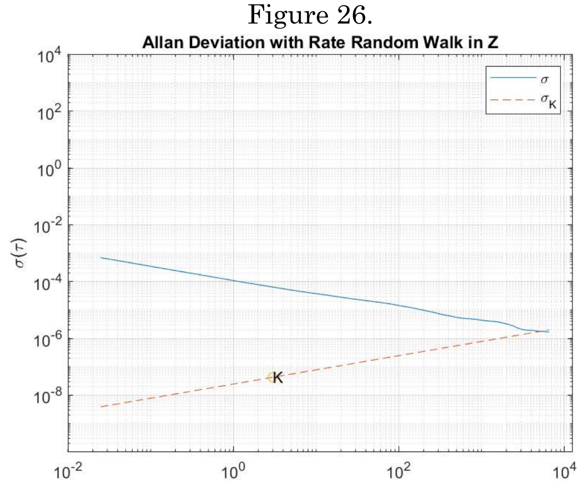


Figure 26.



Allan Deviation with Bias Instability:

The bias instability is characterized by the pink noise (flicker noise) spectrum of the gyroscope output.

Figure 27, Figure 28 and Figure 29 show the Allan Deviation with Bias Instability in X, Y and Z respectively.

Bias Instability walk can be calculated by the formula:

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

Where B is the bias instability constant. We can use the data from Figure 29, Allan Deviation with Bias Instability in Z, to find the value of B.

B = 2.6345x10^{-6}

The unit of B is

$$rad/s.$$

To calculate the Bian Instability we take the point on Allan Deviation with the lowest value and dividing it by 0.664(IEEE Standard number) and the multiply is by 3600.

Figure 27.

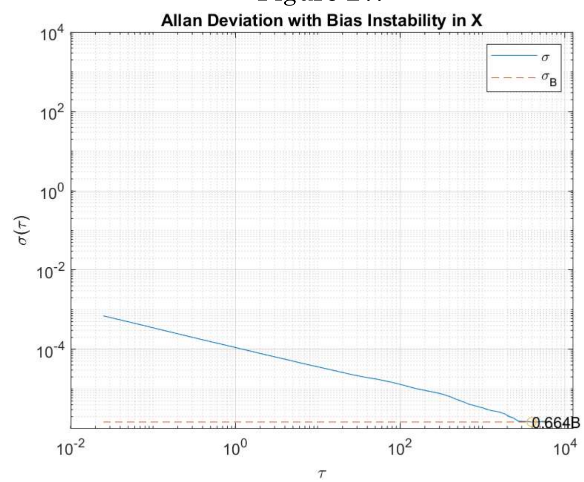


Figure 28.

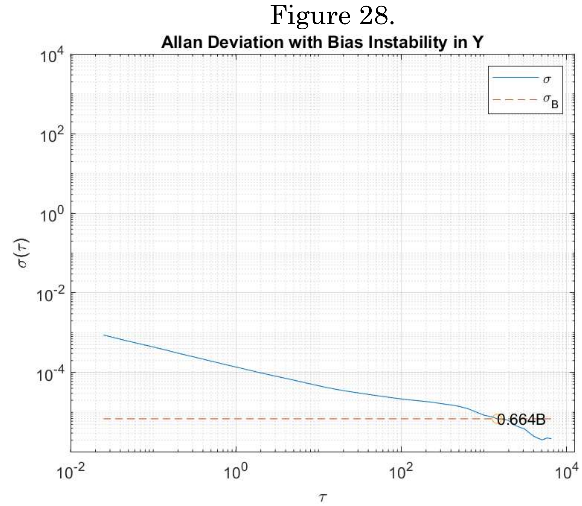
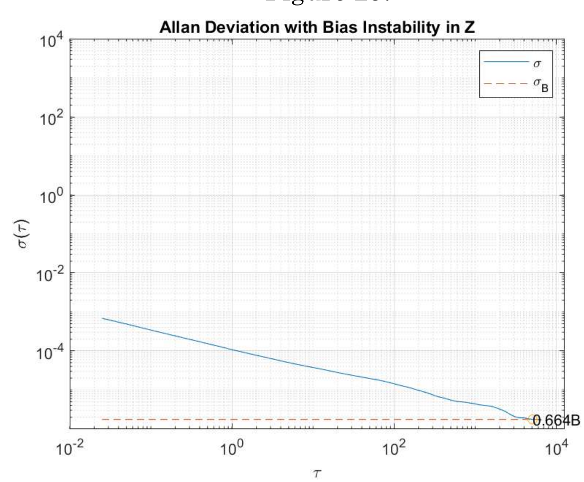


Figure 29.



Allan Deviation with Noise Parameters:

Figure 30, Figure 31 and Figure 32 show the Allan Deviation with all the Noise Parameters in X, Y and Z respectively.

Figure 30.

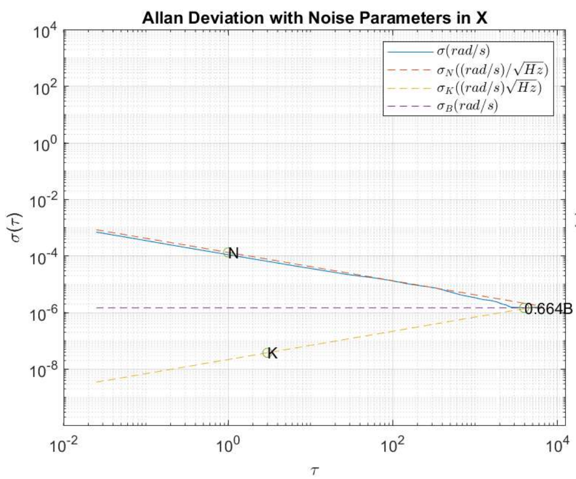


Figure 31.

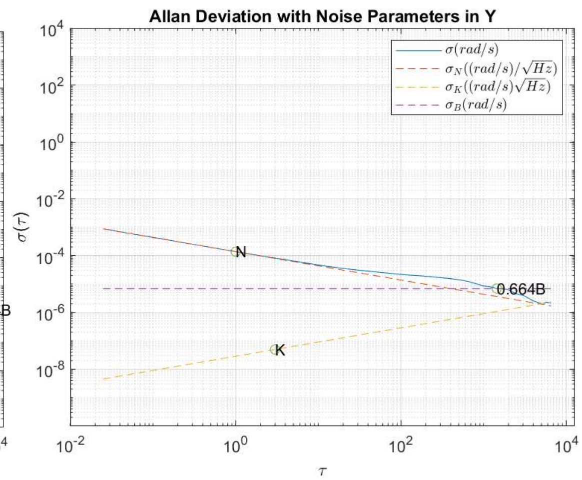
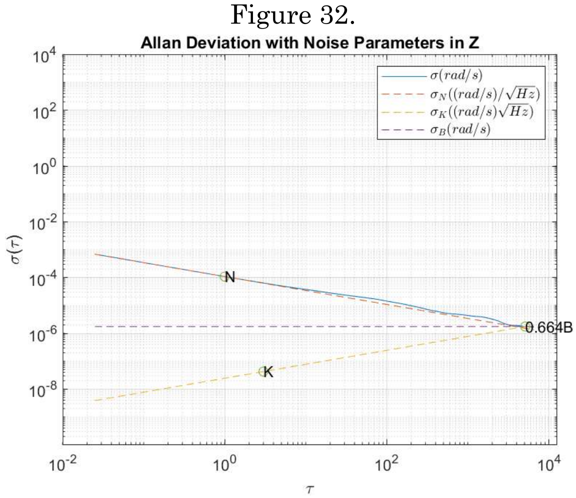


Figure 32.



Allan Deviation of HW and Simulation in X:

Figure 33, Figure 34 and Figure 35 show the Allan Deviation with Simulated data in X, Y and Z respectively.

Figure 33.

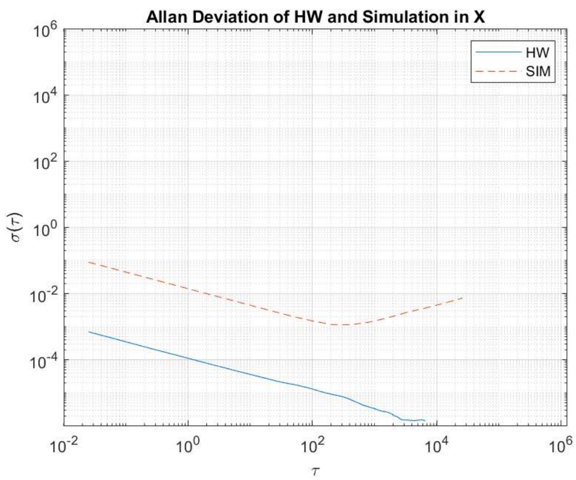


Figure 34.

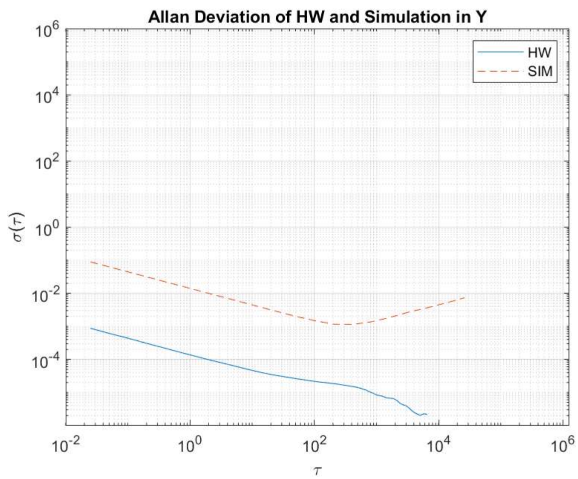
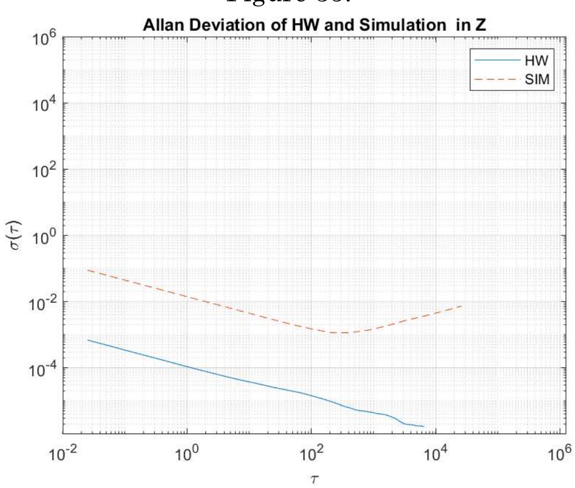


Figure 35.



Q. What kind of errors and sources of noise are present?

Gaussian errors are present in the data collected by the IMU. The different types of noise are white gaussian noise, Red noise (Brownian noise) and Pink noise (flicker noise).

Q. How do we model them?

We can model the different types of noises using Allan Deviation plotted on a log scale and then analysing the different areas of the graph as stated above.

Q. Where do we measure them?

The different noises can be measured using Allan Deviation and Allan Variance using the formulae and N, K and B constants.

Q. How do your measurements compare to the performance listed in the VN100 datasheet?

The measurement seem to be within range of the performance listed in the VN100 datasheet.