Lab 3 report

The lab is divided into two sections –

a. The group data where we collect the IMU data in basement for 5 hours.
b. The individual data where we collect IMU data in a quiet environment for 5 minutes.

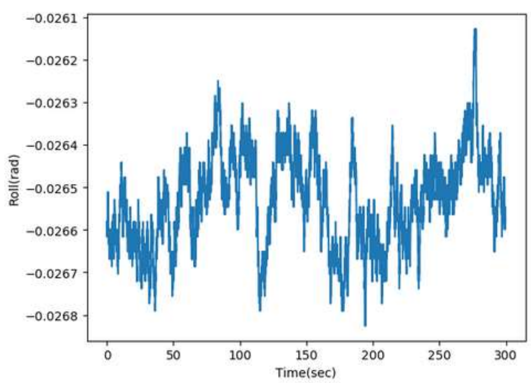
For a. we can analyse the noise associated with the IMU sensor, and for b. we can measure the distribution of errors for small duration readings.

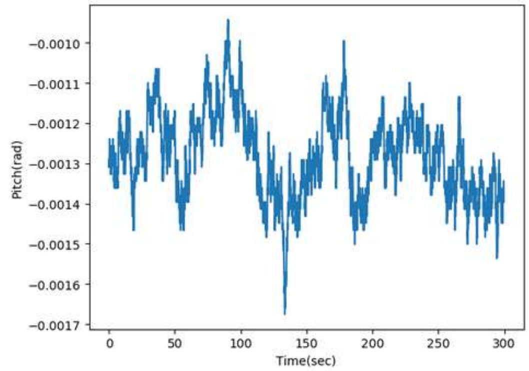
Individual data –

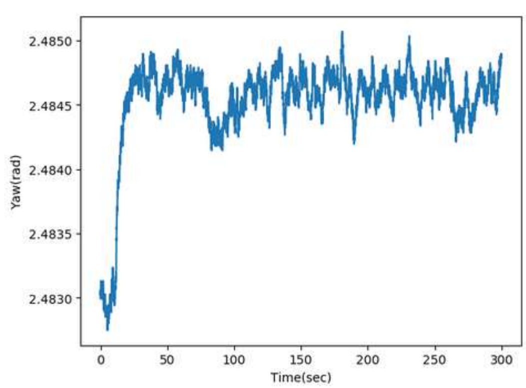
In this section, we placed our IMU sensor in garage at a quiet place for 5 minutes. The conditions for the experiment were not ideal as there were disturbances in the area. There were mainly two disturbances which may have affected the readings of the IMU sensor as the sensor is highly sensitive –

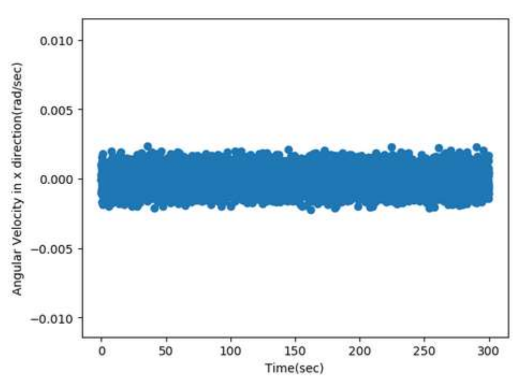
i. The garage air vent fan which may have caused periodic fluctuations in the readings.
ii. The cars passing outside the garage.

Refer to the plots below for analysis of fluctuations in the readings for 5 minutes –









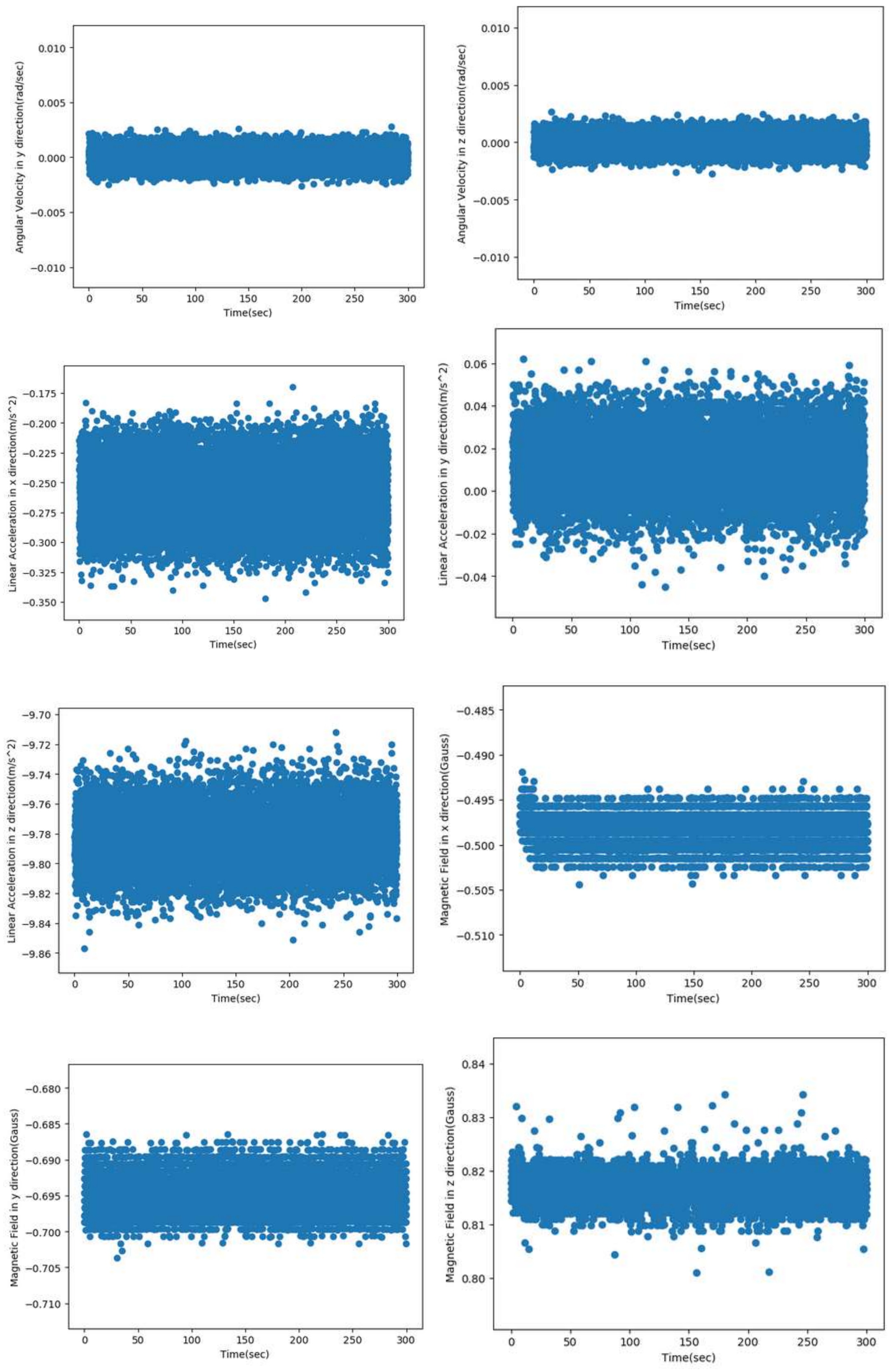


FIG 1. *– Parameter fluctuations w.r.t time*

From the plots we can infer that there are fluctuations in our data in almost all parameters, while other plots seem to have uniform fluctuations, we can see that yaw in radians has a gradual increase w.r.t time. This can be because after initiating the rosbag record command the wire moved slightly which could have changed the yaw angle. For other parameters we can refer the following statistical information.

	IMU.angular_velocity.x	IMU.angular_velocity.y	IMU.angular_velocity.z	IMU.linear_acceleration.x	IMU.linear_acceleration.y	IMU.linear_acceleration.z
mean	-0.000001	0.000014	0.000010	-0.259714	0.012345	-9.782609
skew	-0.002636	-0.014127	-0.040275	-0.005647	-0.010602	0.010679
std	0.000660	0.000746	0.000700	0.027896	0.014141	0.018278
max	0.002362	0.002813	0.002646	-0.170000	0.062000	-9.712000
min	-0.002234	-0.002615	-0.002714	-0.347000	-0.045000	-9.857000

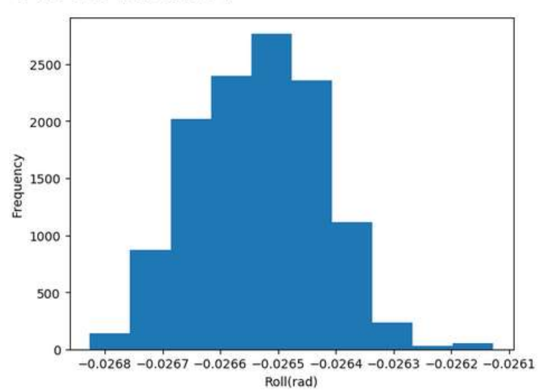
	Roll_conv	Pitch_conv	Yaw_conv	MagField.magnetic_field.x	MagField.magnetic_field.y	MagField.magnetic_field.z
mean	-0.026531	-0.001281	2.484533	-0.498596	-0.694901	0.816697
skew	0.111660	0.046845	-3.293714	0.072840	0.396955	0.108476
std	0.000109	0.000106	0.000355	0.001537	0.002400	0.002468
max	-0.026128	-0.000942	2.485070	-0.491900	-0.686500	0.834200
min	-0.026826	-0.001676	2.482748	-0.504400	-0.703700	0.801000

FIG 2. *– Statistical summary of parameters variations in their respective units.*

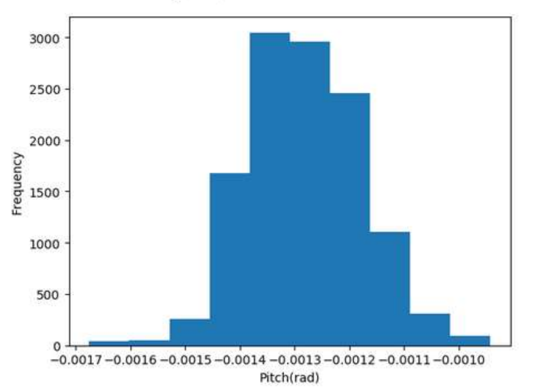
We can confirm from the statistical summary *FIG 2*. about the yaw angle because it has a high skew. For other parameters, we can see the fluctuations in the readings and their respective range, mean value, skew, and standard deviation values.

For analyzing the distribution of these fluctuations, we can plot a histogram with 10 bins. Please refer to the below plots for analyzing the distribution of the errors in the parameters.

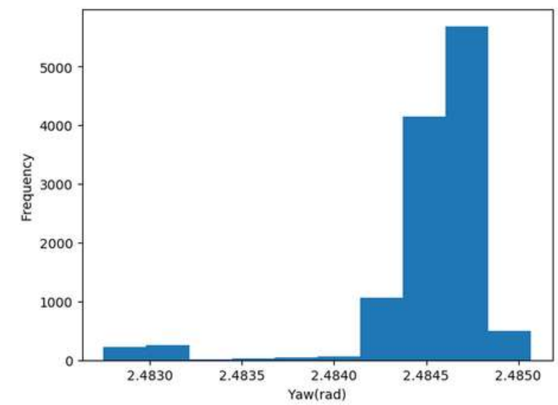
```
(array([ 141.,  871., 2022., 2400., 2769., 2357., 1114.,  233.,   31.,
          52.]),
 array([-0.02682571, -0.0267559 , -0.02668608, -0.02661627, -0.02654646,
        -0.02647664, -0.02640683, -0.02633702, -0.02626721, -0.02619739,
        -0.02612758]),
 <a list of 10 Patch objects>)
```



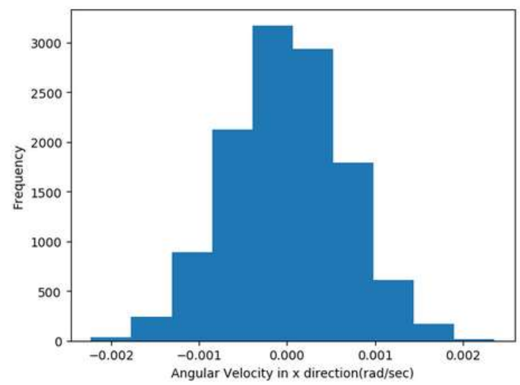

```
(array([  38.,   47.,  258., 1674., 3048., 2961., 2458., 1103.,  310.,
          93.]),
 array([-0.00167552, -0.00160221, -0.00152891, -0.0014556 , -0.0013823 ,
        -0.001309  , -0.00123569, -0.00116239, -0.00108909, -0.00101578,
        -0.00094248]),
 <a list of 10 Patch objects>)
```



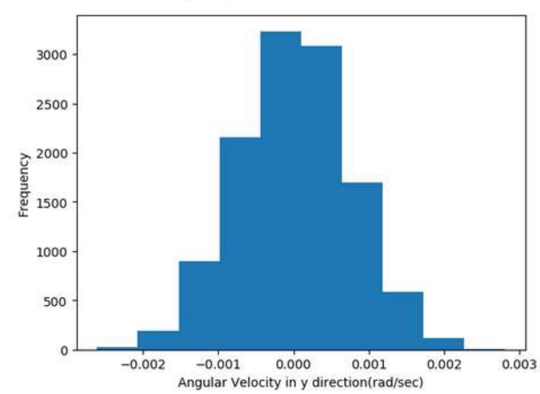
```
(array([ 218.,  251.,    9.,   21.,   43.,   56., 1054., 4151., 5685.,
         502.]),
 array([2.48274831, 2.48298044, 2.48321257, 2.4834447 , 2.48367683,
        2.48390896, 2.48414109, 2.48437322, 2.48460534, 2.48483747,
        2.4850696 ]),
 <a list of 10 Patch objects>)
```



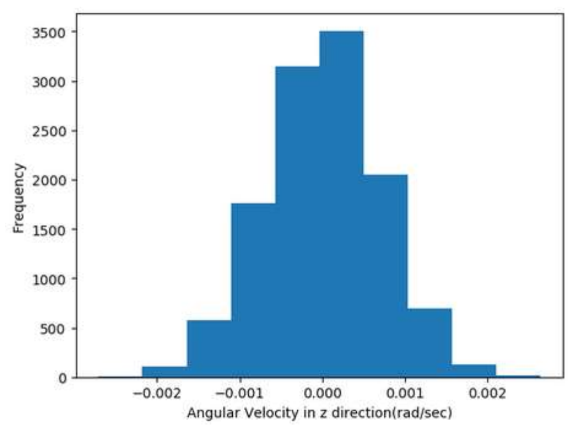

```
(array([  37.,  245.,  890., 2123., 3173., 2939., 1788.,  612.,  166.,
          17.]),
 array([-2.2340e-03, -1.7744e-03, -1.3148e-03, -8.5520e-04, -3.9560e-04,
         6.4000e-05,  5.2360e-04,  9.8320e-04,  1.4428e-03,  1.9024e-03,
         2.3620e-03]),
 <a list of 10 Patch objects>)
```



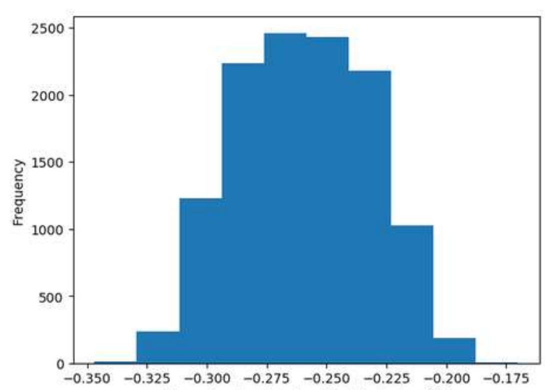

```
(array([  27.,  194.,  893., 2153., 3233., 3084., 1694.,  582.,  119.,
          11.]),
 array([-2.6150e-03, -2.0722e-03, -1.5294e-03, -9.8660e-04, -4.4380e-04,
         9.9000e-05,  6.4180e-04,  1.1846e-03,  1.7274e-03,  2.2702e-03,
         2.8130e-03]),
 <a list of 10 Patch objects>)
```



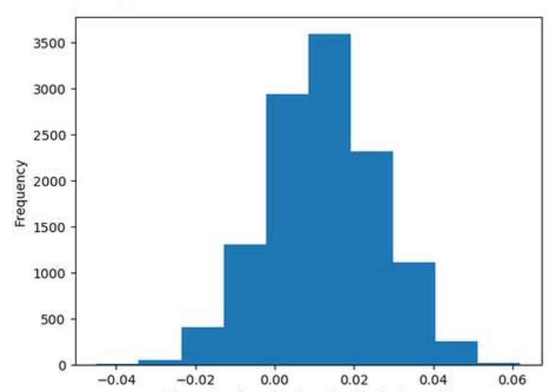

```
(array([  10.,  103.,  574., 1765., 3144., 3507., 2052.,  692.,  129.,
          14.]),
 array([-2.714e-03, -2.178e-03, -1.642e-03, -1.106e-03, -5.700e-04,
        -3.400e-05,  5.020e-04,  1.038e-03,  1.574e-03,  2.110e-03,
         2.646e-03]),
 <a list of 10 Patch objects>)
```




```
(array([  15.,  237., 1225., 2232., 2460., 2430., 2177., 1024.,  184.,
           6.]),
 array([-0.347 , -0.3293, -0.3116, -0.2939, -0.2762, -0.2585, -0.2408,
        -0.2231, -0.2054, -0.1877, -0.17  ]),
 <a list of 10 Patch objects>)
```




```
(array([   9.,   51.,  405., 1303., 2936., 3593., 2312., 1107.,  252.,
          22.]),
 array([-0.045 , -0.0343, -0.0236, -0.0129, -0.0022,  0.0085,  0.0192,
         0.0299,  0.0406,  0.0513,  0.062 ]),
 <a list of 10 Patch objects>)
```



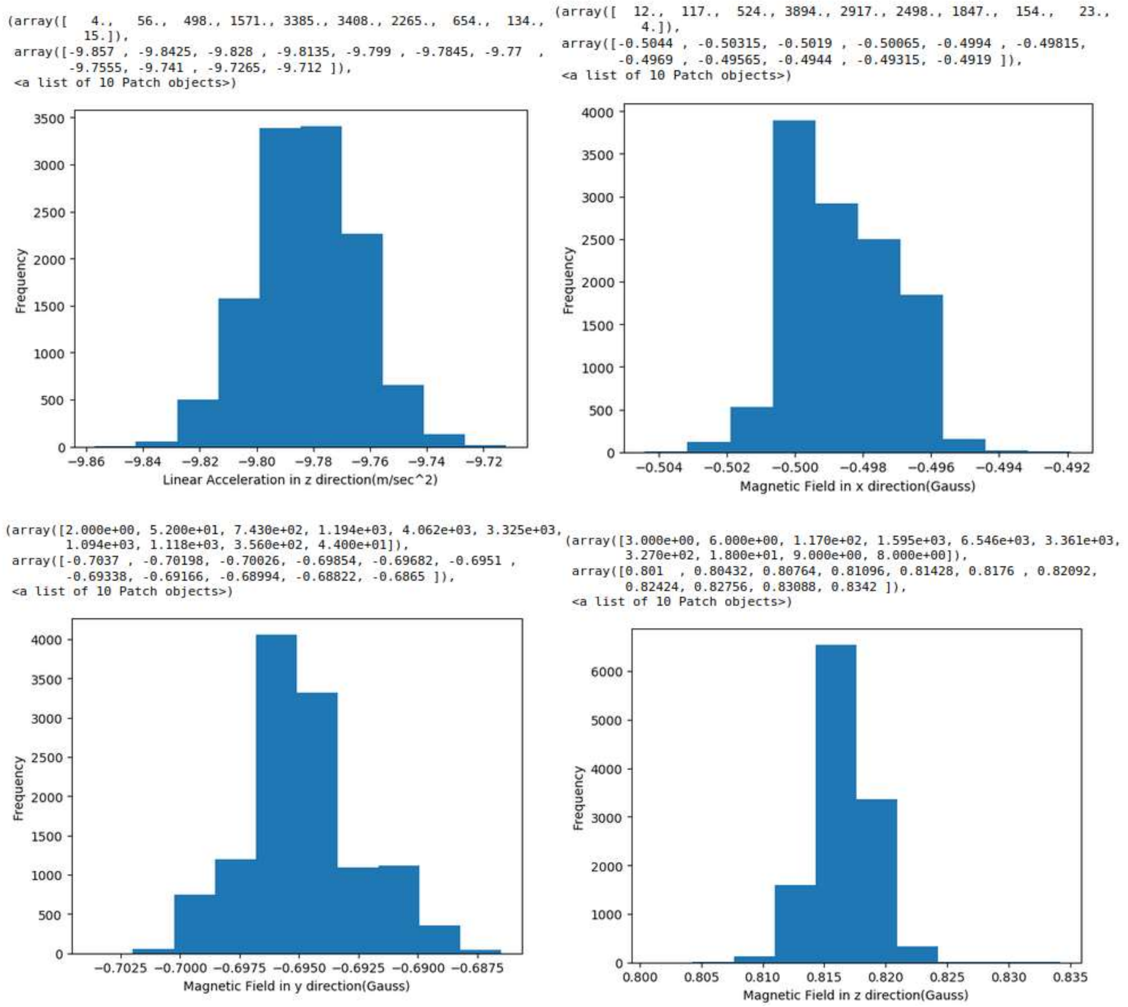


Fig 3. *- Histogram plots of the parameter distribution.*

We can conclude that except roll, pitch, and yaw readings, other readings show a normal distribution while the former readings show a random distribution. The statistics for the readings are shown in Fig 2.

Group Report –

In this section, we placed our IMU sensor in friend's basement for 5 hours. The readings are taken for a long time to analyse the three noise present in an IMU sensor associated with the angular velocity. We'll also extend the same process for calculating the noise in linear acceleration readings. There are three noise parameters which we'll analyse (definition extracted from the link) –

i. *Bias instability* – (Pink noise) 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 measure.

ii. *Angle Random walk error* – (White noise) 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. The specification for random walk is typically given in units of °/s√s or °/hr—√hr for gyroscopes, and m/s/s√s or m/s/hr—√hr for accelerometers. By multiplying the random walk by the square root of time, the standard deviation of the drift due to noise can be recovered.

iii. *Rate random walk* – The rate random walk is characterized by the red noise (Brownian noise) spectrum of the gyroscope output. This is introduced because of fluctuations in the readings because of temperature.

iv. *Acceleration dependency error* – The IMU experiences different values of error when it is experiencing acceleration.

v. *Sensor non-orthogonality error* – The 3 gyroscopes and accelerometers are not perfectly orthogonal to each other. This gives rises to errors

Refer to the figure below to understand how general Allen deviation curve looks like, and how we can differentiate slopes of the lines from various noise parameters.

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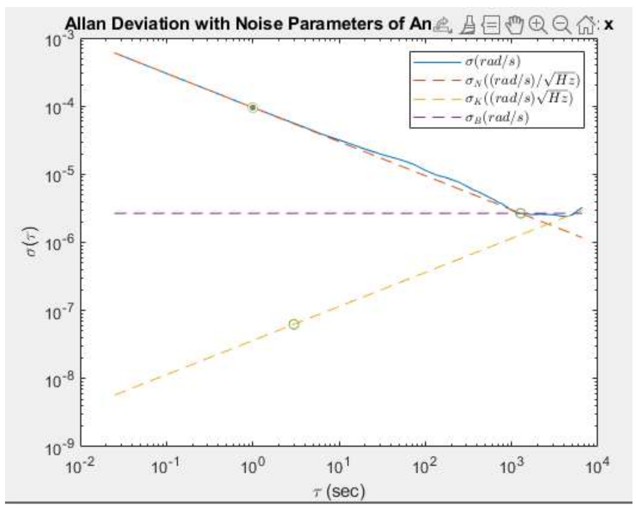
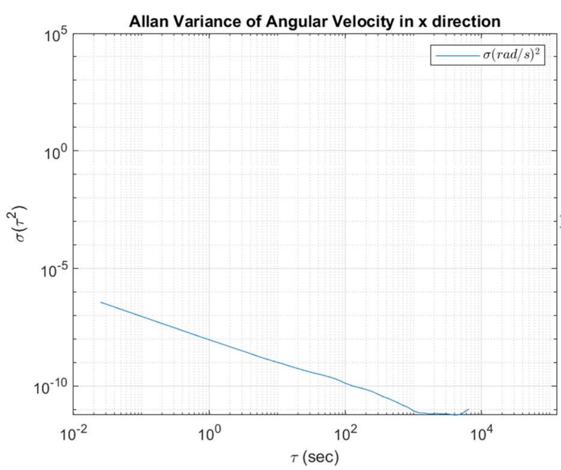
Fig 4.- General Allen deviation curve for a stationary IMU sensor from link.

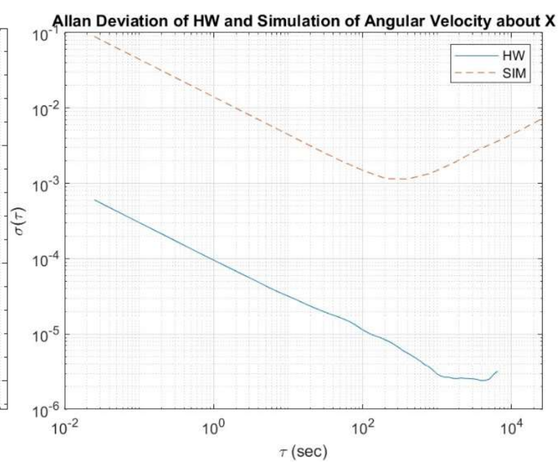
Refer to the figure below which we use for extraction of the noise parameters, by comparing it with the figure we can extract the parameters which characterize the noise associated with our data –

The first study is done for angular velocity in X direction.

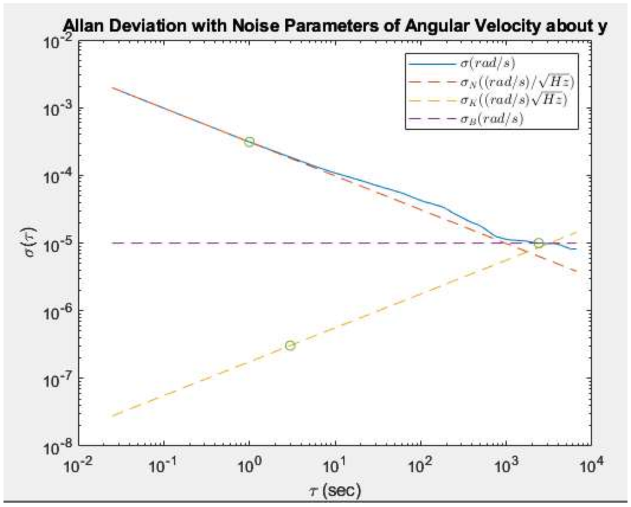



```
N =

   9.5310e-05

K =

   6.2722e-08

B =

   4.0133e-06
```





For Angular velocity in Y direction



N =

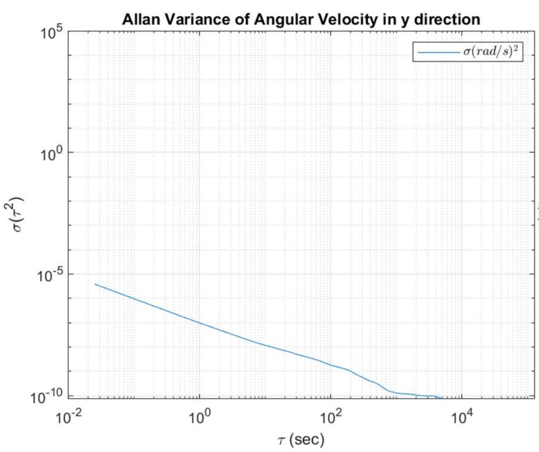
3.1047e-04

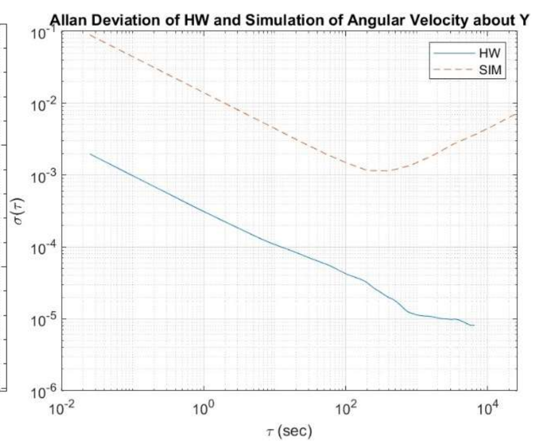
K =

3.0552e-07

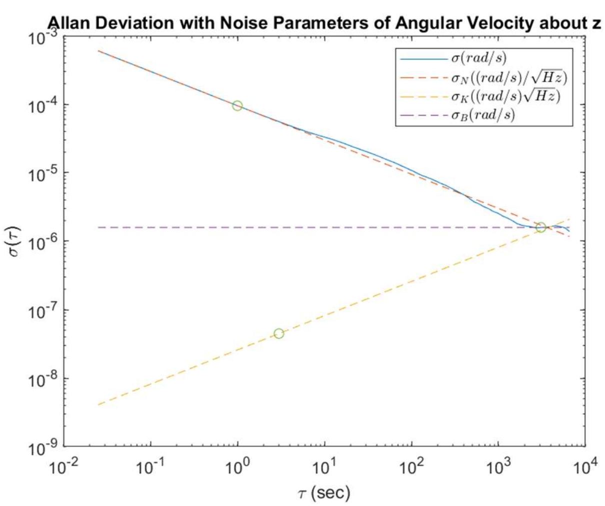
B =

1.5007e-05





For Angular velocity in Z direction



N =

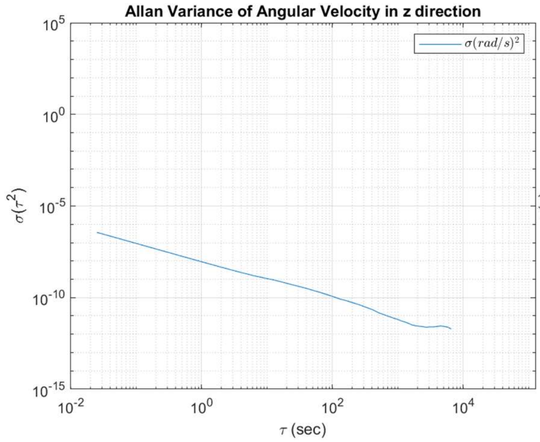
9.5010e-05

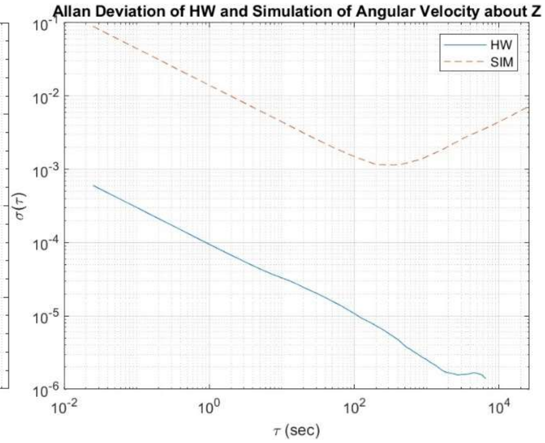
K =

4.4758e-08

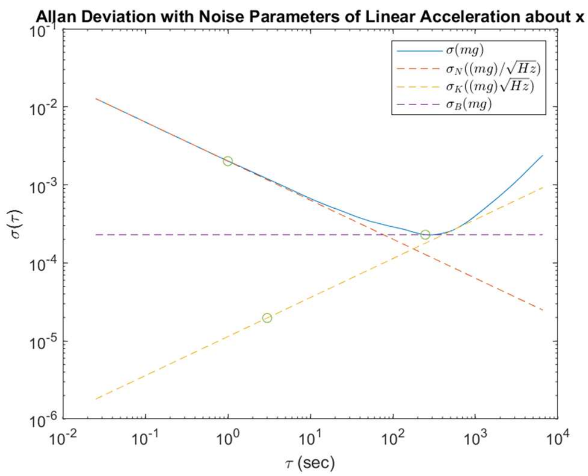
B =

2.3918e-06





For Linear acceleration in X direction



N =

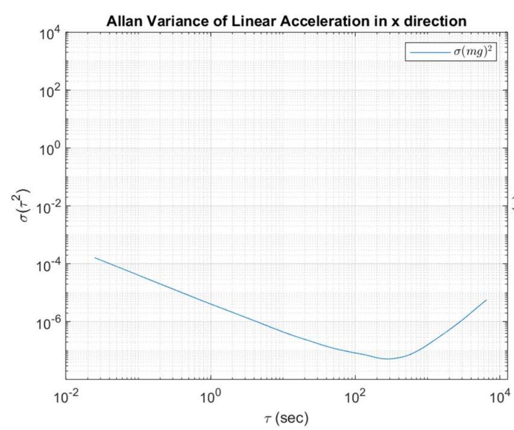
0.0020

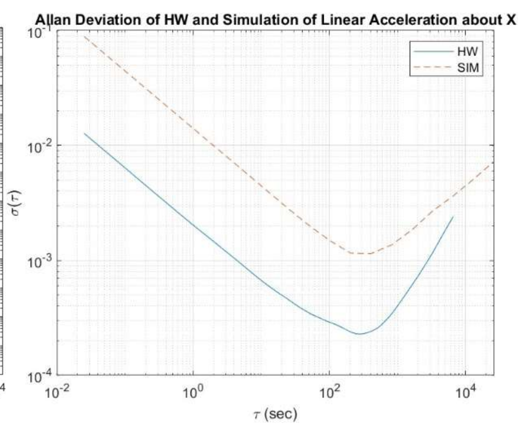
K =

1.9710e-05

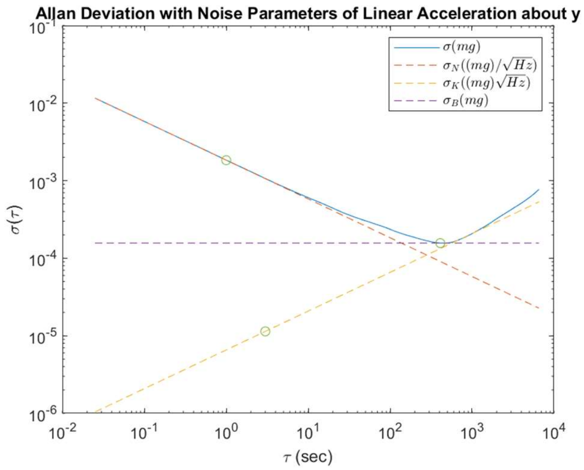
B =

3.4603e-04





For Linear acceleration in Y direction



N =

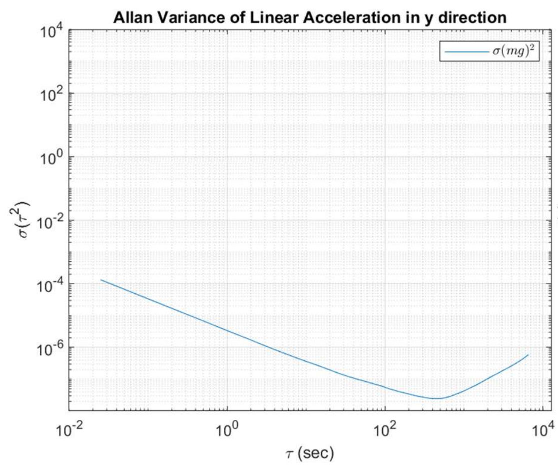
0.0018

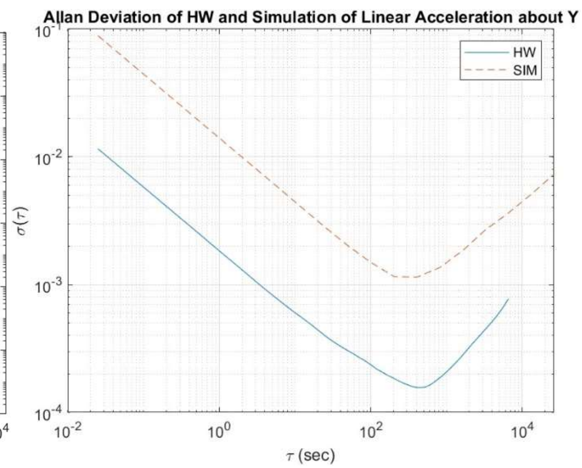
K =

1.1386e-05

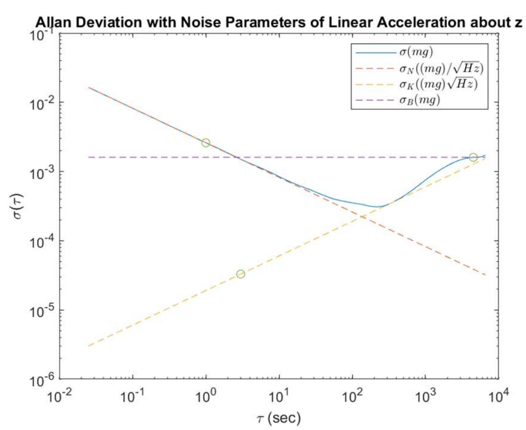
B =

2.3575e-04





For Linear acceleration in Z direction



N =

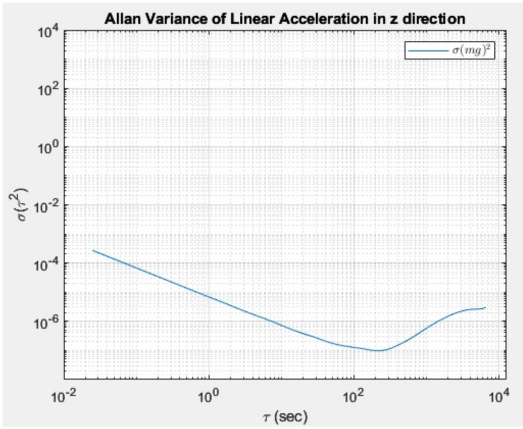
0.0026

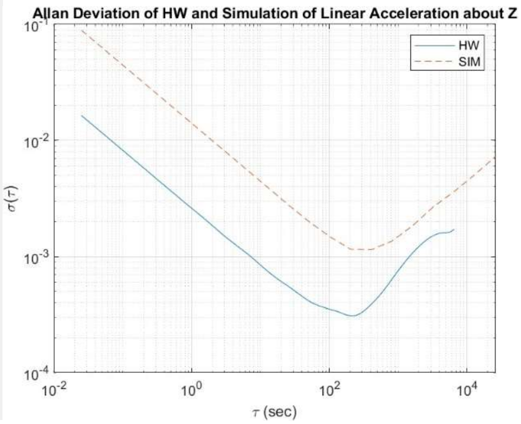
K =

3.2973e-05

B =

0.0024





From the N, K and B values, we can model the errors in data using the simulation script in MATLAB. You can see the simulated values as the yellow dashed line in the simulation plots. These simulated values are compared with actual values (blue line). The simulated values are different from actual values and contain less noise because the script is not using temperature-related parameters for calculations. We calculate the 'N' value at tau = 1 sec, and we calculate 'B' at the minima of the curve.

N values for Acceleration X, Acceleration Y, Acceleration Z, Gyro X, Gyro Y, and Gyro Z axes are given alongside the plots with units mg/(Hz^0.5) and (rad/s)/(Hz^0.5) resp. Whereas the N values for Gyro data and Acceleration data in the datasheet is 6.10865e-0.5 (rad/s)/(Hz^0.5) and 0.14 mg/(Hz^0.5). The N value for Gyro data about Z and X is the closest to the value in the datasheet. The B values for Acceleration and Gyroscope in datasheet is < 0.04 mg < 10°/hr (5-7°/hr typ.). The B values of Acceleration about X, Y, and Z axes, Gyro about X ,Y and Z axes satisfy the requirements from datasheet, but the Gyro about Y axis did not match the value given in the datasheet.

We got different values compared to the values in the datasheet because the data collected for analysis in the datasheet is collected in completely ideal conditions (little to no vibrations, far away from electronics etc.).