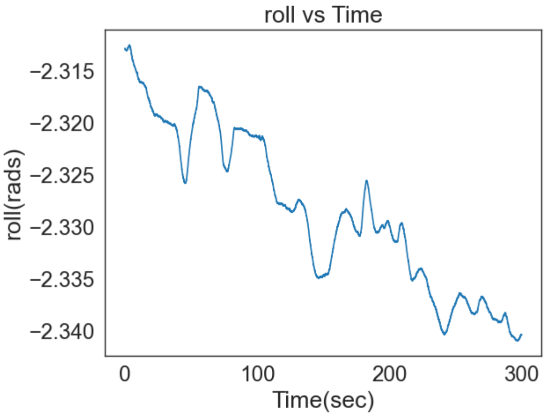
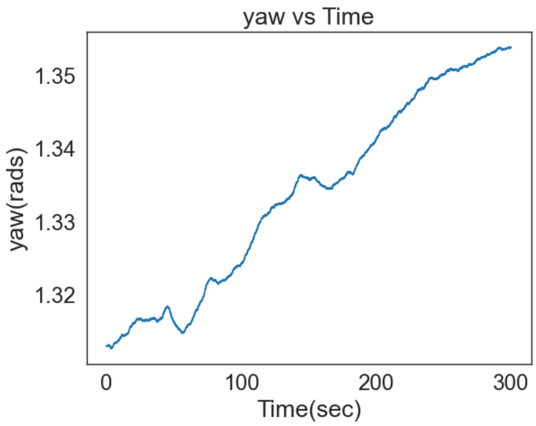
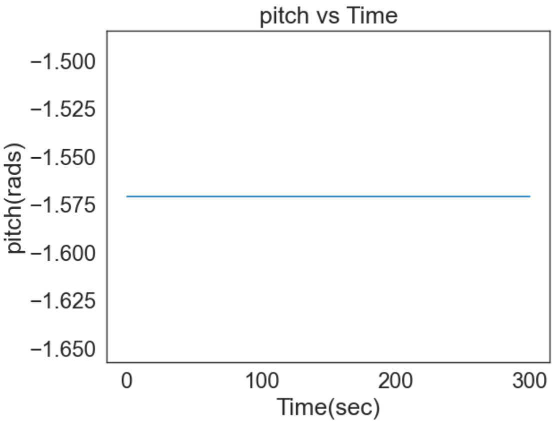
We faced issues while collecting data with the sensor. We could not collect it for 4 days. We discussed the issue with Asjad and he extended our deadline to sunday afternoon.

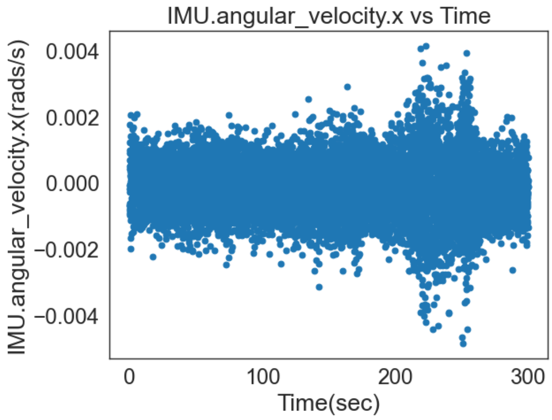
individual data analysis:

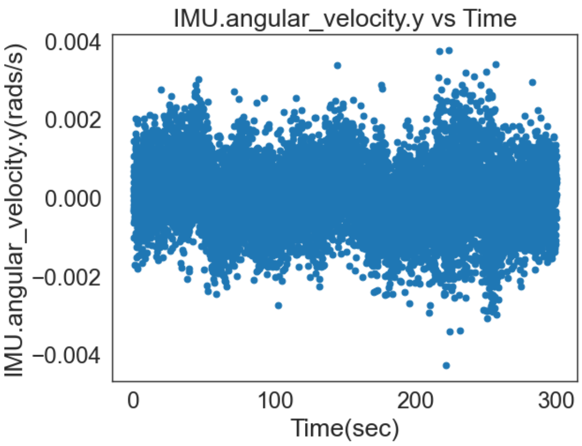
I collected my individual data in the basement of snell engineering for 5 minutes. I plotted the time series graphs to understand how the values are varying across time and plotted histograms to see the how the values are distributed.

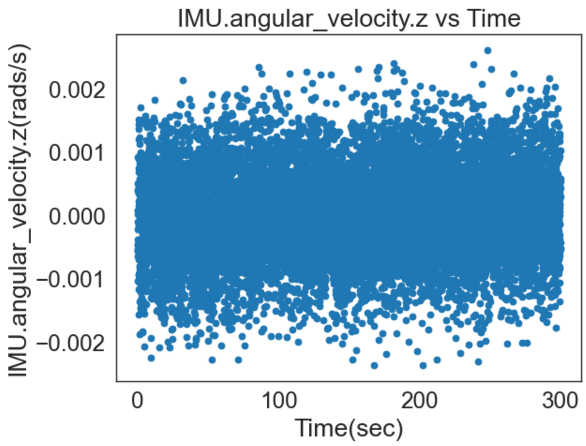


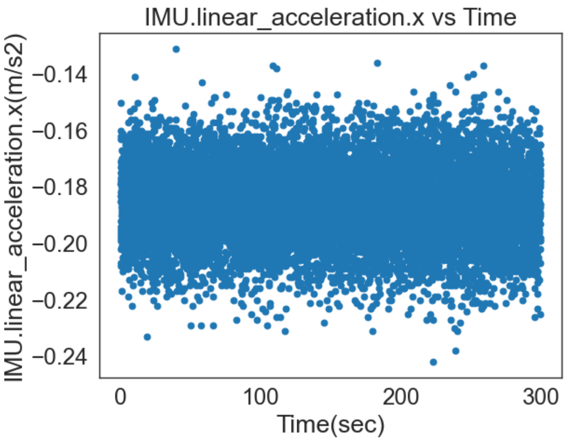


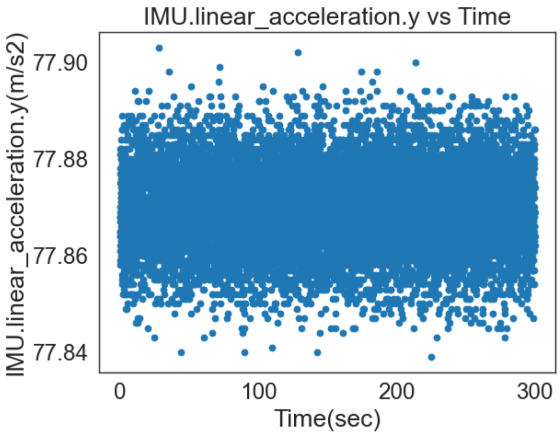


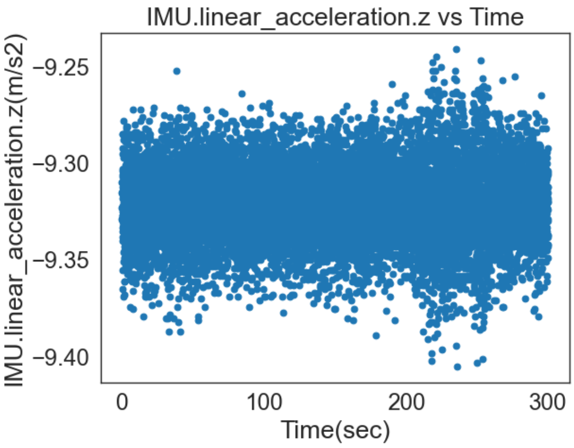


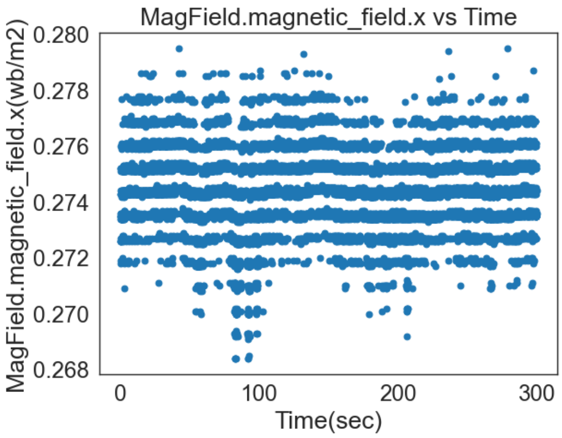


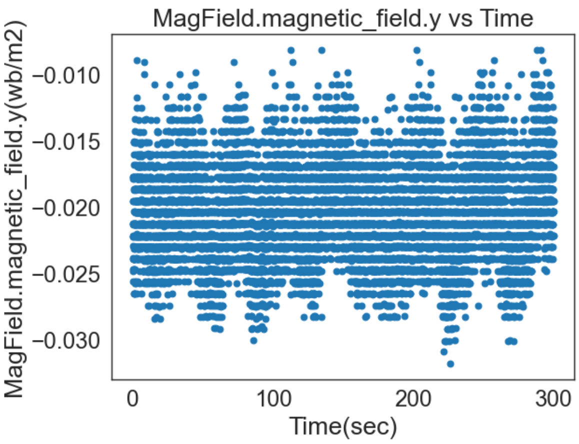


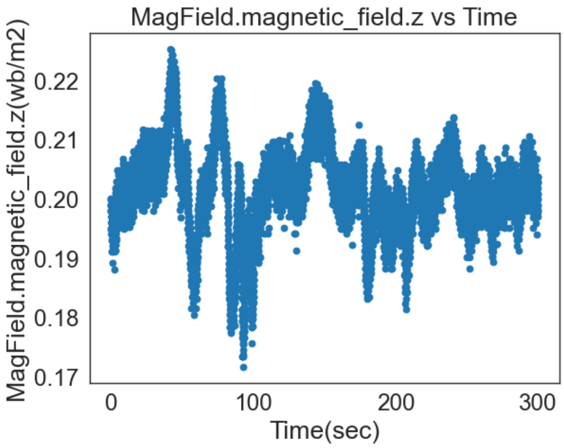




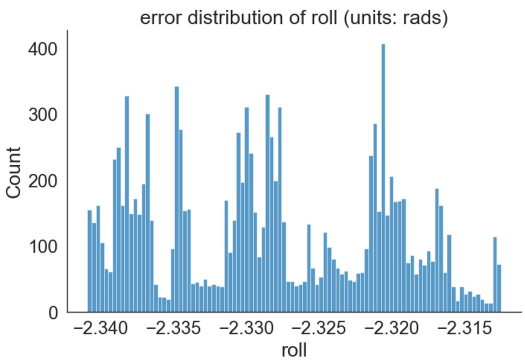


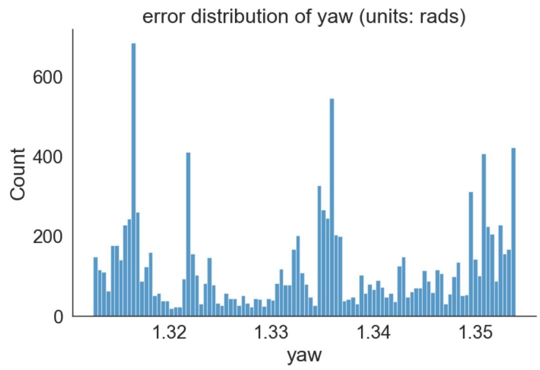


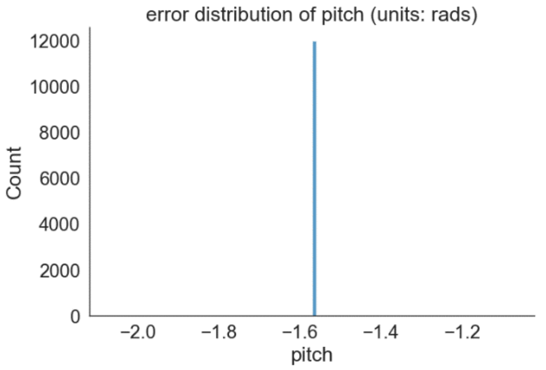


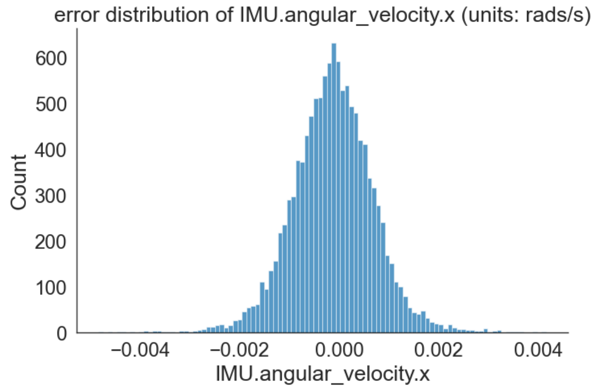


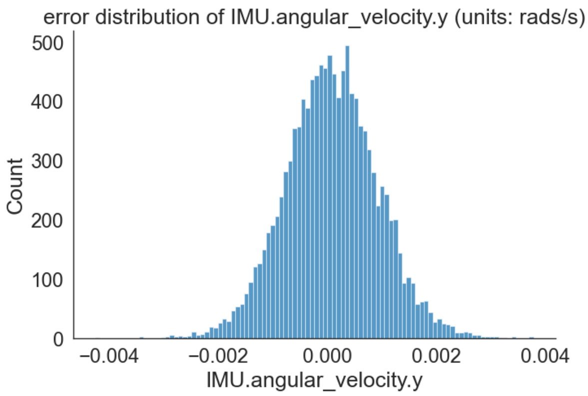
There is a fluctuation of 0.03 rads and 0.04 rads in roll and yaw data respectively but there is no fluctuation in pitch as pitch is rotation about y axis and there is little to no noise in that axis. There is a small amount of fluctuations in accelerometer, gyroscope and magnetometer data. Shown below are the histogram plots of the data I collected:

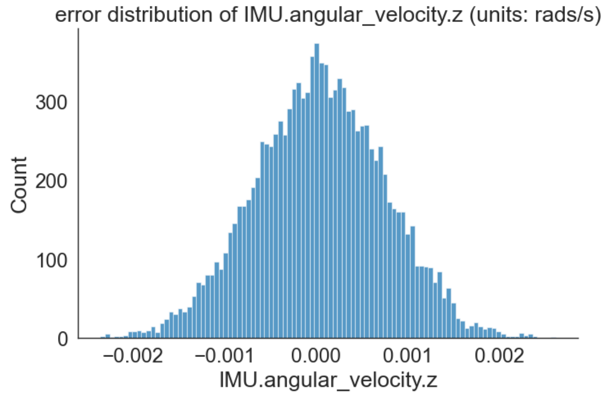


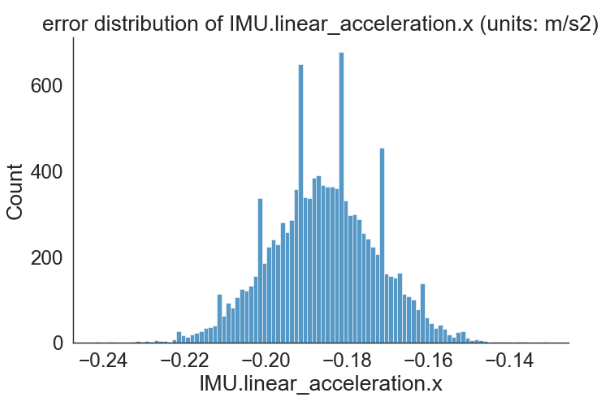


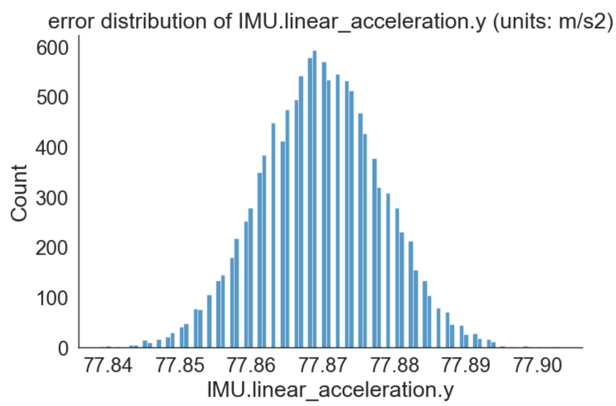

error distribution of pitch (units: rads)
Count
12000
10000
8000
6000
4000
2000
0
−2.0
−1.8
−1.6
−1.4
−1.2
pitch

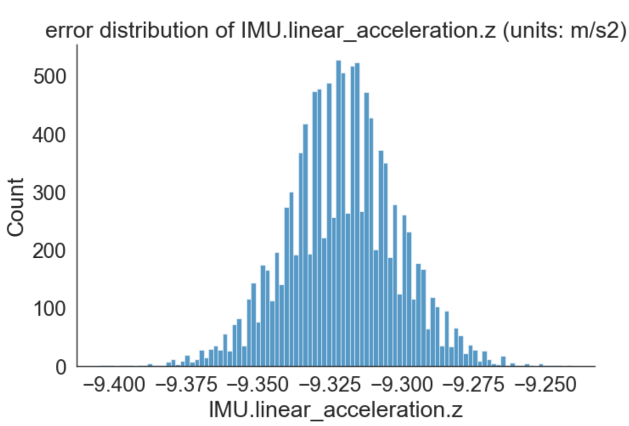

error distribution of IMU.angular_velocity.x (units: rads/s)
Count
600
500
400
300
200
100
0
−0.004
−0.002
0.000
0.002
0.004
IMU.angular_velocity.x

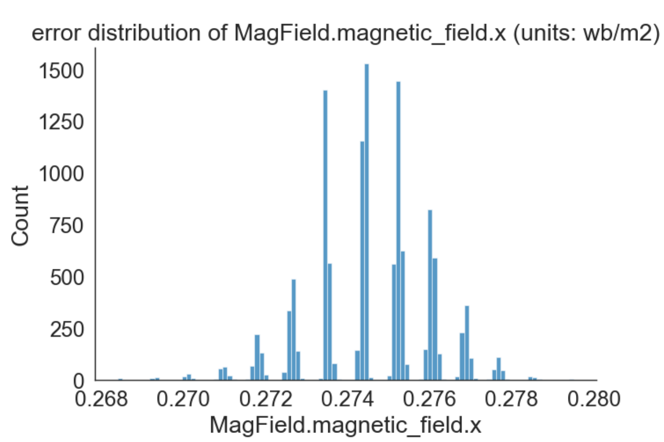

error distribution of IMU.angular_velocity.y (units: rads/s)
Count
500
400
300
200
100
0
−0.004
−0.002
0.000
0.002
0.004
IMU.angular_velocity.y

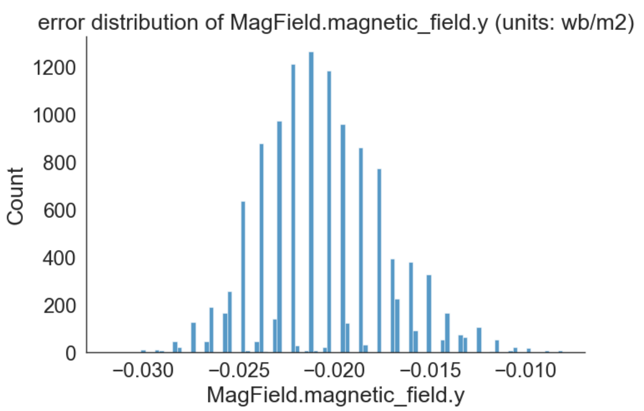

error distribution of IMU.angular_velocity.z (units: rads/s)
Count
300
200
100
0
−0.002
−0.001
0.000
0.001
0.002
IMU.angular_velocity.z

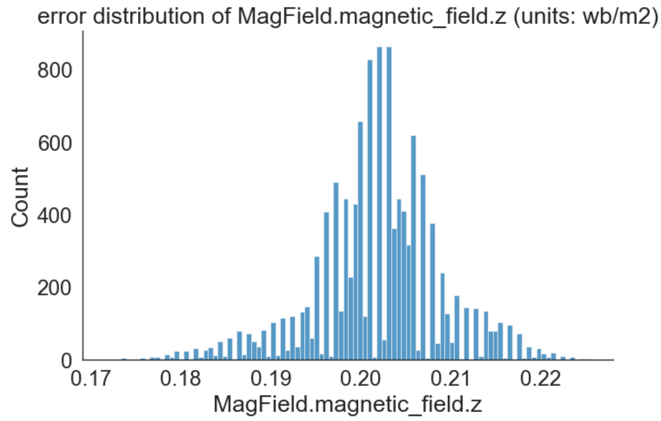

error distribution of IMU.linear_acceleration.x (units: m/s2)
Count
600
400
200
0
−0.24
−0.22
−0.20
−0.18
−0.16
−0.14
IMU.linear_acceleration.x


error distribution of IMU.linear_acceleration.y (units: m/s2)
Count
600
500
400
300
200
100
0
77.84
77.85
77.86
77.87
77.88
77.89
77.90
IMU.linear_acceleration.y


error distribution of IMU.linear_acceleration.z (units: m/s2)
Count
500
400
300
200
100
0
−9.400
−9.375
−9.350
−9.325
−9.300
−9.275
−9.250
IMU.linear_acceleration.z


error distribution of MagField.magnetic_field.x (units: wb/m2)
Count
1500
1250
1000
750
500
250
0
0.268
0.270
0.272
0.274
0.276
0.278
0.280
MagField.magnetic_field.x





The noise distributions of roll, pitch and yaw are not gaussian distributions but they are random distributions. The noise distributions of the rest of the values i.e.. angular velocities, linear accelerations and magnetic fields about x, y and z axes are gaussian distributions. Mean and Standard Deviation of the noise distributions are calculated below:

```
roll mean & std: -2.3284 & 0.0077
yaw mean & std: 1.3337 & 0.0133
pitch mean & std: -1.5708 & 0.0000
IMU.angular_velocity.x mean & std: -0.0001 & 0.0008
IMU.angular_velocity.y mean & std: 0.0001 & 0.0008
IMU.angular_velocity.z mean & std: 0.0000 & 0.0007
IMU.linear_acceleration.x mean & std: -0.1858 & 0.0133
IMU.linear_acceleration.y mean & std: 77.8696 & 0.0084
IMU.linear_acceleration.z mean & std: -9.3208 & 0.0193
MagField.magnetic_field.x mean & std: 0.2746 & 0.0014
MagField.magnetic_field.y mean & std: -0.0206 & 0.0034
MagField.magnetic_field.z mean & std: 0.2018 & 0.0070
```

group data analysis:

We collected our group data at one of our lab mate's basement in mission hill. There were no vibrations in the basement at all for the entirety of the five hours. We are calculating three error metrics from Allan Deviation for the data we collected: Angle Random Walk, Rate Random Walk and Bias Instability. Allan Deviation is used to analyze stability and noise characteristics of a time-domain signal. Allan variance is calculated by using this formula:

$$\sigma^2(\tau) = \frac{1}{2\tau^2} < (\theta_{k+2m} - 2\theta_{k+m} + \theta_k)^2 >$$

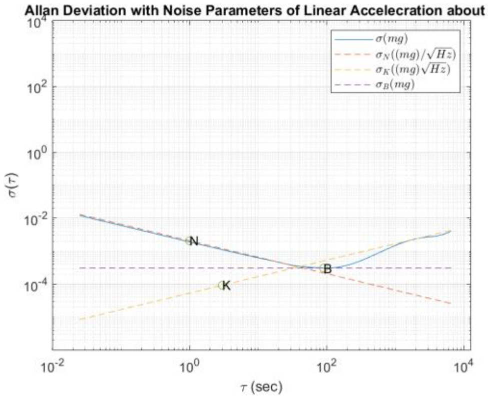
And Allan Deviation is just the square root of that.

angle random walk: Gyro angular rate measurements are integrated with respect to time to compute angles. The integration will drift over time due to noise. This drift looks like random steps. This term is called Angle Random Walk.

rate random walk: This represents bias fluctuations caused in long term primarily due to temperature effects.

bias instability: This is a measure of how much gyro biases drift over time. This is also called turn-on bias.

for linear acceleration about X



N =

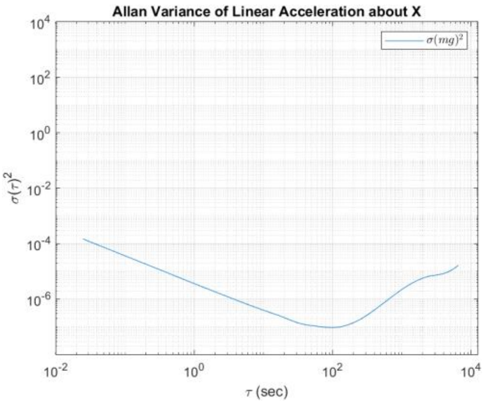
0.0021

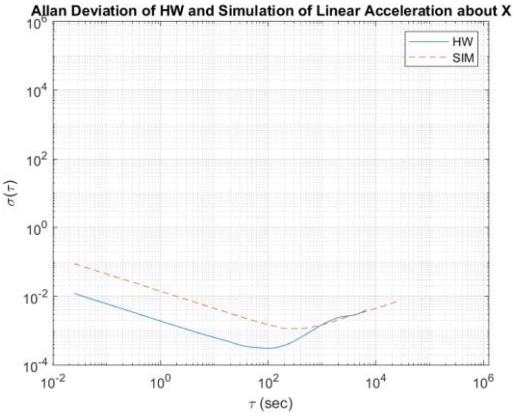
K =

9.2214e-05

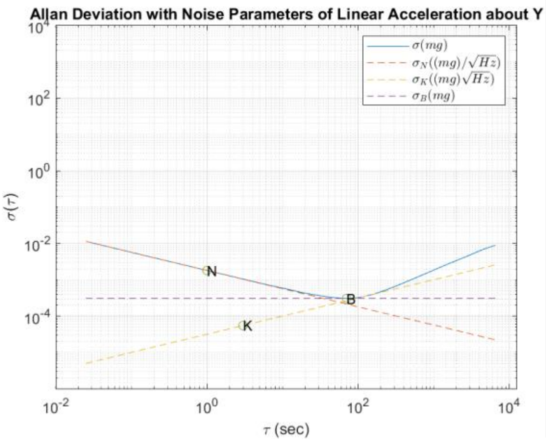
B =

4.6216e-04





for linear acceleration about Y



N =

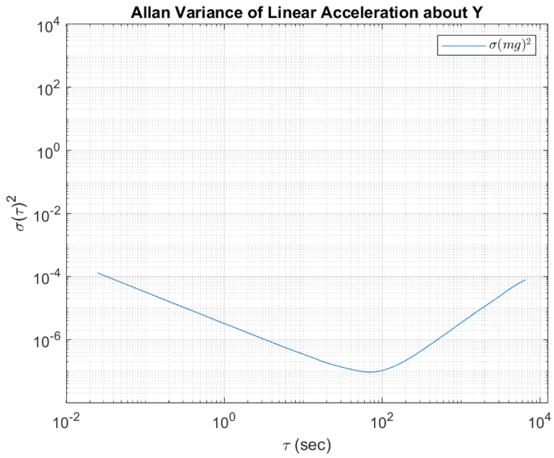
0.0018

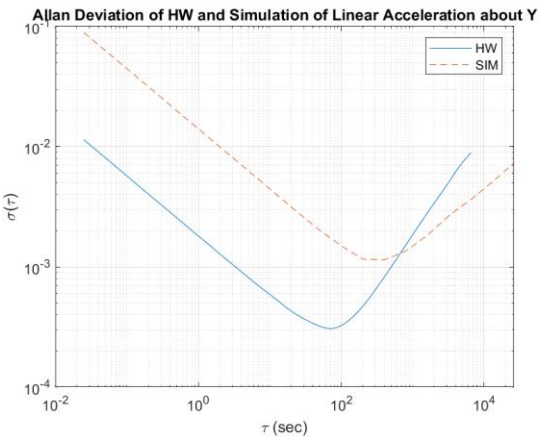
K =

5.5036e-05

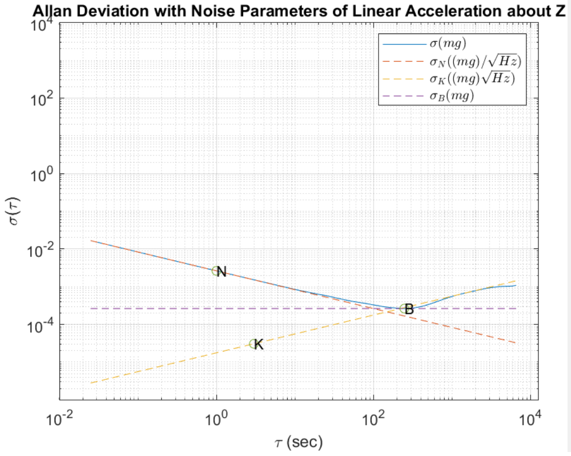
B =

4.6111e-04





for linear acceleration about Z



N =

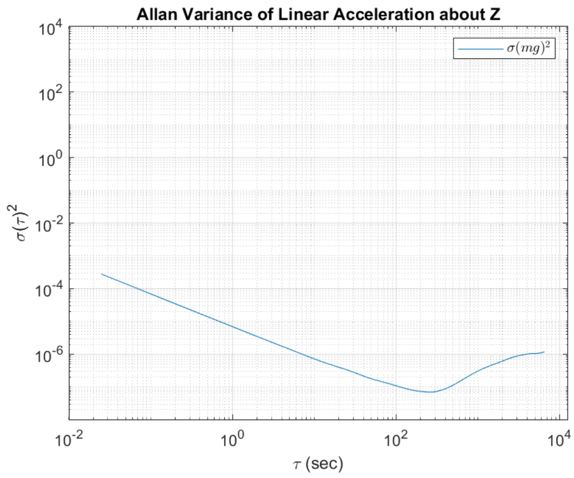
0.0026

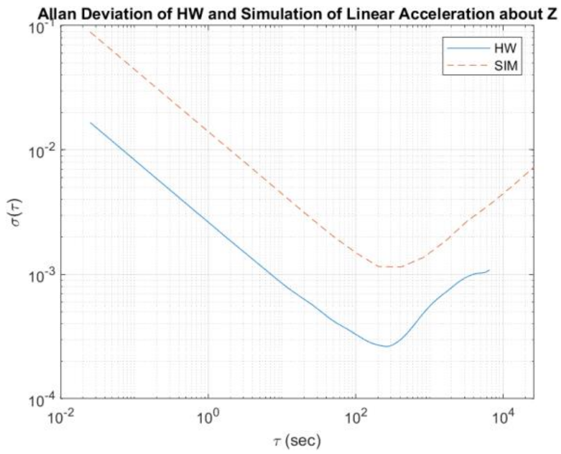
K =

3.0704e-05

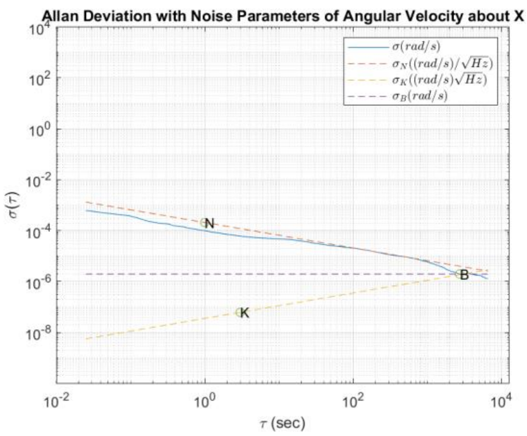
B =

3.9672e-04





for angular velocity about X



N =

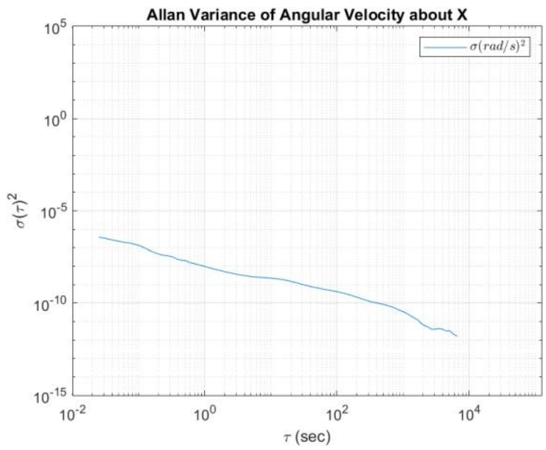
2.0774e-04

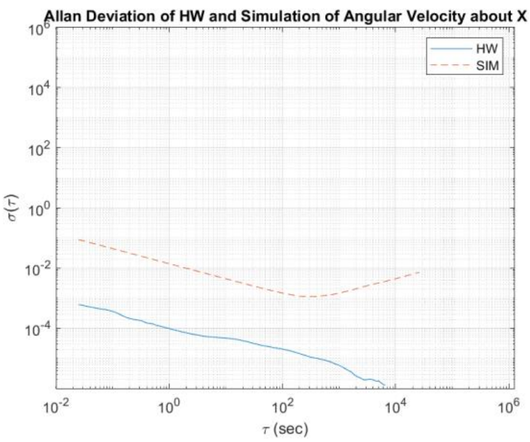
K =

6.1391e-08

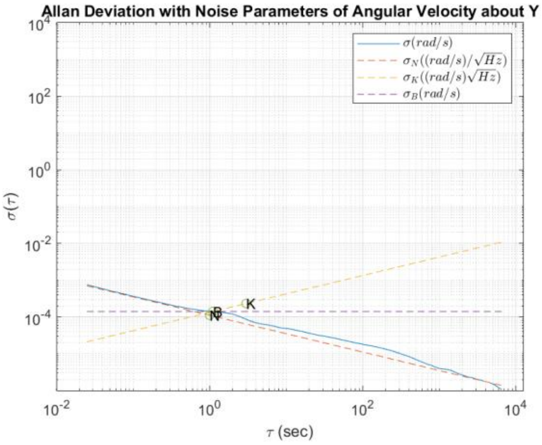
B =

2.9582e-06





for angular velocity about Y



N =

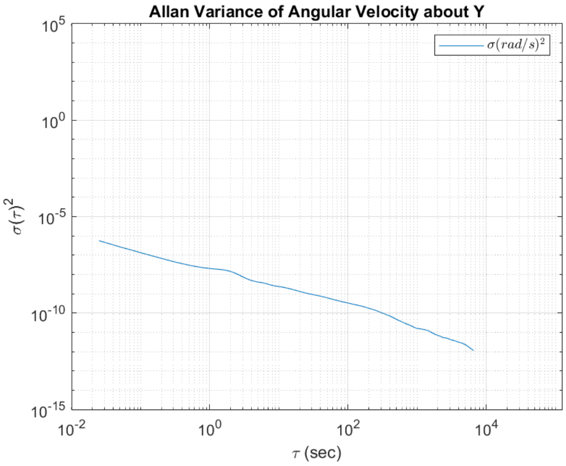
1.1202e-04

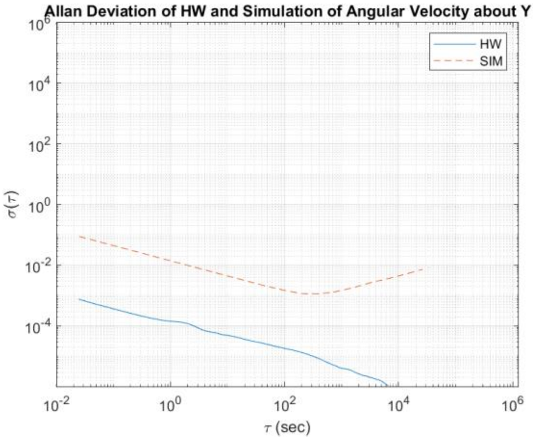
K =

2.3311e-04

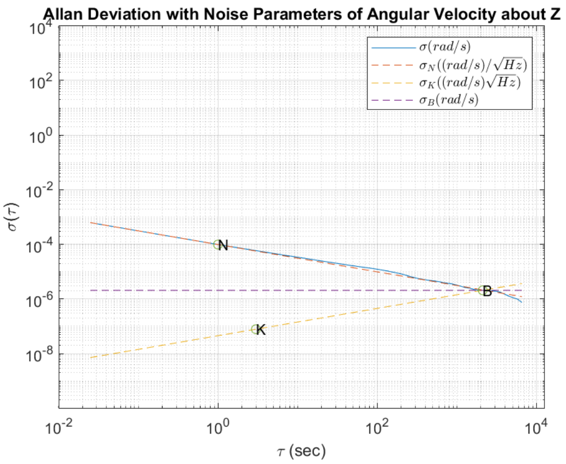
B =

2.1250e-04





for angular velocity about Z



N =

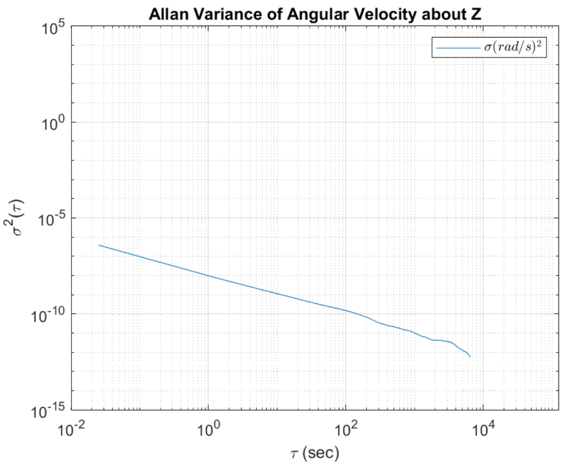
9.8430e-05

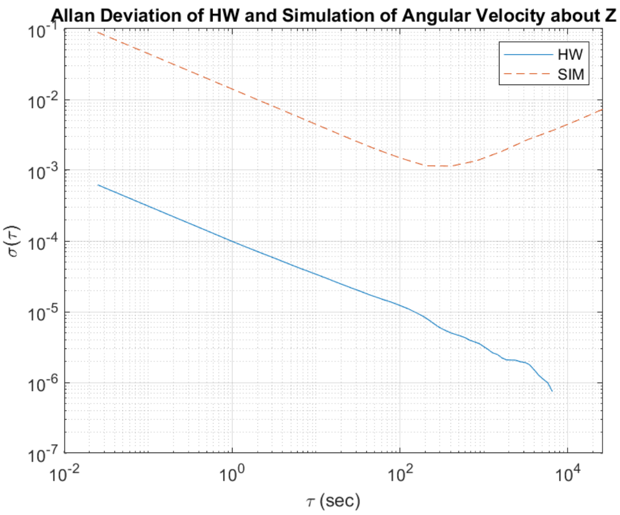
K =

7.8172e-08

B =

3.1195e-06





I calculated Allan Deviation along with angle random walk coefficient(N), rate random walk coefficient(K) and bias instability coefficient(B) for linear accelerations about X, Y and Z axes and angular velocities about X, Y and Z axes. We observe different kinds of errors in the output such as bias, bias instability, random walk error, acceleration dependency errors, and sensor non-orthogonality etc...

bias: for any input, the sensor outputs a measurement offset by a bias.

bias instability error: the bias changes over time when the IMU is powered on

random walk error: When the IMU is measuring a constant signal, there is always some random noise in the measurement. This is called a stochastic process.

acceleration dependency error: the IMU experiences different values of error when it is experiencing acceleration

sensor non-orthogonality error: the 3 gyroscopes and accelerometers are not perfectly orthogonal to each other. This gives rises to errors.

Primarily, three kinds of noises are present in the data: white noise, red noise, and pink noise. Angle random walk is characterized by white noise of the output. That is why the slope of the orange line is -0.5. Rate random walk is characterized by red noise of the output. That is why the slope of the yellow line is 0.5. Bias instability is characterized by pink noise of the output. That is why the slope of the purple line is 0.

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.

The N values for Acceleration X, Acceleration Y, Acceleration Z, Gyro X, Gyro Y, and Gyro Z axes are 0.0021 (mg)/(Hz^0.5), 0.0018 (mg)/(Hz^0.5), 0.0026 (mg)/(Hz^0.5), 2.077e-04 (rad/s)/(Hz^0.5), 1.1202e-04 (rad/s)/(Hz^0.5) and 9.8430e-05 (rad/s)/(Hz^0.5). 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 is the closest to the value in the datasheet. The B values for Acceleration X, Acceleration Y, Acceleration Z, Gyro X, Gyro Y, and Gyro Z axes are 4.6216e-0.4 mg, 4.6111e-04 mg, 3.9672e-04 mg, 2.9582e-06 rad/s, 2.1250e-04 rad/s and 3.1195e-06 rad/s. The B values for Gyro data and Acceleration data in the datasheet is less than 4.8481e-5 rad/s and less than 0.04 mg respectively. The B values of Acceleration about X, Y, and Z axes, Gyro about X 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.).