Robotics Sensing and Navigation
EECE 5554
LAB-3

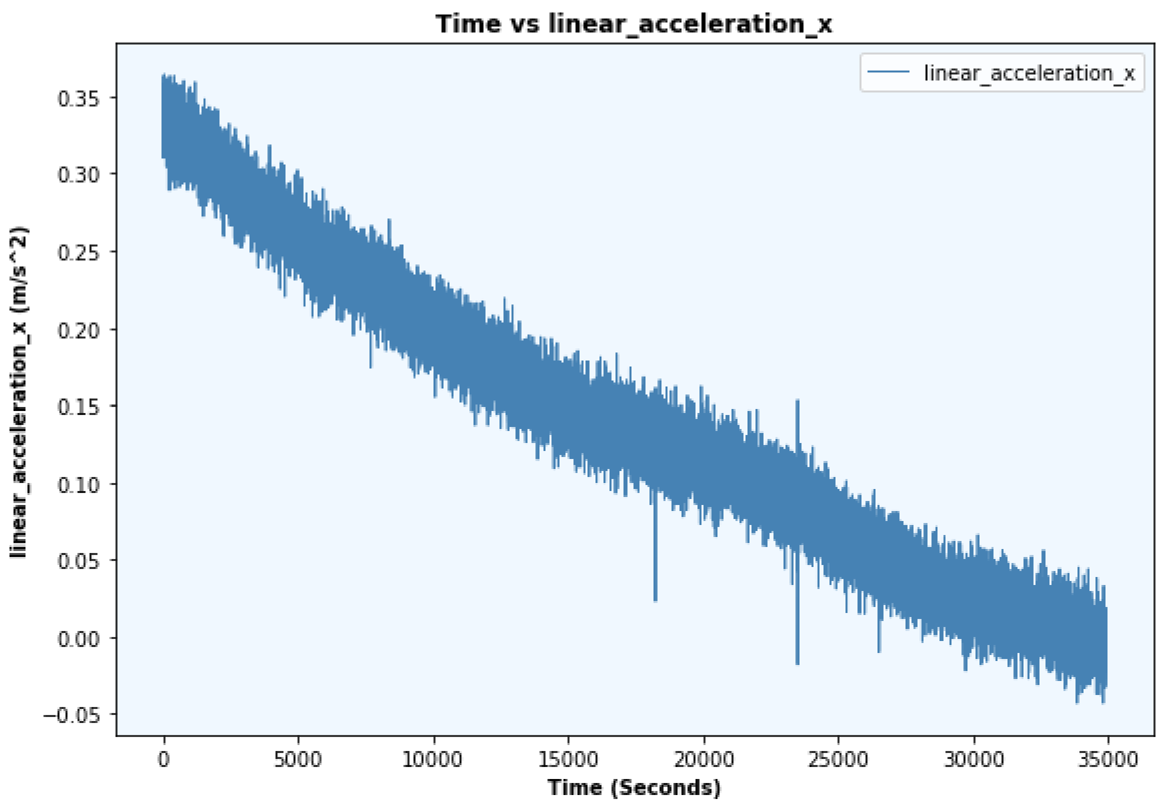
Note for TA: Using the first late submission day for this report updation

A VN - 100 Inertial Measurement Unit (IMU) Sensor from Vector Nav was used to collect two data sets. One set of data for a duration of 15 minutes and another set of data for approximately 5 hours. The VN100 consists of 3-axis accelerometers, gyros, and magnetometers, a barometric pressure sensor and a 32-bit processor. Roll, Pitch and Yaw were converted into quaternions and published back as orientations.

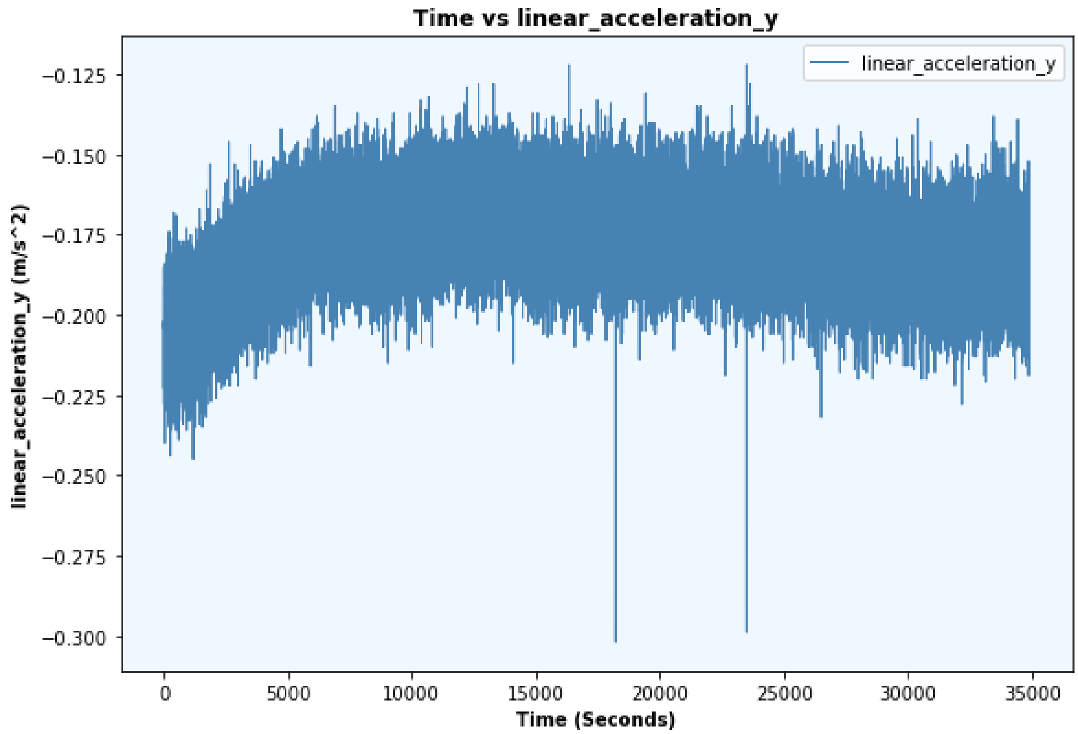
Noise Characteristics and Plots for data collected for a duration of 15 minutes

The data was collected stationarily by taping it into the floor and below are the plots and noise characteristics.

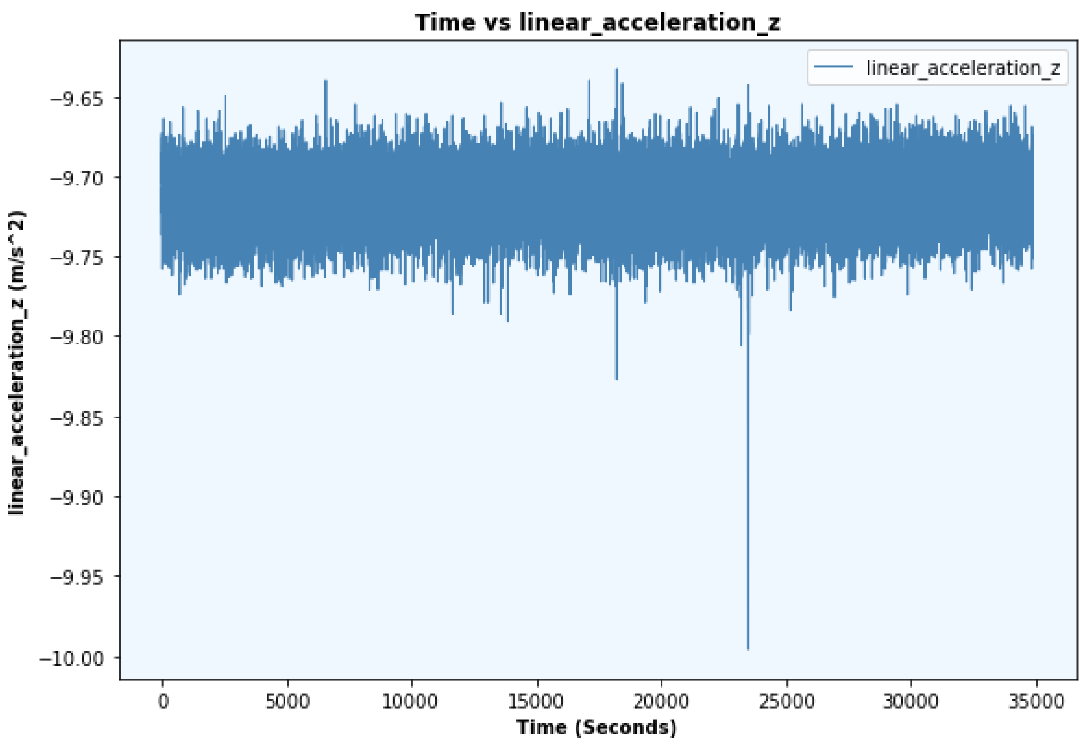
Linear Acceleration:



- The Linear acceleration of the x axis had a mean of 0.1404 meter/second square and standard deviation of 0.0958.



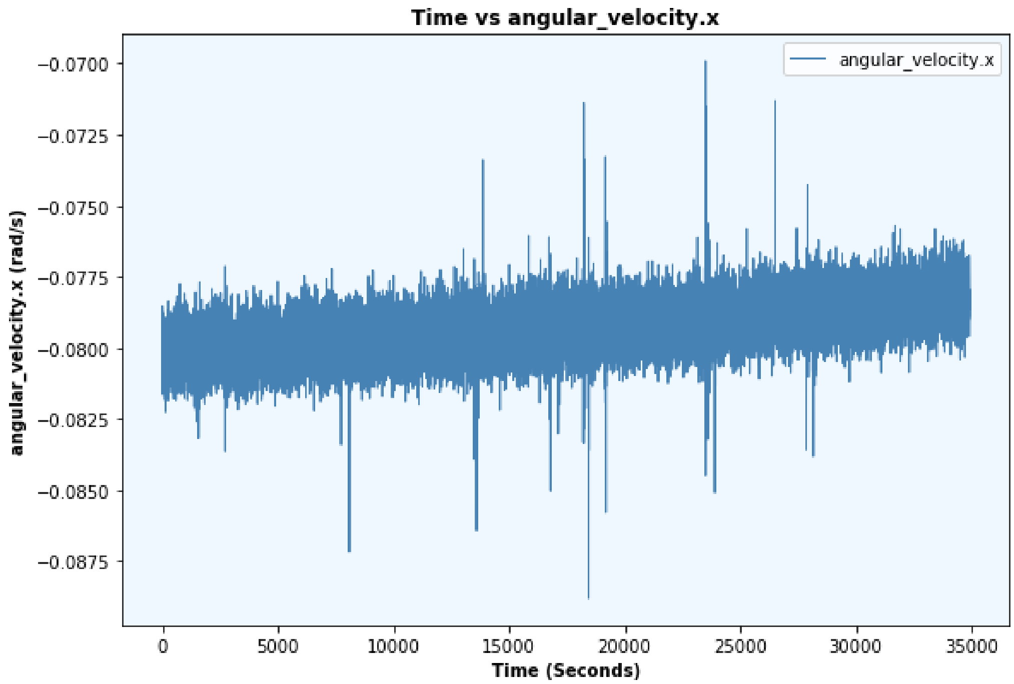
- The Linear acceleration of the y axis had a mean of -0.1778 meter/second square and standard deviation of 0.0144.



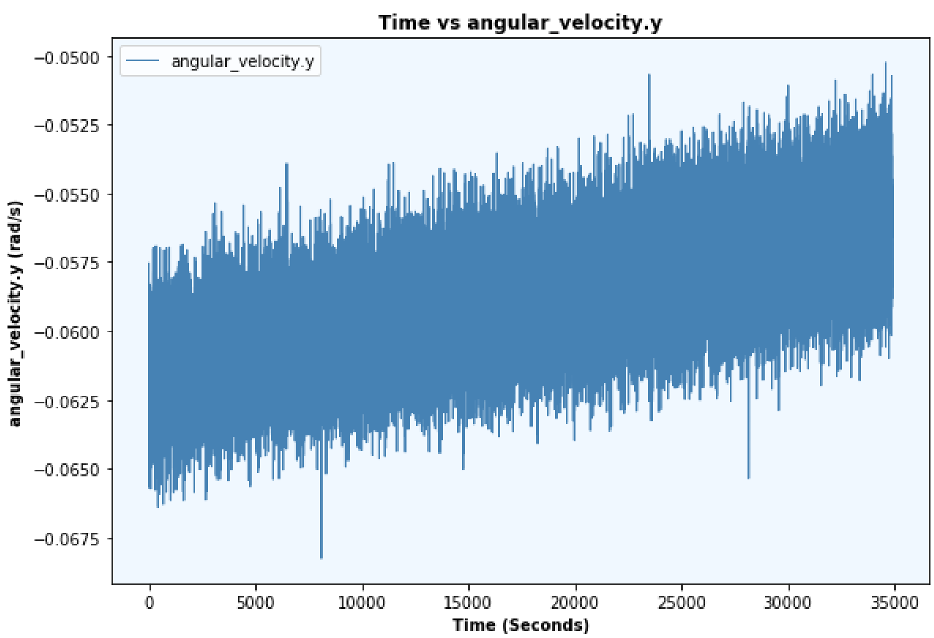
- The Linear acceleration of the z axis had a mean of -9.7143 meter/second square and standard deviation of 0.01696.

- Even though the accelerometer is in stationary position we can see a deviation in the readings and this might be because of a constant bias which is the offset of its output signal from the actual acceleration value. A constant bias error causes an error in position which grows over time. We can get rid of this by calibration and orthogonality measurements.

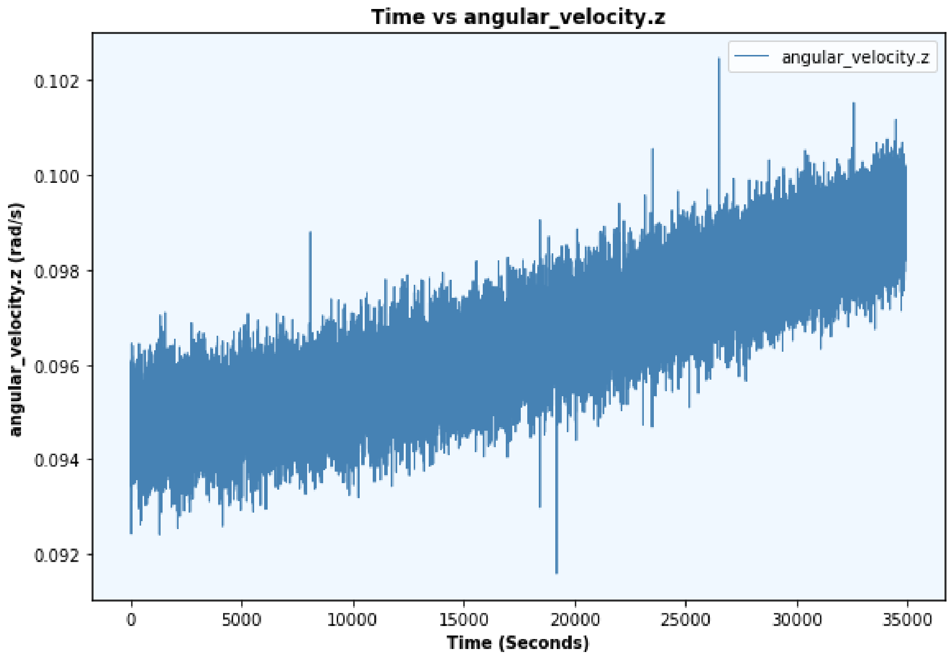
Angular Velocity:



- The Angular velocity of the x axis had a mean of -0.0792 rad/second and standard deviation of 0.00009. The deviation observed is very less and nearly zero.



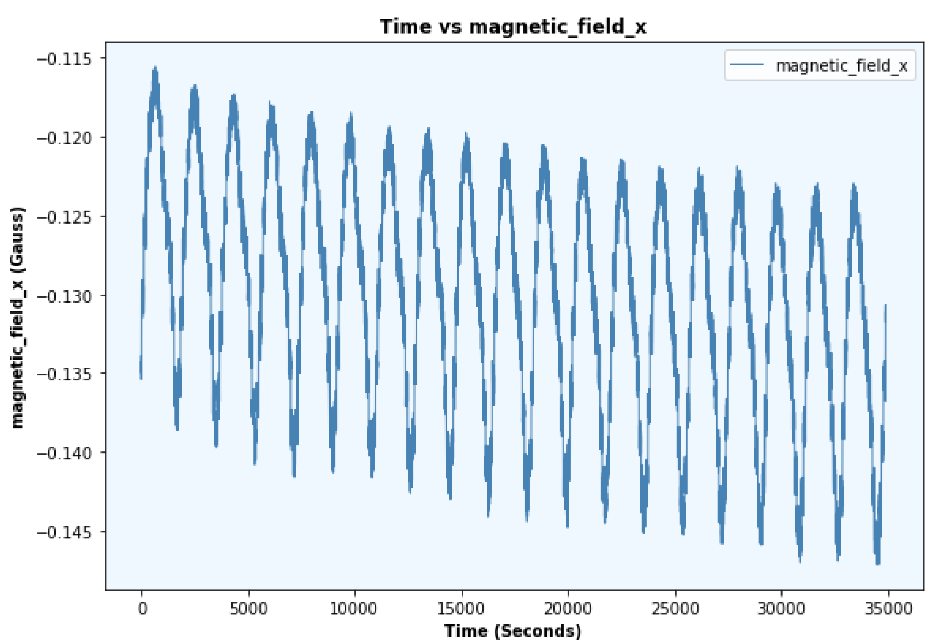
- The Angular velocity of the y axis had a mean of -0.0587 rad/second and standard deviation of 0.0023.



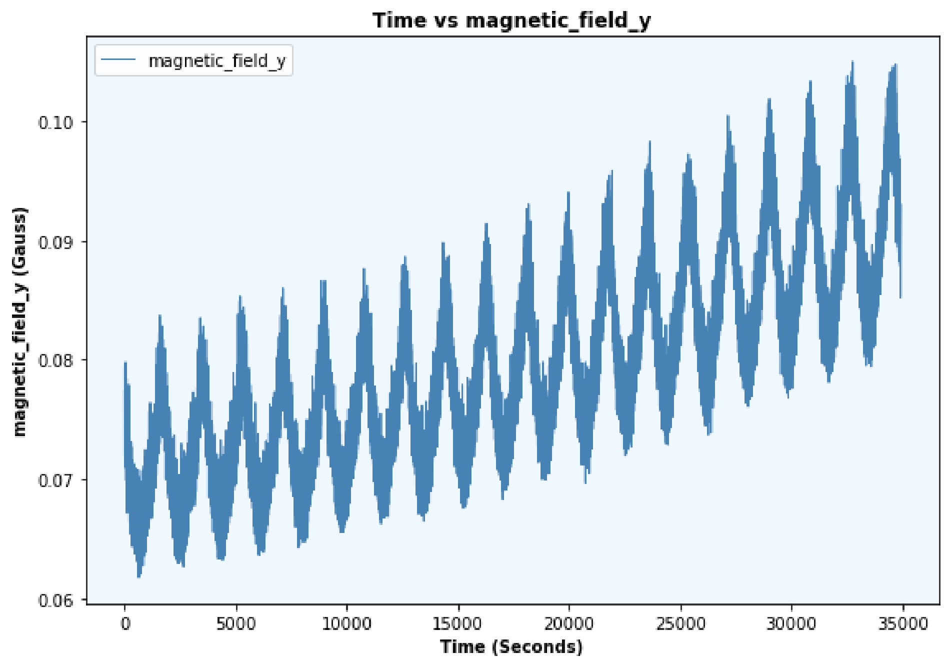
- The Angular velocity of the y axis had a mean of 0.0965 rad/second and standard deviation of 0.0014.

- Even when an IMU is stationary, it still measures forces and these are observed in the inertial frame. Inertial frame is a reference fixed in space and time. Earth moves through the inertial frame and hence its gravity's acceleration can be measured by the accelerometers. This might have caused the deviations seen in angular velocities.

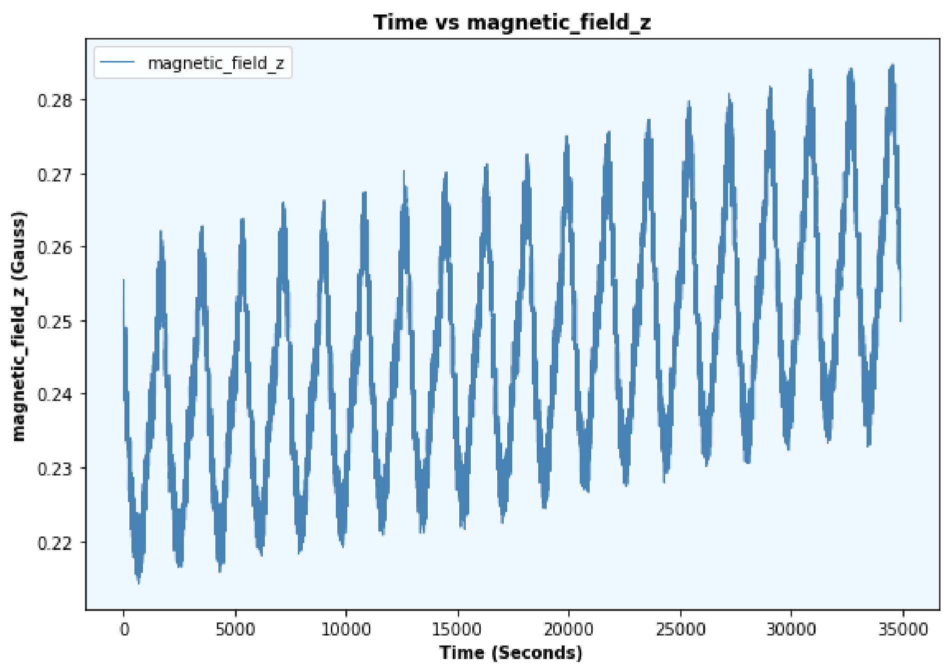
Magnetometer:



- The magnetic field of the x axis had a mean of -0.1301 gauss and standard deviation of 0.0072.



- The magnetic field of the y axis had a mean of 0.0792 gauss and standard deviation of 0.0081.



- The magnetic field of the z axis had a mean of 0.2462 gauss and standard deviation of 0.0150.

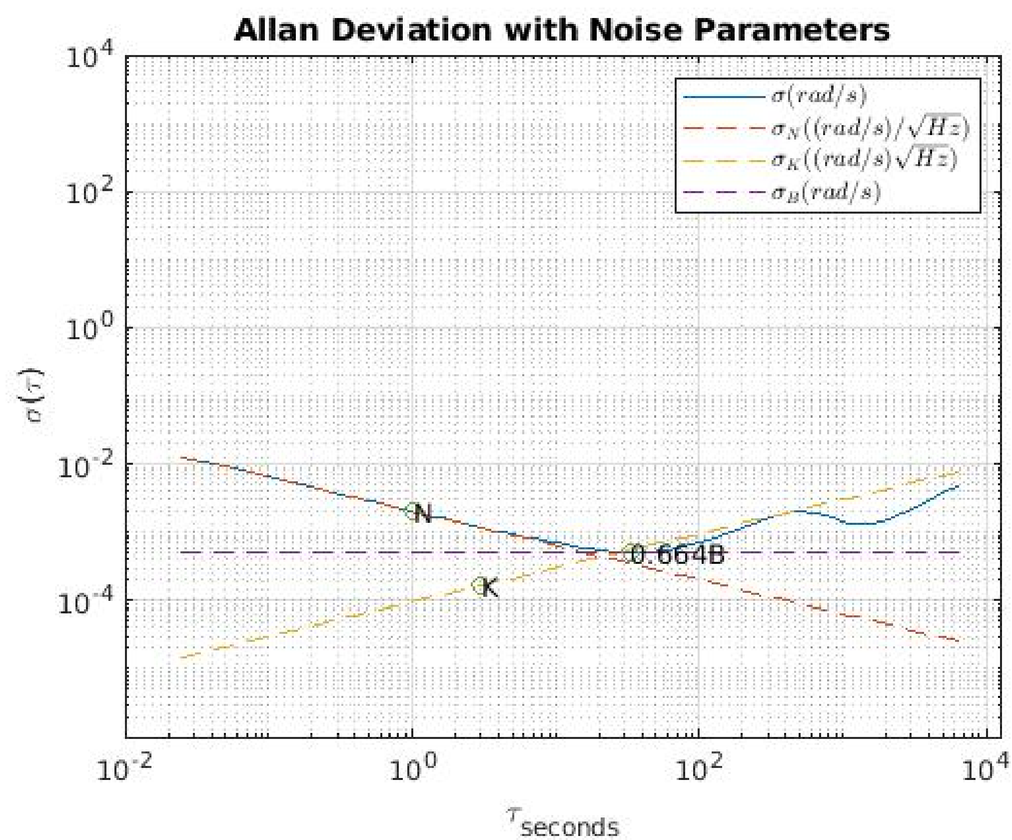
- We can see slight deviations in the magnetometer of the IMU and this might be because of the slight magnetic fields generated in the vicinity of the sensor and sometimes it might also be because of the earth's magnetic field being shifted inside earth's core.

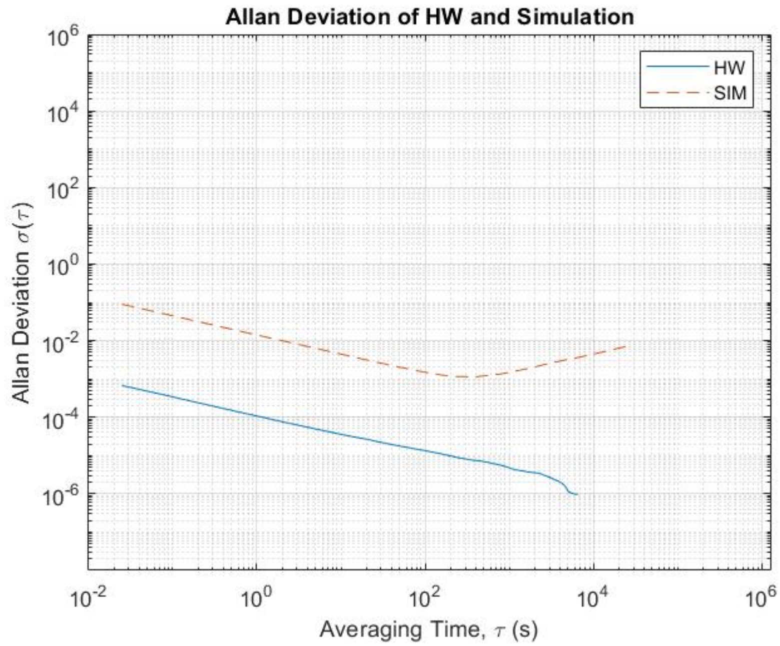
	Linear Acceleration (rad/sec)			Angular velocity (rad/second)			Magnetometer (gauss)		
	X	Y	Z	X	Y	Z	X	Y	Z
Mean	0.1404	-0.1778	-9.7143	-0.0792	-0.0587	0.0965	-0.1301	0.0792	0.2462
Standard deviation	0.0958	0.0144	0.01696	0.00009	0.0023	0.0014	0.0072	0.0081	0.0150

Table1: Statistical calculation for 15 minutes IMU data

Noise Characteristics and Plots for data collected for a duration of 5 hours

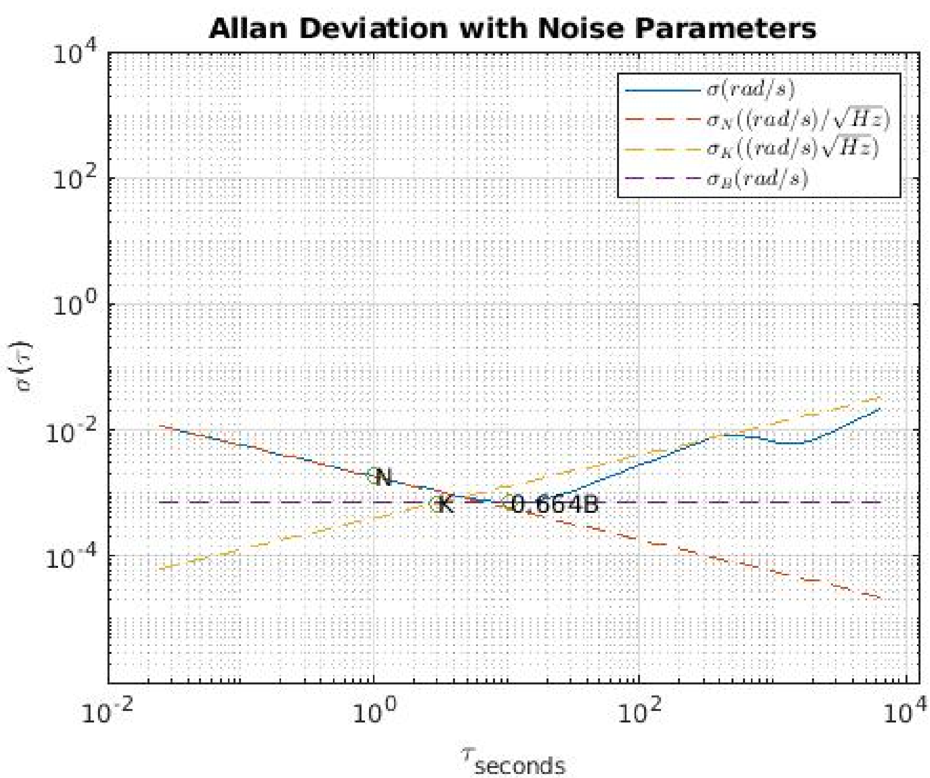
Linear acceleration in X-axis:

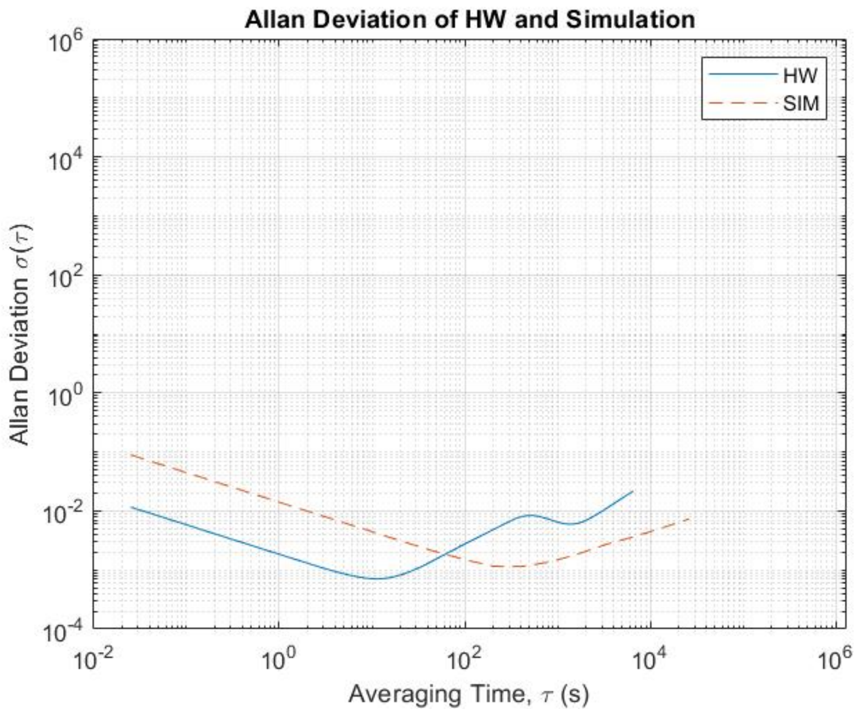




Angle Random Walk Coefficient (N) in (rad/s)/√Hz	Rate Random Walk Coefficient (K) in (rad/s)√Hz	Bias Instability Coefficient (B) in (rad/s)
0.0020	1.6460e-04	7.5064e-04

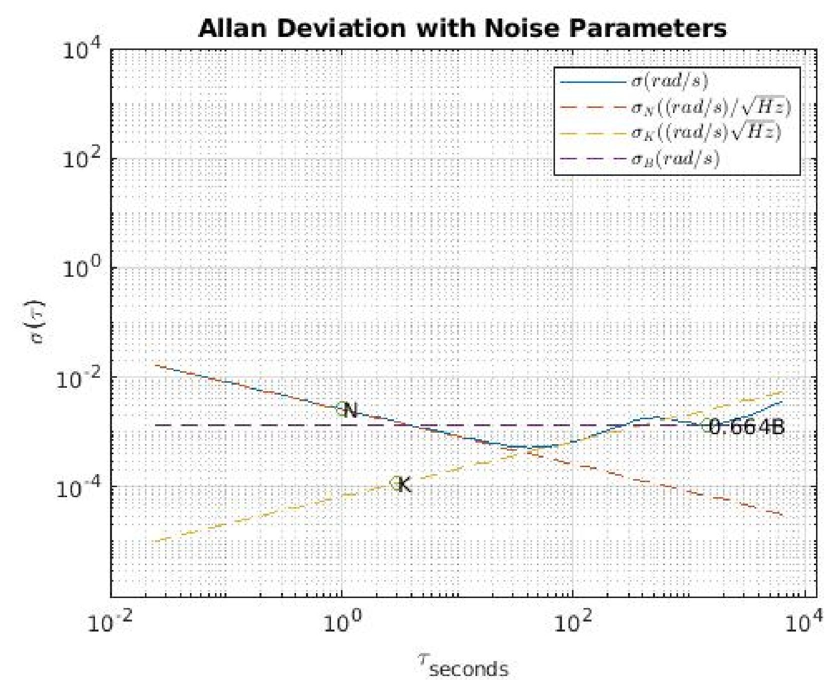
Linear acceleration in Y-axis:

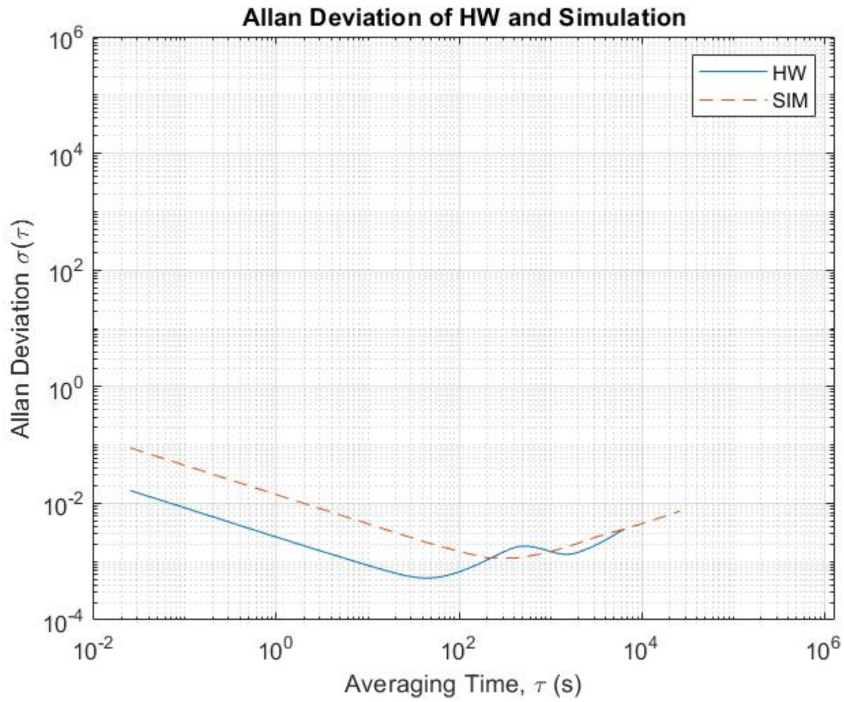




Angle Random Walk Coefficient (N) in (rad/s)/√Hz	Rate Random Walk Coefficient (K) in (rad/s)√Hz	Bias Instability Coefficient (B) in (rad/s)
0.0018	**6.8520e-04**	**0.0011**

Linear acceleration in z-axis:





Angle Random Walk Coefficient (N) in (rad/s)/√Hz	Rate Random Walk Coefficient (K) in (rad/s)√Hz	Bias Instability Coefficient (B) in (rad/s)
0.0026	**1.1527e-04**	**0.0020**

1. What kind of errors/sources of noise are present?
   - The type of errors that might affect IMU's are strong effect of gravity's acceleration(~9.8m/s2) can be measured by the accelerometers, sensor noise, bias instability, timing errors or sometimes sensor misalignment.
   - It can also be pink noise(flicker noise) or red noise(Brownian noise)
2. How do we model them? Where do we measure them? Can you relate your measurements to the datasheet for the VN100?
   - We can model them in the case of an IMU using an Inertial navigation system(INS) which estimates and removes errors from the IMU.
   - Here, we use Alan variance and in this we have angle random walk(N), rate random walk(K) and bias instability(B).For angle random walk we use a slope of -½ and time $\tau = 1$when plotted on a log-plot of $\sigma(\tau)$ *versus* τ. For rate random walk we use a slope of ½ with $\tau = 3$ when plotted on a log plot $\sigma(\tau)$ *versus* τ in which we can read the k value. For bias instability we get a value of ~0.664 by scaling. Alan deviation of Hw and simulation gives comparison of our data with respect to simulated data with quantization and temperature controlled parameters.

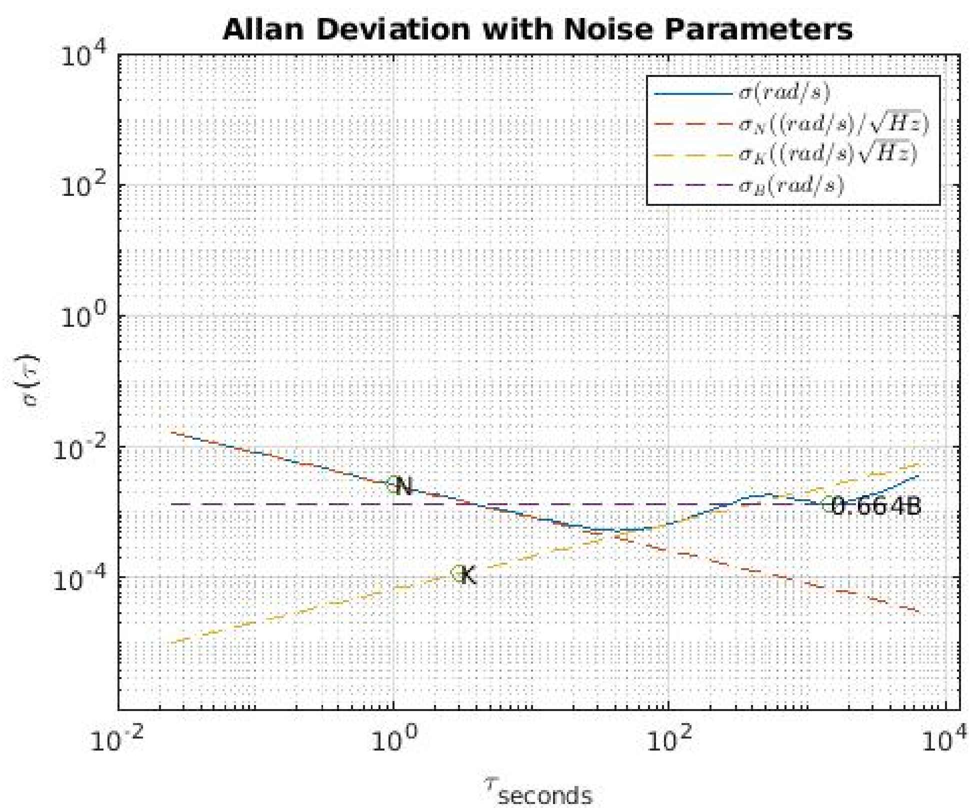
$$\Omega(t) = \Omega_{Ideal}(t) + Bias_N(t) + Bias_B(t) + Bias_K(t)$$

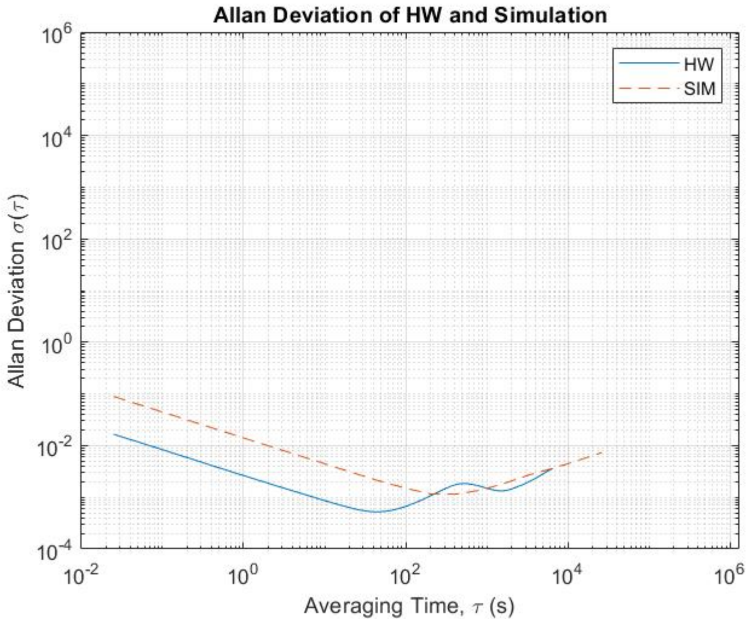
- The model above is used to find out the biasing and utilized in Allan deviation.
- In order to compare with the data sheet We can convert K into m/s/√hr by multiplying K with 60 .
- We can convert B into mg by dividing B with 0.01 .

Linear Acceleration	K (m/s)/√Hz	B mg	Grade
X	0.009876	0.075064	Tactical
Y	0.041112	0.11	Industrial
Z	0.0069162	0.2	Industrial/Tactical

- Comparing it with table 3.1 of [VectorNav library]() It looks like the error terms by sensor grade conveys that this might belong to industry or tactical grade sensor based on rate random walk and accelerometer bias but cannot be certain because this data was collected at 40hz and for 5 hours whereas industrial would have been taken at 800 hz and for long duration than 5 hours.

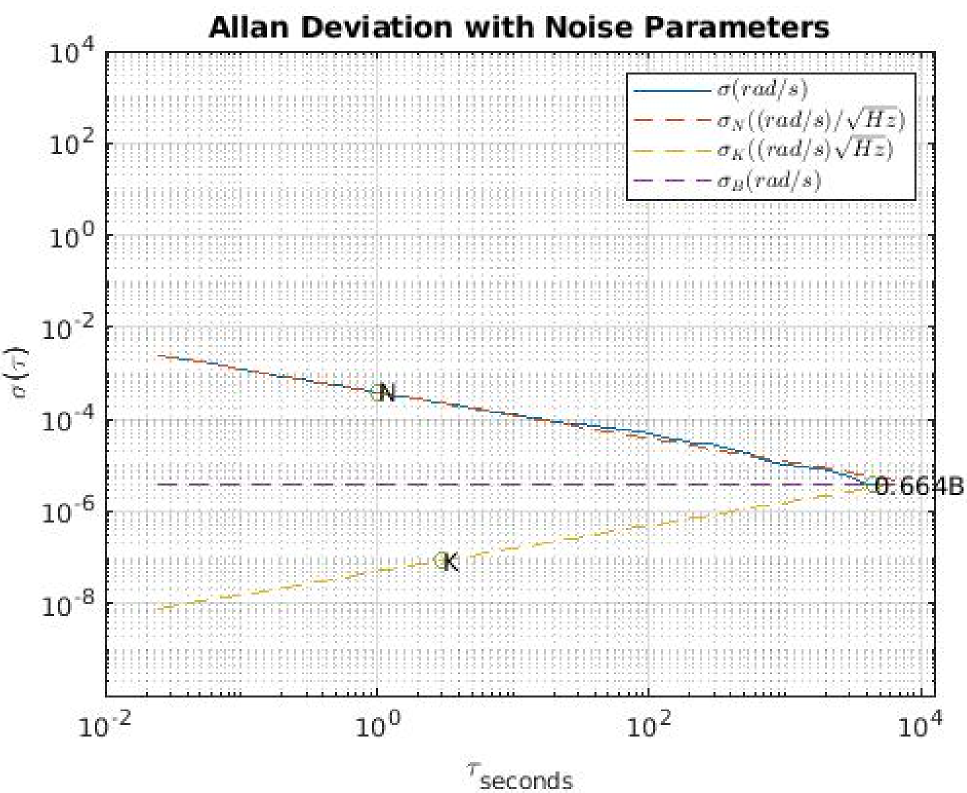
Angular Velocity in X-axis:

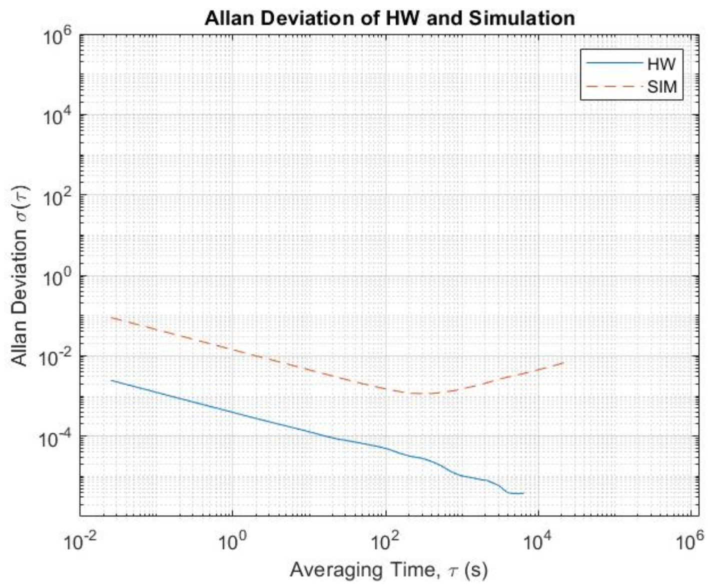




Angle Random Walk Coefficient (N) in (rad/s)/√Hz	Rate Random Walk Coefficient (K) in (rad/s)√Hz	Bias Instability Coefficient (B) in (rad/s)
0.0026	**1.1527e-04**	**0.0020**

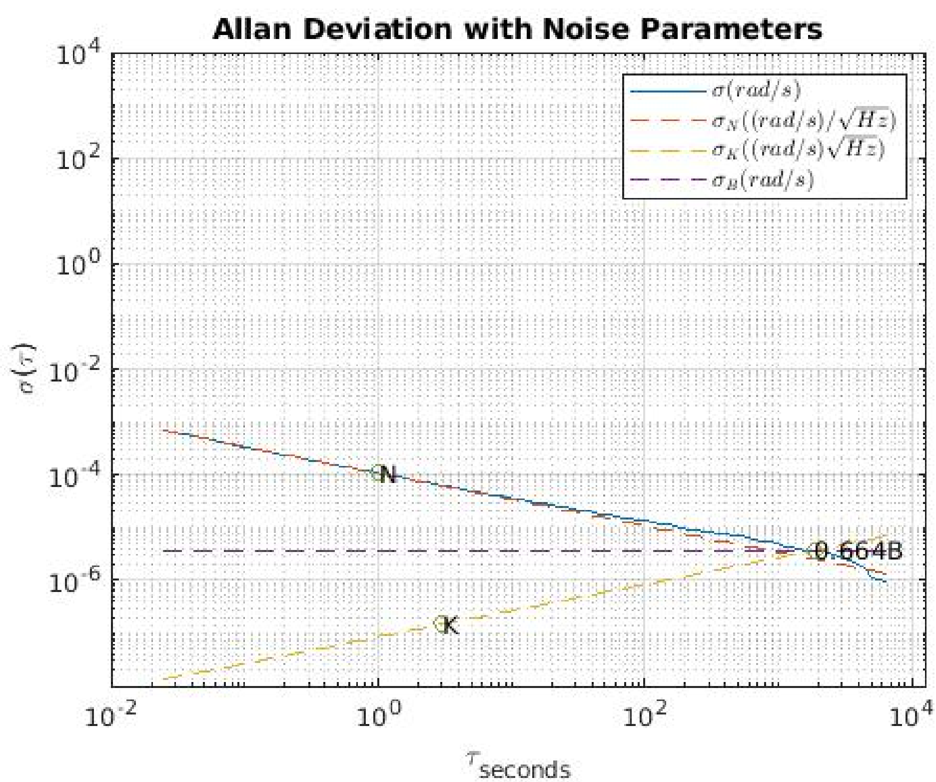
Angular Velocity in Y-axis:

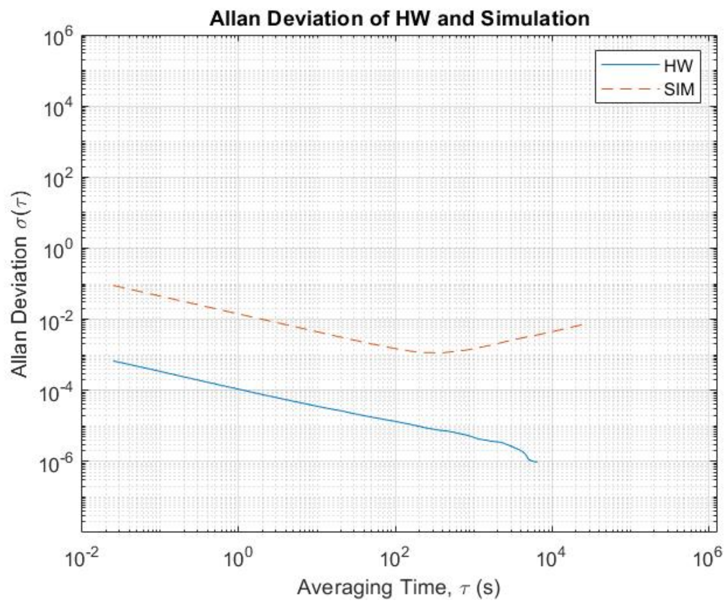




Angle Random Walk Coefficient (N) in (rad/s)/√Hz	Rate Random Walk Coefficient (K) in (rad/s)√Hz	Bias Instability Coefficient (B) in (rad/s)
3.8936e-04	**8.4620e-08**	**5.6886e-06**

Angular Velocity in Z-axis:





Angle Random Walk Coefficient (N) in (rad/s)/√Hz	Rate Random Walk Coefficient (K) in (rad/s)√Hz	Bias Instability Coefficient (B) in (rad/s)
1.0783e-04	**1.4473e-07**	**5.4230e-06**

1. What kind of errors/sources of noise are present?
    - Bias temperature sensitivity, sensor noise, bias instability, scale factors, orthogonal errors, timing errors or sometimes sensor misalignment can be possible errors.
    - Our sensor has Gaussian white noise in it.
2. How do we model them? Where do we measure them? Can you relate your measurements to the datasheet for the VN100?
    - We can model them in the case of an IMU using an Inertial navigation system(INS) which estimates and removes errors from the IMU.
    - Here, we use Alan variance and in this we have angle random walk(N), rate random walk(K) and bias instability(B).For angle random walk we use a slope of -½ and time $\tau = 1$when plotted on a log-plot of $\sigma(\tau)$ *versus* τ. For rate random walk we use a slope of ½ with $\tau = 3$ when plotted on a log plot $\sigma(\tau)$ *versus* τ in which we can read the k value. For bias instability we get a value of ~0.664 by scaling.

$$\Omega(t) = \Omega_{Ideal}(t) + Bias_N(t) + Bias_B(t) + Bias_K(t)$$

- The model above is used to find out the biasing and utilized in Allan deviation.

- Alan deviation of Hw and simulation gives comparison of our data with respect to simulated data with quantization and temperature controlled parameters.
- We can convert N into deg/√hr by multiplying N with $60 * 180/\Pi$
- We can convert B into deg/hr by multiplying B with $180/\Pi$

Angular velocity	N deg/√hr	K (rad/s)√Hz	B deg/hr	Grade
X	8.938	1.1527e-04	412.52	Commercial
Y	1.338	8.4620e-08	1.173	Industrial
Z	0.370	1.4473e-07	1.118	Industrial

Comparing it with table 3.1 of VectorNav library It looks like the error terms by sensor grade conveys that this might belong to industry or commercial grade sensor based on Angle random walk and gyro bias. We cannot confirm 100% because our data was collected at 40hz and for 5 hours whereas the data sheet would have been collected at 800hz or different value and for a longer duration of time.

References:

1. https://hexagondownloads.blob.core.windows.net/public/Novatel/assets/Documents/Bulletins/APN064/APN064.pdf
2. https://www.vectornav.com/docs/default-source/datasheets/vn-100-datasheet-rev2.pdf?sfvrsn=8e35fd12_10
3. https://www.mathworks.com/help/fusion/ug/inertial-sensor-noise-analysis-using-allan-variance.html
4. https://www.vectornav.com/docs/default-source/datasheets/vn-100-datasheet-rev2.pdf?sfvrsn=8e35fd12_10
5. https://www.vectornav.com/resources/inertial-navigation-primer/specifications--and--error-budgets/specs-imuspecs