EECE 5554 LAB 3 Analysis Report

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The following report investigates the noise characteristics of the VectorNav VN-100S IMU. For this purpose, two sets of data were recorded at a sampling frequency of 40Hz:

- Stationary recording for 10 minutes in a basement.
- Stationary recording for 5 hours in a basement.

Brief Recording (10 Minutes – 24000 samples)

Table 1. Measurement statistics (10-minute recording)

Type of Reading	**Angle (rad)**		**Angular Rate ($rad.s^{-1}$)**		**Linear Acceleration ($m.s^{-1}$)**		**Magnetic Field (Gauss)**	
Measure	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Axes Roll (X)	-0.0249	1.1149e-04	-0.4162	0.0095	-0.2030	0.0122	-0.0663	8.2783e-04
Pitch (Y)	-0.0209	9.8660e-05	-0.3836	0.0090	0.2414	0.0116	0.0253	0.0025
Yaw (Z)	-0.0575	5.5169e-04	0.5719	0.0060	-9.6765	0.0168	0.1628	0.0028

Table 1. summarizes the mean and standard deviation values for the sensor readouts on all three axes. The following time-series plots (Figs. 1 through 4) show the incoming data stream for all three axes, for absolute orientation, angular rates, linear acceleration and magnetometer outputs. The Yaw axis measurements are particularly noisy and could be attributed to vibrations caused by walking to and from the device on wooden flooring.

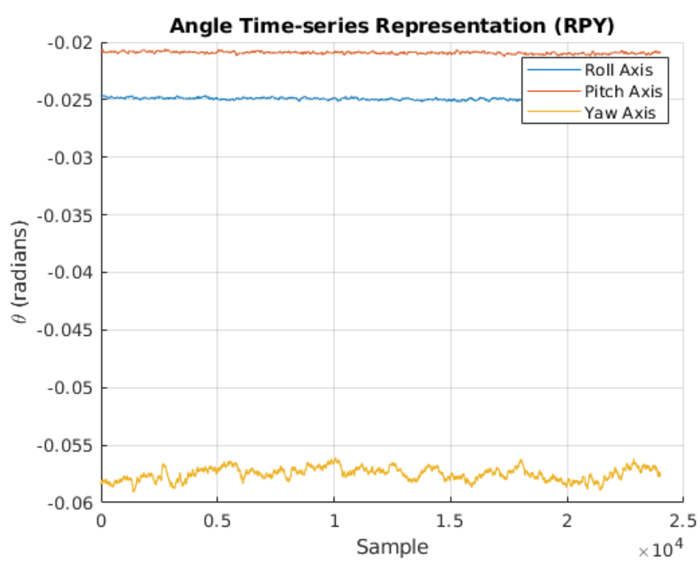

Figure 1. Absolute orientation time-series (10-minute recording)

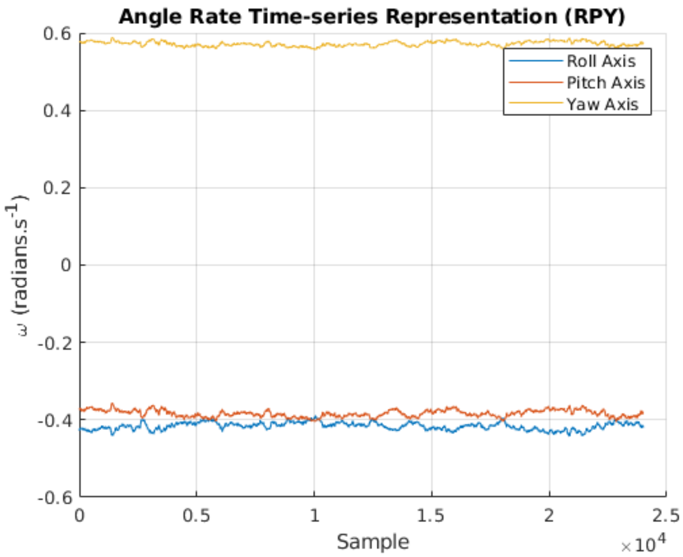

Figure 2. Angular rate time-series (10-minute recording)

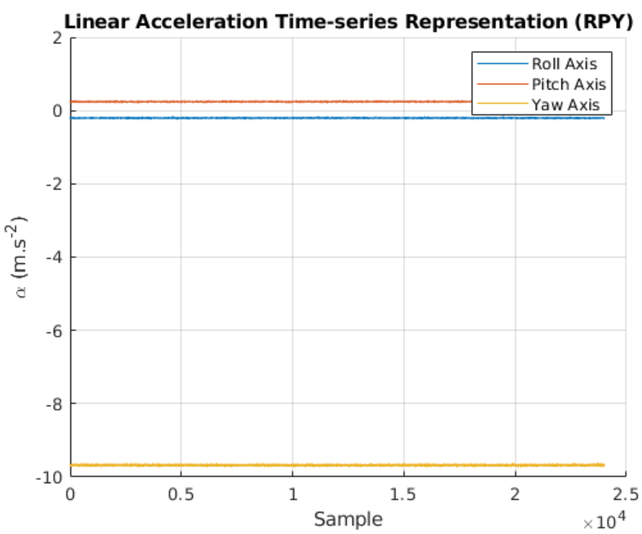

Figure 3. Linear acceleration time-series (10-minute recording)

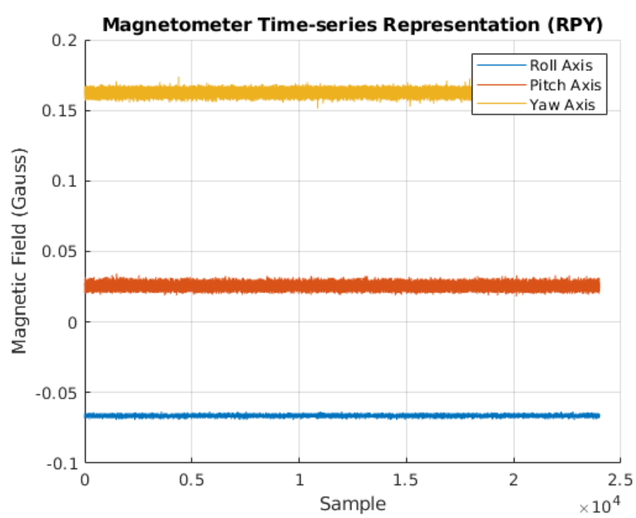

Figure 4. Magnetometer time-series measurements (10-minute recording)

Here we see all of the output values in each of these graphs indicating a high frequency noisy profile centered around a central value with near zero deviations. This profile is further confirmed through the histogram plots of all these time series datasets.

Figures 5 through 8 show the distribution of sensor readouts over the 10-minute interval. It is observed that for each axis, the distribution vaguely resembles a unimodal bell curve and hence are part of a unimodal Gaussian distribution over a short period of time.

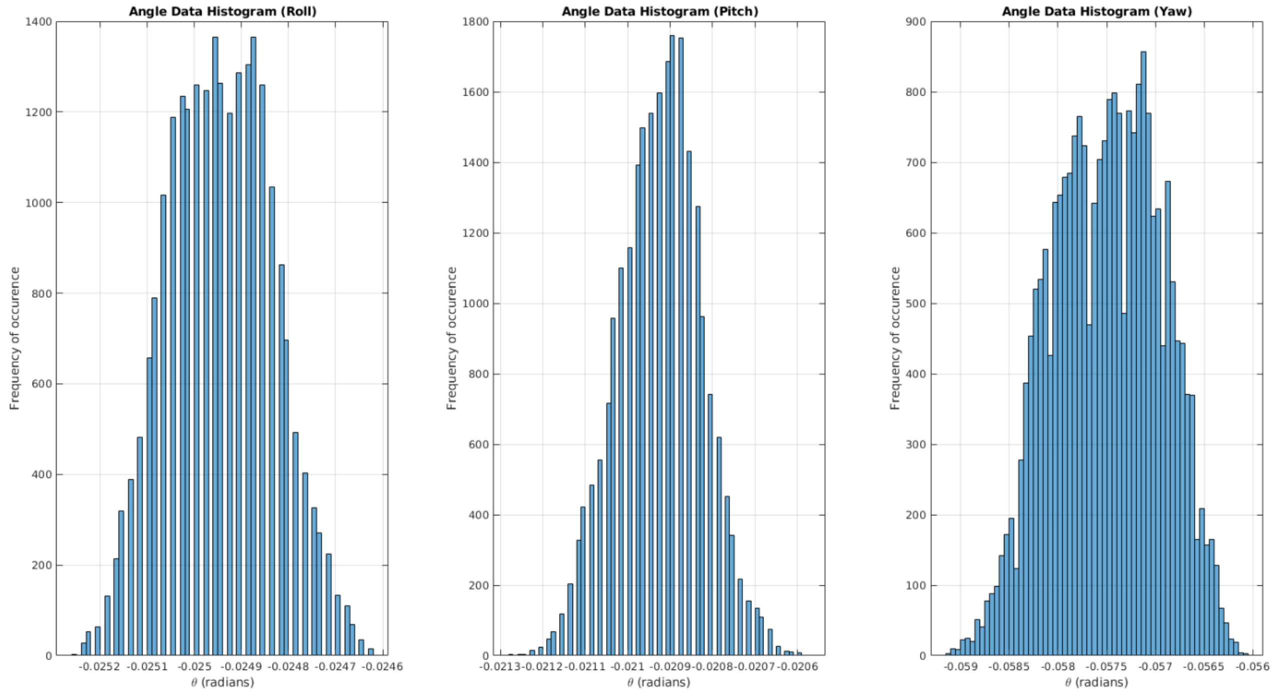

Figure 5. Orientation measurement histogram (10-minute recording)

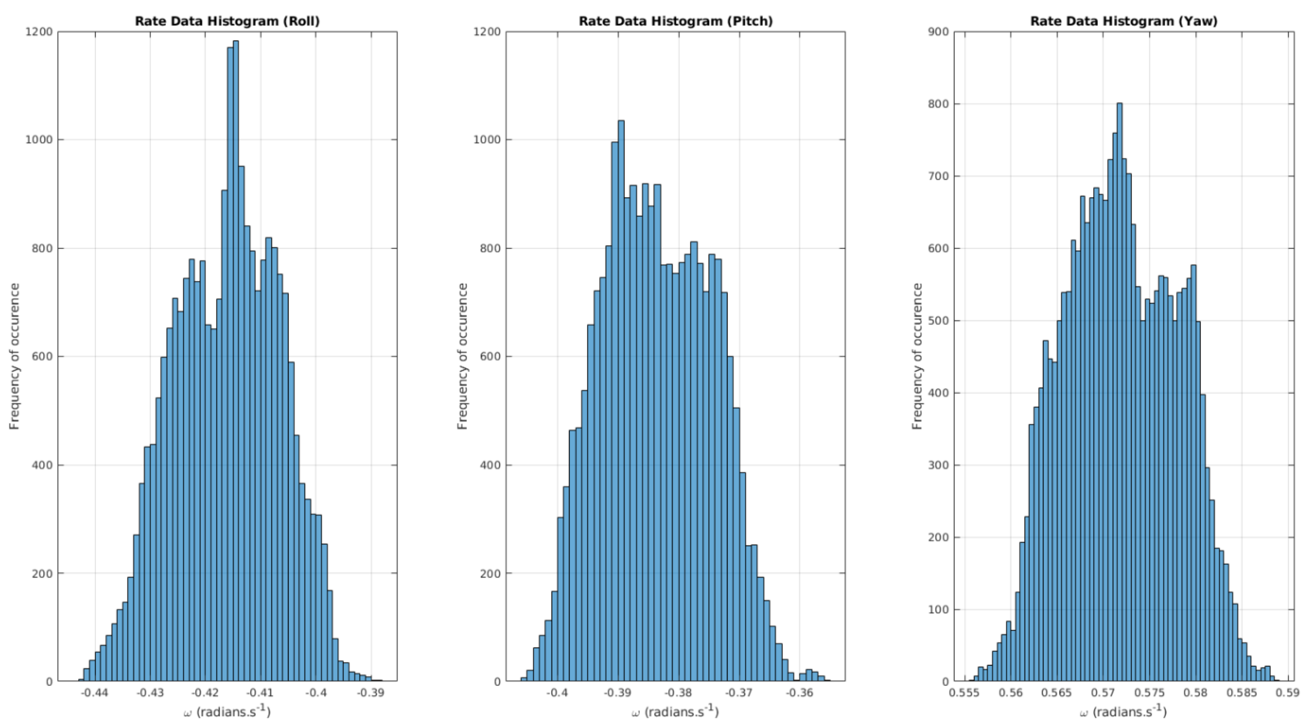

Figure 6. Angular rate measurement histogram (10-minute recording)

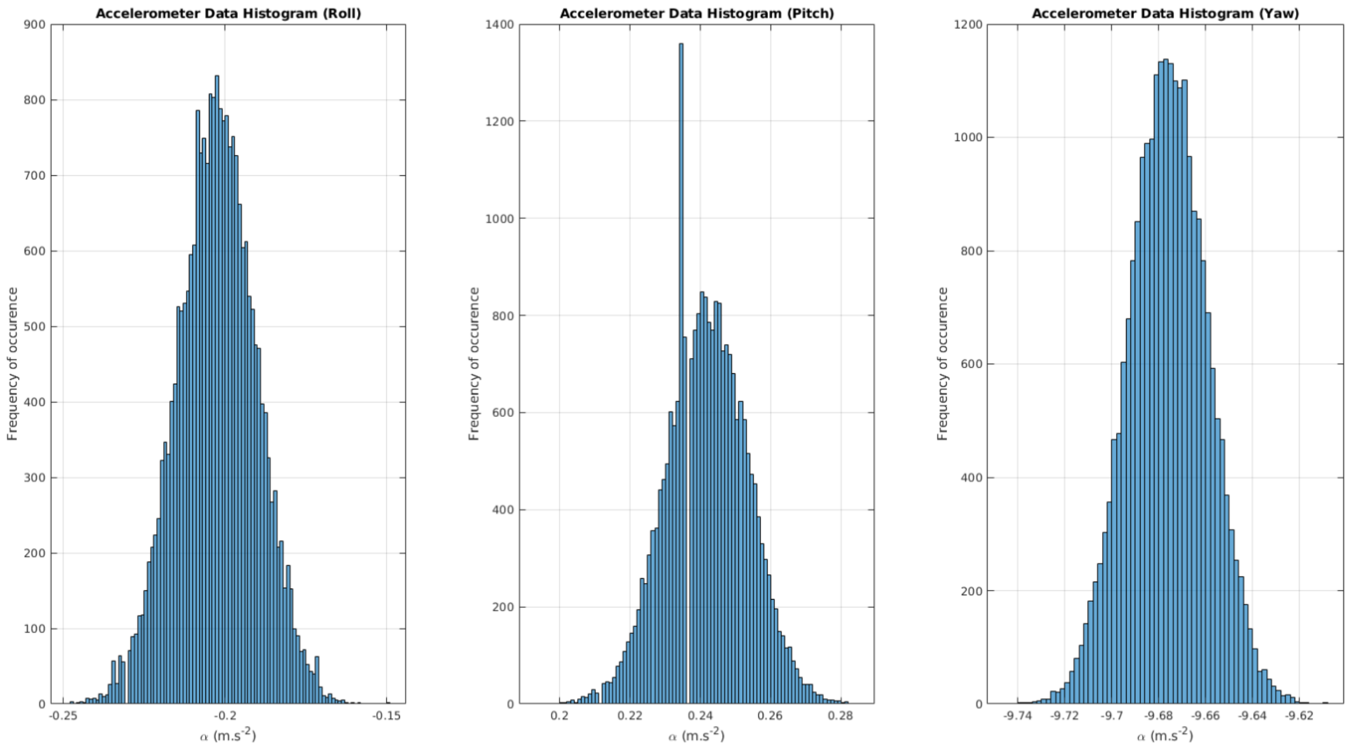

Figure 7. Linear Acceleration measurement histogram (10-minute recording)

Extended static measurements (5 Hour recording)

Allan Deviation (Gyro Output)

This dataset is also recorded in a quiet basement for 5 hours at 40Hz sampling rate. Care is taken not to disturb the setup through acts which may induce base vibrations (like walking, moving furniture etc.). Two sets of Allan deviation experiments are performed, one for the gyro output, and the other is the accelerometer output.

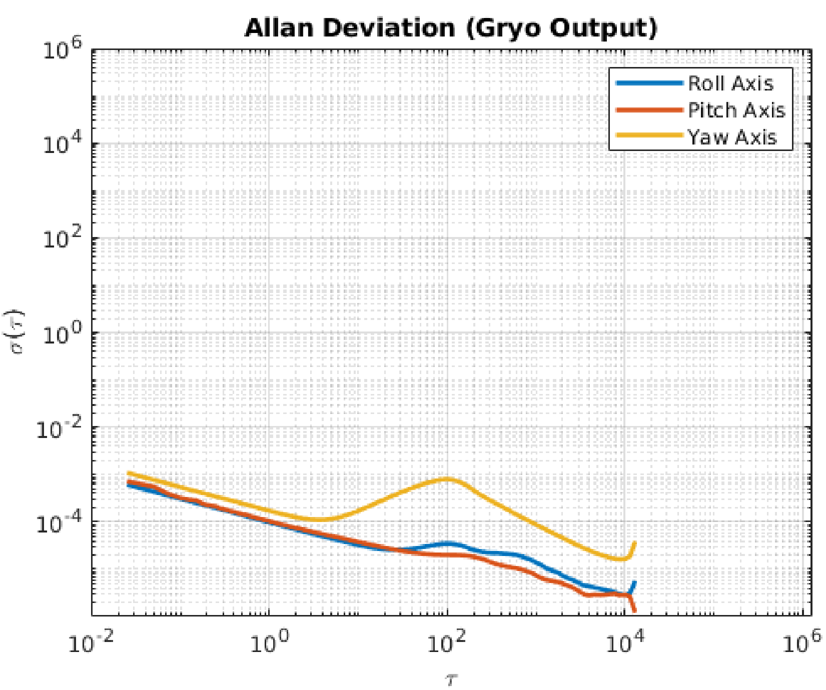

Figure 8. Allan deviation plot for gyro measurements (5-hour recording)

Figure 8 shows the Allan deviation plots for the 5-hour period with respect to gyro measurements of the IMU. The noise coefficients (Angular walk, Angular rate walk, and bias instability) are obtained from these plots. Table 2 summarizes these noise coefficients obtained from the Allan deviation analysis. Figures 9 through 14 show the noise characteristics for the roll pitch and yaw axes.

Table 2. Allan deviation analysis noise coefficients for Gyro output (5-hour recording)

Axis	**Roll Axis**	**Pitch Axis**	**Yaw Axis**
angle random walk coefficient (N)	9.7428E-05	1.0432E-04	1.7083E-04
Angle Rate Random Walk Coefficients (K)	7.0680E-06	7.6911E-08	8.7317E-05
Bias Instability Coefficients (B)	3.3280E-05	3.0052E-05	1.6626E-04

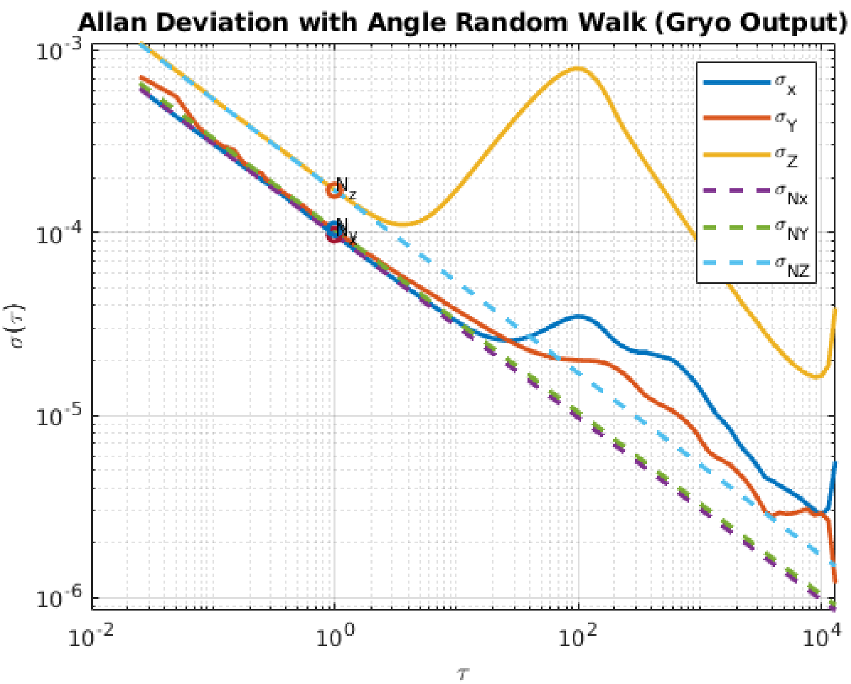

Figure 9. Allan deviation with angle random walk plots for gyro measurements (5-hour recording)

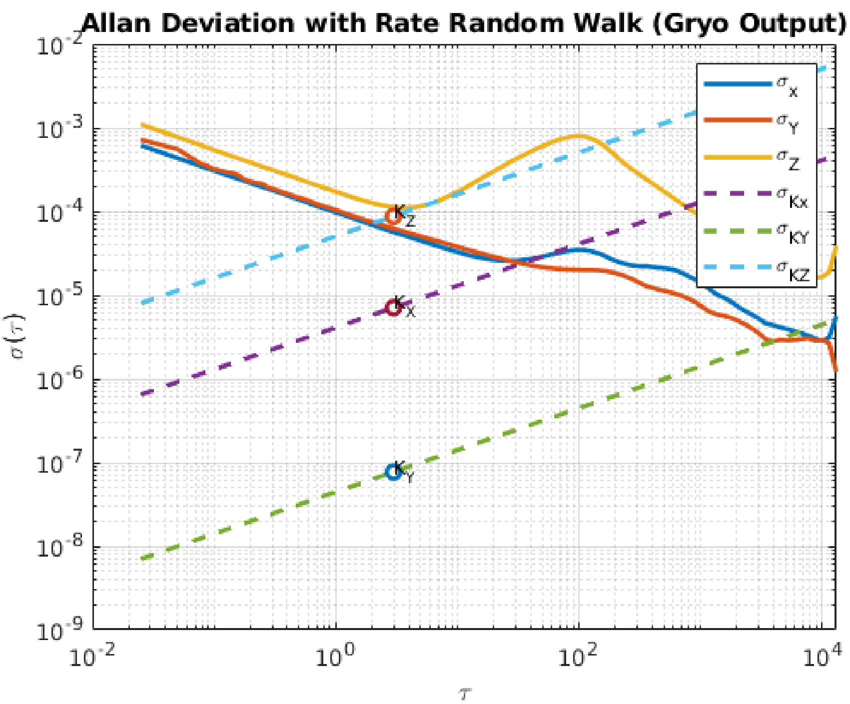

Figure 10. Allan deviation with angular rate random walk plots for gyro measurements (5-hour recording)

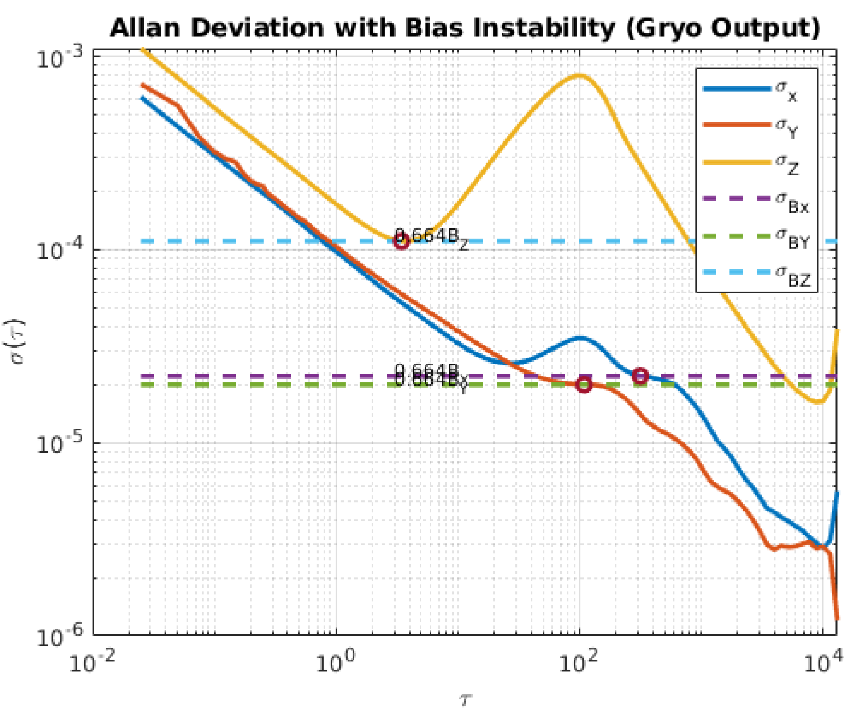

Figure 11. Allan deviation with bias instability plots for gyro measurements (5-hour recording)

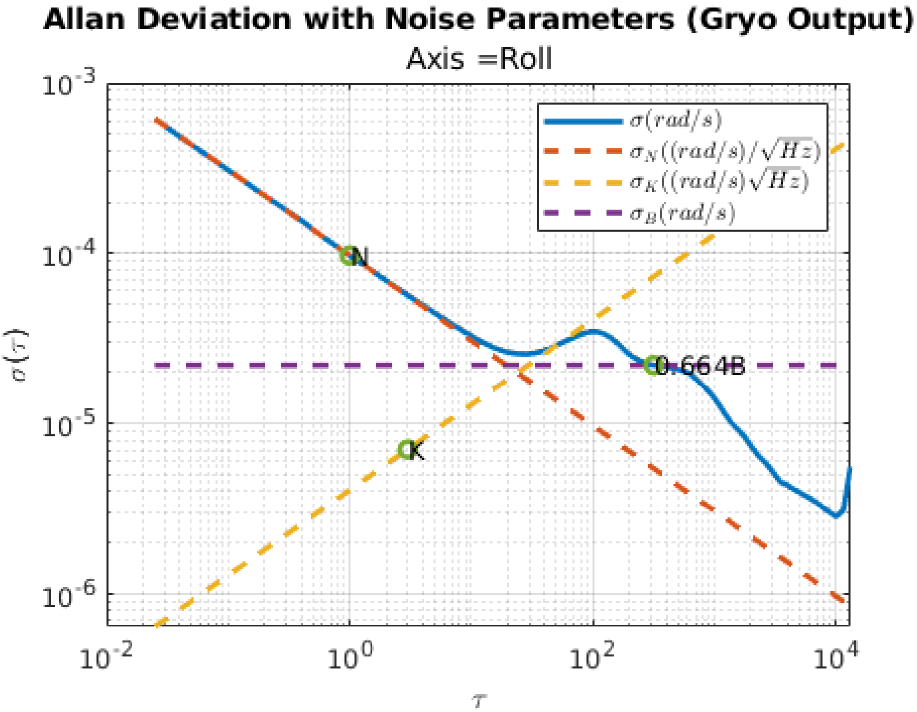

Figure 12. Roll Axis Allan deviation with noise coefficient plots for gyro measurements (5-hour recording)

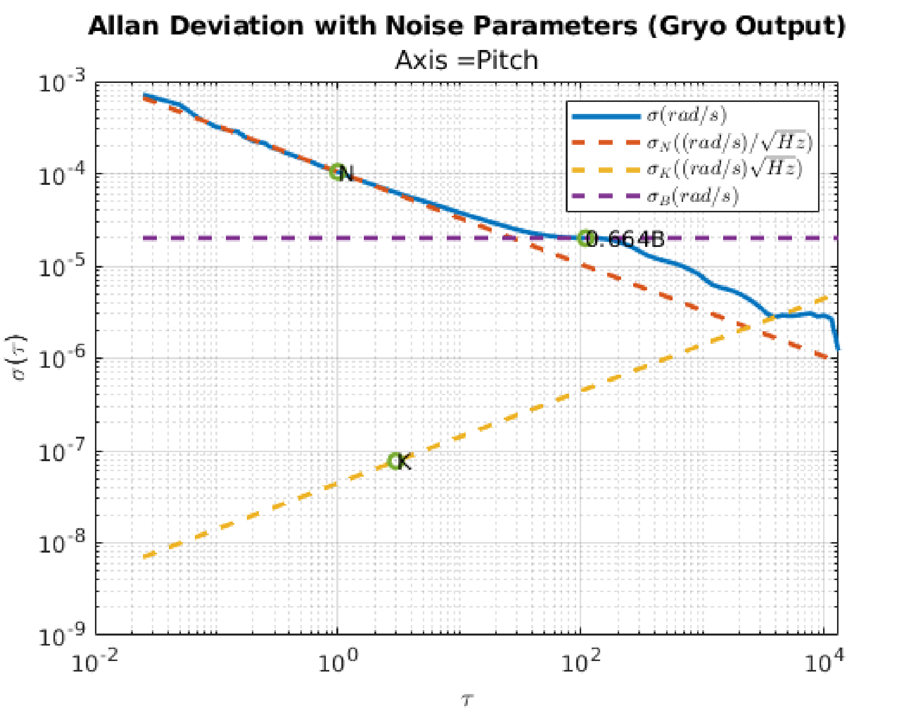

Figure 13. Pitch Axis Allan deviation with noise coefficient plots for gyro measurements (5-hour recording)

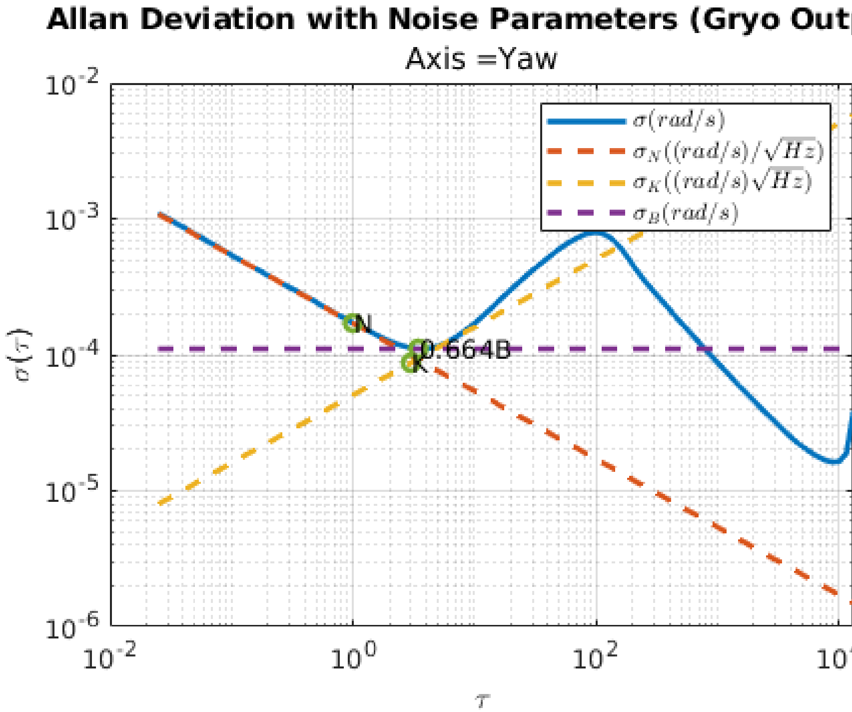

Figure 14. Yaw Axis Allan deviation with noise coefficient plots for gyro measurements (5-hour recording)

Allan Deviation (Accelerometer Output)

Figure 15 shows the Allan deviation plots for the 5-hour period with respect to linear accelerometer measurements of the IMU. The noise coefficients (Velocity walk, Velocity rate walk, and bias instability) are obtained from these plots. Figures 16 through 21 show the noise characteristics for the roll pitch and yaw axes.

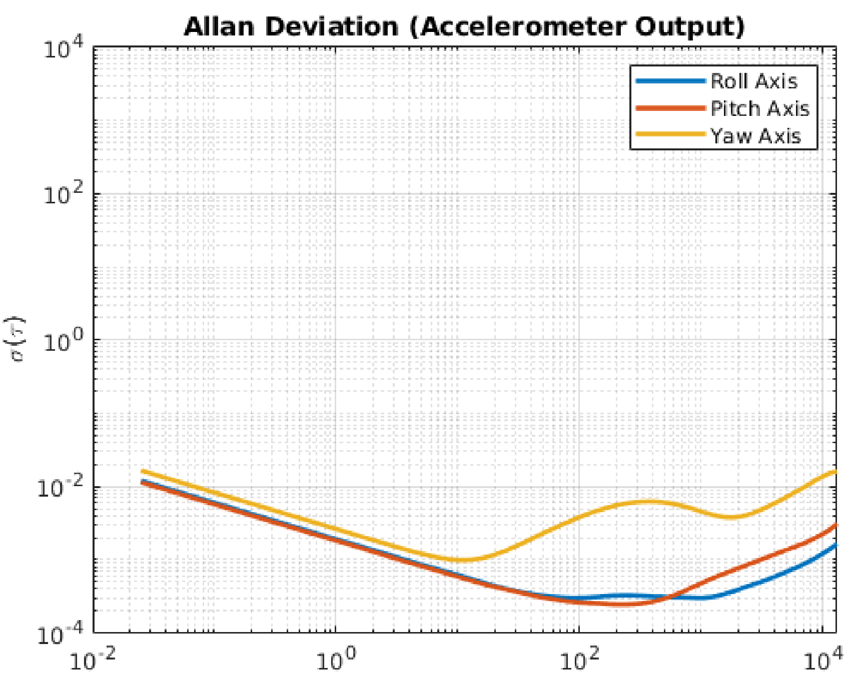

Figure 15. Allan deviation plot for accelerometer measurements (5-hour recording)

Table 3 summarizes these noise coefficients obtained from the Allan deviation analysis.

Table 3. Allan deviation analysis noise coefficients for Gyro output (5-hour recording)

Axis	Roll Axis	Pitch Axis	Yaw Axis
angle random walk coefficient (N)	1.9295E-03	1.8074E-03	2.6319E-03
Angle Rate Random Walk Coefficients (K)	1.4962E-05	2.2850E-05	6.8461E-04
Bias Instability Coefficients (B)	4.5421E-04	3.6812E-04	1.4931E-03

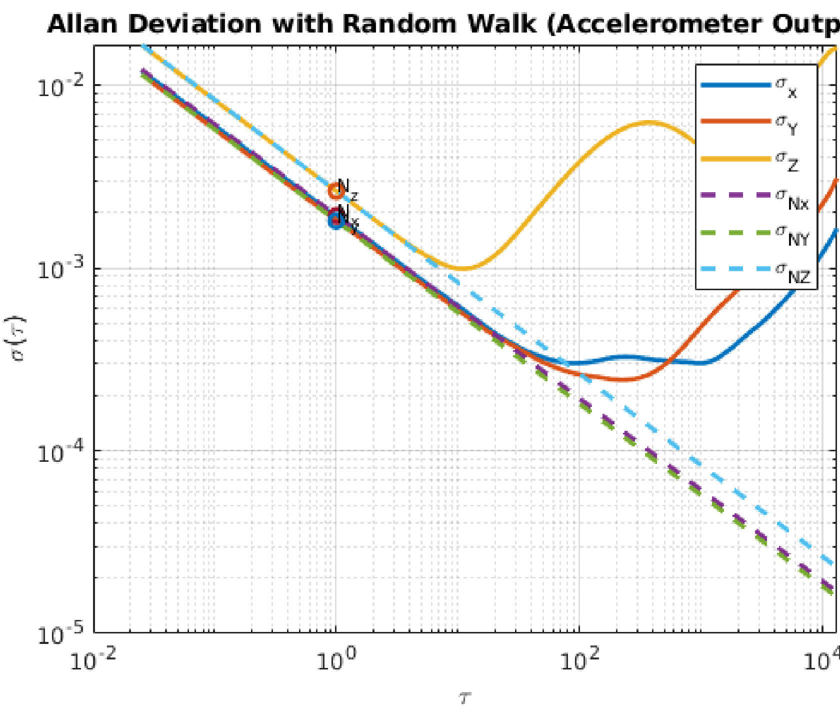

Figure 16. Allan deviation with velocity random walk plots for accelerometer measurements (5-hour recording)

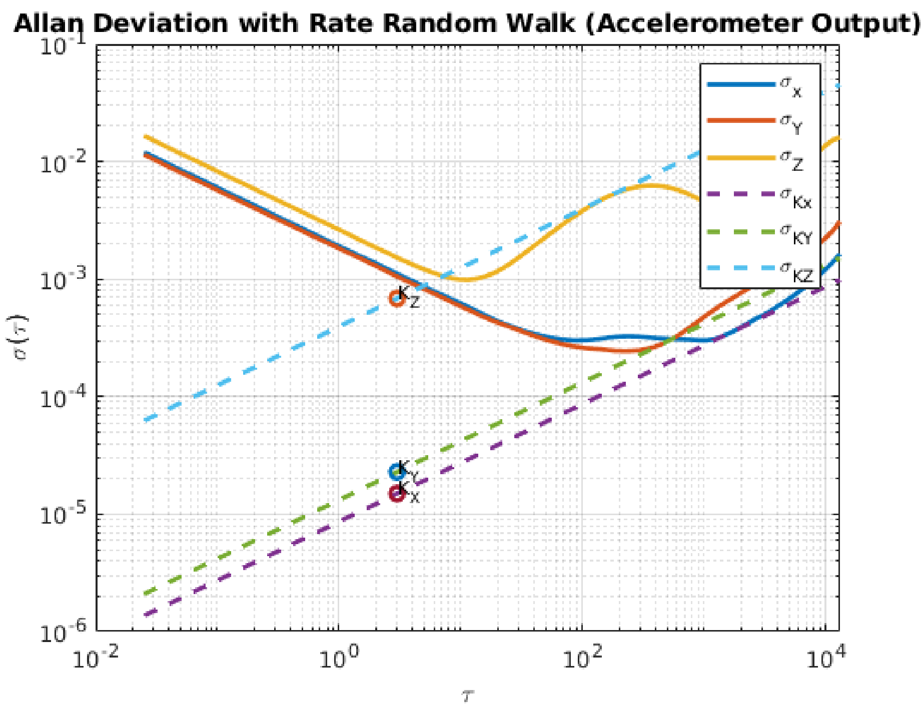

Figure 17. Allan deviation with velocity rate random walk plots for accelerometer measurements (5-hour recording)

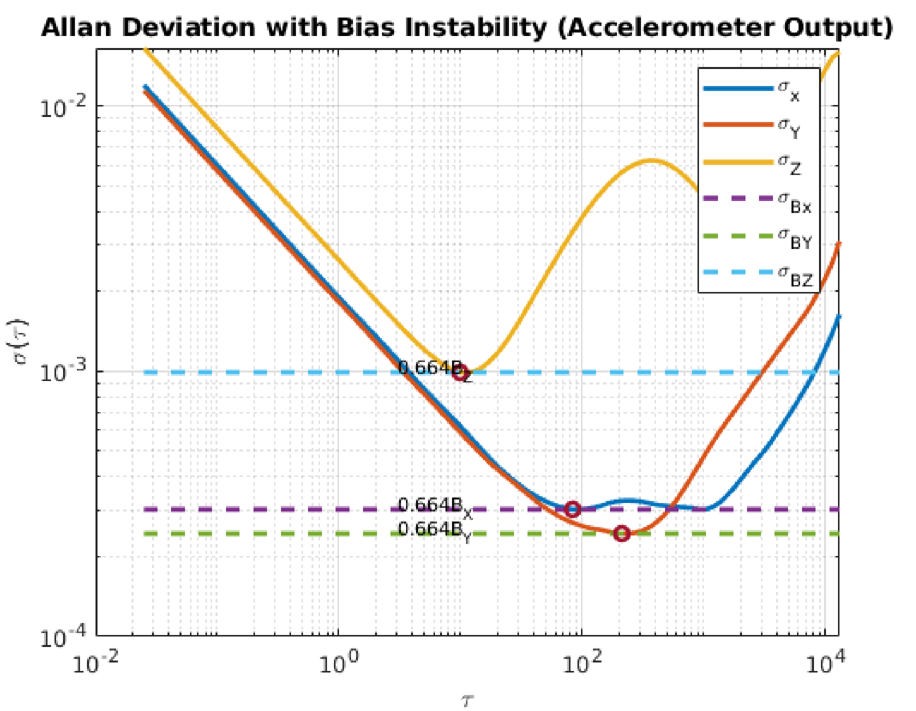

Figure 18. Allan deviation with bias instability plots for accelerometer measurements (5-hour recording)

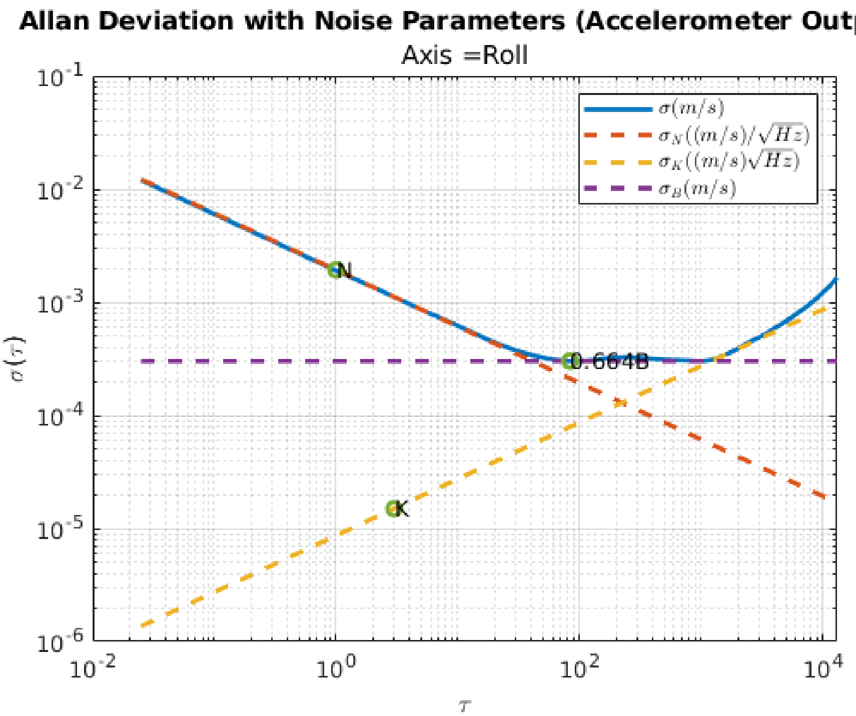

Figure 19. Roll Axis Allan deviation with noise coefficient plots for accelerometer measurements (5-hour recording)

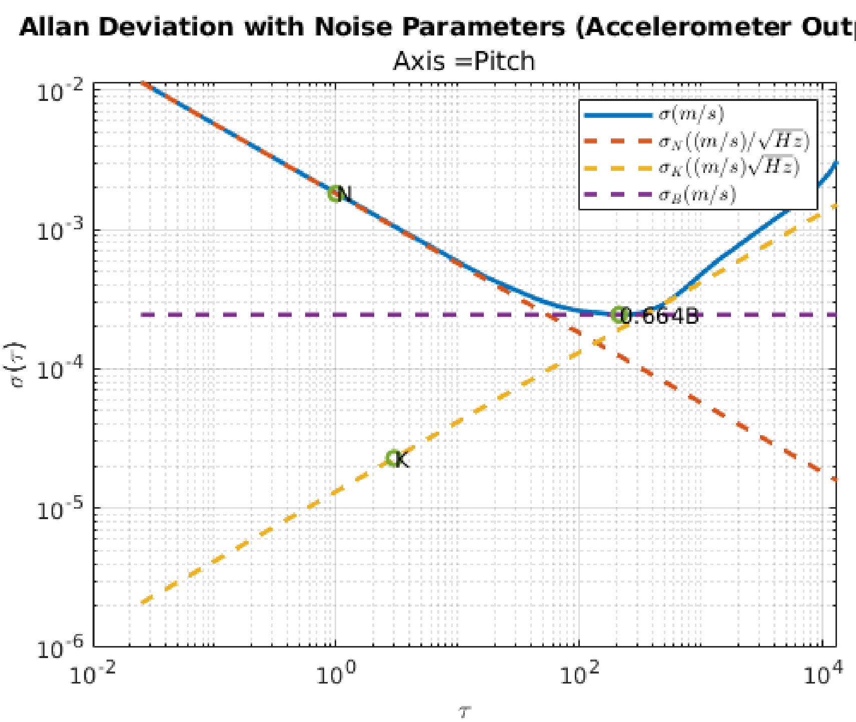

Figure 20. Pitch Axis Allan deviation with noise coefficient plots for accelerometer measurements (5-hour recording)

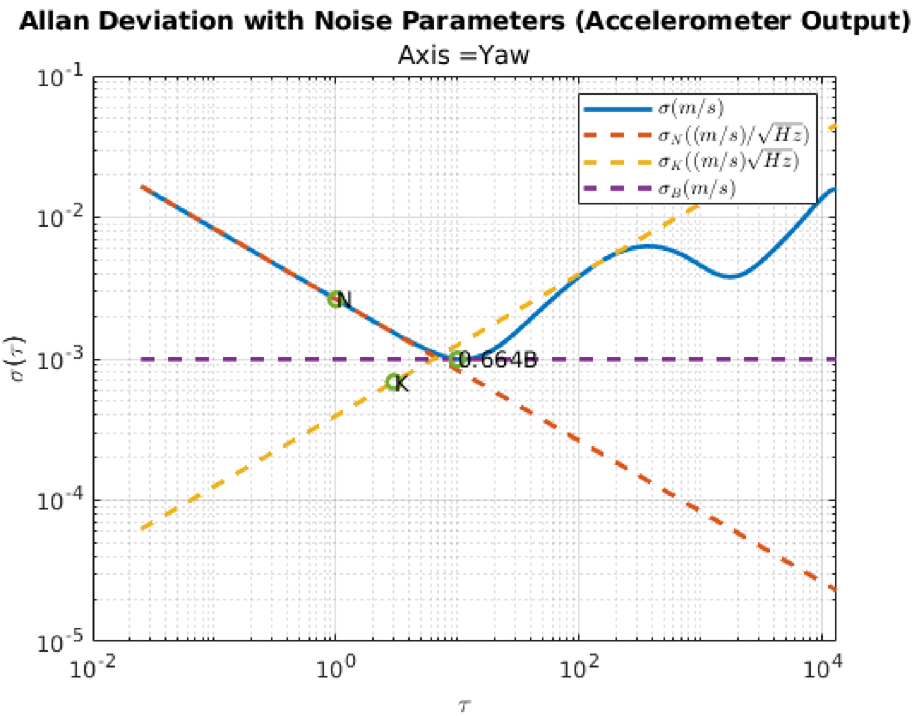

Figure 21. Yaw Axis Allan deviation with noise coefficient plots for accelerometer measurements (5-hour recording)

Concluding Remarks

The types of noise which could affect the sensor output can thus be characterized as quantization noise, random-walk noise, correlated noise, bias instability noise, rate random walk noise. We already have investigated random-walk noise, bias instability noise, rate random walk noise through the Allan Deviation plots. The quantization noise can be eliminated through faster sampling within hardware capabilities, and the correlation noise could be analyzed after mathematical modeling of such correlation along the different axes

From the look at the Allan deviation plot in Figures 8 and 15, it can be observed that an increase in the gyro output ensemble averaging period does not adversely affect the deviation for all three axes, and it follows a smooth declining profile, while the accelerometer Allan deviations are very largely swayed by the ensemble average period.

For the gyro output, this indicates a low impact high frequency noise, with some influence of mid-tier frequencies being dominant (as can be seen in the spike at the $\tau = 10^2$ neighborhood). Further, with an increase in the integration period, the deviation again starts to dip.

For the accelerometer output, the curves follow a typical IMU Allan deviation profile with a direct relation between the integration period and deviation values up until mid-tier frequencies where a higher averaging bin size causes a decrement in the deviation. In this case the accelerometer is impacted by both low and high frequency noises while the mid-tier frequency has a considerably lower impact

If a longer recording is made, a better estimate of the noise characteristics could possibly be obtained for the gyro measurements. The mid-tier noise sources could be attributed to passing vehicular engines outputting rotational speeds in the neighborhood of 100 rpm and shaking the local region at a similar frequency. Random temperature fluctuations could also be a source of the low frequency drift that is observed as the temperatures changed drastically inside the basement in this 5-hour period, which could impact the IMU piezo crystal input-output profile.

It can be observed from the datasheet correlated to the 10 minute recording that the recorded standard deviation values lie within the maximum and minumum error estimates given by the datasheet as shown below and in Table1

```
------------------------------  Imu Measurement  ------------------------------
Current Sensor Measurements:
  Mag X    : -000.866 [Gauss]
  Mag Y    : +001.016 [Gauss]
  Mag Z    : +002.365 [Gauss]
  Acel X   : +004.178 [m/s]
  Acel Y   : -000.637 [m/s]
  Acel Z   : -008.927 [m/s]
  Gyro X   : -000.417 [deg/s]
  Gyro Y   : +000.668 [deg/s]
  Gyro Z   : -001.102 [deg/s]
  Temp     : +027.94 [C]
  Temp Rate: +0.04 [C/min]
  Pres     : +101.36 [kPa]

Current Sensor Noise: (measured over last 5 seconds)
  Sensor    Units     X-Axis    Y-Axis    Z-Axis
  Mag       mGauss    +03.228   +02.934   +04.159
  Accel     mg        +01.854   +02.115   +02.872
  Gyro      deg/s     +0.0631   +0.0544   +0.0580
  Temp      C         +0.0026
  Pres      Pa        +007.36

Minimum Sensor Noise: (since startup)
  Sensor    Units     X-Axis    Y-Axis    Z-Axis
  Mag       mGauss    +02.877   +02.659   +03.673
  Accel     mg        +01.785   +01.966   +02.599
  Gyro      deg/s     +0.0587   +0.0487   +0.0537
  Temp      C         +0.0011
  Pres      Pa        +006.13

Minimum Sensor Measurement: (since startup)
  Sensor    Units     X-Axis    Y-Axis    Z-Axis
  Mag       Gauss     -00.236   +00.244   +00.577
  Accel     g         +00.414   -00.077   -00.949
  Gyro      deg/s     -002.92   -005.33   -002.03
  Temp      C         +27.83
  Pres      kPa       +101.30

Maximum Sensor Measurement: (since startup)
  Sensor    Units     X-Axis    Y-Axis    Z-Axis
  Mag       Gauss     +00.000   +00.271   +00.611
  Accel     g         +00.439   +00.000   +00.000
  Gyro      deg/s     +002.02   +006.44   +000.00
  Temp      C         +28.01
  Pres      kPa       +101.38

Sensor Saturation Events: (since startup)
  Sensor    X-Axis    Y-Axis    Z-Axis
  Mag       0         0         0
  Accel     0         0         0
  Gyro      0         0         0
  Pressure  0
  Temp      0
--------------------------------------------------------------------------------
```