LAB #3 Allan Variance

What is IMU?

An Inertial Measurement Unit (IMU) is a sensor device that combines accelerometers and gyroscopes to measure and record an object's acceleration and rotation rate in three-dimensional space. This compact and versatile technology provides crucial information about an object's movement and orientation. It plays an important role in the navigation of autonomous vehicles and the stabilization of aircraft and drones, by keeping a closed loop information of the movement and orientation of the system.

Accelerometer:

Accelerometers measure a changing acceleration on the sensor. They can be used to measure the tilt of the sensor with respect to the Earth, or the force of a hit. With the help of these values we determine the roll and pitch of the sensor.

Gyroscope:

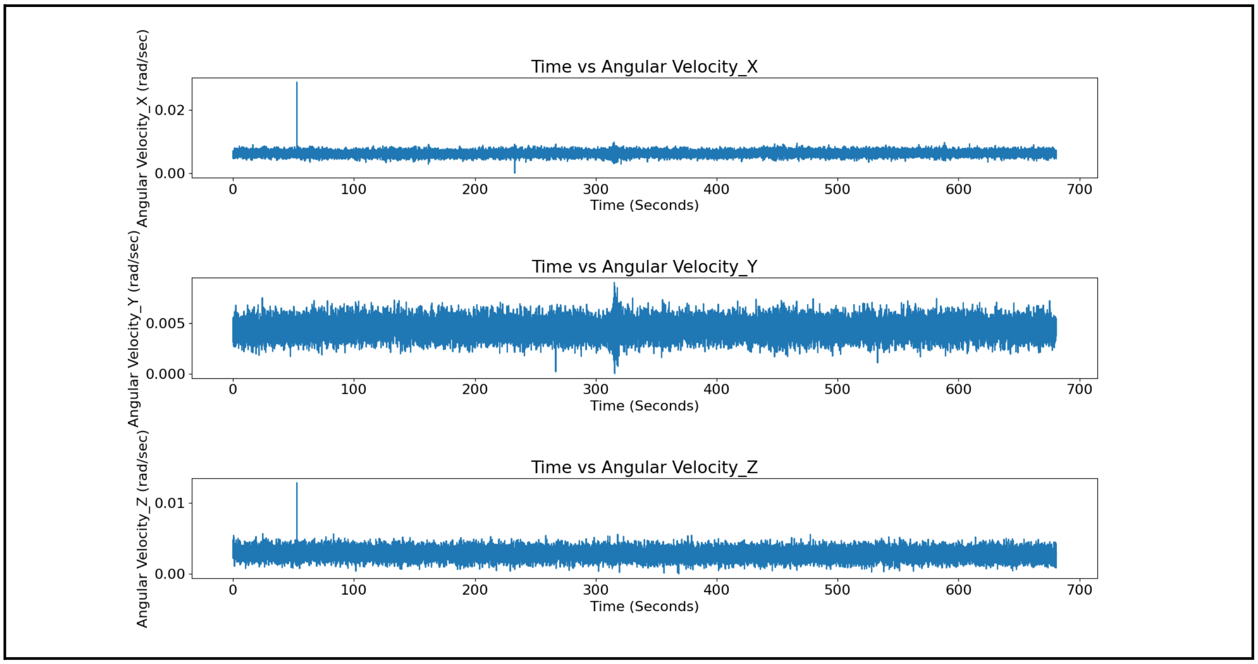
Gyroscopes are inertial sensors that measure an object's angular rate with respect to an inertial reference frame. They can be used to measure rotation.

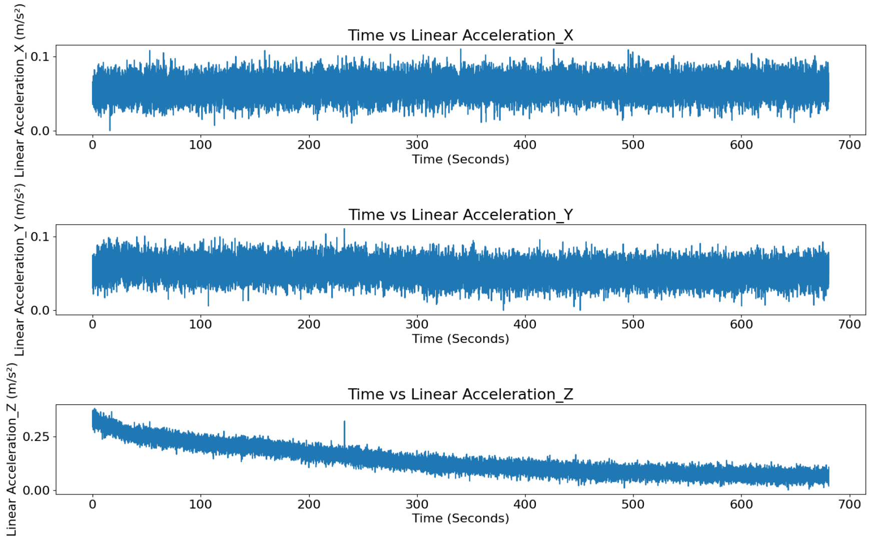
Magnetometer:

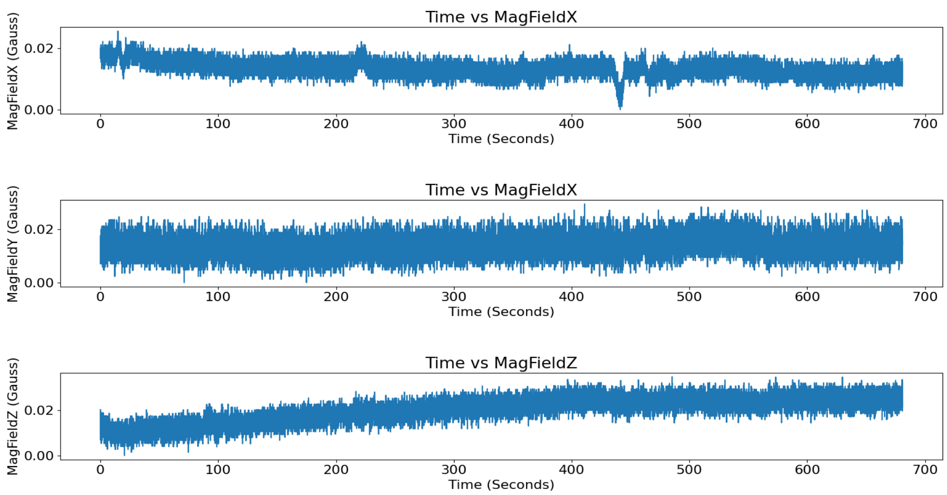
Magnetometers measure the magnetic force on a sensor. These are usually used to measure the Earth's gravitational field in order to determine compass heading.

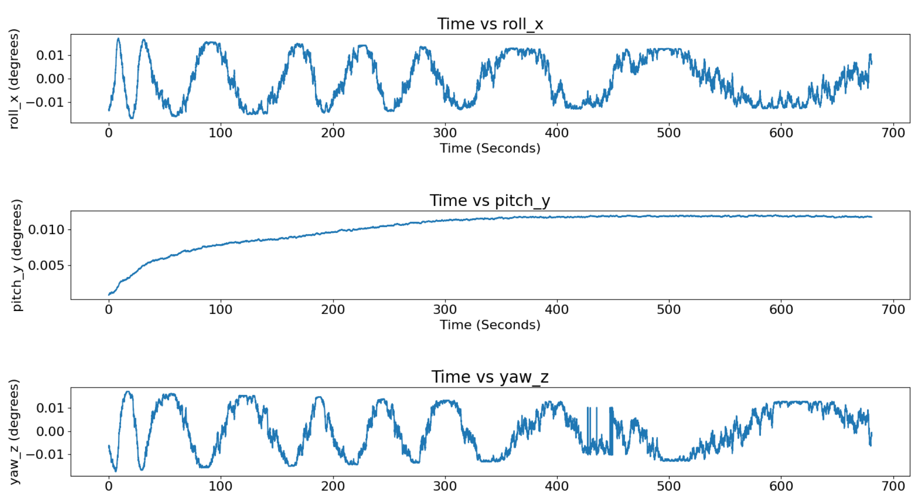
Stationary Data Analysis:

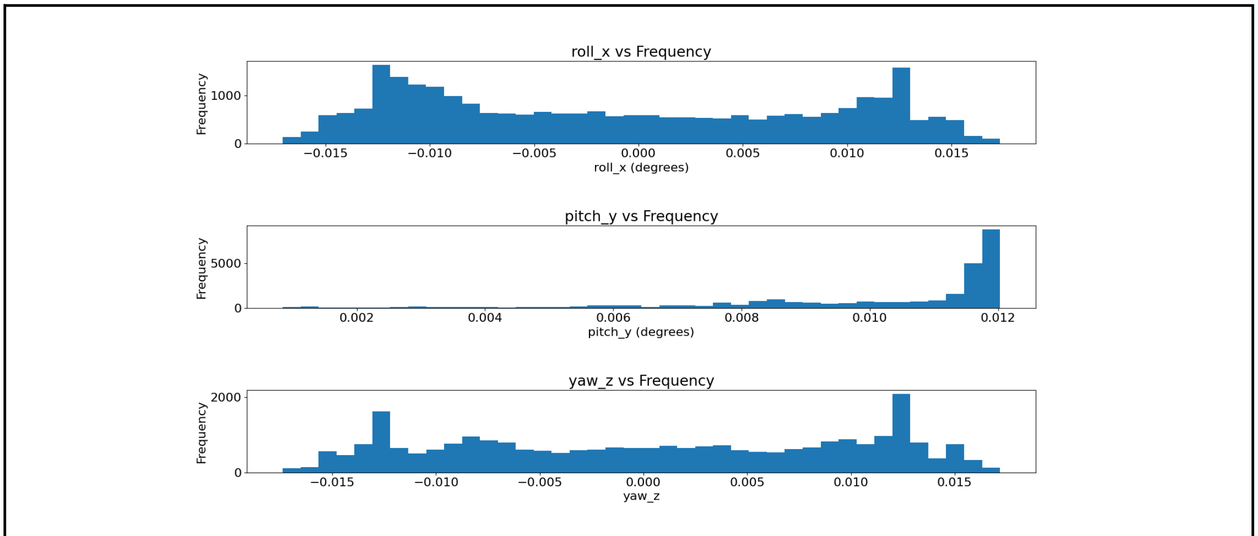
To observe the error in the following IMU sensor, data was collected in a stationary location in the basement for 15 minutes and statistical calculations were done to obtain the standard deviation and mean information for the IMU data. The following are the plots.

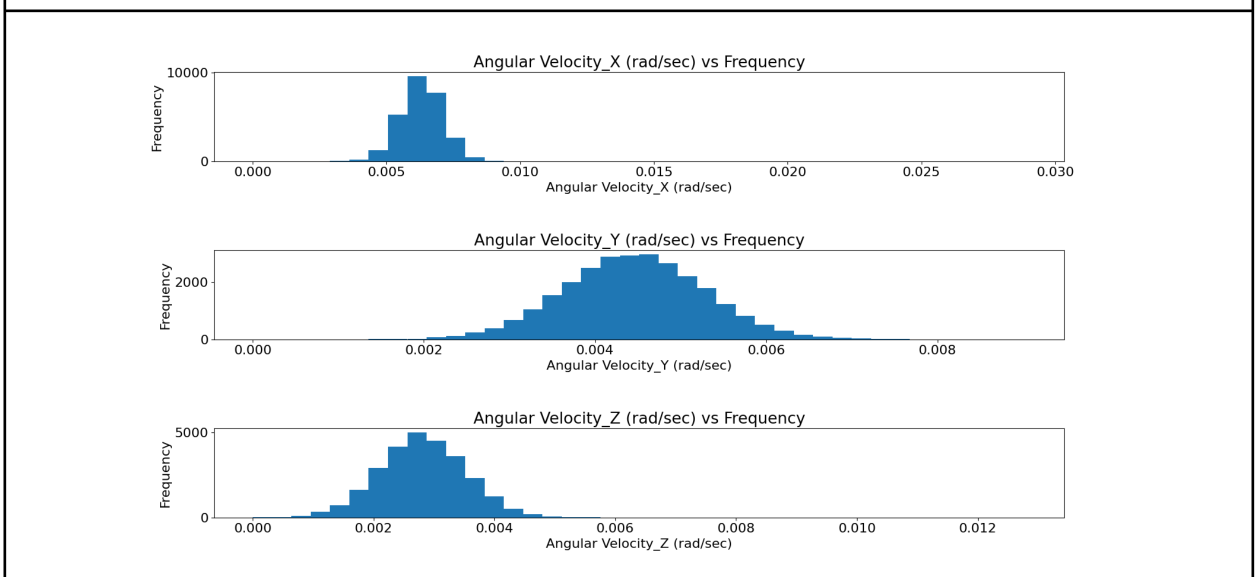


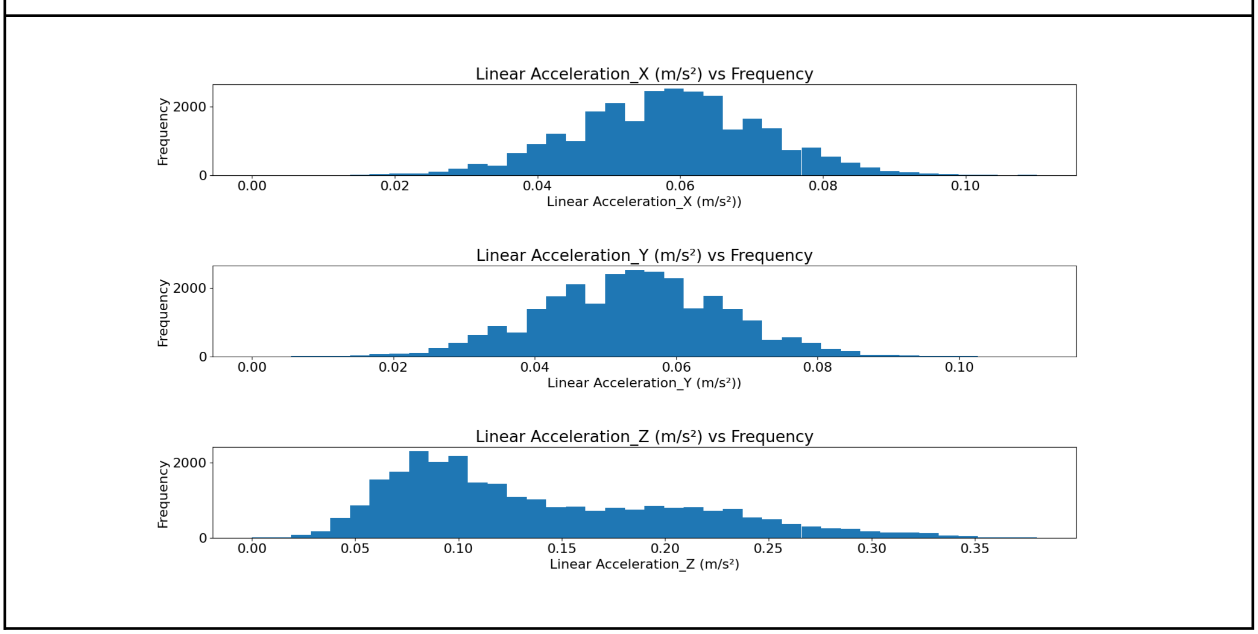

Time vs Linear Acceleration_X
Linear Acceleration_X (m/s²)
Time (Seconds)
Time vs Linear Acceleration_Y
Linear Acceleration_Y (m/s²)
Time (Seconds)
Time vs Linear Acceleration_Z
Linear Acceleration_Z (m/s²)
Time (Seconds)

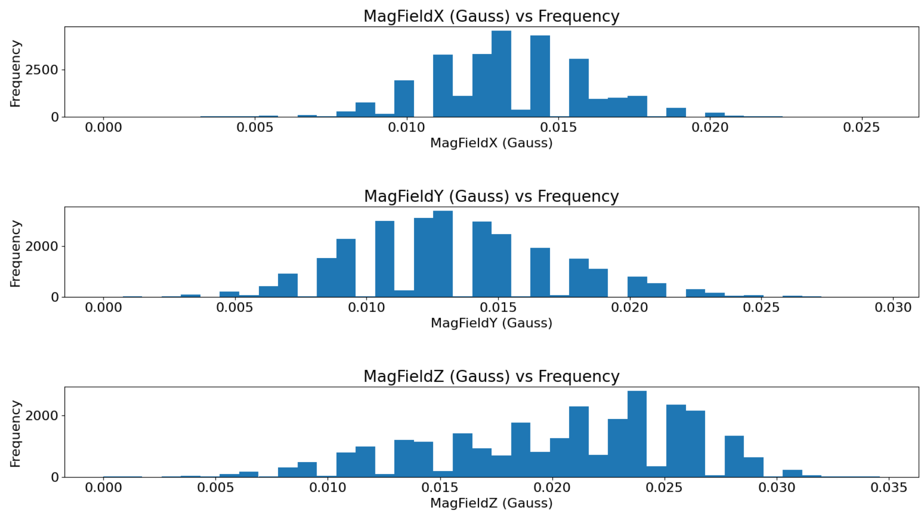

Time vs MagFieldX
MagFieldX (Gauss)
Time (Seconds)
Time vs MagFieldX
MagFieldY (Gauss)
Time (Seconds)
Time vs MagFieldZ
MagFieldZ (Gauss)
Time (Seconds)


Time vs roll_x
roll_x (degrees)
Time (Seconds)
Time vs pitch_y
pitch_y (degrees)
Time (Seconds)
Time vs yaw_z
yaw_z (degrees)
Time (Seconds)


roll_x vs Frequency
Frequency
roll_x (degrees)
pitch_y vs Frequency
Frequency
pitch_y (degrees)
yaw_z vs Frequency
Frequency
yaw_z


Angular Velocity_X (rad/sec) vs Frequency
Frequency
Angular Velocity_X (rad/sec)
Angular Velocity_Y (rad/sec) vs Frequency
Frequency
Angular Velocity_Y (rad/sec)
Angular Velocity_Z (rad/sec) vs Frequency
Frequency
Angular Velocity_Z (rad/sec)


Linear Acceleration_X (m/s²) vs Frequency
Frequency
Linear Acceleration_X (m/s²))
Linear Acceleration_Y (m/s²) vs Frequency
Frequency
Linear Acceleration_Y (m/s²))
Linear Acceleration_Z (m/s²) vs Frequency
Frequency
Linear Acceleration_Z (m/s²)



The following result were obtained:

Mean & Standard Deviation of RPY:

mean = -0.0008853939682320681
mean = 0.010195494333991733
mean = 0.0005178926229546518
standard deviation = 0.009617983460700167
standard deviation = 0.002350544832427937
standard deviation = 0.009584340922419401

Mean & Standard Deviation of Angular Velocity:

mean = 0.0063060477623995016
standard deviation = 0.0007941137511626623
mean = 0.004452680017621792
standard deviation = 0.0008254809751055224
mean = 0.0028090098755460917
standard deviation = 0.0007103652458059252

Mean & Standard Deviation of Linear Acceleration:

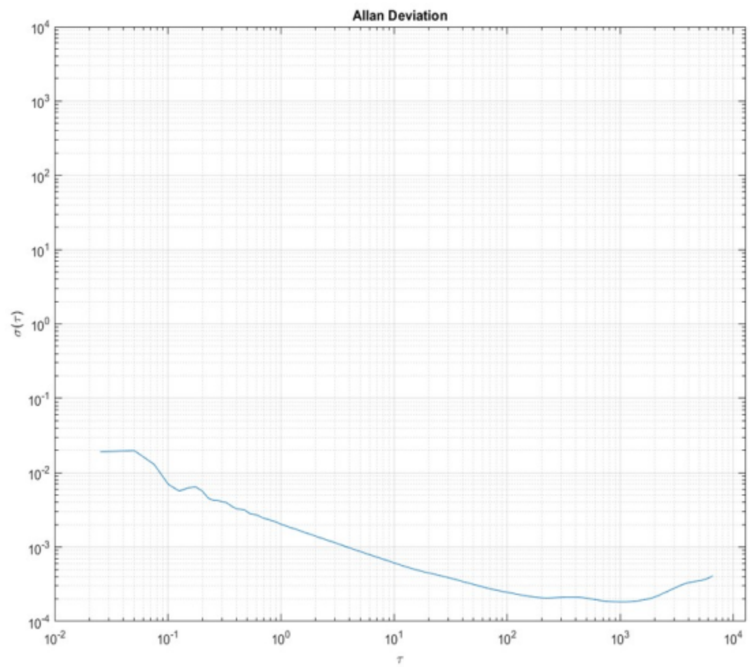
mean = 0.05856778883218836
standard deviation = 0.01292609278388153
mean = 0.05393557032196482
standard deviation = 0.01285599456087763
mean = 0.13834164249788902
standard deviation = 0.06916277689847902

Mean & Standard Deviation of Magnetic Field:

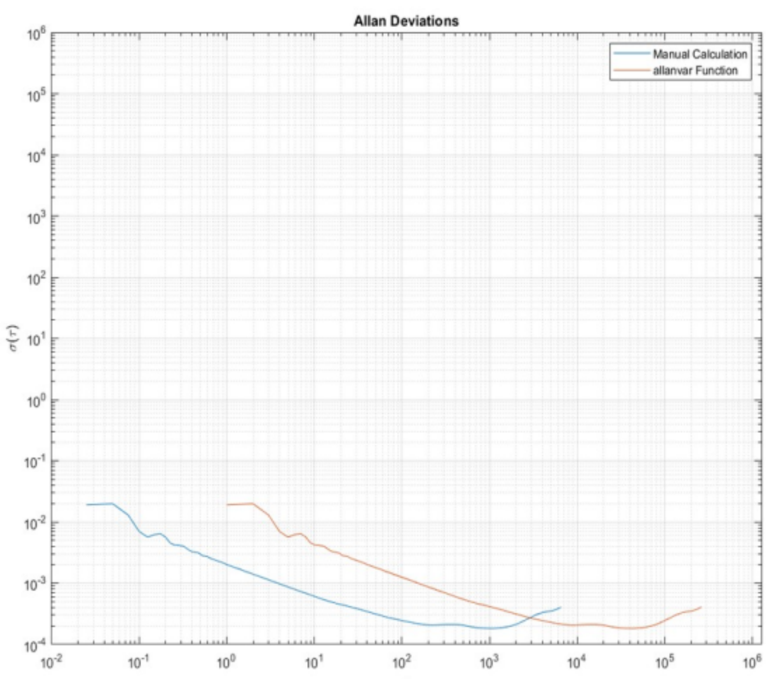
mean = 0.013401189470979106
standard deviation = 0.002574070360520427
mean = 0.0132861595506443
standard deviation = 0.003930415670800572
mean = 0.020393648812364624
standard deviation = 0.005533621714559954

Allan Deviation:

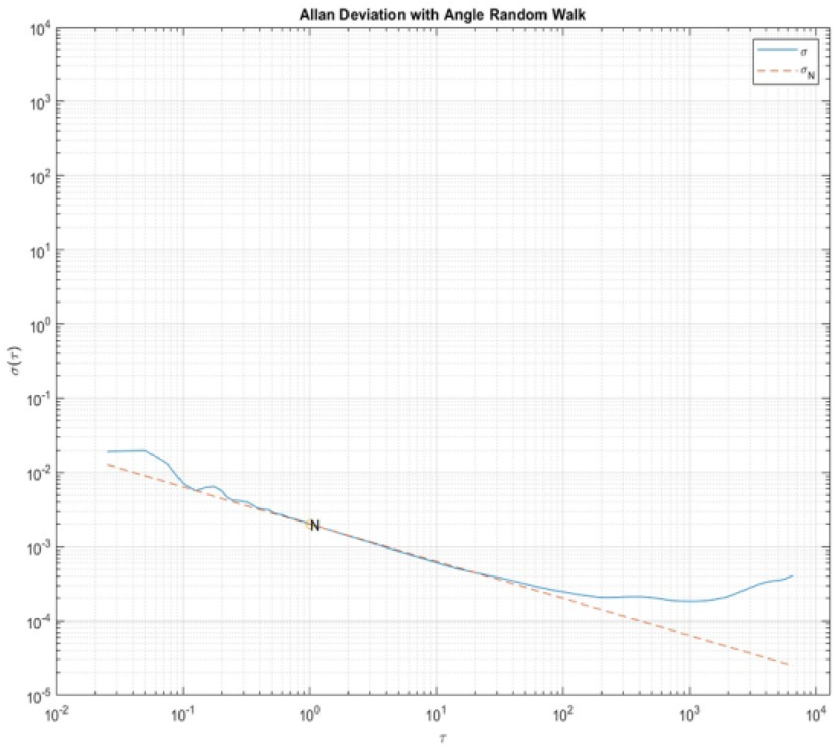
The IMU sensor was running for 5 hrs to observe the nature of allan deviation, the following plots were plotted using this



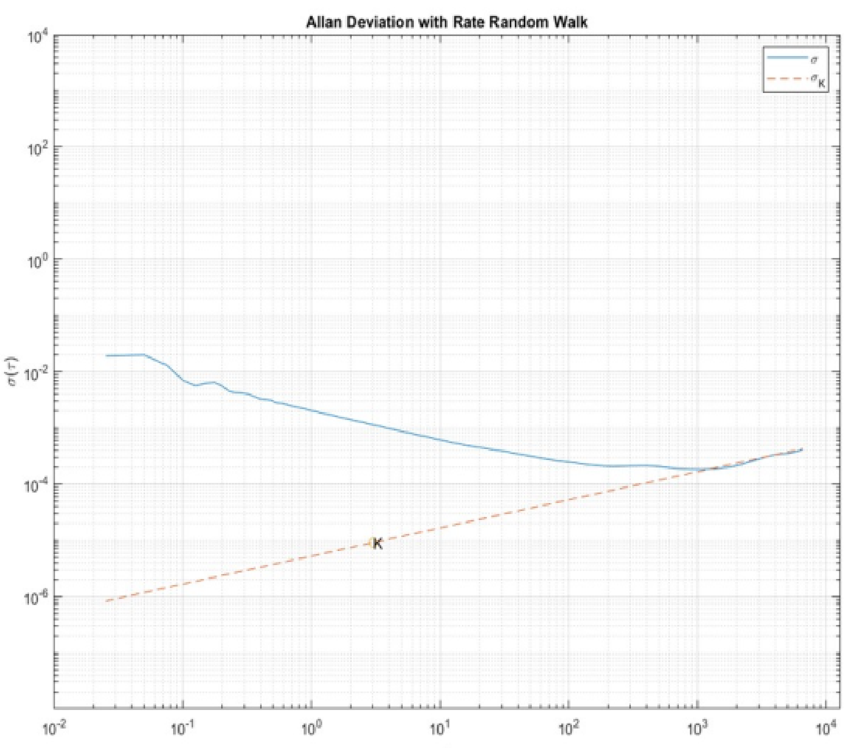
Allan deviation for angular acceleration of IMU



Mechanical data vs Ideal Alan Deviation



Allan Deviation with Angle Random Walk
σ
σN
N
σ(τ)
τ



Allan Deviation with Rate Random Walk
σ
σK
K
σ(τ)
τ

What are the sources of errors?

Sensor Noise: IMU sensors are sensitive to noise, which can be caused by various factors, including electronic noise, temperature fluctuations, and mechanical vibrations. Sensor noise can introduce random errors in the measurements.
Magnetic Interference: Many IMUs include magnetometers to measure the Earth's magnetic field. Magnetic interference from nearby metallic objects or electrical devices can introduce errors in magnetometer readings.
Environmental Factors: Changes in temperature, humidity, and pressure can affect the performance of IMU sensors, particularly those that rely on MEMS (Micro-Electro-Mechanical Systems) technology.
Vibration and Shock: Mechanical vibrations and shocks can introduce errors in accelerometer and gyroscope readings, leading to inaccurate motion tracking.
Other source can include:
Scale Factor
Timing errors
Bias

How to model the error and where do we measure them?

The distribution is close to a gaussian distribution. However, error by external factors can be reduced to make the curve more ideal to a gaussian distribution.
Characterizing errors through experiments and data analysis is a common approach. You can collect data from the IMU in controlled conditions and analyze the statistics of the errors.

Relation of measurement to datasheet of VN100:

• The bias instability, which represents a slowly-varying bias drift over time with downward slope in the Allan deviation plot as the averaging time increases. This slope serves as an indicator of gyro bias drift, as per the specified limit of ≤10°/hr.

• The angular random walk (white noise) results in the Allan deviation decreasing with the square root of the averaging time. It should ultimately stabilize at around 0.25°/√hr or lower, aligning with the product specifications.

• Increased temperature variation during the test will likely lead to increased bias drift and instability due to the temperature sensitivity.

• using the Kalman filter for estimating and compensating gyro biases reduces the bias instability component within the Allan deviation plot. The remaining slope in the plot indicates uncorrected drift.

The Allan deviation plot characterizes the random walk noise and bias drift of the VN-100 gyroscope, as per the datasheet.