LAB 3

IMU SENSOR Noise Characteristics

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Objective:

The aim of this lab is to work with IMU Sensor and figure out it's noise characteristics.

IMU Sensor:

Inertial Motion Unit Sensor is capable of measuring orientation data and to achieve this it uses a combination of sensors.

There are 2 variants of IMU Sensors:

- 6 DOF
- 9 DOF

The device we'll be working with is a Vectornav VN100 IMU which is a 9 Degrees of Freedom device that has 3 sensors:

- Accelerometer:
  Accelerometers measure linear acceleration along all 3 axes.
- Gyroscope:
  Gyroscopes measure angular velocity along all 3 axes.
- Magnetometer:
  Magnetometers measure magnetic fields along all 3 axes.
- Sensor Fusion| Roll, Pitch, Yaw:
  We obtain roll, pitch and yaw from these 3 sensor readings, Accelerometer gives the roll and pitch but not reliable yaw, the sensor uses Magnetometer readings to calculate yaw.

Additionally, we convert the Roll, Pitch and Yaw values to a Quaternion form to make it computationally easier.

Method:

The steps taken to get our readings:

- **Configured Ubuntu:**
  Changed some parameters as guided in the Lab3 word document to make the VN-100 sensor work as intended with our OS.
- **Configured Device Baud rate:**
  set Baud rate to 115200 via minicom
- **Device driver:**
  A python device driver was written to parse data from the sensor and publish it as a sensor.msg, outputting 3x Headers, 3x Gyro, 3x Accelerometer, 3x Magnetometer, Yaw, Pitch, Roll and 4x Quaternion readings.
- **Data Collection / Rosbag:**
  15 minutes and 5+ hours readings were taken by keeping the IMU sensor taped to the floor and were put into a Rosbag.

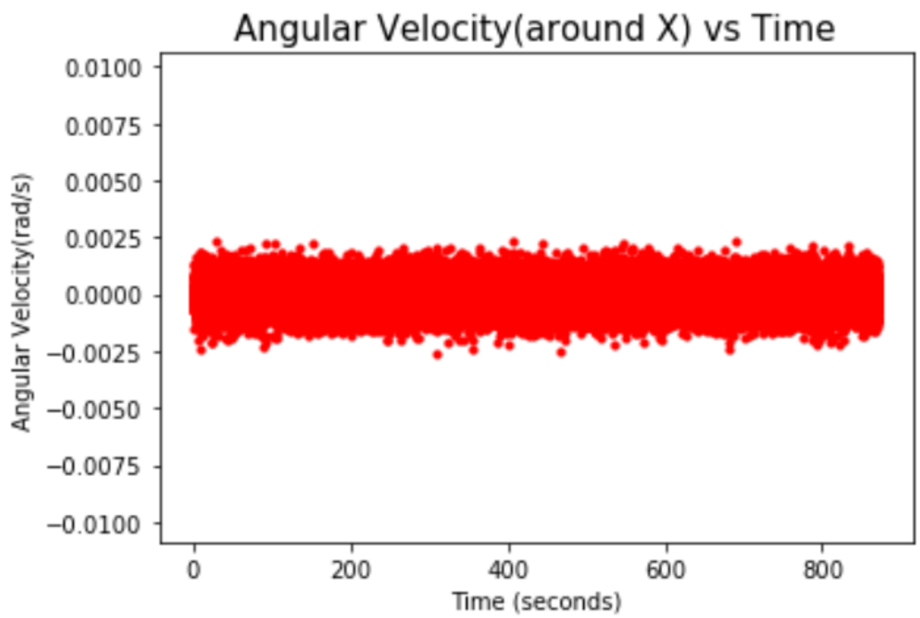
Data:

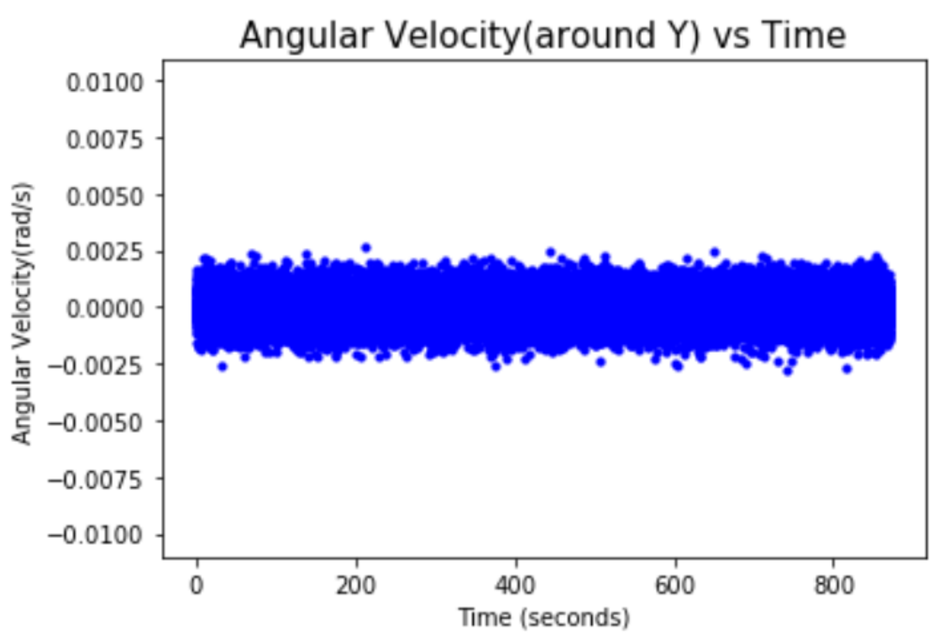
- **Data Location:**
  Data was taken at 400 Mass Ave @ Ground floor level late at night to avoid interference.
- **Convert the ROSBag into CSV readable files:**
  The ROSBag data received was turned into a CSV file using a python script (saved as bagreader.py)
- **Parsing out the parameters needed:**
  The Gyro, Accel, Magnetometer and Quaternion readings were parsed out and used for graphing and analysis as follows.

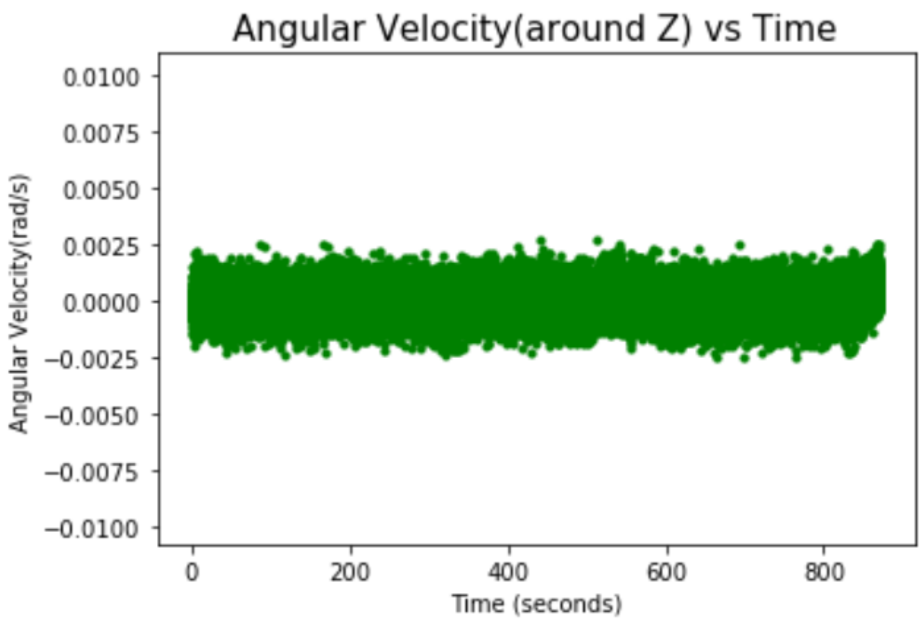
Analysis:

15-minute reading:

Gyroscope:







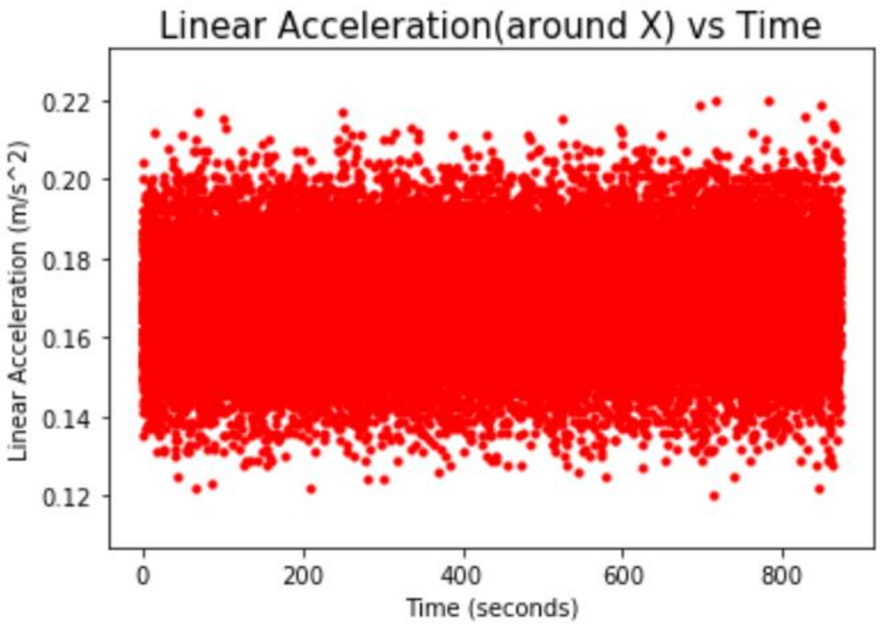
Gyro Axis	Mean	Standard Deviation
X	8.35732e-06	0.000616279
Y	3.68111e-06	0.00065065
Z	2.90612e-05	0.000686514

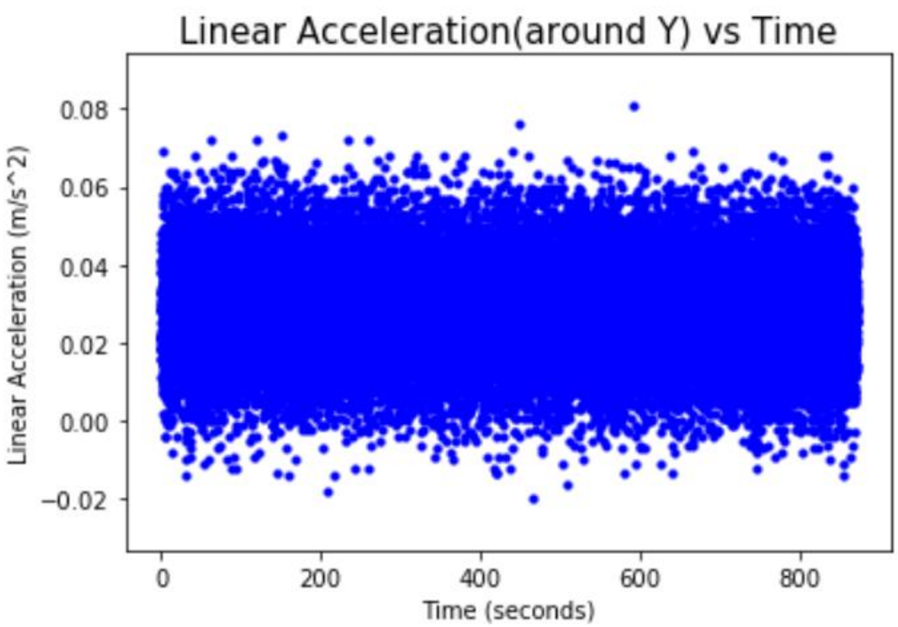
The Gyro values are expected from a stationary device, almost constant with very minimal variation range which could be due to the quality of the IMU device which could cause noise inside the device itself.

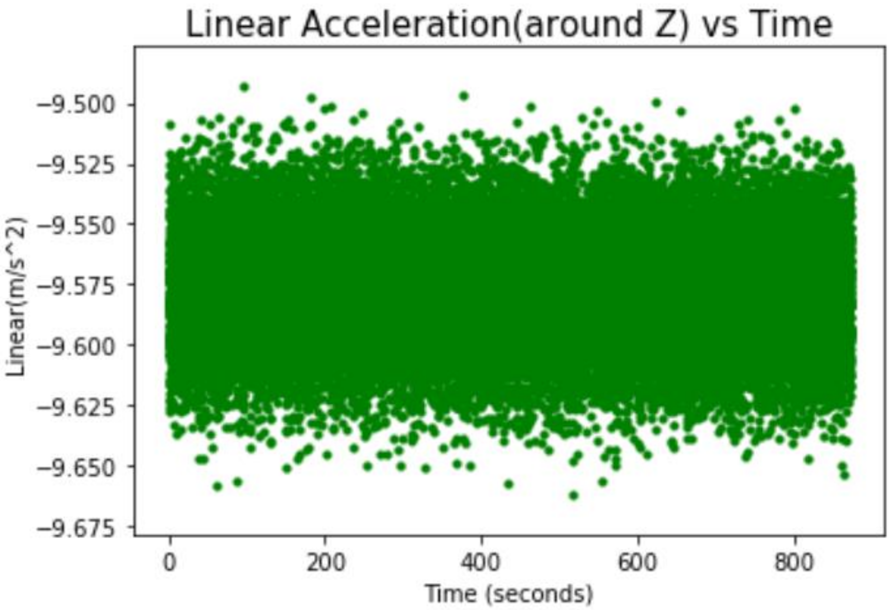
Other reason could be due to noise picked up from the recording environment, footsteps, vibrations, sounds even in small amplitude could've been picked up the Gyroscope sensor and reflected in the reading.

There is also the concept of Bias Instability which currently is not relevant in a 15 minute case as the imperfections integrate overtime to become a noticeable drift which we'll see in the 5 hour case.

Accelerometer:





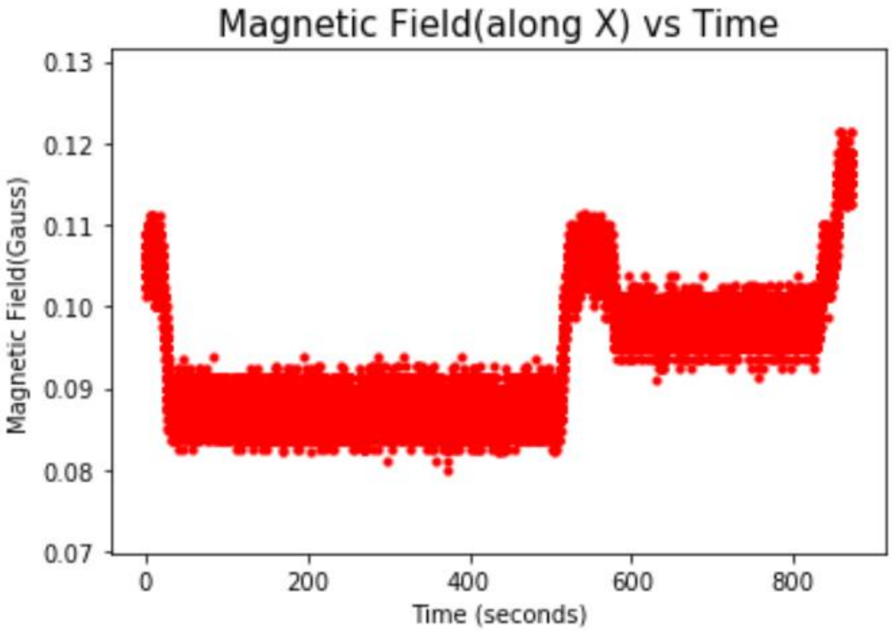


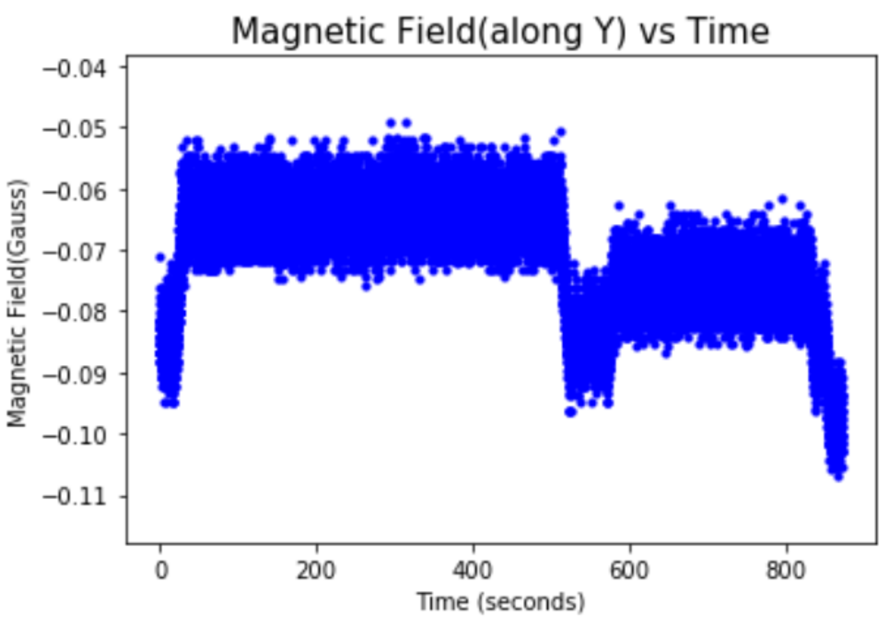
Linear Acceleration Axis	Mean	Standard Deviation
X	0.168957	0.0128677
Y	0.0284293	0.0120025
Z	-9.57641	0.021766

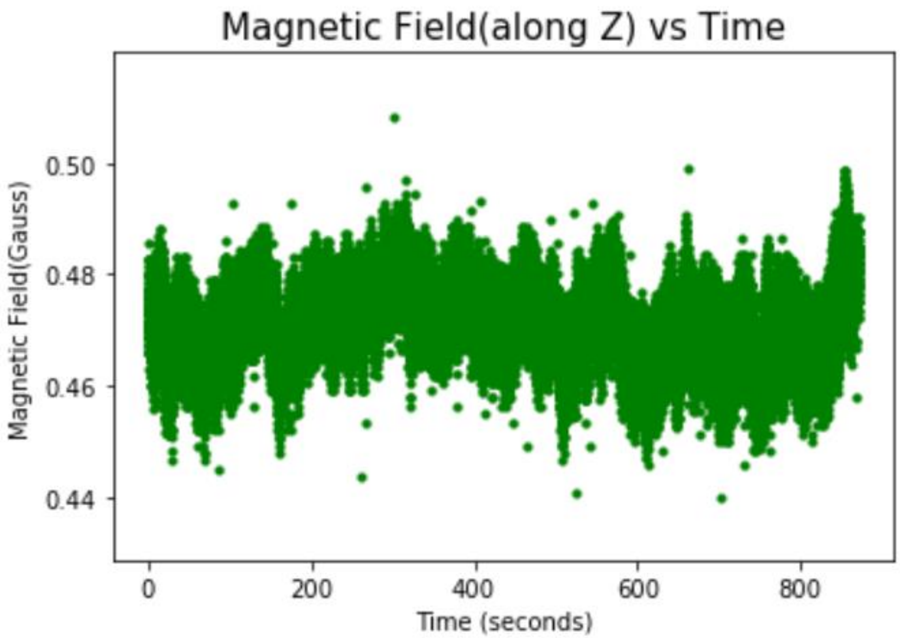
Similar to the gyroscope case the values are almost constant with a little more deviation, this is because you in the case of gyroscope you differentiate the angular distance once whereas you differentiate the linear distance twice to get acceleration which also means the small errors present are going to get differentiated twice as well causing a larger noise margin hence the standard deviation is higher in this case than the gyroscope.

Another peculiar thing to notice from the mean is, the Z direction mean is much higher in absolute value compared to the X and Y mean, this is because the device was kept flat on the floor and Z measures the up and down forces where Z axis is aligned almost in the direction of gravity but not exactly since the ground could be oriented not exactly perpendicular to gravity, this is why the Z axis linear acceleration is very similar to –9.81(gravitational force value) which also affects X and Y slightly since the ground isn't perfectly perpendicular to gravity.

Magnetometer:





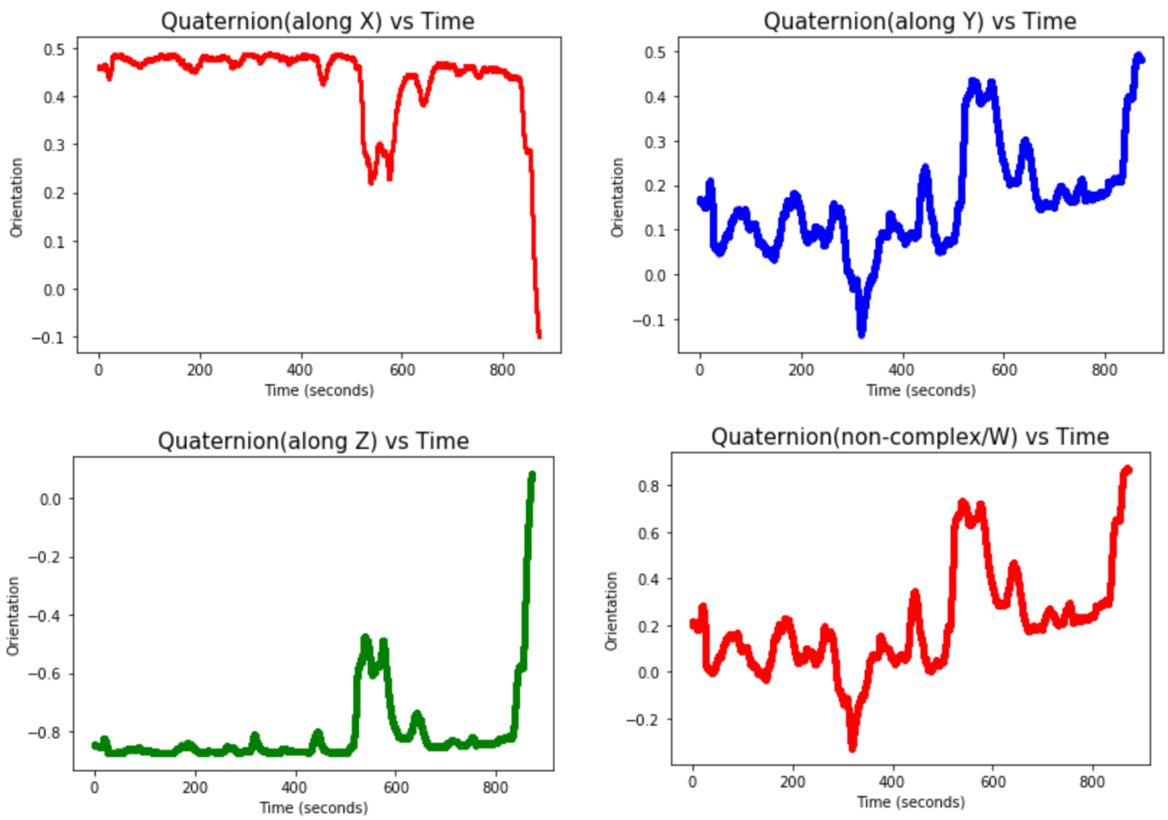


Magnetic Field Axis	Mean	Standard Deviation
X	0.0933729	0.0075528
Y	-0.0708928	0.00911819
Z	0.471149	0.00747405

There is noise present in our readings due to previously mentioned causes like noise inside device but also the presence of electric currents or magnetic materials nearby which could affect the magnetic fields, since the reading was taken at home amidst all a lot of devices even when kept 7 feet apart could've interfered with the magnetic field at that point causing noise.

Another thing to infer is that the earth's magnetic field varies between 0.25 - 0.65 Gauss, from our reading only Z axis comes into that range which could tell us that the Z axis is aligned close to the earth's magnetic field.

Quaternion:

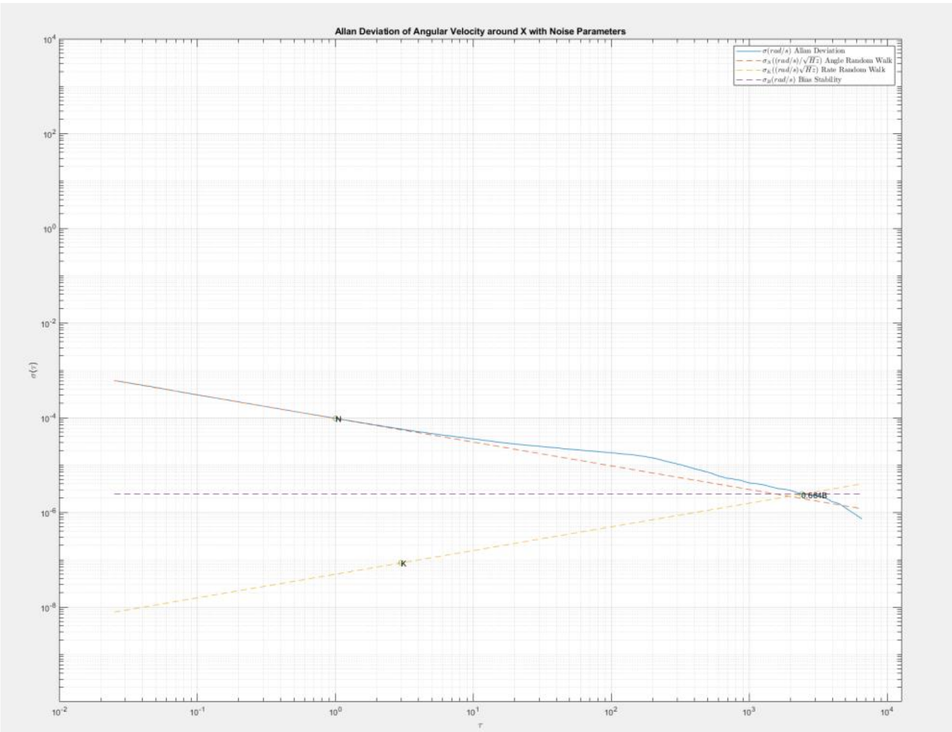


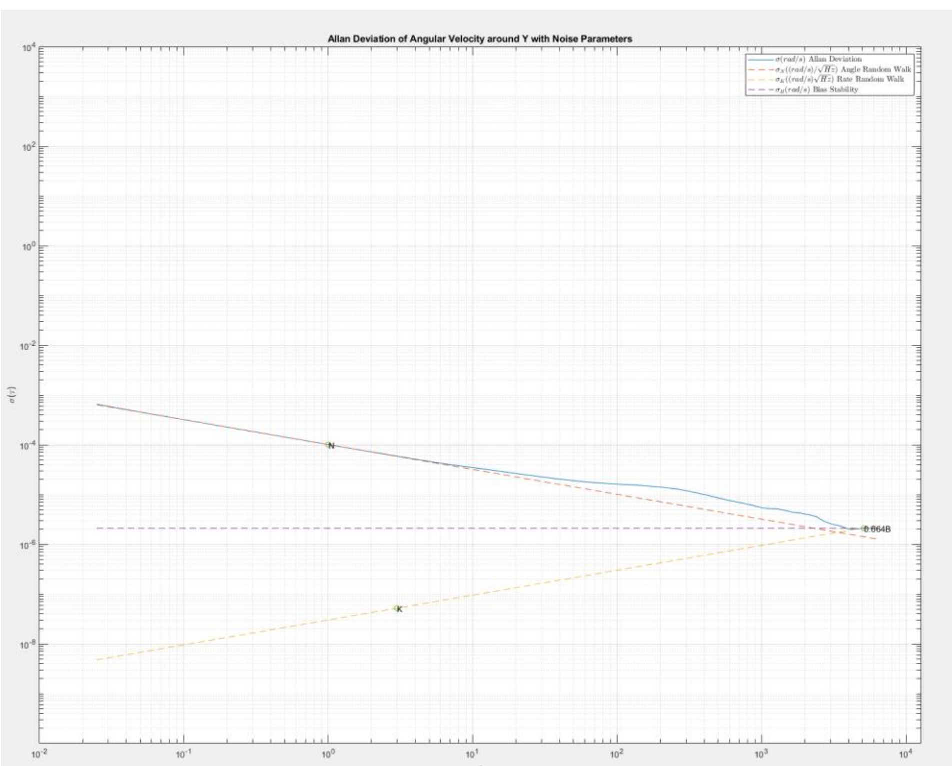
Quaternion Coeffs	Mean	Standard Deviation
i	0.438413	0.0829988
j	0.161056	0.115835
k	-0.809143	0.129669
w	0.203642	0.22035

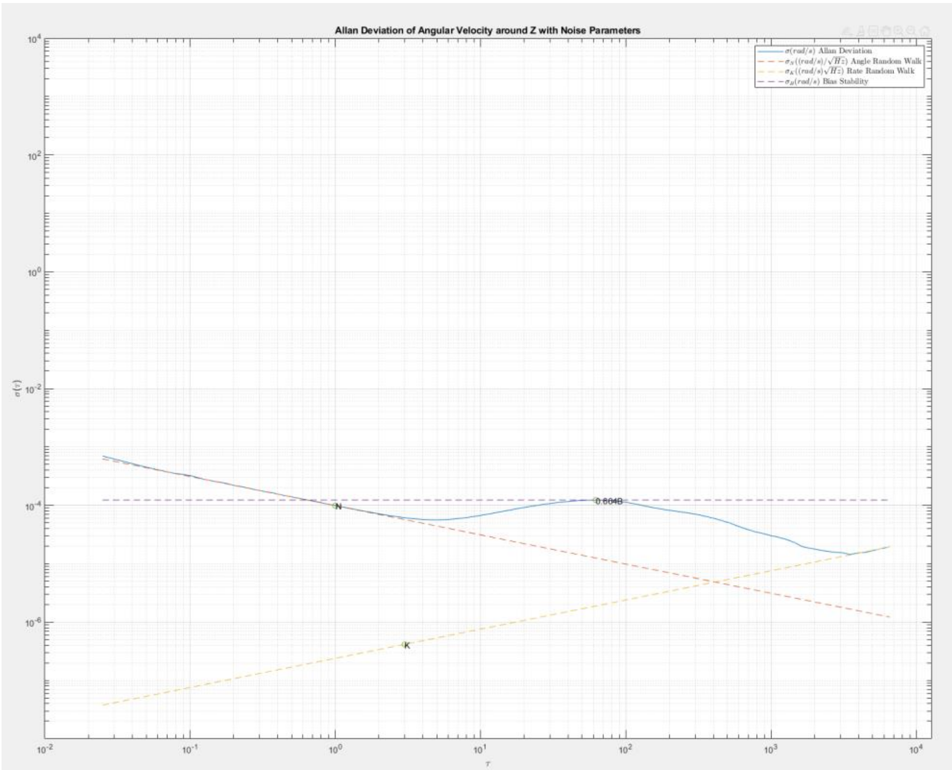
Quaternion values are calculated from Yaw, Pitch and Roll which in turn are calculated from Accelerometer, Magnetometer and their angular rates are calculated from Gyroscope, hence all the noises present from earlier cases would combine in various ways to cause a lot of variations in the Quaternion values and as they integrate overtime the noises cause a drift which is reflected in the X and Z values.

5-Hour Reading

Gyroscope Allan Variance







5-7°/hr (typ.)

Gyro In-Run Bias Stability

Gyro_Axis	Angle_Random_Walk	in_DegreesPerHr	Rate_Random_Walk	Bias_Instability	in_DegreesPerHour
"X"	9.5952e-05	0.32986	8.5538e-08	3.6354e-06	0.74986
"Y"	0.0001011	0.34756	5.2147e-08	3.177e-06	0.65529
"Z"	9.8447e-05	0.33844	4.1442e-07	0.0001848	38.118

Error Terms by Sensor Grade

GRADE	ACCELEROMETER BIAS (mg)	VELOCITY RANDOM WALK (m/s/√hr)	GYRO BIAS (deg/hr)	ANGLE RANDOM WALK (deg/√hr)
Consumer	10	1	100	2
Industrial	1	0.1	10	0.2
Tactical	0.1	0.03	1	0.05
Navigation	0.01	0.01	0.01	0.01

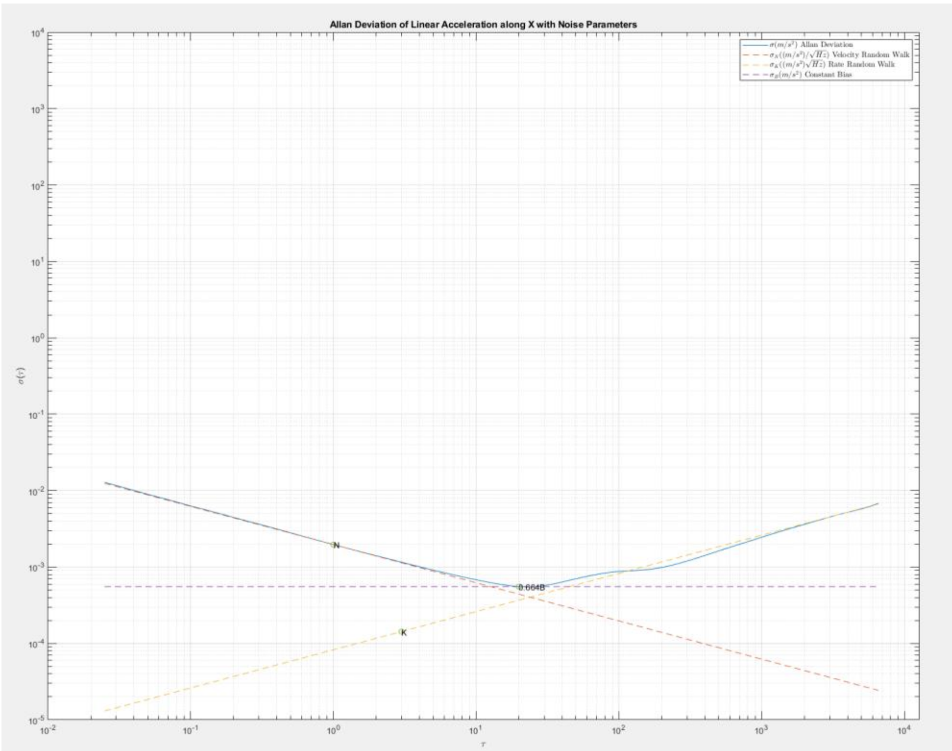
TABLE 3.1

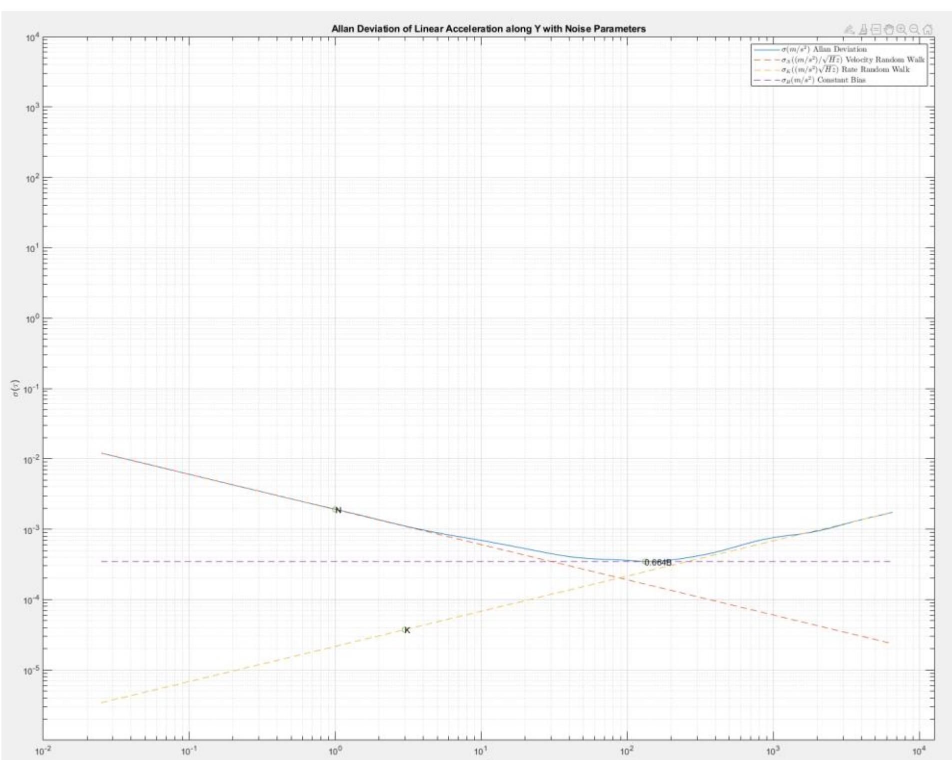
The most important gyro noise characteristics here are Angle Random Walk and Bias Instability. The gyroscope drift is mainly due to the integration of two components: a slow changing, near-dc variable called bias instability and a higher frequency noise variable called angular random walk (ARW)

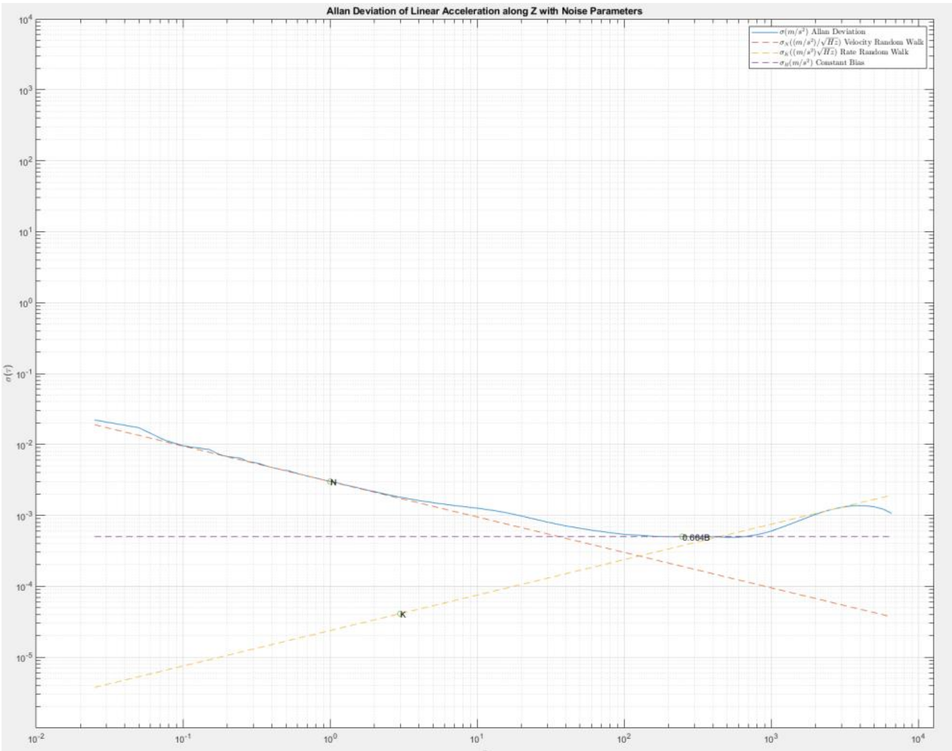
Gyro rates are measurements that are typically calculated by integration over time, the issue is that due to noise present in the system this integration can drift overtime, this characteristic is represented by the Angle Random Walk, the lower the better. According to the Sensor Grade table, our sensor is consumer grade. The slope for ARW also represents presence of white noise, if a –0.5 slope fits well with our graph, it indicates that our sensor has Gaussian white noise.

Gyro Bias Instability is a measurement bias, it is a constant measurement offset from the true value of angular velocity at the same temperature. Bias instability causes the angle drift in time-integrated data, this is evident in our case since there is some angular velocity even when the device is switched on and stationary outputs a slightly non-zero value which is called the turn-on bias. From our sensor grade table, our sensor is consumer grade again, but specific values speak differently as X and Y follow the Industrial grade claim (<10%) from the manual but Z goes high which is probably due to some accumulated error getting integrated over and over causing a large drift.

Accelerometer Allan Variance







< 0.04 mg

Accel In-Run Bias Stability

Accelerometer_Axis	Velocity_Random_Walk	in_meterPerSecondPerRootHr	Rate_Random_Walk	Constant_Bias	in_mg
"X"	0.001968	0.11808	0.00014285	0.00083262	0.083262
"Y"	0.0019073	0.11444	3.7406e-05	0.00052308	0.052308
"Z"	0.0029997	0.17998	4.1144e-05	0.00075783	0.075783

Error Terms by Sensor Grade

GRADE	ACCELEROMETER BIAS (mg)	VELOCITY RANDOM WALK (m/s/$\sqrt{hr}$)	GYRO BIAS (deg/hr)	ANGLE RANDOM WALK (deg/$\sqrt{hr}$)
Consumer	10	1	100	2
Industrial	1	0.1	10	0.2
Tactical	0.1	0.03	1	0.05
Navigation	0.01	0.01	0.01	0.01

TABLE 3.1

Like the previous case, the most important characteristics here are Velocity Random Walk and Constant Bias.

The Constant Bias is a constant offset in the linear acceleration reading from the true linear acceleration value at the same temperature, the least the better since this can cause a drift while being integrated. According to our Sensor Grade table, this sensor comes under the Industrial category.

And similar to the Angle Random Walk, Velocity Random Walk is a measure of how much drift is caused due to noise present and accelerometer bias, the lesser the better meaning less drift white noise. According to the Grade table, this sensor comes under the Industrial category.

Other causes for error again would be because of 40 Hz sampling rate than the standard 400 Hz sampling rate, changes in temperature in the sampling area and interference due to vibrations and such.

Conclusion:

The device we're using mostly shows **Industrial Grade** characteristics and our allan deviation tests give similar results on most cases except for Gyroscope reading around Z axis which is most probably due to errors in testing methods since all the other readings respect the claims given in the device manual.