Northeastern University

Robot Sensing and Navigation - EECE5554
LAB 3 Analysis Report

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Introduction

LAB 3 is dedicated to the exploration of noise origins in the IMU sensor and its environmental context, as well as evaluating the performance to select IMU sensors for robotics applications. We employed the Vectornav VN-100 IMU to gather data on rotation, acceleration, magnetometer, and angular rates. We also developed an appropriate driver program to collect and process the IMU data, and subsequently, we analyzed noise parameters including angle random walk (N), bias instability (B), and rate random walk (K) using Allan variance plots for both stationary and mobile data.

The following data was collected from the Vectornav VN-100 IMU:

1. Yaw
2. Pitch
3. Roll
4. Magnetic field in x, y, z direction
5. Acceleration in x, y, z direction
6. Angular rate gyros in x, y, z direction

Time series, frequency distribution and noise characteristics of the datasets are obtained.

Allan Variance Analysis

Analysis on 5 hours of stationary IMU data which was collected from different locations in Boston, MA. The bag file assigned to me is "**Location C**".

Allan variance plots of Location C:

Gyro

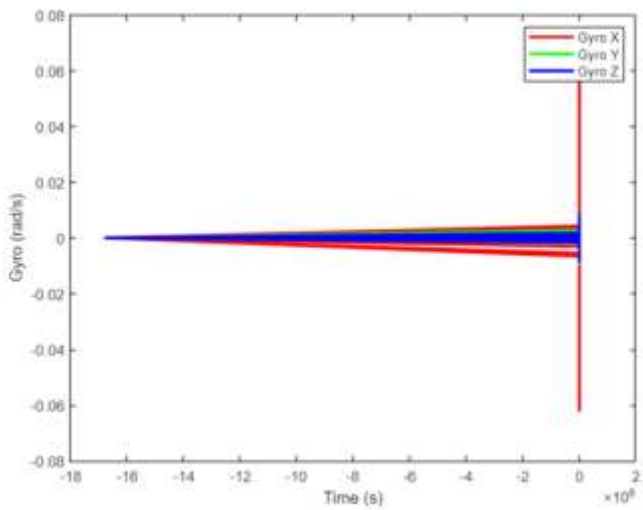


Fig.1 Time series plot of Gyro X, Y, Z.

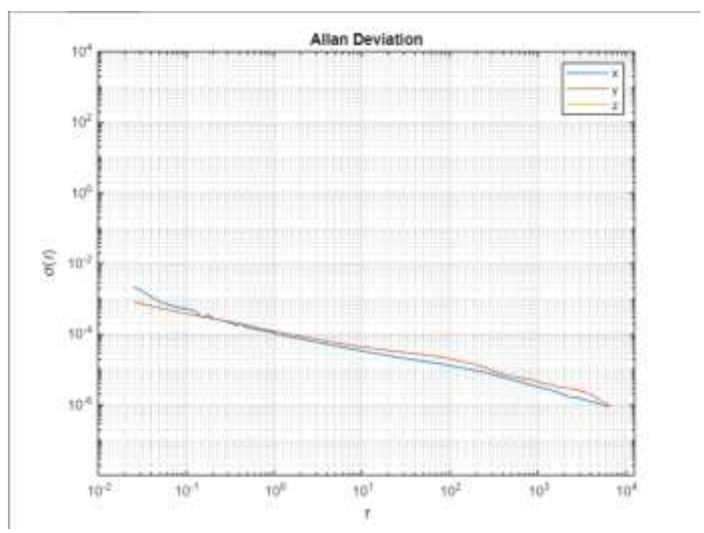


Fig.2 Allan Deviation plot of Gyro X, Y,Z.

Gyro X:

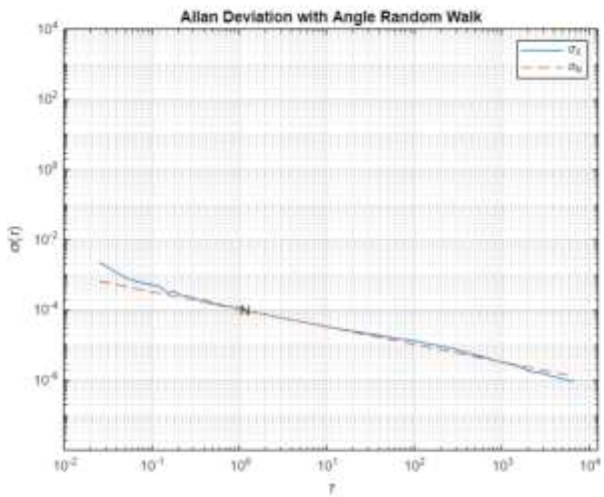


Fig.3 Angle Random Walk for Gyro X.

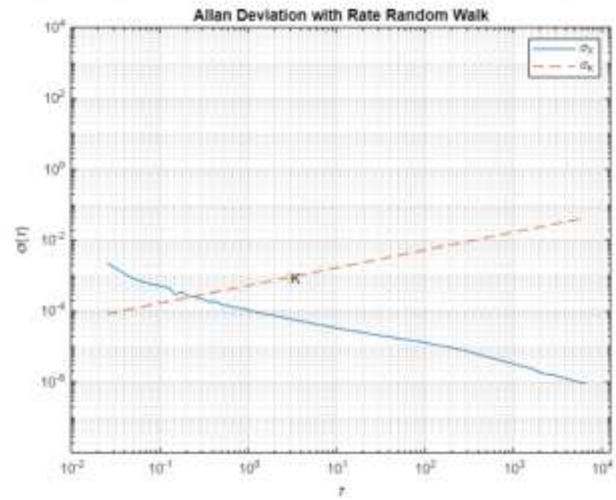


Fig.4 Rate Random Walk for Gyro X.

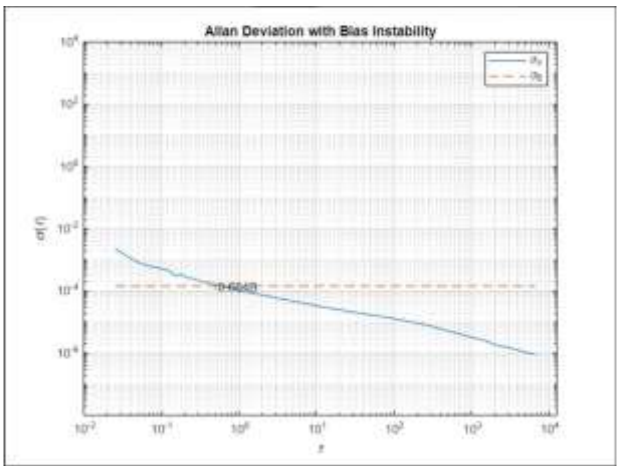


Fig.5 Bias Instability for Gyro X.

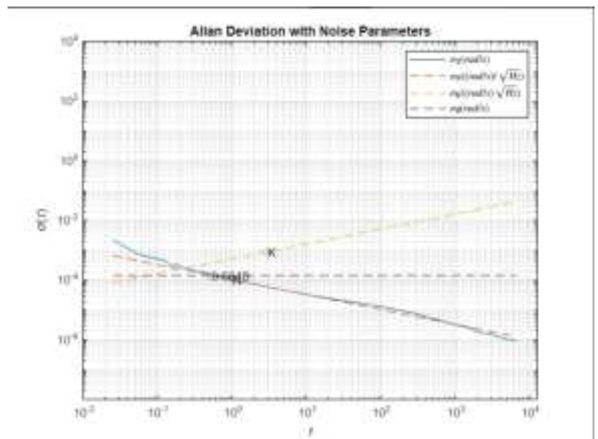


Fig.6 Noise Parameters for Gyro X.

Noise Parameters for Gyro X

Rate Random Walk (K): 3.9555×10^{-7}

Angle Random Walk (N): 9.0084×10^{-5}

Bias stability (B): 7.1553×10^{-6}

Gyro Y:

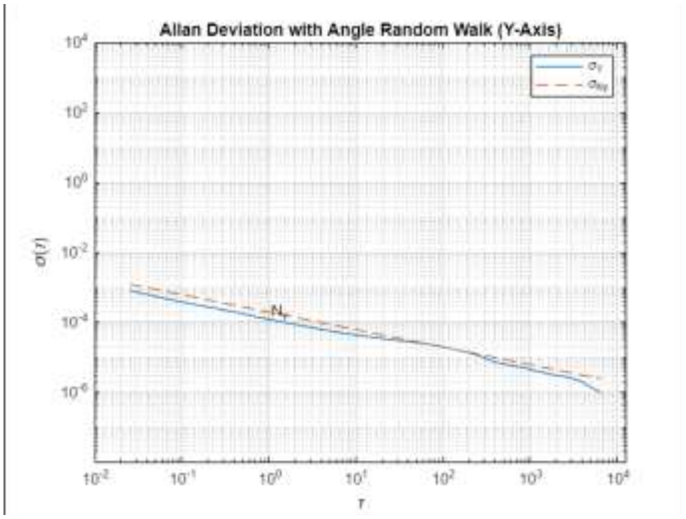


Fig.7 Angle Random Walk for Gyro Y.

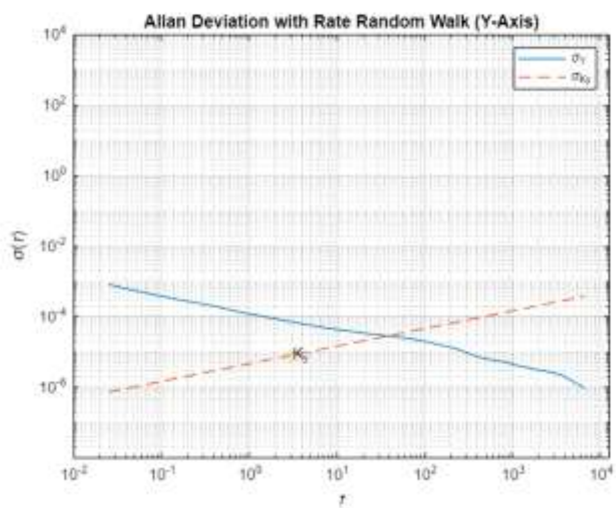


Fig.8 Rate Random Walk for Gyro Y.

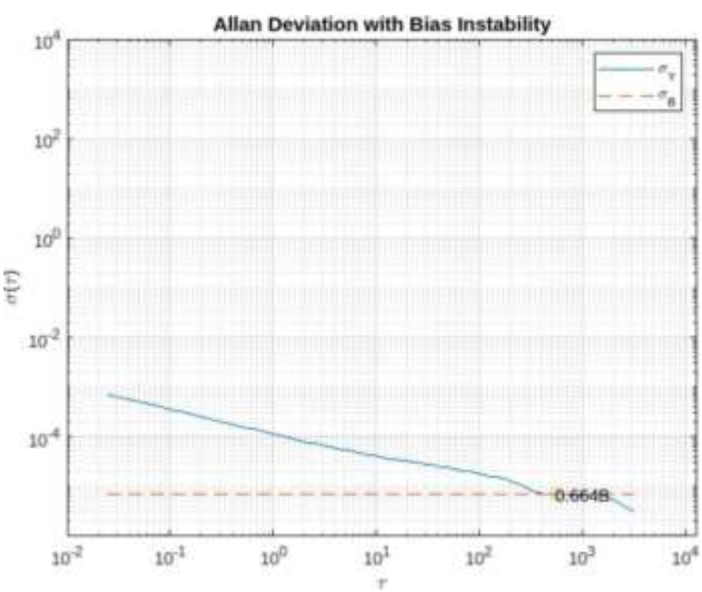


Fig.9 Bias Instability for Gyro Y.

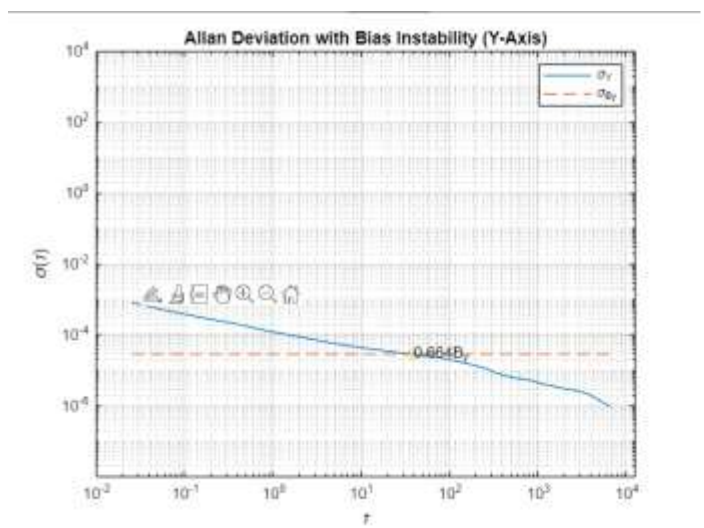


Fig.10 Noise Parameters for Gyro Y.

Noise Parameters for Gyro Y

Rate Random Walk (K):	3.5289×10^{-7}
Angle Random Walk (N):	1.1251×10^{-4}
Bias stability (B):	1.0239×10^{-5}

Gyro Z:

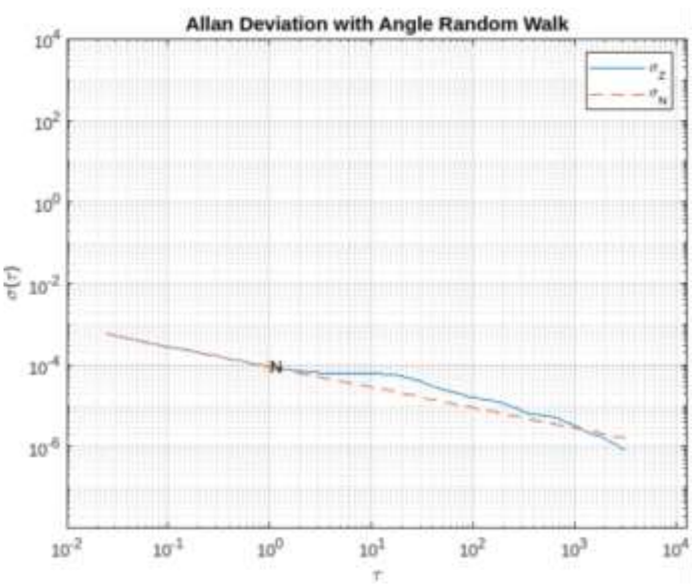


Fig.11 Angle Random Walk for Gyro Z.

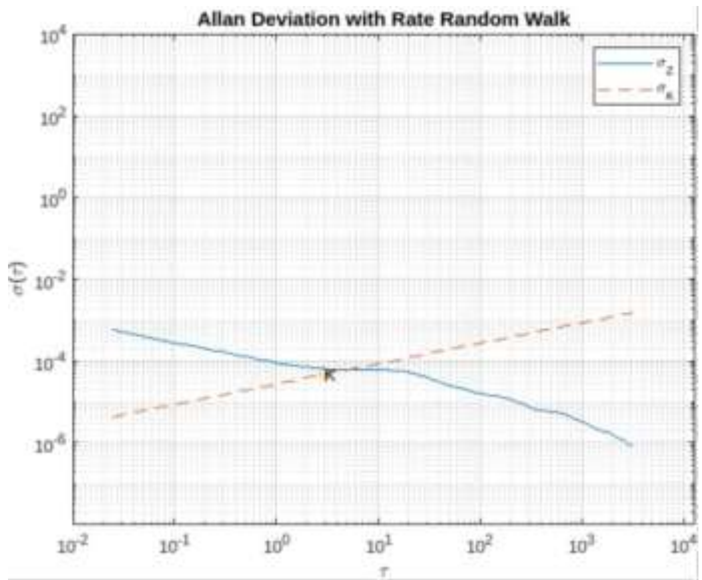


Fig.12 Rate Random Walk for Gyro Z.

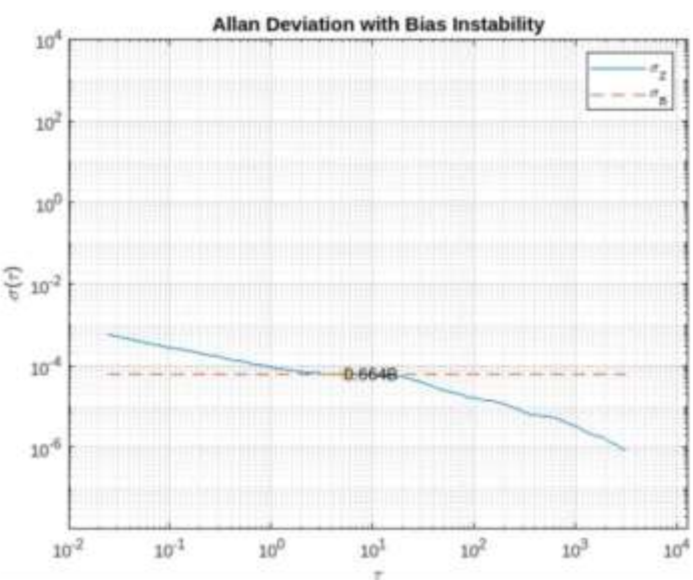


Fig.13 Bias Instability for Gyro Z.

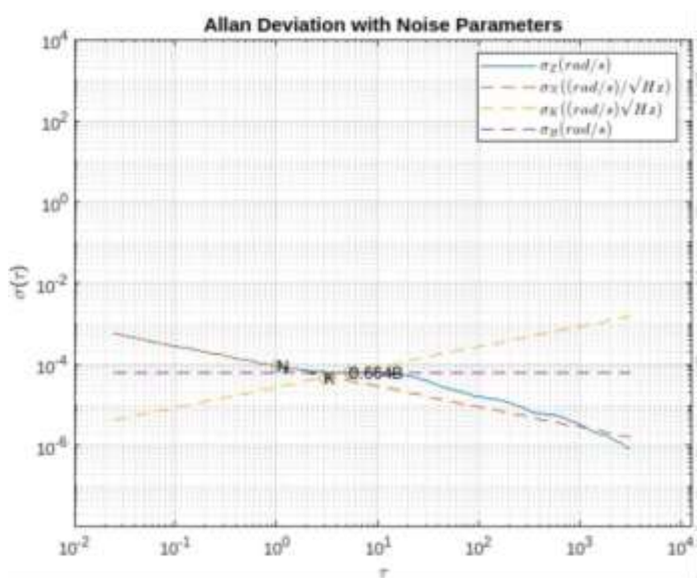


Fig.14 Noise Parameters for Gyro Z.

Noise Parameters for Gyro Z

Rate Random Walk (K):	4.7209×10^{-5}
Angle Random Walk (N):	9.1164×10^{-5}
Bias stability (B):	9.4460×10^{-5}

Acceleration

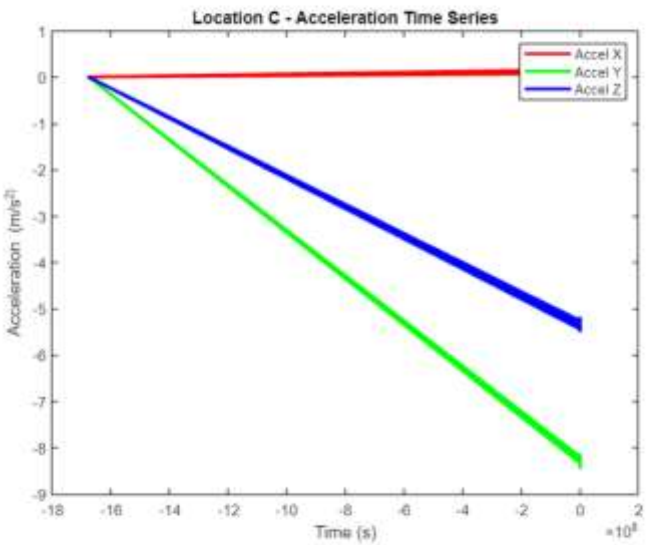


Fig.15 Time series plot of Acceleration X, Y, Z.

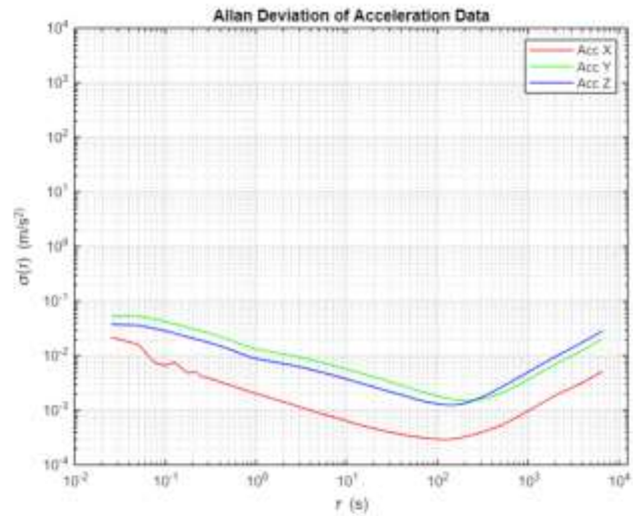


Fig.16 Allan Deviation plot of Acceleration X, Y, Z.

Noise parameters for Acceleration

Bias instability (B)

B (x-axis): 8.5466×10^{-4}

B (y-axis): 5.0139×10^{-4}

B (z-axis): 7.9223×10^{-4}

Allan variance plots of Location A

Gyro

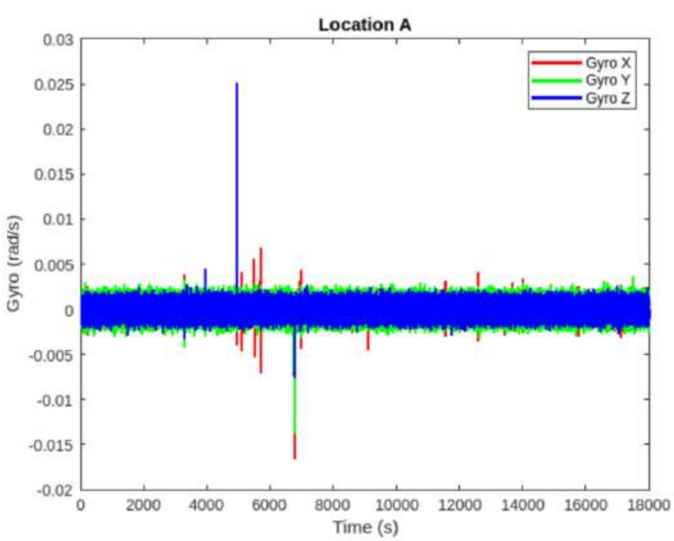


Fig.17 Time series plot of Gyro X, Y, Z.

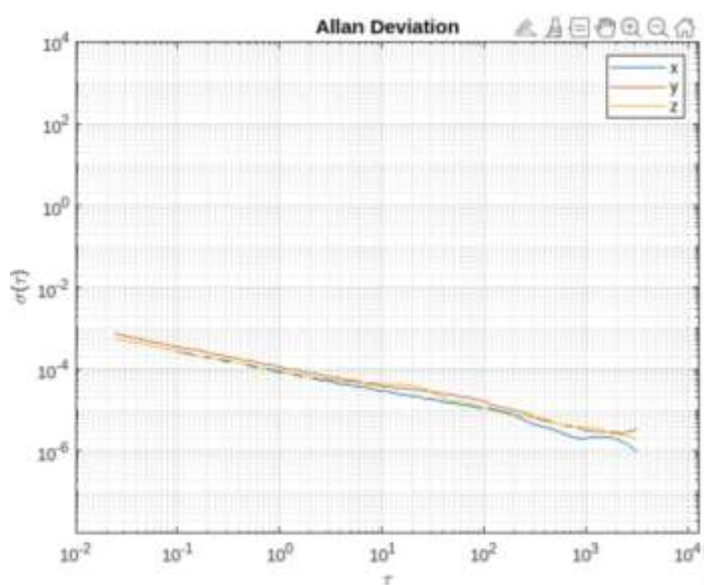


Fig.18 Allan Deviation plot of Gyro X, Y, Z.

Noise Parameters for Gyro

Rate Random Walk (K): 3.1026×10^{-7}

Angle Random Walk (N): 8.7824×10^{-5}

Bias stability (B): 3.1026×10^{-6}

Acceleration

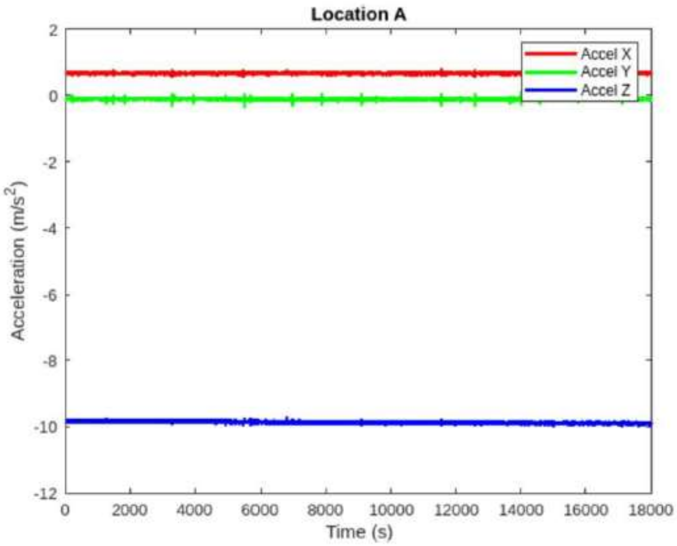


Fig.19 Time series plot of Acceleration X, Y, Z.

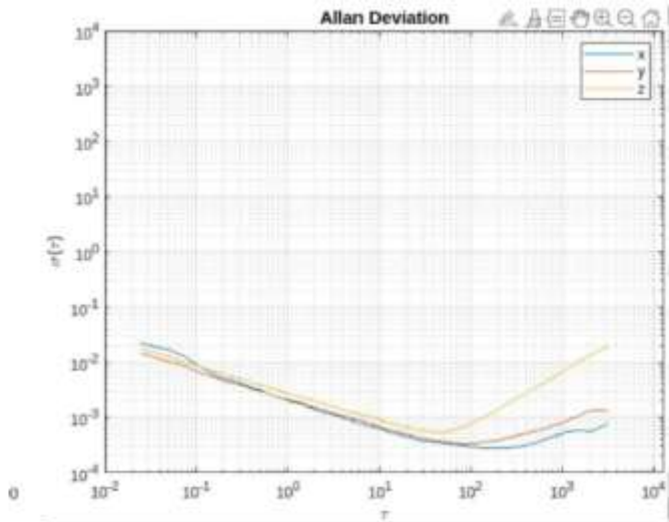


Fig.20 Allan Deviation plot of Acceleration X, Y,Z.

Noise Parameters for Acceleration
Bias instability (B)
B (x-axis): 3.0139×10^{-4}
B (y-axis): 2.9554×10^{-4}
B (z-axis): 6.0113×10^{-4}

Allan variance of Location B
Gyro

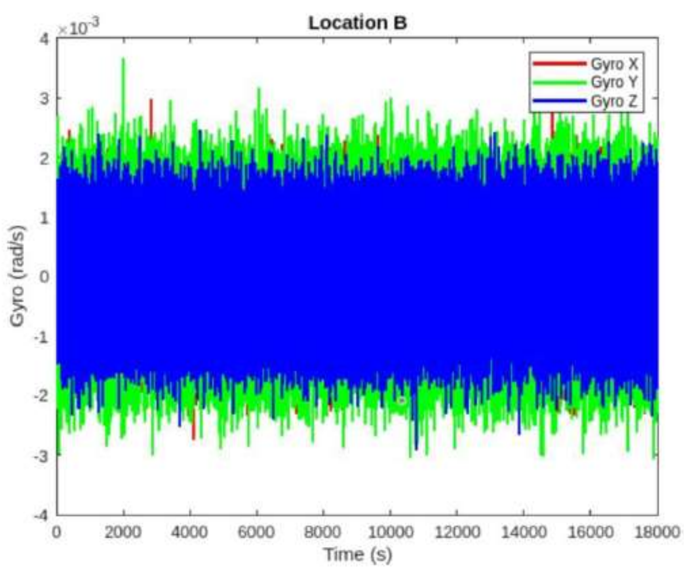


Fig.21 Time series plot of Gyro X, Y, Z.

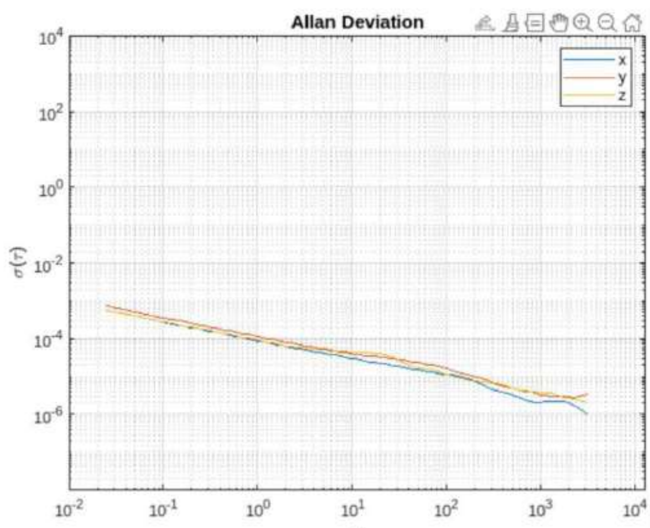


Fig.22 Allan Deviation plot of Gyro X, Y,Z.

Noise Parameters for Gyro
Rate Random Walk (K): 9.0021×10^{-4}
Angle Random Walk (N): 1.0184×10^{-4}
Bias stability (B): 2.1290×10^{-4}

Acceleration

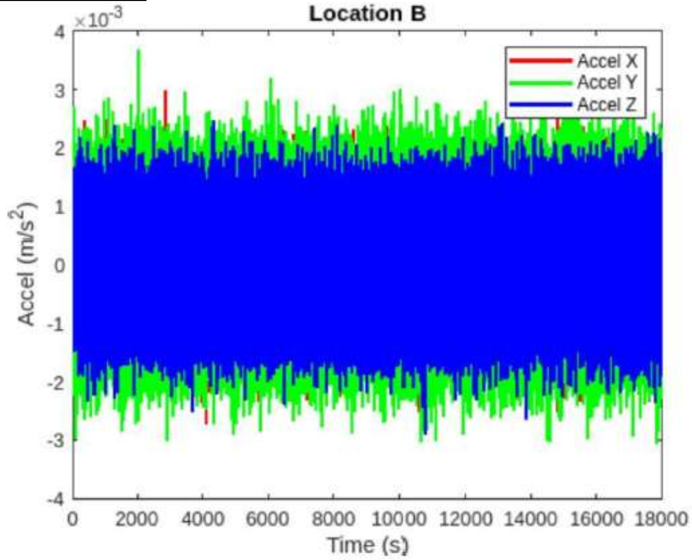


Fig.23 Time series plot of Acceleration X, Y, Z.

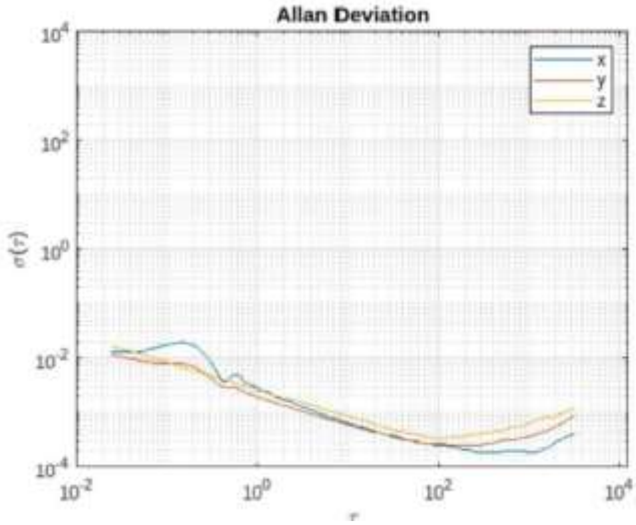


Fig.24 Allan Deviation plot of Acceleration X, Y,Z.

Noise Parameters for Acceleration

Bias instability (B)

B (x-axis): 4.3867×10^{-4}

B (y-axis): 1.4109×10^{-4}

B (z-axis): 2.1638×10^{-4}

Allan variance of Location D

Gyro

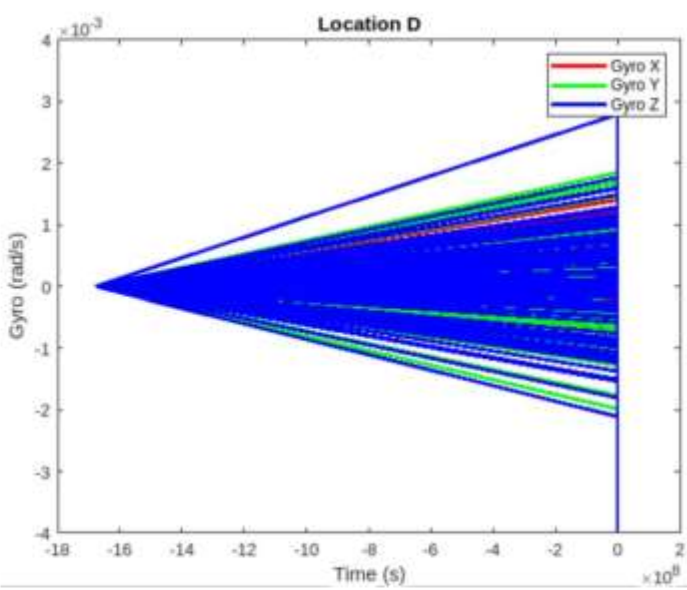


Fig.25 Time series plot of Gyro X, Y, Z.

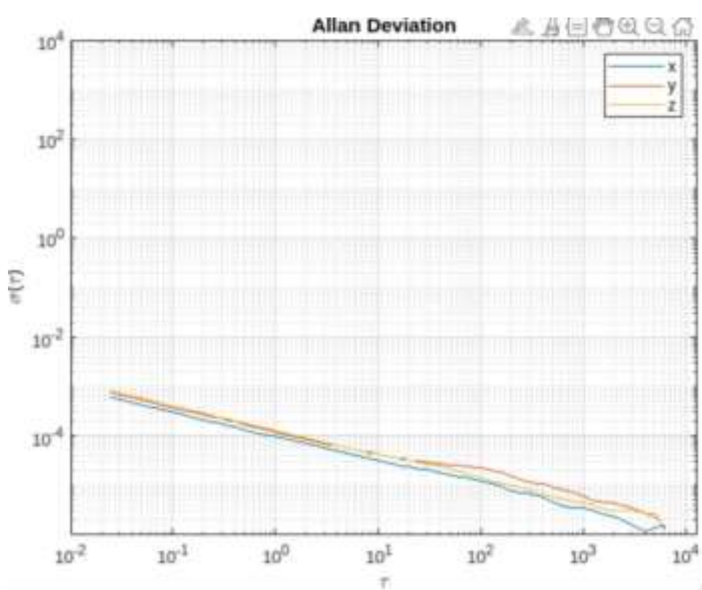


Fig.26 Allan Deviation plot of Gyro X, Y,Z.

Noise Parameters for Gyro

Rate Random Walk (K): 3.1830×10^{-8}

Angle Random Walk (N): 9.5110×10^{-5}

Bias stability (B): 5.1225×10^{-6}

Acceleration

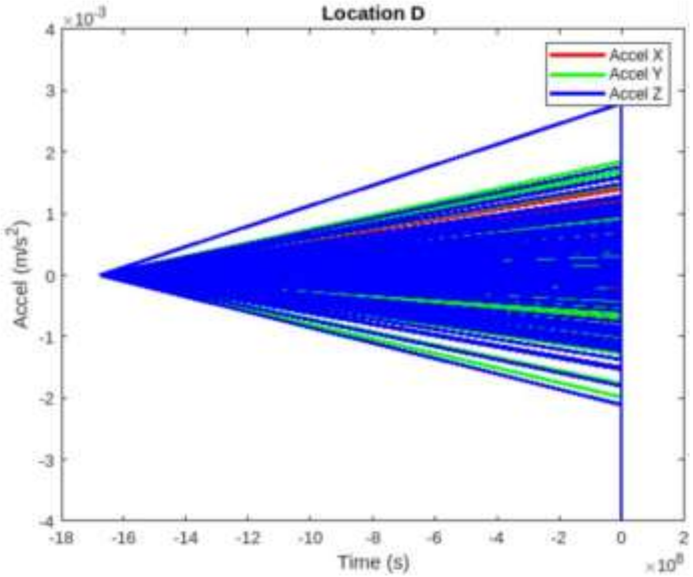


Fig.27 Time series plot of Acceleration X, Y, Z.

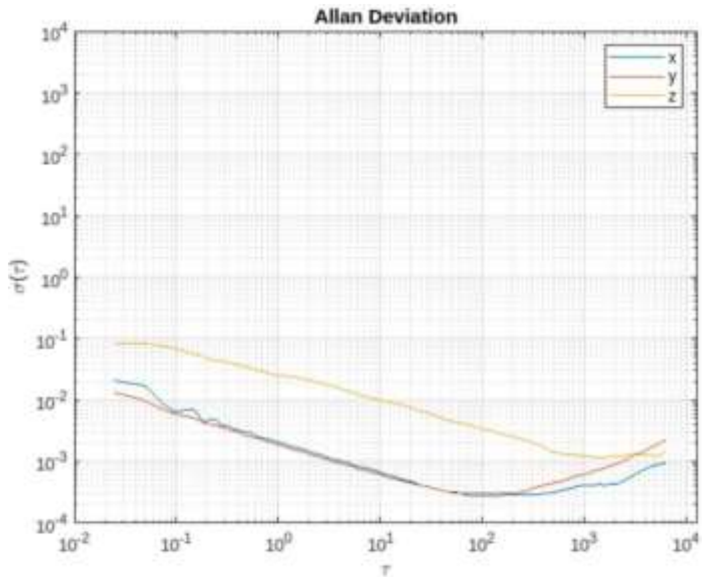


Fig.28 Allan Deviation plot of Acceleration X, Y,Z.

Noise Parameters for Acceleration

Bias instability (B)

B (x-axis): 0.0058

B (y-axis): 2.3307×10^{-4}

B (z-axis): 3.8941×10^{-4}

Stationary Data Analysis

Data was collected keeping the IMU sensor stationary for 5 mins.

Linear Acceleration

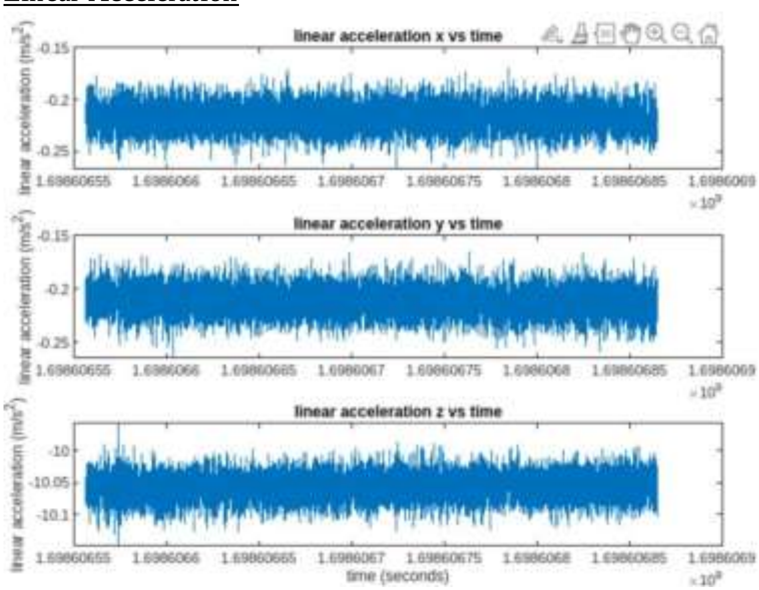


Fig.29 Time series plot of Linear Acceleration X, Y, Z.

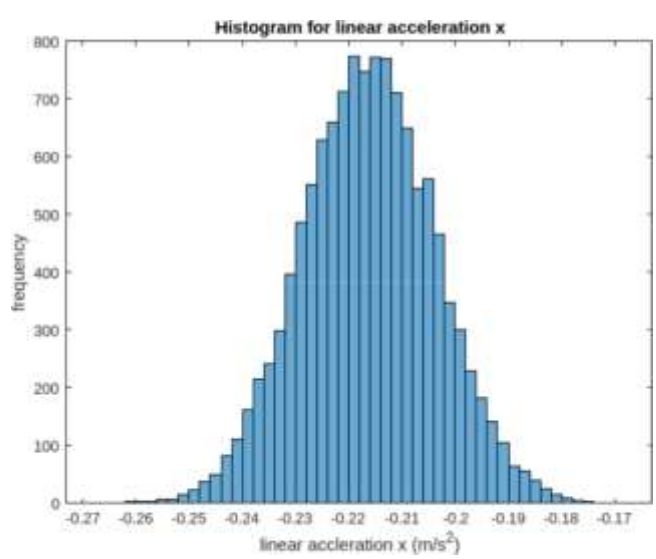


Fig.30 Histogram of linear acceleration in x-axis.

Mean x-axis: -0.2168
Median x-axis: -0.2170
Standard deviation x-axis: 0.0125

Mean y-axis: -0.2120
Median y-axis: -0.2120
Standard deviation y-axis: 0.0128

Mean z-axis: -10.0568
Median z-axis: -10.0570
Standard deviation z-axis: 0.0198

Distribution follows: Gaussian/Normal distribution.

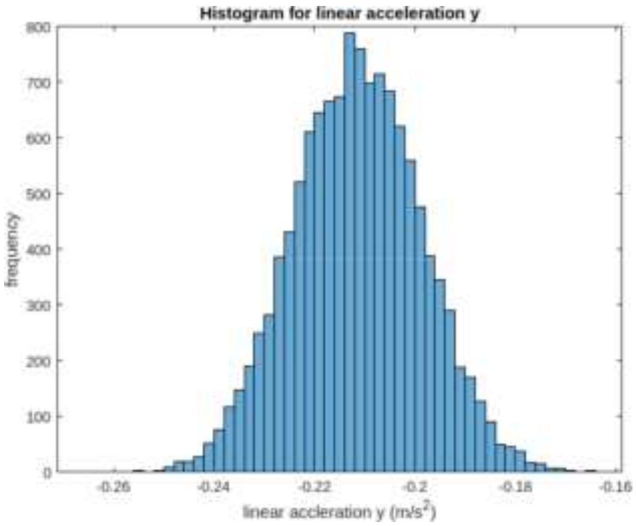


Fig.31 Histogram of linear acceleration in y-axis.

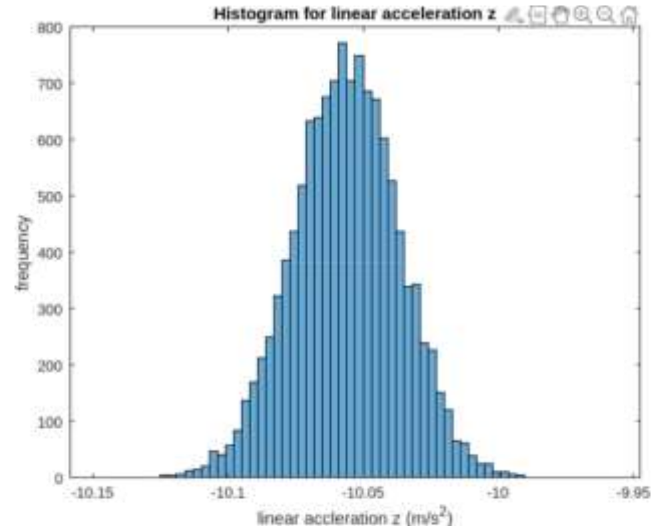


Fig.32 Histogram of linear acceleration in z-axis.

<u>Angular velocity</u>

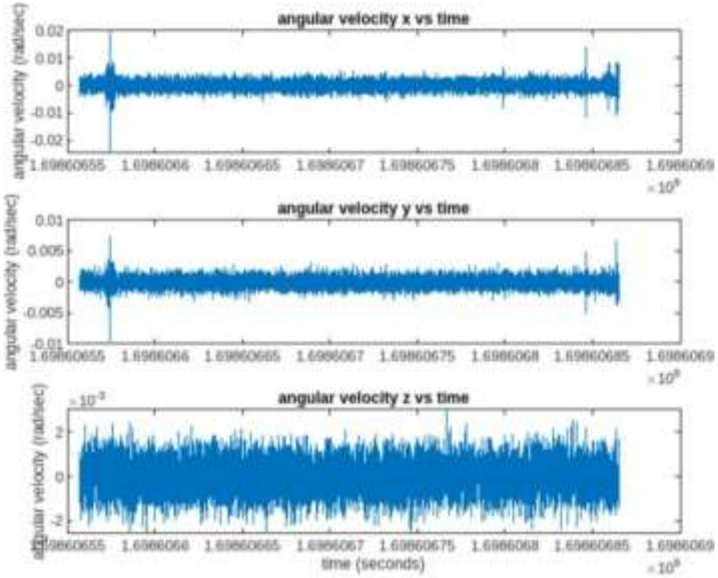


Fig.33 Time series plot of Angular Velocity X,Y, Z.

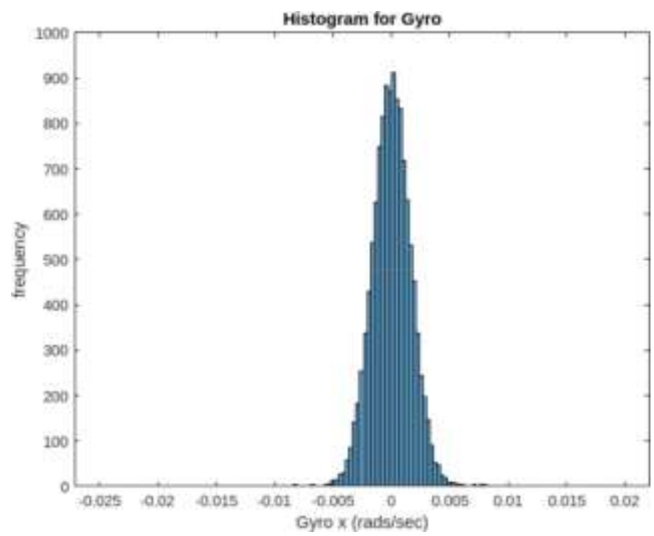


Fig.34 Histogram of gyro in x-axis.

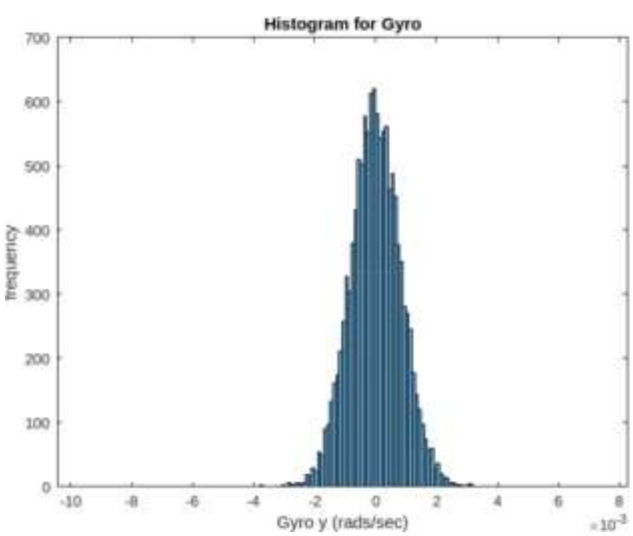


Fig.35 Histogram of gyro in y-axis.

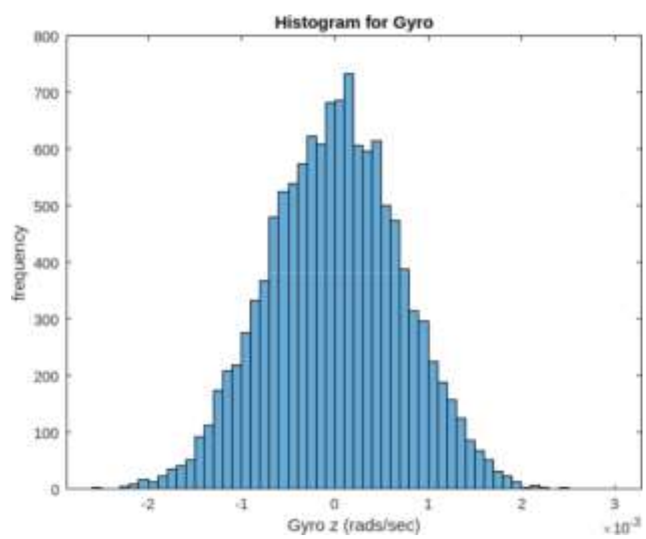


Fig.36 Histogram of gyro in z-axis.

Mean x-axis: 0.0000103
Median x-axis: 0.00001
Standard deviation x-axis: 0.0017

Mean y-axis: 0.000002
Median y-axis: -0.00001
Standard deviation y-axis: 0.00085

Mean z-axis: 0.0000014
Median z-axis: 0.0000145
Standard deviation z-axis: 0.00071

Distribution follows: Gaussian/Normal distribution.

Magnetic Field

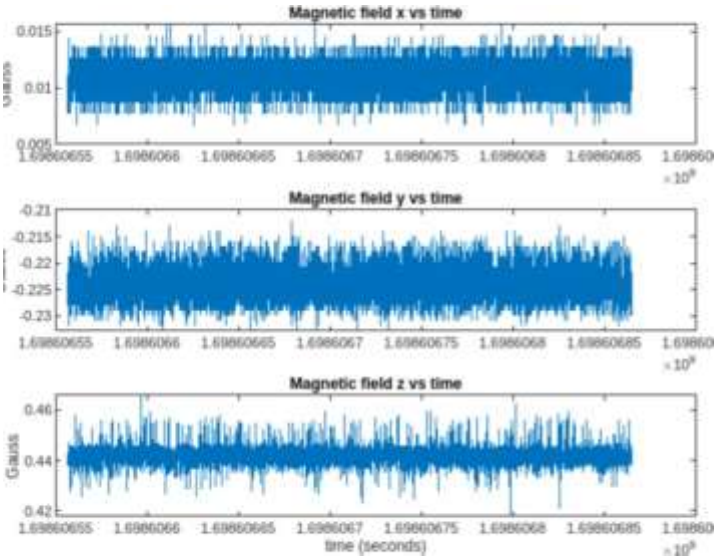


Fig.37 Time series plot of Magnetic Field in X, Y, Z.

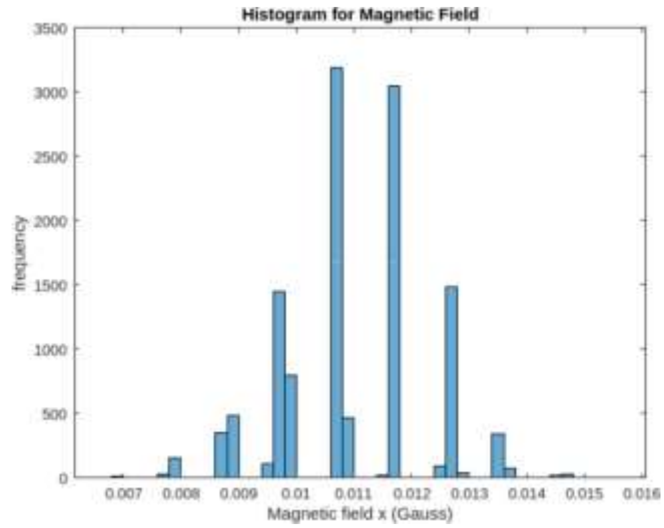
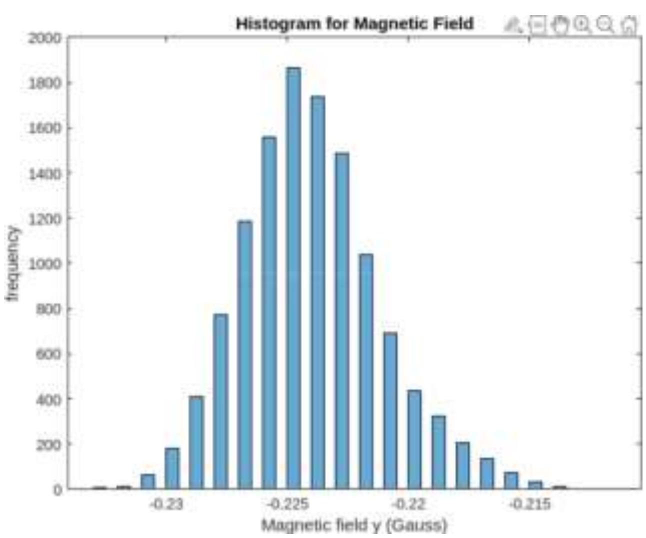


Fig.38 Histogram of magnetic field in x-axis.



(Fig 11, Fig 12)

Fig.39 Histogram of magnetic field in y-axis.

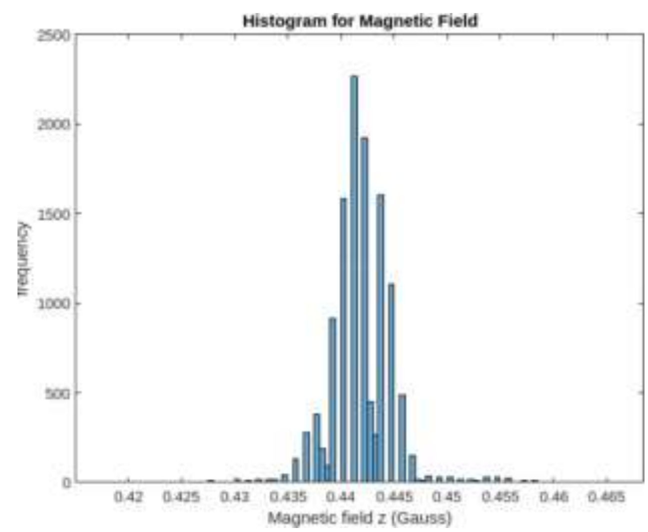


Fig.40 Histogram of magnetic field in z-axis.

Mean x-axis: 0.0109
Median x-axis: 0.0107
Standard deviation x-axis: 0.0013

Mean y-axis: -0.2242
Median y-axis: -0.2239
Standard deviation y-axis: 0.0029

Mean z-axis: 0.4419
Median z-axis: 0.4423
Standard deviation z-axis: 0.0029

Distribution follows: Gaussian/Normal distribution.

Roll, Pitch & Yaw

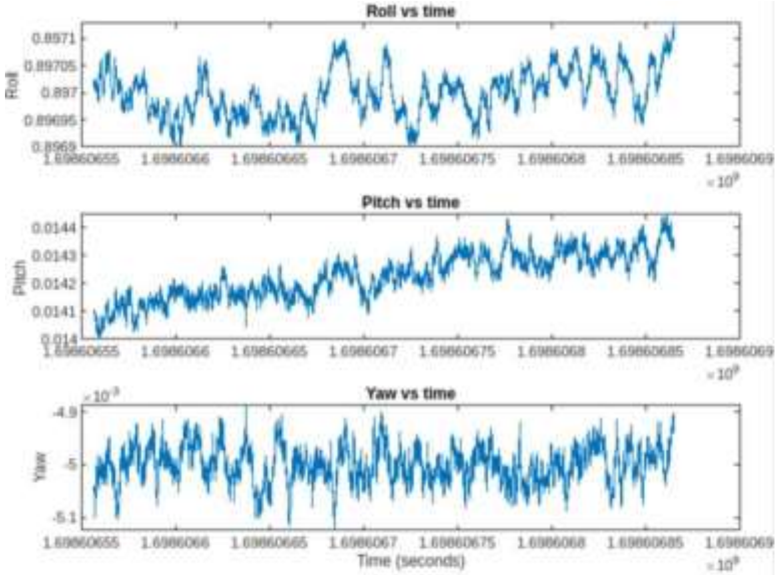


Fig.41 Time series plot of Roll, Pitch & Yaw.

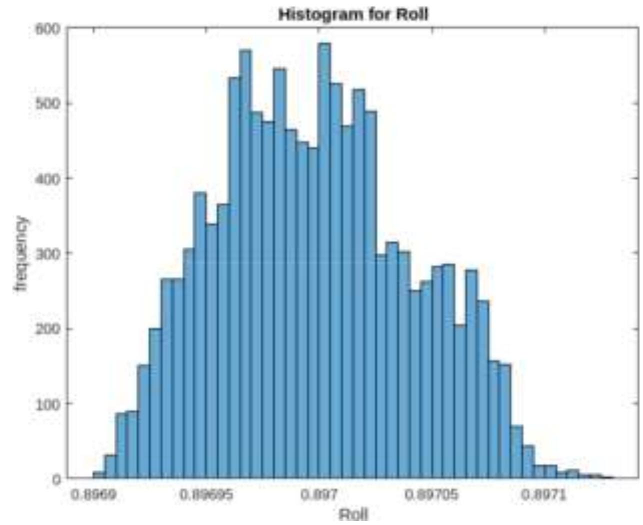


Fig.42 Histogram of Roll.

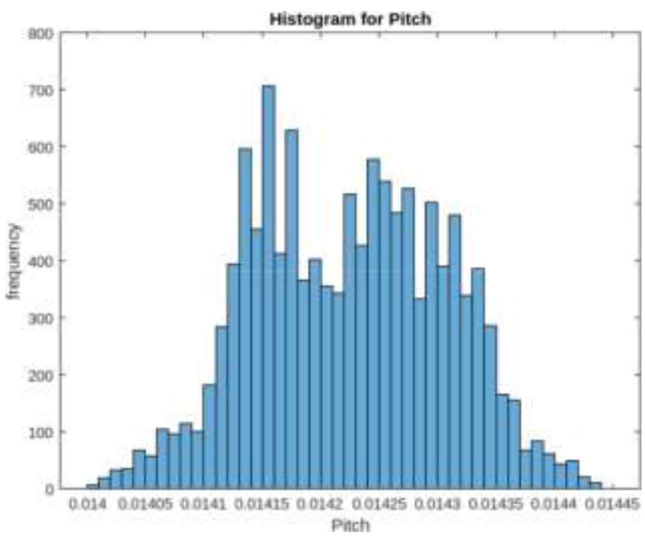


Fig.43 Histogram of Pitch.

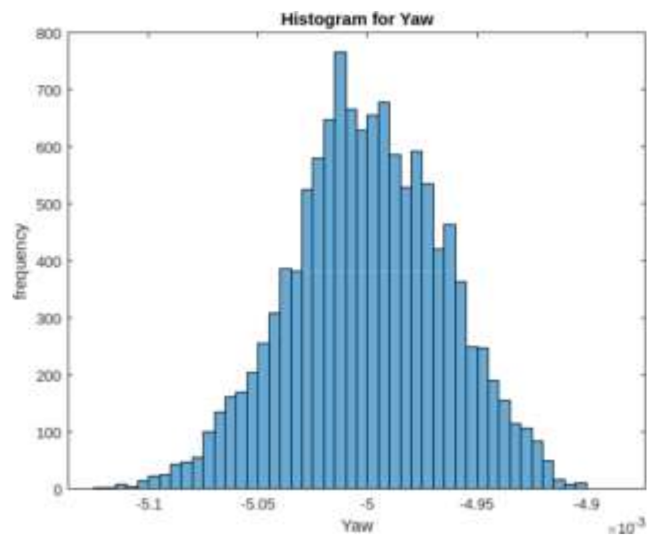


Fig.44 Histogram of Yaw.

Mean roll: 0.897
Median roll: 0.897
Standard deviation roll: 0.00004

Mean pitch: 0.0142
Median pitch: 0.0142
Standard deviation pitch: 0.00008

Mean yaw: -0.0050
Median yaw: -0.0050
Standard deviation yaw: 0.00003

Distribution follows: Gaussian/Normal distribution.

Moving Data Analysis

Data was gathered by subjecting the IMU sensor to motion along all three axes. During Motion 1, the IMU experienced acceleration in the y-axis direction. In Motion 2, the IMU underwent acceleration in the x-axis direction. In Motion 3, the IMU encountered acceleration in the z-axis direction. These movements were repeated several times over a duration, and video recordings were made to document the process. The accompanying images provide snapshots of these motions.

Motion 1:

Fig.45 Motion 1. Movement in y-axis .

Motion 2:

Fig.46 Motion 2. Movement in x-axis .

Motion 3:

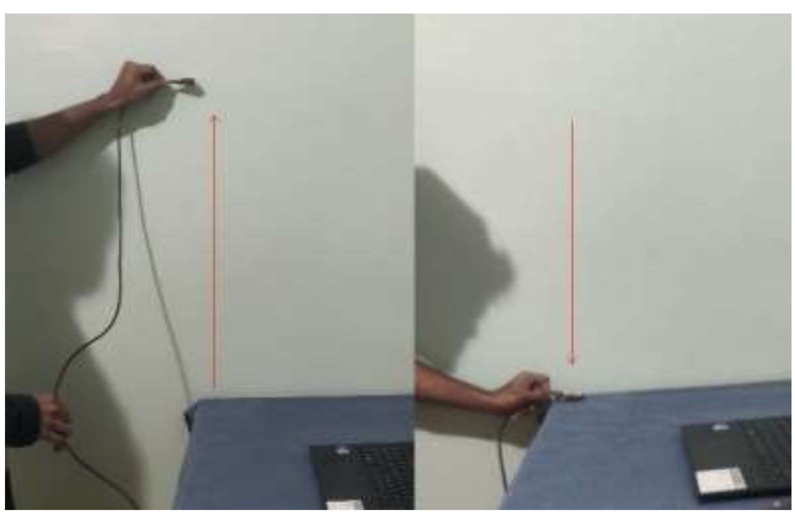


Fig.47 Motion 3. Movement in z-axis .

Linear Acceleration

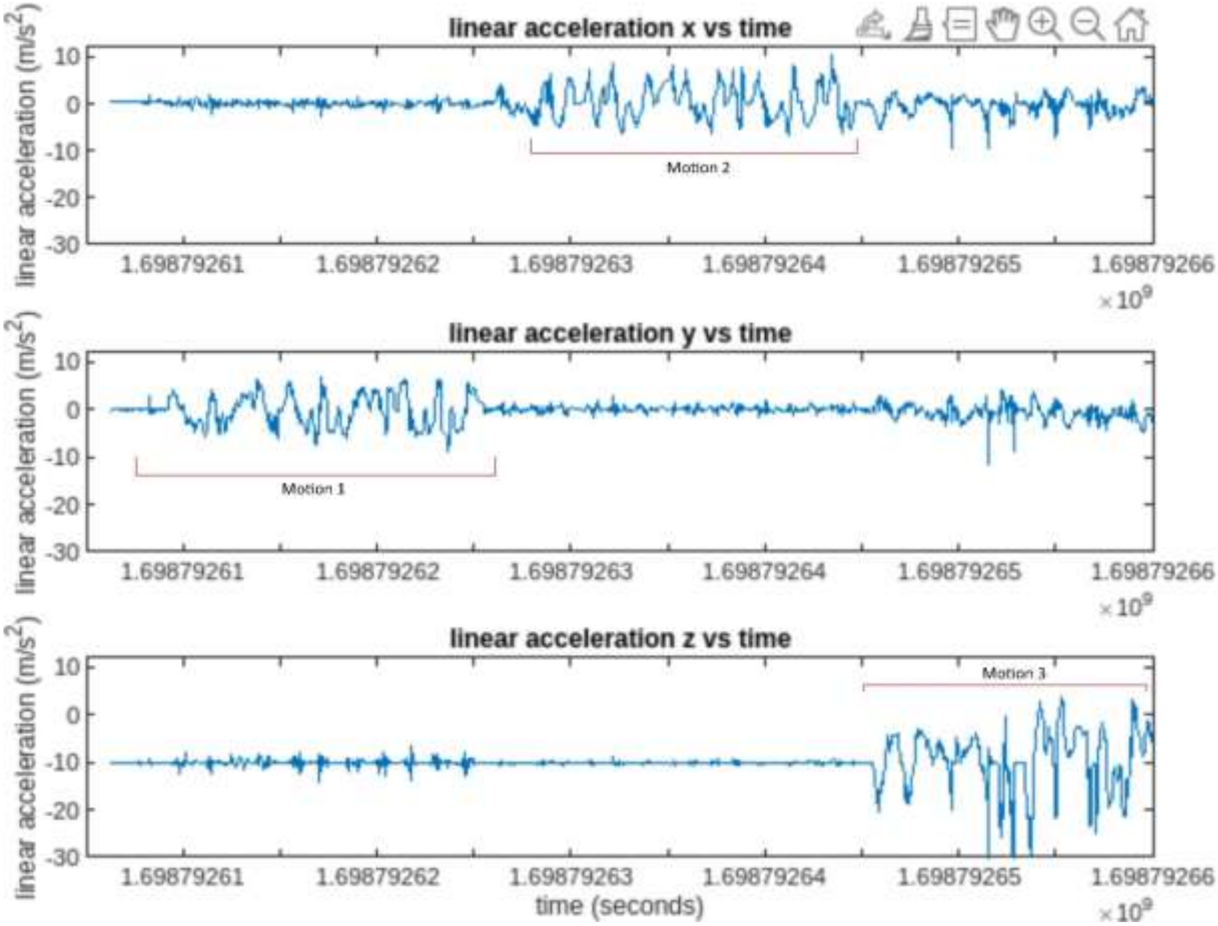


Fig.48 Time series plot of linear acceleration in all 3-axes, highlighting the occurrence of motions.

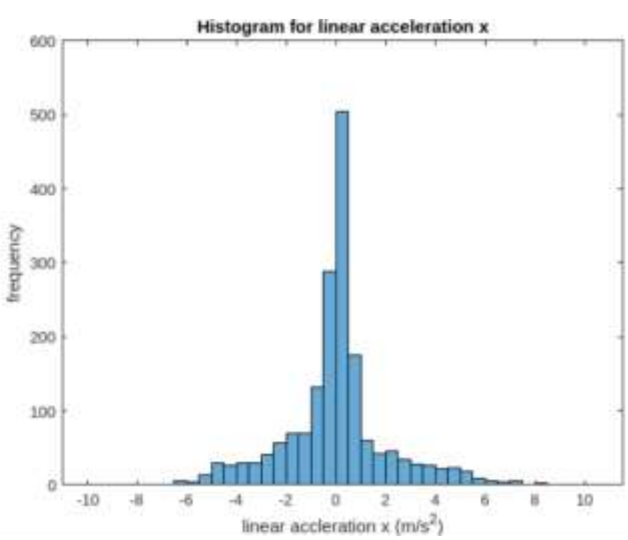


Fig.49 Histogram of linear acceleration in x-axis.

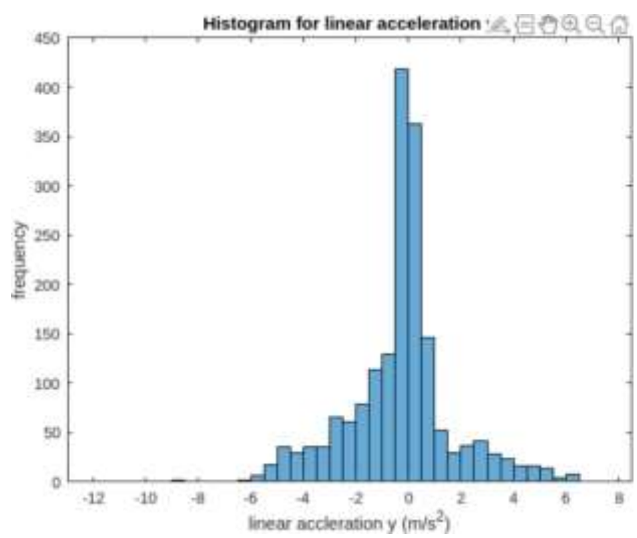


Fig.50 Histogram of linear acceleration in y-axis.

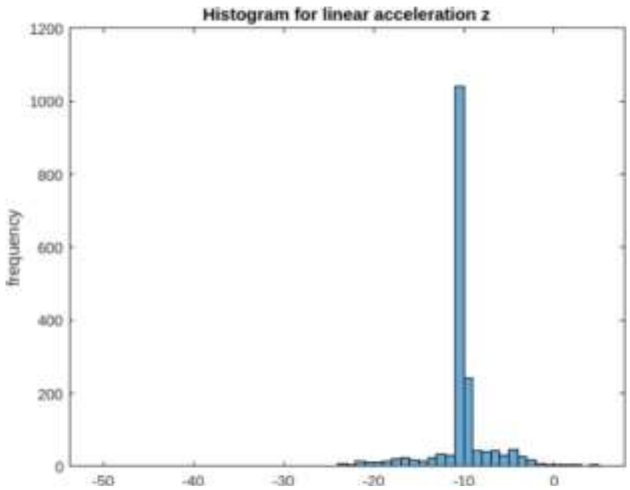


Fig.51 Histogram of linear acceleration in z-axis.

Mean x-axis: 0.0348
Median x-axis: 0.1110
Standard deviation x-axis: 2.1204

Mean y-axis: -0.2931
Median y-axis: -0.0770
Standard deviation y-axis: 2.0336

Mean z-axis: -10.149
Median z-axis: -10.1120
Standard deviation z-axis: 3.7066

Distribution follows: Gaussian/Normal distribution.

Angular velocity

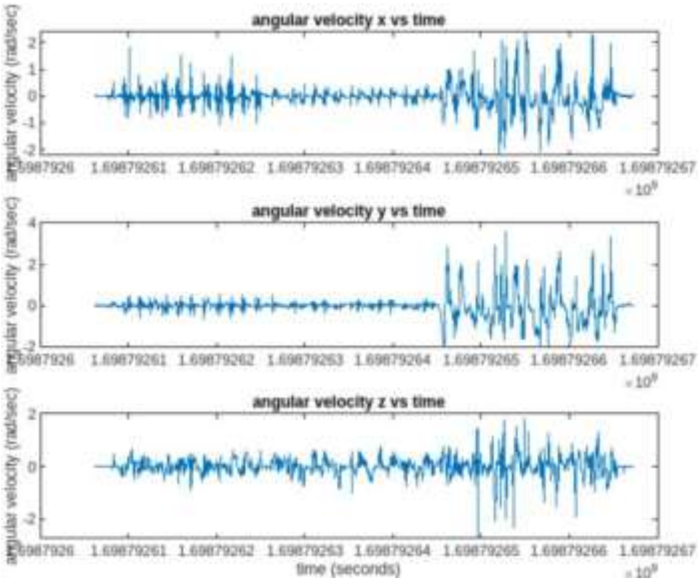


Fig.52 Time series plot of Angular Velocity X,Y, Z.

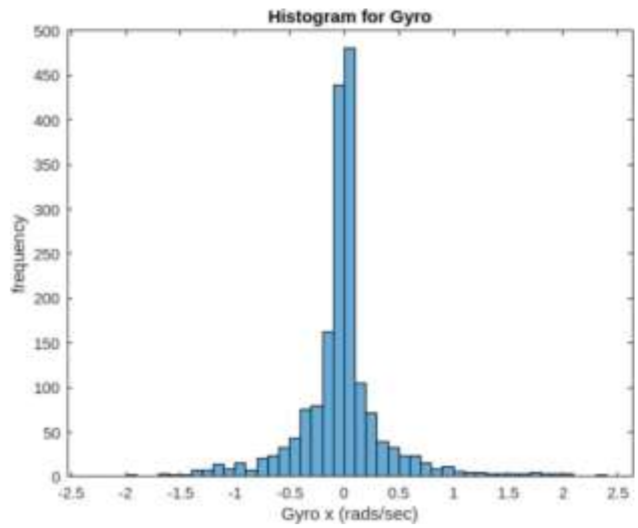


Fig.53 Histogram of gyro in x-axis.

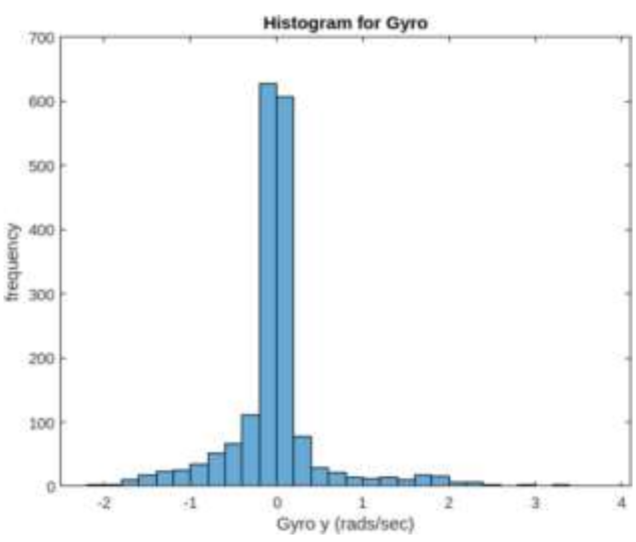


Fig.54 Histogram of gyro in y-axis.

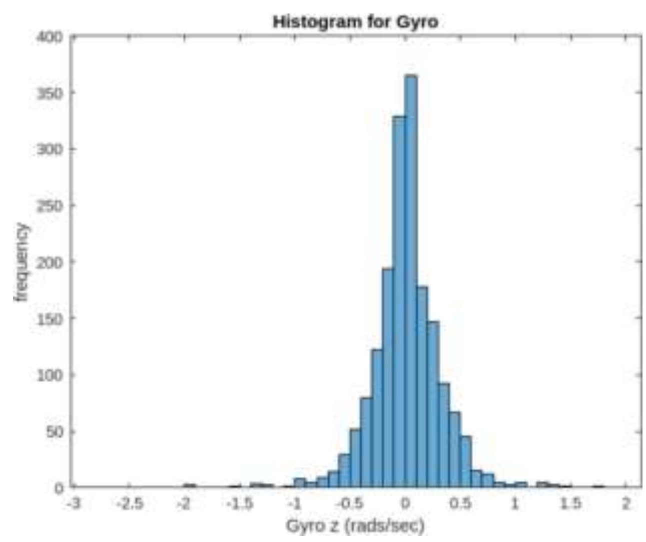


Fig.55 Histogram of gyro in z-axis.

Mean x-axis: -0.0174 Median x-axis: -0.0034 Standard deviation x-axis: 0.4445

Mean y-axis: -0.0143 Median y-axis: -0.0069 Standard deviation y-axis: 0.5659

Mean z-axis: 0.0083 Median z-axis: 0.0011 Standard deviation z-axis: 0.3521

Distribution follows: Gaussian/Normal distribution.

<u>Magnetic field</u>

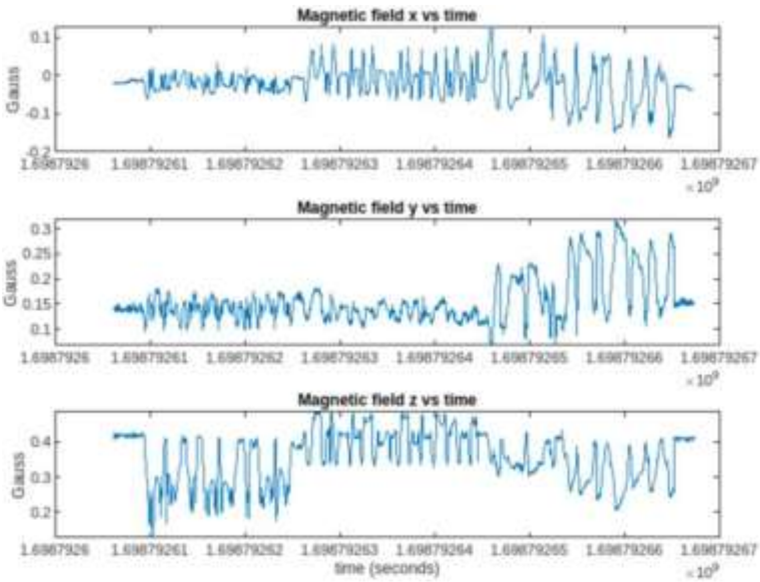


Fig.56 Time series plot of Magnetic field X, Y, Z.

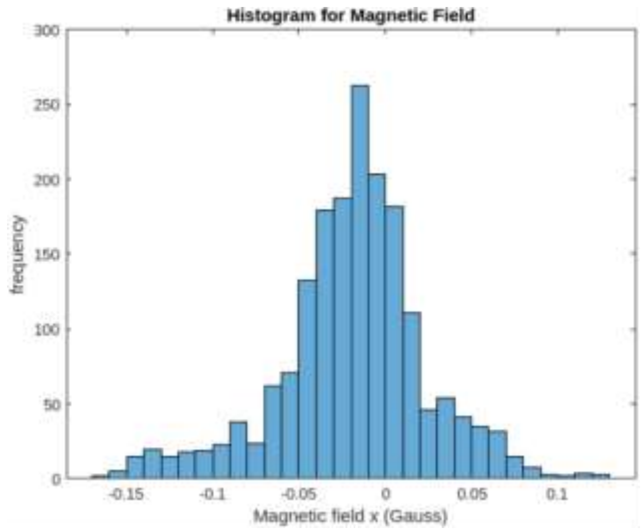


Fig.57 Histogram of magnetic field in x-axis.

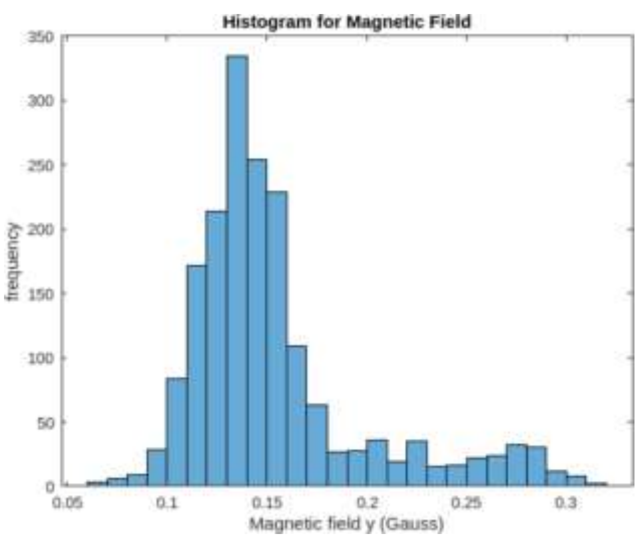


Fig.58 Histogram of magnetic field in y-axis.

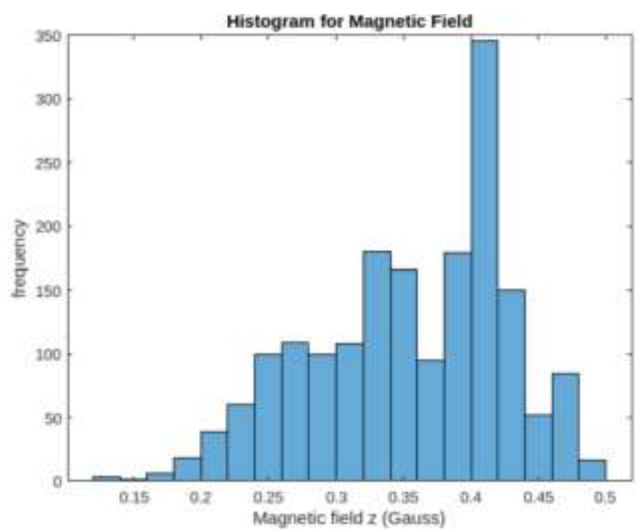


Fig.59 Histogram of magnetic field in z-axis.

Mean x-axis: -0.01907 Median x-axis: -0.0169 Standard deviation x-axis: 0.04313

Mean y-axis: 0.1540 Median y-axis: 0.1414 Standard deviation y-axis: 0.0448

Mean z-axis: 0.3553 Median z-axis: 0.3629 Standard deviation z-axis: 0.0713

Distribution follows: Gaussian/Normal distribution.

Roll, Pitch & Yaw

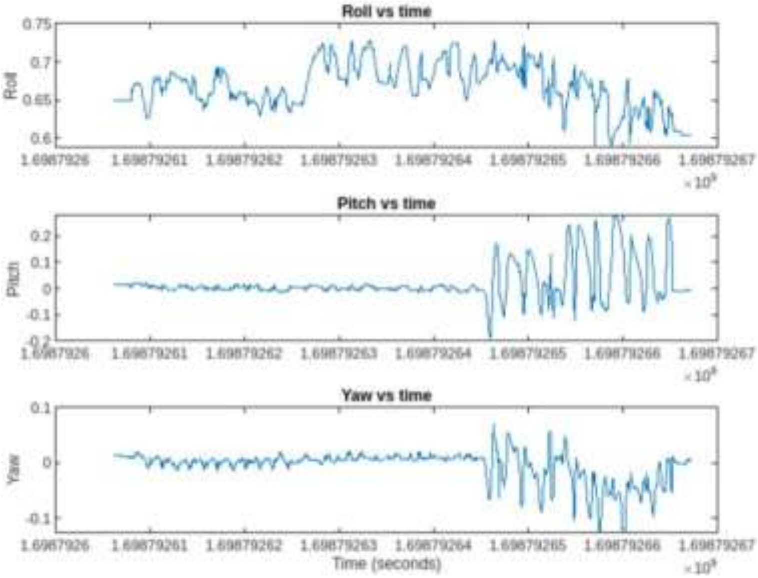


Fig.60 Time series plot of Roll, Pitch, Yaw.

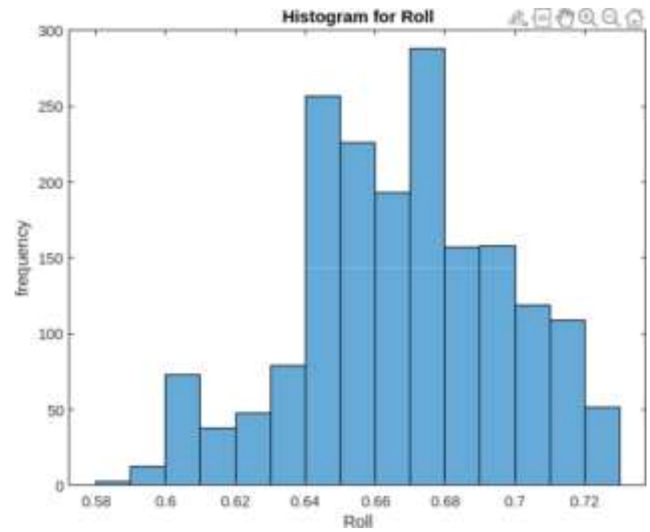


Fig.61 Histogram of Roll.

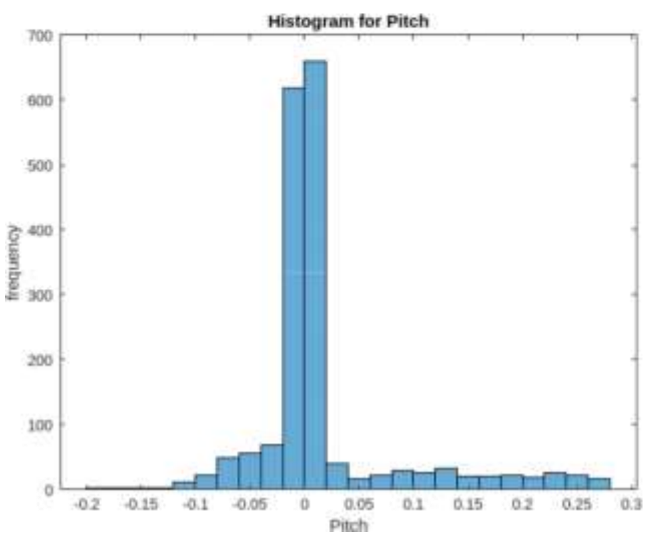


Fig.62 Histogram of Pitch.

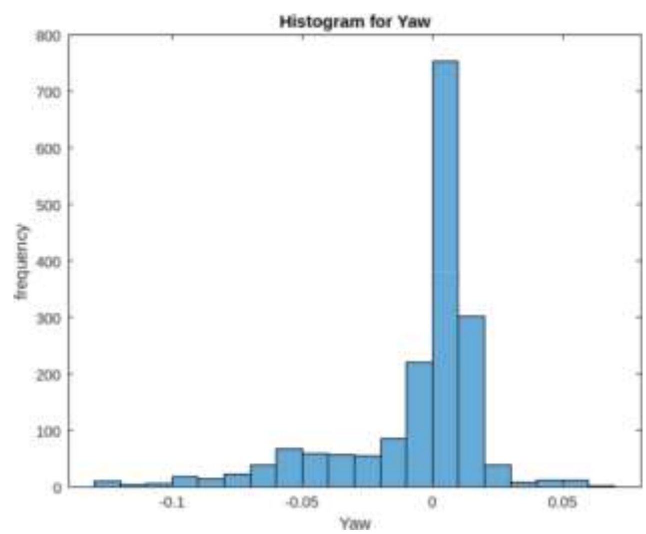


Fig.63 Histogram of Yaw.

Mean roll: 0.6686	Mean pitch: 0.0182	Mean yaw: 0.0060
Median roll: 0.6686	Median pitch: 0.0025	Median yaw: -0.0060
Standard deviation roll: 0.0294	Standard deviation pitch: 0.0685	Standard deviation yaw: 0.0288

Distribution follows: Gaussian/Normal distribution.

Questions and Answers

1. **What can you say about the noise in your short stationary data? What was the median, Mean, and distribution?**
   Even though the Inertial Measurement Unit (IMU) remained still during data collection, the time series plots show the presence of inherent noise and errors. The descriptions of median, mean values, and axis distributions are provided in figures 29 to 44. These plots suggest that the data follows a Gaussian or normal distribution, which indicates the presence of Gaussian or white noise. The variations observed in the data may be attributed to slight vibrations from the sensor or external environmental factors. Additionally, the bias error can gradually affect the sensor measurements, increasing over time.

2. **How did you align the video and Vectornav data? What inferences did you draw from the IMU data to successfully link it with the video?**
   One team member was simultaneously recording the motion video, while another was configuring the rosbag containing Vectornav data. They ensured precise synchronization between these activities. The timestamp in the rosbag message was aligned with the timestamp of the video captured on the phone. The header timestamp captured the system time and served as a means to correlate the data with the video, enabling the extraction of screen captures at specific points of interest in the IMU outputs.

3. **How do your measurements compare to the performance listed in the VN100 datasheet?**
   The performance metrics outlined in the VN100 datasheet exceeds our measurements. This disparity arises from the fact that our data is gathered in an environment prone to various sources of noise and vibrations. In contrast, the performance values documented in the datasheet were achieved through rigorous testing and multiple calibrations at the factory, enhancing their accuracy.

4. **If the performance in your dataset was worse than the datasheet, what sources of noise do you think were present? Why?**
   As previously noted, the angle random walk and rate random walk components are influenced by external vibrations in the environment. The plots illustrate a noticeable drift in the data, which suggests the presence of Gaussian or white noise. It's possible that inherent bias instability errors could be present even in static inertial conditions, stemming from other environmental factors.

5. **If you had to suggest which AVAR (Allan Variance) plots went with which locations/conditions, how would you match them? What sources of noise would be present in this environment?**
   Judging from the plots and the noise parameter data, my assessment suggests that the bag files correspond to the following locations: Location A is the 5th floor of ISEC, Location B is the ISEC basement, Location C is the 3rd floor of a wooden house, and Location D is the Snell library basement. After comparing the noise parameters across all four locations, I infer that the wooden house and ISEC 5th floor are more likely to experience heightened environmental disruptions, while the ISEC and Snell library basements are expected to have lower noise levels with minimal external disturbances. In these settings, it's probable that the angle random noise and bias instability are more prominent.

6. **What do your results tell you about the conditions you should measure Allan variance under to understand the best sensor performance possible?**
   To gain a deeper insight into sensor performance, it's essential to take specific conditions into account when measuring the Allan variance. First and foremost, the sensor must be effectively shielded from external disruptions. Furthermore, collecting a dataset over an extended period is crucial for comprehending the propagation of long-term errors. It's also vital to ensure that data is sampled at the desired rates for accurate analysis. Prior to measurements, correcting the sensor's noise characteristics through calibration is important. By adhering to these guidelines, one can obtain the most accurate assessment of sensor performance.

7. **If you were trying to characterize a new sensor with unknown performance, briefly (2 sentences max) explain what, where, and how you would measure to understand sources of noise in the sensor and environment, and the performance you could expect under its operating conditions.**
   To assess the performance and sources of noise in a new sensor with unknown characteristics, I would conduct extended stationary data recordings in a carefully controlled environment to minimize external disturbances. Analyzing this data would help me comprehend various noise sources and evaluate performance across a spectrum of operating conditions.