REPORT

LAB 04

(NAVIGATION WITH IMU AND MAGNETOMETER)

INTRODUCTION

In robotics and other fields requiring accurate position and orientation data, navigation using an Inertial Measurement Unit (IMU) and a magnetometer is an extensively used technique. Accelerometers and gyroscopes are commonly used in IMUs to measure angular velocity and linear acceleration, respectively. A magnetometer is used to measure the direction of the Earth's magnetic field. The position and orientation of the device in three dimensions can be estimated by combining the data from these sensors.

I. Calibrating a magnetometer involves compensating for both hard iron and soft iron distortions:

- Calibration of Hard Iron:
  1. Detects and corrects for continuous offset biases in magnetometer readings caused by magnetic materials in close vicinity.
  2. Involves gathering information from the magnetometer in different orientations to calculate and eliminate offset biases.
- Calibration of Soft Iron:
  1. Rectifies magnetic field distortions caused by the gadget or adjacent magnetic materials.
  2. Needs collecting data in various orientations to describe the ellipsoidal distortion and using transformation matrices to adjust measurements.

II. Processing and Integration of Sensor Data:

- Noise Reduction:
  1. Low-pass filters can be used to eliminate high-frequency interference from sensor data while maintaining the important signals.
  2. For accelerometers in particular, proper filtering is essential to obtaining precise velocity and position estimates.
- Dead Reckoning:
  1. Estimates of linear motion are obtained by twice integrating accelerometer data: once for position and once for velocity.
  2. Estimates of angular motion are obtained by integrating gyroscope data.
  3. When estimating position without external references, dead reckoning is crucial.
- Sensor Fusion with GPS:
  1. Using GPS and IMU/magnetometer data together improves navigation accuracy.
  2. GPS data is a high-quality external measurement source that sensor fusion algorithms use to correct drift and long-term errors in estimates based on IMUs and magnetometers.

MAGNETOMETER CALIBERATION

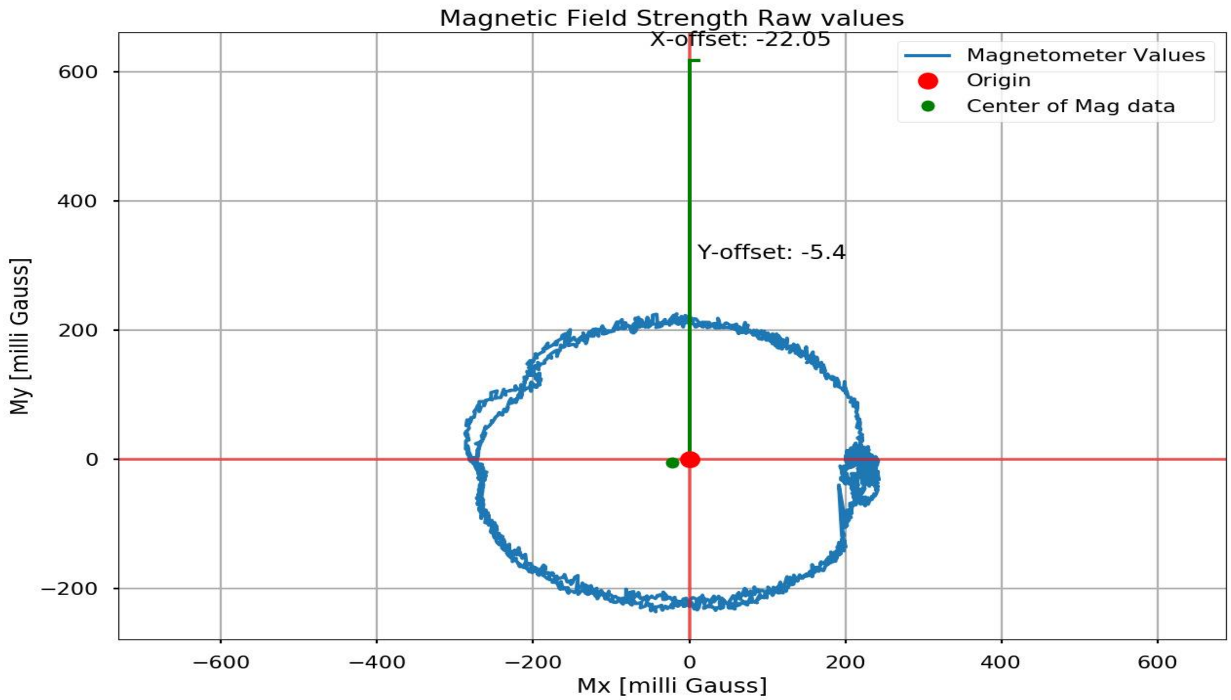

Fig 1: Magnetometer Data Before Correction

Correcting the heading, or yaw angle, of a vehicle is essential for accurate navigation. To achieve this, it is necessary to account for the hard-iron and soft-iron distortions of the magnetometer data. Hard iron distortions result from the sensor location, causing a permanent bias from the true zero of the magnetometer data. Soft iron effects, on the other hand, are distortions in the existing magnetic field, resulting in stretching or warping of the magnetic field. Both effects can be visually displayed and corrected through plotting the magnetometer data. By correcting the raw magnetometer data, we can obtain accurate heading measurements for precise navigation.

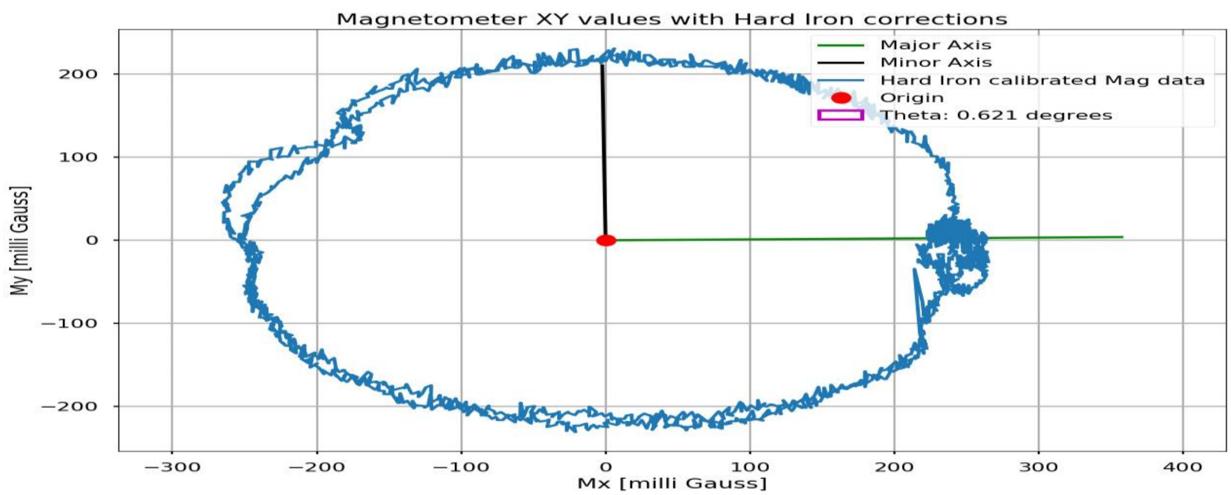

Fig 2: Magnetometer Data with Hard Iron Correction

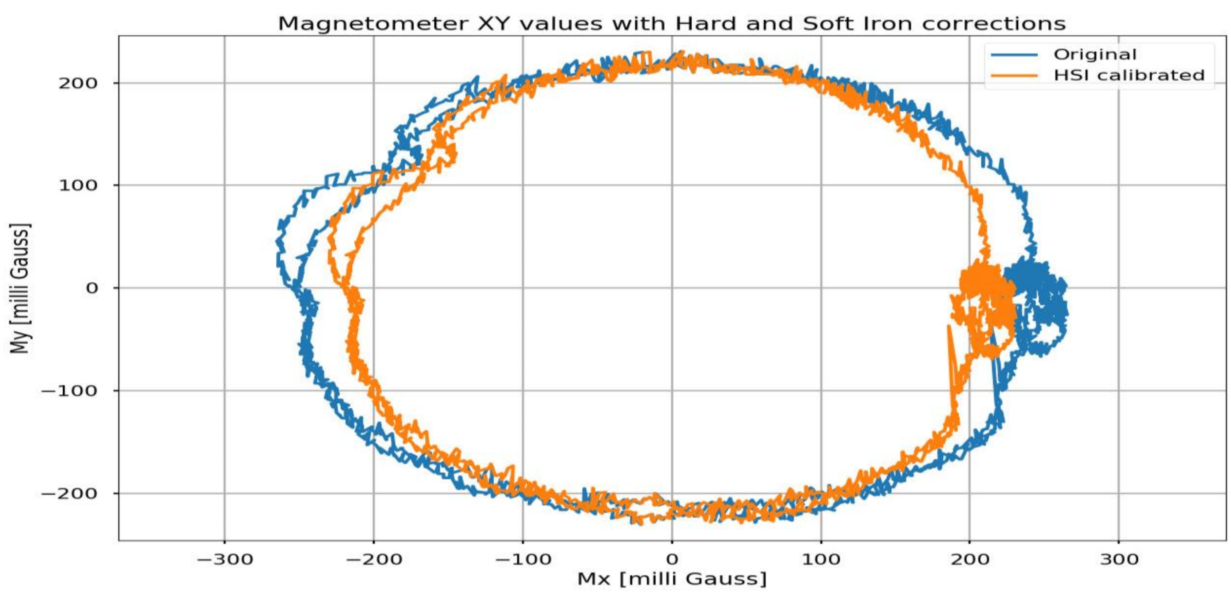

Fig 3: Magnetometer Data with Hard Iron and Soft Iron Corrections

The accelerometer and gyroscope data were combined with a complementary filter to estimate the yaw angle. The complementary filter is a type of sensor fusion technique that combines multiple sensor readings to produce a more accurate estimate than any single sensor alone.

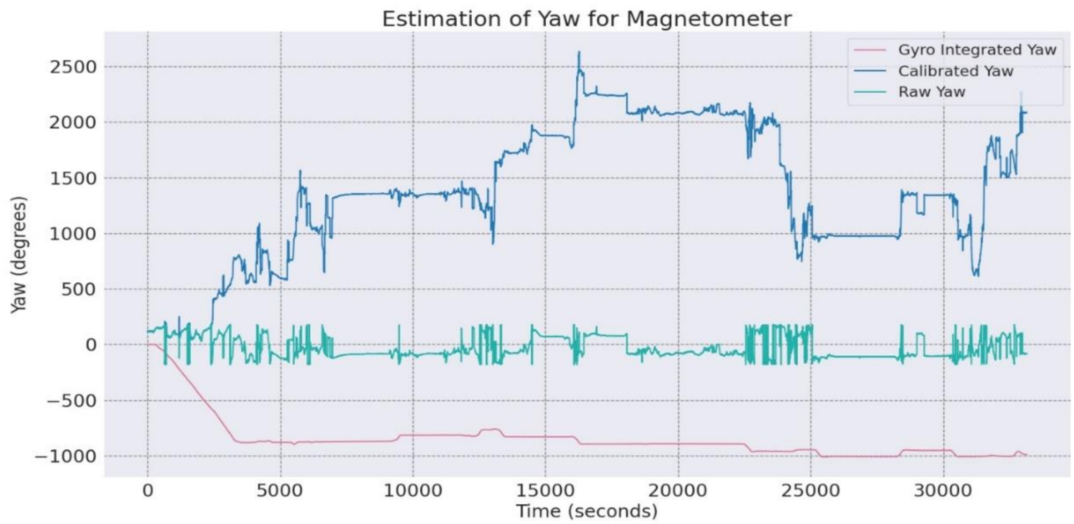

Fig 4: Yaw Estimation & Caliberated Yaw Estimation

The gyro-integrated yaw is calculated based on the angular velocity measured by the gyroscope, while the calibrated yaw is calculated based on the magnetic field measured by the magnetometer.

The gyro-integrated yaw is susceptible to drift, which is an error that accumulates over time. The calibrated yaw is less susceptible to drift, but it is more susceptible to noise and interference from other magnetic fields.

The overall trend of the graph shows that the yaw angle is increasing over time. This suggests that the object is rotating in a clockwise direction (the car moved in circles).

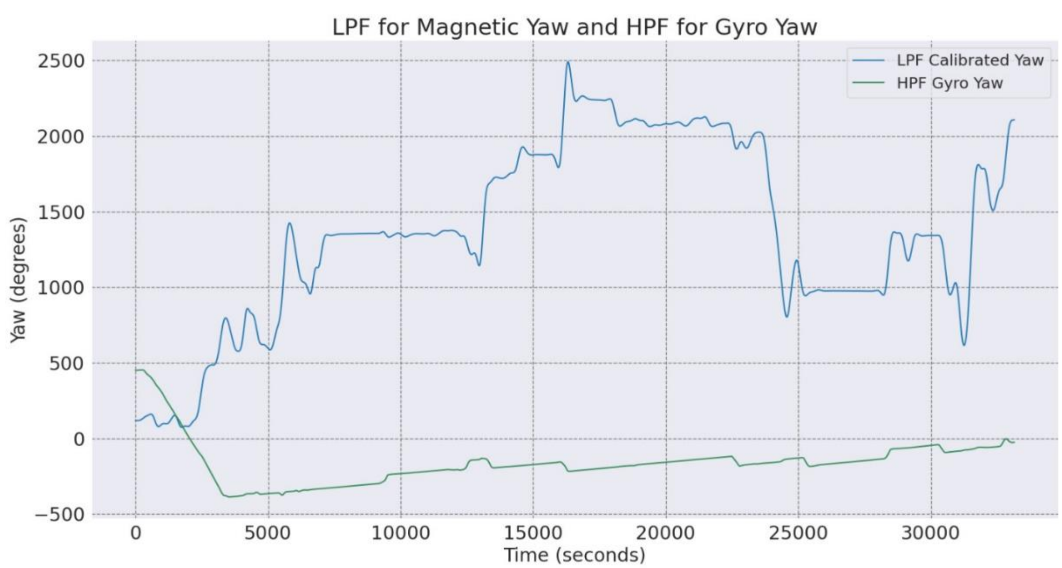

Fig 5: Low Pass Filter and High Pass Filter

A first-order filter with two parts:

1. Low-pass filter for the accelerometer data
2. High-pass filter for the gyroscope data

was used as the complementary filter in this case.

The high-pass filter was applied to eliminate the drift error from the gyroscope readings, and the low-pass filter was used to eliminate the high-frequency noise from the accelerometer readings. The complementary filter was able to produce precise and reliable estimations of the orientation and position of the object being measured by integrating the filtered data from both sensors.

The yaw results to 56.90994539698936

ESTIMATE THE FORWARD VELOCITY

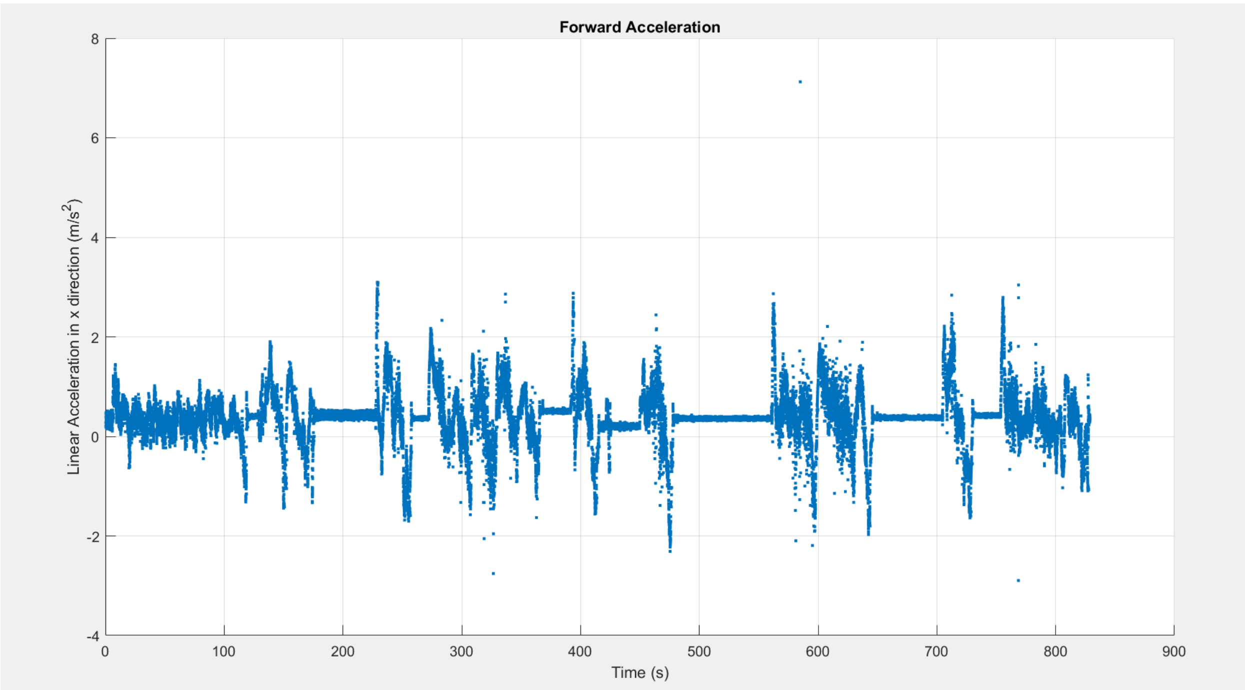

Fig 6: Forward Acceleration

The IMU is installed on the vehicle with the x axis pointing forward. Consequently, an analysis of the linear acceleration in the x direction has been conducted.

The vehicle's forward acceleration was determined by analyzing accelerometer data from the IMU. There were some difficulties when integrating stationary position data, causing a bias in the forward speed estimation. To rectify this, stationary data was filtered out, to enable the eliminating of the bias. There are other places in the plot where the vehicle stops, but it is offset from zero. These data points can be set to zero directly to avoid the accumulation of integration errors, which can be seen as no noise when the car is not moving.

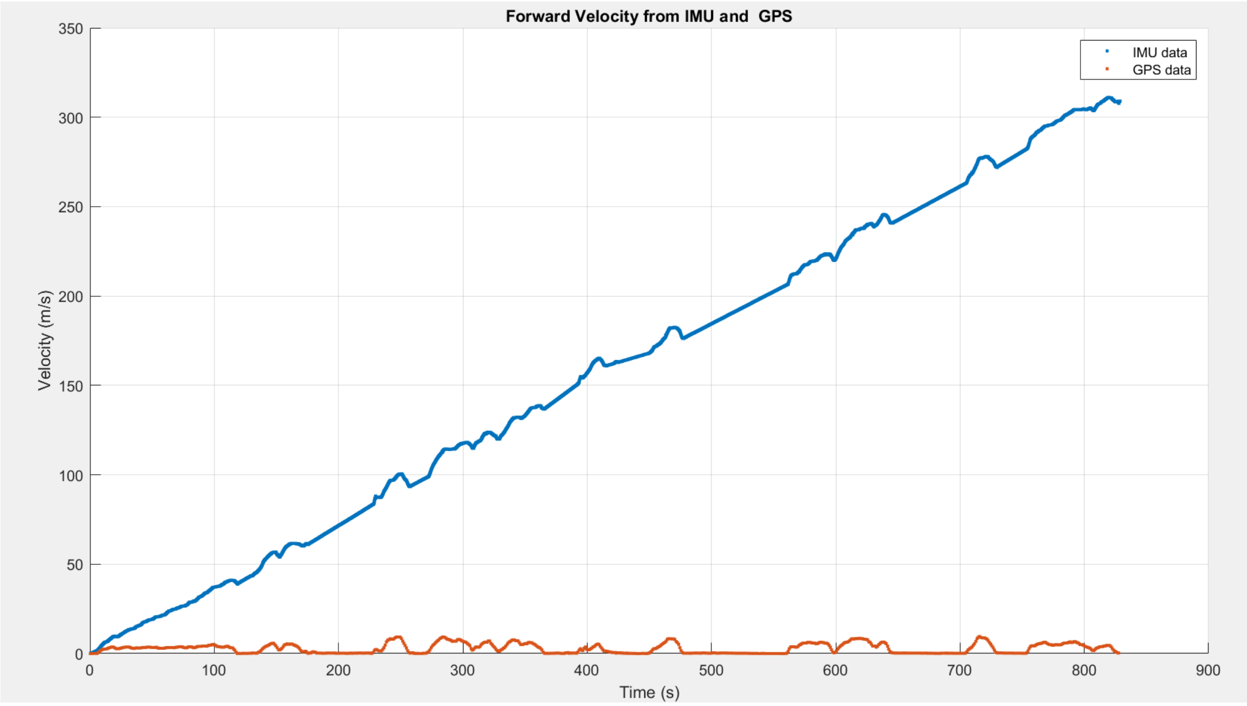

Fig 7: Forward Velocity IMU and GPS

The graph shows that the IMU velocity is slightly higher than the GPS velocity due to the IMU velocity being more responsive to changes in acceleration and the IMU velocity drifting over time. This is because the IMU velocity is integrated from the acceleration data, and the acceleration data is noisy. The GPS velocity is used to correct the IMU velocity, and the corrected velocity is the velocity that is shown on the graph.

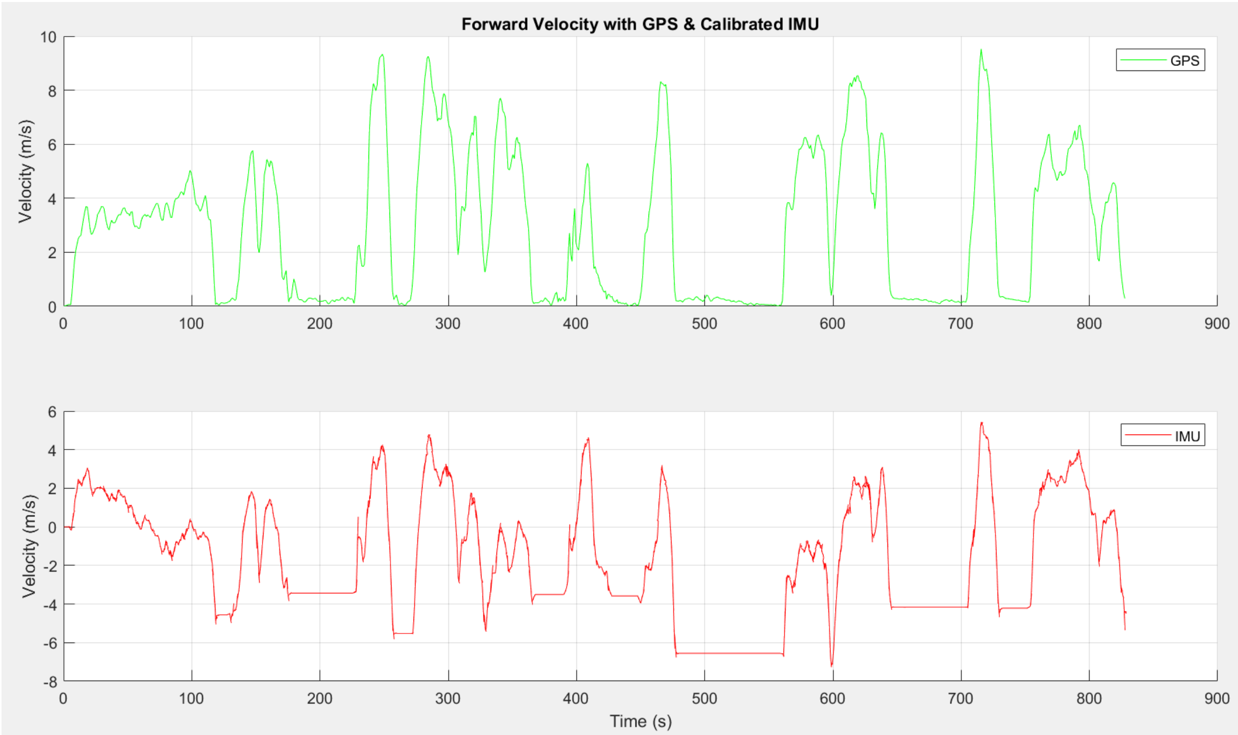

Fig 8: Forward Velocity with GPS and Calibrated IMU

IMU is typically calibrated using the gyroscope and accelerometer data, while the GPS receiver is calibrated using satellite signals. New velocity estimates reveal that the peaks and troughs are aligned in time, but the scale changes over time. This is mainly due to the accumulation of errors caused by the integration of noisy acceleration signals. Additionally, the route traversed is not flat, which may contribute some gravitational component to the forward acceleration in the pitch angle. These findings are significant for understanding the accuracy of velocity estimates and the challenges of integrating acceleration signals.

The plot shows that the IMU velocity is slightly higher than the GPS velocity. This is because the IMU is more responsive to changes in acceleration, while the GPS is more accurate over long distances. The difference between the IMU and GPS velocities is largest at the beginning and end of the graph, when the car is accelerating and decelerating. This is because the IMU can capture the initial acceleration and deceleration of the car more accurately than the GPS. The difference between the IMU and GPS velocities is also larger at higher speeds. This is because GPS can become less accurate at higher speeds.

The car is not always accelerated to calibrate the IMU velocity. Certain points in the data need to be set to zero. For instance, the data from the times the car stopped for a crossing or at a red light needs to be deducted from the recorded data. These data points will therefore be set to zero since the vehicle is at rest. The plot with the calibrated IMU data is shown above.

DEAD RECKONING WITH IMU

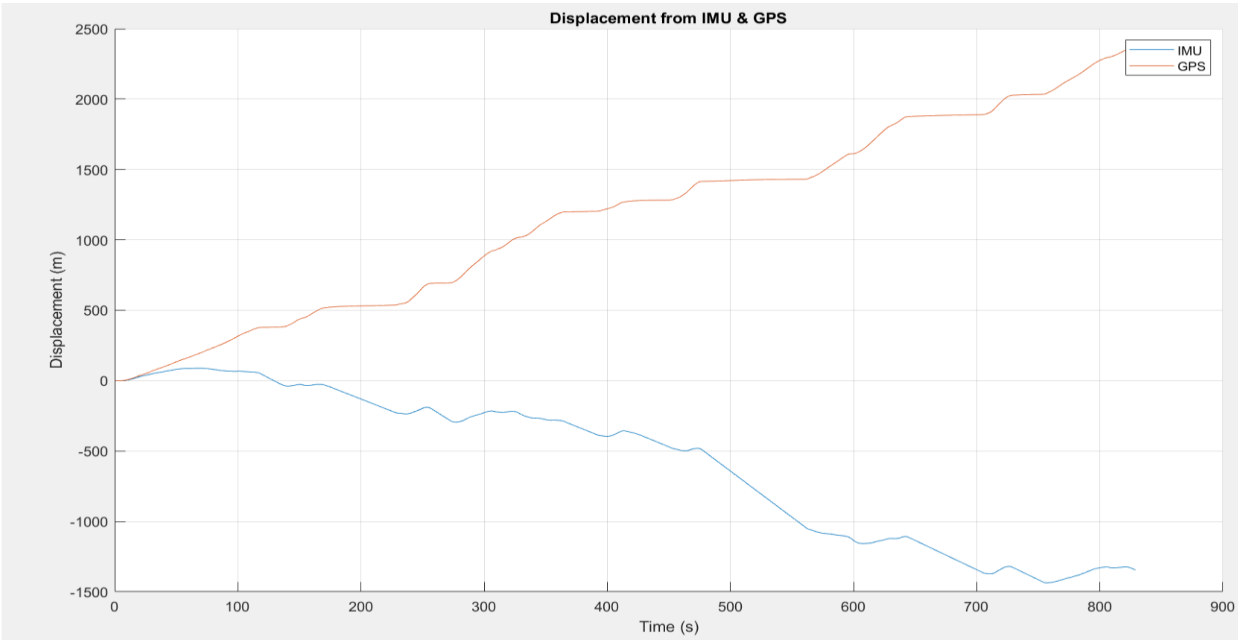

Fig 9: Displacement from IMU and GPS

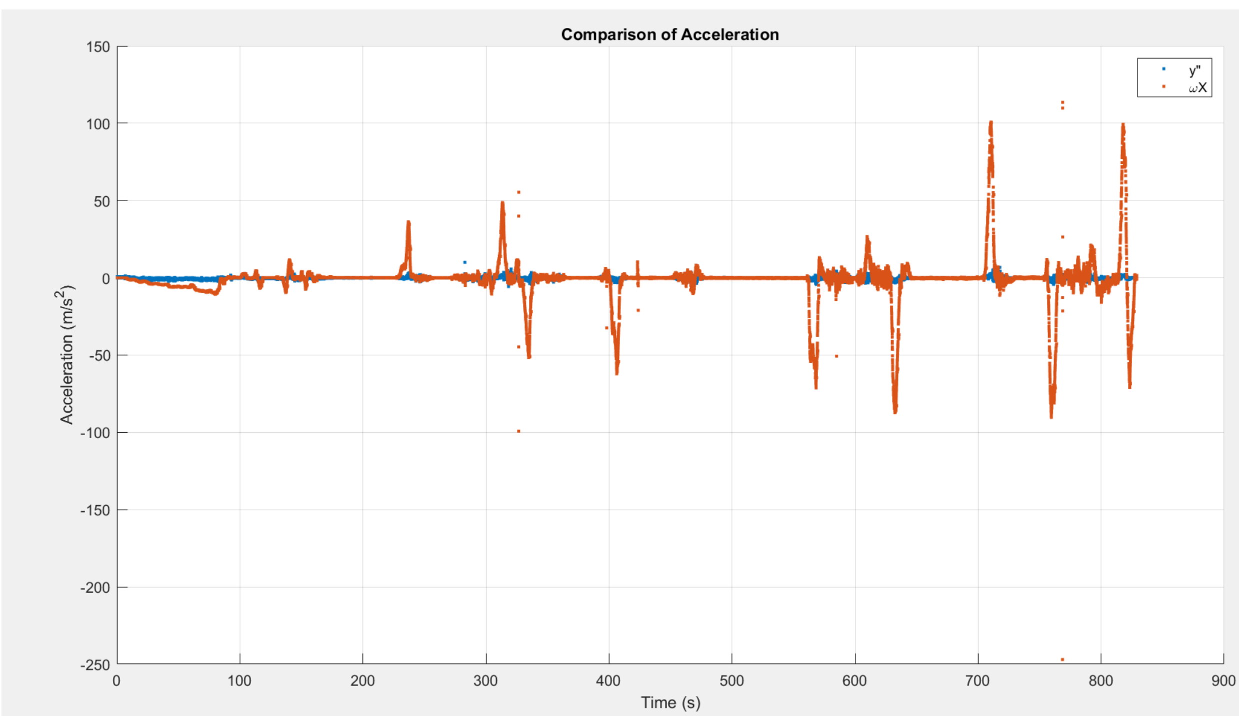

Fig 10: Comparison of Acceleration

The gyroscope measures the rate of rotation around a specific axis, whereas the accelerometer gauges the object's acceleration along a designated axis. Consequently, the gyroscope can only detect changes in the object's orientation, whereas the accelerometer captures alterations in both orientation and velocity. This implies that the accelerometer is more responsive to modifications in linear motion, while the gyroscope is more sensitive to adjustments in rotational motion.

From the plots, the two paths being compared closely align, with a slight discrepancy arising from the various sources of measurements used for linear acceleration in the Y direction ($\ddot{y}$). The accelerometer provides data for $\ddot{y}$ observed, while the computed acceleration ωX, where ωX is obtained from the gyroscope, introduces a minor variance. This disparity is anticipated due to the distinct measurement origins and inherent limitations of each sensor.

Moreover, both sensors are susceptible to noise and other interferences that can impact their precision. Gyroscopes may be influenced by temperature fluctuations and drift, while accelerometers can be affected by external vibrations and shocks. Therefore, the subtle disparities observed between ωX and $\ddot{y}$ measurements may stem from the inherent constraints and disturbances associated with each sensor.

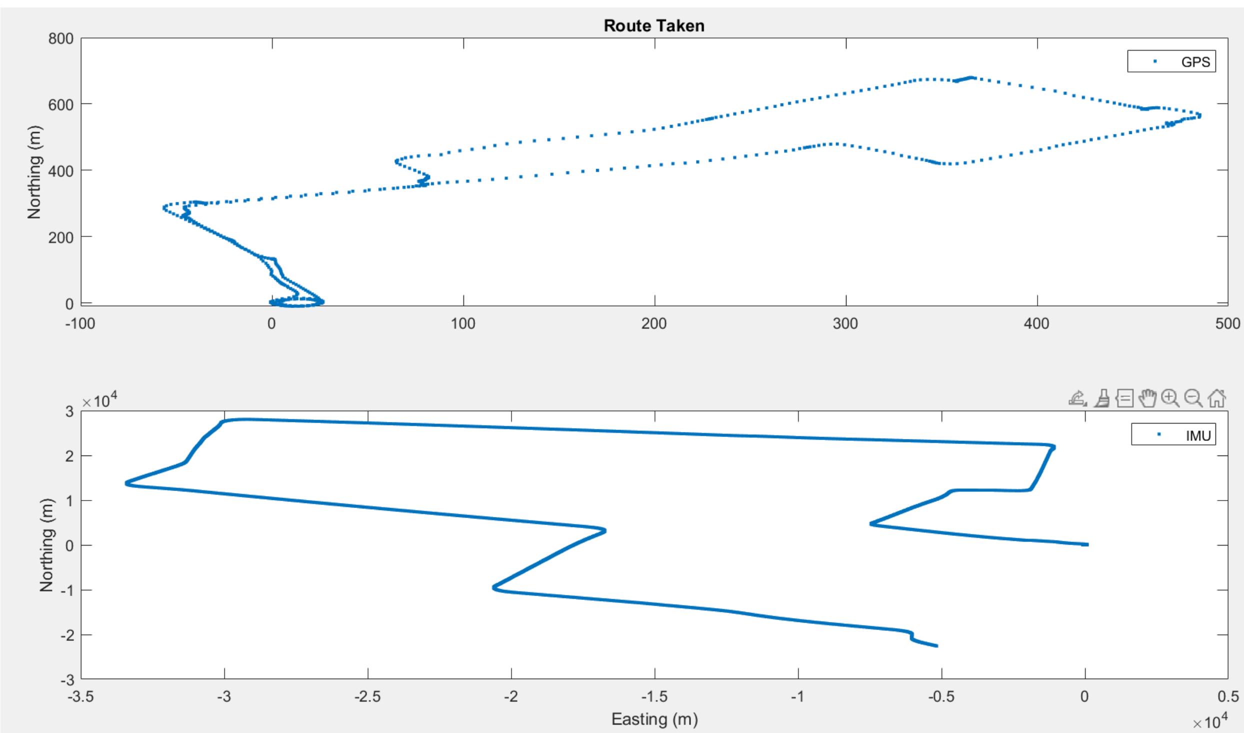

Fig 11: Route Taken for Data Collection

It appears that two routes are inversed, but they have some similarities. It is noticeable that the IMU has a different route than GPS, as GPS is always updating its global position. Due to the slow motion, the IMU may not necessarily need to be as accurate as the GPS, which updates every second and contains more dynamic information. However, the IMU can fill up the gaps between seconds and provide additional information to complement the GPS data. This can be useful for applications that require more precise tracking or real-time monitoring of movement. It is important to consider the strengths and limitations of both GPS and IMU when designing and implementing navigation systems.