EECE 5554 Robotics Sensing and Navigation Fall 2023

Lab 4

Navigation with IMU and Magnetometer

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Magnetometer calibration

Magnetometer calibration is done to correct the hard iron (which results in shifting of the center) and soft iron (which results in stretching of the circle to an ellipse) distortions in the IMU. Plotting the x-y data results in an elliptical shape at some distance from the origin.

Hard Iron Effect: It refers to a constant offset or bias in the magnetometer readings, typically caused by the presence of ferrous materials or permanent magnets near the IMU. This offset shifts the magnetometer measurements away from the true magnetic north. It can be thought of as a fixed shift in the magnetic field readings.

Soft Iron Effect: It refers to a distortion in the shape of the magnetic field, causing ellipsoidal or nonlinear distortions in the magnetometer readings. This distortion is usually caused by nearby magnetic materials that alter the magnetic field's shape. Unlike the hard iron effect, the soft iron effect doesn't result in a simple constant offset but rather skews and scales the measurements in a complex manner.

Ideally, this should be a circle and with center at (0,0). For corrections, we have to apply linear transformations on it to transform it into a circle. One way, is to calculate the mean of the original data and subtracting it from the entire data, which brings the center to the origin. The soft iron correction can be done by adjusting the length of the major and minor axis to make it into a circle.

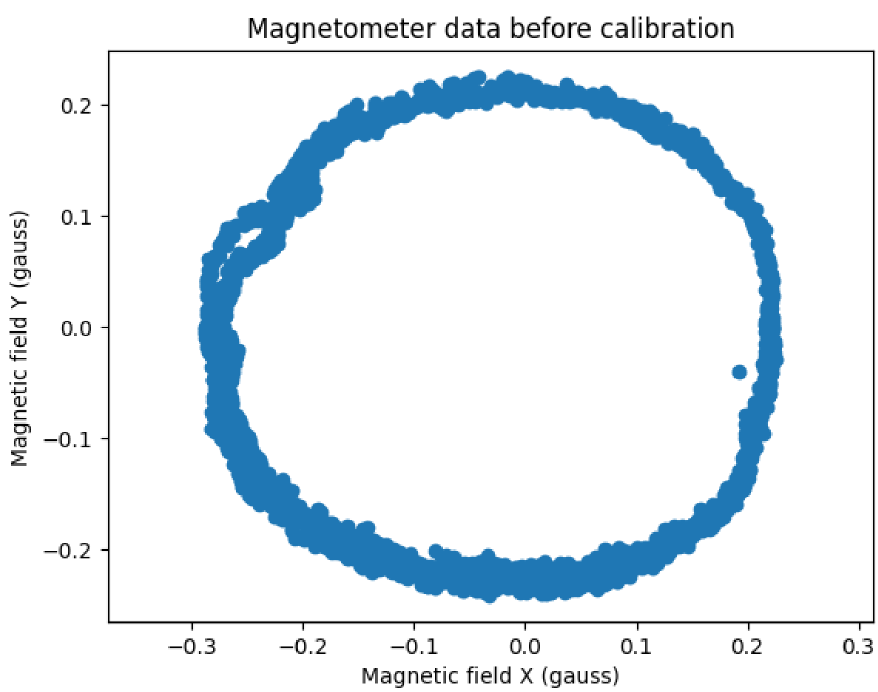


Fig 1.

$X_{shift} = 0.26081860$; $Y_{shift} = 0.2218498$

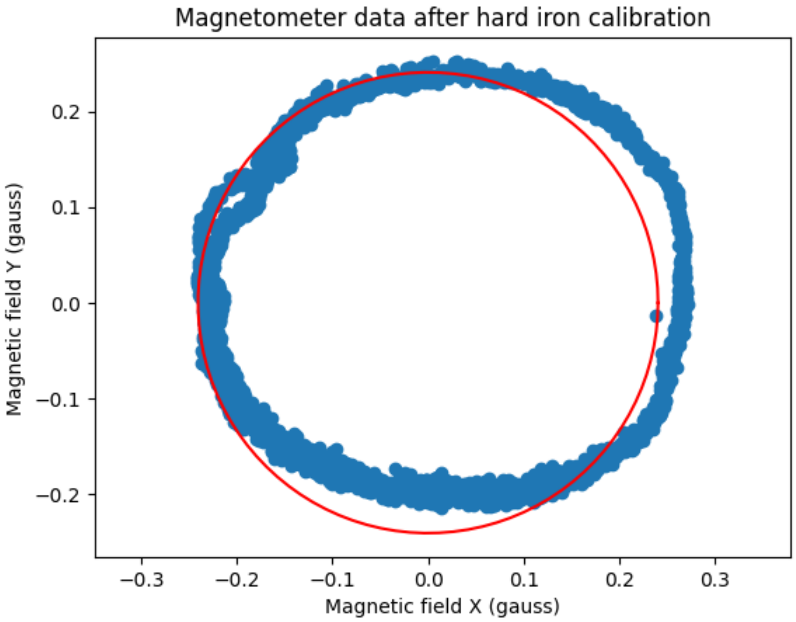


Fig 2.

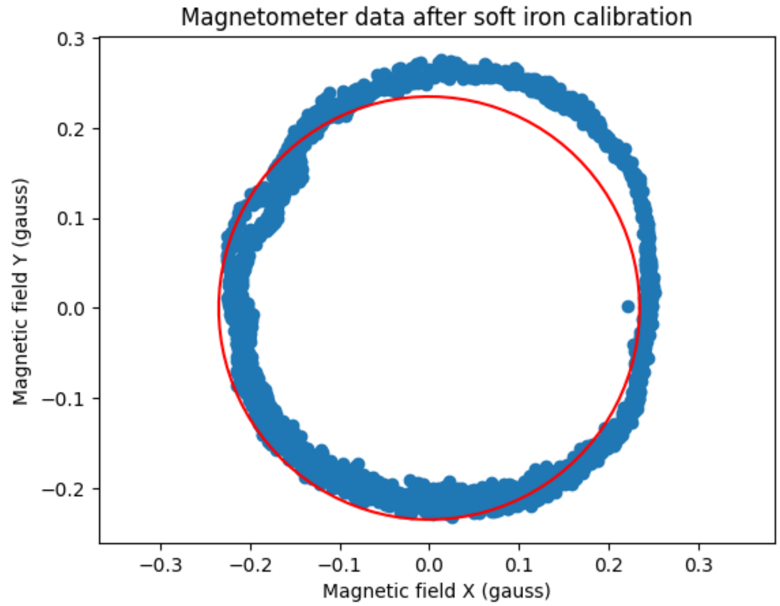


Fig 3.

Magnetic interference from nearby ferrous materials, electrical circuits, hard and soft iron distortions are some of the reasons for errors in the magnetometer.

Yaw estimation

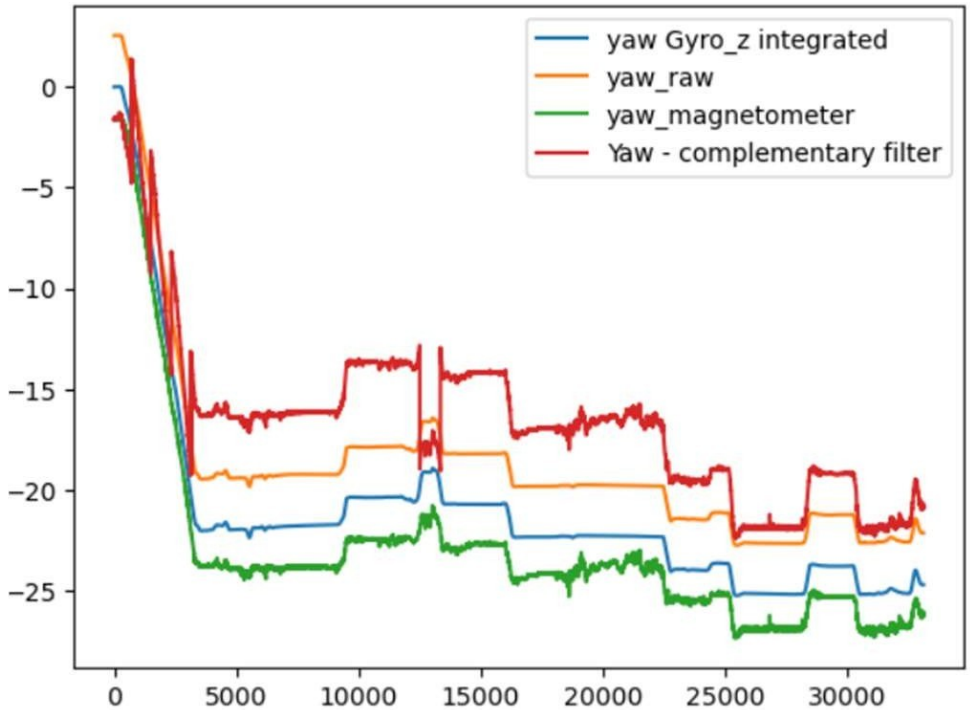


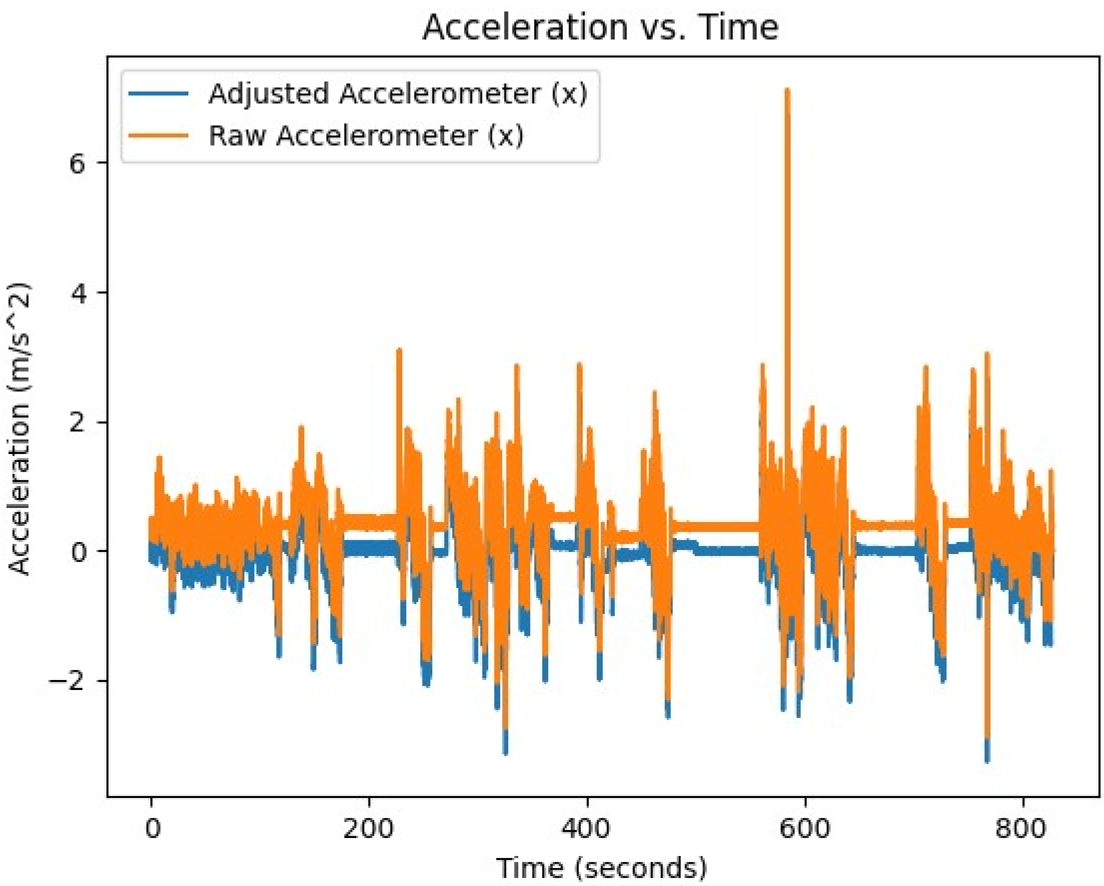
Fig 4.

We get the yaw angle from the IMU by integrating gyroscope value in the z direction, which is denoted in the orange color. The magnetometer data is passed through a lowpass filter to smoothen out the high-frequency noise and the gyroscope data is passed through a highpass filter to add the high-frequency components from the gyroscope. The output of the lowpass and the highpass filter is added to obtain the complementary filter output. We can use the IIR Butterworth Filter for the low and high pass filter, by changing the filter order. Cut-off frequency used was 0.1 Hz.

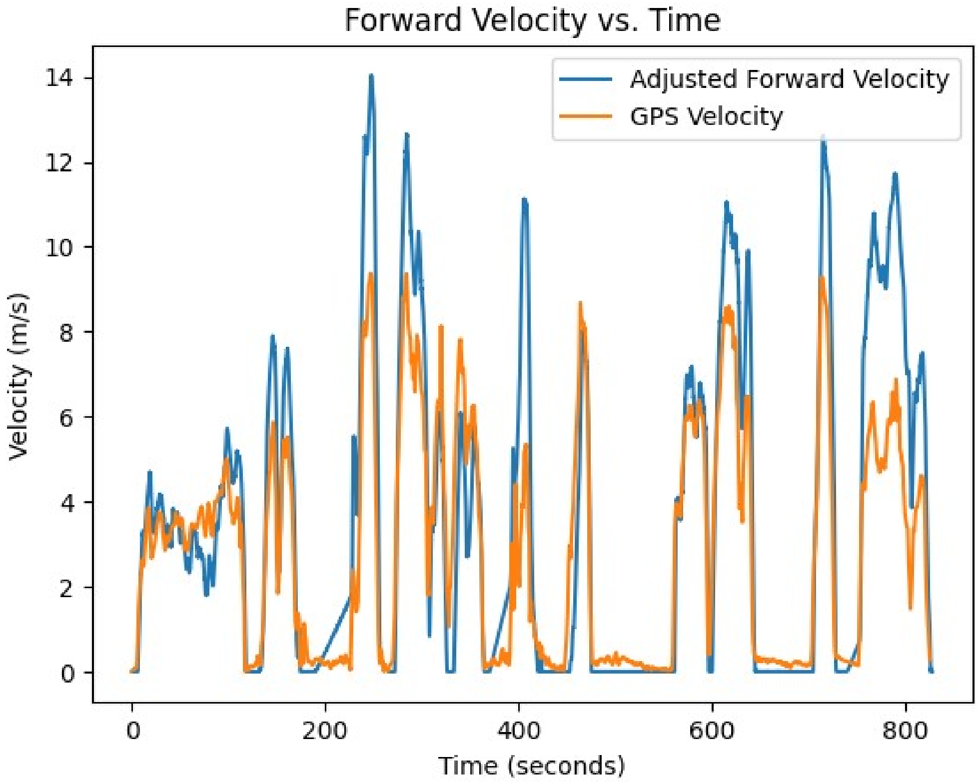
Comparing the yaw angle from the magnetometer and the one from yaw integrated from gyro, the two are almost similar with a deviation of roughly 5^o.

A yaw estimated using a complementary filter can be trusted more than the yaw calculated from only the gyroscope or the magnetometer.

Forward velocity



Integrating the forward acceleration form the IMU with respect to time will give us velocity. We have to integrate in the x-direction as it was facing forward. We can compare this velocity with the one obtained from GPS. Ideally, both of these should be similar but in reality, the velocity of IMU shows an upward or downward slope. This is because of the biases in the accelerometer. Although they are small in magnitude, they add up quickly in the integration and produce a larger offset. We can subtract this bias from the accelerometer and plot the velocity again, which gives comparatively better results. But the bias is not constant.



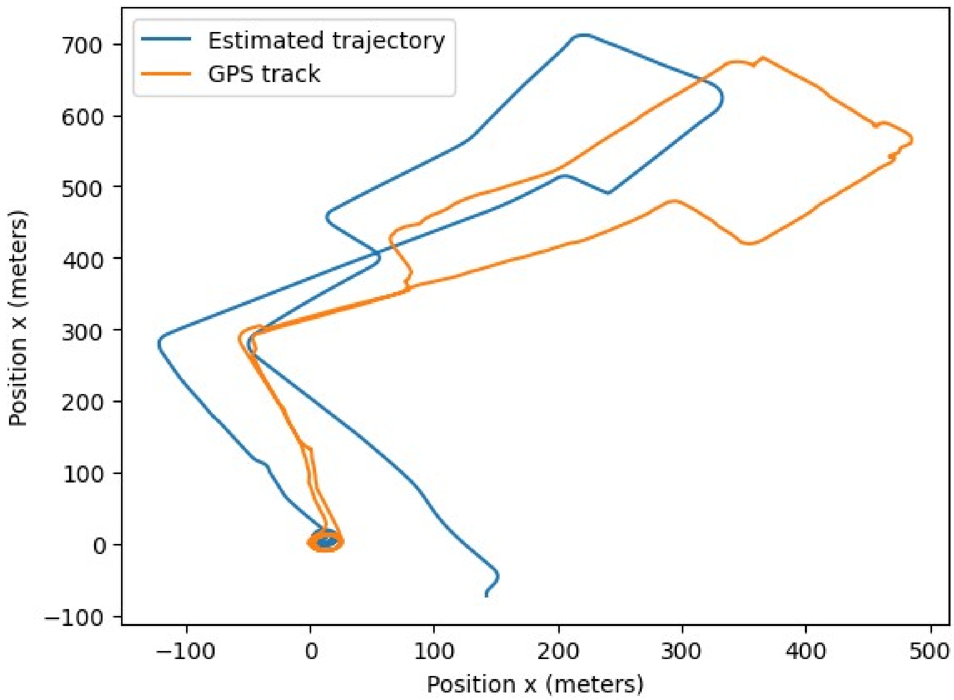
This plot of the adjusted velocities shows that the two velocities aren't exactly same, but they are similar. There are some sections which do not match, as the perfect values of the biases cannot be calculated and these small biases will give significant values after integration. We had to adjust the forward velocity because at times it was showing a negative value, which actually denoted the rest positions of the vehicle. So the negative parts of the graph were replaced with 0 m/s velocity. The discrepancies between the two velocities is due to the varying bias present.

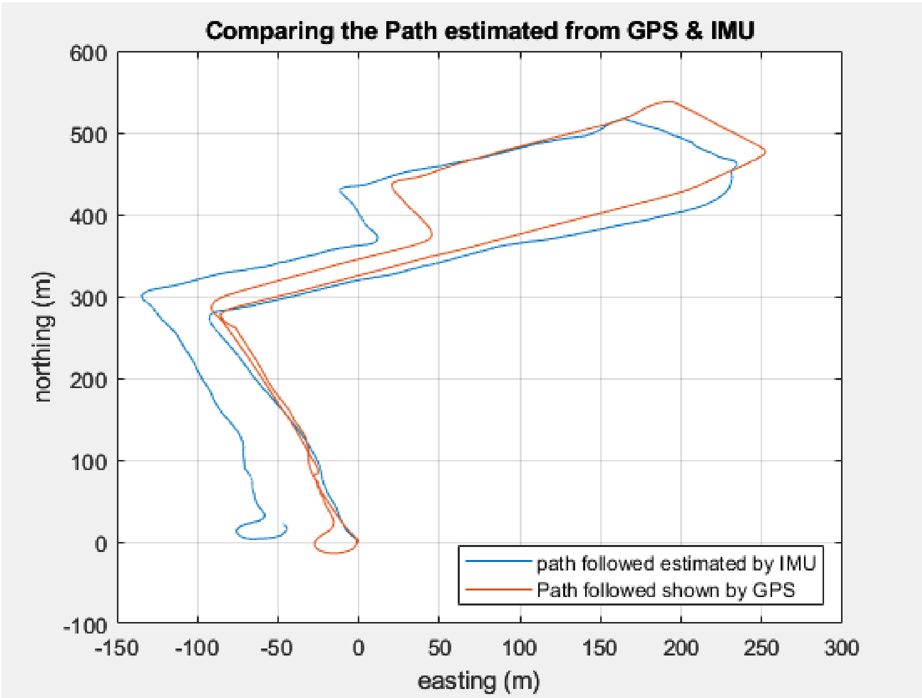
Dead-reckoning

Let the center of the vehicle be $(X, Y, 0)$, its rotation rate about the center of mass be $(0, 0, \omega)$, and the position of the IMU in the vehicle frame be $(x_c, 0, 0)$. Then the acceleration in y-axis measured by the IMU is

$y'' = Y'' + \omega X' + \omega' x_c$

Assuming that $x_c = 0$, i.e the IMU is mounted on the center of the vehicle, and $Y' = 0$ (vehicle is not slipping sideways), we can equate $y'' = \omega X'$. The start point of both the plots is the same. Using this, we can plot:





The reasons for the errors observed in dead reckoning can be due to:
1. Improper estimation of bias in the acceleration, which leads to offsets in the velocities of GPS and IMU
2. Integration of errors in velocity which give rise to large offsets in the position estimation

The accumulated error is much greater than the 0.7 meters mentioned in the datasheet of Vectornav NV-100.

Estimation of Xc

Given:
$y'' = Y'' + \omega X' + \omega' x_c$

In the above equation, we can assume X' to be the velocity calculated by integrating the corrected acceleration. Y'' is assumed to be 0. Thus we have only one unknown x_c , which converts the above equation to the linear algebraic form with one unknown, and 17282 equations.
$Ax_c = B$
We can estimate x_c with least squared eros formula $x_c = (A^T A)^{-1} A^T B$