Matthew Luongo
EECE 5554 — Lab 4 Report
March 25, 2023
Professor Dorsey

In this lab, we combined our GPS and IMU measuring tools to gain understanding of how sensors provide different benefits when used independently, and how they can yield much higher accuracy when combined.

The first part of the lab entailed calibrating the magnetometer data. I used the fit_ellipse package on MATLAB to find an ellipse of best fit, then I

- Subtracted the center point
- Rotated the data
- Scaled the x values to bring the ellipse into a circle shape

$$\begin{bmatrix} x_c \\ y_c \end{bmatrix} = \begin{bmatrix} .8415 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} .9728 & -.2337 & 0 \\ .2337 & .9728 & 0 \\ 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} x - (.0968 \times 10^{-4}) \\ y - (.1528 \times 10^{-4}) \end{bmatrix}$$

The data showed signs of some soft iron distortion and some hard iron distortion, since the data both had an origin that was not at 0,0 and showed signs of rotation/elongation.

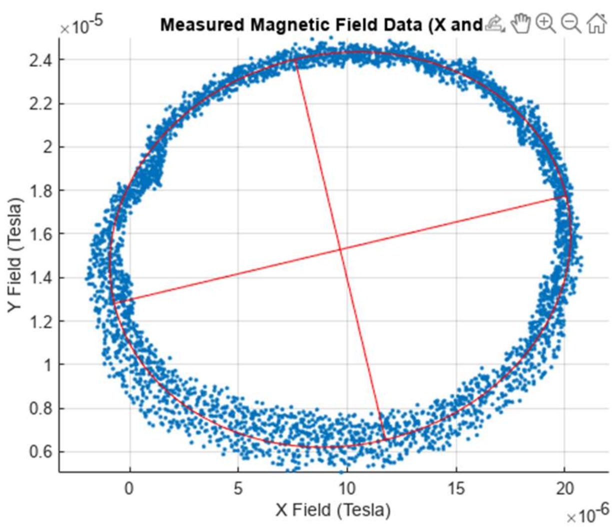

Figure 1: Uncalibrated data

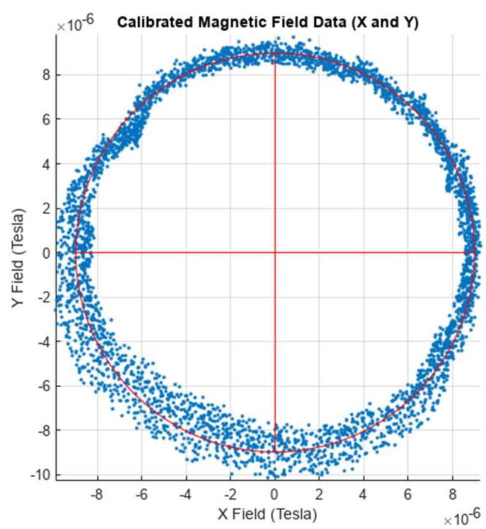

Figure 2: Uncalibrated data

I used an analog complimentary filter:

$$\theta = \theta_{Gyro,HP} + \theta_{Mag,LP}$$

I used MATLAB highpass() and lowpass() functions with cutoff frequencies of .05 and .01 Hz respectively. Overall, I trust the gyroscopic estimate of yaw the most and the complementary estimate the second most. They closely resemble the true yaw from the IMU. For some reason, my complementary-filtered reading was worse quality than both the filtered magnetic data and unfiltered gyroscopic data, but this was the best I could figure out in time.

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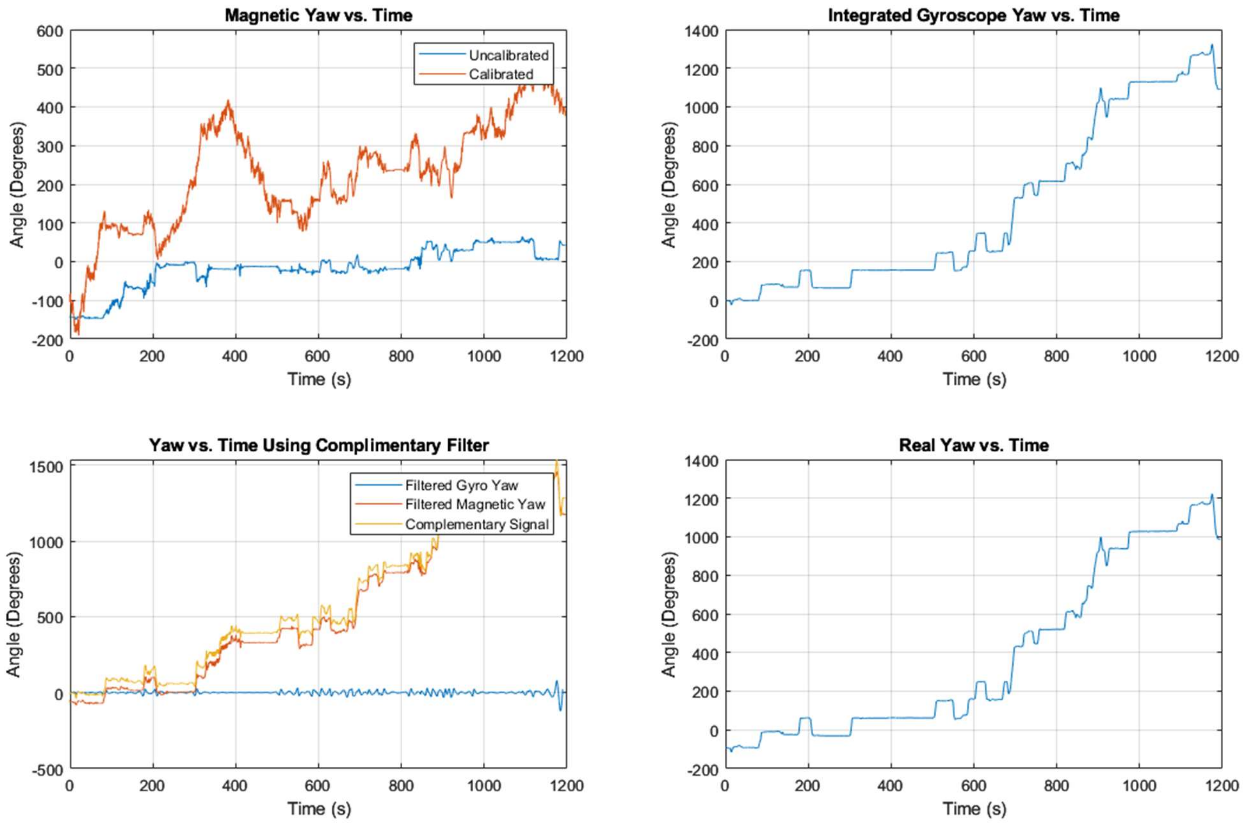

Figure 3: Estimated Yaw Angles and IMU Yaw Angle (bottom right)

My original forward velocity (integrated acceleration) data had multiple biases that caused the plot to ramp up into the 100s. To solve this, I subtracted the mean of the dataset, used a loop that detected periods of stillness (from looking at jerk) and subtracted the means of those periods from the future values, and finished by implementing some hand-calculated bias offsets to make the data 0 where it ought to be zero. I also scaled some peaks to be more in line with the real data.

Note that I was forced to separate the plots because the bounds for the unadjusted integrated raw acceleration data were way too high for the other two plots to be legible.

Differences in the GPS and IMU velocity estimates exist because integration boosts existing offsets/biases in the acceleration data. Any time we hit a pothole or a bump (frequent), and any time the sensor was rotated (e.g., tilted on its side, we are on a hill) and the gravity 'bled' into the other axes, integration would massively distort the ideal result because it essentially multiplies the constant bias by the amount of time that the bias exists.

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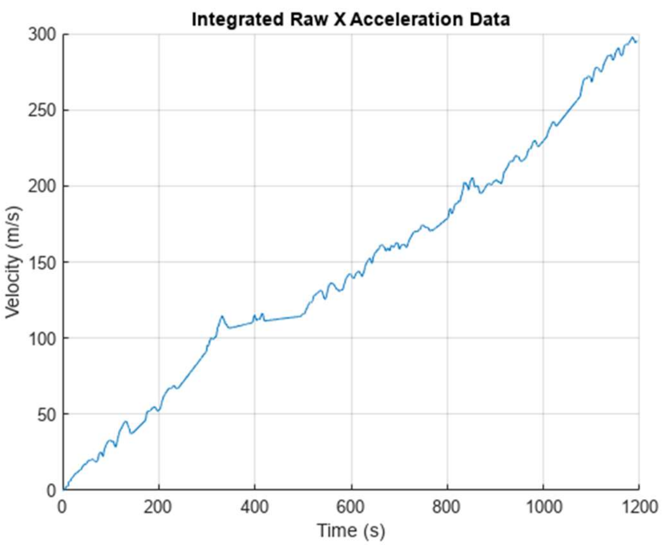

Figure 4: Integrated raw acceleration in X

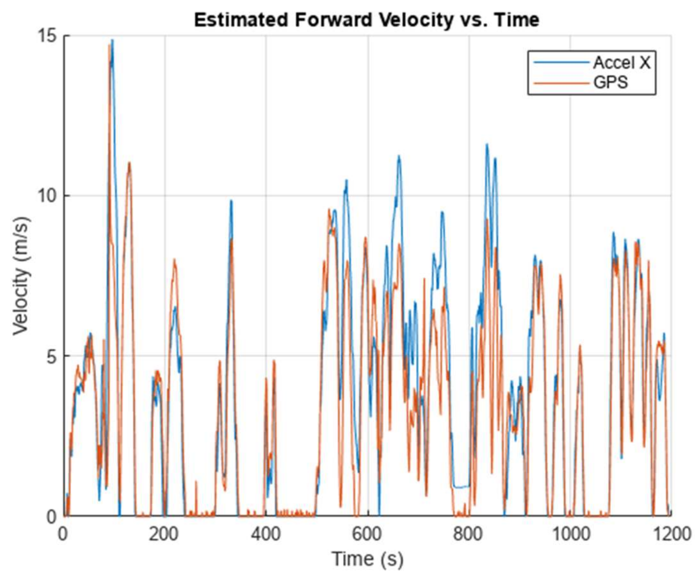

Figure 5: Comparison between velocity from GPS and integrated acceleration (plus bias offsets)

The $\omega\dot{X}$ and $\ddot{Y}$ plots can be found below:

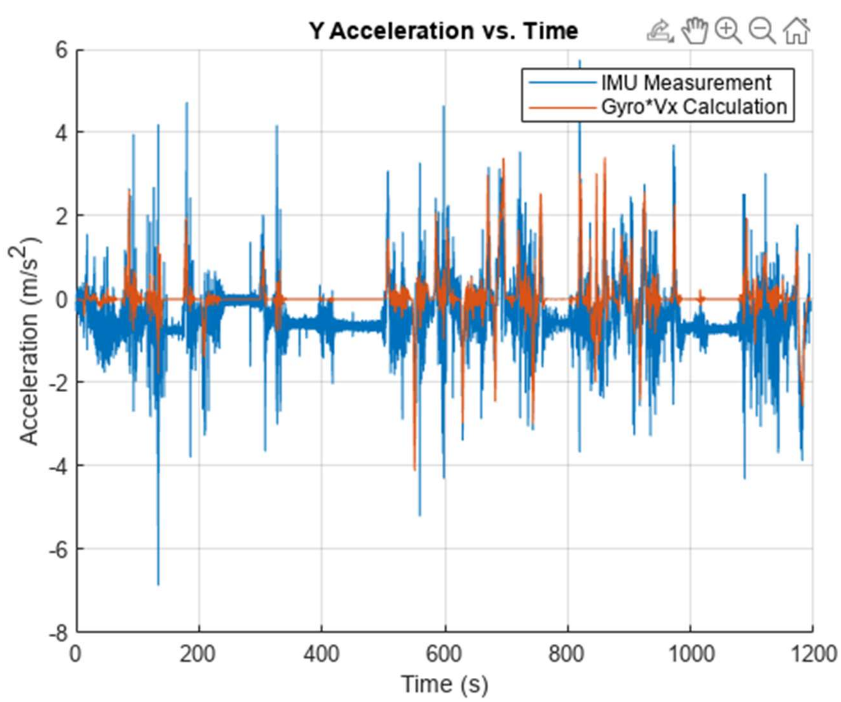

Figure 6: Comparison of observed Y acceleration vs. calculated

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The calculated measurement is smaller in magnitude, but the peaks and troughs somewhat mirror the actual measurements. With more time, the calculated values could be brought inline with the true values—note that the observed y acceleration suffers from biases and jolts that would further differentiate the two values. Also, the heavy conditioning of the V_x data plays a part in this.

The GPS route vs. the dead-reckoning route can be found below:

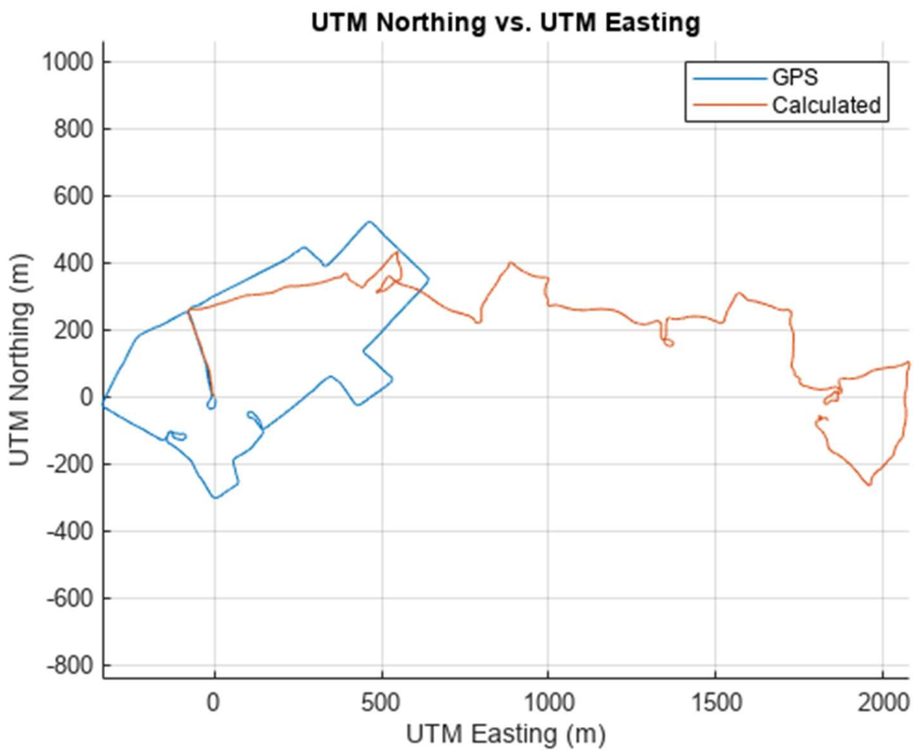

Figure 7: GPS data vs. integrated velocity data

No scaling factor was used to compare the data. Unfortunately, my complementary filter provided poor accuracy for dead reckoning, definitely not in the stated range—the complementary filter data was only accurate for ~200m.

One reason for this was that my group saw a conspicuous jump in magnetic yaw at ~350 seconds. The angle jumped by around 180 degrees. This explains the huge turnaround at the top right corner of our original route.

Using the gyroscope yaw angle instead of the complementary or magnetometer angles provided a much clearer picture of the route. I understand this is not what the lab is asking for, but I wanted to provide evidence that the magnetometer data was clearly disturbed at some point during our trip.

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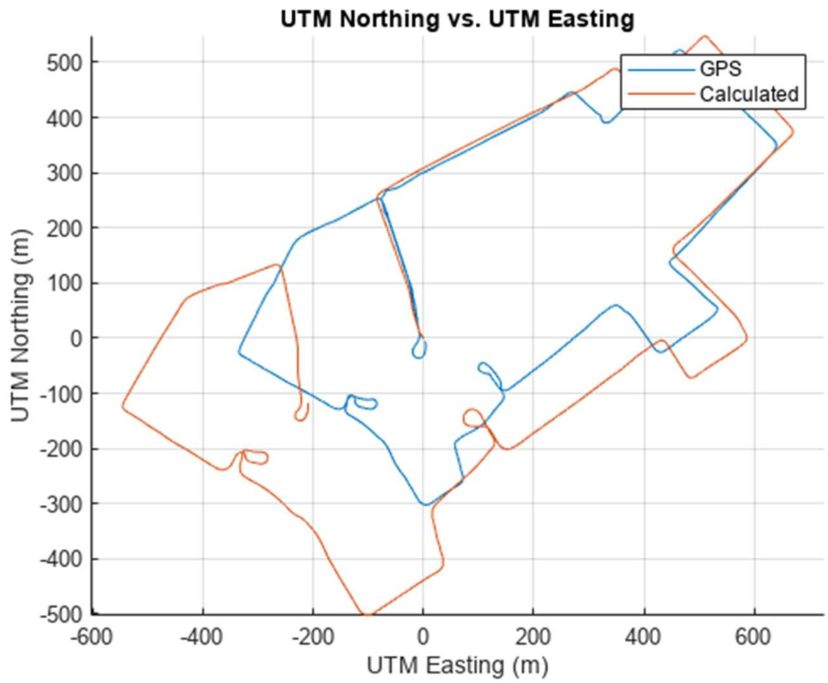

Figure 8: Dead reckoning with gyroscope

If used properly, the IMU can probably maintain course for around 400–500 m, as seen above in the first turn and in the last portion, where the contour clearly resembles the true route.