LAB4 Analysis:

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The car was driven 4-5 times around the Ruggles circle. After that, we calibrated the data to change the ellipse into a circle by aligning the circle's origin with the true origin. To calibrate the data, we apply translation, rotation, and scaling in that order.

The calibration will be done using the below formulae:

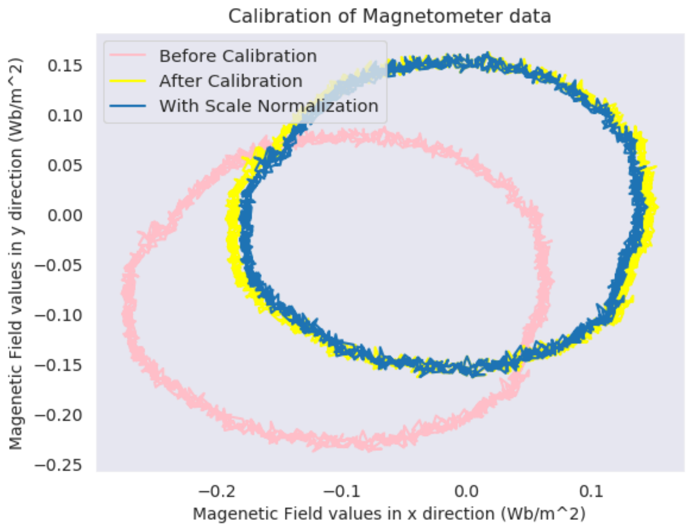
$$m_t = m - \begin{bmatrix} b_{H0} \\ b_{H1} \end{bmatrix}$$

$$m_{rot} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} m_t$$

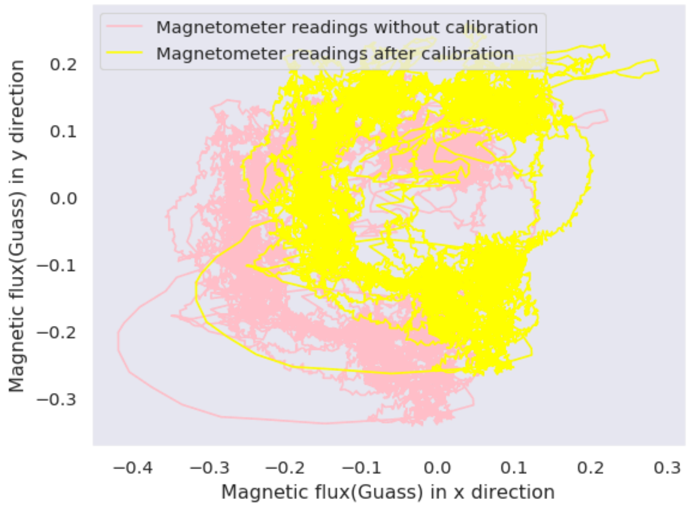
$$\sigma = \frac{b}{a}$$

$$m_{scale} = \begin{bmatrix} \sigma & 0 \\ 0 & 1 \end{bmatrix} m_{rot}$$

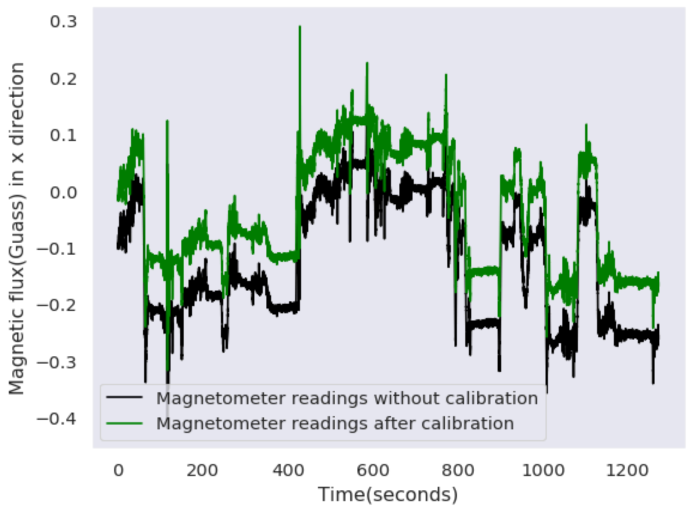
The below figure represents the Magnetic field values about X & Y directions for the circular data (Both before and after calibration). As we can observe, the obtained circular shape is not uniform. It has got some random error in it.

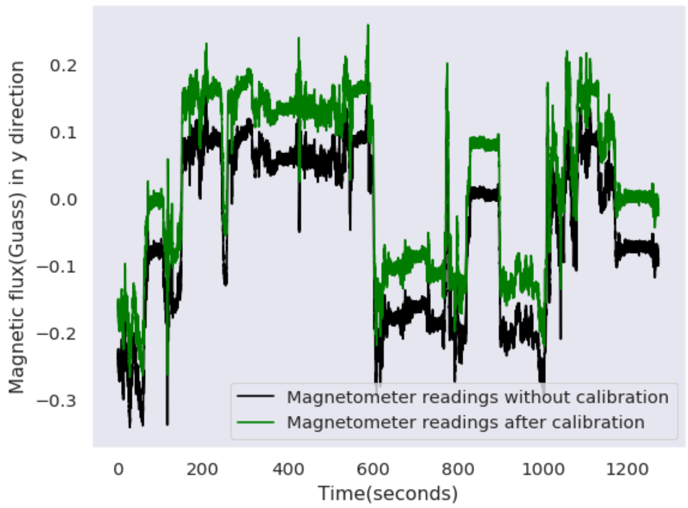


The below plot gives Magnetic field values about X & Y directions for the mini tour data (Both before and after calibration) The slight errors in the plot can be explained by the soft-iron & hard-iron distortions. The Iron which has a low carbon content and is easily magnetised and demagnetized, is what causes soft-iron distortions. Hard-iron distortions, however, are brought on by magnetised iron that might be challenging to demagnetize. The shape of the circle is distorted by soft-iron distortions, while the centre of the circle is shifted away from the origin by hard-iron distortions. I have also included the scale normalisation fit of the calibrated data in the below plot.

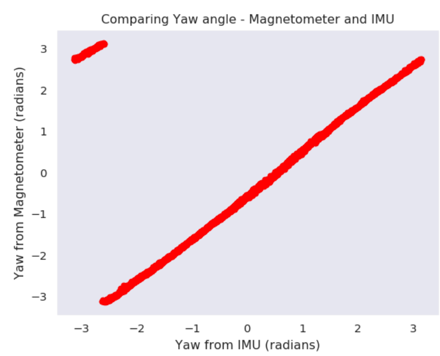


The upcoming plots show the magnetometer readings about X & Y directions before and after calibrating the data.

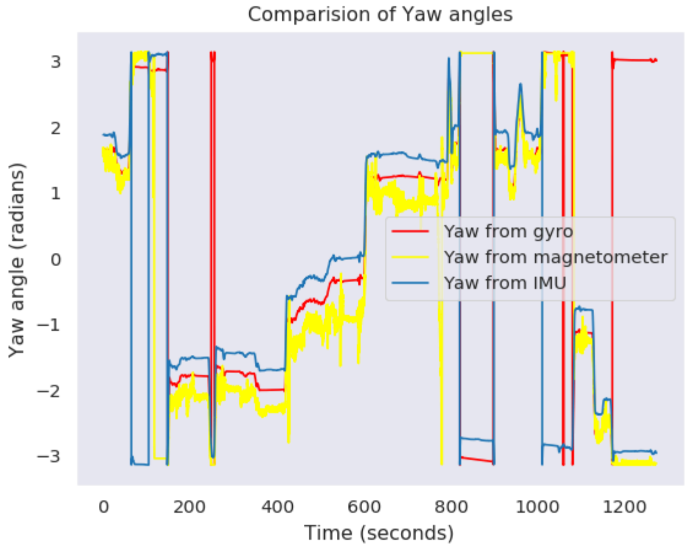




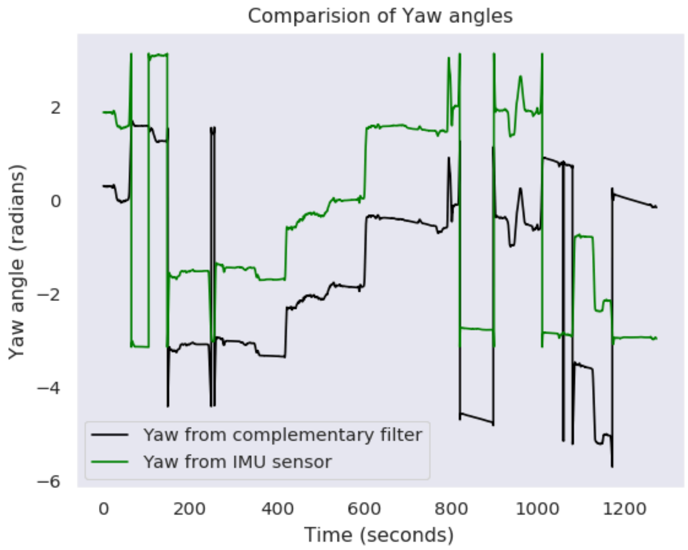
Below is the comparison between the Yaw angle from Magnetometer and from IMU.



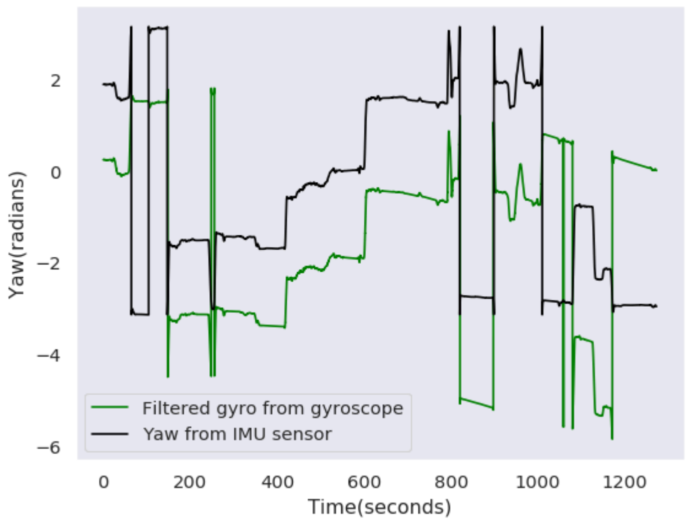
The below figure shows the yaw estimates from the gyroscope and magnetometer together.

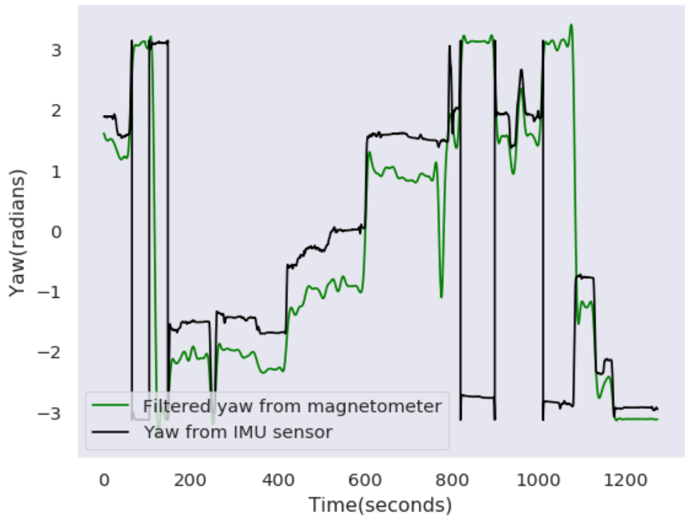


After comparison of the yaw estimate (after applying complementary filter) with the actual yaw values, we obtain the following plot:

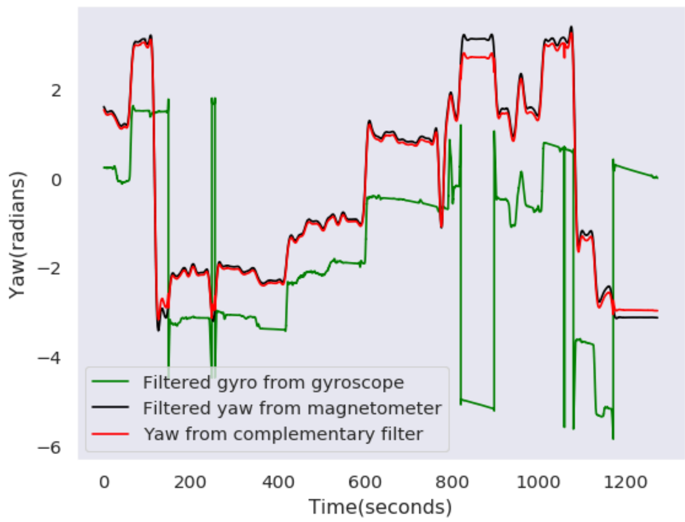


Below are the plots of Filtered yaw from gyroscope and magnetometer with respect to the IMU yaw.

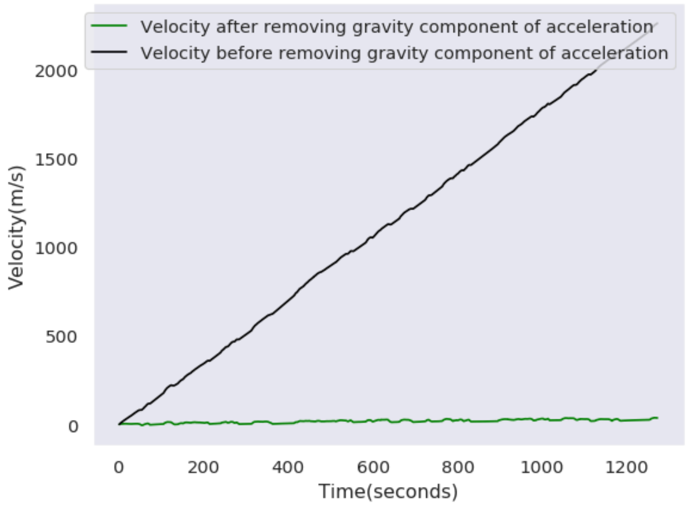


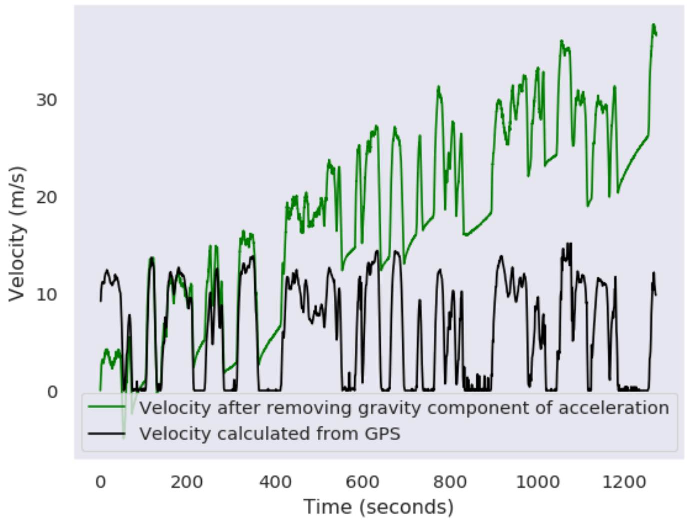


I then added a low pass filter to the magnetometer data and a high pass filter to the gyroscope data. A high pass filter sharpens the curve while a low pass filter smoothes it out. Low pass filters have a cutoff frequency of 0.01* pi rad/sample, while high pass filters have a cutoff frequency of 0.00000001* pi rad/sample. I filtered each of the yaw estimates and then combined both of the filtered estimates to get the final yaw estimate. The complementary filter that I employed has the following formula: yaw estimate = (1 - alpha)* yaw from mag + alpha* yaw from gyro. In my situation, alpha is equal to 0.05

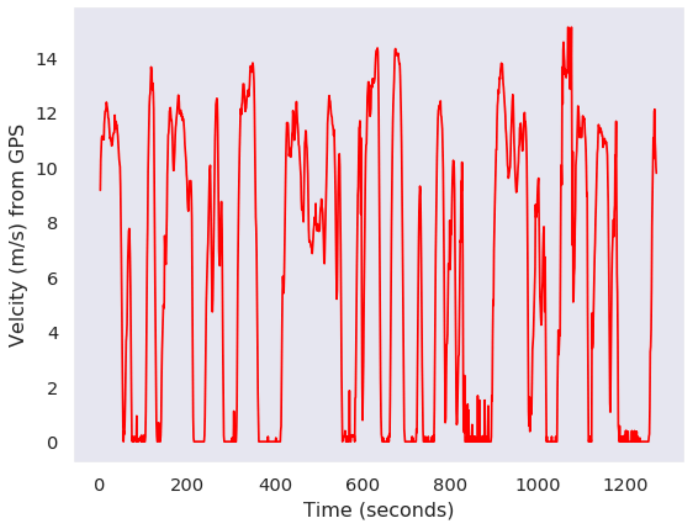


Since the errors in the magnetometer can be calibrated easily by removing soft-iron and hard-iron distortions (and we did it in the first part), I would trust the yaw from the magnetometer more than the yaw computed from the gyroscope. This is because it is much more challenging to calibrate the gyroscope because it has angle random walk, rate random walk, and bias instability. Since the yaw estimate from the complementary filter is near to the yaw estimate from the magnetometer data, I chose the alpha value accordingly. Then, using accelerometer data, I approximated forward velocity by integrating the linear acceleration about x. By differentiating the northing and easting values of the UTM with respect to time and using the L2 norm of those values, I was able to calculate the forward velocity.





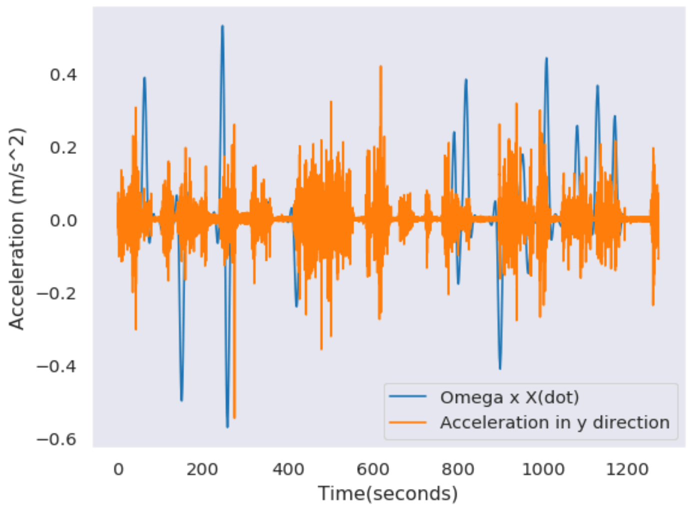
Here is the velocity of GPS with respect to time given below:



Then, using the angular velocity about the Z axis and the forward motion, I estimated the linear acceleration about the X and Y axes.
Using the following formulas, compute velocity:

$$\ddot{x}_{obs} = \ddot{X} - \omega\dot{Y} - \omega^2 x_c$$
$$\ddot{y}_{obs} = \ddot{Y} + \omega\dot{X} + \dot{\omega} x_c$$

Where, Y_dot = 0, x_c = 0 and Y_double_dot = 0. The calculated acceleration (omega times x dot) compensates for the Y component of the acceleration about the X and Z axes, whereas the observed acceleration about the Y axis includes the effects of acceleration due to gravity. As a result, the calculated acceleration and observed acceleration are very different from one another. In order to lessen the impacts of acceleration caused by gravity, I applied a low pass filter on the recorded acceleration, and the resulting graph is as follows:



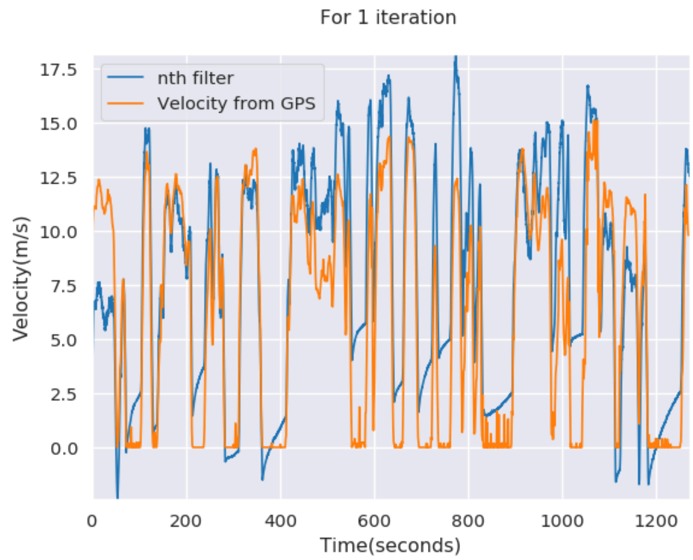
With correction, the measured acceleration approaches the calculated acceleration more closely. Using the following formulas, I am later computing the horizontal and vertical components of velocities from estimated yaw and velocities from parts 1 and 2:

```
v_e = vel_imu .* cos(yaw_compl);
v_n = vel_imu .* sin(yaw_compl);
```

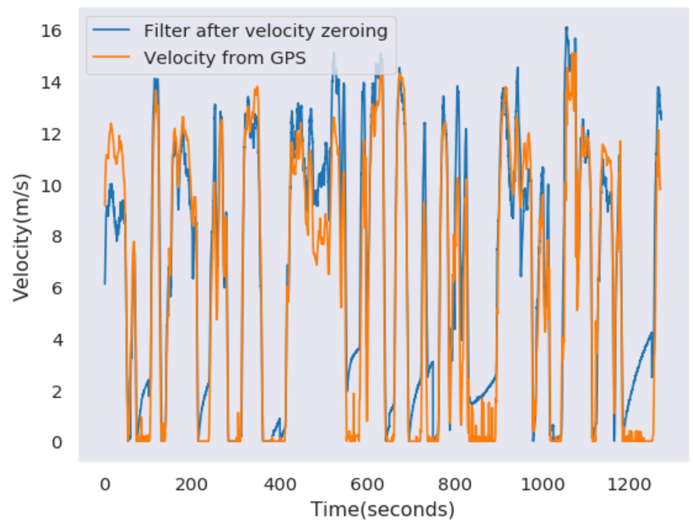
Then, we have to integrate the velocities with respect to time to obtain the easting and northing displacements and I am comparing the calculated displacements with the displacements from GPS data.

```
x_e = x_e * min(utm_northing) / min(x_e);
x_n = x_n * min(utm_easting) / min(x_n);
```

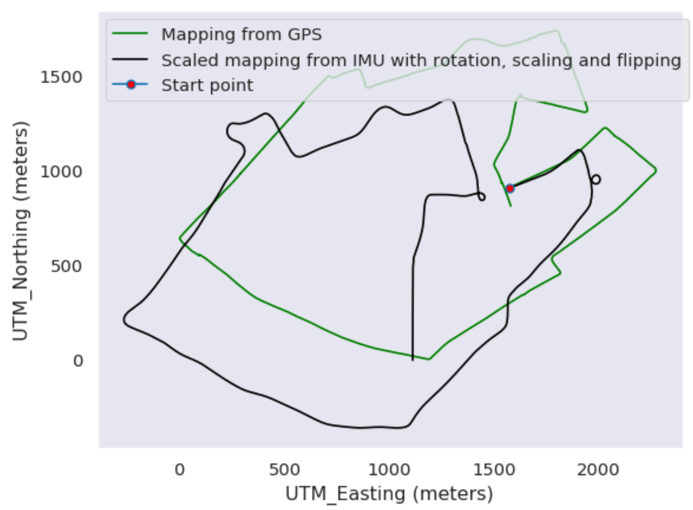
I have filtered the velocity acquired from GPS with respect to time by introducing a nth filter that helps in iterating and refining the velocity values and thus help us in obtaining the proper velocity values.



At the saturation point, the plot looked like:



The nth filter velocity was obtained to be 0.08548590085833307 m/s.



As you can observe, the displacements obtained by the IMU deviate slightly from the displacements calculated using the ground truth.

This is due to the fact that I calculated the UTM displacements using approximated yaw and velocities from IMU data.

Additionally, there are differences between the estimated yaw and velocity and the actual yaw and velocity.

These estimates are susceptible to compounding errors, which means that even if there is a slight bias at one of the timeframes, the bias will spread and grow over time.

The vn100 vectornav datasheet states that the gyroscope's noise density is 0.0035 degrees/sec/(Hz)0.5 and the magnetic heading accuracy is 2 degrees.

For at least half of the course travelled without a position fix, we would anticipate that the UTM values from the IMU and the GPS would be in agreement. However, this is not the case because there are estimates and velocity variations from the actual figures.

They started off in the wrong direction (t = 0s). But as we can see, the UTM from the IMU is on the same trajectory as the UTM from the GPS.

Due to the differences in predicted velocity and yaw noted above, the claimed performance for dead reckoning did not correspond to actual observations.