Robot Navigation Using GPS

Team 2 — Navigation with GPS
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I. Our Challenge

One of the key components to autonomous navigation is a comprehensive localization system. The use of a GPS as a navigation tool is not only an established method but also well proven to be a viable method as well. GPS makes it possible to acquire the exact position on earth, in latitude and longitude coordinates. However, interestingly enough, GPS-based autonomous navigation for autonomous vehicles is not too common. Depending on the actual sensor, it is likely that the accuracy of the data leaves much to be desired. In general, GPS units can be inaccurate when there are weak or delayed signals between the GPS and its respective satellites. This means that the same GPS unit can yield inconsistent results depending on the environment it is in. These shortcomings can be improved when GPS is used in conjunction with other sensors such as cameras, IMU's and LiDAR's. But without a GPS that has low and consistent distribution of error, the addition of other sensors will not improve localization to be sufficient or robust enough for the needs of a self-driving vehicle. Thus, it is necessary that any autonomous vehicle use a GPS that has been proven to work effectively and have a low rate of error and drift.

The race at ThunderHill presents a real-life scenario where an autonomous vehicle would have to navigate on a 2.1 mile outdoor track. A successful drive on this track would require that the localization system be accurate enough to allow the navigation system to stay on track and more specifically stay on the correct lane within that track. This localization and navigation system would also have to be efficient enough to be able to calculate their positioning at high speeds; after all, it is a race.

This paper is the first part of a two part series with the end goal to produce a reliable GPS-based navigation system for autonomous vehicles. In particular, this paper will focus on exploring the performance of the GPS provided to us, the NEO-M8N, and demonstrate the shortcomings of this GPS to prove that we need a more robust GPS to build a navigation system.

II. Data Generation, Description, & Its Relation to Our Problem

In order to gather data to measure GPS drift, we created clear guidelines for the scenarios in which the sensor data would be gathered. The autopilot system that the GPS was attached to had a 1 Hz data rate which limited the speed at which coordinates could be obtained. Additionally, the library interacting with the GPS outputs the data in formatted strings that contain latitude and longitude in a string format.

uBlox NEO-M8N GPS

For the different GPS scenarios, we designed four straight tracks measuring 5, 10, 20, and 50 feet respectively and conducted multiple runs for each track. We also collected data by leaving the GPS at a stationary point. Since the GPS needs around 30 seconds in order to obtain a first fix to a satellite, the stationary data was only collected after it had obtained that first fix.

Our data collection procedures exist in order to solve our immediate problem of experimenting on the NEO-M8N. This allows us to evaluate the capabilities of the GPS definitively in order to determine its usefulness in autonomous navigation.

III. Methodology

GPS generates data in the form of latitude and longitude which represents the world using degrees from its center. The accuracy of the GPS can then be evaluated by comparing the coordinates generated by the GPS against the true coordinates. However, a key limitation for this process is the simple fact that it is exceedingly difficult to get an accurate measurement of the ground truth coordinates of a GPS. This is primarily due to the fact that obtaining the true coordinates of the GPS requires knowledge of some local absolute latitude and longitude coordinates. Even with the use of external sensors to triangulate the position of the GPS on the robot, this calculated accuracy is only as accurate as the known positions of the three external sensors. For our purposes and within our budget constraints, we establish ground truth to be a measurement of the distance travelled rather than a position coordinate. For example, if the vehicle was to run on a 5 feet track, start to end, the ground truth would be 5 feet. The GPS may not output coordinates that reflect this distance travelled however. Thus, we would use ground truth and the calculated distance between the first and last GPS outputted coordinates to determine accuracy.

We will be using root mean square error (RMSE) as our metric to evaluate the GPS's performance when ground truth is a distance traveled. RMSE is a reasonable metric because it is typically used to compare between observations and predictions. Additionally, GPS output can claim to have travelled 5 feet more or 5 feet less than it actually did but both should be considered to be errors of the same weight. Using RMSE will prevent negative and positive errors from cancelling each other out. RMSE will be used to judge the trials when the GPS is in motion and moving through the tracks.

When we want to compare stationary coordinates against coordinates, we will be using Circular Error Probable (CEP) and 2D Root Mean Square (2DRMS) to evaluate the accuracy of the GPS. CEP is the accuracy radius from the ground truth coordinate for

GPS outputs 50% of the time while 2DRMS is an accuracy radius of GPS outputs for 95 - 98% of the time. CEP and 2DRMS are used when the GPS is left at a fixed point. Since we did not have access to equipment that would find the true position, we took an average of all the coordinate outputs as our ground truth position. We used the mean of our data as a substitute for ground truth due to the fact that statistically, the mean of the sampling distribution can be used to represent the mean of the population, which in our case would just be the ground truth coordinate that an accurate GPS would output.

In addition to the statistical metrics we used to evaluate GPS performance, we also visualized the actual coordinates with the visualization library bokeh. This allowed us to overlay the paths each system took, as well as the ground truth path on top of a satellite map. The visual analysis of the reported path next to the actual path allows us to bridge the gap between the numerical value of the GPS error and how it would impact a vehicle in real life.

IV. Results

i. RMSE

To calculate the RMSE of each batch, where the term 'batch' is defined as all the runs for, say, the 5 feet track, we first find the distances outputted by each run in the batch. The calculation is based on the Vincenty formula, a method that finds the distance between two points on a spheroid surface, to mimic the shape of the earth. Then we compile all the reported distances to find the batch's RMSE from the ground truth. What we found was that the RMSE was in the range of 2-4 feet for each batch where the vehicle was not stationary. We can

Distance Traveled (ft)	5	10	20	50
RMSE (ft)	2.733	2.043	2.488	3.884

take this to mean that the GPS output may indicate that it travelled between 2 - 4 feet more or less than the distance it actually travelled. These results show a general trend where RMSE increases as the distance the vehicle travels gets larger (Figure 1).

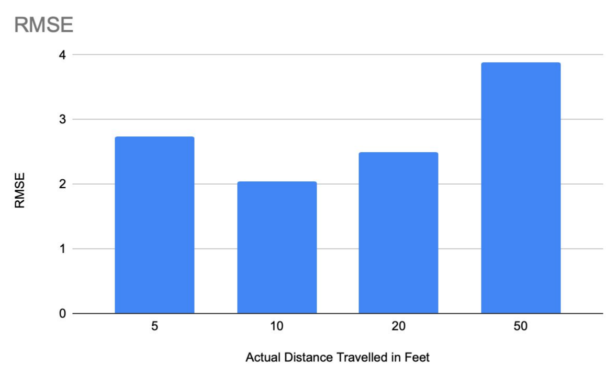

Figure 1: *RMSE per Batch*

ii. Circular Error Probable and 2DRMS

We found the CEP to be a radius of 5.026 feet. This means that NEO-M8N outputs will lie within a 5 feet radius of the actual coordinate 50% of the time. Our data is reflective of this, as roughly 50% of all points are within the inner circle. Our 2DRMS is at 12.171 feet, meaning

NEO-M8N is only accurate up to a 12 feet radius of the ground truth coordinate 95 - 98% of the time. In reality, all of our data points were within the 2DRMS circle but we believe that if we had a larger set of data, then the 95-98% containment would be reflected.

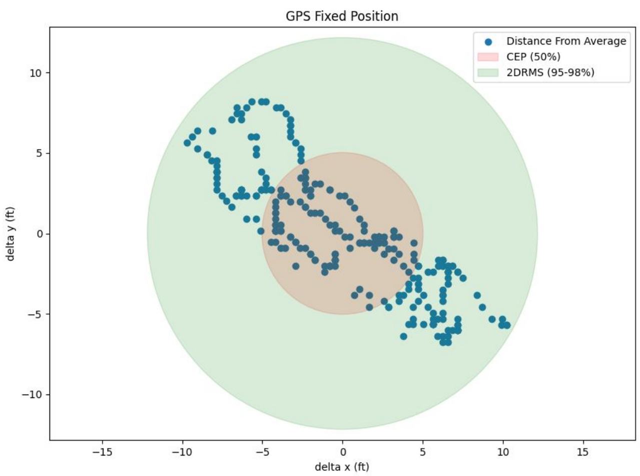

Figure 2: *CEP and 2DRMS*

iii. Visualization

In order to be able to visually see the performance of our GPS, we utilized the bokeh mapping visualization library. Using the provided GPS logs, the bokeh library plots a line of the reported locations of the GPS. This is represented by the red line in Figures 3, 4, 5, and 6 as referenced in the appendix. The blue line represents the true course taken by the GPS. When taking a look at these figures we can see that the GPS repeatedly reported a path that was offset from our actual course. In Figures 4, 5, and 6, we can clearly see that the reported (red) path was almost on the opposite lane of the street. One trend to be noted is that the GPS seemed to drift further away from its actual location the longer it was in motion. We also saw that its drift seemed to push further out with the longer trials of 20 and 50 feet, while with our 5 and 10 feet trials, the GPS drifted slightly less far. Since the CEP of the GPS is 5.026 feet, it makes sense that the 5 ft. straight test, shown in Figure 3, doesn't produce any distinguishable path.

V. Discussion

Through statistical and visual analysis, we arrived at several conclusions about both the performance of our GPS as well as what parameters a GPS would need to have in order to be effective for autonomous navigation. First, the uBlox NEO-M8N GPS would be completely inadequate if it were to be relied upon as the main sensor in a navigation system. This is primarily because of its overall lack in accuracy which was benchmarked with RMSE, CEP, and 2DRMS. Since the CEP and 2DRMS were around 5 and 12 feet respectively, it wouldn't be able to adequately identify what position of the road a vehicle is on. In a scenario where a road has two lanes, the GPS wouldn't be able to determine which lane the vehicle is in and some circumstances it might even report that the vehicle is completely off the road. Figures 3 and 4 in the appendix are indicative of these problems, where the actual vehicle was driving on the edge of one curb, but the reported GPS coordinates put the vehicle on the other side of the street. Lastly, we need a GPS with drift that is random and follows a Gaussian distribution. From Figure 7, the NEO-M8N's drift seems to contain an underlying bias that is illustrated by the fact that points appear to be following a fixed path. Considering that we are integrating at least one additional sensor—the IMU—we expect to need the EKF algorithm for localization in the future. Since the EKF algorithm was designed to work with Gaussian distributions, the GPS we base our navigation system on should ideally have minimal drift and Gaussian distributed drift to be compatible with the EKF algorithm.

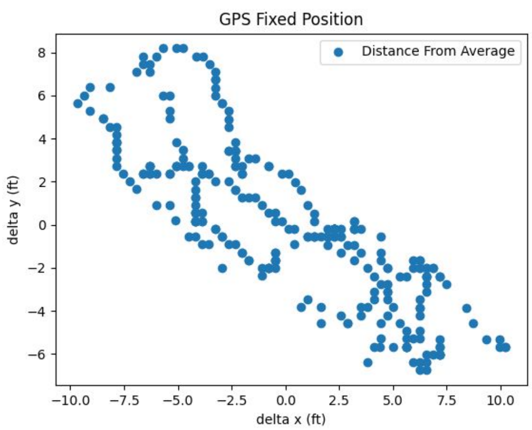

Figure 7: *Error at Fixed Rate*

Thus, through the analyses of our results we can safely assume that the NEO-M8N GPS would not be capable of successfully autonomously navigating around the Thunderhill track. This is, of course, due to the fact that the error of this GPS is simply too high to deal with a high speed, long range track. With a CEP of around 5 feet and 2DRMs of 12 feet when stationary and a RMSE of around 2.5 feet while in motion, it would be too difficult to localize the vehicle and ensure that it is in the correct location on the track. If the GPS had been precise, but not accurate, then that would indicate that there was a consistent error that could be corrected for. However, since the GPS was neither accurate nor precise in all of the tests that we performed, it would be much more difficult to integrate safely and successfully.

VI. Conclusion

In order to feasibly autonomously navigate the Thunderhill Track, it is crucial to obtain a better GPS than NEO-M8N. Specifically, this GPS must be able to localize efficiently, accurately as well as precisely to the point where we can ascertain the lane the vehicle is in at all times. Our research has brought us to many conclusions with the most important being NEO-M8N is not sufficient for our purposes but it has also led to more questions and discussion to be had on autonomous navigation with a GPS. For example, the question arises: what RMSE, CEP, and 2DRMS should a GPS fall within to be deemed reliable enough for autonomous navigation? Additionally, our robot was not tested at a full range of speeds, which is relevant to any autonomous navigation system that wishes to participate in a race. It would be important that a new GPS would be able to have low error even at higher speeds.

This paper concludes the first half of our two quarter project. Through our research, we were able to find that the NEO-M8N would not have been robust enough for autonomous navigation. However, the door is now open for much more to be done in the future, both in terms of obtaining a better GPS but also being able to utilize these tools to create a fully autonomous navigation system.

VII. Appendix

Figure 3: *5 feet*

Figure 4: *10 feet*

Figure 5: *20 feet*

Figure 6: *50 feet*

VIII. Resources

[1] https://www.u-blox.com/sites/default/files/NEO-M8_DataSheet_(UBX-13003366).pdf

[2] https://www.researchgate.net/publication/261088859_An_overview_of_development_GPS_n avigation_for_autonomous_car

[3] https://www.researchgate.net/publication/339766411_Mobile_Robot_Localization_using_GP S_IMU_and_Visual_Odometr

[4] https://github.com/swri-robotics/mapviz

[5] https://www.umesc.usgs.gov/documents/reports/1996/96t002.pdf

[6] https://junipersys.com/support/article/6614