Integrated Receiver Design

Ben Bovee & Samuel Nassar

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ABSTRACT

The purpose of this project is to determine which of two GPS corrections, Differential (DGPS) or Wide Area Augmentation System (WAAS), is more accurate, and then to create a navigational receiver that integrates one or more of GPS, DGPS, or WAAS GPS with LORAN-C. The purpose of this is to provide a more reliable means of navigation that will not easily be impacted by possible terrorist attacks or unintentional blocking transmissions, and can be used by both the aviation and marine industry. This $27.7 K project involves five personnel, including the project advisor CAPT Hartnett, a variety of equipment, including five different GPS receivers, and a sponsorship by the Federal Aviation Administration. Deliverables of the project include the project plan, test results of WAAS and DGPS, receiver selection, integration hardware and software, integration results, a tested integrated receiver, and two project presentations. Mid year milestones are 12 Nov 02 when the project plan is due, 09 Dec 02 when the project paper is due, and the 11 Dec 02 when the actual mid year presentation is due. Milestones for the end of the year include 01 May 02 when the final project presentation is to be given and 05 May 03 when the final paper is due. Through the project it was determined that DGPS accuracy degradation due to range from beacon correction station is not a factor up to 100 NM. It was also concluded that WAAS and DGPS have very similar accuracies, neither being distinctively different than the other.

INTRODUCTION

GPS is a highly accurate, worldwide navigation system that uses signals from satellites and extremely precise timing in order to create a fix on the user's position. However, tall buildings and steel structures attenuate the signal that is sent from these satellites and it may also be easily jammed. A potential terrorist could cheaply buy the necessary parts from a local electronics store to jam the signal for a fifty mile radius or, with a little more planning, build a more complicated device to send GPS receivers erroneous information. Inadvertent jamming from waves produced by television or commercial transmitters may also occur.

LORAN-C is another navigational system that uses land-based antennas with high-powered, low frequency signals that are not easily attenuated or jammed. However, LORAN-C is not currently as accurate as GPS, although it does have a high repeatability rate, and under the regulations of the Federal Aviation Administration (FAA) cannot be used for the approach phase of aviation navigation like GPS can.

The FAA would like to have the GPS navigation system integrated with the LORAN-C navigation system for a more robust and tolerant position solution. The benefits of integrated receivers are they can provide inherent redundancy, helping to ensure that the navigation system will not fail. Should one system become unusable, the other can be used so that billion dollar industries, such as commercial airline and shipping, do not need to come to a devastating halt while the problem is fixed.

There are currently two main types of GPS corrections used to provide a more accurate fix position. They are the Wide Area Augmentation System (WAAS) and Differential (DGPS) corrections. The first problem is how to create a system that can be used to accurately collect DGPS and WAAS GPS positions. The second problem is how to analyze the data obtained from the system to compare the accuracies of Differential and WAAS corrected GPS in order to determine which system should be used for integration. As the project progressed, a particular interest was taken in our DGPS test results from Coast Guard service. As a result of this it was decided that further testing of DGPS would be valuable to the continuation of the project. A third problem became what were the effects of range to the beacon correction station versus precision of the fixes.

OBJECTIVE

The overall goal of this project is to integrate LORAN-C with either DGPS or WAAS GPS using Kalman filtering. The goal for this semester was to study the comparative statistics of DGPS and WAAS GPS. An emphasis was placed on DGPS and the effect of range from the beacon correction station versus precision of the correction. To gain more insight into the Kalman integration, we wanted to compare the differences in the precision of the systems by creating scatter plots of positions found by the different receivers taken simultaneously at different fixed locations over a period of time. If the cluster of positions from one receiver is concentrated to a smaller area than the other receivers, then the system is the most precise. In addition, three receivers accepting corrections from three different reference stations were setup for data collection. This data will be used to make a comparison of distance from beacon versus precision of the fixes. There were a few objectives that had to be met to get this far and there are more to complete before the final completion of the project.

The first objective we set was to become familiarized with prior research and background information concerning GPS, LORAN-C, and integration methods. Studying some of the present issues and learning what has already been researched was significant in finding relevance to the work to be done for the remainder of the semester. The next objective was to collect data. This involved building the system, devising a plan of different places where test data should be taken, and then logging numerous position fixes. The next objective was to take a closer look at the characteristics of DGPS test data to gain a better understanding of the system's accuracy as a function of distance from the beacon. Finally, the last objective this semester was to analyze the WAAS versus DGPS data and make a conclusion about which GPS corrections are more accurate and precise.

SYSTEM DESIGN

The first step was to put together a system to record data strings containing position information from various receivers. In the first phase of the project, three receivers, WAAS GPS, DGPS, and unaugmented GPS, were assembled together and connected to a PC via three COM ports. These receivers, manufactured by Novatel, consist of an OEM-4 model and two Millenium models. The OEM-4 was used to collect WAAS GPS information while the two millennium models were used to collect unaugmented GPS and DGPS fix positions. In the next phase of the project two additional receivers were used. These two commercially available receivers of different costs ranges were also attached to COM ports on the PC in order to record DGPS data. One of the receivers, the Northstar, was approximately $2000 and the other was a $500 dollar Furuno model. All five HyperTerminal programs (one for each receiver) then stored the data in five different text files. Data was taken for approximately 6 hours, one fix every five seconds, from the following locations: Barnegat, NJ, Sandy Hook, NJ, Wildwood, NJ, Ocean City, MD, and Castle Hill, RI. A map of the locations of testing can be seen in appendix C.

In order to collect fix information from three different beacons simultaneously, the setup was later modified and more data was collected. The three Novatel receivers, all configured to accept differential corrections, were connected to three Garmin differential beacon receivers all tuned to different reference stations. All data for this phase of the project was taken

Figure 1a. Novatel Receiver Configuration

Figure 1b. Northstar and Furuno Receiver Configuration

at the United States Coast Guard Academy.
After the data was collected, the text file containing the information was converted to a MATLAB compatible format. The data contained in these new files could then be run through a script created to help us analyze our large quantities of data. One of the first values calculated was the average position. It was assumed that with multiple hours of data collected, if the positions were averaged out than this would be the most correct way of finding the actual position or "ground truth" of the antenna receiving the fix positions. With ground truth at the center, a circle was plotted that included 95% of the rest of the positions collected (this is known as a 95% circle). The radius of these circles from the data collected was used in our comparative analysis.

Another concern was for varying conditions that might affect the quality of the data. Poor satellite geometry can often cause high dilution of precision (DOP). Fortunately horizontal DOP was also included in the data string that was sent to the PC. All fixes with a respective HDOP greater then 2 meters were omitted. HDOP plots and satellite coverage plots were also created for each testing period to ensure that data was being collected during "reasonable" conditions. An example of one of these plots is shown below.

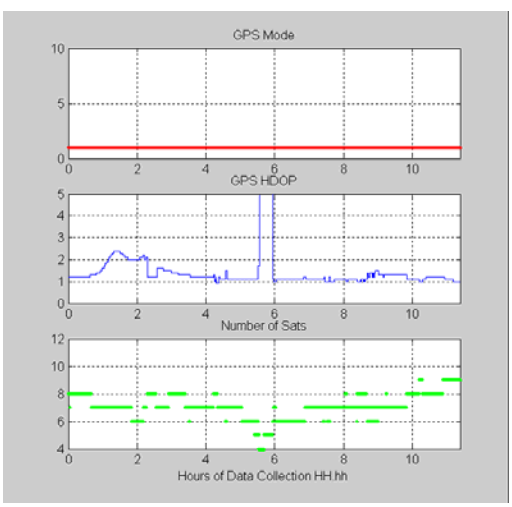

Figure 2. A Satellite Configuration Plot

RESULTS

The results of the project are the comparison of test data from navigational receivers. The output from the receivers was saved into data files. These data files were taken over a period of, on average, 6 hours with a fix position logged every five seconds. To better understand the data and get a sense of how accurate each receiver was, the data was converted from Latitude and Longitude to meters centered on the average point for each of the sets of data. Each of the files was run through a MATLAB script file to perform the calculations. MATLAB solved for a number of different variables including the average position, the average H-DOP, and the radius of the 95% error circle.

The following tables display the total number of positions logged the average HDOP for the location and testing time period, and the radius of the 95% error circle. Above the tables in parentheses is the distance from the location to the beacon correction station. The complete spreadsheet of these tables can be seen in appendix A.

Table 1. At Barnegat receiving Moriches (100.57 nm)

	GPS	DGPS	WAAS
Number of Positions	5106	5119	5071
Average HDOP (m)	1.2997	1.24969	1.33369
95% Error Circle (m)	2.9184	1.45115	1.55407

Table 2. At Barnegat receiving Sandy Hook (55.62 nm)

	GPS	DGPS	WAAS
Number of Positions	7382	7372	6889
Average HDOP (m)	1.9162	1.8961	2.0675
95% Error Circle (m)	3.3303	1.3056	1.3966

Table 3. At Sandy Hook receiving Moriches (61.01 nm)

	GPS	DGPS	WAAS
Number of Positions	3892	3932	3875
Average HDOP (m)	1.4959	1.4943	1.5244
95% Error Circle (m)	4.6525	1.4258	2.1088

Table 4. At Sandy Hook receiving Sandy Hook (5.21 nm)

	GPS	DGPS	WAAS
Number of Positions	5658	5663	5239
Average HDOP (m)	2.1041	2.1045	2.4180
95% Error Circle (m)	3.7727	1.5084	1.971

Table 5. At Wild Wood receiving Moriches (147.73 nm)

	GPS	DGPS	WAAS
Number of Positions	4352	4357	4356
Average HDOP (m)	1.0941	1.0974	1.0963
95% Error Circle (m)	2.6393	1.1296	1.8837

Table 6. At Wild Wood receiving Sandy Hook (99.88 nm)

	GPS	DGPS	WAAS
Number of Positions	11577	11057	11138
Average HDOP (m)	1.4301	1.4442	1.6143
95% Error Circle (m)	2.9047	1.0446	1.3398

Table 7. At Ocean City receiving Moriches (182.07 nm)

	GPS	DGPS	WAAS
Number of Positions	4399	4360	4332
Average HDOP (m)	1.1981	1.1936	1.24
95% Error Circle (m)	5.4544	3.9961	2.6851

Table 8. At Ocean City receiving Acushnet (280.48 nm)

	GPS	DGPS	WAAS
Number of Positions	6569	6036	6334
Average HDOP (m)	1.7035	1.7419	1.6929
95% Error Circle (m)	5.8385	4.4437	1.9599

Table 9. At Castle Hill receiving Moriches (74.68 nm)

	GPS	DGPS	WAAS
Number of Positions	4281	4299	4306
Average HDOP (m)	1.2097	1.2146	1.2112
95% Error Circle	3.2545	1.2399	0.8143

Table 10. At Castle Hill receiving Acushnet (27.05 nm)

	GPS	DGPS	WAAS
Number of Positions	4338	4290	4370
Average HDOP (m)	1.12681	1.3360	1.2781
95% Error Circle (m)	2.4595	1.1886	1.5118

These tables are useful in getting a general idea of the accuracy from various distances from various beacon correction stations for the DGPS fixes. In addition, the WAAS data is useful in comparing to the FAA's new augmentation system. For instance, it can easily be seen from the size of the spread of the GPS data points that WAAS and DGPS receivers are much more accurate then uncorrected GPS. The scatter plots below shown in figure 3 illustrate the position data plotted with the 95% error circles. Notice that the straight GPS error circle is 3.3303 meters while the DGPS and WAAS results yield an error circle just less the 1.5 meters.

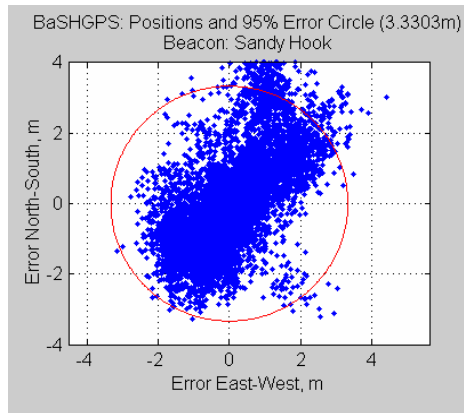

Figure 3a. GPS
At Barnegat, Receiving Sandy Hook

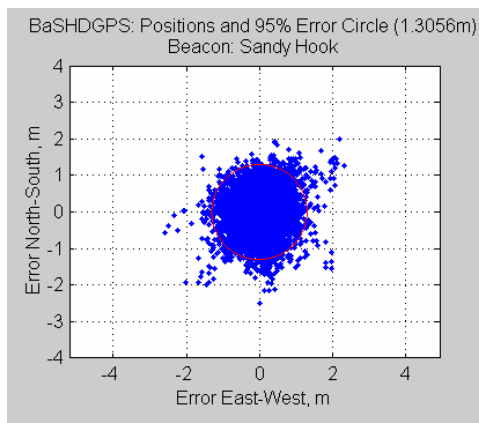

Figure 3b. DGPS
At Barnegat, Receiving Sandy Hook

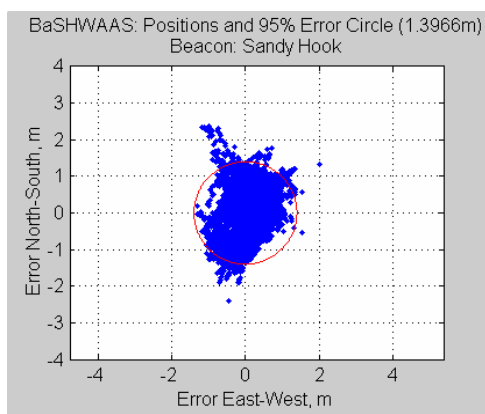

Figure 3c. WAAS
At Barnegat, Receiving Sandy Hook

Looking at spatial degradation, data received from beacons within 150 nm of the GPS antenna did not appear to be significantly effected by the distance. For example, table 1 displays the data results while at Barnegat using the Moriches beacon correction station (100.57 nm). The DGPS error circle was 1.45 m while the WAAS error circle was 1.55 m, both comparable with neither one significantly outperforming the other. Similar results occurred while at Barnegat receiving Sandy Hook (table 2), while at Sandy Hook receiving Moriches (table 3), while at Wild Wood receiving Moriches (table 5), while at Wild Wood receiving Sandy Hook (table 6), while at Castle Hill receiving Moriches (table 9), and while at Castle Hill receiving Acushnet (table 10). Past 150 nm however, a significant degradation was seen while at Ocean City receiving Moriches (182.07 nm). Looking at table 7, it can be seen that the WAAS accuracy was about 2.7 meters while the DGPS error circle was almost 4 m. Similar results occurred while at Ocean City receiving Acushnet 280.48 nm away (table 8). The DGPS error circle was 4.4437 m while the WAAS error circle was 1.9599 m.

As discussed earlier, other commercial receivers were utilized in the experiment. The Northstar and especially the Furuno receivers delivered less accurate results then the Novatel models. Because of this, most conclusions were drawn from data coming from the Novatel models. The Northstar and Furuno receivers had a differential GPS accuracy of about 3 – 5 meters while the Novatel units gave accuracies between 1 – 2 meters.

Table 10. At Sandy Hook receiving Moriches

	Northstar DGPS	Furuno DGPS
Number of Positions	4146	22368*
Average HDOP (m)	0.4602	1.3849
95% Error Circle (m)	3.0830879	5.3045233

*This number is larger because the Furuno receiver can only log every second.

Another study completed was comparing the 95% circles of coordinates logged from three Novatel receivers using the same GPS antenna but tuned to three different reference stations. The three beacons were Acushnet, MA, Moriches, NY, and Sandy Hook, NJ. The complete tables of this information can be seen in appendix B.

Table 11. Differential Beacons Used

	Acushnet, MA	Moriches, NY	Sandy Hook, NJ
Frequency (kHz)	306	293	286
Distance from Antenna (nm)	58.8	45.61	102.2

Six trials were preformed in order to recognize patterns in the data. Degraded accuracy with increasing distance from the reference station was expected before taking data. This occurred in only three out of the six trials performed. The following tables display the number of fixes logged to generate the 95% circles along with the average HDOP for the duration of data recording.

Table 12. At USCGA Trial 1

	Acushnet, MA	Moriches, NY	Sandy Hook, NJ
Number of Positions	12403	12382	12668
Average HDOP (m)	1.5619	1.4831	1.0993
95% Error Circle (m)	2.5267	2.6611	2.9594

Table 13. At USCGA Trial 2

	Acushnet, MA	Moriches, NY	Sandy Hook, NJ
Number of Positions	17450	17114	17160
Average HDOP (m)	1.1787	1.4467	1.4194
95% Error Circle (m)	2.8939	2.6540	2.4716

Table 14 At USCGA Trial 3

	Acushnet, MA	Moriches, NY	Sandy Hook, NJ
Number of Positions	17172	16921	16908
Average HDOP (m)	1.1679	2.6266	1.4474
95% Error Circle (m)	2.9353	2.6266	3.8402

Table 15. At USCGA Trial 4

	Acushnet, MA	Moriches, NY	Sandy Hook, NJ
Number of Positions	17134	17076	16965
Average HDOP (m)	1.2224	1.4049	1.4520
95% Error Circle (m)	2.9186	2.5970	3.6841

Table 16. At USCGA Trial 5

	Acushnet, MA	Moriches, NY	Sandy Hook, NJ
Number of Positions	17539	17243	17174
Average HDOP (m)	1.1803	1.4171	1.4665
95% Error Circle (m)	2.3673	2.0104	2.0374

Table 17. At USCGA Trial 6

	Acushnet, MA	Moriches, NY	Sandy Hook, NJ
Number of Positions	4116	3718	3866
Average HDOP (m)	1.1894	1.5049	1.5349
95% Error Circle (m)	2.8645	2.4632	2.9373

Trials number three, four, and six created error circles that directly relate degradation of accuracy to the distance from the beacon. Sandy Hook, NJ at 102.2 nm (the furthest beacon away) actually had the smallest error circle on trial two. With Sandy Hook (the beacon furthest from the GPS antenna location) outperforming closer beacons during some of our test trials, it is hard to say that spatial degradation as a function of range from the beacon is significant within 100 nm from this data.

CONCLUSIONS

This semesters work included continued testing into the accuracy and repeatability of three different brands of receivers using two augmentation systems. The three different receivers, Novatel, Furuno, and NorthStar, all had 95% circles that agreed with the receivers cost. Novatel, with a price of $7000, had the smallest 95% circle while the Furuno, with a price of $500, had the largest circle. Most important to the project was the comparison of the different Novatel GPS fixes using WAAS, DGPS and no corrections. The DGPS corrections were taken using different beacons from different locations. This was done to see how range to beacon station degrades the receivers accuracy. However, at times the patter did not seem to make sense where on some occasions a beacon five miles away was giving worse accuracy than a beacon sixty miles away. In order to resolves problems in the test taking such as different HDOPs on different days of testing, testing was set up in the lab at USCGA to get corrections from three different beacons at the same time. This proved to be inconclusive to the effects of accuracy degradation due to range because the accuracies from all beacons were relatively close, with the farthest beacon being the most accurate on more than on occasion. Thus it was concluded that accuracy degradation due to range is not a factor with ranges up to 100 NM. Throughout the testing it could be seen that no matter the location along the North Eastern coast the DGPS accuracies were very close to those of WAAS, with only slight differences. It is concluded that with such similar capabilities either could be used in the integration with LORAN-C. Next semester will start the beginning of the integration process. Work will begin on understanding how the integration of LORAN-C and GPS with Kalman filters can be done. Also, next semester will involve finding the best way to accomplish this, working out the software that will perform the integration, and also construction of the hardware for navigational receivers and user interface. Finally, the end of the semester will be a time to test, troubleshoot, and re-test the integrated receiver.

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