Testing VHF-DF Aspects of Rescue 21

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ABSTRACT

The Coast Guard Headquarters Acquisition and National Distress directorate (G-AND) has tasked the Coast Guard Academy with developing a testing device for the modernized National Distress and Response System. The device will test the direction finding capability of the system built by General Dynamics, which began construction in 2002. The testing device consists of two mobile data radios transmitting position information between a mobile station and a base station. The position information obtained from the device was translated into a directional bearing and compared to a SIMRAD commercial direction finder. The difference between the DGPS calculated bearing and the bearing obtained by the SIMRAD direction finder ranged from 1 degree to 179 degrees. Although the results do not conclusively lead one to believe that this method can be used to test the General Dynamics system, I hypothesized that lengthening the signal would lead to more conclusive results. If the project is continued, testing of that hypothesis will occur in the fall of 2005, and, with conclusive results, will lead to the testing of the General Dynamics' Direction-Finding System.

INTRODUCTION

The Coast Guard's current National Distress and Response System was first implemented thirty years ago, and is seriously outdated. The system consists of 300 very high frequency, frequency modulated (VHF-FM) antenna sites that provide coverage out to 20 nautical miles from shore. However, there are several shortcomings with the current system including: "Imprecise direction finding capability, numerous geographic coverage gaps, lack of interoperability with other emergency response services and single-channel radio operation, which prohibits the ability to receive radio calls when the system is previously engaged in a transmission" (reference 3). As a result, there exists a high probability that lives may be lost because the Coast Guard cannot respond properly.

Coast Guard Headquarters' Acquisition and National Distress (G-AND) directorate has initiated the Rescue 21 project to find a solution to this problem. The Rescue 21 project is currently replacing most of the outdated technology on the 300 VHF-FM antenna sites including all consoles at Coast Guard Activities, Groups, Stations and Marine Safety Offices. Equipment on nearly 300 Coast Guard vessels will also be upgraded. All remote transceiver sites as well as the network connecting them to the Coast Guard facilities will be replaced.

The update will also provide coverage along the coast (out to 20 nautical miles) of the United States, eliminating the gaps the previous system had. Figure 1 displays the areas of the New Jersey coastline required to be covered by the new Rescue 21 system.

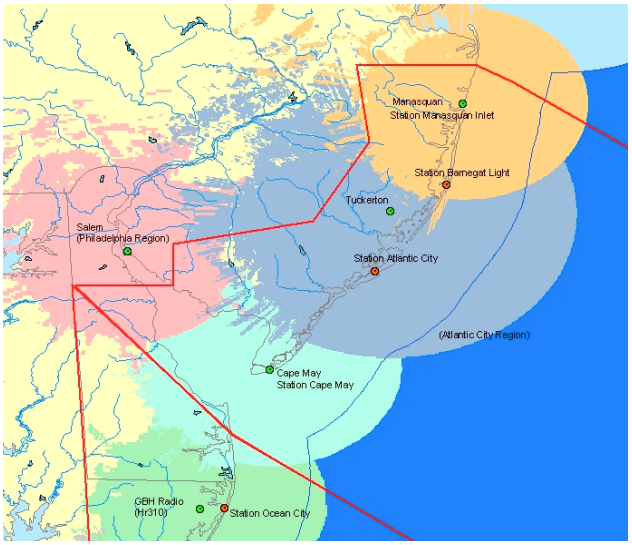

Figure 1: Example of Areas of Coverage

Note that there are no coverage gaps and several stations have overlapping coverage areas. This is just

an example, and the entire coastline of the United States will have coverage out to 20 nautical miles once the project is completed.

Rescue 21 includes the implementation of Direction-Finders with a requirement of an allowable error of +/- 2 degrees, which minimizes the possible search area of a vessel in distress. The overlapping coverage areas seen in Figure 1 will provide for the possibility of multiple lines of bearing to a distressed vessel, which will further decrease the maximum search area. It will also enable Coast Guard stations to distinguish between legitimate and false distress calls, since a signal coming from land is not likely to be legitimate.

The Coast Guard awarded General Dynamics the contract to build a system to meet these needs. Components of this system are currently undergoing installations and prototyping. The Rescue 21 directorate has asked the Coast Guard Academy to design and produce a device that will test the new VHF-DF system for its geolocation capabilities and accuracy. The Coast Guard will be able to use the testing device to determine the accuracy of the VHF-DF system along the United States coast. The device will verify the ability of the VHF-DF system to pinpoint transmissions in real-world situations. The testing setup must be able to assess the direction finding capability of a site, be easy to use, and be portable.

In 2002, LTjg Courtade began the most recent phase of this project. He took a broad set of specifications given to General Dynamics by Rescue 21 and determined the specifications a signal should meet before it would be fair to hold General Dynamics to the Rescue 21 requirements. These specifications include an electric field of at least 1 µV per meter, a frequency within 150.000-165.000 MHz (which is the range that includes VHF Channel 16), a Signal-to-Noise ratio of no less than 15 dB, and transmission time of 200 milliseconds. Rescue 21 still requires that the Direction Finder will be held to the original requirements if the boat in distress has a six-foot height of eye, is within 20 nautical miles of shore and is transmitting at a power of at least 1 Watt. Therefore, the General Dynamic direction finder will be held to a very stringent requirement of +/- 2 degrees in circumstances that it will not be able to meet that requirement.

In the spring of 2003, LTjg Courtade continued his project by researching radios to determine which would be most useful to test a direction finder. His research concluded that two types of modem radios would be sufficient. The first transmitted packets using Frequency Shift Keying modulation (FFSK) while the second transmitted using Gaussian Minimum Shift Keying (GMSK). It was determined that a data modem radio would be a better candidate for the test because it would send out the position to the receiver, while a voice radio would require a person to state the position he or she was transmitting from. In other words, a data radio would make the test more accurate.

In the fall of 2003, ENS Benjamin was assigned to continue the project. She found that the power spectrum of FFSK, at 4800, baud is comparable to FM, while the power spectrum of GMSK, at 9600 baud, is comparable to FM. This is important to note because the radios need to transmit at the comparable bit rate in order to allow for the testing of a direction finder that uses frequency modulated transmission. After discovering the compatibility, ENS Benjamin bought two sets of VHF radios, one that used GMSK and was made by TeleDesign Radio, and another that used FFSK and was made by Key Radio Systems. ENS Benjamin began constructing a system using the TeleDesign radios, but due to time restraints was unable to finish the construction and testing.

OBJECTIVE

The goal of this project is to ensure the General Dynamics' system meets Coast Guard requirements. To accomplish this goal, the first step was to construct a device to test the Direction Finder supplied by General Dynamics. This testing device consists of a stationary unit, which includes a computer to integrate and analyze data, a direction finder to be tested, and a radio to communicate with the mobile unit. The mobile unit consists of a Differential Global Positioning System (DGPS) receiver to calculate position data and a radio to transmit the position data. Once it is confirmed that the device accurately transmits positions and bearings, testing on moving targets will begin and data will be collected.

When the project is complete, five deliverables will be submitted to the Coast Guard Rescue 21 team. A description of the test system, including a block diagram, a functional description of the blocks, and analysis done during the system design will be written. The manufacturing related documentation, which contains schematic diagrams and circuit descriptions, a parts list, assembly drawings, and assembly instructions, and a bill of materials, will also be submitted. The testing device including the software to implement testing, radios and DGPS will be given to Rescue 21. A user's manual will be provided to ensure the Rescue 21 team can use the device. Finally, the results and analysis from the General Dynamics' Direction Finder tests will be included as a starting point for the Rescue 21 team.

SYSTEM DESIGN

This project includes both engineering aspects (i.e. the design and implementation of the test bed) and administrative deliverables.

Due to time constraints, the Key Radio Systems radio was never used. As a result, the testing device consists of a mobile radio that uses Gaussian Minimum Shift Keying to transmit DGPS or Wide Area Augmentation System (WAAS) data. The first mobile radio is located on a moving test bed (ultimately a Coast Guard cutter) transmitting to a base station located in a lab station. During initial testing, the lab station is room 214 in McAllister Hall. For the final testing, it will be in a Coast Guard station. See Figure 2 for a picture of the mobile setup.

Figure 2: Mobile Unit

The base station radio transfers the data to a computer located in the lab where the information is deciphered. The received position information in combination with the base station's known position is used to calculate a bearing to the transmitter. This calculated bearing is compared to the bearing estimate obtained from a SIMRAD Direction Finder (ultimately the General Dynamics Direction Finding System will be used). Figure 3 shows the base station.

Figure 3: Base Station

Figure 4 displays a block diagram of how the system is connected. The DGPS or WAAS information is transmitted to the mobile radio through a serial port connection. The mobile radio transmits the data to the base station radio using GMSK. Once the base station radio receives the data, it is transferred to the personal computer using a serial-to-USB port connection. At the same time, a direction finder at the base station receives the data signal and determines its bearing relative to the North plate of the antenna. It transfers that data to the computer through a serial-to-USB port connection. The computer then uses MATLAB software to interpret the information from the strings that it received. The software compares the two bearings, finding the error in degrees.

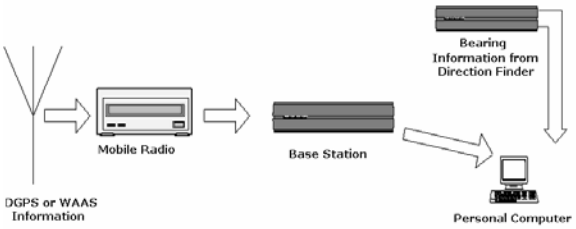

Figure 4: Test System Setup

Throughout the testing, two types of position information were used. In the first test, the Starlink DNAV-212 DGPS receiver was used; it has accuracy to less than 1m. The second test used a Novatel ProPak-G2 WAAS receiver which is rated at accuracy to less than 1.2m.

The position information from either receiver is sent using a NMEA string whose format follows the example:
$GPGGA,134731,4122.3427,N,07205.9988,W,1,03,02.3,-00105,M,,M,,,*63

The $GPGGA means that it is a position string. The next number , 134731, is the time in hours, which is converted into hours, minutes and seconds by the MATLAB software. The latitude, in degrees, is read in next. The MATLAB software converts it into degrees and minutes. The next number is the longitude. These are the only parts of the NMEA string used.

The DF information is sent using a proprietary string made by SIMRAD, which follows the example: $DFBRG,S81,,1,276,R,

The $DFBRG means that it is a bearing string. The first number is the channel the transmission was received on. The next number is not important for the purposes of this test. The third number, 276 in this case, is the direction the signal was received from. Finally, the R means the direction is in degrees relative.

It is important to note that this is a proprietary sentence made by SIMRAD. When testing the Rescue 21 Direction Finder, it will be necessary to determine the format it uses and adjust the MATLAB code to read it.

The engineering aspect of the project also includes the field testing of the device, which is broken into two separate parts. The first part of the testing consists of stationary tests to calibrate the components of the device. The most important part of this test is to ensure that the commercial Direction Finder's antenna is calibrated. The Direction Finder will determine the relative direction of a signal from the North plate of the antenna. Therefore, it is extremely important to determine the true direction of the antenna's North plate so the relative bearing can be converted into a true bearing. The direction finder antenna can be found in Figure 5.

Figure 5: SIMRAD Direction Finder Antenna

It should be noted that the direction finder employed by the Coast Guard will be aligned to true North. This will eliminate any error caused by alignment.

After the system was been calibrated, mobile testing began. Mobile testing consisted of first driving a car around with the moving test bed. Next year, the testing will become more realistic, using a boat to drive up and down the Thames River. Again, the data will be analyzed.

The final testing platform will be a Coast Guard cutter in New Jersey, and will test the General Dynamics Direction Finder.

RESULTS

The first goal to accomplish this year was to complete MATLAB code that would enable a computer to translate a NMEA string into a DGPS position, convert it to a bearing and compare that bearing to the bearing the direction finder calculated to the signal. After several trials, the MATLAB code did that and output the results to a text file that could be opened using Microsoft Notepad. For a copy of the MATLAB code refer to Appendix A.

The First Trial Run

Once the MATLAB code was created, the testing of the system began. The stationary test bed remained in the lab, while the mobile unit was put in a truck and driven throughout Groton, CT. Table 1 contains a sample of the results obtained on the first trial run. Its columns contain the Zulu time of that recording, the calculated GPS bearing to the position received, the bearing calculated by the SIMRAD direction finder, and the difference between the actual and calculated bearings. Appendix B contains the full spreadsheet of results from Trial 1.

Table 1: Results From the First Trial Run

RESULTS TAKEN ON 29-Mar-2005			
ZULU Time	**GPS Brg**	**DF Brg**	**Difference**
19:16:09	31.7832	330	61.7832
19:16:10	31.925496	141	109.074504
19:16:18	31.949492	17	14.949492
19:16:19	31.949492	4	27.949492
19:16:20	31.973258	169	137.026742
19:16:21	32.113681	293	99.113681
19:16:22	32.371596	293	99.371596
19:16:26	33.307224	290	103.307224
19:16:27	33.445397	331	62.445397
19:16:28	33.705194	166	132.294806
19:16:31	33.842733	330	63.842733
19:16:33	34.364406	350	44.364406
19:17:13	7.100168	287	80.100168

During the first trial run, one major unanticipated problem was discovered. When the vehicle drove under a bridge, the DGPS receiver could not find a DGPS signal. As a result, no signal was being transmitted to the base station. Since the MATLAB software did not get the data input it expected, it froze up. Worse, as soon as the DGPS receiver lost the signal, it needed to be restarted using a computer program, so a computer needed to be brought along on the test run. These problems led to thoughts of using a WAAS instead of a DGPS receiver.

The Second Trial Run

With the WAAS installed in place of the DGPS receiver, a second trial run was conducted. The major difference between the first and second runs was that when the WAAS failed to get a signal, it did not need to be rebooted from a computer. This leads me to conclude that the WAAS will be more convenient to use for testing. Table 2 is an excerpt from the results found during the second field test. I added the latitude and longitude to the results to verify that the GPS bearing was correct. Appendix C contains the full spreadsheet of results.

Table 2: Results From the Second Trial Run

RESULTS TAKEN ON 23-Apr-2005					
ZULU Time	**Lat**	**Long**	**GPS Brg**	**DF Brg**	**Diff**
20:09:56	41.37195	-72.10044	262.02	190	72.02
20:09:57	41.37195	-72.10044	262.02	226	36.02
20:09:58	41.37195	-72.10045	261.76	259	2.76
20:09:59	41.37196	-72.10046	263.94	259	4.94
20:10:00	41.37196	-72.10046	263.94	304	40.06
20:10:01	41.37196	-72.10046	263.94	320	56.06
20:10:02	41.37196	-72.10046	263.92	320	56.08
20:10:03	41.37196	-72.10046	263.64	273	9.36
20:10:04	41.37196	-72.10046	263.64	280	16.36
20:10:05	41.37196	-72.10046	263.34	283	19.66
20:10:06	41.37196	-72.10046	263.34	283	19.66

Analysis from both Trial Runs

I discovered a few similarities on the two trial runs. First, the area of coverage that the TeleDesign Radios is smaller than I had originally anticipated. I had never dealt with transmitting over VHF before, and I forgot that a low antenna transmitting line-of-sight would not have a large range. That led to some of the signal failures. The radio simply could not transmit far enough. This is also important to note because the radios were at full power, or 5 Watts. Since the radios do not seem to transmit the required 20 miles, it may be necessary to determine exactly how far they can transmit, and move on to the Key Systems Radio, if necessary. One other consideration to take into account is that the actual test of the Rescue 21 Direction-Finder will occur on water, while this test occurred across a river into a town. When the test occurs over water, it is likely to have a greater line-of-sight, and thus a larger transmission radius. One final point is that the receiving antenna used by the Rescue 21 Direction Finder will be much higher, also allowing for greater line-of-sight transmissions.

The cutout of the DGPS and WAAS signal while in range was due to bridges, trees, and other obstacles that prevented the receiver from getting a position. This will not occur while testing the Rescue 21 Direction Finder because the testing will occur on water where there are no such obstructions.

Looking at the difference between calculated and actual bearings, one can see that they are not comparable.

There is an expected difference of approximately 10 west degrees due to the alignment of the antenna in relation to True North. My hypothesis for the range of difference is that the direction finder may not have enough time to process which direction the signal is coming from due to its small length. To test this hypothesis, I stationed a cadet across the base. The cadet was instructed to hold down the talk button of a hand-held VHF radio until I got a steady bearing from the SIMRAD Direction Finder. Once I knew what the bearing should be, I instructed the cadet to hold down the talk button for ten second intervals ten times. During each interval, I timed how long it took the direction finder to home in on the signal. Table 3 displays the results I found.

Table 3: Time to Calculate Bearing

Attempt Number	Time to Fix (in seconds)
1	5
2	5
3	7
4	6
5	4
6	5
7	3
8	6
9	8
10	10

Since the filed tests I performed involved transmitting a signal that lasted approximately 500 milliseconds every second, it is unlikely that the SIMRAD direction finder was ever able to get a good bearing to it. The results show the signal needs to be three to ten seconds long for the direction finder to resolve the bearing.

The solution to that would be to increase the length of the signal. While it has not been done yet, several NMEA sentences may be able to be transmitted together, which will result in a longer signal. Lengthening the signal will be one of the many tasks to be completed next semester.

CONCLUSIONS

The biggest challenges faced this past semester included fine-tuning the MATLAB coding to efficiently read in data, understanding how the TeleDesign Radios and SIMRAD DF worked, and making all components of the system talk to each other.

Despite an aggressive schedule for this project, work remains to be done. The Key Systems Radios have been taken out of their boxes, but need to be set up and configured for use. It is possible that the Key radios would provide a more efficient platform for testing, and should be examined to determine their characteristics.

My work this semester has not been able to show accuracy in testing a Direction Finder. As a result, the overall goal of the project (to test the General Dynamics system) was not accomplished.

Next year, it is recommended that research is conducted to determine how to lengthen the NMEA sentence to allow the transmission time to be long enough for the Direction Finder to lock in on it. Once this is accomplished, the system will be ready to deploy to test a Rescue 21 site.

The Rescue 21 project is behind schedule and is still in the testing phase, so it is likely that this testing device, when fully developed, will be helpful in ensuring that General Dynamics is meeting requirements.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions of the former cadets who have contributed to this project, especially ENS Benjamin and ENS Courtade; those that assisted in creating a MATLAB program to allow for the analysis of the collected data including Doctor Gross, ENS Pizzuro and Mr. Greg Johnson; Mr. Christian Oates, who assisted with all aspects of this project; and her project advisors, Doctor Gross and CDR Routhier.

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[2] "Look Into NovAtel's ProPak G2 Webpage," available from http://www.navtechgps.com/pdf/propak/pdf; (accessed 13 Apr 05).

[3] "Rescue 21 Project History Webpage," available from http://www.uscg.mil/rescue21/about/phist.htm; (accessed 23 Nov 04).

[4] Work of Jeremy Courtade

[5] Work of Kristen Benjamin

APPENDICES

[A] MATLAB Code

[B] Results from Field Test 1

[C] Results from Field Test 2