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Differential LORAN for 2005

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Abstract. A multimodal group of engineers, scientists, and industry representatives, including the U.S. Coast Guard (USCG) and Federal Aviation Administration (FAA) completed a major effort to define and analyze the performance of a new Enhanced Loran system as a backup for the navigation and timing services provided by the NAVSTAR Global Positioning System (GPS) provided services. Each mode of transportation has defined requirements that the new Enhanced Loran must meet to be acceptable in the radionavigation mix of systems. The group developed a set of requirements for Loran maritime navigation in terms of availability, accuracy, integrity and continuity for the Harbor Entrance and Approach (HEA) requirements defined in the Federal Radionavigation Plan (FRP). This paper discusses the goals of the Loran Support Unit for Fiscal Year 2005 (FY05), and the program to support these goals. The factors related to achieving the objective of moving Differential Loran from the proof-of-concept stage to an operational status will be discussed. Also covered are the results of an initial survey of the Inner Harbor at Boston, MA, USA.

Key words: Loran, radionavigation, GPS, timing.

1 Introduction

The Loran Integrity Performance Panel (LORIPP) and Loran Accuracy Performance Panel (LORAPP) determined that an improved version of the LORAN-C system, called Enhanced LORAN, could meet the operational requirements of the HEA for maritime positioning use and the FAA-derived Required Navigation Performance of 0.3 NM (RNP 0.3). The U.S. Department of Transportation (DOT) Volpe Center completed a benefit-cost analysis covering this move, with favorable results. Both reports were completed and delivered to the Office of the U.S. Secretary of Transportation in March of 2004. At the time of this writing, the Loran community awaits a public decision regarding the future of the LORAN system.

Although a definitive direction for LORAN has not been decided, the USCG Loran Support Unit (LSU) has continued research and development into the Enhanced Loran architecture. Having completed the aforementioned reports, a transition is underway from the proof-of-concept stage to a quasi-operational status, which will promote receiver development and other LORAN research.

2 Differential LORAN

The basic concept of Differential LORAN is to provide two sets of phase corrections to improve the navigation accuracy from the current 0.25 NM level to approximately 20 meters. One set of corrections is called Additional Secondary Factors (ASFs) which are defined as the phase differences between an all seawater propagation path and the actual propagation path and are functions of the ground conductivity and terrain along the path. These ASFs will be obtained by detailed surveys of the coverage area. In addition, there are temporal changes in the observed phase caused by changes in index of refraction along the propagation path and variations in transmitter bias. These variations will be measured at a fixed local monitor site, and communicated to users via modulation of the LORAN signal. For a detailed description of this data channel the reader is referred to Peterson et al (2004).

3 Goals

There are two main goals for FY05. The first goal is to establish Differential LORAN on a 24/7 real-time basis for selected areas of the Northeastern U.S. Previous tests were done either in post-processing or during limited time periods in which Differential LORAN data was broadcast over the air waves from the experimental transmitter at the LORAN Support Unit. While these relatively short broadcasts were useful to demonstrate that the technology was feasible, continuous broadcasting of real-time data is needed in order to refine the implementation. This has the added potential benefit of promoting receiver development.

The second goal is to develop the procedures and working knowledge necessary to establish Differential LORAN in an area. Knowledge gained from the marine and aviation surveys can be integrated in support of this goal. In addition to scientific concerns, some practical considerations may drive the final shape of the new Loran system.

4 Program

Differential LORAN is a technology that is applied to both timing and navigation applications. Consequently, two types of monitor sites have been identified: 1) Tier I sites which possess a GPS independent, highly accurate source of absolute time (within 10 ns of UTC(USNO)) facilitated by one or more atomic time standards disciplined using Two-Way Satellite Time Transfer (TWSTT), and Tier II sites which have a less accurate and possibly GPS dependent source of absolute time. Tier I and Tier II sites are nominally called "timing" and "navigation" monitor sites, respectively. The Tier I sites will support both timing and navigation users. If GPS service is lost the Tier II sites will revert to pseudorange vice absolute corrections whereby one correction will be set to zero, all others calculated as relative corrections, and the corrections will be useful to navigation users but not to timing users. The message format includes bits to notify users of the type of base station the corrections come from and whether on not the GPS time reference is available.

The Northeastern U.S is the area of the country with the highest seasonal variation in phase propagation. Planned monitor sites include: U.S. Department of Transportation Volpe National Transportation Systems Center (USDOT Volpe), to support some marine surveys in the Boston, MA area, The USCG Loran Support Unit (LSU), Wildwood, NJ, The USCG LORAN monitor site at Sandy Hook, NJ, due to its proximity to the metropolitan New York City area, and the United States Naval Observatory (USNO), where official time for the U.S. is maintained.

Boston Harbor will be the initial location for a marine survey. A navigation monitor site has been established at the Volpe Center to support surveys in the area. Once the Boston survey research is complete and as time permits, it is desired to apply the newly refined procedures to another metropolitan area such as New York.

5 Issues

Communications Network: Due to the topography of the areas surveyed, monitor sites may be placed in remote areas and at locations with varied methods of access to the Internet. This requires the establishment of an ad hoc network in which data sources can be added, removed, or moved easily. This capability requires a specialized computer network structure. A next-generation IT network for the Enhanced LORAN system is being developed at the USCG Loran Support Unit, however it is not due to become operational until FY 2007. An interim solution that will allow for real-time data broadcast is being developed at the LSU.

Monitor Site Density: The seasonal variation in phase propagation is region-dependent. Differential LORAN technology reduces the error due to this variance. However, for a given area and a given location within the area, the accuracy achieved using the correction from a monitor site degrades with distance from the site.

6. Survey Considerations

There are several factors to consider when executing a marine survey. Some of the most important ones are discussed here.

(1) Geographic Survey Boundaries: The single most basic question to answer in conducting a marine survey is: what are the boundaries of the area to be surveyed? As an example: consider the Chesapeake Bay, VA area, which is large and has many tributaries and other waterways connected to it. A decision needs to be made concerning the areas of a waterway that require Differential LORAN.

(2) Seasonal Variations: The phase of the signal from a given LORAN station and a given observation point varies temporally. When conducting a marine survey, it is necessary these temporal changes be measured at the local monitor site and that these variations in phase be taken into account in processing the survey data. Once a survey has been completed, a table of geographic points and associated nominal ASF values are calculated. Once calculated, this table or "grid" is loaded into a user receiver module. A navigation monitor site sends out the temporal corrections for the area covered by the grid. In the receiver, the temporal corrections are used to increment or decrement the base offset for the grid values as a whole. This method is effective as long as the phase variation is relatively uniform throughout the geographic region that the grid covers. It is assumed that the temporal variations in phase are constant over the coverage area of a particular monitor site. To verify that this is valid for a particular coverage area it is necessary to survey the area at multiple times during the year.

(3) Grid density: This factor is influenced by the spatial gradient of the ASF for a given area. A spatial gradient develops when there is a significant difference in the land path between a given LORAN station (LORSTA) and two points. Assuming that it is desirable to have a uniform level of accuracy for the area that a grid covers, the existence of a gradient is problematic since it means that the grid points must be closer together for the high-gradient regions of the area. Another solution is to divide the area into sub-grids of different point spacing, or simply restrict grids to cover areas where the ASF gradient is below a certain threshold. Finally the grid must be in a format amenable to receiver manufacturers.

(4) Source of Ground Truth/Geographic datum: There are two possible sources of ground truth for the ASF surveys: the USCG maritime Differential GPS system and the Wide Area Augmentation System (WAAS) operated by the FAA. DGPS is based on the North American Datum of 1983 (NAD 83) and WAAS is based on the World Geodetic System 1984 (WGS 84). Both systems have comparable accuracy. In the surveys done this far, we have logged both DGPS and WAAS data simultaneously and have compared the two sets of fixes and compared the differences to that predicted by the differences between NAD 83 and WGS 84.

7 Loran Data Channel (LDC) Test for 2005

The real-time dissemination of Differential Loran data (i.e.: moving data from multiple monitor sites to a central database and broadcasting the same data from a LORAN station) will represent a major move forward for Differential Loran, allowing more effective test of the technology and process, and will support additional research in the field. The success of this endeavor depends on proper integration of specialty software and COTS hardware.

LORSTA Seneca, NY is the planned first broadcast node in this network. Initially, observations from monitor sites at the US DOT Volpe Center at Boston, MA and USNO at Washington, D.C. will be broadcast from this station.

Communications between the monitor sites, a central server and LORSTA Seneca, NY will be crucial to the success of this endeavor. Currently, the operational network for the LORAN system is being used for the present Loran data collection efforts. There are three obstacles to using this scheme for real-time corrections. First, the architecture of the current operational network coupled with the protocols employed is not amenable to the type of data requirements for research. Second, the security policy for the operational LORAN network does not permit adding users on an ad hoc basis and with varying security assurance levels, and does not allow access from the Internet. Third, the remote possibility that a catastrophic network glitch could be caused by this research makes using the operational network an unattractive option. For these reasons, it was decided that a network other than the operational network would be used. Due to the prohibitive cost of acquiring another research network for this specific purpose, it was decided to use the Internet for communications during this test and research phase.

LSU has undertaken the effort to determine the requirements for the next-generation Loran network, which will support Differential Loran messaging; however the planned operational phase is for FY2007. An interim, Internet-based solution is being developed at LSU to facilitate research and monitoring of the differential messages. This communications scheme will allow dissemination of real-time differential corrections.

8 Architecture of Differential LORAN Data Network

In general, Differential LORAN is being implemented for this experiment in the following way: Monitor sites (navigation or timing) are placed at strategic locations near certain waterways. The sites produce Loran observations at a specific reporting interval which are immediately sent to a central computer at LSU via the Internet. Upon arrival at LSU, the observations are logged and immediately relayed to the applicable LORSTA (initially LORSTA Seneca) for broadcast. So there are three types of nodes in the aforementioned network: monitor, central, and broadcast nodes. Only one central node (the server) exists. The location of the monitor nodes is influenced mainly by available space/real-estate, proximity to desired coverage area (for navigation sites), and proximity to existing sources of high-quality oscillators (e.g.: cesium clocks).

9 Required Equipment

The equipment being used for this experiment is mostly commercial off-the-shelf (COTS). The nodes are connected via the Internet. The central node requires the least amount of equipment, consisting of a fast computer running connected to the Internet and running specialized software to relay the differential messages. The broadcast node requires a computer to receive the messages from the server and encode them for transmission to the standard equipment at the Loran Station. The computer at this node is also connected to a Loran receiver, and a source of absolute time. Finally, an uninterruptible power supply (UPS) will be used to prevent unnecessary loss of power. The monitor node requires a computer connected to a source of UTC and a Loran receiver. A very stable oscillator is required for a timing monitor site. A UPS is also used at this type of node.

10 Boston Harbor Survey

An initial survey of the Inner Harbor at Boston, MA, USA was conducted on July 17, 2004. Although previous marine surveys have been conducted, this survey helped bring some lingering issues to the fore. ASFs are calculated and organized by cells in a two dimensional grid of latitude and longitude. Cell size is a variable to be determined, and it may vary from port to port or even within a port. Specialized software has been developed to perform some calculations on the raw survey data. The software calculates and plots for each cell:

a. Number of samples
b. Mean
c. Standard deviation
d. Maximum difference to any adjacent cell

Figures 1 through 8 illustrate the analysis for Boston harbor. Figure 1 shows the path of the survey on a nautical chart.

Figures 2 and 3 show the number of data points per cell for cell sizes of 0.005 and 0.002 degrees respectively. Figure 4 shows the mean ASF for the 9960Y signal. The ASFs are relative or pseudo-ASFs meaning that they are all relative to the 9960M signal which has its ASF set to zero. The values are therefore the difference between the 9960Y (Carolina Beach) ASF and the 9960M (Seneca) ASF and are negative due the larger portion of land in the path from Seneca to Boston. Figures 5 and 6 show the maximum absolute value of the difference in ASF to any of the eight adjacent cells for cell sizes of 0.002 and 0.005 degrees respectively. Figures 7 and 8 show the standard deviation of ASF for cell sizes of 0.002 and 0.005 degrees respectively. The intent is to determine whether enough data was collected, the data collected is valid, and that the cell density is sufficient such that variations within a cell or between adjacent cells are adequately bounded.

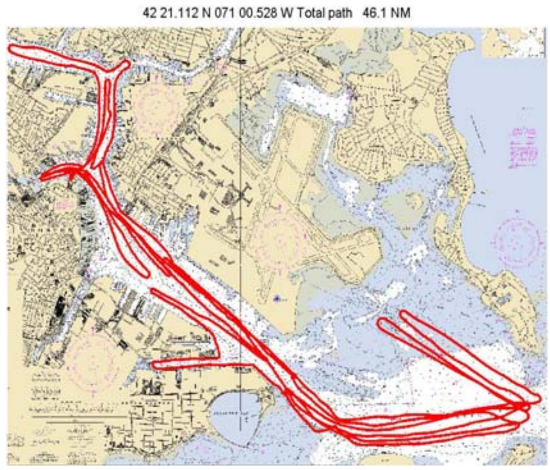

Figure 1. Path of Boston Harbor Survey

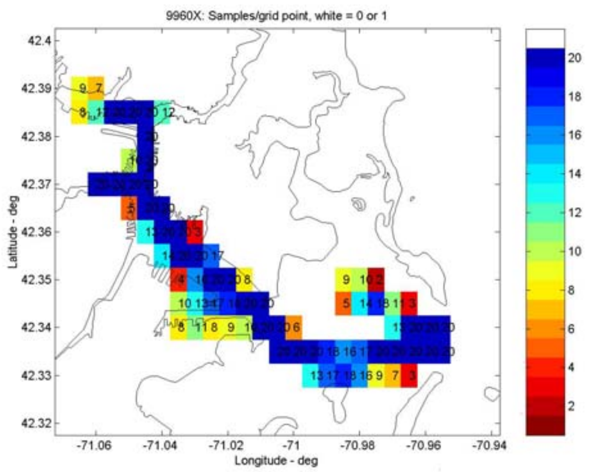

Figure 2. Number of Data Points per Grid Cell (Cell Size 0.005 degrees)

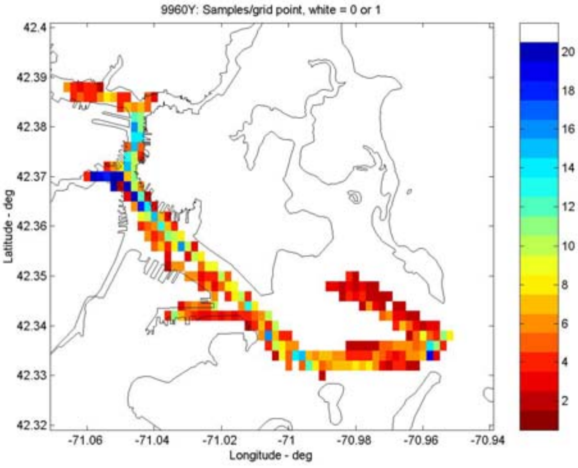

Figure 3. Number of Data Points per Grid Cell (Cell Size 0.002 degrees)

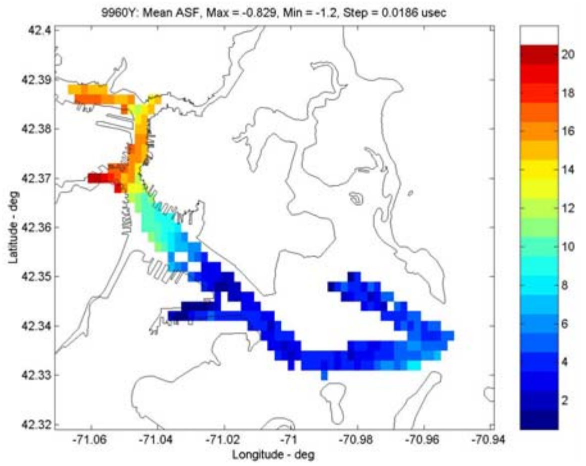

Figure 4. Average ASF for 9960Y (Carolina Beach) Signal

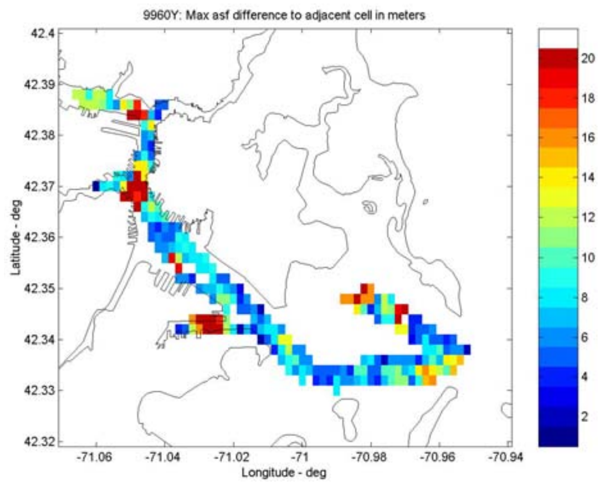

Figure 5. Difference in ASF Between Adjacent Grid Cells (cell size 0.002 degrees)

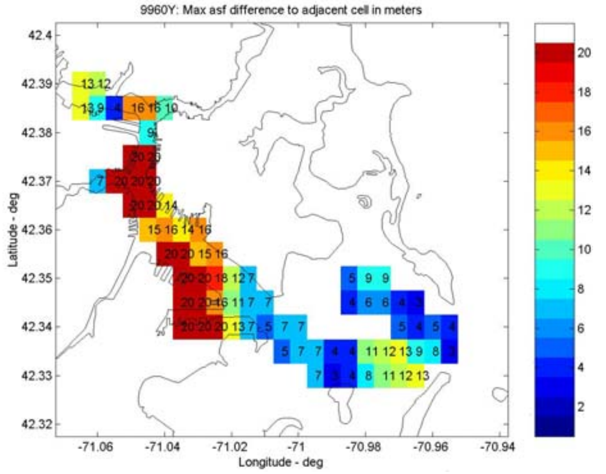

Figure 6. Difference in ASF Between Adjacent Grid Cells (cell size 0.005 degrees)

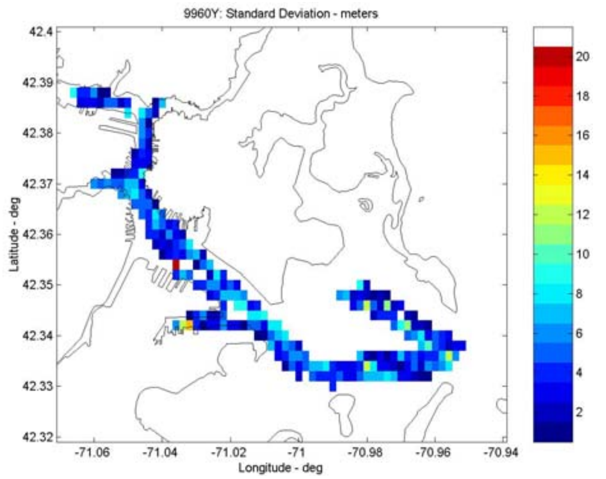

Figure 7. Standard Deviation of ASF By Cell (cell size 0.002 degrees)

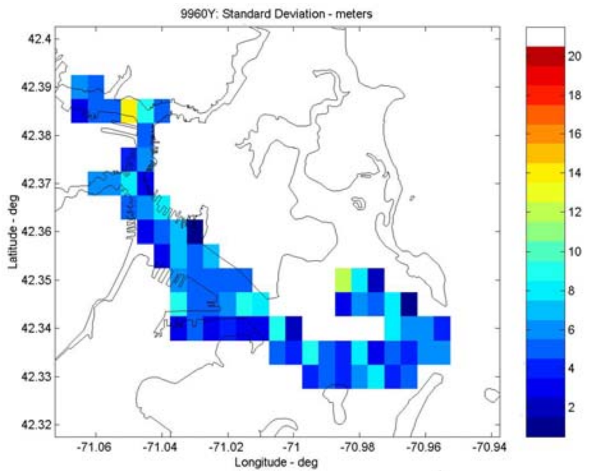

Figure 8. Standard Deviation of ASF By Cell (cell size 0.005 degrees)

11 DGPS vs. WAAS

Figure 9 shows the comparison of DGPS and WAAS positions for the survey. The mean East difference is 0.05 m with a standard deviation 0.24 m and the mean North difference is -1.05 m and with a standard deviation 0.26 m. The values predicted by HTDP.exe from NGS Geodetic Tool Kit (www.ngs.noaa.gov) are 0.18 m East and -1.01 m North.

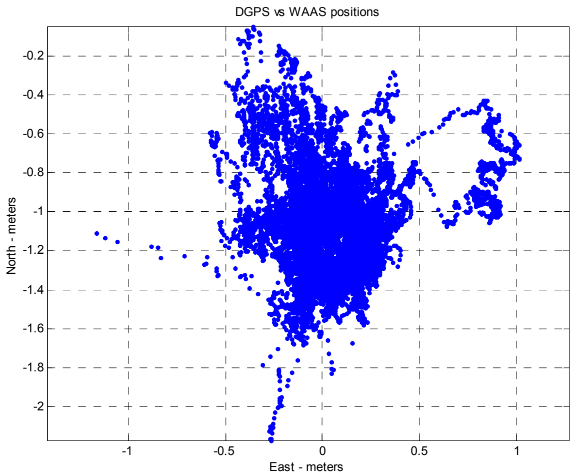

Figure 9. Difference between GPS and WAAS positions for Ground Truth

12 Conclusions and Recommendations

We have presented an outline of the effort to take differential LORAN from the proof of concept stage to an operational system. The main issues discussed include the communications network necessary to broadcast real time differential data and the methodology of conducting and analysing ASF surveys.

Acknowledgements

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References

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