NAVIGATING WITH FULL-COLOR ELECTRONIC CHARTS: Differential Loran-C in Harbor Navigation

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ABSTRACT

Computer technology is ushering in a new generation of navigation equipment. Microprocessor computers together with improving graphics allow advances both in the interpretation and utilization of radionavigation signals, as well as in the integration of those signals with navigation instruments in a new range of useful tools. Systems now being built offer improvement both in positioning accuracy and useful visual displays for navigators.

INTRODUCTION

This paper is an extension of a report submitted by the author at the IEEE Plans 80 Navigation Symposium. In that report the author predicted the advent of new solutions to navigation problems based on advances in microcomputer technology. It is now possible to describe an existing integrated navigation system founded on the principals presented at the previous symposium.

This new navigational system is based on the utilization of Loran-C radionavigation system in combination with a radar interface and electronic charting that results in a full-color, integrated graphic display.

When the differential Loran-C ownship position and the radar images are combined on the electronic chart, the resulting full-color display presents the navigator with an integrated image of ownship, waterborne radar targets, land and bottom contours, and navigation aids. This enhanced presentation is especially useful in harbor navigation where precise maneuvering is essential.

Navigation Sciences Inc. has developed this integrated system and markets it under the name VIEWNAV. The system's reliability and accuracy have been demonstrated by the U.S. Coast Guard, commercial users and a number of pilot associations.

Moreover, the integrated technology has applications far beyond use by vessels in harbors. For example, when signals from the Global Positioning System (GPS) are substituted for Loran-C, the resulting display will have significant land-based applications, too.

VIEWNAV: THE INTEGRATED SYSTEM

Despite sophisticated navigation devices, harbor navigation remains a difficult proposition, especially in foul weather. Accidents, groundings, rammings and down time due to poor operating conditions hamper harbor traffic, delay critical schedules, and result in additional expenses to marine operators.

The bridge of the modern commercial maritime vessel is equipped with an array of electronic systems to aid the pilot and captain, but the task of locating exact position and steering a vessel is a labor intensive job. Plotting fixes, for instance, is still done manually on a paper chart. Computation of waypoint information is another example. Of course, the instinct and experience of a good skipper, pilot or navigator are invaluable, but any help they can get from new technology to aid in quick and correct decision-making and therefore reduce the chance for mistakes and accidents is quickly appreciated and applied.

A good example of a problem that remained unsolved was navigating when floating aids were missing or off station. In northern waterways, ice often pushes buoys off station; or the Coast Guard may completely remove buoys in anticipation of the ice. The navigator is left to find the safe water -- the channel -- without the properly positioned channel markers.

The need here is for an easy to interpret navigational system which will show the decision maker current ownship position relative to the channel. In addition, the same display, by interfacing to the ship's radar can provide current and accurate tactical information -- such as other ship movement -- necessary to ensure safe passage.

The result is a display which serves as the single command center on the bridge. The first of this type of system -- called VIEWNAV -- now exists and it is being used daily in various harbors on the East coast of the United States.

To achieve this visual presentation, which includes a precisely-located image of the vessel (ownship) and waterborne radar returns updated in real time against the background of an electronic chart, three fundamental maritime navigation and maneuvering tools must be combined:

- Loran-C radionavigation signals are refined through calibration and data processing in a differential mode to yield repeatable accuracies of 15 feet.

- Paper charts are digitized and converted to accurate, flexible electronic charts.

- A radar image is superimposed on the electronic chart and through the use of different colors, only waterborne returns are displayed.

ACCURATE POSITIONING WITH DIFFERENTIAL LORAN-C

Most modern means of fixing a vessel's position on water -- whether a ground-based system such as Loran-C or a space-based system such as NAVSTAR -- relies on emission and reception of radio signals. The signals remain constant, but the way they are received and interpreted determines the relative accuracy of a given vessel's position.

Refining the Loran Signal

In the case of Loran-C, all receivers, coordinate converters and plotters available today use Loran time differences (TDs) measured to the nearest tenth of a microsecond. These TDs are then applied to Loran charts based on mathematical predictions rather than actual measurements to locate the Loran lines of position (LOPs). Existing systems allow the potential for large margins of error. When TDs are measured *to a tenth of a* microsecond and converted to LOPs, the actual position can be off as much as several hundred yards. Given these parameters, few systems have been able to attain steady position accuracies more precise than 100 yards.

The use of differential Loran-C breaks through these limitations. First, TDs are measured and displayed to the nearest nanosecond, which represents approximately one foot. Then, the differential variation is achieved by correcting the existing Loran readings by applying offsets observed at a stationary monitor.

Stabilizing the Loran Grid

Loran signals in a given waterway are surveyed and calibrated. The surveys measure the actual geographic position of the lines of constant time differences rather than their predicted position. Calibration consists of determining the Loran time differences that correspond to carefully surveyed latitudes and longitudes. These correlations are used to convert Lorad TDs to vessel position.

In addition, a land-based Loran monitor is established to identify and correct for any grid shifts that occur during the survey. The result is a highly accurate "snapshot" of the Loran-C grid.

Loran Monitor System

Loran signals received in the same location frequently change by a small amount due to minor variations in radio wave propagation between the transmitters and ownship. These signal fluctuations are due to natural atmospheric phenomena The effect of the changes is to randomly offset position by as much as hundreds of yards during the course of a year and up to tens of yards in one day.

This difficulty is overcome by carefully observing monitor receivers in the local area and broadcasting any shifts to vessels that, in turn, use this data as a correction to the Loran signals being received on board both during the survey period and operational vessels.

It has been demonstrated that when the Loran grid is stabilized and monitored, and the Loran signal is read to the nanosecond, the result is repeatable position accuracy of 15 feet.

The U.S. Coast Guard contracted Navigation Sciences Inc. to survey the Loran-C grid in the Upper Chesapeake region. A lengthy study of observed TDs in this region demonstrated that the correlation of hourly and daily changes between TDs at scattered locations was very strong. If the TDs at monitors within this region were compared, the difference in computed position resulting from using changes at one monitor location to compute position at another resulted in position errors of about 4 yards (90% CEP). In other words, TD variations monitored at one location can be the basis for making corrections at any place within this region of correlation to an acceptable degree of accuracy. In the case of the Upper Chesapeake, this region of correlation extends all the way from the C & D canal to Baltimore, a linear distance of 40 nautical miles. Other regions will vary in their behavior, and have to be measured in order to establish the area over which sufficient correlation exists to be considered a single region for the purpose of differential Loran.

ELECTRONIC CHARTING

Electronic charts are an application of computer technology whereby a digitized version of a marine chart is displayed, in color, on a cathode ray tube (CRT) monitor. Numerous advantages flow from the act of liberating the chart from its classical paper foundation; the electronic medium endows the chart with a degree of flexibility that has been unthinkable in the paper version.

The utility of the electronic chart as both a valuable single advancement and as the background for displaying additional information are recognized in a report assessing the technology's impact on Canadian shipping. A report from the University of New Brunswick says, "Our most significant conclusion is that a major breakthrough in marine navigation is occurring and its success is inevitable. This is because, for the first time since high technology began producing aids such as the gyrocompass, radar, and Loran-C for the mariner, rather than adding to his workload these interactive navigation systems relieve him of the tedious part of his duties and aid him with real-time information on the most important part -- navigating his ship safely. Given that the widespread use of these systems will occur in the near future, it follows that the day-to-day use of the electronic chart will surpass that of the paper chart."

There are a number of methods that can be used to accurately produce an electronic chart. Navigation Sciences' electronic charts are generated by tracing chart contours on a digitizing table. The contour tracing methods possess the advantage of producing a selective degree of detail from the printed original.

The electronic chart allows the addition of a great deal of associated chart data than can be displayed or repressed with the traced contours. This can include water depths, channel boundries, the location and identification of various aids to navigation (buoys, lights, structures, tanks, towers, etc.), as well as place names and other labels.

Chart accuracy is high. The present state-of-the-art of electronic digitizers permits reproducible positioning of the tracing cross hair to within 0.003". A typical nautical harbor chart, drawn to a scale of 1:10,000, will cover approximately six nautical miles on 36 inches of paper. This reduces to one yard in 0.003". Thus, the electronic stylus or cross hair will be able to resolve details on the original printed chart that are one yard apart. This degree of resolution probably equals, or even exceeds (in some places on the chart) the resolution of detail available to the cartographer. Thus, when the electronic chart is well made, it can approximate the accuracy and resolution of a printed chart.

The content of the electronic chart can vary from a complete duplication of the paper original, to a simplified rendition of just a few features contained in the original. However, one important feature of the electronic chart is that detail can be selectively added and subtracted, as in layers, because of the flexibility of the process. Thus, a Mercator grid can be displayed to help locate a particular chart feature, and then eliminated in order to clarify the remaining features. These layers of detail are created by reading from the many individual data files that are the source of features on the chart. There can be individual files on shore contours, depth contours, channel edges, buoys, lights, coordinate grids, etc. These files can be read as required, and then the features associated with each of these files can be removed from the electronic display when it is desirable to simplify the presentation.

The scale of the chart can be changed by a simple manipulation of the data processing constants involved in the electronic display. The actual chart displayed can be thought of as that portion of the digitized area that falls within a "window" of the required dimensions. Changing the chart scale is a matter of changing the height and width of the window.

One of the principal problems associated with paper charts is the need to stay current. Harbor information changes daily; buoys are moved, dredging operations create new or temporary channels, obstacles appear, etc.

One of the principal necessities associated with charts used for navigation is the rapid, timely, accurate updating that allows the user to see any changes that may affect safe navigation in the area covered by each chart. The electronic chart lends itself to this requirement because each individual item of data is accessible to the computer that drives the display. Any element of the chart can be changed by making the appropriate change to the file that contains that particular element. These changes are made electronically, for example, by data transmission via a telephone line, or over a radiotelephone or satellite communications data channel. As another alternative, a memory disk can be introduced that contains the required changes.

Detail concerning these changes is available from various government authorities (NOS, NOAA, USCG, DMA) that normally maintain the aids to navigation that are affected by the changes. To keep abreast of the changes and transmit them to electronic chart users, Navigation Sciences gathers the information on a regular basis and communicates with all the appropriate sources.

TRUE MOTION VESSEL DISPLAY

The first integration involves the computerized differential Loran positioning system and the electronic chart.

With proprietary software, the Loran signals are translated to a constantly changing presentation of ownship on the electronic chart. The vessel appears as a to-scale, hull-shaped image advancing across the electronic chart in true motion matching the ship's path on the water. In operation, when the vessel passes a buoy directly to port, the ship's image on the electronic chart will pass the same buoy at the same time.

As the vessel nears the edge of the currently displayed electronic chart, the screen automatically advances to the next chart.

Radar Interface

The second integration involves radar returns that can be superimposed on the electronic chart.

The radar interface, which is a proprietary raster scan converter, enhances the way radar information is displayed. This device converts the distance/bearing coordinates of radar targets to their corresponding latitude and longitude based on the accurate ownship position determined from Loran-C and the current ship's heading provided by the gyrocompass. Once this conversion is accomplished, the radar image can be added to the electronic chart.

Color can now be assigned to the radar returns, the water, and the land mass. Land masses on the chart are opaque yellow so that the red radar image of the land cannot be seen through the yellow color of the chart. Radar images, colored red and magenta for high and low intensity, are seen only in the blue water areas. Thus, there is an immediate clarification of the display by the simple elimination of the radar's usual land clutter.

As a system safeguard, any ownship position error will result in an alignment error between the red radar shore line and the yellow charted land contours.

The integration of the electronic chart with radar and the true motion display of ownship enhances safety at sea and in harbors by making out-of-position buoys and channel markers clearly visible. The electronic chart shows where the buoy should be; the radar return shows the buoy's actual location. If the buoy is placed correctly, these two images will coincide; if not, the radar return will be separated from the symbol of the buoy on the electronic chart.

The electronic chart presentation also permits a history of radar returns to be retained on the display. If the radar target is a moving vessel, the track indicates its true course and speed.

CONCLUSION

The next generation of computer-aided navigation equipment is entering the market. It involves the use of microprocessors to measure and refine existing radionavigation signals and computer graphics software for displaying a whole range of navigation information. The key feature of this system is an integration of various existing and developing electronic aids into a single screen. The screen can serve as both a graphical and alphanumeric presentation of navigational and tactical information.

The combination allows the mariner to see, at a glance, where he is in relation to the harbor and other vessels, without looking beyond the intgrated electronic display.

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