GPS-Based Vessel Position Monitoring and Display System

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ABSTRACT

The problem of monitoring the location of vessel fleets has traditionally been solved by various combinations of radar tracking, voice reports, closed circuit television or other position determination and reporting methods, all generally lacking in some required aspect of the tracking and monitoring problem. The marriage of the precision and accuracy of the NAVSTAR Global Positioning System (GPS), the availability of long-range data communications, and the advances in computerized digital maps have now established the possibility of reliable, inexpensive positive vehicle tracking today. Ocean search-and-rescue, large vessel harbor traffic control, vessel route verification, and other "command-post" based operations will benefit from this next generation of marine tracking systems. This paper provides a description of the first fully operational, GPS/Loran based vessel monitoring system whose monitoring workstation, communications solutions, and variety of on-board navigation systems provide an integrated capability for the marine fleet operator and serve as the basis for consideration for large scale systems such as might be implemented for hazardous cargo or oil and gas product transport on the seas.

INTRODUCTION

The NAVSTAR Global Positioning System (GPS) is rapidly gaining acceptance as a reliable and precise positioning system. As the operational Block II satellites are launched, receiver manufacturers continue to refine their offerings in terms of performance, size and cost. Indeed, it already appears that specialization of design is occurring such that receivers are specifically designed to meet the needs of a particular application, such as survey, marine navigation, or aircraft navigation. Such specialization indicates the emerging maturity of the system and of the industry. However, we are now going to see systems applications of GPS emerge which exploit the wide availability and superior performance of GPS for specific system solutions. This paper describes the functions and application issues of one of the first such system applications, a GPS-Based Vessel Position Monitoring and Display System, VTRACK™.

VTRACK is a total systems solution to the requirement to continuously track the position of vessels, in real time. The major components comprise on-board positioning with GPS and LORAN, integrated communications between the vessels and the control center, and display and other functions at the control center. Features of the display console are designed to meet the various needs of the fleet operator or the monitoring authority. Figure 1 depicts the overall configuration of VTRACK. The specific details of the functional design are described later in the System Description section.

Along with systems implementation, particularly in a safety environment, comes a host of issues which must be resolved before the tracking problem can be considered to be "solved." Such issues bring into focus the reliability of GPS, stemming from inherent capability of the system as well as from artificially or environmentally induced effects such as Selective Availability accuracy degradation, signal blockage and multipath interference. In a tracking application, GPS is often compared to radar which is the classic offshore sensor employed to maintain surveillance of a fleet of vessels. Of course, cost is a major comparison parameter when considering the attractiveness of a GPS-based solution. This is more than just an economy issue, however. For major and extensive applications such as hazardous cargo or oil tanker tracking, the lower cost of a GPS solution may be the sole enabling factor for implementation, the competitive techniques being so prohibitively expensive that they cannot possibly be implemented within any reasonable timeline.

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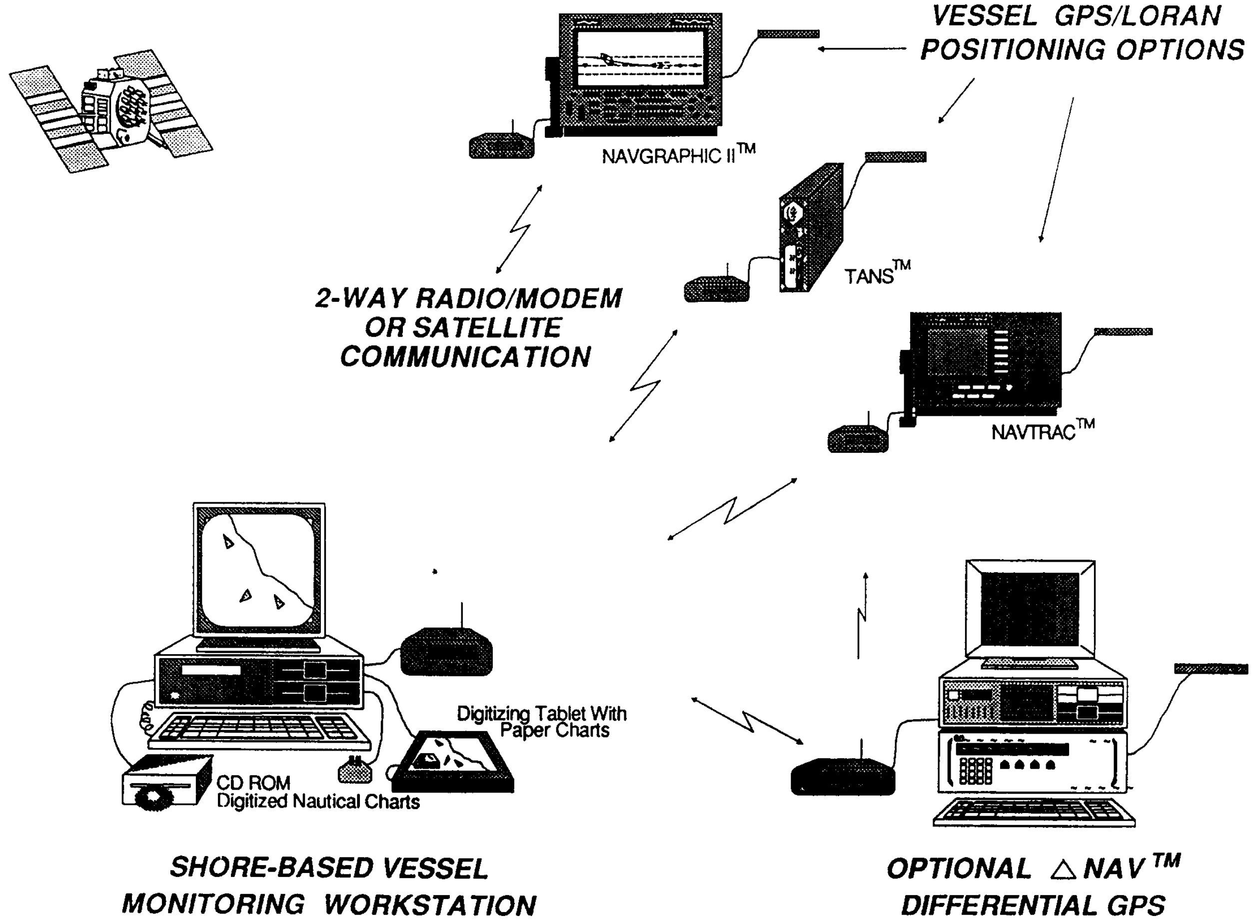

Fig. 1. GPS-Based Vessel Position Monitoring and Display System

ISSUES CONCERNING THE IMPLEMENTATION OF GPS-BASED VESSEL TRACKING

The major issue concerning GPS use for vessel tracking, especially in hazardous or safety-related applications, is the reliability of GPS. In fact, in a regulated industry such as air transport, a user may have to actually prove GPS and system reliability to meet standards.

The inherent reliability of GPS is very good, due primarily to the fact that system reliability was a major design parameter of the system when first conceptualized by the Department of Defense [1]. In particular, all components of the system are designed with multiple redundancy and error checking to preclude catastrophic failure. The satellites have multiple clocks and onboard checks for fault tolerance. A major reason for the orbital altitude at half-synchronous is so that any single satellite failure will be mitigated by the visibility of other satellites as they appear over the horizon (in addition to the redundant satellites in view at any instant).

The control station has a completely redundant installation, and a great deal of error checking is built into the upload process to preclude an erroneous upload being broadcast. In fact, the latest version of the control station will employ a complete end-around check to an actual GPS receiver to verify the upload in addition to the internal checks built in.

Receivers are built to a variety of specifications, some much more reliable than others. It has been shown that it is possible to build a receiver with tracking of at least 5 satellites to automatically detect any "failed" satellite signal, for whatever reason, and a 6th satellite allows failure identification for fail-safe operation [2]. Of course, completely dual installations can be considered as well.

So does this qualify GPS-based tracking for safety-related applications? Not necessarily, however, there is an interesting precedent in this area. In the early 1980's, the Air Force decided to develop a GPS-based range tracking system to replace tracking radar at many of its test ranges [3]. One of the functions of the new GPS-based system was to maintain range safety concerning aircraft separation. This official use certainly seems to justify serious consideration of GPS for such critical applications.

There is quite a bit of concern, especially in Europe, that GPS operation is available only at the whim of the U.S. Department of Defense. Indeed, occasional statements by DoD personnel seem to reinforce this phobia. However, it is a stated policy of the DoD to make the Standard Positioning Service (C/A Code) continuously available to the civil community. Furthermore, an excellent antidote for most ills conceivable with GPS is the use of differential GPS, which corrects for the errors observed at a local reference station [4,5,6]. In fact, the added

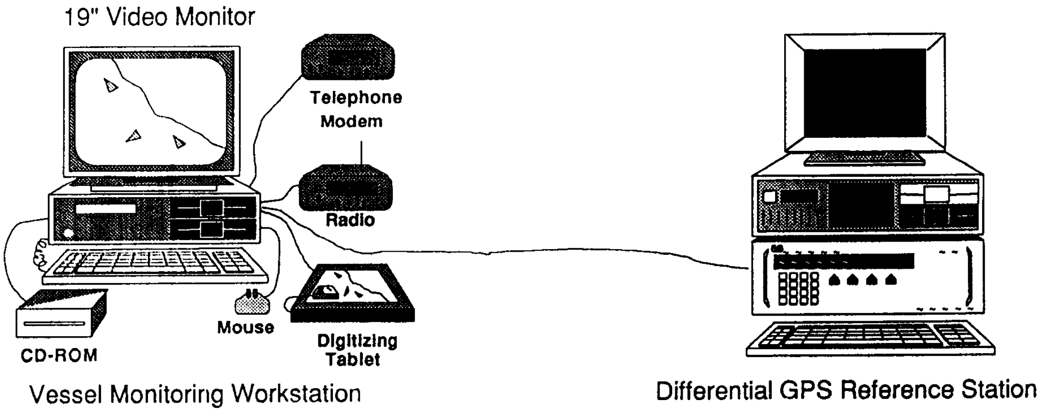

Fig. 2. Vessel Monitoring Workstation

benefit of differential GPS to vessel tracking makes its use in the overall system practically mandatory.

There is an additional issue when a GPS system is used as described in this paper. The use of electronic charts, or more specifically digitized Nautical Charts, is an area of controversy as no one is interested in picking up the liability for consequences stemming from their use. However, it seems inevitable that the liability issue must give into the clear distribution gains and safety enhancement from their use. For example, the International Maritime Organization (IMO) is developing a provisional specification now for the dissemination of electronic charts, to be finalized by 1993. The essence of the IMO standard is to make the electronic chart the legal equivalent of the paper chart, which means that the standard must be regulated by a government organization just as the paper charts are now (regulated by NOAA and the U.S. Coast Guard). Such government control is in progress in other countries outside of the U.S.; it is only a matter of time before the U.S. takes up the issue in earnest.

SYSTEM DESCRIPTION

Shore-Based Vessel Monitoring Workstation

The Vessel Monitoring Workstation is the hub of the vessel monitoring system, VTRACK. This display system can be configured with a variety of digital maps of varying scales and selected geographic areas. Any one may be displayed upon operator command or automatically displayed based upon a selected vessel's position. A world coastline database also is included for a global view of vessel locations and for vessels operating in areas for which charts are not available. Full roam, zoom, and centering capability is included in all maps.

For compatibility with paper charts and maps, a digitizing tablet is an option which allows entry of map data into the computer map database. Figure 2 illustrates the components of the workstation.

The current version of the monitor station operates on an 80386-based IBM compatible computer with an 80387 math co-processor, mouse, and VGA graphics board and monitor for resolution appropriate for required map resolution.

Major functions provided in the workstation include vehicle navigation status data, operator-entered vessel identify and database information, range and bearing between vessels and geographic locations, route graphics and location icon functions, paper chart data transfer to digital form, map manipulation, data archival, and current date and time.

The integration of an optional digitizing tablet for interactive paper chart use provides a "multi-media" environment to maximize operator efficiency, comfort with the technology, and transition to computerized formats. This tablet is also used as a "scratch pad" for entry of data into the monitor's data base.

VTRACK operation and data display is initially configured with data from an initialized file. This file is not required, and, if it is not found, VTRACK starts up in a default operating mode. Upon shutdown of VTRACK, this initialization file will be updated or created and will contain the current configuration of VTRACK. For a monitoring environment that has multiple operators using the same workstation, VTRACK can manage several of these files so that the run-time configuration of the monitor station can be different for each operator.

The parameters that are stored in an initialization file include current color settings, which data tables are displayed, current vessel selections, and map scale.

Workstation Display and Control

The display screen is arranged with the majority of screen space dedicated to the map when in an "interactive" mode. When in this mode, display fields and option "buttons" may be presented along the right edge of the screen. Tables presented here include the current date and time; the selected vehicle's position, course, and speed; the range and bearing to a selected object or to the mouse cursor; a graphics symbol, icon and line drawing menu; the vessel selection window; vessel track control; and the color specification table. This right edge column of menus and tables is dynamically reconfigurable by the operator. That is, only the data and control tables in which the operator is interested are displayed and may be dismissed by selecting their respective dismissal button. All dismissed tables are re-displayable by their selection from a non-dismissable, one-line menu at the bottom of this column.

A sample VTRACK screen in the interactive mode (data tables presented on the right edge of the screen) showing a selection of tables and a section of NOAA chart #18720 is presented in Figure 3.

Along the bottom of the map window are the pan and zoom buttons, the button to change the map displayed from the inter-

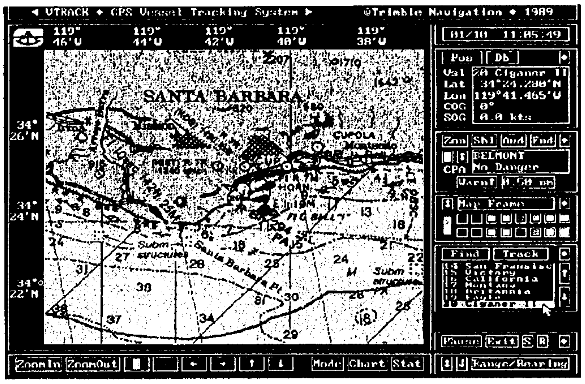

Fig. 3. Sample VTRACK Screen Showing NOAA Chart #18720

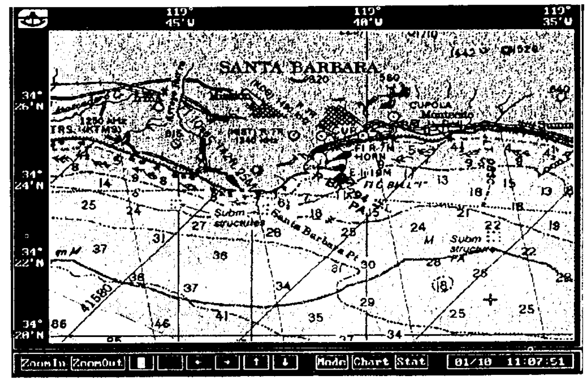

Fig. 4. VTRACK in Monitor Mode

nal coastline data base to a digitized chart of the area, and the button for changing the display mode from "Monitor" to "interactive."

When in the monitor mode, almost the entire screen is used for the map. Figure 4 shows the same monitoring area as Figure 3 but now the workstation is in the monitor mode.

A major design feature of the Vessel Monitoring Workstation is ease of operation and adaptability of display. All operations are accomplished with on-screen menus and buttons that are selected with a mouse or trackball. Mouse functions include roam, zoom, and centering of the map, selection of a vessel for which to display position, course, speed, etc.; place, move, or erase symbols and line segments on the map; change the color of symbols or lines to be drawn; and change the color of most of the objects displayed on the screen to suit user preference. Pressing the center mouse button when the mouse cursor is on the map will cause the map to be redisplayed with the selected position now being at the center of the map window

In addition, graphics functions are available which allow the operator to enter basic overlays such as harbor approaches, routes, and nav-aid locations. The system allows two levels of graphic overlays: The first level is used for map additions, buoy placement, shipping lane definitions, etc., and is always displayed over the current map. The second allows more "scratch pad" graphic entries for objects such as vessel route lines and route destination symbols. This second overlay level is easily erasable and displayed at the user's discretion.

Digitized Nautical Charts

The Vessel Position Monitoring and Display System offers a variety of digitized maps for reference situation display. A vectorized world coastline database constitutes the default reference. This database is used for displaying global views of vessel locations and for vessels operating in areas for which digitized charts are not available. Figure 5 presents a VTRACK track displaying the coastline database and all vessels being tracked from Mexico to Alaska.

In addition, charts from a library of raster-scanned NOAA and other nautical charts are available for display. The charts are scanned on a chart-sized full table scanner by Maptech, Inc. of Ventura, California. The storage medium for these charts is a CD-ROM or the computer's hard disk or perhaps both.

The graphical display of computerized NOAA charts aids in complete situation awareness on the vessel and at the monitor site.

Chart Scanning Resolution. The NOAA nautical charts are scanned in on a full page scanner at a pixel resolution of 160 dots per inch (DPI) in 16 colors. At this resolution, a 3-inch by 4-inch section of a typical NOAA chart would fill a 640 by 480 pixel video screen. A full-size chart is stored in approximately 100 separate sections. Up to 4 of these sections are decompressed and used to form a single map display on the workstation.

Loss-less graphic data compression techniques are used to save space on the CD-ROM allowing more charts to be stored on a single compact disk. The data compression used to store the charts is a widely accepted industry standard that decompresses rapidly and offers up to a 95% reduction in storage space required for the charts. For example, some of the chart sections have been compressed from the 150,000 byte size of the uncompressed image to less than 5,600 bytes.

Each compressed chart section begins with a header that contains information about the entire chart and the individual chart section. This information includes the NOAA chart number, chart title, agency (e.g., NOAA), chart scale, depth sounding units, map projection, horizontal and vertical resolution, and the latitude and longitude boundaries. These headers contain all of the information necessary to locate a point on the chart, select which chart sections to display, where to place the chart sections on the screen, and perform all pan and zoom functions of the vessel monitor.

Zooming and Panning. Chart zooming is done by simply displaying the next chart in scale sequence that contains the desired position. The new chart is located by first sorting all charts in order of increasing scale. Then when the operator selects "Zoomin" (or VTRACK determines that a zoom is required for another reason), the list is scanned, starting at the current chart, for any other chart that contains the current latitude and longitude. If one is found, it is displayed. If a chart is not located, an audible beep is heard, indicating that a new chart is not available. If the operator selects "ZoomOut," the list is simply scanned in the other direction.

Figure 6 shows the location of the same vessel as Figure 3 except the monitor station map has been zoomed in. The zoom

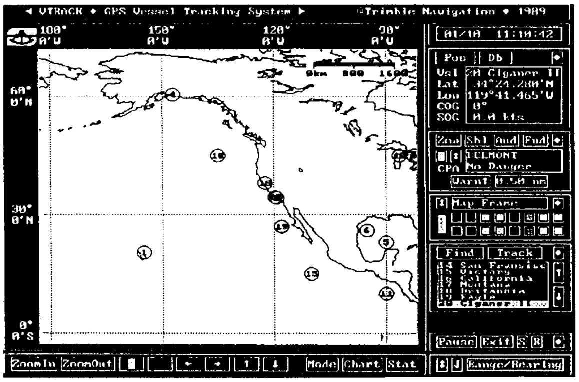

Fig. 5. VTRACK Displaying the Vectorized Coastline Map

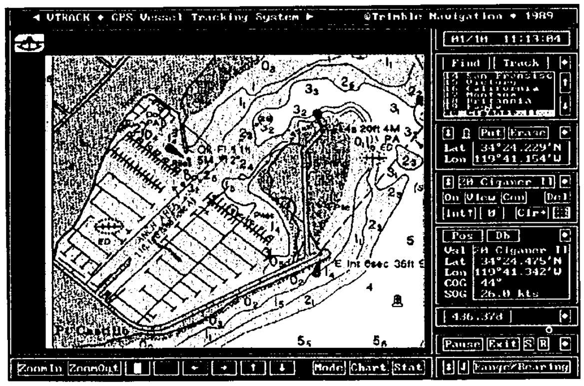

Fig. 6. "Zoomed In" Screen Showing NOAA Chart #18725

did not "blow up" the previous map but actually changed charts and is now displaying one of the insets on NOAA chart #18725.

Monitor Station Vessel Database

Every ship, whether currently monitored or not, will have an entry in the workstation's database. Some of this information is that which is broadcast by the ship, while some is entered by the monitor station operator.

The information in the database is categorized as being permanent (vessel data such as the ships registry and voice telephone number), semi-permanent (voyage data such as vessel draft, type of cargo and destination), or volatile (status report data such as position, course, and speed).

Other, non-vessel data is also stored in the database. This data could include the nearest Coast Guard station and phone number, local weather service and other situation data and free-form notes about a ship, harbor, or cargo entered by the monitor station operator.

Nautical Navigation Hazards

A database of operator-entered navigation hazards may be used aboard the vessel and at the monitor station. Having the database aboard the vessel and at the monitoring station allows the hazard proximity alerts and/or alarms to be generated completely independently.

An example database currently being used in the system is a list of oil drilling platforms off the southern California coast. If any monitored vessel breaches the warning zone around any of these platforms, audible alarms will be activated aboard the vessel and, simultaneously but independently, at the monitor station. The selection of a single button on the monitor station screen will display the fully zoomed-in NOAA chart of the area and all information tables on the screen will display data pertinent to the situation.

Tracking Data Archive and Replay

Data is archived at the monitor station for documentation purposes as well as later playback. Virtually every transmission from all of the ships is stored. Situation playback may contain all of the vessels that were tracked over the time period, or a single ship. This archival of data allows the operator to recall vessel tracks for analysis of situations or for historical or liability reasons. This establishes an "audit trail," in the positioning sense, for fleet operations.

Integrated Vessel Simulator

When VTRACK is operating in its simulation mode, up to 20 vessels may be placed in various places around the world according to positions specified in a simulation configuration file. The positions of the vessels are propagated at a random speed for a random amount of time. This integrated simulation mode allows for hands-on training on the operation of the system using the actual tracking system.

Workstation Software

All monitor station and vessel software has been developed internally in the company, including all display windowing software. That is, no outside vendor packages are used in this system. This approach guarantees the control and integrity necessary to develop a system that can be used with assurance in very critical operations involving the safety of both vessel property and personnel.

VESSEL NAVIGATION AND POSITION REPORTING SUITE

Navigation aboard the vessels is accomplished with any one of Trimble's line of marine GPS or GPS/LORAN receivers, including the NavGraphic II GPS/Loran Navigator, NavTrac GPS, or 10X Navigator GPS Navigation Equipment. Interface to these receivers is achieved with hand-held size computers that control the data reporting from the receiver and the radio link to the monitor station. Optionally, the shipboard navigation system may receive differential corrections datalinked from the shore-based ΔNAV™ Reference Station to realize much greater position accuracy.

Differential GPS introduces the possibility of greatly improved navigation accuracy, especially in light of the U.S. Government degradation of the signal to 100 meters, 2 drms. In addition, the reference station provides significant integrity monitoring features so that the Vessel Monitoring and Display System that is equipped with ΔNAV can perform the important job of on-line determination of the health and status of the GPS satellites and control segment, detecting most anomalies before they are acknowledged by the Government. This is an important collateral benefit included with the Vessel Monitoring and Display System equipped with Δ NAV Differential GPS.

The differential reference station may be integrated with the monitoring station. The differential range corrections from the reference station are either broadcast directly to the vessels on a separate radio link or are incorporated into the data exchanges on the position reporting channel for differential GPS accuracy for all monitored vessels.

When the NavGraphic II navigator with its attached CD-ROM chart drive is used for the vessel navigation system, the same computerized NOAA charts that are used at the vessel monitoring station are also used on the vessel. For many applications, identical views of the monitor area on board the vessel as well as at the monitor station greatly enhances necessary situation awareness.

When a vessel is tracked with this system, there are no required changes in current vessel operations. Position reports are completely automatic. No operator interaction is required.

COMMUNICATION OF DATA

Ship-To-Shore Position Report Content

Data transmitted from vessels to the monitor station routinely include a vessel identifier, time-tagged vessel position, course over-ground, speed-overground. Other data include planned course (with waypoints and times), destination, estimated time of arrival. Also transmitted are ship's name, captain's name, ship call letters, tonnage, cargo type, bridge telephone number, and vessel registry. Not all data must be transmitted on each position report. Other information that is exchanged could include free-form text messages, emergency transmissions, ship operational data (such as fuel consumption, engine data, etc), and differential GPS corrections. Entirely new database elements may be created by the monitor station operator to store new types of data as the needs arise. This data is stored in a database that is accessible to the monitor station operator for display and modification.

Ship-To-Shore Data Link

The INMARSAT satellite-based Standard C service, which is now being implemented by INMARSAT, is very attractive for VTRACK applications. In fact, the U.S. signatory to INMARSAT, COMSAT, has taken a very progressive position on the use of Standard C for maritime vessel tracking within U.S. waters. For infrequent position reports at sea, position/data reports can be sent very inexpensively from ship to shore; they can be initiated automatically by the vessel or by the VTRACK monitoring station. The INMARSAT system supports world-wide service, and requires only a standard telephone line at the monitor station. In addition, INMARSAT will soon provide a point-to-multipoint polling mode that enables very inexpensive fleet interrogation. This will support Vessel Traffic Service (VTS) operations in harbor areas, and could be used to support Offshore Vessel Traffic Management (OVTM) systems in order to provide monitoring outside harbor areas.

The VTRACK system can be configured to support users who have access to other data links they wish to utilize. For inland and coastal operations, cellular telephones can be used with the VTRACK system. The system has been designed to be easily configured to a wide variety of data links.

Communication Strategies

Using data link services that charge by the call or by the time used, communications costs could be high if proper design strategies were not followed. However, with the right strategies, these costs can be minimized. While voice telephone calls from ships are typically \$10 per call, the Standard C price for a minimum data packet will be about an order of magnitude lower. Thus a few calls per day for ships at sea will be quite inexpensive. In a VTS application, however, even a dollar per call would be too expensive, since the reports would be required at a rate more like once per minute, involving dozens of ships. However the polling mode is expected to reduce the reporting cost by another order of magnitude, so the costs will ultimately be quite reasonable.

Advantage can be taken of the intelligence and information in the onboard sensor suite to minimize unnecessary position reports. The onboard equipment can be programmed to report when specific events occur, rather than on a periodic basis. Such events could be turns, waypoints reached, or alert/alarm conditions.

It is expected that cellular telephone data techniques will be introduced, along with pricing strategies, which will make cellular service at least as inexpensive as satellite service.

The VTRACK monitoring station can be configured to accommodate several different data links, operating simultaneously. Similarly, the onboard equipment can be configured to report through several data links at once, although most likely only one would be utilized at one time. As a consequence, the system is very flexible, adaptable, and easy to configure.

Data Integrity. The guarantee of data integrity is ensured through several error detecting procedures over and above those provided by the communications medium. These procedures include parity encoding of all transmissions with parity decode failure causing a retransmission of the entire data packet. For extremely critical data exchanges, the data is sent a minimum of twice to ensure data integrity and eliminate even subtle transmission flaws.

VESSEL MONITORING SYSTEM APPLICATIONS

The tragic accident of the EXXON VALDEZ, which ran aground near Bligh Reef outside of Valdez, Alaska in March 1989, spilling some 11 million gallons of oil into the neighboring waters shocked the United States into the realization that more effective control of tanker navigation was required. Valdez was under the advisory service of the U.S. Coast Guard radar-based Vessel Traffic Service, yet the accident still occurred. Accounts of the events that day point to the possibility that the VALDEZ was under ra dar surveillance, yet its position was not certain nor was the identity of the vessel.

A GPS-based tracking system could play an important role in such a situation. First of all, GPS accuracy, especially with differential GPS, provides vastly superior accuracy to radar-based systems. In fact, the U.S. Coast Guard Research and Development Center in Groton, CN has concluded that differential GPS was precise enough to allow harbor/harbor entrance navigation totally without reference to landmarks or land-based navigation aids.

Secondly, since the position solution is transmitted to a shore monitor station (e.g., the VTS), ship identification as well as other operational data could be transmitted along with the position report. For example, if current draft is transmitted, the ship navigation with respect to clearable depths as well as shoreline hazards could be monitored.

While the on-board navigation sensor can be Loran-C, Omega, or even manually entered fixes, the full utility of the system becomes evident when the sensor is a GPS receiver. By the end of this year it is anticipated that 2D coverage will be available worldwide for close to 24 hours a day. Position accuracy will be nominally 100 meters (95%), and it can be better than 5 meters in the differential mode where it is needed. Ship speed can be directly measured to better than a knot. GPS does not suffer from occasional lane slips that plague other positioning systems.

This capability, along with the existence of electronic charts and highly reliable communications for carrying position reports, makes possible for the first time a dependable monitoring system. The system supports an alarm function at the base station, and an independent alarm on a properly equipped vessel. For example, the alarm function can be easily tailored to meet the particular local requirements of each Vessel Monitoring System.

The VTRACK system's strengths complement those of ground-based radars for monitoring applications. The cost of a VTRACK system is a fraction of that of a radar. It requires no real estate, is not line-of-sight limited in range, is more accurate, and is unambiguous. The single important advantage of radar is that it requires no operating shipboard equipment. The combination of VTRACK and radar is exceptionally powerful.

When used in a VTS, VTRACK provides positive identification of each vessel, as well as accurate position, COG and SOG. Alarms can be configured by the VTS operators to trigger visible and/or audible alerts when critical maneuvers or areas are being approached, and audible alarms when vessels are projected to be going outside traffic lanes or to be in danger of grounding.

It is possible that accidents such as the EXXON VALDEZ oil spill could be avoided if a system such as the GPS-based Vessel Monitoring and Display System is installed. There were several crucial minutes during which appropriate action could have been taken by the VTS operator, based on alarms and information available from the system.

There are other applications where a government agency needs to monitor vessels and where VTRACK offers a cost-effective solution. Waste disposal vessels can be tracked to determine if they have indeed travelled to the disposal sites; VTRACK provides an archived record of vessels' tracks. Vessels carrying hazardous waste can be monitored to ensure they are carefully controlled within narrowly specified track and speed limits.

The system can be used to track fleets of vessels worldwide, using the INMARSAT Standard A or Standard C system as the data link. The ship-to-base station message can be easily tailored to provide ship operating data in addition to position reports. Such fleets include tankers, barges, container ships, fishing boats, and tugs. The polling capability of VTRACK can be used to advantage to keep communication costs low.

SUMMARY

The design of a GPS/Loran-based, fully operational vessel monitoring system has been described. The system is a powerful tool for the fleet operator in such applications as shipping, scheduling, harbor operations and route verification. Moreover, the application of this concept to the larger problem of safe transport of hazardous cargo is obvious. The analogy of control of air traffic in the Air Traffic Control System (ATC) is valid; no longer can we view navigation at sea as free from regulation and controls to ensure safety of life and property. Unfortunately, the accident of the EXXON VALDEZ was a poignant one. But on the positive side, it is technologies such as GPS, satellite communication and digital maps that can mean the difference between prohibitively expensive solutions and effective solutions that are within reach of the available budgets.

REFERENCES

1. *"NAVSTAR: THE ALL-PURPOSE SATELLITE,"* IEEE Spectrum, May 1981.

2. "SELF-CONTAINED GPS INTEGRITY CHECK USING MAXIMUM SOLUTION SEPARATION," Brown, R.G. and McBurney, P.W., NAVIGATION, Spring 1988.

3. *"DIFFERENTIAL GPS IN THE RANGE APPLICATIONS PROGRAM,"* Beser, J. (with M. Lyon), presented at the National Technical Meetings of the Institute of Navigation, Long Beach, California, January 1986.

4. *"NAVSTAR GPS SIMULATION AND ANALYSIS PROGRAM,"* Kalafus, R.M., Knable, N., Braemer, J. and Vilcans, J., US Department of Transportation, Research and Special Programs Administration, DOT-TSC-RSPA-83-11, December 1983.

5. *"DIFFERENTIAL OPERATION OF NAVSTAR GPS FOR ENHANCED ACCURACY,"* Denaro, R.P. (with R.M. Kalafus), NATO AGARD Lecture Series #161, September 1988.

6. *"STATUS OF UNITED STATES COAST GUARD SPONSORED DIFFERENTIAL GPS DEMONSTRATION SYSTEM DEVELOPMENT,"* Pietraszewski, D., Spalding, J., Viehweg, C. and Luft, L.

Author biographies and pictures for this article will be found on page 28.