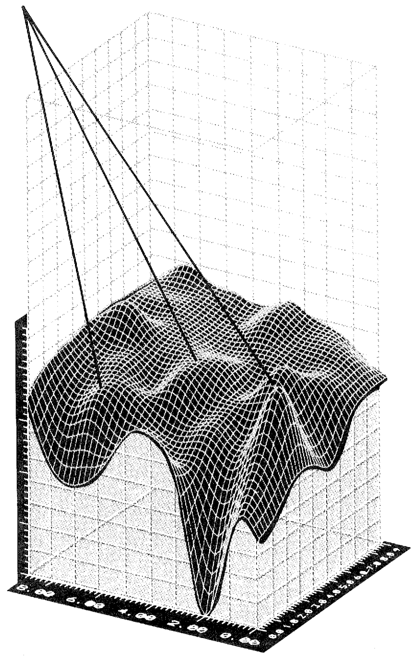

Electronic Charts and GPS

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"Innovation" is a regular column in GPS World *commenting on GPS technology, product development, and other issues and needs of the GPS community. In this issue we look at the use of GPS in conjunction with another new technology – the electronic chart.*

This column is coordinated by Richard Langley and Alfred Kleusberg of the Department of Surveying Engineering at the University of New Brunswick. We welcome your comments and suggestions for future columns.

The chart is one of the oldest navigation tools known to mariners. Hellenic and Phoenician sailors likely used "paper" charts to sail across the Mediterranean Sea, and Caesar used charts of one form or another to plan his conquest of the British Isles. Long before the compass was discovered, mariners were using charts to plan their voyages to avoid the reefs and shoals upon which they could perish and to mark out areas wherein their enemies lay in wait for plunder.

James Cook, the famous British navigator, is considered the father of the science of modern hydrography. His eighteenth century surveys of Newfoundland and the South Pacific are on record as being the first to approach marine charting in a methodical way. His survey work was the foundation of some of the St. Lawrence River charts that were in use right up until World War II. If Cook was alive today, he would be proud to see that his methodology and insistence on excellence are still the norm.

The time comes when alternatives highlight the weaknesses of the old ways. As we approach the close of the twentieth century, we stand at a milestone where the limitations of the classic approach to navigation can be overcome through the use of two exciting new developing technologies: the Global Positioning System (GPS) and the Electronic Chart Display and Information System (ECDIS). Let's begin with a review of what the ECDIS is and what it can do.

ECDIS — ITS CAPABILITIES

The Electronic Chart has been described as one of the greatest advances in navigation technology since John Harrison's invention of the marine chronometer in the 18th century. Coupled with a positioning system such as GPS, the ECDIS provides the mariner with a chart display that animates an icon of the ship's actual position with respect to the surrounding hydrographic features. Soundings, aids to navigation (such as buoys, beacons or lights), the shoreline, and bathymetric contours can all come alive on a full color CRT display.

But ECDIS is far more than a simple machine rendering of the paper chart. It integrates the full chart information package with other aids to navigation such as the ship's gyro compass, GPS, and radar. It is designed to present to the mariner all the information necessary to carry out the safe passage of the vessel through the charted area. It gives the mariner new capabilities to aid in ship navigation, maneuvering, and voyage planning. It opens up a whole new world to a clientele formerly bewildered by the black magic associated with the art of navigation.

ECDIS Display Features. ECDIS display features alone are significant achievements. For example, the operator can zoom from one scale to another to view critical areas of the chart in greater detail. Windowing allows several views of the same chart or coincident charts on the same screen. Information screens specific to the ship such as propulsion data or cargo status can be displayed alongside the chart. Graphs and photos normally contained in such publications as *Tide Prediction Tables* or *Coastal Pilots* can also be viewed on-screen in a multimedia type of presentation. Ease of pilotage can be improved through the on-screen availability of Vessel Traffic Systems (VTS), which provide information such as open anchorage zones. This time sensitive type of information could be broadcast to in-bound vessels for down-linking onto their displays.

ECDIS allows users to custom tailor their own chart display to show only the information which is of most interest to them. For example, commercial fishermen could use the ECDIS to display the position of their nets and preferred fishing areas. Some navigators may wish to display only those depths less than a certain critical level, while a second group may want to see only the floating aids. A third group might want to view only the shoreline. All these features and more will become feasible as ECDIS products mature.

Safety of Navigation Features. There are several other features of ECDIS that substantially improve the safety of navigation. In addition to showing the present ship's position, it will be possible to display a quantitative accuracy estimate of the position of chart features. Similarly, it will not be difficult to calculate and display a forecast of the most likely position of the ship as it continues on its current course. Linked to a chart data base, ECDIS will be able to search forward along the forecasted track for hazards and provide warnings about potential dangers. Many multimillion dollar groundings such as the Exxon Valdez (as well, perhaps, as multibillion dollar clean-up operations) could be prevented by implementing such simple systems.

An important ECDIS safety feature is its ability to superimpose a radar image onto the chart image. By displaying radar targets in real time relative to the vessel's position and projected course, the navigator can evaluate collision avoidance options much faster than if bearings are read from the radar and then plotted on a paper chart or input manually into the ECDIS.

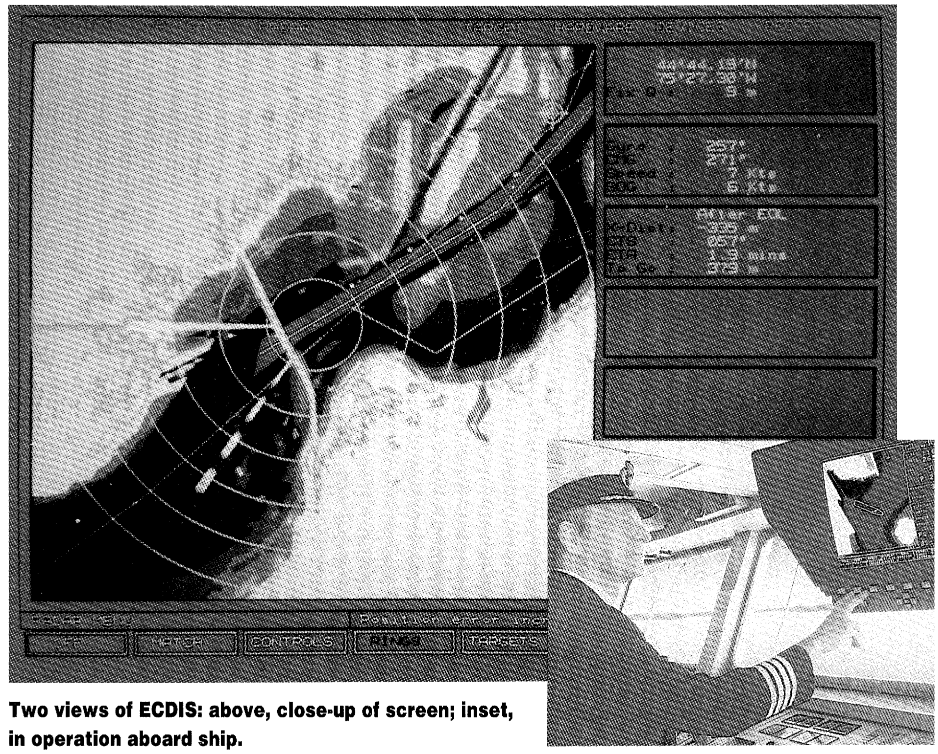
An interesting innovation would be the display of "actual depth now." In this mode, tide-corrected depths and contours would be displayed and updated as new tidal information takes hold. With the 3-D nature of GPS positioning, it is possible to foresee an era of "tideless" charts in which the effects of changes in tidal height are automatically reflected in the displayed chart.

ECDIS allows for display of the actual track of the vessel and/or the vessel's planned route. This intended route information can be interactively composed and verified, then stored in or retrieved from a library to insure that coordinates for routine voyages are correctly entered before each trip. Direct interfacing of the ECDIS to an autopilot can insure that these verified routes are followed precisely. All vessel movements and changes in status can be indelibly logged in the ECDIS computer for future reference. This feature has already proven useful in determining liability following a marine accident. All these ECDIS features will make the mariner's job easier and will greatly improve the safety of navigation.

Corrections and Updating Issues. The nautical chart is a constantly changing document. In busy ports, there is endless construction of new facilities, while in many estuaries siltation requires regular dredging to maintain a safe clearance. During these activities, floating aids to navigation are accidentally pulled from their proper locations and lights are regularly discontinued. New hazards to navigation are created and old ones removed. These events create an endless series of changes to the basic chart data.

Many of these changes, if unreported or uncorrected, could lead to a disaster. It is the responsibility of the chart producers to sell their charts as fully "up-to-date" as is feasible and to provide previous chart purchasers with information concerning such chart corrections. This is done through the publication and distribution of weekly *Notices To Mariners,* documents that contain all the information needed to bring charts up to date. As new charts are sold, they are hand-corrected to make them current. In 1989 the Canadian Hydrographic Service performed more than three million hand corrections to 300,000 charts.

To reflect the chart changes contained in *Notices To Mariners,* an ECDIS must be able to receive digital chart corrections through the maritime radio network and on magnetic medium. The design of an ECDIS data structure that efficiently accommodates this function, as well as many other practical data base considerations, is a matter of great debate in the hydrographic community these days. In this early stage of ECDIS development, it is imperative that international standards for digital chart data be adopted so the tremendous task of converting old, graphical chart data can proceed. Although much work has been done in this area, many technical details have yet to be resolved.



Two views of ECDIS: above, close-up of screen; inset, in operation aboard ship.

ECDIS AT WORK

The ECDIS market at the present time is split into three main subdivisions: military, low end, and commercial systems. The military systems address both the navigational and fighting capability of the ship and, as such, are both very sophisticated and very expensive. The low end systems are designed for the recreational boater. A number of these products have been introduced as software products running on standard PC hardware. A large market acceptance of ECDIS products for cars and trucks will provide the base technology to move these inexpensive systems up in power and sophistication.

Offshore Systems Limited of Vancouver, B.C., produces a commercial-grade ECDIS called PINS which is used by the ferry operating between Sidney, Nova Scotia, and Port aux Basques, Newfoundland. This passage is notorious for its poor visibility in the extremely narrow harbor entrance to the Newfoundland terminal. PINS has allowed the ship to enter the harbor on a regular schedule without any delays due to visibility. The ship's captain views the system as a basic and necessary tool to complete the mission. Other commercial systems are in use for such varied applications as icebreaking in the St. Lawrence River and tanker docking at the mouth of the Mississippi River.

Charting Problems Associated with Using ECDIS and GPS. The introduction of ECDIS/GPS is not without its unique problems. New technology that brings advantages to the user often brings headaches to the supplier. Chief among these problems is the creation of a new phenomenon, the "precise navigator." This term refers to the fact that mariners now will be using positioning systems as good as, if not better than, those used during the original hydrographic survey. The likely effects of this change are as follows:

- A reduction in the distance that mariners will keep from sources of danger
- The use of difficult channels previously avoided
- A tendency to stray beyond the buoyed channel in order to perform more efficient passages
- More exploratory sailing by recreational boaters through inside passages and up estuaries previously unsounded
- The opening of harbors to ships previously denied access due to their limited maneuverability

Each of these changes results from the increased confidence level the mariner feels when using the ECDIS/GPS combination. Unfortunately, much of this new confidence is unfounded since the original surveys were conducted under the assumption that mariners would use charts of a much smaller scale than the survey and that they would possess a much less accurate positioning system. Prudent mariners who would normally hesitate to sail close to dangers due to limited positioning control might not be so prudent

Navigating narrow channels – such as the one at Port aux Basques, Newfoundland, above – poses a rigorous challenge to vessel operators and underscores the interest in improved navigation technologies such as ECDIS.

once they are given tools that enable them to zoom to scales in excess of that of the original survey and to position themselves to an accuracy superior to that previously used by the hydrographers.

Hydrographic offices around the world will be focusing their energy on how to handle this issue. In some cases, it may mean resurveying some areas previously considered charted. In other cases, it will be possible to educate the users on the limitations of the charts they are using. One way to do that is through the display of some figure of chart "integrity." This solution may include some accuracy diagrams which show the accuracy of plotted hazards. In other cases, it will be possible to show confidence limits for the depth contour lines or depth uncertainty plots. While these solutions are possible, they will require a careful application of spatial statistics to determine proper probabilistic values.

Another ECDIS/GPS issue deals with the underlying chart coordinate system. Many charts in the Canadian Arctic and elsewhere are not referenced to the World Geodetic System (WGS'84) used by GPS. Therefore, correction factors will be needed for these charts to be used in conjunction with GPS.

GPS ACCURACY AND RELIABILITY ISSUES

In light of the potential safety problems that may arise by integrating GPS technology and ECDIS, we must ask ourselves the following questions:

- How much positional accuracy does an ECDIS need?
- How much positional accuracy can GPS provide?

The Integrity Issue. Before trying to answer these two questions, we should first consider just what the term "positional accuracy" really implies. Accuracy and reliability are in fact two separate concepts that are inextricably bound together in this term. We must evaluate them separately when trying to determine the suitability of any positioning system for a specific navigational task. If, for example, GPS could provide a positional accuracy better than +/- 1 millimeter 95 percent of the time, but only +/- 1 kilometer for the other five percent of the time, then we would say that it has a very high accuracy but a very poor reliability or "integrity."

Safety is of prime importance to all navigators, be they on land, at sea, or in the air, so the integrity of any positioning system must govern its use. In the example just given, navigators would have to assume at all times that GPS was only providing an accuracy of +/- 1 kilometer and use their ECDIS accordingly. If the positioning system could somehow provide an instantaneous warning to alert them when its positional accuracy had degraded, then we would say that the system has an "integrity monitor." An integrity monitor allows navigators to proceed with confidence during periods of high accuracy, yet know when they should refrain from high risk maneuvers due to degraded positioning performance.

Integrity monitoring has become a major field of interest for navigational users of GPS. The literature generally refers to two major approaches for monitoring GPS integrity: receiver autonomous integrity monitoring (RAIM) and the GPS integrity channel (GIC). RAIM is a mathematical analysis of GPS measurements that eliminates from calculations satellites out of tolerance, while GIC monitors GPS error ranges to determine if the system is usable for North American navigators. (See "The Limitations of GPS" in the March/April 1990 issue of *GPS World* for a more thorough description of RAIM and GIC.)

Differential Operation. The common denominator to both the RAIM and the GIC approach is that neither seeks to improve the accuracy of GPS. Instead, their goal is to improve the reliability or integrity of GPS, with 100-meter C/A code accuracy being the integrity goal shared by both approaches. A third method of integrity monitoring, called differential GPS (DGPS), is very similar to the GIC approach.

Differential GPS involves operating a GPS receiver at a known location, where it observes the range errors associated with each satellite in the same way as a GIC monitor. However, instead of communicating the differential corrections to a central authority for processing into an integrity status judgment, the receiver broadcasts the corrections directly to mobile GPS users. The mobile users' GPS software can then make the same type of integrity assessment that the central GIC authority would perform using the same monitor information. Since the monitor used for differential operations is typically much closer to the user than a GIC monitor, its integrity assessment would in fact be somewhat more meaningful to the user. While the integrity monitoring function provided by differential operation can be essentially the same as that of GIC, navigators also can use the differential corrections to improve the positional accuracy of their GPS positions. -

"How much positional accuracy and integrity does an ECDIS need?" The answer to this question really depends on what we're trying to use the ECDIS for. If we consider a ship voyaging offshore, then an ECDIS horizontal accuracy of +/- 100 meters is more than sufficient; in many cases +/- 1 kilometer would be adequate to maintain safe passage toward the destination. If we consider a vessel as it prepares to dock at night in thick fog and very tight quarters, then clearly +/- 100 meters is not sufficient. Under these conditions, the ship's captain would wish to use the ECDIS to maneuver the vessel with respect to the hazards near the wharf. A large scale chart of the wharf with even a few meters' error, perhaps magnified for close detail, could cause expensive mistakes as the ship pulled alongside. To perform these critical maneuvers, the captain must be confident of the quality of the position measurements. Thus we could say that the integrity monitoring requirement during docking with an ECDIS is 100 percent reliability—the captain must have complete confidence that an ECDIS alarm will be triggered if the positioning system is not accurate enough to safely carry out the maneuver.

The positional accuracy requirement becomes even more stringent if we consider the vertical positioning needs of mariners that might be met by GPS. The depths displayed on a paper chart are referenced to the lowest possible tidal heights experienced in that region based on chart datum. To use a chart, the navigator must estimate the actual tidal height above this datum and then add that height to the charted depths to know the actual water depth at the vessel's location. Tidal estimates presently must be performed by interpolating between predicted high and low water values at some reference port, and then applying some offsets to reduce this value to the current ship's position. This process is laborious and often introduces significant error into the reduced charted depths.

When in differential operation, the limiting GPS integrity factor is the reliability of the differential data link itself.

Ideally, an ECDIS would be able to constantly perform all these tidal corrections in real time and thus display a chart that changes constantly with the tide. To do so, the ECDIS must be provided with an accurate height of the vessel with respect to chart datum. Theoretically, a 3-D positioning system such as GPS could provide these observed local tidal heights, although the accuracy and integrity requirements would be very stringent indeed. Since the GPS tidal heights would be applied directly to the charted depths, their required accuracy would be that of the charted depths themselves: +/- 1 decimeter. Since the depth values are so crucial to safe navigation, the integrity of these depth corrections would have to be correspondingly stringent.

"How much positional accuracy and integrity can GPS provide?" This is the big question. GPS was never intended to provide the sub-meter, highly reliable positioning to civilian navigators that would be needed to realize the full potential of ECDIS. Is it just a utopian dream to speculate that it can?

Despite the initial DoD design specs, it is now obvious that GPS can be made to exceed all performance expectations. The proceedings from any of the recent GPS symposiums contain experimental results showing that, by applying differential corrections to the observed GPS ranges and using the information available from tracking the GPS carrier frequency, we can dramatically improve the accuracy of kinematic GPS positioning to the 1–3 meter level. As explained earlier, the integrity of this level of accuracy is assured by the constant stream of incoming differential corrections which monitor satellite performance. In fact, when in differential operation, the limiting GPS integrity factor is the reliability of the differential data link itself. Experience has shown that any level of data link reliability can be obtained through use of redundant communications technologies.

"What about Selective Availability?" The 1–3 meter DGPS test results shown in the literature were generally obtained under minimal Block I satellite coverage. What will be the effect of the Block II satellites which will have their signals intentionally degraded for unauthorized users?

Since whatever distortions imposed on the satellite signals will be common to both the monitor and remote receivers of a DGPS system, applying differential corrections will effectively remove the impediment of Selective Availability (SA). The one proviso here is that the corrections be updated rapidly enough to resolve the SA distortions. Tests on the first Block II signals indicate that update rates faster than once every 5 seconds will effectively remove the effects of SA. This means that fairly simple radio data links can broadcast the required volume of information to navigators. Cellular telephone, HF, VHF, INMARSAT, MSAT...there are a vast number of r.f. data link options available that could accommodate any requirement for coverage and reliability. This being the case, it's hard to imagine how SA could be enforced other than by censoring all r.f. communications worldwide.

Even if DoD decided tomorrow not to implement SA, the requirement for differential operations in ECDIS applications would still remain. Stand-alone C/A code GPS without SA would indeed provide accuracies better than 100 meters (15 to 30 meters is a reasonable estimate). If positional integrity monitoring was not a factor, then this improved level of stand alone GPS accuracy would indeed broaden the range of ECDIS applications that could be performed using GPS. However, since integrity monitoring is in fact a crucial consideration for all navigators, the need for real-time differential corrections still remains, not for the increase in positional accuracy but for the necessary integrity monitoring they provide.

FUTURE GPS PERFORMANCE

GPS accuracies of 1–3 meters with full integrity monitoring are already available today by making use of real-time differential corrections. Can we expect this performance to get even better in the future?

Full Block II satellite coverage will definitely improve satellite geometry and the amount of redundant information that can be used in the position solution. The analysis techniques now embodied in the RAIM approach to integrity monitoring will no doubt make full use of this extra information. Receiver technology will also improve the accuracy of GPS. The use of multiple channels to track all visible satellites will result in more reliable tracking of the GPS carrier phase. Improved channel hardware may even be able to resolve code phase to the point of determining the carrier phase ambiguity directly without any filtering algorithms. For applications requiring the ultimate level of accuracy and reliability, DGPS will be integrated with low cost, low performance inertial sensors to bridge through momentary GPS outages.

The stakes are high in the ECDIS/GPS development game. Advances are being made daily, although many manufacturers are timing their product development to coincide with the 24-hour availability of GPS. When all the development opportunities are exploited, it is quite probable that ECDIS users will be able to navigate reliably to within a few decimeters. ■