Electronic Chart of the Future:
The Hampton Roads Demonstration Project

Richard Brennan, Colin Ware, Lee Alexander, Andrew Armstrong, Larry Mayer, Lloyd Huff, Brian Calder, Shepard Smith, Matt Plumlee, Roland Arsenault, and Gerd Glang

Center for Coastal and Ocean Mapping/Joint Hydrographic Center
University of New Hampshire
Durham, New Hampshire, USA

Abstract: ECDIS is evolving from a two-dimensional static display of chart-related data to a decision support system capable of providing real-time or forecast information. While there may not be consensus on how this will occur, it is clear that to do this, ENC data and the shipboard display environment must incorporate both depth and time in an intuitively understandable way. Currently, we have the ability to conduct high-density hydrographic surveys capable of producing ENCs with decimeter contour intervals or depth areas. Yet, our existing systems and specifications do not provide for a full utilization of this capability. Ideally, a mariner should be able to benefit from detailed hydrographic data, coupled with both forecast and real-time water levels, and presented in a variety of perspectives. With this information mariners will be able to plan and carry out transits with the benefit of precisely determined and easily perceived under-keel, overhead, and lateral clearances. This paper describes a Hampton Roads Demonstration Project to investigate the challenges and opportunities of developing the "Electronic Chart of the Future." In particular, a three-phase demonstration project is being planned:

1. Compile test datasets from existing and new hydrographic surveys using advanced data processing and compilation procedures developed at the University of New Hampshire's Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC);
2. Investigate innovative approaches being developed at the CCOM/JHC to produce an interactive time- and tide-aware navigation display, and to evaluate such a display on commercial and/or government vessels;
3. Integrate real-time/forecast water depth information and port information services transmitted via an AIS communications broadcast.

Introduction

Today's Electronic Chart Display and Information System (ECDIS) provides significant improvements over the paper chart. ECDIS and the Electronic Navigational Chart (ENC) database that supports it offer the mariner a powerful and flexible tool for route planning and route monitoring. The incorporation of GPS position data provides a continuous update of vessel position on the display. Nonetheless, with the exception of this continuous position, the ECDIS display is like the paper chart: a two-dimensional display of fixed data. In order for ECDIS to evolve into a true decision support system capable of providing the mariner with both real-time and prospective navigation information, new approaches must be developed to improve the content, management, and display of ENC data.

With the increasing use of swath sounding systems (e.g., multibeam), hydrographers now have the capability to conduct high-density hydrographic surveys and acquire highly accurate sounding data capable of producing ENCs with decimeter contour intervals [Hudson 2000]. Furthermore, a variety of organizations have developed observation, prediction, and modeling capability that permit us to obtain real-time and forecast water levels in many of the world's major harbors. The Physical Oceanographic Real Time System (PORTS) and the Chesapeake Bay Operational Forecast System (CBOFS) are examples of these types of observation and prediction systems [NOAA 2003]. However, existing ECDIS systems and ENC specifications do not permit us to make full use of these capabilities. While there may not be a consensus on how it will occur, it is clear that the electronic chart of the future must incorporate high-density hydrographic data and water-level information into a system in which position, depth, and time are displayed in an intuitive and understandable way. In the near-term, the "next generation" ENC (i.e., IHO S-57 Edition 4) is expected to be able to accommodate some level of time-varying, 3-D, and high-density bathymetric data. However, in the longer term, the electronic chart of the future should be designed to provide mariners information that is optimized for both display and decision support. For instance, mariners using the electronic chart of the future should be able to plan and carry out transits with precise and easily perceived overhead, horizontal, and under-keel clearances.

Project Description

The Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM-JHC) at the University of New Hampshire will be conducting a demonstration project in the Hampton Roads area to investigate some of the challenges and opportunities in developing this electronic chart-of-the-future. We plan to carry out this project in partnership with NOAA's National Ocean Service. We also plan to involve the U.S. Coast Guard (USCG) Command and Control Center (C2CEN) in Portsmouth, Virginia. C2CEN is the lead facility in USCG dealing with ECDIS and other electronic charting systems for USCG vessels.

The ideal electronic chart will vary considerably depending on the vessel and the situation in which it is employed. We hope to develop approaches that are adaptable to this variety of demands. Hampton Roads thus provides an ideal site for an electronic chart of the future demonstration project. As one on the nation's busiest ports, it handles extensive commercial and military shipping, with vessels covering a complete range in size, type, and complexity. Hampton Roads comprises several major commercial port operations, including both container and bulk cargo handling facilities. It is the home of two forward-looking Pilot Associations (the Maryland Pilots and the Virginia Pilots), the home of the world's largest naval base, and is a regional headquarters for NOAA, the USACE, and the USCG. This concentration of maritime expertise offers us the opportunity to get feedback on our approaches from those who will ultimately be the users of the electronic chart of the future. Our goal is to have the first prototype displays ready to demonstrate and evaluate during the summer of 2003. We plan to carry out the demonstration project in three phases.

Phase 1

Phase 1 will comprise the identification and compilation of existing bathymetric data in the Hampton Roads project area, and the acquisition of new bathymetric data where considered necessary. We have already begun the process of identifying and gathering existing hydrographic surveys from the Office of Coast Survey. New data acquisition has also begun in connection with NOAA's annual hydrographic training program in Norfolk. We plan to process (or reprocess) these data sets using *CUBE* [Calder 2002] and the "Navigation Surface" [Smith et al 2002] software developed at CCOM/JHC in order to create a high-resolution digital elevation model (DEM) of the project area.

Phase 2

Phase 2 will have two separate, but sometimes overlapping tracks:
Track 1 - Develop new methods to incorporate vertical and time dimensions into existing NOAA ENCs. These "next generation" ENCs will be tested with existing ECDIS and ECS equipment currently installed onboard government and commercial vessels.
Track 2 - Develop, test, and evaluate the effectiveness of entirely new approaches to the visualization of chart and navigation-related data. These approaches will be developed without the constraints of current IMO ECDIS Performance Standards (IMO 1995) or IHO S-57 standards (IHO S-57). Instead, they are intended to provide fresh insights and new concepts for the electronic chart of the future.

Track 1 – Next Generation ENC

Track 1 will be evolutionary in approach, seeking to work within much of the existing IHO and IMO framework for ENCs and ECDIS. In the realm of ENCs, individual charted depths (soundings) are fading in significance, and will be replaced by "depth areas". Depth areas are contiguous areas in an ENC containing water deeper than the designated contour bounding it. The use of depth areas in navigation has the benefit of removing much of the clutter plaguing all charts today. Properly used, it can also provide the mariner with an unambiguous "highway" in which to safely navigate. However, for these depth areas to be useful, they need to be created at decimeter intervals so as to be able to coincide with a ship's actual draft. Up to now, creation and maintenance of depth areas at this resolution has been problematic from a cartographic standpoint.

Even if the hurdle of having decimeter resolution depth areas (or better) is overcome, knowing where they reside in relation the water's *actual* surface is a missing link. To accurately accomplish this, information needs to be imbedded into the ENC that will describe the difference in the time and range of tide over the entire area covered by the ENC. Once this data is incorporated into an ENC, the capability to apply predicted, real-time, and forecast tide values can become a reality. This capability will enable mariners to display actual water depths, and take advantage of (or precautions for) the effects of meteorological events on water depth to plan their passages.

This track's primary objectives are to:

- Expand the current S-57 Edition 3.1 ENC Product Specification, by developing three prototype ENC datasets.
- Integrate a Water Level model into each of the three prototypes.

The first prototype ENC will be based on the current IHO S-57 ENC Product Specification and will serve as the baseline for comparison. The second ENC dataset will be an enhanced version of the first, but with a greater density of depth areas and contour intervals. The third ENC dataset will replace all depth areas and contours with a high-resolution digital elevation model (DEM) based on the Navigation Surface algorithms. This ENC will be capable of computing standardized or user-defined, real-time depth areas and water depths.

This effort will build on research currently being conducted at CCOM-JHC to develop a DEM that is optimized for navigation. This type of DEM, called a "Navigation Surface" uses the highest density bathymetric data available and creates a model of the seafloor that honors the least depths of all significant seafloor features and incorporates an uncertainty value for the depth at any point. At the same time, it "defocuses" derivative product grids to allow automatic creation of logical and contiguous depth areas and contours [Smith et al, 2002]. This automatic defocusing approach avoids the jagged and "orphaned" contours typical of many direct contouring techniques, and thus greatly reduces the cartographic effort associated with creating ENC depth areas.

Each of these prototypes will be built using a DEM based on the Navigation Surface concept. The DEM will be created from a combination of existing single-beam bathymetry and new high-resolution multibeam data. All cartographic features, buoyage, landmasses, traffic patterns, and other chart information for the prototype ENC cells that are not covered by new hydrographic data will be derived from the existing ENC data.

Each of these prototype ENCs will be tested using predicted, real-time, and forecast tidal information for calculation of actual water depths and depth areas, and for time-dependant route planning and risk assessment. NOAA's Coast Survey Development Lab has developed the CBOFS, a program that provides detailed a water level nowcast and forecast model for the Chesapeake Bay, including the Hampton Roads project area. Methods are being investigated for scaling this model for implementation into the prototype ENC format. This model can work using predicted or real-time water levels for use in computing either forecast or nowcast water levels respectively, based on both tides and meteorological conditions.

Compilation of the bathymetry, features, and water levels into the prototype ENC data format will be accomplished using CARIS and SevenC's software. Comparison between, and validation of, the three prototype formats will be accomplished using SevenC's ECDIS kernel and CCOM's GeoNav-3D software.

The goal of this effort is to fully utilize the high-resolution multibeam data acquired by today's hydrographers by augmenting the existing ENC and ECDIS technology to provide mariners with a navigational tool that will allow them to exploit the time dependent nature of the waters they transit. We hope that the results of this research will contribute to the next edition of IHO S-57 (Ed. 4.), planned for 2005. In particular, producing a prototype ENC based on a navigation surface will provide considerable insight into what is required to develop a product or content specification for high-density bathymetric data.

Track 2 – Electronic Chart of the Future

Our second approach will, in general, be revolutionary rather than evolutionary. We will consider current electronic charts mainly as being useful sources of information about chart functionality, rather than as models. Instead, the focus will be to discover what functionality is likely to be possible and useful in the long-term (~10 years) and to work towards the best way of providing that functionality. Our goal is to regard a chart in very broad terms as a decision support system for the mariner. Thus any and all information will be considered, including vessel parameters, weather information, other marine traffic, tides, and currents. In addition, we will consider diverse means of presenting this information, including 3D animated displays, multiple linked displays, head mounted displays, stereoscopic 3D displays, and audio. These will be evaluated according to task requirements and issues such as cognitive loading. The tasks we hope to support include voyage planning, hazard alerting, harbor management, training, real-time navigation support, and dealing with unplanned incidents.

A key part of our approach will be the development of proof-of-concept prototypes of new human-chart interfaces, coupled with the evaluation of these prototypes, both in the lab and in the field. For the most part, these will by built on a platform provided by the UNH GeoZui3D visualization systems [Ware et al 2001]. GeoZui3D is a highly interactive 3D visualization system that has provisions for real-time input from a number of sources, and the capability to playback events in faster-than-real-time. It supports the interactive display of bathymetry, draped imagery, channel markers, and similar chart features as well as a variety of display modes. Currently the system has two distinct purposes. Firstly, it provides visualization tools to NOAA scientists as well as to a number of groups around the world. The second purpose is more important to the Hampton Roads project. GeoZui3D is also designed to provide a flexible, in-house tool to allow us to test out new ideas relating to the presentation of oceanographic data. To support the electronic chart of the future project we are creating a variant on GeoZui3D called GeoNav3D.

This project has both short- and long-term objectives. In approximately the next eighteen months, we plan to use GeoNav3D to explore three sets of innovations. Firstly, we are incorporating real time tide model information into the system, to show predicted depths for any instant in time. We are also implementing the ability to plot out a planned navigation path as a set of waypoints and arrival time, which will allow us to show the predicted depths *at the expected times of arrival* along the designated corridor. Secondly we are investigating the application of multiple linked views into the GeoNav3D system, including plan views showing shaded bathymetry linked with perspective views from different station points relative to the ship. The kinds of views we will consider will include: cross track profiles, along track profiles, under-the-keel view, over-the-shoulder view, plan view, north up or heads up, and enlarged views of particular objects. These views may contain different information subsets, such as radar and information about currents. In addition, we will consider the usefulness of designing GeoNav3D so that alerting signals can trigger particular views to appear. To support the alerting concept, Plumlee and Ware have developed a cognitive model that can be used to determine when more than one linked view is likely to be useful as well as an investigation of the value of different methods for linking views, including the use of proxies, tethers and coupled perspectives [Plumlee and Ware, 2002; Plumlee and Ware, 2003]. Both the real-time tide display and the multiple linked views are described in more detail elsewhere in these proceedings [Arsenault et al].

The third short-term project is to investigate ways of incorporating information about currents into the displays. Predictive models are under development that can estimate both harbor and littoral currents as they vary over time. These are based on both predicted tides and predicted weather. In the future, such models may become widely available. We propose to investigate ways of integrating information about currents in the chart of the future display and also to understand where such information may be most useful to the mariner or to vessel traffic control personnel. We have completed a preliminary investigation into the use of particle traces in displaying currents generated from models. Our partners in this current display effort include Atta Bilgili at Dartmouth, and Tom Gross and Dick Schmalz at NOAA.

In the longer term, we also expect to investigate the value of augmented reality displays as aids to the mariner. Augmented reality (A/R) displays involve superimposing computer graphics imagery over a view of the directly viewed environment. Augmented reality techniques can make it possible to look though a device and see labeled or otherwise enhanced shore features, buoys, surface or submerged hazards, AIS and radar data, etc. We plan the construction of a set of wide field A/R viewers that could visually show the location of various transponder sources superimposed on the environment. (One solution would be use PDA- sized screen, together with a mirror). For specialized projects, imagery of the seabed, or water-column objects, could be shown as if the water were transparent.

Phase 3

Phase 3 of the demonstration project will integrate real-time/forecast water depth information and port information services transmitted via an AIS communications broadcast into both the "next generation ENC" and with the electronic chart of the future. Tidal, water level and current flow information will come from a variety of sources:

- real-time (PORTS and/or CBOFS)
- predicted (CBOFS)
- forecast (PORTS & CBOFS) with National Weather Service input

This information will be transmitted via Automated Identification System (AIS) using AIS Broadcast message format that was developed by the Volpe National Transportation Center for the St. Lawrence Seaway [U.S. DOT 2002]. This AIS Messaging Format has now been finalized under close coordination with both U.S. and Canadian Coast Guards. It provides a baseline for electronic chart manufacturers who are developing the software needed for on-board computer displays (e.g., ECDIS) for vessels required to carry AIS.

Anticipated Benefits

We anticipate that the results of Hampton Roads Project will provide a variety of benefits to the hydrographic and maritime community.

For the International Hydrographic Organization (IHO), the results of this project should contribute to next edition of IHO S-57 (Edition 4). In particular, our development of a Navigation Surface-based ENC should assist the IHO Transfer Standard Maintenance and

Applications Development Working Group to deal with developing the "Next Generation S-57" (see IHO website, www.iho.shom.fr). Specifically, this should aid in the development of specifications for Time-Varying and 3D data (Work Item 2.4), and for a Bathymetric Data Product Specification (Work Item 2.7). For the longer term, we hope that GeoNav3D will provide fresh insights in the development of specifications for electronic charts beyond the "next generation."

For NOAA, useful insight will be gained about the process required to use a "navigation surface" database approach to produce the "next generation" ENC (i.e., IHO S-57 Edition 4), and a better understanding of what may be done to incorporate vertical and time dimensions into electronic charts. In the near term, ENC, ECDIS and ECS shipboard systems could have the ability to incorporate PORTS and CBOFS information into a dynamic electronic chart display that can be used for decision support. For the longer term, the opportunity to evaluate mariner reactions to new concepts such as multiple linked views and augmented reality techniques should assist the charting program in planning for the technology of the future.

For the U.S. Navy, the Navigation Surface DEM can be used to produce various types of electronic chart products and services. This includes the Digital Nautical Chart (DNC®), Additional Military Layers (AMLs), and Tactical Electronic Chart Overlays. Having more detailed ENC and DNC data, coupled with real-time/forecast water levels, should also provide a greater margin of safety for U.S. Navy deep draft vessels when entering the Norfolk Naval Base. Also, given the increased interest in Homeland Security, these types of datasets, available in flexible and intuitive displays, could become increasingly important in terms of sea-floor classification, small bottom objects (e.g., mine-like objects), and large bottom objects (debris, wrecks) in major U.S. ports and waterways.

For USCG, shore-based AIS messaging will provide real-time and forecast tide and water level information to underway vessels that can be used with existing onboard ECDIS and ECS systems. Also, knowing both real-time and forecast water level information, and having that information displayed in an electronic chart format, will be of benefit to the USCG Captain of the Port in terms of under-keel clearance determinations and enforcement.

Perhaps most importantly, for the entire maritime community, there will be significant benefits to be gained in the development of new electronic charting capabilities and technologies—both in the near term and the longer term—that could significantly improve the ability of vessel masters and pilots to plan their transits and navigate their ships with accuracy, precision, and an intuitive understanding of their position, situation, and clearances.

References

Arsenault, R., Plumlee, M., Smith, S., Ware, C., Brennan, R., Mayer, L. 2003. Electronic Chart of the Future: A Proposed Hampton Roads Demonstration Project. *U.S. Hydro 2003 Proceedings*, Biloxi. CD-ROM Proceedings.

Calder, B. R., and Mayer, L. A., *Automatic Processing of High-Rate, High-Density Multibeam Echosounder Data*, submitted to Geochem., Geophys., Geosyst. (G3, gcubed.org), DID 2002GC00486, December 2002.

Hudson, M., 2000. Electronic Navigational Charts from Survey Source Information – The Australian Experience. *International Hydrographic Review*, Vol. 1, No. 2, December 2000. p. 13-23.

NOAA, CO-OPS, 2003, Physical Oceanographic Real Time System http://www.co-ops.nos.noaa.gov/cbports/cbports.html, and Chesapeake Bay Operational Forecast System, http://www.co-ops.nos.noaa.gov/CBOFS/cbofs.shtml.

Plumlee, M. and Ware, C. 2003. An Evaluation of Methods for Linking 3D Views. *Proceedings of ACM SIGGRAPH 2003 Symposium on Interactive 3D Graphics*, Monterey, California, ACM Press,NewYork, in press.

Plumlee, M., and Ware, C., 2002, Modeling Performance for Zooming vs. Multi-Window Interfaces Based on Visual Working Memory, Advanced Visual Interface, Trento, Italy, May, Proceedings, 59-68.

Smith, S.M., Alexander, L., and Armstrong, A.A., 2002, The Navigation Surface: A New Database Approach to Creating Multiple Products form High-density Surveys, *International Hydrographic Review*, Vol. 3, No. 2, August 2002. p. 12-26.

U.S. DOT, *St. Lawrence Seaway AIS Data Messaging Format and Specifications (Revision 4.0A)*, Volpe Transportation Systems Center, 9 May 2002, 24 p.

Ware, C., Plumlee, M., Arsenault, R., Mayer, L.A., Smith, S., and House, D. (2001) GeoZui3D: Data Fusion for Interpreting Oceanographic Data. Oceans 2001, Honolulu, Hawaii, Proceedings, p. 1960-1964.