The CCOM Chart-of-the-Future Project:

Maximizing Mariner Effectiveness through Fusion of Marine & Visualization Technologies

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Abstract

The Center for Coastal and Ocean Mapping (CCOM) at the University of New Hampshire has undertaken the Chart-of-the-Future Project to aid in the development of future generations of navigational charting systems. The goal of the Chart-of-the-Future Project is to develop a marine decision support system that takes full advantage of existing and emerging technologies in order to maximize safety and efficiency in routine marine responsibilities. We are developing a working research prototype called GeoNav3D. Our approach is to integrate relevant technologies into a dynamic system that presents a comprehensible unified interface to the responsible mariner. We are integrating detailed bathymetric models, tide models, vessel models for under-keel clearance and maneuvering, models of wind and currents, GPS, and sonar into a single computer interface. Features of the user interface include: multiple 2D and 3D views, methods for linking information in separate views, methods for integrating disparate information into a single view, fluid flow visualization methods, and methods for emphasizing information most relevant to the mariner while reducing clutter by de-emphasizing irrelevant information. We will present the system in its state of development at the time of the conference and discuss our future plans. We plan to refine the GeoNav3D system by means of field trials on vessels in busy channels in various environmental conditions.

Introduction

The economic forces of efficiency and flexibility are driving trends toward deeper drafts, wider beams, increased traffic, narrowing margins, and increasing risk. These trends have been supported by advances in such things as vessel construction, dredging capabilities, mapping accuracy, and sensor capabilities such as radar, sonar, or GPS. Each of these advances has provided the mariner with another source of data with which to plan and to make real-time decisions. However, the human capacity to understand and process this information directly is relatively limited. We are rapidly approaching a point where existing navigation interfaces may not be sufficient to aid the mariner in making timely, sound decisions in command of the vessel every time the need arises.

To help make it possible to take full advantage of technological advances, the Center for Coastal and Ocean Mapping (CCOM) at the University of New Hampshire has undertaken the Chart-of-the-Future Project. The focus of the project is to develop new components for a marine decision support system that can help the mariner take advantage of the increasing deluge of information without becoming overwhelmed. Our approach is to look at the technologies likely to be widely available within the next ten years, and design prototype computer interfaces for presenting that technology to the mariner. Rather than applying new technology to old practices,

For the MTS (Marine Transportation System Research & Technology) Conference

we are also investigating how mariners interact with the data, and what questions they are really asking when they look at the data. We call the prototype platform we are building GeoNav3D.

This paper is organized in three parts. The first identifies the new marine technologies that are becoming available, and how we expect the capabilities they provide could be of use to the mariner. The second describes interface technologies we are developing for GeoNav3D to help incorporate the new marine technologies into the everyday routine of the mariner. The third part briefly lists the collaborations we have formed to spur innovation and test prototypes.

Marine Technologies

Over the next several years, a number of technologies should be reaching a level of maturity that will make them useful to mariners. This section briefly describes some of these technologies and how they can be used together to provide more accurate and relevant information to the mariner.

Continuous Bathymetry from Multibeam Sonar

Within the last decade there has been a rise in the use of multibeam sonar technology in shallow water. The resolution and accuracy of these sonars has made it possible to create high-resolution models of the seafloor, in some cases with horizontal resolutions as high as 0.5 meter. While this level of detail may be of interest for geophysical and engineering purposes, it may be inappropriate from a navigational standpoint. To this end, automated algorithms have been developed at CCOM/JHC that can cartographically generalize these grids based on their horizontal accuracy and the scale of the product or presentation desired to produce what are called Navigation Surfaces [1].

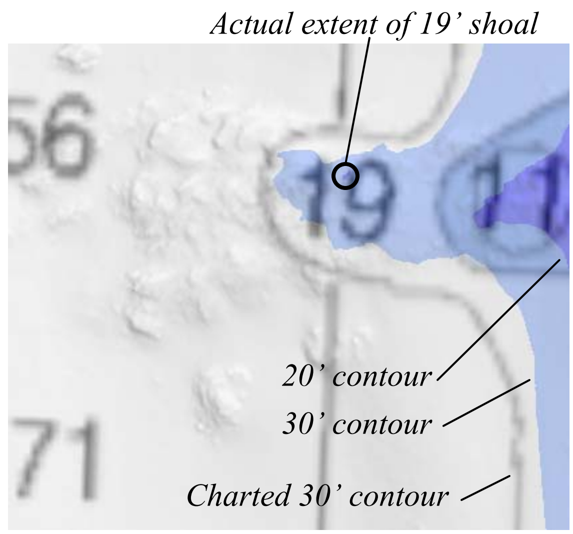

Figure 1: A 1:20,000 chart (black lines and digits) overlaid on a 1-meter resolution bathymetric model.

Navigation Surfaces provide significant advances over the static bathymetry and contours currently found in modern Electronic Navigational Charts (ENC's). The most useful of these is the ability to create safety contours on the fly based on a vessel's own draft. Existing ENC's have a predefined contour interval. This interval is fixed and not at a sufficient resolution to meet the loading accuracies of draft constrained vessels. Use of such technology can show areas where the lateral maneuvering room may exceed the channel limits or those limits shown on the current, lower resolution charts. In areas where the slope of the bottom is very gradual, this could mean that the entrance to a corridor may be recognized as navigable at the time of approach, whereas older charts would have caused the mariner to wait for higher water. Of course for this to be implemented in real-time, real-time water level corrections must also be possible and available.

Water Level (Tide) Models

The power of high-resolution bathymetry can only be unlocked if real-time water level corrections can be properly applied. Two distinct navigational activities are currently under investigation: real-time route following, and pre-arrival route planning. Each activity has unique requirements and limitations.

Real-time route following must accurately represent the water levels in the navigational basin at the time of transit and also take into account the water surface topography. A method of interpolating between standard National Ocean Service (NOS) tide gauges that meets this need has been developed at the Coast Survey Development Laboratory (CSDL) called Tidal Constituent and Residual Interpolation (TCARI) [2]. TCARI generates gridded water levels, which may be used for correcting high-resolution gridded bathymetry. Methods for expanding the capabilities of TCARI to a real time application are currently underway at CCOM.

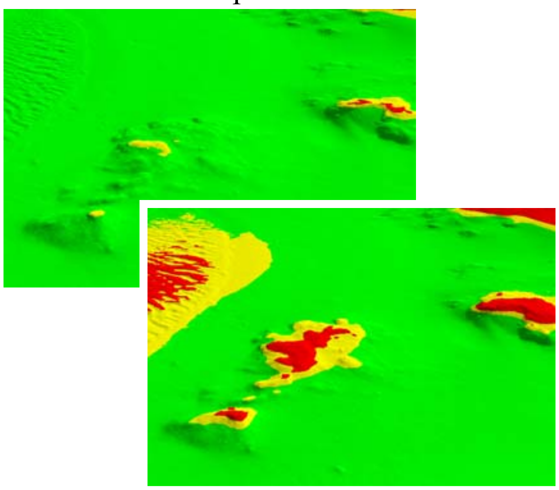

Figure 2: Depth areas color-coded based on vessel draft, with green and red colors indicating go/no-go areas. The top frame corresponds to a high water condition while the bottom frame is near MLLW.

Pre-arrival route planning must be able to forecast the expected water levels in a given navigational basin in advance. To accomplish this, water level forecast guidance provided by NOS's operational hydrodynamic forecast models are currently being investigated. These models are currently operating for Galveston Bay, Texas, Chesapeake Bay [3] and the Port of New York and New Jersey [4]. They predict water levels for the next 1 to 2 days based on forecast meteorological conditions over the estuary and forecast water levels at the mouth of the estuary. While not meeting hydrographic accuracy standards, the water level information can provide useful information to the mariner to see if water levels will be higher or lower than the predicted astronomic tides. By providing the mariner with continuously updating depth areas that reflect forecast water levels, underkeel and lateral tolerances could again be made tighter, as could overhead clearance tolerances for bridges and cables. In addition, predicted water level information can enhance short-term route planning, particularly in deciding when to enter or leave a harbor.

Wind and Current Models

Winds and currents can affect the speed at which a vessel can travel, as well as its maneuverability. Of course, sailboats are particularly concerned about such effects, but winds and currents also have significant implications for large vessels in situations such as docking and passages in narrow or confined waterways. In addition to providing forecast water levels, a few of the NOS operational hydrodynamic forecast models also provide current, water temperature, and salinity predictions. These models will continually be refined to increase accuracy, and over the next few years several other areas on the east coast and in the Great Lakes are likely to have similar models [5]. On the other hand, surface wind forecasts are provided by NOAA's Weather Service numerical weather prediction models such as the NWS Global Forecast System [6] and the Weather Research and Forecasting Model [7]. In addition, gridded meteorological predictions generated by weather forecasters using weather prediction model forecast guidance will soon be available (e.g. the National Digital Forecast Database, or NDFD [8]). While providing the raw information can help the mariner avoid areas of strong head currents or decide when to tack, the power of these models may best be realized when combined with high-resolution bathymetry and dynamic vessel models.

Dynamic Vessel Models

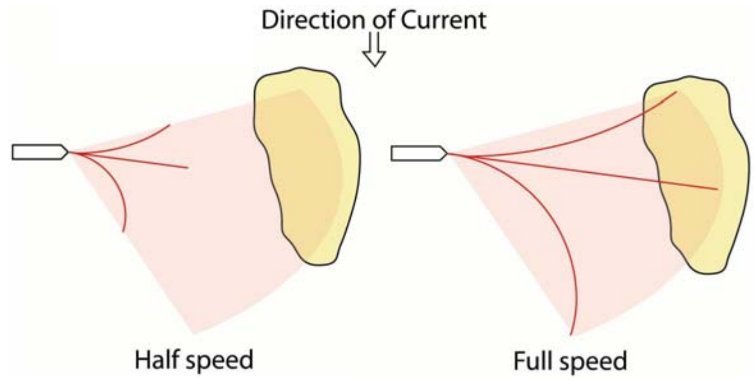

Figure 3: An illustration of how vessel modeling could aid a mariner in determining where a vessel will be at given rudder angles and engine speeds, while accounting for the depth of the water underkeel.

The depth of water beneath the keel, the speed of the vessel through water, sea state, and the strength and direction of winds and currents can affect how deeply a vessel sinks into the water surface and how deftly it maneuvers. We have initiated discussion with Andrew Silver and Paul Kopp of the Naval Surface Warfare Center to see if models originally created to aid in the development and construction of ships and in the design and management of channels [9] could be adapted to create more dynamic navigation models. Such models can help refine underkeel and overhead clearances, and provide a standardized way of specifying margins of safety. They may also aid in training mariners piloting a given vessel for the first time, telling them where they could expect to be in 30 seconds given an engine speed and rudder angle (as shown in Figure 3). In addition, the models could support the running of simulated near-term scenarios involving maneuvers for coming into and out of a harbor.

Digital Vessel Communication Systems

Digital communication is already becoming more commonplace with the advent of AIS (Automatic Identification System). Such systems are useful for communicating vessel positions and some basic information about the vessels themselves, but they are of limited bandwidth. Furthermore, there is no easy way to link AIS identities with voice communications, via the Digital Selective Calling (DSC) capabilities of VHF, for instance. A new generation of communication capabilities is on the horizon, embodied in the IEEE 802.16e standard for wireless communication. This standard specifies communication technology that can deliver broadband data speeds—16.6 Mbits/s at 31 miles, or 74.8 Mbits/s at 4 miles [10]. Market implementation (primarily for cell phones and laptop computers) is expected in 2006 [11], which could make the technology prevalent enough for a marine standard to follow not long afterward. With these kinds of communication speeds, much of the detailed information described in this section can be broadcast from shore at regular intervals. In addition, such systems would allow the tagging and logging of ship-to-ship and ship-to-shore voice communications, useful both for identifying who is speaking, and creating a record for post-hoc analysis of accidents and close-calls.

The advent of high-bandwidth digital communication also makes it possible to leverage existing technologies by stitching patchworks of information together into consistent wholes. Examples of this include weather radar, and radar returns and wind measurements from ships of opportunity. Weather radar is already stitched together from stations on land, but the newly available bandwidth will make it possible for mariners to have ready access to such information before it becomes stale. Having a great deal of bandwidth available also makes it possible for vessels to report their radar and wind data, and retrieve a composite picture assembled on shore from many such reports.

Convergence

As each of the technologies described matures and becomes more pervasive, efficiency and flexibility should increase everywhere from the operation of individual vessels to the management of traffic in ports. These advances should enable incrementally deeper drafts, larger ships, and reduced fuel and crew costs, while at the same time providing better information for ensuring safety. However, for the technology to make good on this promise, it must be properly integrated into the systems that human operators will use to make decisions.

Visualization Technologies

In order for the mariner to be able to use these new sources of information, electronic navigation systems must become smarter in the way they present information. It is not enough to just keep adding symbols or numbers to maps, or adding different screens or menu items. Electronic navigation systems must provide enough information to aid the mariner in the task at hand, be flexible enough to allow rapid switching among tasks, and at the same time be simple and plain enough to keep from overwhelming the mariner. This section briefly describes some visualization technologies that are implemented in our prototype GeoNav3D system that will aid in building such electronic charts.

Linked 3D Views

GeoNav3D has the capacity to display several different 2D and 3D perspectives on a situation, while providing visual cues that help the mariner to see how these windows relate in a common context. Views can be attached to moving locations that make the object they are attached to stand still while the rest of the world moves. For example, consider a forward-looking view from the bridge of the mariner's vessel. This view can help the mariner correlate what is seen out the real bridge window with what is visible in the virtual world of the electronic chart—an especially useful feature at night. The interface allows the mariner to pan the view left and right, or scale out to get an above-and-behind contextual view of the surrounding area. Other examples of how multiple views can be linked together to aid in understanding and decision support can be found in [12, 13].

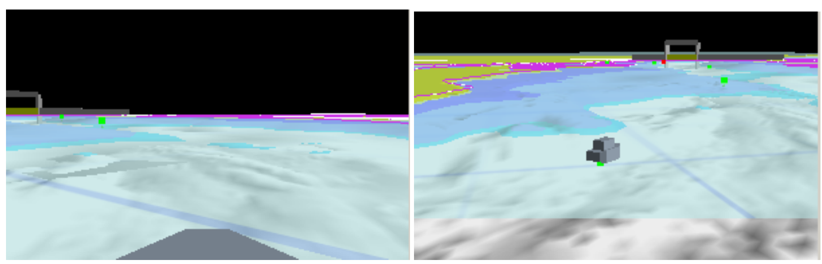

Figure 4: 3D views in the reference frame of a vessel. At left is a view from the bridge, while at right is a view from above and behind. Both views can be helpful in aligning what is seen out the bridge window with what is on the computer display.

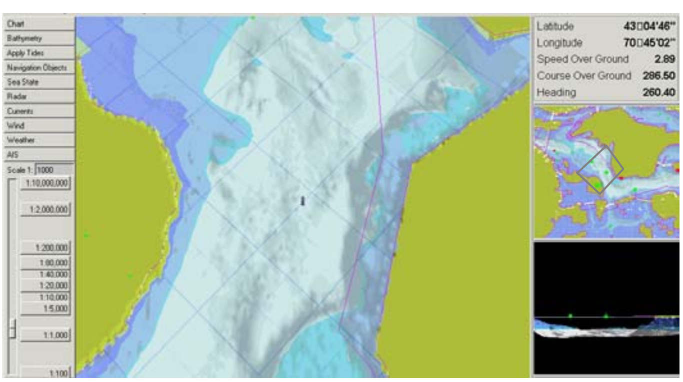

Figure 5: A sample configuration of the GeoNav3D interface. At center is a view of the immediate surroundings of the vessel, while at right are a map overview and a cutaway view from behind the vessel (good for illustrating lateral tolerances in a channel.

In its current form, the GeoNav3D system supports a variety of basic information sources that can be rendered in any view. It can display Navigation

Surfaces, S57 chart objects, photographs of key landmarks, mosaic photographs of the shore ("shorecam"), 3D representations of vessels, buoys, bridges, or just about any 2D or 3D object. It can take a GPS feed, and automatically updates all views attached to the mariner's vessel according to GPS data. It also has the ability to periodically download predicted and measured tides from the web, and use these to display both the water surface and dynamic depth areas at a given instant in time (anywhere from days into the past to days into the future).

Another possible idea of note is the use of live video feeds. LookSea [14] presents the mariner with an augmented-reality display of chart and intended track information overlaid on a live video feed from a specially designed video camera. This idea looks promising, and may be worthy of expansion.

Visualizing Fluid Flow

GeoNav3D supports visualization of fluid flow, for use in understanding the strength and direction of winds and currents. The most basic way to visualize fluid flow is to draw lines or arrows in the direction of the flow, with their length and boldness indicating their strength. We have done this, but we also vary the number and spacing of these lines depending on the viewing scale. In addition, we have added support for dropping particles into the flow to track the behavior of a frictionless particle moving in that flow over time.

We are currently developing visualization methods for fluid flow that more directly support the types of queries that mariners often make. For example, we are working on specialized tools that illustrate flow only in particular areas of interest, such as in anchorage areas or at waypoints along a planned path. We also plan to consider how to refine the use of the particle capability to support man-overboard and spill-tracking scenarios. Figure 6 illustrates a field of surface currents in part of the Chesapeake Bay [3] along with a string of particles dropped into the flow at a prior instant in time. The particles were dropped in a small region that might represent the extent of an oil spill at moment shortly after the spill began.

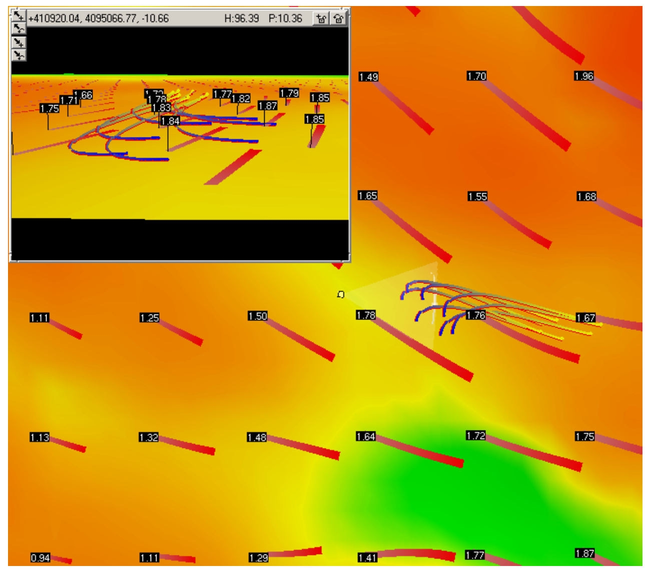

Figure 6: A vector field showing currents in the Chesapeake Bay [3] at an instant in time, where each vector is labeled with a magnitude at its origin. Streaks in this vector field illustrate how particles on the surface move, with the dark end representing history, and the light end indicating the current location of such particles.

Task-specific Display Emphasis

Different tasks require different behaviors from the display, and have different priorities with respect to one another. An overarching requirement for a mariner when {conning | navigating | piloting} a ship into or out of port is situational awareness. Situational awareness consists of several substasks, including collision avoidance, following a planned route, and monitoring forces from currents & winds. In support of these tasks, the display can remain relatively plain, making it easy for the mariner to quickly glance between the electronic information and the situation out the window. However, sometimes a short-term subtask requires more information to be displayed. For example, the mariner may want to know what kind of currents should be expected at the next bend, or where and how close another vessel will cross at its closest approach. Such subtasks require lightweight display capabilities such as hover queries (modes where special information appears only within a couple inches around the mouse cursor) or layered information that can be added or removed at the touch of a button or ship icon. We are currently developing such lightweight display capabilities for GeoNav3D.

Another important task is route planning. GeoNav3D supports the ability to see the effect of water levels on underkeel clearance along a planned path. As seen in the image at the top of the next page, GeoNav3D colors the bathymetry along the corridor of a planned path according to the water levels expected *at the time of transit* along each point. Outside the corridor, the colors reflect the water levels estimated for the current time. Additional capability under consideration is the addition of indicators for expected winds and currents along the path, with some indication for the uncertainty reported by the model that generated the data. We expect that availability of such decision support tools would help a mariner save time and money, finding he or she can speed certain legs of the transit by taking advantage of currents, or safely increase the amount of cargo being carried.

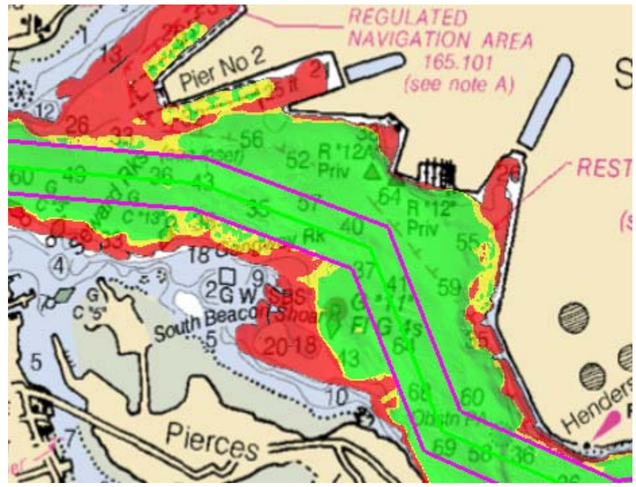

Figure 7: A planned path (bold corridor), along which water levels expected at the time of transit are shown. Outside the corridor, water levels are shown for the current instant in time (notice the sharp discontinuities along the corridor near Pier No. 2).

Finally, two tasks that are not supported in existing navigational software are the abilities to either review past transits or play out possible future scenarios. GeoNav3D is especially well suited to such tasks because of the freedom it can make available to move a viewpoint to virtually any location at any time in the recording or scenario. GeoNav3D can fast-forward a vessel along a planned path to aid the mariner in preparing for a future transit. GeoNav3D can also record and replay NMEA strings from inputs such as GPS, AIS, and depth sounders, making it possible to recreate a situation as it looked according to instrumentation at the actual time of transit. This can be especially useful in a disaster investigation where information that was not available at the time of transit can be included.

Collaborations

In determining the requirements for support of navigation, we have met frequent with various marine representatives. We have observed operations and demonstrated GeoNav3D capabilities on the NOAA survey ship Thomas Jefferson, and we have met with Virginia and Maryland pilots, Sydney pilots, a group of researchers in Rimouski (the St. Lawrence River area in Quebec), the Portsmouth (NH) Coast Guard, and members of the local fishing community. From these encounters, we have learned about the requirements and desires of several different constituent groups, demonstrated our prototypes, and gotten valuable feedback. Some of these groups have expressed a willingness to help facilitate field trials of GeoNav3D capabilities in the Hampton Roads [15] and Portsmouth Harbor. We have also met with Andrew Silver and Paul Kopp of the Naval Surface Warfare Center to learn more about vessel modeling. We anticipate a regular cross-pollination of experiences and ideas from these relationships.

Conclusion

As new marine and visualization technologies become available, it is necessary to continually look at the needs and practices of marine decision support from fresh perspectives. As we have described, there are numerous capabilities available with technologies that either exist already or will be available soon, and through GeoNav3D our Chart-of-the-Future Project is already beginning to take advantage of a number of them. GeoNav3D is not intended to be a fully functional navigation support system, but instead an incubator and test bed for new ideas. Those ideas that prove especially beneficial can then be used to inform standards development and find their way into more mature commercial products.

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