Fusing Information in a 3D Chart-of-the-Future Display

Roland Arsenault, Matthew Plumlee,
Shep Smith, Colin Ware, Richard Brennan, and Larry Mayer

ABSTRACT

The Data Visualization Research Lab at the Center for Coastal and Ocean Mapping is investigating how three-dimensional navigational displays can most effectively be constructed. This effort is progressing along multiple paths and is implemented in the GeoNav3D system, a 3D chart-of-the-future research prototype. We present two lines of investigation here.

First, we explore how tide, depth, and planning information can be combined (fused) into a single view, in order to give the user a more realistic picture of effective water depths. In the GeoNav3D system, 3D shaded bathymetry, coded for color depth, is used to display navigable areas. As in ENC displays, different colors are used to easily identify areas that are safe, areas where under-keel clearance is minimal, and areas where depths are too shallow. Real-time or model-generated tide information is taken into account in dynamically color-coding the depths. One advantage to using a continuous bathymetric model, versus discrete depth areas, is that the model can be continuously adjusted for water level. This concept is also extended for planning purposes by displaying the color-coded depths along a proposed corridor at the expected time of reaching each point.

In our second line of investigation, we explore mechanisms for linking information from multiple 3D views into a coherent whole. In GeoNav3D, it is possible to create a variety of plan and perspective views, and these views can be attached to moving reference frames. This provides not only semi-static views such as from-the-bridge and under-keel along-track profile views, but also more dynamic, interactive views. These views are linked through visual devices that allow the fusion of information from among the views. We present several such devices and show how they highlight relevant details and help to minimize user confusion. Investigation into the utility of various linked views for aiding real-situation decision-making is ongoing.

INTRODUCTION

The Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM-JHC) at the University of New Hampshire has recently initiated a "Chart of the Future" project. The goal of this is to take a revolutionary, rather than evolutionary approach to building decision support systems for the mariner. Our design strategy is to start from scratch in the hope of better taking advantage of new technologies such as inexpensive 3D displays, voice interfaces, and augmented reality displays. Although we pay attention to current ENCs, we use them more as sources of functional requirements rather than as a foundation for building on. This paper represents the first products of this initiative. Here we report on our early work in providing real-time tidal information to the mariner and also some studies we are undertaking to make use of real-time inter-linked views in and interactive 3D display.

A key part of our strategy in the Chart of the Future project is to develop proof-of-concept prototypes. The development of prototype elements is done on the GeoNav3D platform. With GeoNav3D installed in limited real-world environments, these prototype elements can be evaluated against each other, against existing charting technology, and against emerging ENC technologies. GeoNav3D is based on GeoZui3D [Ware et. al. 2001], built as a flexible interactive 3D data visualization system supporting georeferenced and time referenced data.

GeoNav3D is built based on the assumption that the chart of the future will have available to it detailed, continuous bathymetry in the form of a digital terrain model, such as a navigation surface [Smith et al. 2002]. A *navigation surface* is a bathymetric terrain model modified from the raw data to take into account safety of navigation issues. We also assume the availability of tidal information and predicted current information. Our long-term goal is to present to the mariner all relevant information in the most intuitive manner possible. This will include real time tides, estimated currents, detailed bathymetry, AIS information about other vessels, radar, and weather.

As a starting point we are developing a system that supports multiple inter-linked views that can be either plan view or from a particular viewpoint. This system also allows for the input of real-time information from external sources or from stored databases. Our general approach is to build innovative prototypes and field-test them by placing them on operational ships. From our field experience we intend to then undertake iterative incremental improvement in response to feedback from potential users. The present paper reports on new functional capabilities of GeoNav3D. The capabilities have been designed with input from NOAA hydrographers, but have not yet been evaluated.

FUSING TIDE, DEPTH AND PLANNING INFORMATION

An advantage of having a full bathymetry model is that it supports arbitrarily defined bands of color at any desirable depth. GeoNav3D allows hundreds of color zones to be specified which do not have to be equally spaced. This allows for contour lines to be defined to support particular tasks. For example, danger zones of appropriate colors can be specified based on the draft of a given vessel (we are investigating various schemes for color-coding depth). We implemented a method for adjusting the color-coding based on a dynamically changing tidal model. This allows us to display color-coded depth contours that are a function of the estimated state of the tide at every point in the displayed area, updated in real-time.

Tide Surfaces

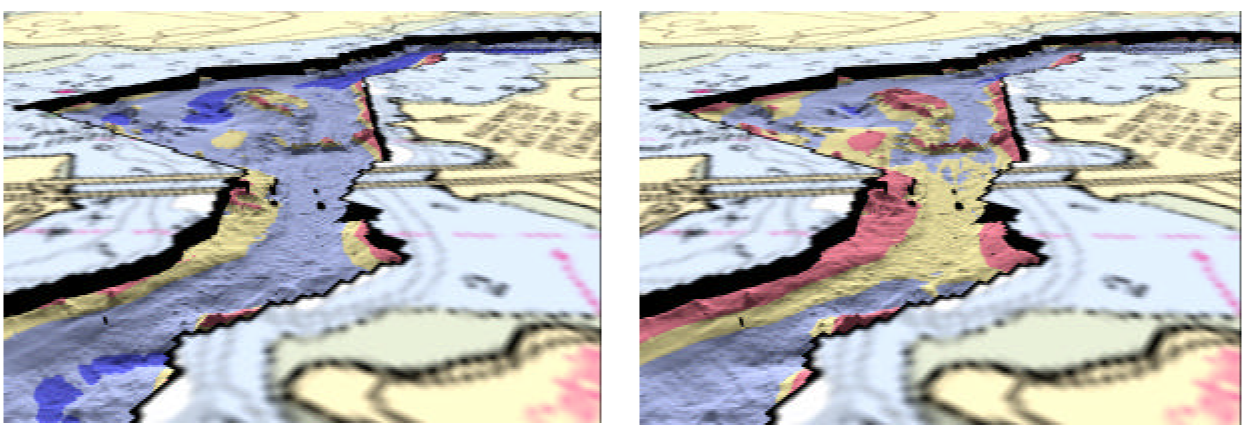
The goal of the tide model for real-time 3D navigation is to create a model that represents the difference between the chart datum (MLLW) and the water's surface at a particular time. By summing the instantaneous tide model and the digital terrain model, a display can be created that represents the actual depth of the water over a large area for a particular time. An additional goal of this demonstration project was to be able to forecast the water level along a track for the time when the vessel will transit the area. This requires a series of tide models ranging in time from the current time to hours or even days into the future.

From the discrete zones supplied by CO-OPS, a representative centerline was chosen and an inverse distance-weighting algorithm was used to create a gridded model of time offset and range coefficient. These were then used in combination with a time series of water levels from an appropriate station to create a tide model for a particular time. The resolution of the tide grids was chosen as 200m so that the difference between adjacent cells would be visually imperceptible, but not so small as to be computationally intensive. The time steps were chosen at 6 minutes so that interpolation would be unnecessary.

This approach lends itself well to a real-time application, since it neatly separates the tide modeling part from the visualization, so that a tide engine, sitting alongside the navigation system, could be continually creating forecast water level models for the coming hours and passing them to the navigation system for analysis and visualization. The water level information used in the model could be anything from simple constituent-based astronomic predictions to PORTS-based broadcast measurements to TCARI-based residual analysis.

Displaying Real-Time Tides

GeoNav3D can be used either in a real-time mode showing actual ships positions and tidal states, or in a planning mode, where voyages can be laid down and ship transit simulated at accelerated rates. GeoNav3D displays tides by continuously adjusting the color contours to take into account the estimated water surface based on modeled tides. GeoNav3D can display adjusted color contours for any time for which tides are available. Figure 1 shows two views of part of the Portsmouth Harbor, Great Bay estuary system at different states of the tide. The bathymetric color scheme is designed to show safe and warning levels of under keel clearance.



(a) (b)

Figure 1: Portion of the Great Bay estuary, and the entrance to Little Bay from the Piscataqua River at the General Sullivan Bridge. The color scheme illustrates the under keel clearance by using blues for safe areas, yellow for warning areas, and red for danger areas. At high tide (a) a mariner can safely transit under the bridge. At low tide (b), the mariner must be cautious, or elect to wait for higher tides.

Tides in Navigation Path Planning

While planning a route, a mariner may need to know the tide not only at a given time and place, but at different times for different places. A transit through a large estuary may take several hours and tidal state along the path will depend on the expected time of arrival. In order to support voyage planning we have developed the capability in GeoNav3D to show the *anticipated* tides displayed in a corridor along the planned path. The mariner only needs to enter a series of waypoints and anticipated arrival times, and the system automatically computes adjusted depths along a navigation corridor. Alternatively, the mariner can enter waypoints and ground speed between waypoints. GeoNav3D constructs a corridor based on a specified width either side of the planned navigation path.

Once a path has been entered, GeoNav3D shows color-coding within the navigation corridor based on the state of the tide at the estimated time of arrival. Outside the corridor, the bathymetry is shown adjusted for tides at the current time. Figure 2 shows an example. As a ship moves through the corridor, time advances. If the ship arrives at the predicted times, the corridor depths ahead of the ship will remain constant in the display. If the ship deviates from the planned arrival time by a significant amount, the estimated tides in the corridor are recalculated based on the new arrival times.

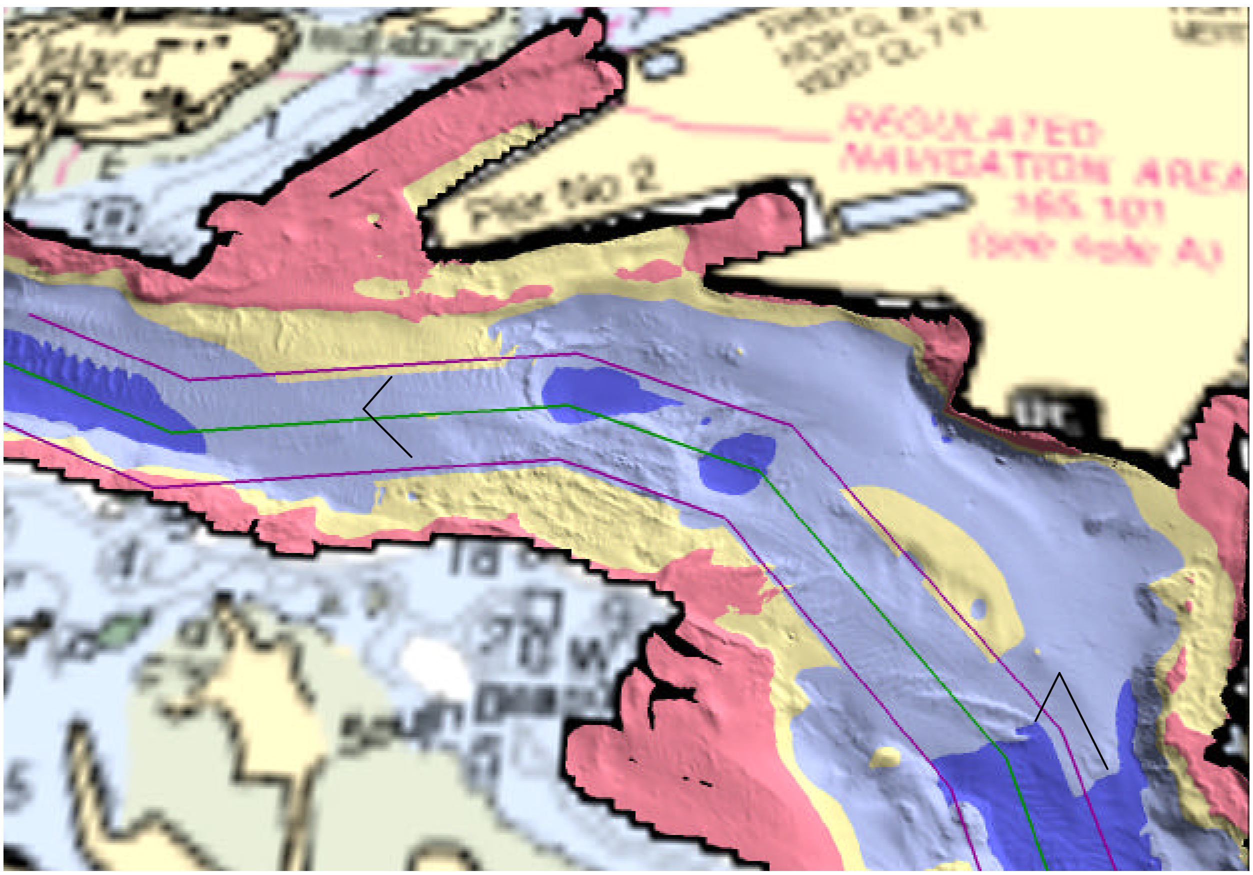
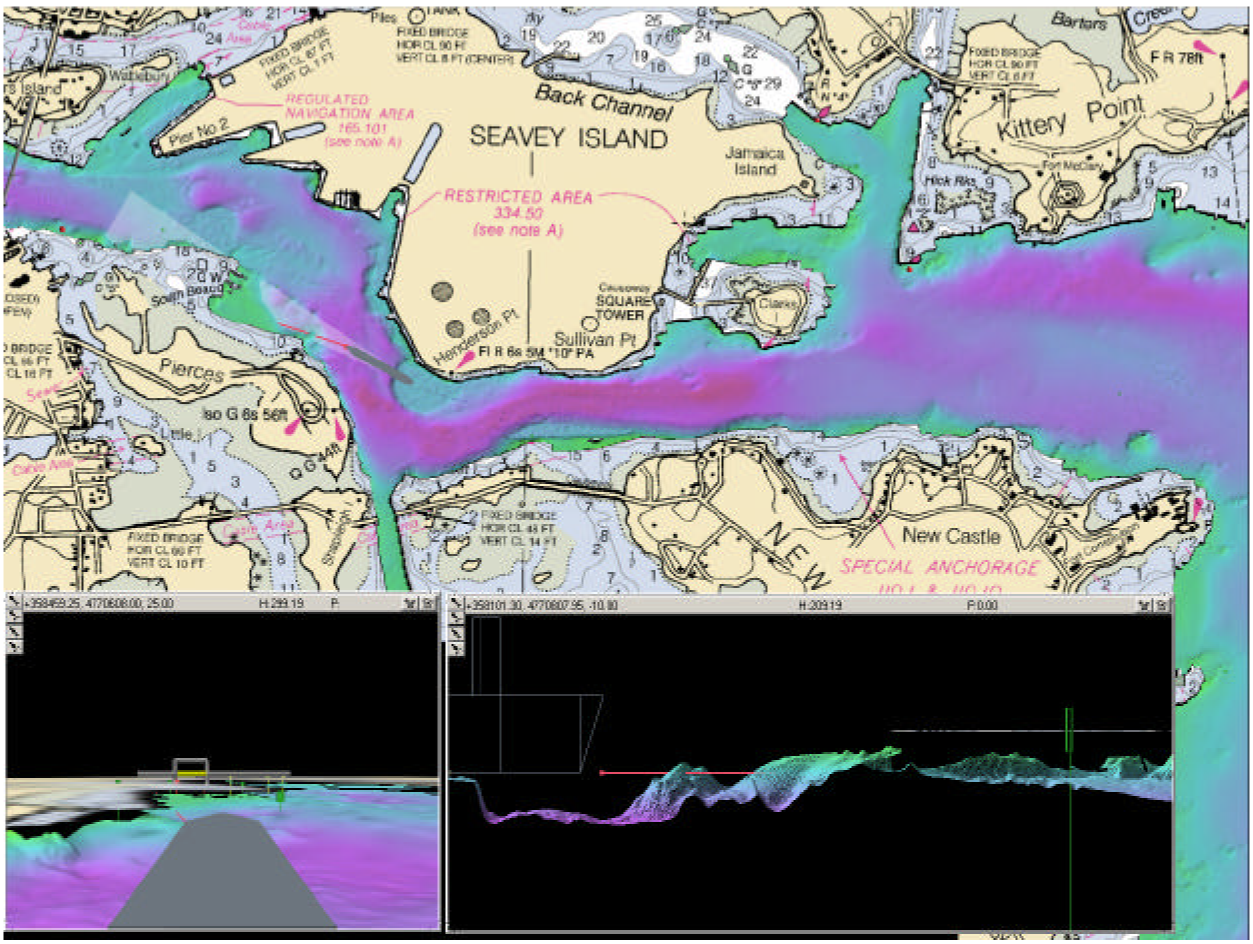


Figure 2: A navigation path showing a transit in Portsmouth Harbor, up the Piscataqua river. At the present time, a transit would go through an area where the under keel clearance is at a warning level (yellow zone) as can be seen outside the navigation corridor. Inside the corridor, which shows the predicted level at the estimated time of arrival at this location, the under keel clearance is adequate (blue zone). Note the discontinuities in color near the arrows, indicating the difference in time and tide inside the corridor.

LINKING MULTIPLE 3D VIEWS

Our second line of investigation involves linking information from multiple views. The reason for having more than one view is that each can be specialized to answer specific questions. For instance, a plan view (such as map, or the background view shown in Figure 3) provides an overview that can answer questions regarding long-range distance and heading. A side view (such as the window on the right in Figure 3) provides instant answers to questions about depth (the bottom) and height (bridges). Meanwhile, a small-scale perspective view (such as the left window in Figure 3) supports situational awareness and makes apparent the vessels and obstructions that require the most immediate attention. This view also helps the user to correlate chart and other data items with real-world features (i.e. “That’s the rock I see three points off the starboard bow”).

Plan View



Bridge View Profile View

Figure 3: Linked views combining an existing chart with bathymetry, buoys, and a bridge. The plan view (background) provides the wider context for the two inset views. The profile view (right window) is height-exaggerated and displays in wire-frame everything immediately in front of the vessel. The bridge view (left window) provides a way to link what one sees from the real bridge with the information available to the navigation system.

While individual views excel in answering specific questions, a navigation system must combine these views in ways that lead attention to the right view at the right time. GeoNav3D achieves this through various linking mechanisms. One such mechanism is a *view proxy*—a representation of one view within another. A semitransparent view proxy is shown in Figure 3 as a “headlight” shining from the front of the vessel. This proxy exactly matches the extents of the profile view to provide a way to correlate the two views in the user’s mind. In this particular situation, the proxy also performs secondary duties. First, it points in the direction of the bridge view, highlighting what is essentially the middle third of the angle visible in that view. Second, because it is situated at the depth of the keel of the vessel, it slices through any bathymetry on which the vessel could run aground—anywhere that the bathymetry appears to “poke through” helps answer the question, “where should I avoid going given my current draft?”

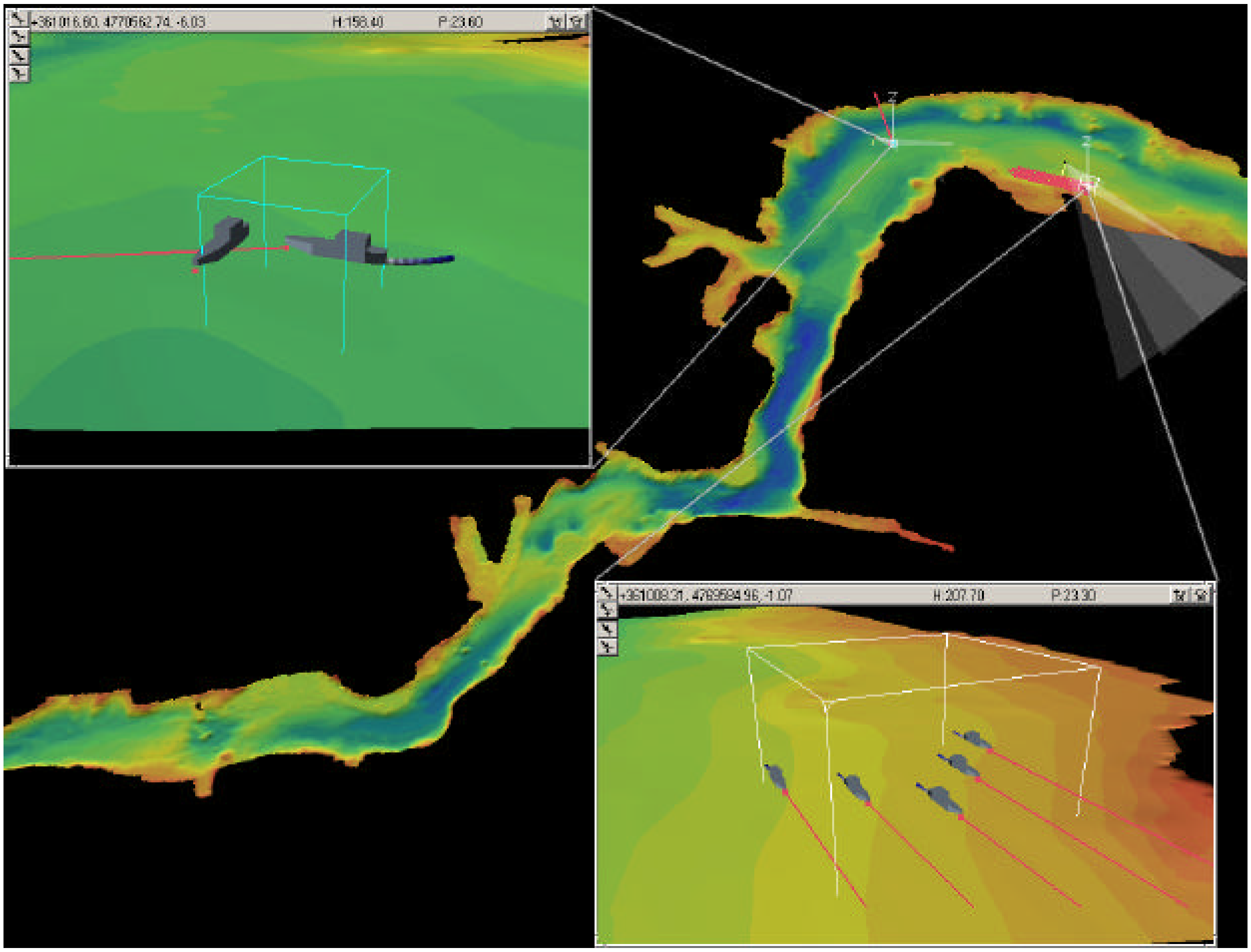


Figure 4: A view linked to the two closest items at a given time (top left), and a view linked to a small fleet of vehicles (bottom right).

GeoNav3D makes available several other mechanisms for linking views. Figure 4 demonstrates the use of *tethers* for indicating where the central point of attention is for each view. These tethers are simple semitransparent lines connecting two corners of a view to the associated proxy on an overview map. Since tethers can add clutter to the display, they are generally only present at the times they are most likely to be needed: when the mouse cursor is moved into a view or when the user is moving a view to a new location by clicking and dragging its proxy across the display. Tethers are useful for monitoring views of multiple locations. For instance Figure 4 shows a potential vessel traffic-control display. The bottom-right window maintains a fleet of ships near its center, even as they spread apart or come together again. Meanwhile, the top-left window is designed to center itself on the two closest vessels at a given time. If two vessels are about to collide, this collision view jumps to their location. Without tethers, not only would it be difficult to know which window went with which proxy, but it would also be hard to identify where the collision was occurring in the overview display.

Other mechanisms are not readily illustrated in a static picture. One of these is a 3D mouse cursor. This cursor indicates in every other view what is currently under the cursor in one view. Another mechanism is the coupling of views, so that both have the same heading and central position, for instance. Such couplings can be used to rotate maps to align with a forward-looking view (such as a bridge view) or to establish side-looking views such as the profile view in Figure 3. Two of us (Plumlee and Ware) demonstrate empirically the effectiveness of proxies and view couplings in a task that requires a novice user to fuse information from forward-looking views and a plan view [2003]. For such a task, proxies reduce the number of errors by about 50%, while view coupling reduces errors by 25%, and the effects of both are cumulative. Even when errors are made, these mechanisms reduce the magnitude of the error (by about 2/3^{rds} for proxies and 1/3rd for view coupling, but the effects here are not cumulative). Although we have no data concerning trained users, we believe the results would be applicable to trained users in high-stress situations.

CONCLUSION

It is our goal in the Hampton Roads demonstration project discussed elsewhere in these proceedings [Brennan et al. 2003] to place GeoNav3D on a NOAA ship in active use. We hope to also migrate to other vessels with other task requirements, such coal colliers and container vessels, as well as, possibly, vessel traffic control facilities. We plan to carry out this project in partnership with NOAA's Oceans and Coasts. We plan to involve the U.S. Coast Guard (USCG) Command and Control Center (C2CEN) in Portsmouth, VA.

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