CHAPTER 2

A User-defined Virtual Reality Chart for Track Control Navigation and Hydrographic Data Acquisition

Andrew Ternes[1], Peter Knight[2], Antoni Moore[3] and Holger Regenbrecht[4]

[1]Hydrographic Survey & Spatial Data, Port of Melbourne Corporation, Melbourne, Victoria, Australia

[2]School of Surveying, University of Otago, Dunedin, New Zealand.

[3]School of Surveying / Department of Information Science, University of Otago, Dunedin, New Zealand.

[4]Department of Information Science, University of Otago, Dunedin, New Zealand.

Abstract

In hydrographic surveying dynamic electronic displays are used to assist in navigating the survey vessel to a desired waypoint or maintain a desired track. The visual display for the coxswain (the “driver” of the ship) is typically a two dimensional (2D) planimetric view which is oriented so that the vessel direction is facing up on the display. This can be confusing at times for the coxswain, as he / she has to relate the virtual desired track on the display to the surrounding spatial reality, sometimes with few references to aid the process. The coxswain has to mentally visualise the desired track as an invisible line across the sea surface and attempt to steer the vessel down the line. The objective of this project is to investigate the use of a three-dimensional (3D) nautical chart with intended users of the chart involved as a focus group at the design and feedback stages of its development. The intent of the project is to create a virtual environment that will aid in track control and other forms of navigation. It is proposed that the chart will increase the spatial and situational awareness of the mariner and allow intuitive and quicker decision making in running desired tracks for hydrographic surveys. The project makes use of a perspective view from the helm of a virtual vessel, modelled on the actual vessel used to trial the system. The mariners in the user focus group agreed that the 3D chart was effective, creating an enhanced cognitive appreciation of where the vessel was in relationship to its surroundings, while faithfulness to the 2D chart was also commented on.

Keywords: three dimensional nautical charts, virtual marine environment, user focus groups, hydrographic survey, seamless bathymetry-topography, Electronic Nautical Charts (ENC), navigation

1 Introduction

Hydrographic survey operations routinely utilise electronic charts to visually display desired tracks allowing a regular spacing of sounding lines to cover the seafloor. The importance of maintaining track during survey operations is critical to upholding hydrographic standards. Therefore the coxswain has to comprehend accurately and precisely what he/she perceives on a navigation display in order to make a decision on how much steerage needs to be applied to maintain the desired track. Furthermore, a coxswain must be able to locate beginnings and ends of survey lines and be able to switch between runlines and runline blocks in a timely manner.

Currently in hydrographic surveying the positioning of vessels is run in a two dimensional (2D) space. A global positioning system (GPS) is coupled with a computer running an electronic chart. This enables the vessel's position to be displayed and constantly monitored by the master alongside other instrumentation to maintain position or track. Orienting and positioning a vessel being displayed in 2D, while remaining aware of the three dimensional (3D) reality surrounding the vessel, can sometimes be confusing to the coxswain. The stimulus for developing this technology comes from the experience of observing coxswains attempting to get on and to maintain track during hydrographic surveys in areas where there might be few references connecting reality with the 2D display.

The main objective of the research is to demonstrate the practical use of a virtual reality display of a 3D nautical chart, in which a perspective view from the helm of a virtual vessel can be used. In theory, creating and implementing a 3D nautical chart should increase the spatial and situational awareness of the coxswain, and allow intuitive and quicker decision making in running desired tracks for hydrographic surveys. The chart will have a 3D baseline dataset of sonar-derived singlebeam and multibeam bathymetric data. It will be enhanced by survey-accurate virtual points of reference (e.g., navigational aids) to enhance the associations between the desired track and reality. Also, shore topography and some land-based vector features will be included in the virtual model.

With any form of land based virtual environments for 3D maps, users usually have multiple points of reference, such as buildings and landmarks for self-orientation and positioning. The situation is similar at sea, as many mariners refer to shore-based points of reference, such as lighthouses and lead beacons. Additionally, when far offshore or in times of poor visibility (such as at night or in fog), certainty in position is reduced, leaving the mariner to rely upon GPS, radar and compass. In such circumstances, track control may be extremely difficult. This is where a virtual beacon or lead system within a virtual environment with a helm perspective, might be of benefit. These visualisations together with other virtual navigational information could form the basis of a 3D chart that a vessel could use for navigation. Although such charts have been implemented before (e.g. Ford 2002), the development of the chart at the centre of this project is user-led. Mariners were consulted at the initial design stage and the prototype development stage (which bookends the stages of development reported on in this paper).

The next section of the paper will be a short review of hydrographic charting with specific reference to 3D charting. This will be followed by a fuller presentation of the project scope and aims. The methods section will then cover the consultation with the user focus group, development of the virtual environment and dataset; and linkage with realtime GPS. Results and feedback from a focus group will be reported on before discussion and conclusions.

2 Review

2.1 2D Charts

The first electronic 2D nautical chart was NAVSHOALS, produced in 1976 from digitised charts (Ward et al. 2000; Ford 2002). Since then, Electronic Nautical Charts (ENCs) have become an almost universal navigational tool, perhaps as significant to the history of navigation technology as the implementation of radio[1]. The International Maritime Organisation (IMO) and the International Hydrographic Office (IHO) together set international standards for the production and display of Electronic Chart Display and Information Systems (ECDIS). Many users however, rely on ENCs produced by private sector suppliers, in formats which, while not conforming to the IMO-IHO standards, are nevertheless often supported by the national hydrographic agencies because of their manifest usefulness (Pasquay 1996).

2.2 The 3rd Dimension and 3D Charts

The benefits of 3D display have long been acknowledged and are intuitive. Support for use of the third dimension is offered by Swanson (1999, p 183), who noted that 3D display engages "…a larger portion of the brain in the problem solving process." This support for 3D display echoes with the findings of Porathe (2006), who saw 2D displays as being less efficient than a 3D display in test conditions. If there is an improvement overall, this would contribute to an enhanced situational awareness on the part of the user (mariner) in relation to the tasks that they have to do (hydrographic operations and general nautical navigation), "… [awareness] of what is happening around you and understanding what information means to you now and in the future" (Endsley et al. 2003, p 13). Techniques for establishing usability of the display (e.g. Nielsen 1993; Hackos and Redish 1998) can indicate whether such awareness is being fostered.

However, the inability of the 3D view to show all the viewable information at one time has to be taken into account. The supporting use of a 2D representation has been suggested for assessing layout and distance estimation, two tasks that are difficult to do in 3D (Ware and Plumlee 2005).

The initial idea of three dimensional digital nautical charts was conceptualised in 1976 at the time of the development of NAVSHOALS (Ward et

[1] Captain Pace of Canada Steamship Lines addressing the Canadian Hydrographic Service in 1995

al. 2000; Ford 2002). Ford reasoned that 3D charting would improve safety and efficiency of transportation on water. Gold et al. (2004) added that such a realistic simulation "…should be an advantage in navigation and training". Ford's (2002) 3D chart allowed the collection, processing and application of nautical data, incorporating the use of bathymetric, topographic (height – TIN data), environmental and nautical data (e.g. real-time tide and current data) in the formation of an integrated three dimensional visual system (Ford 2002). Although supported by differential GPS to give abilities approaching 4D (i.e. real-time update), the chart and topographic map are raster scans of paper-based media.

Gold et al. (2004) developed a 3D "Pilot Book", providing navigational assistance for ships (particularly non-local ships) entering Hong Kong harbour. They developed an application that utilised interactivity and dynamics (of viewpoint, objects and relationships – including collision detection) attributes, already well-developed in games development. Froese and Wittkuhn (2005) reported on an application that was conceptualised as a 3D chart (a European project known as the Electronic Pilot Display and Information System - EPDIS). Responding to a call by mariners for new navigation technology to take advantage of recent innovations, a project was undertaken to provide a 3D navigation product aimed at serving pilots – in this case pilots operating in the Baltic and Mediterranean Seas.

The use of 3D and stereoscopically enhanced 3D visualisations is explored and summarised in the hydrographic context by Ostnes et al. (2004a, 2004b). Their papers present evidence from fields such as aviation and geophysical science to support the superiority of 3D and enhanced 3D visualisation over planar views for hydrographic applications.

2.3 Virtual Reality

"A virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence" (Steuer 1992, p 76) or in more technological terms as a computer-generated, three-dimensional, interactive system. Virtual reality (VR) was and is successfully applied in different domains such as automotive design review, military training or geological surveying. There is strong reason to believe, that (tele-) presence in such a virtual environment leads to good orientation, wayfinding and awareness. Thus defined, it can be regarded as the interface through which interaction with 3D models such as those outlined in the last section, takes place.

VR can either be of the desktop variety or immersive (Fisher and Unwin 2002). With desktop VR, the virtual environment is delivered through a conventional computer set-up and in an immersive environment the user experiences the virtual world with specialised equipment such as head-mounted displays or large, stereoscopic, multi-display setups. Even though the immersive method would seem the most realistic VR experience, it needs expensive equipment and can induce disorientation. Most of the time, the same information can be delivered effectively using desktop VR, which induces none of these effects (Fisher and Unwin 2002). For the mariner's scenario, immersion would also represent a step away from the real world, where constant vigilance is needed for navigation. Context may also be important for navigating through virtual environments (see Purves et al. 2002, for an exploration of this theme in mountain environments), implying that virtual content for an experienced mariner may differ in certain aspects from virtual content for a recreational boat user (though both examples have to adhere to maritime regulations).

Bodum (2005) has categorised virtual environments according to their degree of realism and time dependency. Taking a marine navigation beacon as an example, the former criterion can vary along a continuum from a realistic depiction of that specific beacon, through indexed representation (where the beacon, depicted through a generic example of its type, is embedded in a semantic structure), rendering as icons (a simplified beacon retaining pictorial meaning – this is the 3D type used in this example – see 4.3.1), symbolisation (a more abstract explicitly cartographic representation) to language-based depictions (description of the beacon, for example as set out in the NZ Pilot).

Time dependency can be of static (specific space at a specific time), dynamic (model is fixed in space but information within changes) and real-time types ("…coordination of changes in a model that can affect the representation in several different spaces at exactly the same time", Bodum 2005). According to this definition, the application reported on in this paper lies somewhere between dynamic (e.g. the action of a flight simulator) and real-time (update from differential GPS, or dGPS, operating in real-time though there are no other autonomous objects in this virtual environment).

2.4 The Use of Focus Groups

The assessment of virtual applications, being an example of an interface, is normally accomplished through usability testing (e.g. Nielsen 1993; Hackos and Redish 1998; Endsley et al. 2003). It is user-focused and often the cognitive affinity of the user with the interface is being assessed. User focus groups have been used for such evaluations and are a cost-effective way of generating qualitative data (also as a preliminary to a more intensive usability assessment – Harrower et al. 2000). Monmonier and Gluck (1994) sees them as "…useful in addressing a broad range of cartographic problems".

In the cartographic or visualisation domain they have often been used to assess interfaces, with members of the group first exploring the interface to assess effectiveness, then expressing their feedback to the developer (Monmonier and Gluck 1994; Harrower et al. 2000; Lucieer and Kraak 2004). We have used several mariners from Dunedin and Melbourne to form our user focus group. Although there will only be a limited review by way of analysis, such an approach can be effective (Monmonier and Gluck 1994).

3 Aim and Scope

3.1 Aim

The aim of the research is to create a 3D model of the real world environment to which virtual navigation aids may be added. This model can then be displayed to represent the coxswain's field of vision as if seen in a forward looking camera image, similar to the perspective of the coxswain's own field of vision in reality. This would inform the mariner of the vessel's location and orientation. The master of the vessel will then have an immediate reinforced perception of his/her position in reality and in relation to the chart. The technique utilises more recognisable associations between 3D chart objects and real world objects thereby closing the conceptual gap between the real world's environmental surrounds and the electronic chart.

Currently trying to maintain track with 2D displays requires the master to consult the chart, check the compass, check the surrounding environments, pick a point of reference to steer towards, then correct the helm (Figure 2.1, left flow chart). Creating a 3D chart display in combination with vessel heading and 3D objects, such as virtual leads, the master will not have to consult the chart in order to apply steerage, all he/she needs to do is steer towards the point of interest on the virtual display (Figure 2.1, right flow chart). This eliminates two steps in the reaction process, as three processes are combined into one.

It is envisaged that the result of the project can be applied to many aspects of hydrography from the positioning of oil rigs, pinpointing geological sample sites, and aiding navigation; to general shipping, navigating dangerous waters, and collision avoidance in periods of bad visibility such as bad weather, fog and darkness.

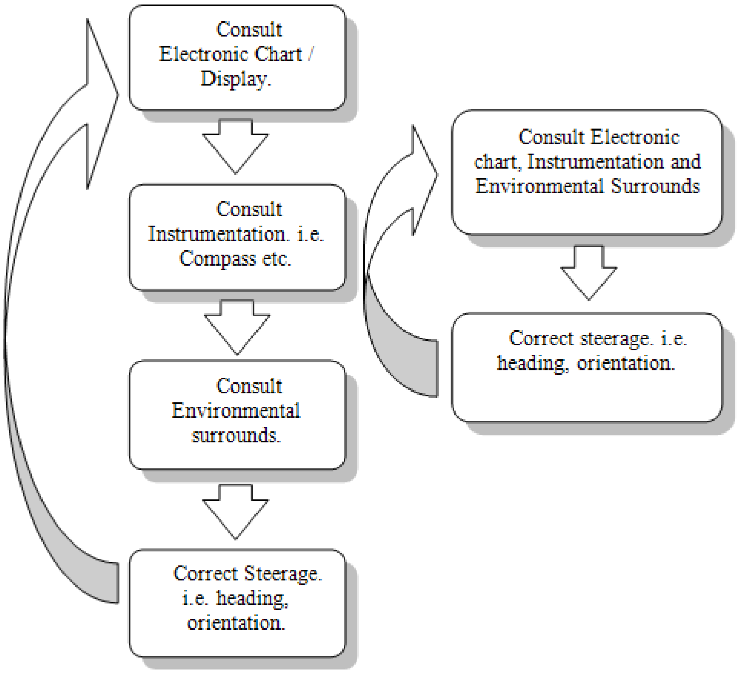

Fig. 2.1. The process on the left follows the method used to apply steerage using a 2D display. The proposed system (right), utilising a 3D chart, will attempt to reduce this process

3.2 Project Scope

In order to gather information relevant to the design of a 3D chart, a questionnaire was given to vessel handlers with experience in hydrographic surveying. These experienced mariners formed the focus group that would inform the design of the 3D application. Insight was sought into the importance to the helmsman of each piece of navigation equipment and also how well that equipment currently performs. Also identified were current problems in displaying navigation information, and ideas were considered concerning how this information might be presented more effectively.

The 3D model which was eventually developed combined information from the nautical chart (including bathymetry) and, unusually for a hydrographic application, elevation information of the surrounding land area (topography) to create a digital elevation model (DEM). All of the relevant navigation objects (marks, buoys, shoreline features) were digitised off a 2D nautical chart and transformed into similar 3D symbols in the virtual space, which were designed with International Hydrographic Organisation (IHO) 2D symbol standards in mind. The area modelled is Otago Harbour near Dunedin, New Zealand including its surrounds up to the harbour entrance.

In order to use this model for navigation a perspective was created which represents the real world vessel's perspective. This was achieved by creating a digital (virtual) model of one such vessel from vessel diagrams. The virtual vessel is geographically referenced dynamically, by regular updates in real time through GPS fixes on board the vessel. The master then has a visualisation of the 3D chart in real time from a similar perspective to that of a helmsman's view in the real world.

By creating a 3D chart, populated by virtual reference beacons (working in the same way as lead lights or range lights) as well as the vessel itself, it is intended that the navigation of the vessel to a desired location or maintaining the vessel on track will be greatly facilitated. The focus group was returned to after implementation of the demonstration 3D chart, to collect feedback and recommendations (by discussion / interview) for the next stage of chart development

4 Methodology

4.1 User Survey Results

The requirements and specifications are the base upon which the model is initially designed. It is therefore important to gain preliminary user information. For this project surveys and questionnaires were conducted with four masters and skippers of Otago University School of Surveying (OUSS) and the Port of Melbourne Corporation (PoMC), forming an experienced user group (with most of the participants having at least 15 years survey experience). Only the OUSS staff were involved with the implementation, interpretation and testing of the application. Summarising their nature of experience, all members of the focus group possessed domain (marine or hydrographic) expertise, not VR expertise.

The questions that were chosen for the survey were formulated to assess; what is liked and disliked about current electronic navigation charts; how effective current electronic navigation charts are; what information is critical to maintain track; which instruments mariners rely on the most; what information they would like to see added to an electronic navigation chart; how effective mariners think a 3D chart would be; and finally how electronic navigation charts and navigation information might be improved.

The results of the questionnaire show that mariners were pleased with ENCs and find them useful for making immediate decisions. However, the mariners cautioned that ENCs must be set up properly and / or verified with a paper chart or RADAR. The mariners showed great interest in the possibility of viewing the ENC in three dimensions. Questionnaire results indicate a 3D model must comply with the following:

- Be useful for making immediate decisions
- Aid the mariner with his / her visual and spatial awareness.
- Be in a defined projection working in conjunction with the GPS.
- Be able to plot vessel position and plot vessel tracks and waypoints.
- Be able to display vessel heading, course made good, speed over ground, compass bearings and depth possible from the echo sounder.
- Have enough information for safe navigation.
- Have clear symbology representative of the current standard symbols and good representation.
- Visual display of vessel in relation to dangers, obstructions and land.
- Must not overwhelm the mariner and distract from the navigation from the vessel.

These principles guided the implementation and were revisited with the user group after the demonstration system has been developed. An appendix containing the questions posed and summarised feedback is provided after this paper.

4.2 Datasets

The gathering of reference material came from a multitude of sources. For example maps, topographic and bathymetric data sets, building and vehicle designs, photos, video, recordings, sound and light sources. For this project topographic data, vessel data, beacon data, reference photos and nautical charts were used for the creation of the virtual environment.

The structuring of the virtual model was done in the 3D visualisation software application Fledermaus™ (Interactive Visualisation Systems 3D – IVS 3D 2008). The data for the surrounding topography of Dunedin is a 20m Digital Elevation Model (DEM) which was acquired by point elevations and digitisation of 20m contours from the Land Information New Zealand (LINZ) topographic chart series. This Universal Transverse Mercator (UTM) coordinate system was chosen for this and all subsequent datasets, predominantly because the metre unit would facilitate 3D object dimensioning but also for hardware and software compatibility. Data for the project were obtained from surveys by the Port of Otago and by digitising depths from the current nautical chart of Otago Harbour (NZ 6612). Additional data for certain areas around the harbour surveyed over the years (by OUSS) were also added to the combined dataset. All datasets were converted from their existing projections, coordinate systems and datums to WGS84 UTM (Zone 59 South). This is a solution for visualisation purposes only, as additional complex rectifications to account for tide, for example, would have to be made to create a dataset that can support navigation. The conversion and compilation was accomplished using ESRI ArcGIS and Fledermaus, with the resulting DEM having a final resolution of 10m.

Colours for the 3D chart were copied from NZ 6612 with the bathymetry closely resembling the colours and contours associated with that chart. (see Figure 2.2 and Figure 2.3). This was to maximise affinity of the 3D chart with the mariners who predominantly use the source 2D chart in navigation and associated and established conventions of colour and symbology.

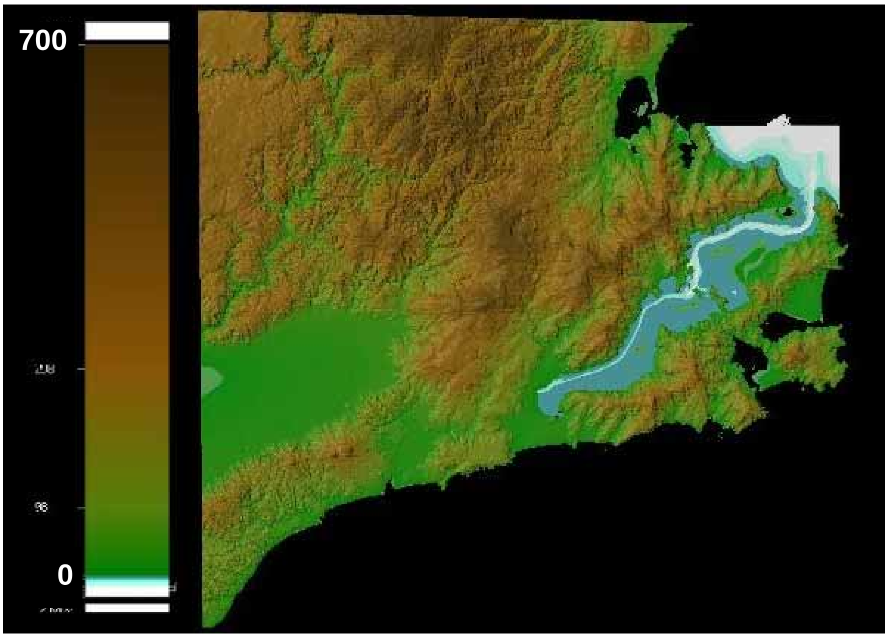

Fig. 2.2. Final combined dataset to give a seamless appearance, with designed colour scale

Fig. 2.3. Perspective view seen from the top of Otago Harbour. The city of Dunedin surrounds the head of the navigable harbour channel (in light shade)

4.3 3D Objects

Construction of objects from the reference material was performed in Autodesk 3D Studio Max 9™, which is a three dimensional model builder which can be coordinate-based, and so helped facilitate the positioning of objects within Fledermaus™. The objects constructed fall into two categories, the 3D navigation aids (such as beacons and lead lights) and the virtual vessel itself.

4.3.1 3D Navigation Aids

Often in track control there are no navigation aids present. To address this, virtual reference beacons or leads were created for the master to steer towards (i.e. a virtual lead light or range light). This system uses two lights or signals, one located above and one a distance further behind the first lead. When the leads align, the boat is in the navigation channel (Toghill 2003).

Additional key navigation information needed to be identified and designed. This included the design of beacons, light houses, leads, and other principal marks. The symbols on chart NZ 6612 were standardised using the International Association of Lighthouse Authorities (IALA) Maritime Buoyage system – Region A (Red to port) (see Figure 2.4). Using NZ 201 symbols terms and abbreviations (HO of RNZN 1995), the chart NZ 6612 and photos of the actual beacons, three dimensional renderings (which would be regarded as “iconic” on Bodum’s realism-abstraction scale, 2005) were created using basic primitive shapes within 3D Studio Max 9™ (e.g. see Figure 2.4a, b and c). Gold et al. (2004) drew from IHO standard Electronic Navigation Charts for the design of their symbols for navigational features such as bouys, lights and underground rocks. These were positioned using their known coordinates and were designed to mirror reality as closely as possible, but with appropriate abstractions (Figure 2.5 and 2.6).

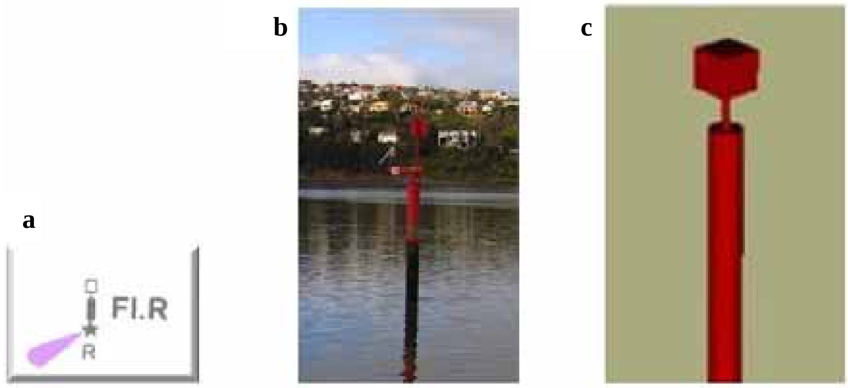

Fig. 2.4a. IALA Port Beacon, **b.** Real Port Beacon, **c.** 3D Port Beacon

Fig. 2.5. A view from the vessel in reality

Fig. 2.6. A view from the virtual vessel within the model

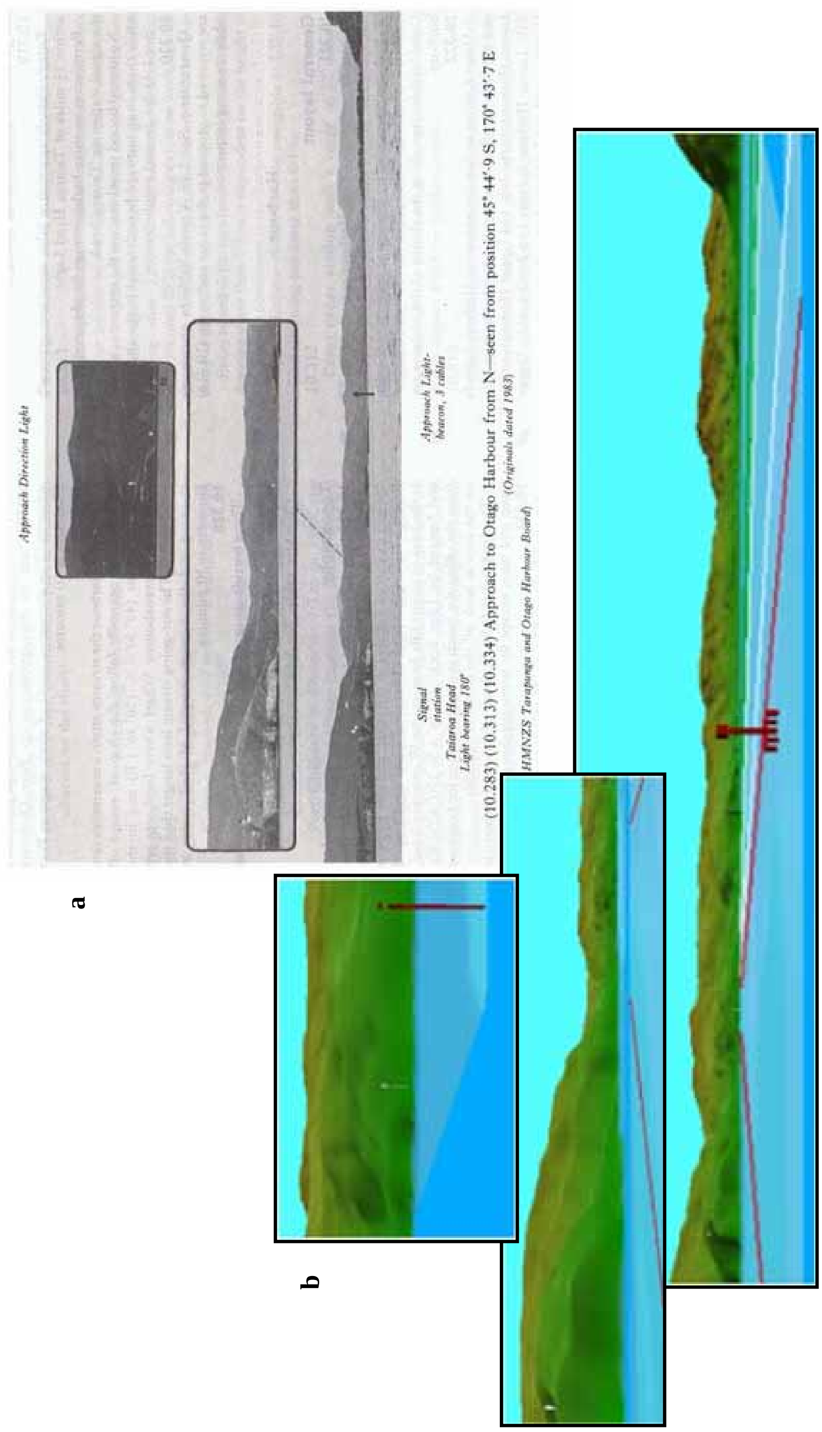

Fig. 2.7a. The approaches as displayed in the New Zealand pilot (Watts 1987). Taiaroa Head and the Approaches light beacon are signified, **b.** The simulated view of the New Zealand Pilot approaches

A key aid during this process was the chart NZ 6612 and the New Zealand pilot guide. Using the New Zealand Pilot as a guide, an attempt was made to model the approaches and coastline features as closely as possible. This meant including as many of the principal navigation marks that are used around Otago harbour as possible. Among those included were the church steeple at Port Chalmers, the memorial on Memorial Hill, the lighthouses at Taiaroa Head and Heyward Point, the East Cardinal beacon on the Mole, and the Approaches light beacon (see Figure 2.7). These landmarks and other aids to navigation were represented by abstracted 3D symbols. The attempt to simulate the NZ Pilot is another strategy to strengthen the mariner's affinity with the 3D representation, which as the review has shown, has been known to lead to incomplete data display. Gold et al.'s (2004) 3D marine GIS implementation draws from the Hong Kong pilot book as source, the challenge being to render as 3D a "graphics-free description of a simulated Real World" (p 21).

4.3.2 3D Vessel Design

A three dimensional model of the University of Otago's vessel, the *MV Polaris* was also designed in 3D Studio Max, using refurbishment plans, reconnaissance photos, and hand measurements of deck features. This virtual vessel was imported into Fledermaus. The helm of this 3D model Polaris provided the dynamic real time viewing point with the 3D chart (see Figure 2.8), enabled by GPS.

Fig. 2.8. The real Polaris (left) and virtually (right)

4.4 GPS Integration

The virtual vessel's position was obtained dynamically in real time from MV Polaris' differential GPS. The differential GPS Antenna was mounted on the Polaris approximately amidships on the roof of the cabin. The location of the antenna was measured with an offset tape to get an approximation of its position. These values were required to ascertain the position of the camera view from helm of the 3D model Polaris. Fledermaus has a function in its vessel manager function where it can input a National Marine Electronics Association (NMEA) string that carries a GPS data message. This allows for the positioning of the virtual vessel to match the real vessel in real time. A view can then be generated from the helm of the virtual vessel. The master then has a visualisation of the 3D chart in real time from a similar perspective to that of the helm in the real world.

4.5 Post-implementation Focus Group Interviews

A discussion and interview with the mariners following the field test (see next section for details of this) took place to gain feedback on the performance of the 3D chart. In a question-answer format the mariners were asked how well the 3D chart displayed information, and whether the information was clear and easy to interpret. Like the initial questionnaire, the feedback was recorded on paper. This feedback formed their qualitative evaluation of the 3D chart in relation to the real-world environment it was trying to depict.

5 Results and Discussion

A final demonstration of the system was organised, with the original Otago focus group (section 4.1). The objective of the demonstration was to set up a survey run line similar to that of a normal Hydrographic survey and use the model and the perspective from the virtual helm to navigate (see Figures 2.9, 2.10 and 2.11). The set up of the survey line to be run included the use of some virtual beacons along the survey line transect. These were set up to aid the helmsman maintain track.

Many mariners when running survey lines judge how far they are off the desired track by using a port and starboard offset indicator. What is lacking, however, is a point of reference to steer towards. A mariner will typically look at the bearing of the desired track and try to steer that bearing on the compass while looking towards a distant object on land. When at sea and far from land, the mariner has no point of reference to orientate themselves. It was hoped that by placing a virtual beacon within the scene the mariner will obtain a point of reference to spatially orientate themselves.

Fig. 2.9. The real-world setting of the 3D chart (on the laptop). The model is used to navigate the vessel along a survey line

The test went well, with the master steering using the model to navigate down the survey line (see Figure 2.12). However, there was some latency (time delay) in the system, which caused the virtual vessel to be slightly hard to steer.

Latency and slightly awkward steering were due to a number of factors, such as the GPS heading being based upon the previous recorded positions, rather than an accurate observed heading (this could be improved by using a dual GPS antenna arrangement for accurate heading observation). The model was also run on laptop which is not as well-suited as most desktops for running high power graphics. There were also hardware issues (i.e. GPS-laptop data connection) contributing to the latency. Despite these limitations the system ran well using what was available and showed that the concept can work.

Feedback from mariners was obtained by an interview and discussion process. A replay of the field test was displayed to two members of the focus group, emphasising the other capabilities of the software, in particular, the features which can aid navigation when run in conjunction with a 3D nautical chart. The mariners agreed that the display was extremely effective in conveying the location of the vessel with respect to real and virtual objects. The mariners both agreed that the display helped to create a better and greater understanding of location and attitude of the vessel, particularly when it was necessary to navigate to a geographic position by coordinates without a real world point of reference.

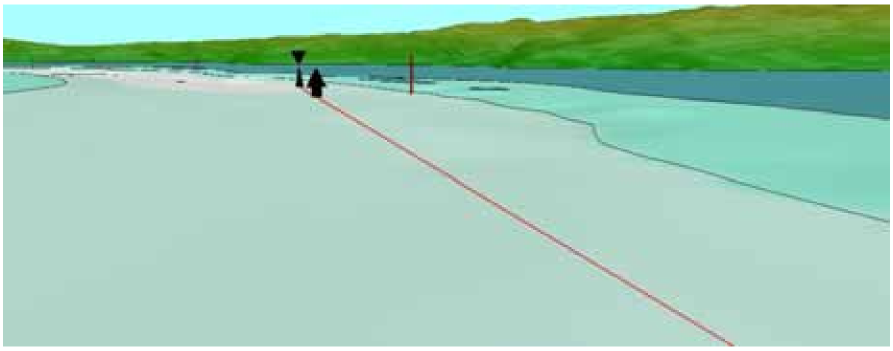

Fig. 2.10. Too far to port, so the virtual beacons are not in line so the vessel needs to steer starboard. View is from the helm of the 3D model of Polaris

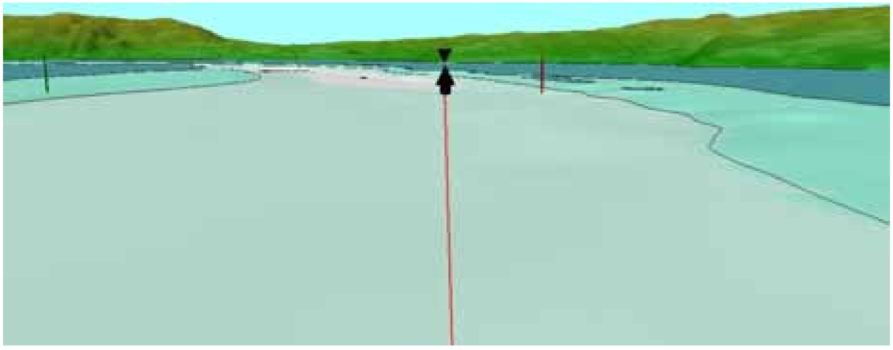

Fig. 2.11. The virtual beacons are in line, so the vessel is on the desired track. View is from the helm of the 3D model of Polaris

The mariners both liked the presentation of the model and thought that it related approximately to that of the official paper chart NZ 6612. The task of creating the model presented a challenge, particularly in relation to the representation of the symbology for the navigation aids. The beacons had to closely resemble reality so the cognitive association can be made between the real beacons and the virtual beacons. However, the 3D beacon symbology also had to be conveyed in such a way that the beacon would be clearly identified and associated with the real world beacon as well as with the symbol on the chart NZ 6612. The real and symbolised objects were quite different, making it difficult to design a 3D symbol that resembled both. The decision was made to closely copy reality as a starting point, so all the associations between the real world and the model can be made by the mariner (in this way the mariners' feedback aligned with the aims of the research group in developing a 3D application). Using the chart NZ 6612 all necessary navigation information was then incorporated into the model, such as, leading lights, navigation markers and principal marks. The International Hydrographic Organisation (IHO) is already setting standards for electronic navigation chart symbology, and it is hoped that in time, these could be extended to 3D symbology standards as well (Froese and Wittkuhn 2005).

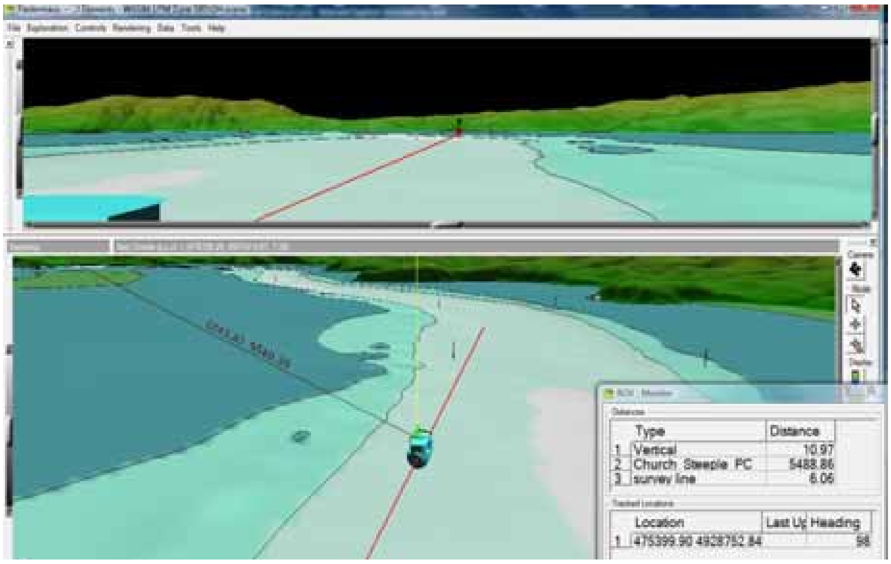

Fig. 2.12. The display used to navigate the vessel. The bottom display shows a remote 3D perspective view, while the top view shows the model from a user defined perspective from the helm of the 3D vessel model

6 Conclusions

The user-led implementation of a 3D nautical chart for any given area can be advantageous to mariners, hydrographers, and geologists, to name but a few. The literature reviewed for this research project clearly showed the potential effectiveness of the use of a three dimensional chart used in real time. The literature also provided a guideline or general procedure to follow in the construction of this kind of virtual chart. The project constructed a virtual chart of Otago Harbour using 3D software, employing numerous sources for datasets, including digitised chart information, digitally acquired data, and unusually for such an application, Digital Elevation Models (DEMs) of land topography (included in deference to the role of land-based landmarks for navigation in coastal waters). The 3D or virtual chart was constructed and designed with mariner feedback and suggestions leading the development. The information was obtained by questioning mariners who are familiar with existing methods of navigation for hydrographic surveys. The information provided by the mariners provided the insight to what to include and display within the virtual chart.

Operational demonstrations of the use of the virtual chart in hydrography and education of GIS proved to be successful. Interviews and discussions with the mariners after demonstration of the system found the display to be an improvement upon existing implementations. The mariners found the 3D chart to be advantageous in making decisions for hydrographic survey and general navigation and great potential was foreseen for diverse marine applications.

Associations were quick and clearly made between the 3D chart objects, features and hazards with reality. Similarities to Chart NZ 6612 and clear representation were made and aided the formulation of one's spatial awareness without distraction. For example, the use of virtual beacons and a bridge perspective from the helm of the model vessel in the virtual chart was identified as a more intuitive display as one can clearly see the desired track for the vessel, unlike conventional 2D charts which require greater interpretation.

The scope of this project included only a demonstration of the model. Constraints with this limited implementation were mostly down to data and hardware issues. Issues relating to the latency and accuracy of the system were mainly due to limited resources and information. There was no pre-existing reference frame for the Polaris, as it was recently acquired by the university. The design of the vessel model was based upon hand measurements and old refurbishment plans. This allowed the basic model to be constructed and used for demonstration purposes.

Differential rather than real time kinematic (RTK) positioning was used. This provided a good solution for horizontal position but not vertical. Future research could implement a RTK system to obtain real time tide and study the depth underneath the keel, making for a truly dynamic (4D) virtual model and refining the accuracy of the seamless bathymetry-topography surface. The GPS used for the survey also only had a heading based on the velocity of the GPS antenna. The heading could be greatly improved by using a dual antenna system GPS compass (an echo sounder would also be useful).

It was noted with the construction of the virtual chart that the New Zealand pilot guide was very useful in establishing the navigation aids, principal marks and sailing directions to be incorporated into the virtual chart. It was also noted that for future development, a survey or questionnaire could be circulated amongst a larger sample of the local marine operators on Otago Harbour. This would help identify the unofficial, but useful, principal marks, such as buildings and other features on the skyline that are commonly used. These could then be modelled and positioned in the virtual chart.

Consultation with such participants may also include usability testing (Endsley et al. 2003) for navigational tasks to simulate operative and quantitative assessment of the system. One such test would have the mariner verbalising their thoughts and actions as they perform the same navigation task action with both the 3D virtual system and the traditional system. This is collection of qualitative usability data by think-aloud protocol (Hackos and Redish 1998), which can subsequently be analysed by techniques such as emergent themes analysis (Wong and Blandford 2002). This would move the emphasis to an assessment of the simulation itself, rather than satisfying the requirements of field testing that we have seen here.

The application of augmented reality is also suggested for displaying a three dimensional nautical chart in the field of view of the mariner. The possible addition of real time images from a video camera was also theorised to be a useful application to hydrography. However, given the accuracy issues with the 3D boat model, a proper vessel reference frame still has to be constructed before these innovations can happen.

The benefits from a virtual chart (and possible implementation with augmented reality applications) are significant. Spatial awareness of obstructions, geographical locations, desired tracks and routes in reference to the vessel are greatly increased. This may facilitate intuitive and quicker decision making, which is highly important in positioning a vessel or equipment in hydrographic surveying, offshore mining, fishing and scientific research.

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If you would like a copy of the Fledermaus™ 3D .sd or .scene files for this application, please contact the lead author.

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Appendix: Focus Group Questions and Summarised Feedback

Initial Questions and Summary of Answers

Question 1: What do you like most about the way navigational information (on electronic and paper charts) is displayed?

The general response to this question was that the data displayed on Electronic Navigation Charts (ENCs) is good for quick and immediate reference to the mariner, often in association with the RADAR. It was commented that although paper charts are very accurate and more reliable, ENCs are more immediate, but are often verified with RADAR and paper charts. One mariner commented that there was less of a need to refer to the paper charts when using an ENC particularly for plotting vessel position and laying off courses. In reference to navigation for surveying, the coast file is often lacking information for safe navigation. Paper charts and some ENCs use standardised symbols and presentation, which allow for clear interpretation, this was a particular representation that was also commented on.

Question 2: What do you like least about the way navigational information (on electronic and paper charts) is displayed?

When using paper charts alone there is an amount of time needed to plot the position on the chart, and there is always the possibility of an error occurring, whereas ENCs are more immediate. For any given chart the soundings are always obsolete and some paper charts have not been updated from the original survey. This can sometimes be transferred to the ENC if it is based upon a paper chart. Negative aspects of ENCs are that they are hard to keep updated. For example notice to mariners' corrections are difficult to update on an ENC. There is also a lack of information, such as buoys, and beacons around some secondary ports and harbours which makes it difficult for some mariners. There also appears to be differences between standard symbols and representation with varying ENCs and this is a concern for the mariner, as it can often make it confusing when trying to verify the information on a paper chart. There seems to be some lack of faith in the production and use of ENCs. There have been instances in marine reports where vessels have accrued damage due to improper use and set up of their ENC (Graham Turner, pers.comm). Some of the main areas of danger in the set up of an ENC relate to use of projections and matching these with the incoming GPS information. Incorrect projection or GPS datum can cause shifts in the position and misinform the mariner of the boat's actual real world position.

Question 3: What do you rely on the most to maintain position and track as regards navigation displays, for example heading, speed over ground, course made good?

The navigation displays that mariners mostly rely on to maintain track are heading; course made good; Radar (at night); GPS chart plots; paper chart plots; their own local knowledge of the work area, and the use of a ENC. Current ENCs being used by the mariners questioned are MaxSea and Cmap.

Question 4: What do you rely on the most to maintain position and track as regards the instrumentation, for example compass, radar, etc.?

The instrumentation that mariners mostly rely on to maintain track are the echo sounder; radar at night or restricted visibility in conjunction with an ENC; compass headings and bearings; and GPS plotted position with speed over ground in an ENC. Another comment that was made by a mariner was visual awareness to judge the drift of the boat or how the boat is tracking with the wind; this is of great importance when in close proximity to land and obstructions.

Question 5: What information do you find is vital to safe navigation, maintaining track and position?

Vital elements to safe navigation as stated by the mariners questioned are position; heading; speed over ground; echo sounder; compass headings and bearings; position in relation to any obstructions and hazards; relation to other vessels in our immediate area and navigation aids, for example beacons, lights, hazards, etc.

Question 6: How useful are current systems in relaying the information needed to maintain your position and or track?

Currently most ENC systems like MaxSea and Cmap are very useful and are utilised on a daily basis. Mariners found them to be invaluable in setting waypoints, setting tracks and estimating a time of arrival (ETA). However some of the programs can be clumsy by allowing a deckhand to accidentally knock a button and altering the display. Or they could be highly distracting causing the mariner to focus on the display too much and neglect what is happening to the vessel in the real world.

Question 7: Are there any particular kinds of information you use, that you would like to see displayed better?

Elements that mariners would like to see implemented into a ENC include vessel heading, a three dimensional view around the vessel to give reference to land and other obstacles when manoeuvering at close quarters, tidal information built into the chart plot. There are concerns, however, that adding all this additional information will clutter the screen and overwhelm the mariner.

Question 8: Do you think a 3D model of a nautical chart would convey the chart details better than a 2D model (i.e. and electronic or paper chart)?

When asked if a 3D model of a nautical chart might improve their navigation all replied that it would be, especially in close to land and confined waters. They liked the idea that by having a model they could manipulate the view to suit their needs, for example scanning a work area ahead for possible dangers, obstacles and prominent landmarks, especially if the area is unfamiliar to the mariner.

Question 9: Have you ever been in a situation where navigational information could have been improved, to avoid an incident?

Due to the small amount of people interviewed only a few of the mariners had been in incidents whereby navigation information could have been improved, one mariner had a chart plotter plot a position 150 metres off course. While another commented that Radar is only useful when other vessels are outside of the vessel’s sea clutter or inside of the Radar's vertical beam, so it is no good at really close quarters.

Further Comments

Other comments raised by the questionnaire were that integrated displays have the potential to seize and hold the navigator's attention. In some ways it is preferable to have separate instrumentation – thus forcing the navigator to move from one instrument to another, maintaining a visual lookout at the same time. An integrated display is best used by a junior officer, relaying information to the master as required. It can be extremely dangerous for a master to concentrate on a single display.