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3D Computer Graphics and Nautical Charts

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Abstract: This paper gives an overview of an ongoing project using real-time 3D visualization to display nautical charts in a way used by 3D computer games. By displaying the map in an egocentric perspective the need to make cognitively demanding mental rotations are suggested to be removed, leading to faster decision-making and less errors. Experimental results support this hypothesis. Practical tests with limited success have been performed this year.

1 Introduction

Mistakes in navigation are not seldom the cause of shipping accidents. This type of accidents is most often classified as “human error” as much of the time no malfunctions in any of the technical systems onboard it is to be found. In 2007 the Chinese container ship Cosco Busans struck the San Francisco-Oakland Bay Bridge in heavy fog. She was conned by a local pilot with 25 years of experience in the area. No malfunctions in equipment were found. In 1999 the Norwegian high speed ferry Sleipner crashed on a rock in darkness and bad weather. The two experienced officers had for a few seconds been inattentive to the course steered and when they looked up the ship had turned. They did not manage to recover their orientation before they struck the rock. No malfunctions in instrumentation were found. And in 1989 the tanker Exxon Valdez grounded during night spilling huge amounts of oil. For some unknown reason the third officer waited a few minutes too long to make a crucial turn. All navigation instruments were working. Just to mention a few. In all of these cases the presence of all modern navigational aids did not stop the bridge crew from losing their orientation for a short but significant period of time. Why do highly trained bridge officers serving on technically sophisticated ships, often in areas well known, lose their orientation? What if it is not “human error” but instead inherent problems with the user interface of the navigation system?

2 Navigation

Navigation is the aggregated task of finding where your are (position fixing) and establishing a direction to go (course setting). When moving around in our everyday environment humans base way finding decisions on information from our senses, mostly the vision (so called bottom-up processing) and from experience and learned skills (top-down processing). The input to the visual perceptive system is a 2D picture of the surrounding world projected upside-down on the retina, at the bottom of our eyes. This picture is then interpreted by higher order processes in the brain: turned right side up, depth cues like linear perspective and occlusion is used to transform the 2D picture into the experience of a 3D world [WH00]. As time goes on we get very skilled at acting on the world from this *egocentric* perspective.

The egocentric view is the one most of our everyday decision making is based on.. Observe for instance yourself the next time you walk through a crowded shopping mall, avoiding colliding with people. Way finding based on visual input is fine as long as the area is not larger than what can be overviewed from the point you are at. But if the area becomes larger than that we need help from some kind of tools. If you are well known to the area you will use an inner cognitive construct termed *mental map* by Toleman [To48]. This inner map is built up by experience in a three step process of acquiring spatial knowledge as we learn to know a new area [SW75]. First we acquire *landmark knowledge* as we learn to recognise particular buildings or other unique features of the environment. When we have learned to group together landmarks into paths we have reached the level of *route knowledge*. And finally, at the highest level, we reach *survey knowledge*, which is the level where we are able to infer short cuts through places not visited before and make judgements on distances based on the cognitive map.

The mental map is the most common cognitive tool we use for navigating areas larger that we can overlook. And as fog or darkness limits our vision these areas can become very small. The precision of the cognitive map has been questioned by Barbara Tversky [Tv93] to the point that she instead wants to call it a *cognitive collage* to make explicit the inherent mistakes caused by limited memory and misconceptions and a warning to place too much trust to the mental map.

If we look at external cognitive tools to help us navigate the world we find aids like the not quite useful bread crumbs in the fairy tale of Hans and Gretchen, roads and signs in the traffic environment or buoys and cairns as in the maritime domain. But the most commonly used navigational aid of all is *the map*.

The map is at least 3500 years old. As a way-showing device it is built on the somewhat surprising concept that we observe ourselves and the world from above, from an *exocentric* bird's-eye view. To locate our position in the map we need to make comparisons of angles to known objects in the world and their representations on the map which involves comparing our egocentric view of the world with an imagined egocentric view from the proposed position on the map. When the imagined egocentric view corresponds to the real view we have found where we are in the map. These are cognitively quite demanding operations that tax our limited working memory to the fullest. We call these operations *mental rotations*, a notion that was investigated by Shepard and Metzler in the 60's [SM71]. Especially demanding are these operations when you are southbound on a north-up oriented map and first need to mentally rotate the map 180 degrees around the vertical axes and then 90 degrees around the horizontal axes. Most of us know the situation when we in an unknown city have to turn the map upside-down to figure out if it is to the left or to the right we should turn in the coming street corner. Although the problems associated with navigation using maps, the exocentric bird-eye view is the most commonly used navigational aid, maybe because its ability to grant instant overview. One can for instance acquire immediate survey knowledge without passing the stages of landmark and route knowledge, simply by climbing up in a high building or looking at a map.

The hypothesis tested in this project is that by presenting the map in an egocentric 3D perspective, we can remove the need for making mental rotations and thus make faster and more accurate decisions.

3 The egocentric 3D map

What is an egocentric 3D map? If you want to remove the need for doing any mental rotations your map should look just like the real world in front of your eyes. In Figure 1 you can see a sphere and a cube depicted on three different maps. If you look at the two objects facing south their internal relationship will be reversed on a north-up map (the one to the left). Then pretend that this was a city plan and you were to turn right after having passed the green cube. This right turn will be a left direction on the north-up map! By turning the map around so that what is in front of you is also up on the map (called *head-up* orientation, the middle map in Figure 1) the need to mentally rotate the map around the vertical axes is removed. Left and right directions on the map and in the real world now coincide. The final transformation is to remove the need for a 90 degree rotation around one of the horizontal axes (the map to the right). This is for instance beneficial to see topographic features like heights and shapes of buildings or cliffs not visible from the orthographic perspective of traditional maps. Like for instance if the red object is a sphere or a cone.

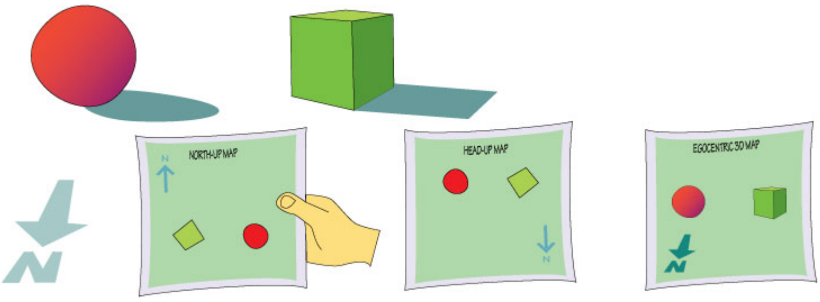
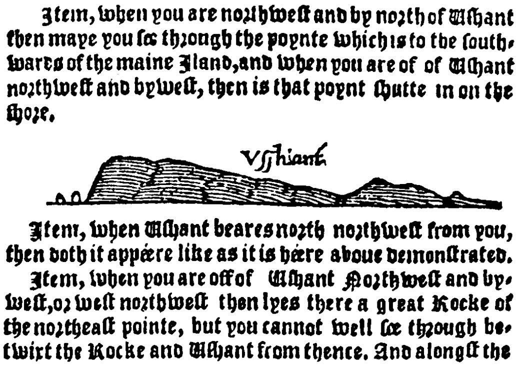


Figure 1: A sphere and a cube. If you look at them facing south their internal relationship will be reversed on a traditional north-up map (to the left). By rotating the map head-up (middle) you will remove one mental rotation. By presenting them in an egocentric 3D view (right) you have removed the need for any mental rotation. Illustration by the author.

Before the nautical charts became common onboard ships verbal descriptions called *sailing directions* was used. But to be able to tell different islands apart words alone were not enough and very soon these sailing directions became illustrated by wood cuts depicting the special features of important landmarks, like the French island Île d'Ouessant ("Ushant" in English) in Figure 2.



Item, when you are noꝛthweſt and by noꝛth of Vſhant then maye you ſee thꝛough the poynte which is to the ſouthwardes of the maine Iland, and when you are of of Vſhant noꝛthweſt and byweſt, then is that poynt ſhutte in on the ſhoꝛe.

Item, when Vſhant beares noꝛth noꝛthweſt from you, then doth it appéere like as it is héere aboue demonſtrated.

Item, when you are off of Vſhant Noꝛthweſt and byweſt, oꝛ weſt noꝛthweſt then lyes there a great Rocke of the noꝛtheaſt pointe, but you cannot well ſee thꝛough betwixt the Rocke and Vſhant from thence. And alongſt the

Figure 2: A coastal view incorporated in a sailing direction over the French west coast: Ushant was the English name for Île d'Ouessant at the western tip of Bretagne. Woodcut from Robert Normans 1590 Safegarde of Saylers, a translation from a Dutch original [Ta56].

These coastal views were based on drawings made from the deck of the ship in that egocentric perspective we talk about. The idea was to be able to recognise the features of the coast just as it was seen from the ship and they can still be found in modern Pilot Handbooks (see Figure 3).

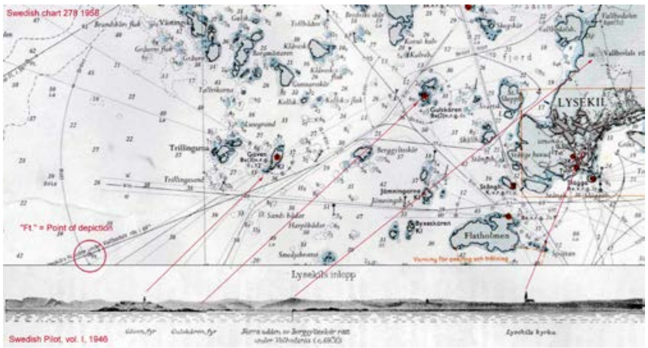


Figure 3: Top: a nautical chart from 1958 over the approach to Lysekil on the Swedish west coast. On the leading line at the bottom left of the chart the letters "Ft" ("Förtoning") is visible. This code tells you that there is a coastal view to be found in the pilot handbook of the area (the bottom part of the Figure). Ft is the point from which this egocentric view drawing is made.

The drawback of the coastal views was that they were only valid for one particular spot, the "Ft"-point in Figure 3. However, modern computer graphics technique makes it possible to produce dynamic coastal views by building a 3D topographic model based on digital terrain data and chart information as seen in Figure 4.

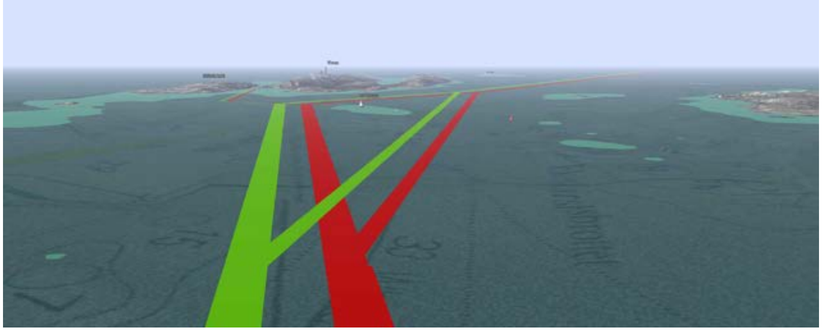


Figure 4: A 3D nautical chart over Vinga in the Gothenburg archipelago.

By positioning the virtual camera based on GPS position and heading an egocentric 3D map in real-time can be displayed as seen in Figure 5, bottom. The visual iconicity can be judged by comparing the 3D map to the photo in Figure 5, top.

Figure 5: A photograph from a boat approaching Vinga lighthouse. The camera is placed 2 meters above the water. Bottom, the same view in the egocentric 3D map.

4 Experiments

The hypothesis presented above was tested in a maze experiment with the three different map types presented in Figure 1. The results are presented in detail elsewhere [Po06], [PP07], but the general conclusion confirmed the hypothesis that removing the need to make mental rotations improves decision making: head-up maps showed faster decision making and less errors than north-up oriented maps and egocentric 3D maps were better than head-up maps.

5 Prototyping

In this project several prototypes have been built based on bathymetrical underwater data merged with laser scanned (LIDAR) over-water data and manually built 3D buildings. Terrain data have been merged in Arc GIS™ and exported to Terra Vista™ where the terrain was draped with ortho photos. The terrain was then exported in blocks with three different levels of detail. Terrain blocks with buildings were then remodelled in 3ds Max™ (see Figure 6) before the final assembly in the VR prototyping software EON Studio™.

Figure 6: Top, the raw interpolated LIDAR terrain model. Middle, the manually modelled beacon and building added in 3ds Max. Bottom, a photograph from the actual site.

The main idea with this project was not only cognitive off-loading by removal of the need to make mental rotations. Many other mentally demanding tasks needs to be performed when navigating a ship using nautical charts, tasks which can be aided by computerized information visualization. Some of these features can be seen in Figure 7. For more details see [Po06].

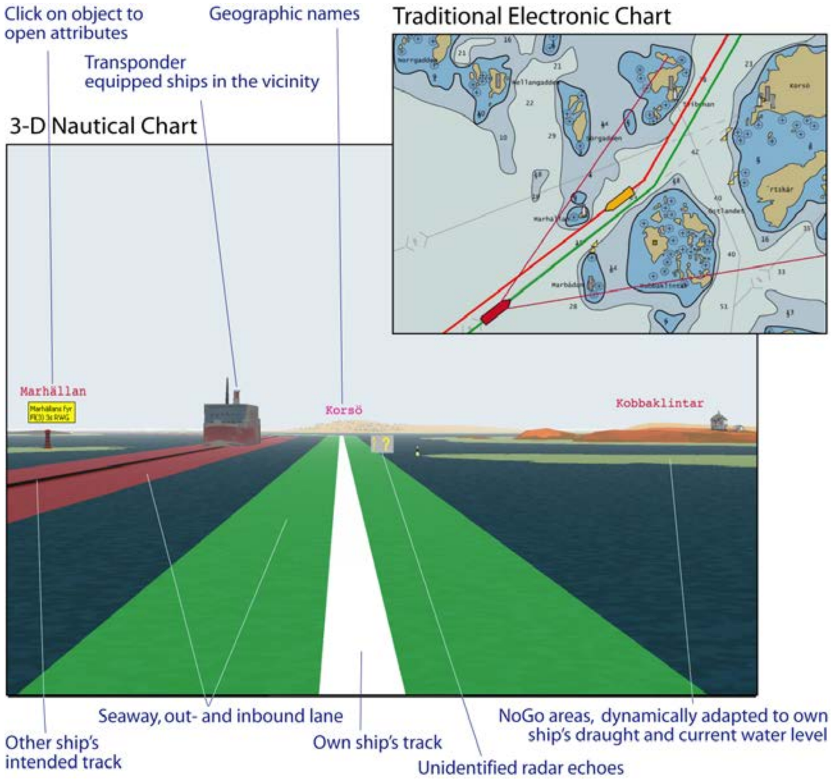


Figure 7. The egocentric view 3D chart to the left, compared with the traditional exocentric bird’s-eye view chart top right [Po06].

The visualization prototypes made have received good acceptance when presented to domain experts but they have not been built to a standard that would allow actual sea test.

During the spring of 2011 tests of a prototype 3D chart of the port of Zeebrugge in Belgium was conducted using the survey ship Ter Streep. This 3D chart is based on high resolution bathymetry produced by the Flemish Hydrographic Office and official LIDAR data and placed in a HarborView™ platform from Harris Corporation (see Figure 8).

Figure 8. Top, the Belgium survey ship Ter Streep in the port of Zeebrugge. Bottom, a screen dump from prototype chart.

The Harris platform allowed presentation of geographical data with high precision. Real-time input from the GPS positioned the target ship in the application and also the camera following the ship. The experiment was conducted as a part of the EU North Sea Region project BLAST (Bringing Land and Sea Together) and the final analyses will be presented later this year. However, preliminary findings show good data fidelity in the model and good positioning fidelity but lack of important navigational features (e.g. heading line and hull contours) made it difficult to use the prototype in practical navigation. The shortcomings and benefits of the conducted tests will then be fed into a new prototype in a coming project.

6 Conclusions

The traditional electronic chart system with its exocentric bird's-eye view will in times to come remain the major strategic and voyage planning tool. The objective is to develop the 3D nautical chart as a tactical display, being a last barrier to navigational errors in stressed situations. Experimental and practical results areso far is promising, but much research still need to be done.

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