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A 3-D Nautical GIS targeting Cognitive Off-loading and Decision Making

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Abstract. A 3-D Nautical GIS is suggested in this paper. The system is aimed at nautical navigation and simplifies navigation by adding three major features to existing chart systems: *The egocentric view*, by allowing the geographical data to be viewed from an bridge perspective the problem of mental rotations is removed; *the seaways*, displaying traffic separated fairways and individual track lines and *the NoGo area polygons* displaying warning areas for waters too shallow for the individual ship in the current tidal situation.

1 Introduction

A lot of people find map reading difficult; particularly in environments where landmarks are scares and easy to confuse like in coastal and archipelago navigation or when hiking in mountain or forest areas. When we walk in the forest where the trees are high and obscure the view, we are pleased when we find a path or a track going in the right direction. Not only because it is easier to walk on a path but also because some of the burden of navigation will be lifted of our shoulders: "people have walked this way before," the path will now do the navigation for us. Man is a path follower. We make paths and we build roads. If we ask for instructions we get a list like: "Go strait two bocks, turn left after the church, then pass the bridge…" Roads make wayfinding easier. The ancient Romans were famous for their roads. And they used lists for wayfinding, *itineraries* they called them and they listed places and distances like Venta Silurum VIIII, Abone XIIII, Traiectus VIIII…[1] [1].

Historians like Janni,[4], Broderssen [2] and Whittaker [8] suggests that the Roman empire was build on a different understanding of space based on a *road thinking*. Janni calls this spatial understanding *hodological* after the Greek word *hodos,* which means road. Their suggestion is based on the fact that very few evidence or references to our kind of spatial maps are found, while on the other hand references to itineraries are frequent. One of the very few "maps" that actually has

[1] From the Antonine Itinerary no. 14 Isca Silurum to Calleva Atrebatum over England. The itineraries consisted of names of places and the distance between them in thousands of paces. One Roman pace was a double step, about 1.4 meters, so the Roman mile (1000 paces) would be about 1.48 km.

survived as a Medieval copy of a Roman original from the 4th century is the Tabula Peutingeriana (see Figure 1). The map is 7 meters long and only 35 cm wide and depicts Europe and Asia from Britain on the far left to India on the right.

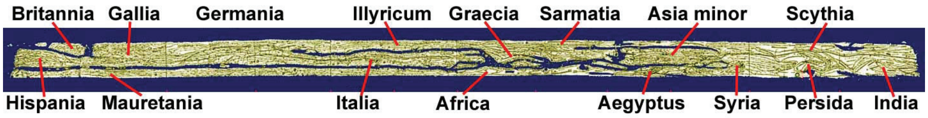

Fig. 1 Tabula Peutingeriana is a 7 meters long and 34 cm wide schematic "map" of the world from Britain to India.

This type of schematically maps are well known from public transportation now a days and the British graphical designer Henry Beck is often referred to as the inventor when he in the 1930's remade the London Underground map. Still we know that maps in the modern sense existed in the antique era, e.g. the maps of Agrippa and Ptolemy. But somehow the itineraries must have been more practical in actual way finding. Maybe we can learn something from this?

The first written nautical information to survive to our days is the *peripili* of the ancient Greeks. Scylax of Caryanda, wrote a set of sailing directions in the fifth century B.C. from which some fragments remain. They consist of the same type of lists of names and distances between safe havens along the coasts of the Mediterranean and the Black Sea [3]. The fist nautical chart does not appear until the end of the 13th century and not until the 18th century has the chart become the major mean of mediating navigational information, before that the hodological view of the sailing directions were prevailing. As stated the sailing directions first appeared as lists of places and distances, then incorporating geographic landmarks and navigational warnings. In the 15th century the French pilot Pierre Garcie started to add *coastal views* to sailing directions. These were simple wood cuts of the coast and islands as seen in an egocentric perspective from the deck of the ship (see figure 2).

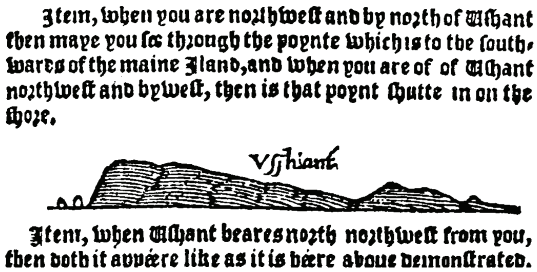

Fig. 2. A coastal view Île d'Ouessant at the western tip of Bretagne in France. A woodcut from Robert Norman's 1590 *Safegarde of Saylers* [7].

Sailing directions and coastal views are today losing their importance as satellite based systems present accurate positions on precise electronic charts. But as the speed of ships increase the decision times become shorter. More and more modern equipment crowd the bridge and the information overload becomes a problem. The need to limit the amount of information and present it just in time becomes apparent.

Today the hodological view could be the just-in-time presentation of geographical information, tailored to fit the limited human brain.

2 The 3-D Nautical Chart

High speed and short decision time has played a major role in a number of accidents at sea. One problem has been related to map reading and the inability to maintain a correct situational awareness. In an information design research project at Mälardalen University in Sweden a 3-D nautical chart has been suggested [5]. Three concepts form the bases for the chart system: the egocentric view, the seaways and the dynamic NoGo area polygons.

2.1 The Egocentric View

By tradition geographical information is most commonly presented to the bridge crew in an exocentric north-up orientation. When comparing map information with the physical world it is necessary to mentally rotate the map to align it with the physical world. The linear relationship between the time needed to mentally rotate an object and the degree of rotation needed was discovered by Shepard & Metzler in 1971 [6]. The implication for the mariner is that decision making on southbound courses will be slower than on northbound.

The suggested solution is to allow the navigator to access the map database in an egocentric perspective (see Figure 3). The egocentric view would display a scene on the display similar to what the navigator see outside the windows but with the addition of the navigational information.

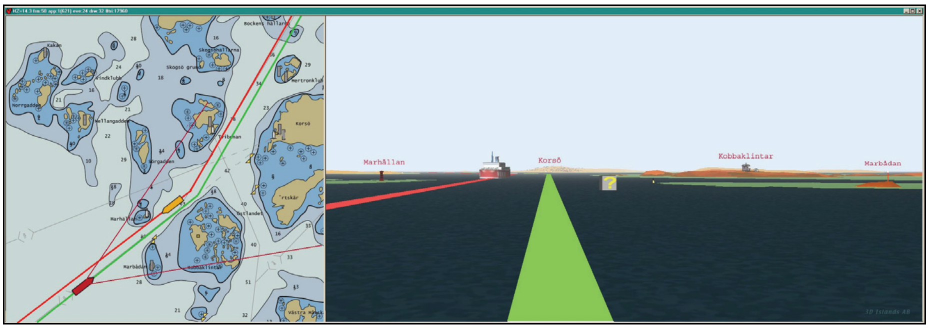

Fig. 3. The exocentric and the egocentric view of the 3-D chart. From the authors prototype chart over the entrance to Mariehamn in the Åland archipelago.

The chart can be viewed just as a traditional chart in an exocentric orthographic perspective, but at any time the user can dive down into the chart and view it as a dynamic coastal view, from an egocentric perspective.

To allow this, land height information had to be added to the map database. Different prototypes have been built using elevation contours, photogrammatically measured bare earth elevation models but laser scanned data has so far showed the best results. A 2 m by 2 m grid is used as a target resolution for the elevation data and the terrain skin is draped with orthophoto with a resolution of 25 cm per pixel. With this data resolution I have found the visual iconicity to be good enough to allow direct recognition (see Figure 4).

Fig. 4. A photo from the physical world (top) and a screen dump from the same position in the 3-D chart (bottom). Vinga lighthouse in the Gothenburg archipelago. Photo by the author.

2.2 The Seaways

Roads are cognitive tools that facilitates decision making (a secondary property is that they provide us with a smooth surface to drive on). Once on the right side of the road the driver is relieved of constant decision making until he reaches a cross road, and once there he is aided by road signs.

At sea a similar system is used in traffic separation schemes while in other areas the fairway is depicted by a single line in the chart. Many downloadable waypoint libraries the world over uses one and the same track for both directions. The suggestion is to use our experience from land road networks and traffic separate all fairways adding traffic signs displayed in the 3-D chart where so needed (see Figure 5).

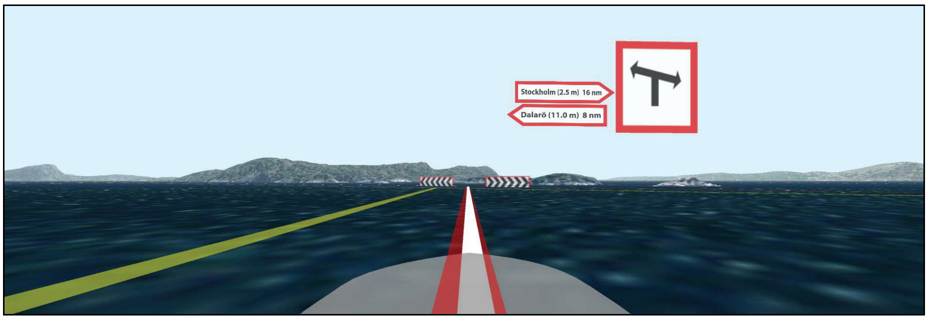

Fig. 5. Examples of seaways, an individual track line and signs displayed in the chart.

Individual track lines. Based on the route of the individual ship separate "own ship's track" should be displayed. These tracks could also be broadcasted from port authorities to approaching ships leading them to the correct berth, they could be used for remote piloting and they could also be broadcasted through the AIS system to, together with a symbol of the ship, show other ships and their intended route.

2.3 The NoGo area polygons

Normally the areas free to navigate for a ship has to be calculated based on the soundings displayed in the chart, the current draught and squat of the ship and the water level. If something unexpected should happen in confined waters this calculation has to be done under time stress. By entering relevant data from on-board sensors and tidal information from on-line sources, NoGo areas could be calculated in real-time and displayed in the chart system. With a reliable bathymetric data these polygons could be displayed for any depth in high resolution, not just the pre-drawn depth contours of the chart (see Figure 6).

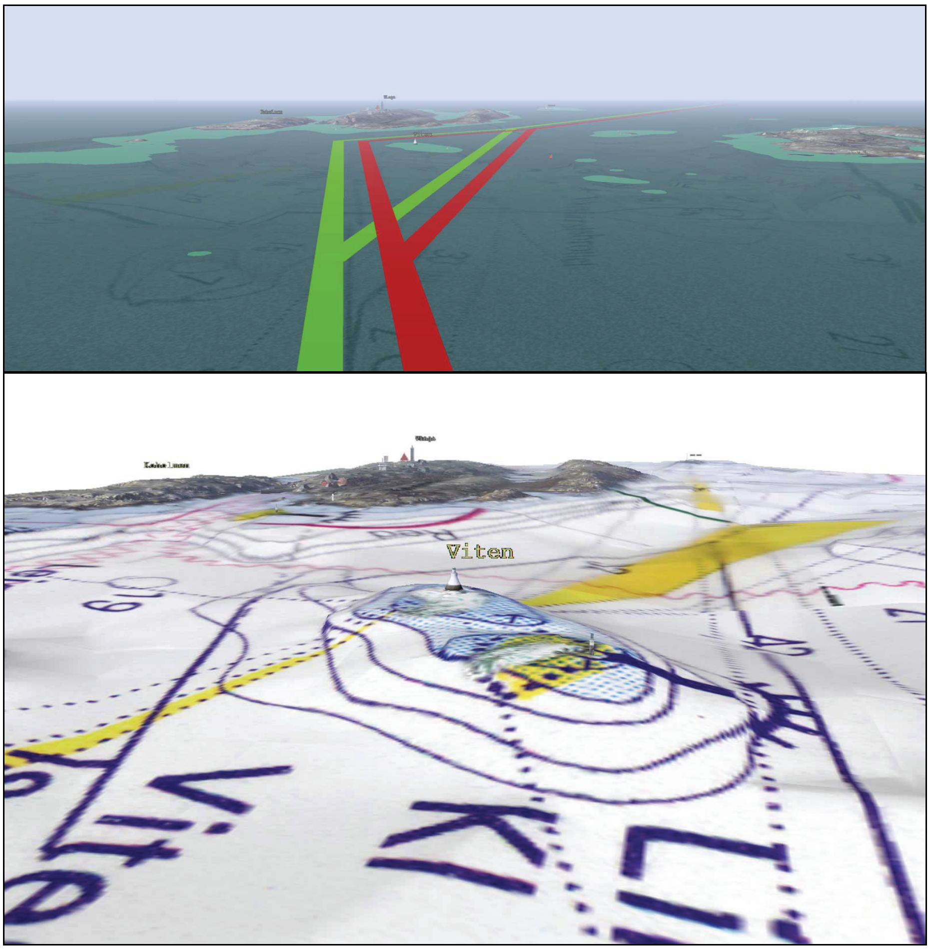

Fig. 6. The northern entrance to Gothenburg harbour looking west, out to sea, from a position east of Vinga lighthouse. Top: The in- and outbound seaways and the NoGo area polygons set to show depths less than 10 meters. Bottom: the sea surface removed showing the traditional chart texture used to drape over the bottom topography. The resolution of the bathymetrical data is in this case no better than in the normal chart – the intention is to have high resolution data.

3 Laboratory Testing

3.1 The Experiment Setting

A laboratory experiment was designed to test the general concept of navigation using the egocentric view. A 6 m by 6 m large studio area was prepared to act as the confined waters of a complicated archipelago. As a “ship” a small cart was used. Forty five subjects drove the cart along a designated track in the archipelago. The track was the only allowed “navigation channel” in the otherwise “shallow waters” where a “grounding” was registered. The track could only be viewed on the chart, not on the studio floor. As visual navigation aids some boxes, a chair and a paper tube was used (see Figure 7).

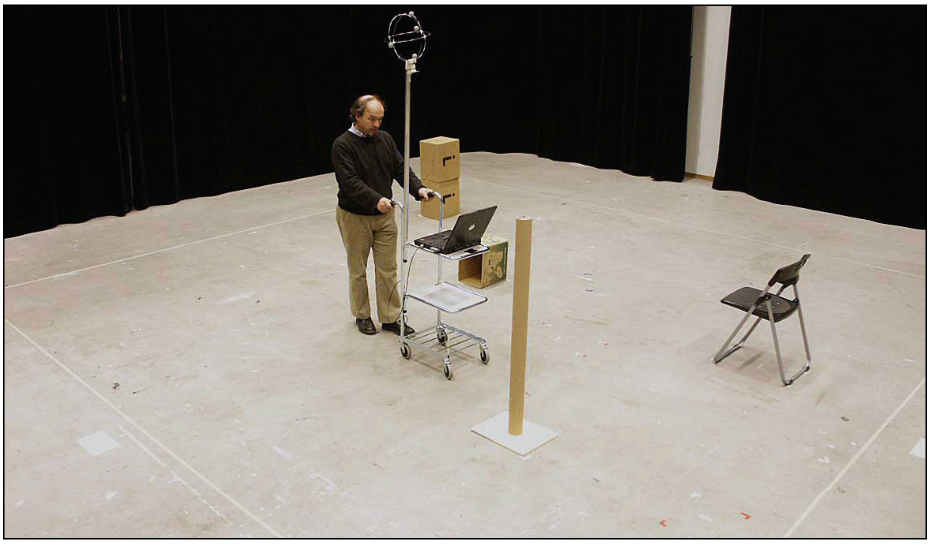

Fig. 7. The experiment area: 6 m by 6 m square marked on a studio floor. As navigational aids some boxes, a paper tube and a chair. The chart is displayed on the laptop screen (see Figure 8).

As an indoor GPS system the position and heading of the cart was tracked by an infrared tracking system (accuracy < 2 cm, 120 Hz) which sent the data back to a laptop computer fitted on the cart. On the laptop computer the different map types tested, could be displayed.

3.2 The Map Types

Four map types were tested (see Figure 8). In each map the no-go areas were marked in red colour and the allowed track in yellow. The four navigational aid (two boxes, a tube and a chair) were also marked. The four map types were:

The Paper Map. A traditional paper map, similar to map A in Figure 8, but without the green arrow. The subjects held the map in their hand while they drove the cart through the track. They were allowed to orient the map as they whished.

The North-up Map. The map was displayed on the laptop screen and functioned as an electronic chart in north-up mode (see Map A in Figure 8). The map was static on the screen and the green arrow moving over the display showed the position and the orientation of the cart.

The Head-up Map. The map was displayed on the laptop screen. In this case the small green arrow was static in the centre of the lower portion of the screen (see Map B in Figure 8). Instead the map moved and rotated as an electronic chart in head-up mode.

The 3-D Map. A simple 3-D model of the “archipelago” was made and displayed on the laptop screen (see Map C in Figure 8). The position of the cart was marked by a green pole and the virtual camera was looking on the scene from an over-the-shoulder egocentric position.

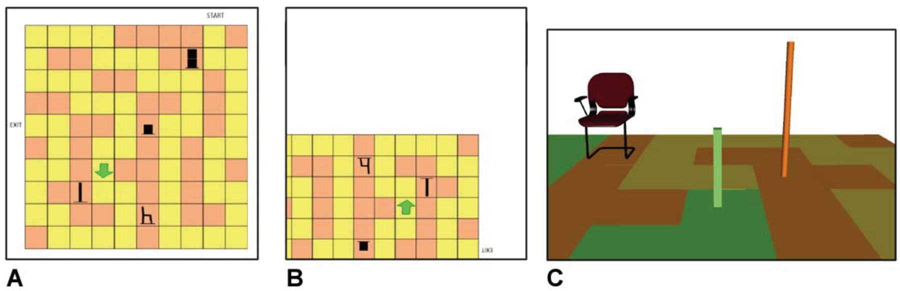

Fig. 8. Three of the four map types used in the experiment. They here show the position the cart have in Figure 7. A is the north-up map (static map, moving arrow), B is the head-up map (static arrow, moving map) and C is the 3-D map (static green pole, moving environment). The fourth map was a paper print out of map A (without the green arrow).

3.3 The Experiment

Forty five volunteers from available students, staff from the university and their family members were used as test subjects. 21 were female and 24 male in ages 16 to 63.

Each subject drove the cart four times through four different track designs. One new track for each map type. The length and the number of turns in each track was about the same, also the order in which the different track designs was used was always the same. The order of which they used the four map types was, however, randomized, so one subject would start with the egocentric 3-D display on track 1 and the next subject might start with the paper map on the same track.

The test subjects were instructed that the purpose was to drive the cart along the track (yellow squares) as fast as possible without groundings (entering into the red areas on the map). It was explained to the subjects that this was no competition; the purpose of the experiment was to test the efficiency of different maps, not the skills of the participants. They should pick a strategy (from quick and sloppy to slow and careful) that they felt comfortable with and try to stick to that same strategy throughout the experiment. Then they were guided through a practice session. When the subject felt ready, the experiment started.

During the experiment sessions the time on track and the number of groundings were automatically logged by the system.

After the sessions a short interview took place. The subjects were asked about their previous navigation experience and they were asked to fill in a ranking form where they ranked the four map types after user friendliness. They also made a standard spatial ability test.

3.4 Results

As shown left in Figure 9 the result showed that the 3-D chart was “fastest” with a mean time-on-track for all 45 participants of 111 seconds, the head-up chart came second with a mean of 142 seconds, then north-up map with 167 and the paper chart with 230 seconds. In this test, decision making using a head-up map was 28 % slower than using a 3-D map, and using a north-up map 50 % slower. Decision making using a traditional paper map was over 100 % slower than using the 3-D map.

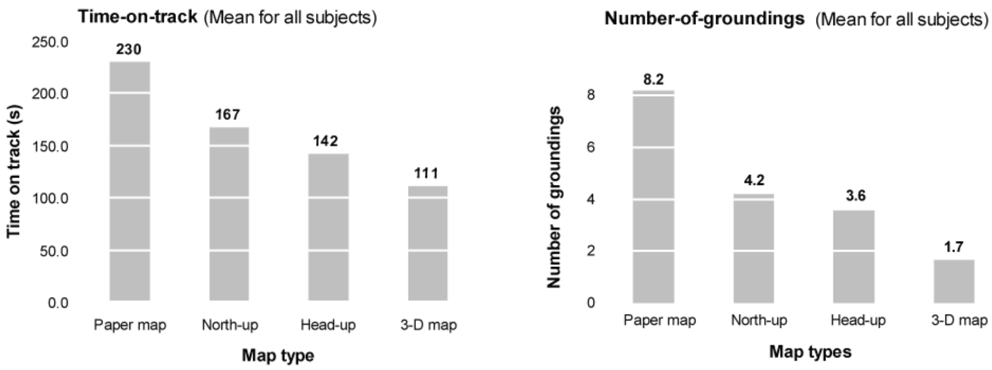

Fig. 9. The left diagram shows the mean time for all subjects on the track according to the four different map types. The right diagram shows the mean number of “groundings” made by the subjects for the four different map types.

Looking at mean for the number of “groundings” gave the same results. Use of the 3-D map resulted in the least number of groundings with a mean of 1.7 groundings for the whole group; the mean number of errors using the head-up map was 3.6, north-up 4.2 and the paper map 8.2. So wayfinding using a head-up map resulted in more than twice as many groundings as navigation using the 3-D map and using a north-up map resulted in one and a half times more groundings. Using the paper map resulted in almost five times as many groundings as using the 3-D map. The means of all subjects' time on track and number of groundings according to map type are shown to the right in Figure 9.

The difference in time on track between the map types was statistically significant at the 1% level. ($F_{(3,132,0.01)} = 46.6$, $p < 0.01$). The influence of the map type on the number of groundings is statistically significant at the 1 % level ($F_{(3,129,0.01)} = 3.94$, $p < 0.01$).

The subjects were also asked to rank the user friendliness of the different map types from 1 – 4, where "1" was the easiest and "4" the most difficult map to use. The 3-D map was classified as the easiest with a mean index of 1.13 followed by the head-up map with a mean index of 2.29, north-up had 3.24 and the paper map 3.33. The paper and the north-up maps were considered almost equally difficult to use.

For a more thorough presentation of this experiment and how age, sex, navigational experience and spatial ability influenced the results, see [5].

4 Discussion

4.1 The Egocentric View

Today navy and high speed passenger ferries navigate in speeds of about 40 knots. There have been several accidents in Scandinavia where the bridge officers have lost their orientation and not been able to regain it in sufficient short time. Speeds at sea continue to increase, like for instance with the so called RIB boats used for tourist excursions and the new Norwegian fast patrol boats of Skjold class with speeds of 60 knots. But it is still the same human brain behind the wheel.

There is less time for decision making and there is more information to consider in our evermore effective information systems. We need to think of ways of displaying the right information at the right time and in an unambiguous and easy to understand way.

One could say that the hodological perspective of the ancient Romans has a point in the step by step navigation of the itineraries, hiding unnecessary information, just giving what was needed to reach the next stop.

A translation of this concept into a modern nautical perspective for the conning situation might be to show an egocentric map in front of the navigator with high resolution in the foreground and a low resolution overview in the background, a track to go and the dangers in the vicinity. This is what is offered by the egocentric view, the seaways and the NoGo area warnings.

The laboratory experiment described above showed the efficiency of egocentric conning, and planned sea tests during 2007 will show if this holds out also in real life situations.

4.2 A Nautical GIS

Of course an ideal nautical chart should contain all the geographical information relevant to the mariner. Today the mariner has to search several different sources to gather necessary route information (e.g. pilot books, lists of light and fog signals, tide tables).

The 3-D nautical chart prototype consists of both a digital, "flat" map and a so called 2.5-D terrain skin draped with orthophoto and map texture. The ultimate goal of this project is to suggest a Nautical GIS where all information relevant to the mariner could be stored and easily updated without having to regenerate, for instance, the whole terrain skin. An ideal GIS might consist of a true 3-D database storing currents, temperatures and salinity of the sea in volume *voxels* allowing for time-based simulation of, for instance, tidal currents. Such a database structure would, however, need huge amounts of data storage space and processing power, and we will not be there for a long time. But we will eventually.

It should be possible to update the bathymetrical database with areas of high resolution as these data become available, so the database resolution need to be dynamic.

In cartography the concept of *map generalisation* has augmented the legibility of maps, they are not just an air photo, they display the relevant information for the target group. In the same way the photorealistic rendering of the present egocentric view will need further research to reach a higher level of generalization to improve legibility. Cartoon rendering techniques offers interesting possibilities here (see Figure 10). This will be one area of future research.

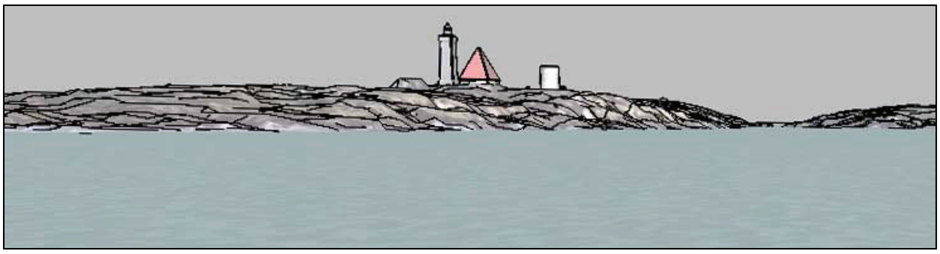

Fig. 10. Here is an example of so called "cartoon rendering" techniques used on Vinga lighthouse in the 3-D chart. Future research will show if this is a way to improve the legibility of egocentric view maps.

5 Conclusions

This paper has summarized an ongoing research project at Mälardalen University in Sweden. In the coming year cooperation has started with the Maritime Academy at Chalmers University of Technology to evaluate the chart, test it at sea and try to predict possible consequences in practical navigation.

The chart is targeting human factors issues in the maritime domain trying to address some of the problems of information overload by removing the need for cognitively demanding tasks and presenting information in a way more adapted to the human brain.

The experiment presented in this paper appear promising and studies planned for the coming years will tell if the suggestions are ecologically valid.

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