“If this will be the way to drive a ship - just anyone could do it”: 3D Nautical Charts. About creating acceptance and building standards for a VR within the maritime domain

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Abstract

This paper is presenting a short overview of a human factors project aiming to improve decision-making in navigation by removing the need to conduct mental rotations. This is done by presenting the map in an egocentric view, here called a 3D map. Laboratory experiments have shown clear advantages for the 3D map compared with traditional exocentric map displays. Finally a short description of ongoing work is presented.

Categories and Subject Descriptors (according to ACM CCS): H.1.2 [Information Systems]: User/Machine Systems—Human factors H.5.2 [Information Systems]: User Interfaces—Standardization

1. Introduction

In 1999 the Norwegian high-speed ferry *Sleipner* crashed against a rock at full speed causing the death of 16 people. In spite of the fact that the vessel was equipped with all modern technical facilities and that the bridge officers knew the route very well they lost their orientation for some 20 fatal seconds. However, the navigation system onboard never lost orientation, all the instruments showed the right digits, but the humans were not able to interpret the information in the short time frame available. The interaction between the human and the system had failed.

During a period from 2001 to 2006 I conducted a Ph.D. research project where I developed and tested a VR based 3D navigation system based on an egocentric view display. The assumption being that this system should be better adapted to the human and allow for faster and more error resistant decision making. I have called this map system *3D nautical chart*. This paper gives a very brief overview of the project so far.

2. A 3D navigation system

Navigation is the aggregated task of wayfinding and motion [DP01]. Not long ago this was a very difficult task. Today, thanks to satellite based positioning systems this is all done automatically. Before the voyage the navigation officer enters the waypoints of the decided route into the navigation system. The track is then displayed on the electronic chart as a line together with a symbol showing the ships present position. The autopilot will then take care of course keeping. All the navigator has to do is to monitor the system. But sometime situations occur when the human is forced to take manual control. It may be incidents involving other ships, or bad weather which the autopilot cannot cope with (like in the *Sleiper* accident). It is then important that the electronic map system has kept the human in the loop to facilitate a switch to manual control.

Whenever an area is larger than one can overlook from a single position some kind of mental support is needed and maps have been around for a long time (see Figure 1).

The view has been that of a bird looking down from the sky. To compare the real world and the map the map reader has to imagine that he is standing on the map surface looking in the right direction and imagine what he would see in front of him. This imagined picture must then be compared with what he really sees in front of him. This is the complicated act of mental rotations. The problem with mental rotations [SM71] is well documented and effectively compli-

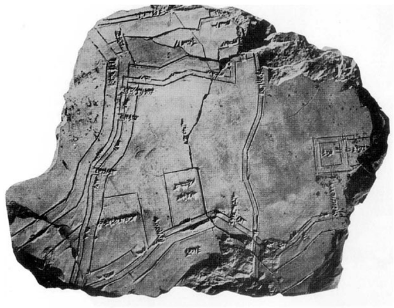

Figure 1: *Early exocentric map. Clay tablet from Mesopotamia from the 16th century B.C. British Museum, London.*

cates map understanding. A talent called spatial ability plays a major role in this process. Furthermore, spatial ability decline with age and favors male [Hal00].

Parallel to exocentric, bird's-eye maps, so called sailing directions have since long been used by mariners. These were verbal descriptions of the coast from a deck perspective and they were soon to be illustrated with egocentric coastal views (see Figure 2).

Figure 2: *Early egocentric map. A coastal view incorporated in a sailing direction over the French west coast: Ushant is the English name for Île d'Ouessant at the western tip of Bretagne. A woodcut from Robert Normans 1590 Safegarde of Saylers.*

The coastal view could be directly compared with what the mariner saw in the real world. No mental rotations were needed. The only problem was that the coastal view only was valid form one particular position. However, today the technical means of creating dynamic coastal views exist. By creating a 3D model of the map and letting the navigation system position the camera, a dynamic egocentric view can be created (see Figure 3).

The question is then of course: does such an egocentric view really facilitate navigation as to become intuitive and direct in a way that could have hindered the Sleipner accident and several similar accidents involving sudden loss of situation awareness?

3. Maze experiment

To answer that question a laboratory experiment were conducted. On a 6 m by 6 m area in a studio a 10 by 10 invisible grid was created. In this grid four mazes were designed, each

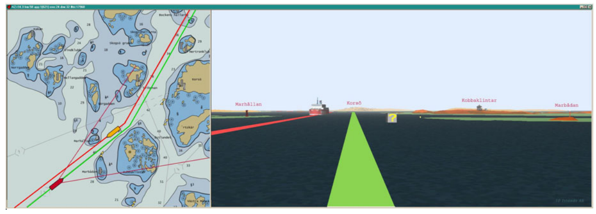

Figure 3: *Two nautical chart displays. To the left the traditional exocentric north-up bird's-eye view and to the right the new egocentric out-of-the-window view. (Screen dump from prototype application).*

with an equally long track with an equal number of turns. Each track lead from a start position to a goal and for each design one traditional exocentric map and one 3-D map was prepared (see Figure 4).

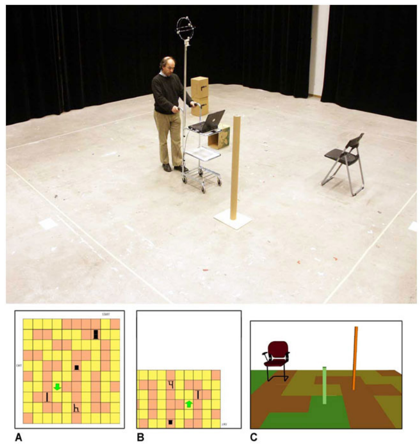

Figure 4: *Top, the studio area acting as the maze with its landmarks (boxes, a tube and a chair). A cart was wheeled manually through the maze. Bottom left (A) the 2-D map in the north-up mode as it was shown on the screen of the lap top computer on the cart for the very position shown in the top picture. The middle (B) map is the 2-D map in course-up mode and right (C) is the 3-D map. The maps depict the cart's position in the large photo.*

In a first block 45 amateur navigators (students and university employees) and in a second block 30 professional bridge officers drove once through each of the four different tracks. Each time using one of four different map types. The order of the map types was randomized. The four types can be seen in Figure 5.

An infrared tracking system mimed the GPS system and sent the position of the cart to a laptop computer fitted on the cart. The subjects were told to drive through the maze as fast as possible with as few "groundings" (entering into

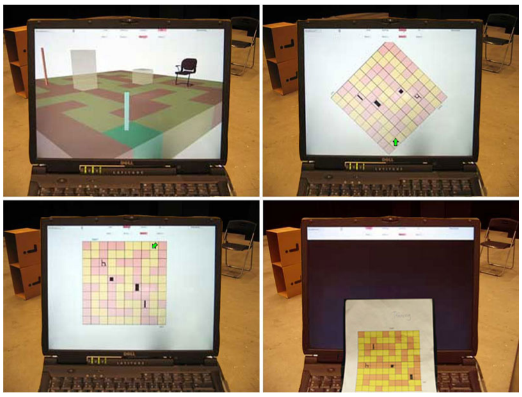

Figure 5: *The four different map types: Top left the egocentric view 3-D map; top right the exocentric head-up map; bottom left the exocentric north-up map and bottom right the traditional exocentric paper map.*

the red squares) as possible. The results were statistically significant and showed that the egocentric 3D view provided faster decision making and fewer errors than the traditional map types (see Figures 6 and 7).

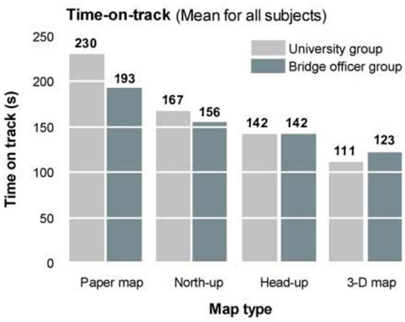

Figure 6: *The time it took for subjects to pass through the maze.*

For more details of these experiments see [Por06] and [PP07]. After having done their four sessions with different maps each subject were asked to rank the user- friendliness of the four different map types on a scale between 1 and 4. The egocentric 3D map was clearly ranked as the most user-friendly (see Figure 8).

In the first block the experiment was conducted on available students and staff at the university. They were all amateur navigators. The study clearly showed that maps supporting cognitive off-loading were more efficient: when the subjects needed to do fewer mental rotations they made faster decisions about the way through the maze and fewer errors. Next we wanted to test if these results would hold for professional navigators schooled in performing precisely these

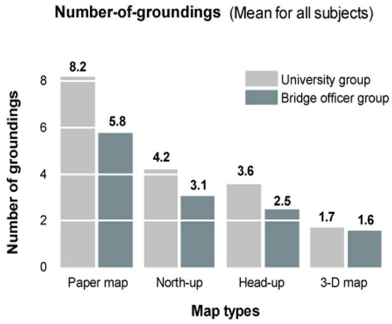

Figure 7: *The number of groundings (cart entering a forbidden red square).*

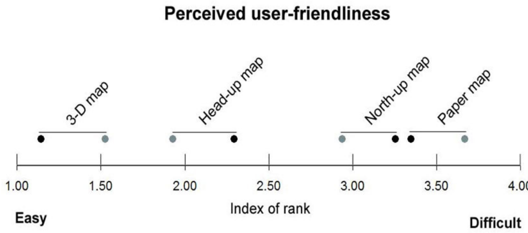

Figure 8: *Results from the ranking of user-friendliness.*

kinds of mental rotations. Much to our surprise they did. They had the same trend of higher efficiency with fewer mental rotations. As expected they did better than amateurs when using exocentric maps in north-up, but surprisingly they did equally well as amateurs using head-up maps (an orientation mode seldom used by mariners), and worse than amateurs on the 3D map. We did not ask the amateur group for computer gaming habits, but we did ask the professional group and found no significant correlation between gaming habits and results in the maze.

The professional group is doing over all better than the amateurs when it comes to errors. We interpret this as a result of the professionals' knowledge of the true consequences of a grounding. In a speed-accuracy trade-off they prioritize accuracy which may not be the case with the amateurs, which also has to be taken into account when looking at the speed results.

Never the less there is a stable trend that the differences in navigation performance between the schooled and the unschooled group is equalized when using displays modes that remove the need of making mental rotations.

By removing the need of performing mental rotations the 3D egocentric map display lessens the cognitive workload of the user. A known problem in automation is that operator tasks changes from manual control to monitoring [End96, WH00]. This in turn leads to what has become known as out-of-the loop performance problems, meaning that if something goes wrong forcing the human to retake control, she often lacks in situation awareness and valuable time is then lost trying to regain situation awareness and control which might lead to a potentially disastrous situation. When vehicles navigate on autopilot and a monitoring crew members need to retake immediate control, for example to make an evasive maneuver for another ship, the time to re-align the map with the real world through a number of mental rotations, might be just too much. A cognitively less demanding display system might save those valuable seconds.

Map applications in cars and mobile phones become more and more frequent. So called "3D modes" are today standard in most applications. Very little research is presented on the human-machine interaction of these map systems; we hope that these findings may add to the knowledge in this field.

4. Gaining acceptance in the maritime domain

The laboratory experiment, the construction of several visualization prototypes and a Ph.D. thesis concluded the first phase of this project in 2006. During this work, and later, I have presented my findings for more than a thousand professional experts from the maritime domain and gained much interest. This has encouraged me to continue working on making the 3D chart become reality. In 2008 I joined the Maritime human factors researcher group at Chalmers Technical University in Gothenburg which gave me a much better platform to continue with the most difficult part of this project: to create acceptance, and finally open for possible standards within the regulating organizations of the maritime domain, IMO (the International Maritime Organization), IHO (the International Hydrographic Organization), IALA (the International Association of Marine Aids to Navigation and Lighthouse Authorities), etc. If the rules that regulate international shipping do not permit the use of 3D nautical charts they will never be, thus much energy needs to be put into letting the findings of this project become known to the international maritime community.

In 2009 two EU financed project started: the *EfficienSea* project headed by the Danish Maritime Safety Administration and the *BLAST* project headed by the Norwegian Hydrographic Service. Both these projects involve the 3D chart. In the BLAST project a 3D chart demonstrator over Zeebrugge in Belgium will be built in the autumn of 2010 and the surveys for this is already underway (see Figure 9).

This chart demonstrator will be evaluated with officers and pilots going in and out of Zeebrugge harbor both on a real ship and in a simulator in Antwerp in the spring of 2011. The results from both these projects will be feed into the so called e-Navigation initiative of the IMO, IHO and IALA.

In October 2010 I am invited to present my research to the Hydrographic Safety and Standards Committee of the IHO. This will be a very important moment.

Figure 9: *Surveying for the 3D chart from the Belgian hydrographic surveying ship Ter Streep in the port of Zeebrugge in September 2010.*

5. Conclusion

This has been an extremely brief summary of an almost ten years long project. The prospects for the 3D charts becoming a reality looks at the moment bright, also because that we can see that in the parallel world of car navigation the same paradigm of exocentric head-up display of maps are the dominant mode used.

During a presentation a number of years ago, a navy captain said: "If this is going to be the way to con a ship - just anyone could do it." I suspect the comment was not entirely meant so, but I took it as a compliment. If a 3D chart can help officers in the same situation as the men on the bridge of *Sleipner* to regain their situation awareness in the split of a second much will be won. It remains to be seen if we will come that far.

References

[DP01] DARKEN R. P., PETERSON B.: Spatial orientation, wayfinding, and representation. In *Handbook of Virtual Environment Technology*, Stanney K., (Ed.). Erlbaum, Hillsdale, N.J., USA, 2001. 1

[End96] ENDSLEY M. R.: Automation and situation awareness. In *Automation and human performance: Theory and applications*, Parasuraman R., Mouloua M., (Eds.). Erlbaum, Mahwah, N.J., USA, 1996, pp. 163–181. 3

[Hal00] HALPEN D. F.: *Sex Differences in Cognitive Abilities*. Erlbaum, Mahwah, N.J., USA, 2000. 2

[Por06] PORATHE T.: Improved situation awareness in navigation using egocentric view 3-D nautical charts. In *IEA 2006* (2006), Elsevier Ltd. 3

[PP07] PRISON J., PORATHE T.: Navigation with 2-D and 3-D Maps: A comparative study with maritime personnel. In *NES 2007* (2007), Nordic Ergonomic Society. 3

[SM71] SHEPARD R. N., METZLER J.: Mental rotation of three-dimensional objects. *Science 171* (1971), 701–703. 1

[WH00] WICKENS C. D., HOLLANDS J. G.: *Engineering psychology and human performance*. Prentice-Hall, Upper Saddle River, USA, 2000. 3