Paper for Consideration by the Nautical Cartography Working Group (NCWG)

Data Quality Indicators for bathymetric data on ECDIS display

Submitted by:	UNH Center for Coastal and Ocean Mapping (UNH/CCOM)
Executive Summary:	New portrayal for bathymetric data quality indicators

Introduction / Background

Zones of Confidence (ZOC) are used with Electronic Navigational Charts (ENCs) to inform mariners about the confidence the producing nation places in bathymetric data. Accident reports show that failing to account for the varying data quality may result in maritime accidents, environmental disasters, and loss of life (e.g., (BSU, 2020; DSB, 2017; RMIMA, 2020)). A major concern with the ZOC concept has been the utilized symbology with glyphs consisting of stars. Due to its recognized deficiencies, star symbology has been rejected for use with the Quality of Bathymetric Data (QoBD) (DQWG, 2019a), the successor of ZOC in S-101, and, therefore, alternative methods are being investigated.

Recognizing the importance of the visualization of bathymetric data quality, the Center for Coastal and Ocean Mapping of the University of New Hampshire (UNH/CCOM) has been working toward new intuitive symbology for the QoBD numerical scheme (1 for best quality and 5 for worst). One potential solution is with the use of see-through textures consisting of countable elements. Two *countable textures* were developed, one consisting of lines and one of clusters of dots, while three more color-based schemes were developed building upon ideas previously discussed within the hydrographic community. The five coding schemes were evaluated through an online survey specifically designed for professionals in the field working with nautical charts and an in-lab, controlled, experiment. This paper presents the coding schemes, the findings of the survey and experiment, discusses future work, and seeks feedback, recommendations for improvements, and collaborators.

Analysis/Discussion

Previous Work:

Geospatial data uncertainty has been displayed side-by-side (adjacent) as well as overlayed (coincident) to the data. Overlayed methods have the benefits that readers do not need to switch their focus back and forth between the maps of the attribute and the uncertainty (Sun & Wong, 2010) and make it easier to perceive correspondences, however they can affect the perception of the underlying data. Overlayed visualizations can employ intrinsic or extrinsic approaches (Howard & MacEachren, 1996). The intrinsic approaches modify the appearance of objects (e.g., changes of their transparency), whereas the extrinsic methods use separate symbology to provide the necessary information (e.g., area color coding for the data and textures for the uncertainty). Slocum et al. (2003) showed that intrinsic methods are better for communicating the uncertainty, while extrinsic methods for extracting specific locational uncertainty information.

To investigate the visualization of data uncertainty on charts, the Data Quality Working Group (DQWG) studied line textures with different levels of transparency (DQWG, 2015), while the Nautical Cartography Working Group (NCWG) presented a collection of four visualization techniques, two of them utilizing pie charts, one a ring pattern with variation in color hue, and one with varying levels of color value (NCWG, 2016). However, both the DQWG and NCWG works targeted the four quality tiers that were under consideration at the time (i.e., good, fair, low, and unassessed (DQWG, 2015)) but later abandoned (DQWG, 2016). Gladisch and Ruth (2016) investigated the use of noise, transparency, and textures for the visualization of QoBD on charts. Their proposed grid and hexagon textures could be easily adapted for use in all ECDIS modes, however, as the (DQWG, 2019b) points out, their textures for the different QoBD levels "are not intuitive and add considerable clutter". The most recent effort is that by the DQWG (2017) that utilized a color coding that combined the safety contour, safety depth, and the four shades of blue used for depth areas in Electronic Chart Display and Information System (ECDIS), method similar to that in Jiang et al. (1995).

To date, the new visualization scheme of S-101 QoBD sectors has not been decided.

The following sections provide a summary of the research conducted at UNH/CCOM for a new intuitive QoBD symbology. The survey and in-lab experiment design and analysis are detailed in Kastrisios & Ware (2022a) and Ware & Kastrisios (2022), respectively, while additional information on the overarching project on data visualization and integration in ECDIS may also be found in Kastrisios and Ware (2022b), Kastrisios and Ware (2021), Kastrisios, Ware, Calder, Butkiewicz, Alexander, and Broekman (2020), and Kastrisios, Ware, Calder, Butkiewicz, Alexander, and Hauser (2020).

Requirements:

In investigating the QoBD visualization methodology, we set five requirements so for it to be effective for the application. Ideally, the new symbology, should:

1. Minimally interfere with the charted information (to avoid continuous zoom-in/out and activating/ deactivating that is otherwise required to resolve legibility conflicts).
2. Unambiguously relate to the QoBD categories (to prevent confusion and misinterpretation of data quality).
3. Emphasize the areas of greater uncertainty (to act as a clear warning when navigating areas charted with low quality data).
4. Be easy to remember (to minimize the need for accessing the legend and reduce the cognitive load).
5. Be effective in all ECDIS modes (for when the QoBD is accessed in different ambient light conditions).

Proposed Coding Schemes:

The solution that seems most promising uses see-through textures consisting of *countable elements*. Two coding schemes were developed: one consisting of lines (*Lines*) and one consisting of clusters of dots (*Dot-Clusters*). The fundamental principle of the proposed solution is that the QoBD is represented by the number of lines or dots creating the texture. In detail, QoBD 1 is represented with single lines (or dots), QoBD 2 with two lines (or clusters of two dots), QoBD 3 with a texture consisting of one double and one single crossing solid lines (or three dots), and so on. For the category U (“Unassessed”), following a Boolean approach, distinct textures are utilized.

For comparison we developed two more schemes based on ideas previously discussed within IHO for use of color fills. In detail, the third scheme consists of opaque color fills (*Opaque-Colors*) where colder colors represent better quality data and warmer colors represent worse quality data. For the fourth scheme we combined different transparency levels with variation in color saturation (*Transparent-Color*). Lastly, to overcome the anticipated problems of color fills, such as the obscuring of underlying bathymetry and color blending, we combined different levels of textures and colors for a fifth coding scheme (*Color-Textures*). Figure 1 illustrates the five coding schemes with the respective QoBD and Figure 2 how they look over a section of a chart.

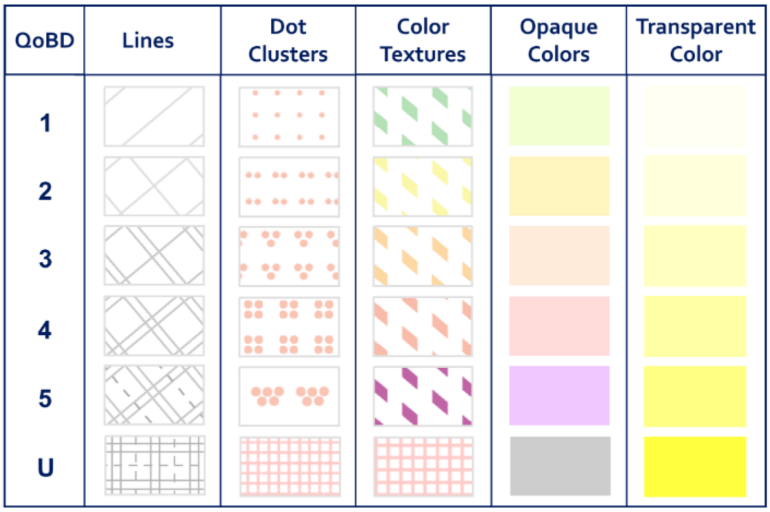

Figure 1. The alternative coding schemes for the visualization of the QoBD

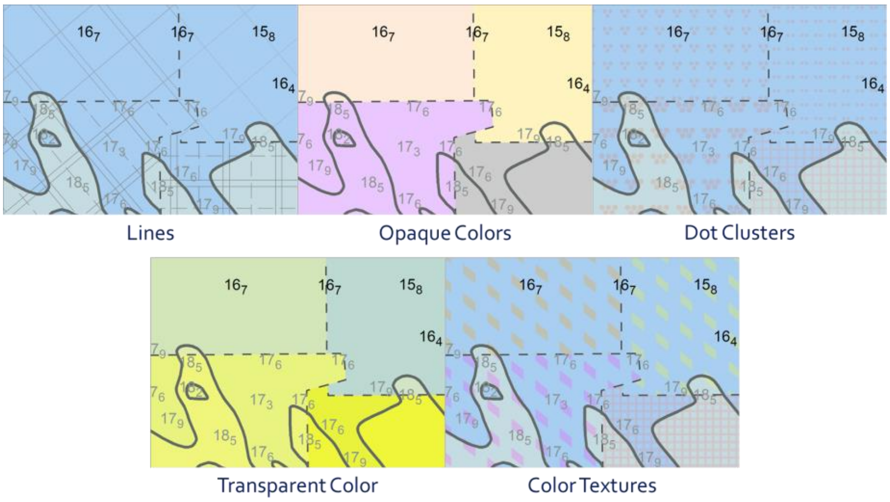

Figure 2. Excerpt of the five coding schemes overlaid a chart section.

Evaluation:

To test the performance of the five coding schemes, we run an online survey for professionals working with charts (mariners, cartographers, hydrographers). The evaluation consisted of four evaluation areas (Figure 3) followed by two final rankings in day bright and dusk ECDIS modes (Figure 4). In Area 1 six QoBD categories (i.e., 1, 2, 3, 4, 5, U) were displayed, in Area 1 Dusk the same six categories were displayed but in the ECDIS dusk mode, in Area 2 two quality areas were displayed, while in Area 3 only one QOBD category was visualized. Participants were asked to rate the performance of the coding schemes using a 0-6 Likert scale in 16 subjective questions. There was also one objective, multiple-choice, question that tested respondents' ability to recognize the visualized QoBD of Area 3. In the two final rankings, respondents were asked to rank the five schemes from best (1) to worst (5) in both day (Figure 4) and dusk ECDIS modes.

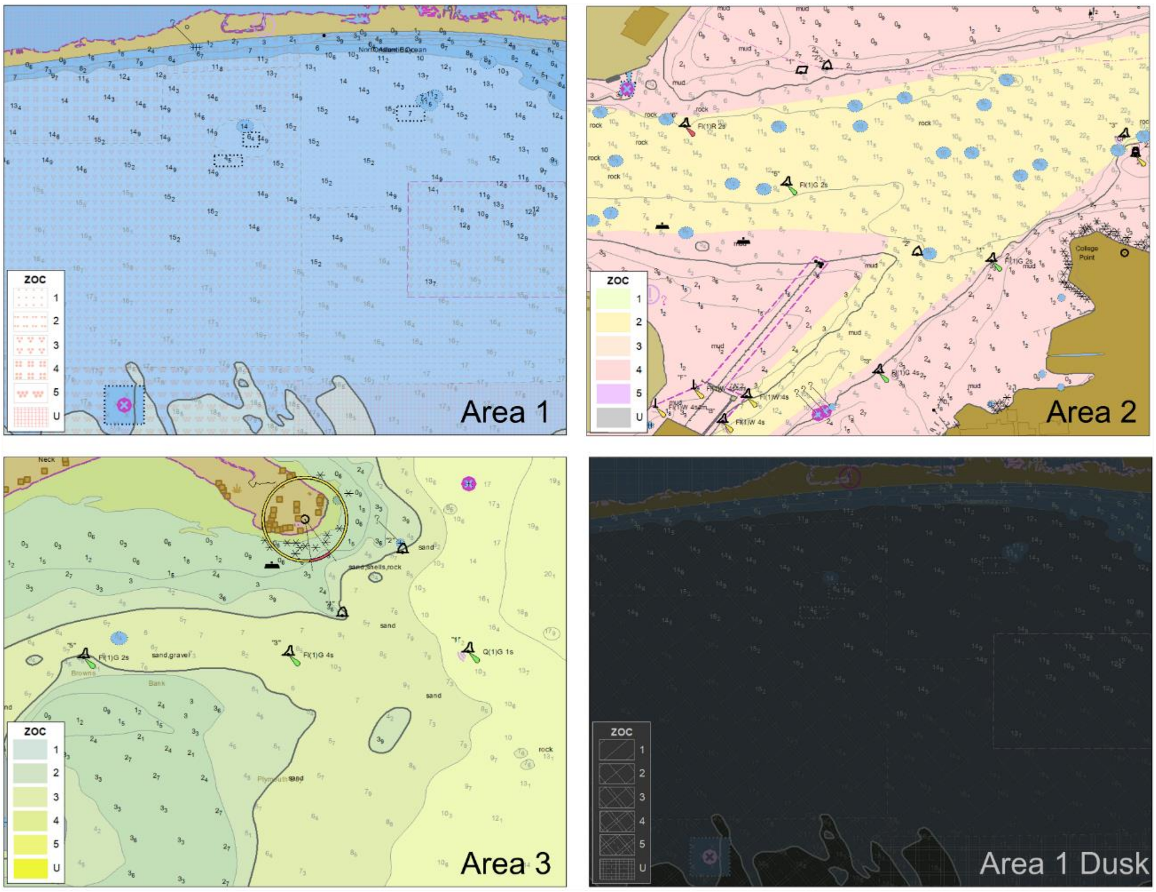

Figure 3. The four survey evaluation areas: Area 1 with *Dot-Clusters*, Area 2 with *Opaque-Colors*, Area 3 with *Transparent-Color*, and Area 1 Dusk with *Lines*.

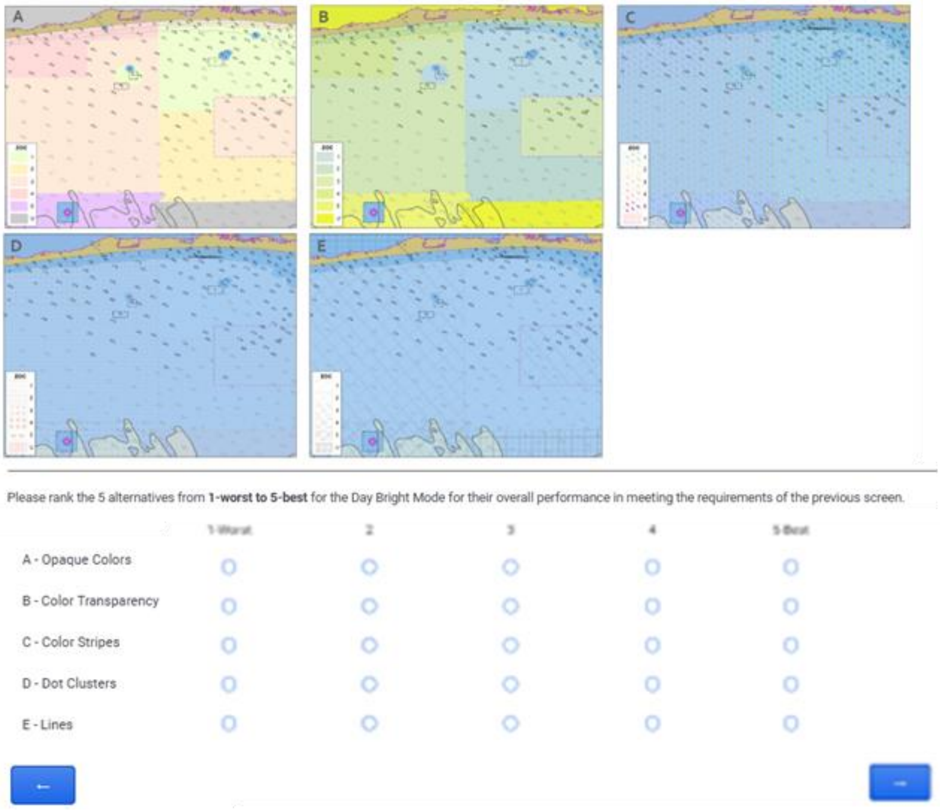

Figure 4. The day rankings section where participants were asked to rank the five coding schemes from 1 for worst to 5 for the best scheme overall in day bright ECDIS mode.

To further investigate the performance of the coding schemes, we ran an in-lab experiment to objectively test the speed and accuracy of decoding the visualized QoBD levels with the alternative coding schemes (EXPT1) and their memorability in the absence of a key (EXPT2). We used chart generation software, developed in-house, to create chart-like displays as the map background for QoBD coded overlays (Figure 5). This allowed for generating a new chart-like background for each trial, based on random parameters, with the aim to eliminate familiarity effects and easily tune stimuli to answer different questions. Participants were asked to identify the QoBD at a randomly determined position of a crosshair on each randomly generated chart view.

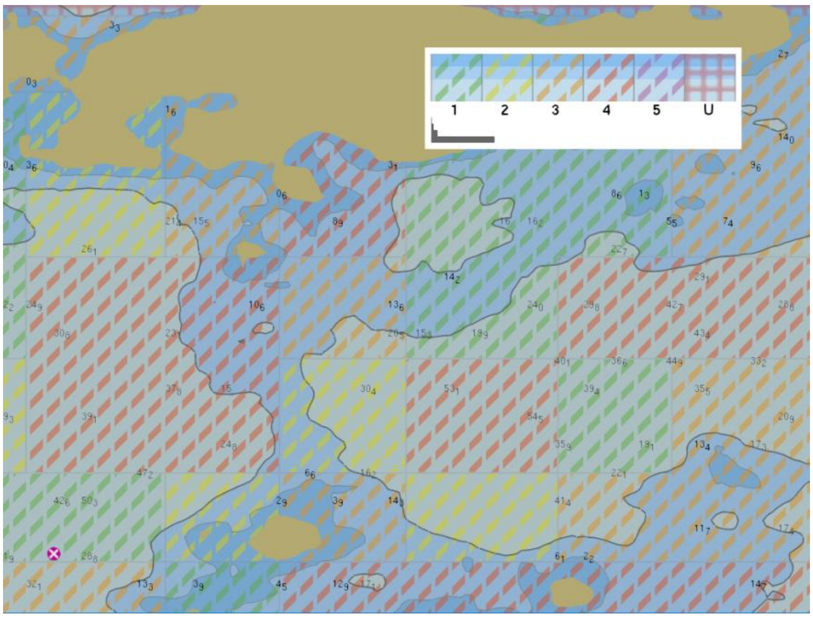

Figure 5. Example of the in-lab experiment display with *Color-Textures* generated with the in-house developed Chart Generator.

Participants:

To recruit survey participants we collaborated with three US based maritime academies, the United States Merchant Marine Academy (USMMA), Maine Maritime Academy (MMA), and Maritime Institute of Technology and Graduate Studies (MITAGS). The survey received 94 responses among which 76 reported only maritime experience, eight cartographic and/or hydrographic, while 10 participants reported experience both as professional mariners and cartographers and/or hydrographers (Figure 6a). From the 86 with maritime experience, 76 were in the merchant fleet, seven in the navy, and three in coast guard. 20 of mariners had less than 2 years of experience, 15 had 2-10 years, and 51 more than 10 years with 25 having over 25 years of experience. Figure 6b shows the license level of professional mariners and Figure 6c the voyage types that they have been involved in. For the in-lab experiment, we recruited UNH undergraduate and graduate students (N = 26).

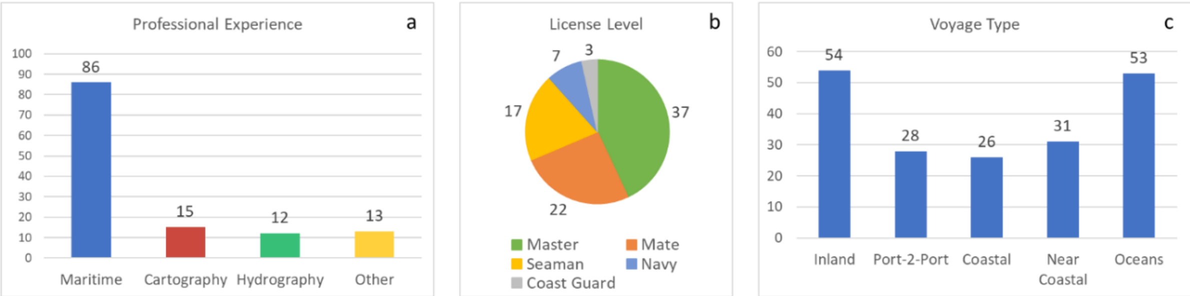

Figure 6. Respondents' professional experience (a), license level of professional mariners (b) and type of voyage (c).

Results:

Lines and Dot-Clusters were the preferred coding schemes in participants final rankings. They were ranked significantly higher than the other three coding schemes and together they received 70.9% of best rankings in Day (Figure 7) and 60.5% in Dusk mode (Figure 8). Lines received the most positive ratings overall. It was the only coding scheme with mean ratings over three in all four evaluation areas (Figure 9), and the only one with mean ratings over three in the combined questions against the five requirements (Figure 10), while it was participants' first choice in both Day and Dusk modes (Figure 7 and Figure 8 respectively). Dot Clusters was the second-best coding scheme in participants' rankings (Figure 7 and Figure 8). It performed well in not interfering with charted information and was judged to be easy to remember. However, it was found to be less effective in emphasizing areas of greater uncertainty and in Dusk mode. Opaque-Colors was ranked third, very close to Dot-Clusters in Dusk but significantly lower in Day mode, while it performed comparatively to, and in some cases better than, Dot Clusters. It was particularly good in separating the QoBD categories, but it was found to interfere with other chart information, however less than expected, and to be relatively poor in its ability to be memorized. Transparent-Color and Color-Textures performed worse overall (except for Requirement 3 for the Transparent-Color), and, in most cases, these differences were statistically significant (particularly in the case of Color-Textures) (in Figures 7-10, statistically significant differences are denoted with the use of different letters over bars, i.e., A is significantly different/better than B and C but not than AB).

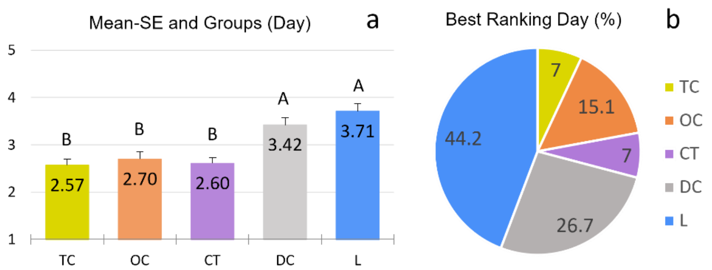

Figure 7. Means and groups (a), and best ranking percentages (b) of the final rankings in Day mode.

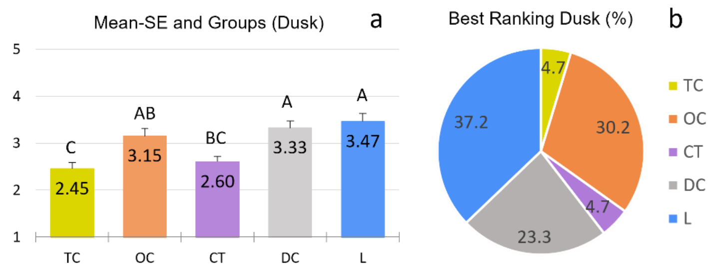

Figure 8. Means and groups (a), and best ranking percentages (b) of the final rankings in Dusk mode.

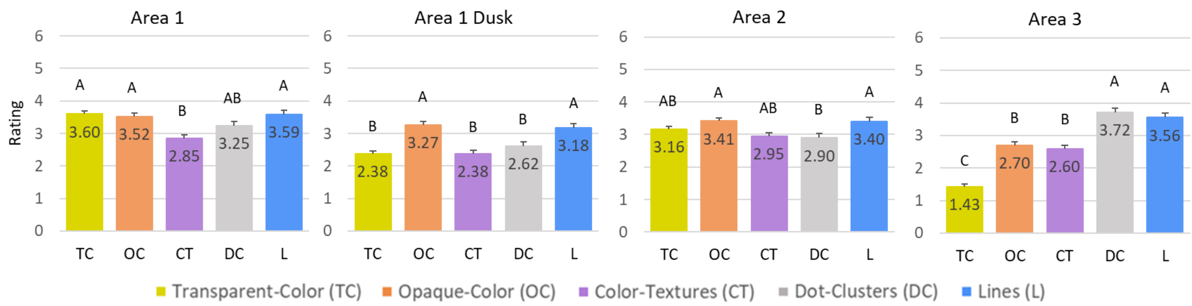

Figure 9. Means-standard errors and formed groups of ratings in the four evaluation areas.

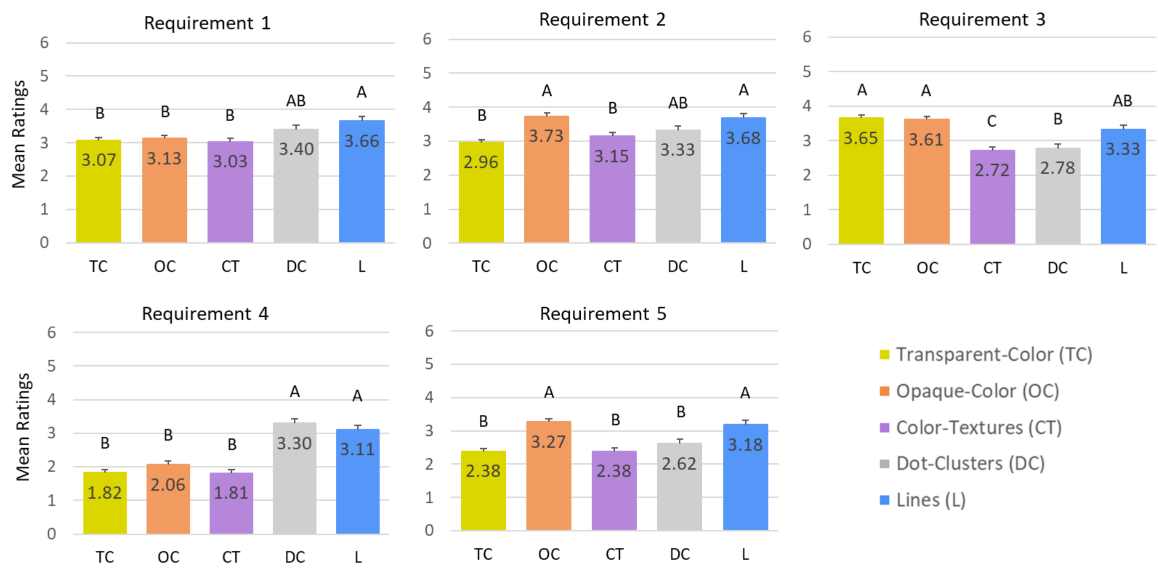

Figure 10. Means-standard errors and formed groups of ratings for the five requirements.

In the objective experiment, *Dot-Clusters* produced the fastest response times in both experiments with and without the legend (Figure 11b and Figure 11c respectively) and the lowest error rates (Figure 11d), followed by *Lines* and *Opaque-Colors*. On the other hand, the *Transparent-Color* yielded the slowest response times and very high error rates in the experiment.

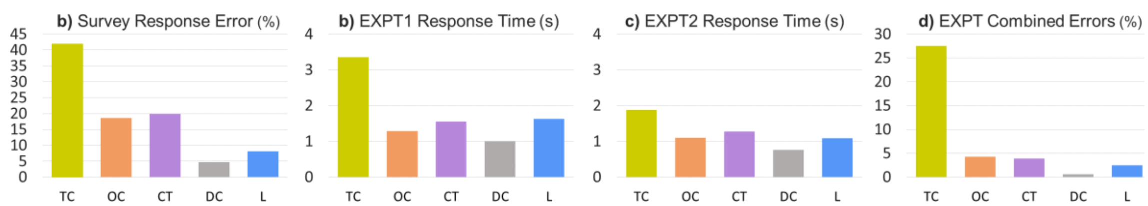

Figure 11. a) User survey objective question error rates and b), c), d) in-lab experiment results.

Conclusions and future work

This paper presented a research effort for the visualization of QoBD sectors on ECDIS displays. The survey and experiment demonstrated that countable textures is a successful compromise between the (unavoidable) visual weight added to the chart with the additional QoBD layer and the ability to unambiguously communicate the represented QoBD while providing a warning for navigating areas of low quality data. An interesting finding of the survey was that generally two broad categories of users exist: one with preference to textures and one with preference to colors. As such, and to accommodate preferences, more than one visualization techniques could be made available in the new generation ENCs.

The UNH/CCOM plans to continue the visualization effort, in parallel with an integration effort of the data quality in ECDIS safety checks. This includes making improvements to the coding schemes (and particularly the two countable textures and that of opaque-colors) (e.g., density and transparency levels of lines, color and density of dots, selection of colors for the Opaque-Colors) as well as testing traditional and novel techniques of safety checks. For the evaluation of the integration methods we are planning to develop interactive experiments on site maritime academies using the in-house developed chart generator software.

Action Required by the NCWG

The NCWG is invited to:

a. Note this paper,

b. Discuss and consider the proposal,

c. Collaborate with UNH/CCOM on the visualization and integration efforts.

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