Evaluating Countable Texture Elements to Represent Bathymetric Uncertainty

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Abstract

Measurements of the depth of the seabed vary widely in both horizontal and vertical accuracy. To convey this information to mariners, Zones of Confidence (ZOC) are defined for charts. A mosaic of ZOCs can be represented as a chart overlay. This study evaluates two novel designs for textures to represent ZOCs. Both use textures with countable elements to represent different ZOC levels. One uses a texture made of lines where the number of lines in a texture cell represents the confidence level; the other uses dot clusters where the number of dots similarly represents the ZOC level. In the study, these were compared with three alternatives that used color to respond and accuracy as dependent variables. The dot clusters design yielded the fastest responses overall. A method using levels of color transparency proved to be the slowest and least accurate.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [Information Systems]: User Interfaces—Evaluation/methodology H.m [User/Machine Systems]: Miscellaneous—Colormapping

1. Introduction

Measurements of the depth of the ocean are basic to the construction of nautical charts, although unfortunately there are areas where no measurements have been made. Where they do exist, measurements vary greatly in accuracy; older technologies were often inaccurate both in horizontal and vertical positioning. The earliest measurements were made using a sextant for positioning and lead lines for depth, later innovations included single beam echo sounders and improved positioning, and currently, much more accurate measurements are made using GPS positioning and multibeam echo sounders. Nevertheless, much of the source data for charts, both paper and electronic, is from older surveys and as a result significant uncertainty exists in the positioning and depth of charted features, including such hazards as rocky outcrops. Because of this uncertainty the International Hydrographic Organization (IHO) has specified that bathymetric data be categorized into Zones of Confidence (ZOC) [IHO14]. These areas specify a range of uncertainty of both depths and horizontal position, with the exception of ZOC "U" for areas where the data quality has not yet been assessed. The ZOC areas are intended to be applied as overlays on electronic charts.

The display of ZOC information on a chart is achieved by means of an overlay of a mosaic of polygonal regions with each region having one of six designated ZOC categories. The category assignments are based on estimated positional and depth uncertainties in the source data [IHO14]. These are shown in Table 1. The purpose is for the mariner to better understand the uncertainties associated with the charted bathymetry and apply this knowledge in voyage planning, for example by giving a shoal with a high uncertainty ZOC value a wider berth.

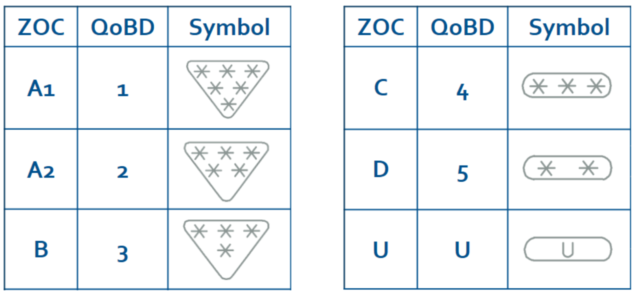

Figure 1: *Current Symbology for Zones of Confidence (ZOC). Replacements are being studied.*

Currently ZOC categories are represented on charts using glyph overlays where each glyph is an outline shape having rounded corners filled with a number of stars (Figure 1). These symbols have received a number of criticisms: the star count does not correspond to the ZOC category, the coding results in data of the highest quality being most cluttered from the overlay, the glyphs are large and sparse and may not be represented in small areas and the star symbols add too much clutter. As a result of these design problems, the IHO Data Quality Working Group (DQWG) has called for alternatives to be proposed [DQW19]. In addition to the problems with the symbols, the ZOC categories were originally designated by alpha-

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betic codes (A1,A2,B,C,D,U). The IHO has determined that these should be replaced by a simple number series 1-5 representing the Quality of Bathymetric Data (QoBD) [IHO18], 1 designating the highest quality and 5 designating the lowest quality; with the letter 'U' meaning "undefined". In what follows we only use QoBD codes.

2. Design

In designing a chart overlay to display bathymetric uncertainty the goal should be to make the codes both clear, memorable and easy to read accurately. In addition, an overlay should minimally interfere with other information represented on a chart.

One option would be to use color codes, either as solid colors or transparent overlays [DQw17]. However, color coding is problematic because color coding is already used extensively on charts, and opaque colors will necessarily obscure under laying information such as color coded depth regions. Transparent colors may obscure less, but transparent colors will combine with the underlying hues to produce an appearance different from either and may be difficult to read accurately. For these reasons we chose to investigate the use of see-through "lacy" [WC96] textures to represent ZOC values.

We also determined to design quantitative textures so that the ZOC categories could be read directly without reference to a key. At this point we will turn our attention to briefly review the way that textures have been previously used to represent spatial information.

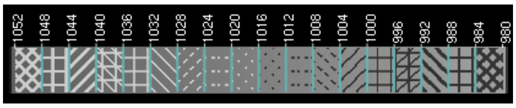

Figure 2: *A set of ordered textures (from [WP13])*

To be useful in displaying quantitative data it is important that a set of textures be perceptually ordered in some way so that the quantity represented be understood intuitively. Ware and Knight [WK92] proposed, based on perceptual theory, that the primary orderable dimensions of texture are the size and density of elements as well as their orientation if elongated, and amplitude or contrast. Bertin [BBW83] recommended using the texture grain – defined as the number of marks per unit area. Healy and Enns [HE99] showed that texture density, regularity and height could be used to display independent variables. However, a drawback of using a continuous variable like element density, size or orientation is that any continuous single variation (such as element size) is likely to be susceptible to simultaneous contrast effects causing errors in the same way that simultaneous lightness or color contrast can cause errors in color-coded maps [CC83, WK92]. As an alternative, Ware proposed the use of quantitative textures [War09]. These are a series of textures, where each texture is qualitatively distinct from the previous one, and where the textures appeared to be ordered as a sequence, for example in density. Ware and Plumlee [WP13] used a sequence for these textures to show atmospheric pressure in a weather display as illustrated in figure 2. In the designs we present here, we went one step further and designed textures with countable elements so that no key would be needed in reading the codes. Since there are only a small number of QoBD categories, orderable quantitative textures are ideally suited to this problem.

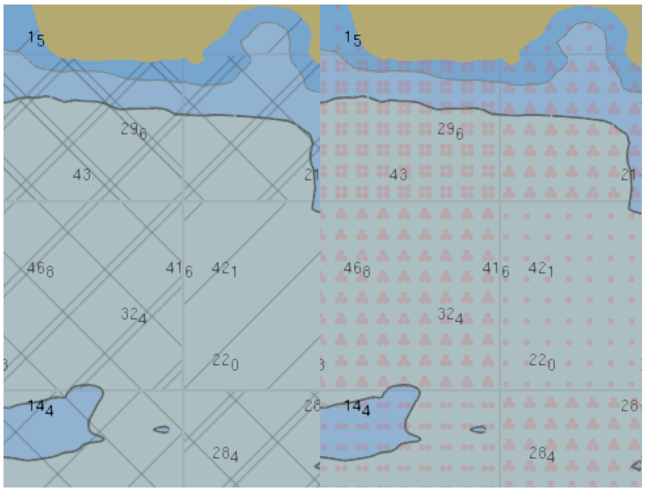

Figure 3: *Textures with countable elements: Lines and dot clusters.*

We used an iterative design process to develop two solutions for the representation of QoDB categories. The authors each developed one of the designs and iteratively refined it, taking into account comments and suggestions from the other author. Both of the designs incorporate the idea that as uncertainty increases the density of the texture should also increase. This ensures that safe areas are minimally cluttered, while unsafe areas stand out clearly. Both designs also incorporate the idea of quantitative textures, achieving this by means of countable features: the number of features in a single texture element corresponds to the QoBD category. A OoBD region consists of texture elements repeated in a regular square grid. There were many design decisions, for example, the dots clusters were more closely spaced than the lines, giving the a more textured appearance. The designs we present here are the result of this iterative process; however,w make no claims that they are optimal. The designs are illustrated in Figures 3 and 4 and described below, together with three alternative color-based designs.

- **Line Count (LINES):**In this solution, the QoBD category is represented by diagonal lines sloped 45 deg left and right, constructed such that the number of lines in a texture element represents the ZOC category, as shown in Figure 4 . The spacing and size of the elements was set to achieve a minimal level of clutter with a reasonable amount of detail.
- **Dot Clusters (DOTS):** In this solution, the QoBD category is represented by a dot cluster, constructed such that the number of dots in a texture element represents the ZOC category, as shown in Figure 4. Small elements closely spaced make that this solution capable of representing smaller QoBD regions.

For comparison with the texture solutions we included the following other coding schemes in the evaluation.

- **Opaque Colors (COLS):** QoBD categories are represented by means of five opaque colors. We include it because it is frequently suggested as a solution in the hydrographic community.

While color has been shown to be effective for representing area uncertainty, this method completely obscures depth area color coding.

- **Transparent Colors (TRANS):** QoBD categories are represented by means of a single color (yellow) with five levels of transparency. Transparent color overlays blend with background colors which can make them difficult to read.
- **Color Textures (COLTX):** Transparent colors are used with trapezoidal texture elements. The use of texture makes it easier to distinguish QoBD colors from the background colors. The purpose of this solution is to better preserve background information through transparency and partial coverage while being easier to read compared with continuous transparent colors.

We chose to use a vertical-horizontal grid coding for the "unassessed" QoBD category to make is qualitatively different from the other categories which have specific error bounds associated with them.

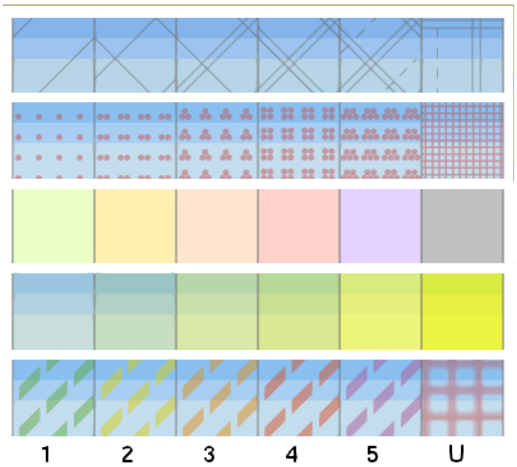

Figure 4: *The two texture codes and three color codes used in the study. Top to bottom: Line Counts, Dot clusters, Opaque Colors, Transparent Colors, Color Textures*

3. Rationale for the Evaluation

We have previously conducted an evaluation of these textures and colors by means of an on-line survey of the maritime community [KW22]. On average, the results suggested that the texture solutions were preferred. However, the overall preference data was somewhat bimodal. Some of the participants strongly preferred textures and some preferred color. Even though participants were asked to judge according to objective criteria, factors such as how much the difference schemes obscured other data, how clear or memorable the coding schemes were, there was some evidence that some were not being objective. For example, many of them rated opaque colors highly on the criterion of not interfering with other chart information, even though the opaque colors completely obscured color coded depth areas. Hence the development of the present study designed to provide a more objective evaluation of how quickly and accurately the alternative codes could be read, and also how easily codes could be remembered and used in the absence of a key.

4. Method

Synthetic chart generation software was used to create chart-like displays as the background for ZOC coded overlays. An example is given in figure 4. The purpose of this synthetic chart was to create a background having the appropriate level of detail and chart features for the purpose of evaluation. It makes it possible to create a new synthetic chart, based on random parameters, for each trial. Had real charts been used only a small number of backgrounds would have been possible. Moreover, the synthetic chart software means that the stimuli can be easily tuned to answer different questions.

The sequence of a single trial in Experiment 1 was as follows: • Blank 0.5s • 2 sec showing synthetic chart display with one on the coding schemes. • 1 sec showing synthetic chart display with cursor designating a randomly determined position on the chart. • Wait response – The chart remains, but the cursor disappears. During this interval the participant had to respond by hitting the key on a computer keyboard corresponding to the appropriate category. Each trial involved a different randomly generated synthetic chart with a different ZOC zone overlay and a new, randomly determined cursor position.

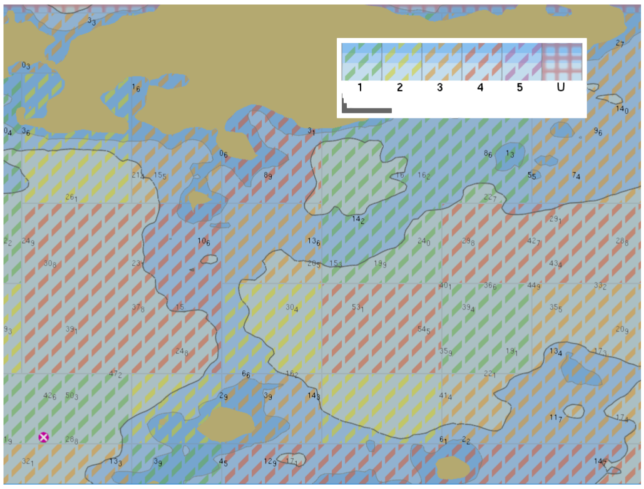

Figure 5: *Example of synthetic chart display with Colored Textures.*

4.1. Procedure

Participants were first given a Snellen eye chart to determine that acuity was 20/20 or better. They were then seated in front of the screen and shown the 5 different ZOC overlays with the features of each being explained. Following this they were given a training session with blocks of 3 trials, with trials within a block having the same ZOC encoding. ZOC trial blocks were presented in a different random order for each participant. Following this, experimental trials were arranged in blocks of 10 trials having the same ZOC encoding. The 5 trial blocks (one for each encoding) were presented in a different random order for each participant. The set of 5 trial block was repeated once yielding 20 trials for each ZOC encoding per participant. Within a trial block the cursor was randomly placed; there was no attempt to ensure that ZOC categories received the same number of trials, although since they were equally likely, this would be approximately the case. Experiment 2 immediately followed experiment 1. It was designed to test the ability of subjects to remember the different coding schemes and use them without a key. It was always run immediately following experiment 1, to take advantage of the learning that had already taken place. The sequence of a single trial in Experiment 2 was almost identical to that of Experiment 1. There were two critical differences: the key was not shown on the chart during the trial, so that study participants had to rely on memory in making their responses; also, prior to each block of 10 trials, the key was shown for 30 second as a memory aid.

5. Results

The results from Experiment 1 are summarized in Figure 6. Response times were measured from when the location indicator first appeared on the screen. A two way ANOVA (Subjects, Conditions) and a set of Tukey HSD comparisons was run for the mean response times. This revealed the following four overlapping groups labeled A, B, C and D [(DOTS A), (COLS A,B), (COLTX B,C), (LINES C), (TRANS D). Coding schemes not sharing a group label are significantly different. For example, this means DOTS and COLS were not significantly different (both A), but DOTS were faster than the other codes. The transparent codes had their own group (D) and were significantly slower than all other conditions. There were much greater error rates for the TRANS coding, while the other error rates were low and not significantly different.

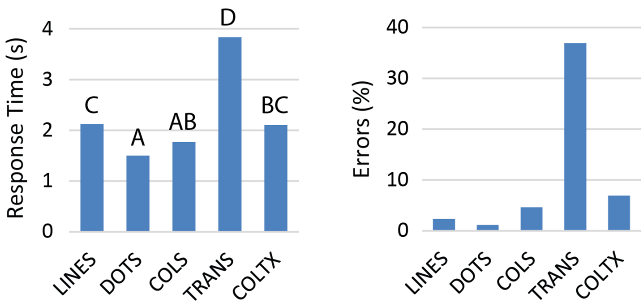

Figure 6: *Experiment 1 results: (left) Response times. (right) Errors*

The results from Experiment 2 are summarized in Figure 7. Response times were measured from when the location indicator first appeared on the screen. A two way ANOVA (Subjects, Conditions) and a set of Tukey HSD comparisons was run for the mean response times. This revealed the following four overlapping groups labeled A, B and C [(DOTS A), (LINES A,B), (COLS B), (COLTX B), (TRANS C). DOTS and LINES were not significantly different (both A), but DOTS were faster than the other codes. The transparent color codes had their own group and were significantly slower than all other conditions.

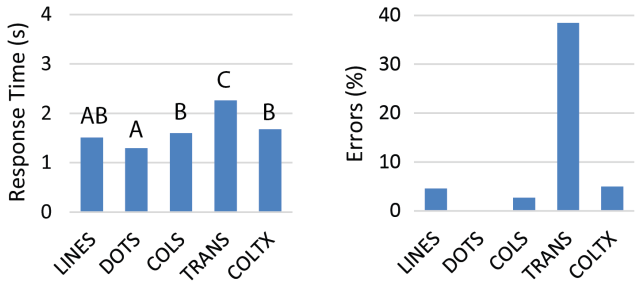

Figure 7: *Experiment 2 results: (left) Response times. (right) Errors*

6. Conclusions

Overall, the dot cluster coding produced the fastest response times and the lowest error rates. The transparent color coding scheme yielded the slowest response times with very high error rates and clearly would not be suitable. Although the differences between most of the conditions appear relatively small, except for the case of transparent color coding, this is somewhat misleading. These times represent a sequence of perceptual and cognitive processes. First the target location is identified; second, a saccadic eye movement made to that location; third, the type of ZOC code is identified, fourth a key response is programmed into the neural system controlling the fingers and a key press is executed. A choice reaction time can be expected to take at least 0.55 sec.(e.g. [WWY*15]) and the visual search for the test cursor location may have taken an additional few hundred milliseconds. Therefore, it is safe to say that there are *relatively* large differences between cognitive processing times for the different coding schemes. When route planning a mariner will look at many areas of a chart using rapid eye movements. The benefits of an easy to read symbology could be considerable because it reduces the cognitive load and frees capacity for reasoning about the planned route.

Nevertheless, there are other criteria for choosing a representation of data quality. The dots clusters may be judged to add more clutter to the chart relative to lines, for example. Or, if people strongly prefer color, the transparent textured color solution produced far more accurate results than the transparent colors, while not obscuring the background, like opaque colors.

The results differ from those obtained with the prior survey of mariner preferences [KW22]. For example, in the survey the textured colors were rated lower than transparent colors and dot clusters were not rated as highly as lines. This is perhaps unsurprising given that mariners are not trained in the the kind of visual task analysis that graphical designers develop with experience. However the results agree with the one survey question that objectively assessed the identifiability of a single QoBD code.

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