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GENERAL GUIDELINES FOR THE USE OF COLOUR ON ELECTRONIC CHARTS

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Abstract

An Electronic Chart Testbed has been developed by the Canadian Hydrographic Service for the purposes of investigating design and safety aspects of using electronic charts as a navigational aid for mariners. The proper selection and specification of colour is a fundamental aspect of effective display design. This report outlines the issues involved in the use of colour on displays as they relate to the Electronic Chart Display and Information System (ECDIS). Topics include luminance, high and low ambient illumination, brigthness, display background, colour selection, information clutter, colour coding convention, stimulus size, image location, visual effects, and user characteristics. Since ECDIS is relatively young in its development, the purpose of the review is to provide some general guidelines for selecting and using colours on electronic charts.

THE ELECTRONIC CHART DISPLAY SYSTEM

The Electronic Chart Display and Information System (ECDIS) is a computer-operated navigational display system that allows the mariner to track the course of his ship on an electronic chart. The display provides an overhead view of the ship and surrounding water, land, and objects. Radar information may also be overlaid on the electronic chart. ECDIS is updated in real time, displaying information quickly and realistically. The main purpose is to provide the necessary information in close pilotage conditions such as busy harbours [1].

The chart aspects of ECDIS are, in many respects, similar to conventional paper charts. However, designers recognize that merely digitizing the paper chart is not appropriate [2]. Numerous factors including clarity, clutter, reliability, and

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priority of information must be considered in the design of efficient electronic charts. The use of colour is also important. The purpose of this paper is to outline how the proper use of colour can enhance the transfer of information from the display to the mariner.

Colour Display Issues

Most of the research on the use of colour on electronic displays investigates the discrimination of colour coded items with relatively little emphasis on a more overall analysis of display design. Findings based on simple laboratory studies may not provide the complete basis required for the selection and application of colour on complex charts. The perception of complex images is often governed more by global characteristics than local and isolated details. The designer should always consider the overall appearance of the chart and recognize the importance of conspicuity (relative emphasis) and comprehensibility (understanding meaning). Composing graphic elements in a manner that corresponds to the practical requirements of the user and the relative importance of displayed information will lead to order and clarity on charts. Chart design should be driven by overall integrity of the display.

Numerous complex and interacting environmental, hardware, and human factors issues determine the effectiveness of colour display systems. The following discussion is aimed at addressing the most important factors and issues to be considered when designing electronic charts. The topics include luminance, high and low ambient illumination, brightness, display background, colour selection, information clutter, colour coding convention, stimulus size, image location, visual effects, and user characteristics. Principles derived from cartography will be included where applicable.

Luminance

Currently, the shadow mask Cathode Ray Tube (CRT) is the only feasible option for electronic charts. With the CRT, one-third of the shadow mask is dedicated to each primary colour (red, green and blue) and each phosphor dot has a surrounding inactive area. The result is that a shadow mask CRT produces less than one-third the luminance (measured intensity of light) of a monochrome display. The implication is that the luminance range for colour monitors is not as great as for monochrome displays. The restricted luminance range of the CRT limits display contrast, which is an increasing function of the luminance difference between the target and the background.

Changes in the luminance of a coloured image can cause changes in perceived colour and saturation (saturated colours appear pure and rich; desaturated colours appear weak and washed-out). At either very low or high luminance levels, colour images may appear to lose their colour, depending on the size and nature of the display background. For display purposes, effective colour range and perception can be obtained between 30 to 300 cd/m^2 [3]. A typical luminance value for white paper on an office desk is about 200 cd/m^2.

High Ambient Illumination

ECDIS will be installed on the bridge of a ship where the surrounding light or ambient illumination can reach very high levels, (approximately 80,000 lux in bright sunlight on a cloudless day). Different colours used for coding information on a screen must be discriminable in the highest levels of ambient illumination. Applications under these conditions require high luminance output from the monitor. Incoming sunlight can reflect off the display, significantly reducing luminance contrast of displayed information. During daylight operations, ambient illumination can mix with display luminance, thereby changing CRT colours. The most apparent effect is a washing out of colours or desaturation. The number of discriminable colours is reduced with desaturation [4].

The reduced contrast of the colours on displays, and desaturation caused by high ambient illumination from the sun, make it necessary to reduce the amount of sunlight falling on the CRT. Screening daylight can be accomplished by using filters or anti-reflection coatings on the faceplate of the monitor. The best solution to this problem is to shield the entire workspace from daylight by separating the display workstation from its surroundings; for example, by building a compartment enclosing the workstation. This solution, however, is not practical rator to see out of the bridge windows as well as read information from the display. of the requirement for the opeA compromise solution is to fit the windows of the bridge compartment with neutral density or polarizing filters. Cross checking the display with surroundings is difficult with curtained compartments, whereas filters allow some daylight to pass through, permitting observation of the ship's environment from the bridge. Another method often used to block sunlight is a viewing hood placed over the display. The use of a viewing hood allows observation of surroundings, but consequent rapid changes in light intensities from daylight to the viewing hood causes fatigue and increases the chance of overlooking signals on the display [5].

Displays must be able to accommodate changes in the state of adaptation of the operator's eyes. In some situations, an operator may be visually adapted to a higher luminance level than that produced by the display. Such situations are likely on the bridge when operators are visually adapted to the high luminance levels of sunlight. The adjustment of the eyes to higher luminances causes degradation in the perception of colour when displayed on lower luminance displays. In general, investigators have found that visual recovery is very rapid if the adapting luminance is no more than 100 times the display luminance [6]. This level can be exceeded when an average amount of sunlight comes in through a window of a bridge. Again, the problem of using colour displays in the presence of sunlight may require some way of reducing ambient illumination.

Low Ambient Illumination

For night viewing, the luminance of the monitor must be sufficiently low so that it does not interfere with the performance of tasks that require good night vision. Specifications for aircraft colour displays state that the maximum luminance for night operation should be equal to 5% of the peak day-time levels [6]. This specification is probably too high for ship operations because at these levels the luminance radiating from the display may interfere with the performance of bridge personnel, who must maintain dark adaptation. It would be useful to establish an equivalent for use on ships.

It is difficult to maintain colour tolerances and uniformity requirements when low luminance levels are used. As a rule of thumb, most display systems are capable of meeting the requirement that most colours will be discriminable down to a luminance level of 0.34 cd/m^2 [3]. Below this level, problems of distinguishing between some colours may occur. On many displays, luminance is controlled by a manual dimming control that varies the display luminance. As the luminance is decreased by means of this control, colours with more input from the blue and red gun will be affected before others. Automatic luminance adjustment rather than manual adjustement is recommended and the system should be set so that the minimum setting is still within colour tolerances.

Alternative methods of controlling luminance include automatic luminance compensation which changes the luminance of the display as a function of the ambient illumination falling on the screen, and automatic contrast compensation which varies the contrast ratio of the display as a function of ambient lighting. These methods require extensive testing to ensure the maintenance of colour specifications.

Luminance tends to decrease as distance from the centre of a CRT display increases, because of the electron beam geometry of a CRT. Luminance degradation between the centre and edges of the CRT increases when the overall luminance of the display is low. The luminance variation of any one colour between the display center and any other location within the usable area of the display should not vary by more than 20% over the entire luminance range [3].

The problems caused by low illumination can be partly overcome by placing the display in a screened compartment as described earlier. Screens can be kept in place at night to prevent the light from the display interfering with other bridge operations. If low luminance levels can be maintained without violating colour tolerances, the screens can be removed to allow viewing of the surroundings. The use of an enclosure, however, may conflict with other needs of the mariner on the bridge such as easy mobility and unobstructed and clear view of the surroundings.

Brightness

The terms *luminance* and *brightness* are not synonymous. Luminance is measure of light energy based on the relative sensitivity of the eye. Brightness is the subjective attribut of light sensation. Brightness is more difficult to assess than luminance and is influenced by viewing conditions such as display background and viewing conditions. Measures of luminance can yield relatively poor estimates of brightness. Colours that have the same measured luminance do not necessarily appear equally bright. The most obvious discrepancy between luminance and brightness occurs in the comparison of colours with blue. Blue can appear more than twice as bright as yellow when compared at equal luminance levels. Brightness differences can result in altered performance. For example, under high ambient lighting conditions, (10^5 lux) the use of red and blue can result in better performance than green or yellow. To be equally visible under these conditions, green should be three times the luminance of red [7]. Equal luminance measures cannot be used as an indication of equal brightness for different colours. Luminance levels needed to make colours appear equally bright have been derived and are available [8, 9].

The control of colour brightness in cartography is imperative for transmitting information. Thought should be given to how bright different colours should appear. In some cases, it is desirable to have some colours brighter than others. In other cases this variation in brightness may interfere or distract from the task, and equal brightness across colours may be more appropriate. Important symbols should stand out by being brighter than the surround and less important symbols. To avoid distraction, large colour-filled areas should be adjusted so that they are not as bright as smaller symbols and areas.

A number of studies have indicated that observers have some difficulty in focusing on edges that do not differ in colour brightness. In these circumstances, edges appear fuzzy and indistinct [10]. Optimal borders should have both colour and brightness contrast to enhance discrimination.

Display Background

For enhanced colour distinction, a light display background is better than a dark display background [3]. Colour symbols and lines on a light background are perceived as more pure or saturated than the same colours presented on a black background. It is also likely that the effects of small symbol size and dark background combine to produce desaturation. Colour displays using small symbols against a dark background will result in a noticeable decrease in the perceived colours of the symbols. This is especially true under low ambient lighting conditions, as found on the bridge of ships at night. Colours that are low in purity, such as yellow or cyan, may appear colourless and confused with white [11]. In addition, imperfections in the display such as misconvergence, internal reflections, and positional instability are more perceptible when the background is dark. Increasing visual sensitivity to colour by surrounding symbols with a light background facilitates discrimination and reduces confusions.

A light background, however, may not be ideal under all circumstances. For instance, the extra light from large background areas may interfere with personnel who are required to maintain dark adaptation at night. Under these conditions, the luminance of the background may have to be reduced to maintain contrast.

On a black background where symbols and background vary only in luminance contrast, acuity increases with increasing contrast. The best legibility can be expected when colours from the mid-range of the spectrum (i.e., green, yellow) are used. As colours move towards blue or red, legibility degrades. These effects occur when observer's acuity is pushed to the limit (e.g., by small symbol sizes).

Colour Specification

As the use of colour on electronic charts becomes common, it will be necessary to standardize colours. A major problem with using colour displays is the lack of clear standards for colours and symbols. Typically, colour-coding has been specified only by identifying the colour name without specifying a quantitative measure of colour. This lack of quantification has led to the use of colour sets that differ from one another. The best method of specifying colours is the 1931 or 1976 CIE (Commission Internationale de l'Eclairage) system of colour notation. There are numerous colour standards using the CIE coordinate system. A comparison of these standards reveals that there are considerable differences between them [12]. Standards are specified either as a set of specific colours or as colour regions with tolerable ranges of colours. The problem with using a single set of colours is that it is unlikely that all display systems will be able to reproduce a specific colour set. On the other hand, the difficulty with the use of colour regions is determining the extent of the allowable ranges. Various attempts have been made to overcome these problems using computational [12] and empirical [13, 14] methods, however, no satisfactory solution that can be used under all conditions is apparent. Despite some of the problems with the CIE method of colour measurement, it is the best method for colour specification. The use of CRT-specific units (such as RGB, HLS notation) are not recommended since they can result in colours that differ from one ECDIS to another.

Another approach to ensuring discriminability among colours is based on the CIE colour difference formula [15, 16]. This method requires that colours be separated by at least 40 units on the 1976 CIELUV colour space. Although the use of this criterion offers some advantages, it has been questioned whether this metric is appropriate [6, 17]. Selecting colours on the basis of colour differences presents a problem because this procedure does not consider the actual appearance of the colour. Colours chosen by this method may be discriminable but they may not meet viewers expectations. Recognizing these problems and the limitations of the CIELUV system, an optimized colour set with specific chromaticities, or regions from which specific colours can be chosen have been developed [14, 18].

Colour Selection

In general, as the difference between the dominant wavelength of two colours increases, the ability to discriminate between those colours also increases, [13]. However, there is a trade-off between heterogeneity and homogeneity when colours are used on charts. Displays can appear unorganized and cluttered when using heterogeneous colours. Large differences across colours should be used for classes of information that are unrelated in order to maximize separation. Related classes of information should be coded with small colour differences to achieve integration. On most maps, discriminable differences for the same class of information are coded using smoothly graded saturation differences of the same colour, whereas distinct features such as water and land are coded in different colour. Saturation coding (the same colour with different levels of luminance) increases the number of colour dimensions available. Caution should be taken to ensure that saturation coding does not produce colours that are difficutlt to see under some conditions, e.g., high ambient lighting conditions.

The number of colours required for an effective colour coding strategy is closely related to colour selection. Colour discrimination is strongly affected by the number of colours used. As the number of colours used increases, so does the probability of confusion between colours, the time required to detect any specific colour, and the demands on the hardware for reliably reproducing each colour [19]. The optimal number of colours chosen will depend on the visual task. Absolute colour discrimination involves the recognition and identification of colour. Comparative colour discrimination requires the comparison of simultaneously displayed colours. The number of discriminable colours and the accuracy of colour selection is much greater for comparative judgements than for absolute judgements [3]. Thus, for example, it is much easier to distinguish between the different depths of sea from their colour coding than to identify the exact depth range from the colour. Typically, colour coding involves applications that use colour to qualitatively distinguish between members of a set, thereby requiring recognition and identification. Numerous investigators have attempted to determine the exact number of colours that can be recognized with varying results. Up to as many as fifty colours can be recognized reliably depending on the methodology and training [6]. However, for operational colour displays, a repertoire of three to four colours is recommended if absolute colour judgements are made. Six or seven colours can be used with a maximum of ten when applications require comparative discrimination [3].

Given the restriction of easily discriminable colours, an important consideration ECDIS is to determine the total number of symbols and classifications that require colour coding and assign colours to them. The total number of colours used should be kept at a minimum, and there should be careful consideration concerning the priority of information to be colour coded. If the number of colours are determined before implementation, the difference between them can be maximized for the best possible discrimination using colour difference formulas.

Information Clutter

Closely related to the problem of choosing the optimal number of colours is deciding how much information should be displayed to ensure maximum performance. Empirical studies repeatedly show that performance deteriorates as information density on a display increases [20]. A common theme in display guidelines is that only relevant information should be displayed and that the total amount of information should be kept to a minimum. Large amounts of displayed information can cause confusions and increased error rates. As more information is added to the display, there is potential for resulting clutter to cause a decrease in performance. A field study conducted on the Canadian electronic chart development investigated the effects of information quantity on ECDIS. Nine cartographers and navigators were asked navigation questions on three different displays. The displays consisted of a standard paper chart, an electronic chart with the same amount of information as the paper chart, and another electronic chart with the minimum set of information required for safe passage. Results showed some evidence that simple charts are easier to use than complex charts [21].

Colour Coding Convention

Similar colours should have the same or similar meaning across displays. Colours should also be compatible with the experience of the user. For example, the conventional meaning for the colour red is danger or threat and is reserved for important information. If this meaning is used for one display, it should be used consistently whenever the same colour is used. Electronic charts should use the colour coding conventions of paper charts as a starting point.

Conventional uses of colour that are generally accepted for hydrographic charts include the following associations.

1. Blue — water, depth shades and contours
2. Green — intertidal foreshore, drying areas
3. Yellow, tan — land areas
4. Brown — topographical contours, built-up areas
5. Red, magenta — navigational aids, routes, limit lines, important information
6. Black — used for text, buoys, line features

Conventions are useful only when they convey the intended meaning more effectively than any other method, and this is difficult to predict unless empirically tested. Violations of conventions may attract attention [22]. Relatively inconspicuous items will attract attention if they are coded in an unusual colour; this may be undesirable.

Colour Stimulus Size

The size of the colour field or image can have dramatic effects on the perception of colour. The perception of colour is reduced for small symbols such as those used on hydrographic charts. Smaller symbols appear less saturated and sometimes appear different in colour compared to larger targets [23]. Hue, saturation, and brightness appear to increase up to field sizes of 10°. The ability to discriminate along the blue-yellow continuum is particularly reduced for small field sizes. In general, the use of symbols subtending less than 15 minutes of visual arc (about 3 mm for a symbol viewed a half meter away from the display) seriously reduces colour perception and discrimination. However, reduced sensitivity to colour differences can occur when field size was reduced from 2 degrees to 30 minutes of visual arc [24]. Symbols coded in the blue-yellow continuum should maintain a size larger than 20 minutes of visual arc. Minimum size requirements increase with the number of colours used. If six colours are used, 45 minutes of visual arc is recommended . Coloured symbols should maintain the conventional width/height aspect ratio of 5:7 or 2:3; a standard recommendation for characters [7].

The choice of size of coloured symbols and the width of coloured lines are important for electronic charts if scale changes are implemented. One method of scale change is similar to a photographic zoom, where the symbols change in size with scale changes. Coloured symbols on the electronic chart at the smallest scale would be difficult to distinguish because of their reduced size. The smallest symbols should not be smaller than the recommended criterion for small symbols. This is especially critical if symbols are non-redundantly coded, since important information may be lost if colours are not perceived. A preferable method of implementing the scaling feature for symbols is for the size of symbols and characters to remain constant over all scales changes. The scale of the chart should be displayed to inform the user of the current scale level of the chart. A standard size for symbols would ensure that all colours would be discriminable. This size should be larger than the standard size used for paper charts because of reduced resolution on electronic displays.

Colour Image Location

Perception is influenced, in part, by the area of the human retina that is stimulated by the visual input. The density of cone receptors (i.e., receptors required for differentiation between colours) reduces rapidly towards the peri-phery of the retina. The foveal region encompassing the central 1° to 2° of visual angle has the highest concentration of cones. Beyond 10° to 15°, rod concentration predominates and there are only a few cones. The fovea, which is maximally sensitive to detail, is less sensitive to blue. Consequently, small symbols requiring maximal sensitivity to detail are not seen well in pure blue. Pure blue is not recommended as a colour to code alphanumerics or thin lines, unless they are unusually large [7]. In addition, areas on the retina are not equal in sensitivity. Blue/yellow sensitivity extends further than red/green sensitivity [3]. In general, it has been suggested that colour can be used effectively only up to 10 to 15 degrees of visual arc towards the periphery. In most cases, scanning and fixating on stimuli located in the periphery of the visual field overcomes this problem. Red appears to be the poorest colour for peripheral colour perception [7].

Visual Effects

Designers and users of colour coded visual displays may be confronted with peculiarities produced by the human visual system. Most notable among visual oddities is the effect of chromatic induction, a phenomenon that occurs when the perceived colour changes drastically in the presence of adjacent colours. In general, the change in colour will be in the direction of the colour that is complimentary to the one producing the effect [25]. For example, a green background will result in shifts in the direction of red for the foreground colour and vice versa.

Another visual effect occurs when a change in the luminance of coloured lights is accompanied by a change in colour. Known as the Bezold-Brucke effect, it occurs when a rise in intensity causes colours in the middle to long wave range of the spectrum (towards the red end of the spectrum) to shift in the direction of yellow. Also, a rise in the intensity of colour in the short wave region of the spectrum (towards the blue end of the spectrum) will result in a shift towards blue. This effect occurs even when the dominant wavelength is held constant and only the perception of brightness changes. If, for example, the perceived brightness of an orange light is reduced by surrounding it with a brighter background, then the perception of the orange light will shift towards red.

An optical effect that may cause difficulty when viewing over a wide spectrum of colours is chromatic aberration. This refers to changes in accommodation required for focusing of different colours. The use of maximally different colours may be tiring over time because the eye must continuously refocus.

Users of colour displays have noticed that some colours appear to be at different plans from others. Colour stereoscopy is most notable with red and blue symbols, with red appearing nearer than blue. If this effect is found to be annoying, less saturated colours are recommended. However, it should be remembered that desaturated colours are less discriminable.

The effects of these visual anomalies may be minimal, but under certain conditions, for example, under stress or fatigue, they may be bothersome or cause confusion between colours. For these reasons, the sources of visual anomalies should be avoided where possible when designing colour displays.

Visual Characteristics Of The User Population

Important visual characteristics that affect colour discrimination include acquired and congenital colour vision defects. These defects not only include problems due to injury and disease, but defects acquired as part of the normal aging process. Visual acuity and the ability to discriminate between colours gradually deteriorates after the age of 25 (23). The ability to discriminate between colours with blue or yellow components deteriorates first, followed by discrimination between colours containing red or green (3). Colour vision defects also include congenital deficiencies. The incidence of all deficiencies is higher in males than in females with red-weak and green-weak accounting for 5.9% of the male population (26). The age and colour vision characteristics of potential users of colour displays are important considerations in display design. For most applications that require colour displays, the population can be screened for colour vision deficiencies (for example, professional mariners), however, screening does not provide a complete solution, since potential users of ECDIS may not be subject to such tests (for example, yachtsmen). If older or untested operators are to use coloured displays, a number of options should be considered. These include: the use of colours that contain a mixture of all three primaries; avoiding small symbol sizes; using luminance differences between colours, and using redundant coding.

CONCLUSIONS

The use of colour can enhance the way people process information by drawing attention to, emphasizing, organizing, and differentiating images that appear on a chart. Using colour can improve performance by reducing the time to detect targets, increasing the probability of accurate responses, and reducing the amount of mental effort needed to deal with information. Given the benefits of colour for coding information, it is clear that electronic charts can use colour to communicate effectively. Some of the issues that influence effective communication of colour coding on displays have been discussed. In all cases, the design of electronic charts must begin with an awareness of these issues combined with an understanding of the user's task, information needs, and how information should be structured to match the priorities of the task.

The discussion of colour display issues can be summarized in the following points and recommendations:

1. High ambient illumination desaturates colours, thereby reducing discriminability. An enclosed compartment using filters to screen daylight is recommended.
2. Low luminance levels can cause colours to be less discriminable. Some colours are likely to disappear if luminance levels are too low, for example during night viewing.
3. Luminance uniformity across the screen should not differ by more than 20% for any of the colours used on the display. Variation across the screen is minimal for most high quality CRT displays.
4. Colour perception is enhanced when symbols are displayed on a light background rather than a black background. However, a light background should not be too bright, and in some cases, a dark background may be more appropriate. This is the case for night viewing when the dark adaptation of observers must be maintained.
5. The relative brightness of specific colours should be adjusted according to task demands. Colours that are too bright can be distracting.
6. Colour or shaped coded symbols should subtend more than 15 minutes of visual arc, and preferably 45 minutes of arc.
7. Redundant coding should be implemented for small, important symbols.
8. As the number of colour used for coding increases past an optimal amount, both error rate and reaction time increase. The number of colours recommended usually ranges between four and ten.
9. Where possible, colours should have the same meaning across displays. Coding in an unconventional way using unusual colours may cause interference by emphasizing unnecessary features. A survey of potential users should be conducted to identify the most widely accepted colour use convention.
10. Pure saturated blue should be avoided for alphanumerics and small symbols.

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