

# **Chromo-stereoscopy for Enhanced Viewing in Opaque Environment**

**Iman ABDEL HAMID, Victor ABBOTT, Samantha LAVENDER and Kenneth KINGSTON, the United Kingdom**

**Key words:** Chromo-stereoscopy, marine, dynamic, opaque

## **SUMMARY**

Varying depth perception resulting from using different colours is a phenomenon known as Chromo-stereoscopy (CS), in which objects equidistant from the viewer appear at different distances. This phenomenon has been deployed as a 3D visualising technique in different scientific presentations, such as remote sensing, and solar physics. In hydrography CS has been applied to static images of bathymetry, where the depth value was colour coded such that red was assigned to shoals, while the deepest values were coloured blue. Further applications of CS investigated its suitability when applied obliquely along the line of sight to perceive the distance separation between objects and varying view points. Both applications used static images which can be useful for visualising post processed data.

Considering the advantages of both CS applications, the tendency to present real time data and the unconventional use of colour, further research was needed to investigate the usefulness of CS in hydrographic applications in dynamic environments and the consequences of altering the colour conventions for some predefined cartographic symbols.

This paper will overview the research process including the identification of user groups and definition/ creation of application scenarios using the programming language Matlab. The results of interviewing different user groups and their opinions will also be presented.

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## **1. INTRODUCTION**

Depth perception is quicker and more reliable if the images have a three-dimensional (3D) content (Wickham, 1994). Humans perceive the world as 3D, although the input to their visual system is only two retinal 2D images. Seeing in depth requires a different set of properties commonly known as visual depth cues. These cues contain information, which when integrated with the 2D retinal image, enable viewers to reference the objects of an image to 3D space (Blundell, 2007; Toutin & Vester, 2000). Similarly, presenting a 3D dataset on 2D media (e.g. overheads, slides and computer screen) causes the loss of the sense of depth.

Depth in such cases can only be approximately inferred from visual clues in the image, such as perspective projection, shading, relative size and interposition. Such images do not require special lenses for viewing. In dynamic images, additional cues, such as motion parallax, and changing view angles can be used to overcome the shortage of dimensionality and reconstruct a clearer mental image.

More sophisticated methods employ binocular vision to reconstruct 3D images based on two images of a scene taken from slightly different points and channelled to the corresponding eye through hardware. This stereopsis is technically achievable in stereoscopic and auto stereoscopic methods, with equipment prices ranging from almost free to several thousands of pounds. A comprehensive review is available in Bouos & Robinson (2009). Yet the 3D effect can also be simply produced from a single image and very cheap glasses through Chromo-stereoscopy (CS).

This paper will explain the concepts of CS, and its current applications. Section two presents the focus of the current work, and the methodology used to investigate the factors that may interact with CS when deployed in a dynamic environment. The results are presented in section three, followed with a discussion and conclusion in sections four and five.

## **2. THE CONCEPT OF CS**

CS is a phenomenon in which the apparent depth of two coplanar identical objects can be perceived differently according to their colours (Toutin & Vester, 2000). Bright-coloured objects will appear to be closer than dark-coloured ones (Slocum, 1999). This is attributed to the transversal chromatic dispersion and the asymmetrical relation of the visual and optical axes (Howard & Rogers, 1995) that produces a physiological phenomenon known as advancing and retreating colour (Robinson, 1995); light entering the eye is refracted in

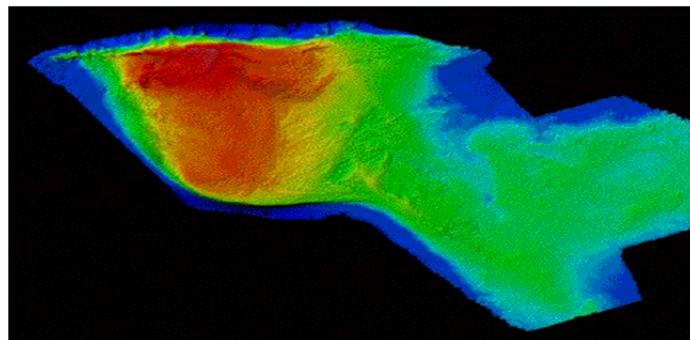
inverse proportion to its wavelength. Normally red colour looks closer than blue and this is known as Positive CS; rarely, the position of these colours can be reserved, causing Negative CS. CS effect is a function of several factors: viewing distance (Yamauchi, 2004), sight deficiency and the background colour of the image.

Although CS can be naturally perceived, most individuals are unable to see it. It can be significantly enhanced with chromo-stereoscopic optics commercially labelled as ChromaDepth glasses (available from Chromatek Ltd). The lenses of these 3D glasses are made of very thin clear diffractive micro-optic film that has the efficiency of the super-chromatic prism to increase the diffraction of the visible spectrum (Steenblik, 1987). A cross-section in the grating shows a saw-tooth profile with regular groove spacing (Ucke, 1998). When light rays of different colours hit the grating, they will be refracted to different angles.

### 3. CHROMA-STEREOSCOPIC APPLICATION

Many areas of research have benefited from the simplicity of CS. In remote sensing, Toutin (1997) and Petrie et al. (2001) investigated the application of CS to improve spatial perception of data by colour encoding of elevation variances in 3D maps. Verwichte and Galsgaard (1998) utilized CS in solar physics for numerical experiments with 3D data. Bailey and Clark (1999) tested the suitability of CS to present landscapes, 3D maps, 3D CAD models and models of chemical particles. McAllister (2005) used CS for interactive visualization of geographic and geophysical data. In different applications, Wallisch et al (2001) applied CS to highlight abstract information where the priority of the objects are linearly mapped to the perceived depth. The most recent use of CS, was in the medical sector to create an illustrative rendering framework for enhancing depth perception of complex vascular structures (Alan et al., 2008).

In hydrography, the Canadian Hydrographic Services (CHS) applied CS to enhance interoperating water depth in bathymetric data in a 'bird view' mode, where the spectral colour scheme (red, orange, yellow, green, blue, indigo, and violet) is conventionally used for displaying topographic and bathymetric data. In the CHS presentation (Figure 1), the number of colours used was based upon a histogram analysis of the depths instead of a linear application.



– **Figure 1 Image of seafloor generated from EM1000 multi-beam data collected on the FG Creed by the Canadian Hydrographic Service -Atlantic. It took sixty days and over 120 million soundings were acquired on Browns Bank:~ 130 km by 70 km (Lamplugh, Kearns & Craft, 1996)**

Ostnes (2005), unconventionally applied the spectral order colour to scale distance from the view point, hence the closest parts of the bathymetry were red coloured, and most distant parts blue-coloured. By presenting four models of hydrographic applications, Ostnes (2005) demonstrated the suitability of this 3D viewing system.

#### **4. RESEARCH FOCUS**

The two previous applications of CS in hydrography presented static data, but hydrography is an operational service carried out in a 3D dynamic world. Therefore, the potential use of CS in kinematic surroundings needed to be investigated. Although the oblique application of colours is useful; it does not follow the conventional display of bathymetric data where colour signal changes according to depth. Furthermore, the restricted use of colour associated with CS forces a change to some pre-established cartographic conventions, due to the loss of the categorization function of colour, in order to scale distance. These alterations from established cartographic rules and hence, user group acceptance is a major issue that required investigation.

The study was established to investigate participants' opinions about the benefits of using CS as a visual aid for hydrographic data i.e. its limitations and strengths. Further, the research investigated the interaction between chromatic aberration and hill shading and the consequences of changing view angles and changing cartographic conventions.

#### **5. METHODOLOGY**

To answer the research questions previously stated, two approaches were required: create models for the concepts in question; consult an appropriate user group to analyse their attitudes.

##### **5.1 Stimuli**

Based on the programming language Matlab, three marine-environment scenarios were created, an understanding of a bathymetric surface; navigation along a buoyed route; and flying a Remotely Operated Vehicle (ROV) along a seabed pipeline. All scenarios were implemented in a graphical user interface (GUI), to facilitate running the test, applying shading and changing view angles.

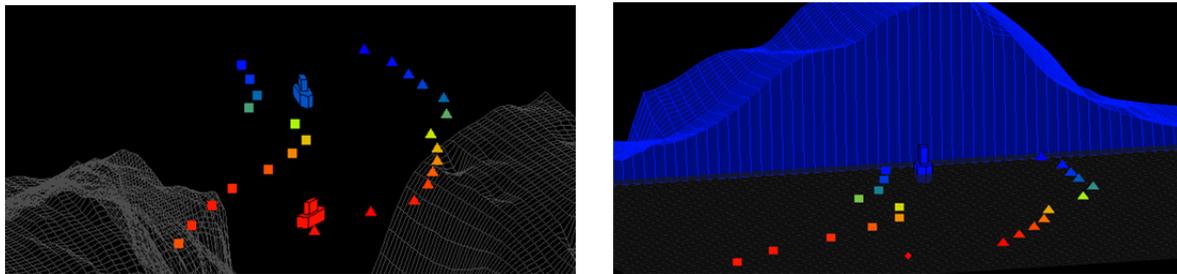
##### 5.1.1 Rotating Bathymetry

This scenario introduces the concept of CS and contrasts i) the differences between conventional displays for bathymetric data where colour is assigned along the Z axis (depth or height) and ii) the CS view where colour is applied along the line of sight. The two views are shown from a camera that is located at 30° above the horizontal plane, and rotating 360° around the view with 1° increments.

##### 5.1.2 Navigation Scenario

This scenario represents a navigation channel marked with lateral (red and green floating marks) buoys, and a vessel approaching the viewer. The buoys were represented with triangles and squares to model the reality of conical and can buoys aligned with conventional symbols used on navigational charts. In Figure 2 all objects are referenced to the nearer, red vessel. The left image is a snap shot of the scenario where the reference point is static (the

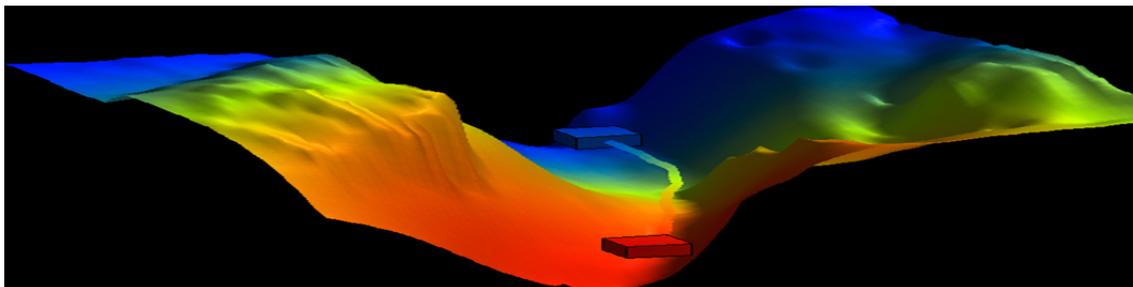
only moving object is the blue vessel), while the right image is a snap shot of the scenario when the reference vessel is moving (i.e. the point of view, the red vessel is apparently out of view as its position is represented by the nearest plane of the image).



**Figure 2** Two snap shots of navigation scenario in CS where colours are applied obliquely from a static reference point (left), and a moving reference point or plane (right)

### 5.1.3 Underwater scenario

Here the components are the seabed, two manifolds represented by two cubes, and a pipeline symbolized by a cylindrical object stretching between the cubes (Figure 3). The goal is to investigate if CS can aid underwater operators, to understand the topological relationships between ROV position, the objects and the seabed.



**Figure 3** A snap shot of underwater operation scenario

In these scenarios, objects colours were constantly updated according to their distance from the new position of the view point.

### 5.1.4 Additional effects

Besides the representation of CS in moving images, the interaction of shading and the view angle with CS were tested.

## **5.2 Subjects Sample and Recruiting**

A group of 30 marine-environment users were recruited. They represent divers, professional navigators and recreational navigators. In behavioural research, sample size should be 10% size of parent population (Alreck & Settle, 1995) and between 30 and 500 is recommended, with a minimum group size of 30 (Roscoe, 1975). However, a smaller size sample is justifiable for interview-based studies where each individual provides large amounts of qualitative data (Isaac & Michael, 1995).

Hence, the sample size was limited to 30 to be manageable in terms of budget (time and money) and acceptable to draw valid statistical conclusions for the general elements about 3D CS effect. Sub-groups of only 10 of experts are enough to give qualitative assessment for the

scenarios (Nielsen, 2000). The principal methods of recruiting participants were snowballing and gatekeepers (Flowerdew and Martin, 2005) occurred through the researcher network within and outside the University of Plymouth (UoP) Marine Institute. The invitation letter described the scope of research and what the participants were required to do. All participants were volunteers and interviewed according to their availability and convenience.

### **5.3 Conducting the survey**

Prior to commencement of research, the researcher gained Human Ethics Committee approval for the use of human subjects in this study. Contributors were individually interviewed. For some interviews, the researcher had to meet volunteers at their place of work, but most interviews occurred in a pre-booked, quiet office in UoP. Stabilising the interview environment assisted in eliminating external factors that can affect CS perception, like the viewing distance from the screen, the room illumination, providing a welcoming space for the volunteers and performing a smooth uninterrupted interview. All contributors were shown the same scenarios. For specialized questions, answers were given more weight depending on the interviewee's background and experience. For instance, navigators' responses to navigation scenarios were weighted more highly than responses from participants with no experience in navigation or sailing.

## **6. RESULTS**

### **6.1 Changing cartographic conventions**

#### 6.1.1 Use of colour to scale distance from view point instead of depth along Z

The immediate response of the participants on observing the rotating bathymetry and its changing colour was confused. The unexpected use of colour according to the distance from the view point proved perplexing until it later in the exercise as the participants got used to it.

Respondents attempted to understand the scene and to interpret the depth of the seabed in the vertical axis (Z): this was obvious by their behaviour and by what they said. With the obliquely coloured digital terrain model, they tried to re-orientate the colour to match their expectation by tilting their heads at right angles to the Figure, and focused their eyes to interpret it. They stated that this oblique view was strange; they were used to seeing vertical stratification of colour; and the new scheme did not help to understand at what they were looking. By running the scenario for a second time, the respondents were reminded that colour is scaling distance and not water depth. They grasped the new concept, and acknowledged its advantage in providing proximity information about the scene.

Recreational navigators, enthusiastically expressed interest in knowing the distance of seamounts, and shoals; even not necessarily knowing their depths. This understanding would warn them to a potential danger. They considered CS could be a useful additional tool to have, provided that it could accurately scale distances and synchronise with radar. Experienced participants, habituated to bathymetry coloured from red to blue, found it troublesome to interpret the scene with the oblique application of colour.

Professional navigators confirmed seeing the potential advantage of CS, but their acceptance varied between opponents and supporters. Supporters said that the CS scenario unexpectedly helped them to understand the form of the bathymetry, even though depth is not scaled, and that it puts objects in perspective. Some reported that the striking 3D CS effect highlights distance, which would be perfect if it could be combined with a depth scale. The objection to the application of CS stemmed from the belief that only depth matters to surface navigation: they would prefer to see bathymetry depth colour-coded (Z-axis) only. Most importantly, because depth is readily available from their traditional working tools such as paper charts, they are already familiar with it, and do not desire any modification to their conservative navigation world.

### 6.1.2 Altering the colour convention of Lateral Buoys

The majority of respondents, agreed that colour is one but not the most important visual characteristics of buoys for several reasons.

Buoys are uniquely differentiated in four respects: colour, numbers, top marks and lights. Thus, the absence of colour will not inhibit understanding their relevance. Changing colour is actually conventional, as even professional navigators are used to see two different colour conventions of lateral buoys - IALA B in USA waters and IALA A in western Europe. Also, in a situation of blind navigation very low visibility and / or going into the sun, the buoys' colours are unrecognisable and surface navigators rely on the buoys' shapes to recognise what they represent. On charts, objects are represented with black symbols and users interpret the shape only.

On the other hand, participants reported that confusion is likely to occur in the initial use of CS, especially when the screen shows a buoy as red due to its distance; it could be misinterpreted as a (European/ starboard) red channel marker. However, this confusion can be eliminated with training and clearly stating that navigation buoys are based purely on shape. The shape will be enough for people to recognise that a yellow conical buoy in the virtual display is green in the real world.

Recreational navigators, emphasized the changing colour convention is trivial compared to the improved aid of CS in situation awareness in a completely opaque environment. Most professional navigators approved its usefulness in fog, but considered it unnecessary as they could define the buoys representation through conventional methods and one of them declared the concept to be dangerous.

## **6.2 CS in kinematic representations**

The application of CS in a dynamic view has been demonstrated in navigation and underwater scenarios. In both scenarios, the colours of moving objects were altered frequently, according to their relative positions to the new view point or reference point; however the size was intentionally kept the same.

In navigation scenarios lateral buoys were represented with small triangles and rectangles, but ghosting and double vision occurred. The first reaction of some recreational navigators and some divers affirmed the usefulness of CS for anti-collision. They explained; the combined

effects of CS 3D and colour correlation helped users to perceive the relative position of the moving vessel and the buoys to the reference vessel.

In the underwater scenario, in isolation, CS will be a great tool to understand the proximity of targets. It helps to understand relative positions with the surrounding environment. It would be useful to see the scene in 3D .in conjunction with other tools, as in submarine operations the source of information is limited. For example, when ROV operators rely only on 2D images, it is difficult to deduce the distance between objects.

Divers stressed that CS can be enormously useful for pre-trip preparation, to explore a diving area or to visually brief them about how their journey underwater may become easier in both murky and clear water.

### 6.3 Interaction between CS and other methods of revealing information about 3D objects

#### 6.3.1 The effect of view angles

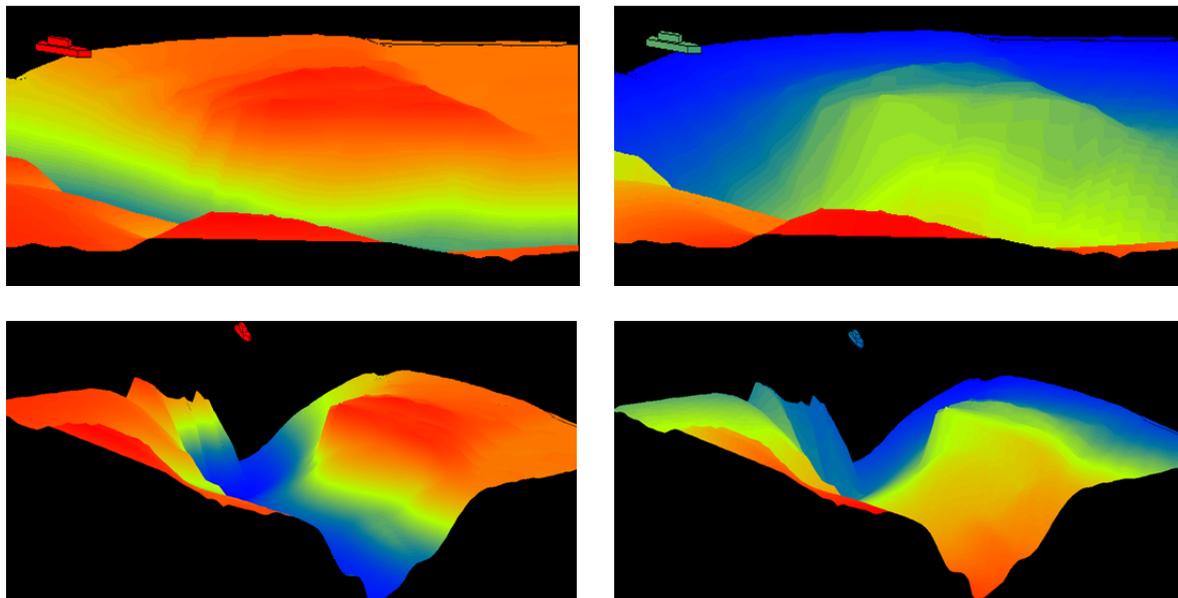


Figure 4 Set of snapshots for the view angles (elevation  $30^\circ$  and azimuth  $90^\circ$  (top row) and  $135^\circ$  (bottom row)). Left image are conventionally coloured along Z, the right images are obliquely coloured along distance from the view point.

With the scene viewed from different angles, participants perceived more information about the spatial awareness of the object, and some view angles were more useful than others. With the colour applied obliquely, and the image seen with ChromaDepth glasses, it aided participants to comprehend the content of the picture. The perceived enhancement varied in scale according the view angle: see figure 4.

The CS-based enhancement was clear when combined with a poor view angle,  $90^\circ$ , where the front section of the terrain obscured the sections behind. However when the scene is viewed from a view angle that revealed more details about the scene (such as  $135^\circ$ ), the advantage of CS was insignificant, even sometimes confusing (figure 5). Overall, displaying a scene with

CS technique from different view angles (figure 6) is beneficial, revealing more details about the scene from a specific view angle, than changing the view angle only.

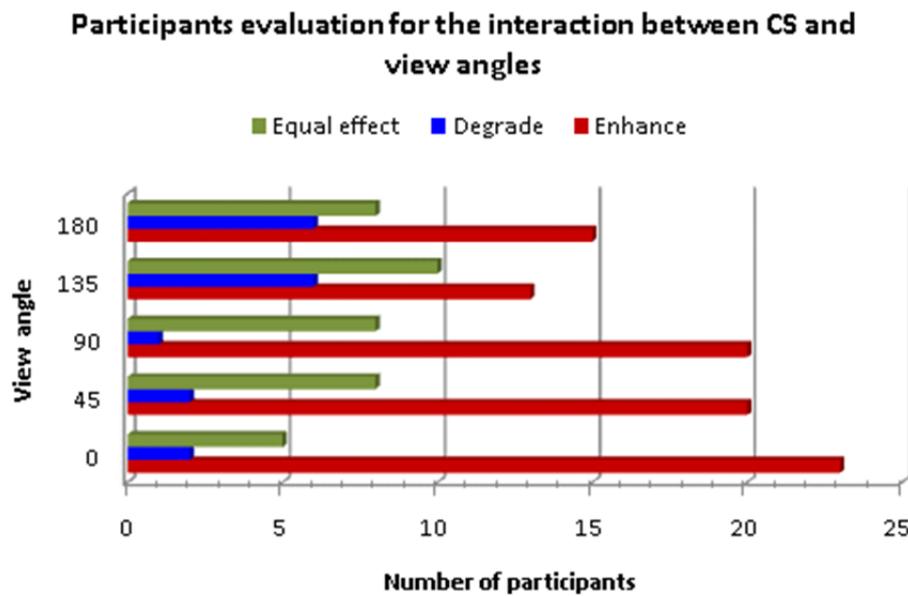


Figure 5 Participants evaluation for the interaction between CS and each view angle

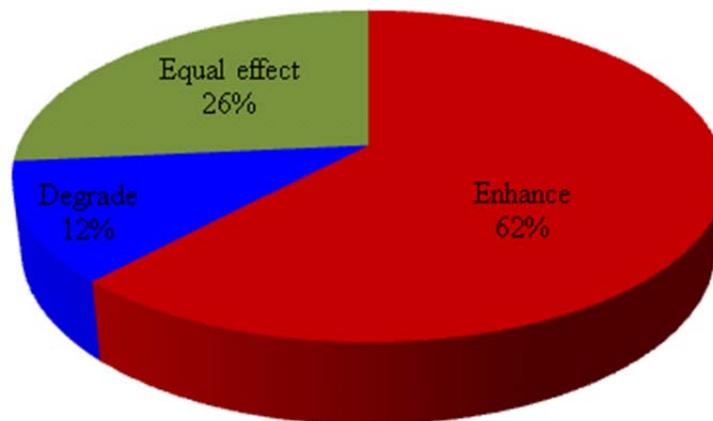
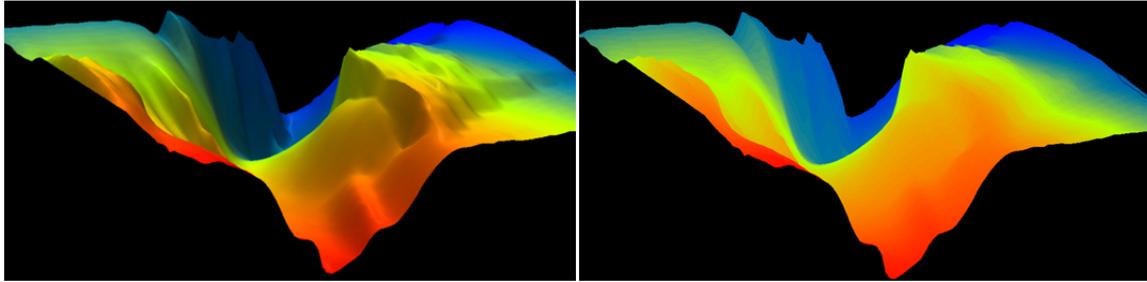


Figure 6 Statistical summary about the usefulness of CS combined with view angle

### 6.3.2 Shading

When objects are lit from one direction, they cast shadows providing information about their orientations and relative positions (Murray, 1994) to the light source (McAllister, 2005), and hence the further away the object, the less it is lit. To investigate how CS can benefit from shading, the rotating bathymetry was illuminated.



**Figure 7 Shading effect on CS: Bathymetric surface represented in CS with shading effect in the left, and without shading in the right image.**

The observers reported that shading assists them to recognize the shape of the bathymetry, and the orientation of the different parts. The image becomes more realistic and easier to interpret. They agreed that the overall 3D perception for the scene is significantly enhanced. However, whether shading amplifies or diminishes the colour stereo effect is debatable. The majority said that shading does not have any effect of the 3D perceived from colour. Only three participants, interestingly one from each subgroup, stated that shading degrades the pure CS 3D, but adds more details. Four participants declared that the details helped them to understand the scene; this in turn aided their attention to CS.

## 7. DISCUSSION

Participants with no experience with CS stated that the 3D they perceived was due to other depth cues they are aware of such as perspective, and relative size. Despite the intentional absence of these cues in the scenarios.

Ship navigators reported that the 3D colour-base is clear and useful in highlighting distances to objects. However, some professional navigators rejected its potential use in navigation by reasoning that their skills were sufficient to accurately and easily interpret the radar to obtain distance. The rest of that group found CS is ideal to simplify interpreting radar data, for both novice and skilled mariners, as they can offload the mental image that they have to create for the situation for the 3D image on the screen. In general professional navigators are sceptical about new technologies, and very conservative about conventional parameters. This is more pronounced in long-experienced people who have been trained to use traditional methods to navigate safely.

Kinematic CS is useful for briefing divers and underwater operators about the task they are going to take. It permits an enhanced simulation of the underwater environment and generally this group found it useful.

CS 3D quality is a function of the size of objects on the screen. When small objects (lateral buoys in the navigation scenario) were viewed with the 3D glasses, participants experienced some ghosting and duplication. This is colour decomposition where colours on a screen result from a combination of three primary colours (red, green and blue) so when the ChromaDepth 3-D glasses are used to view any tiny part of a combined colour, such as yellow, it will be decomposed into its original components causing blurring the region (Ucke, 1998)

Acceptance of new concepts varied depending on the way people are trained and how strictly they accept the current rules. For professional navigators, where the rules of the road are well established, they are less willing to change than recreational sailors. Throughout each one hour interview, the application became more acceptable to the volunteers. This indicates new concepts can be promoted via education and familiarity. However, the more individuals are absorbed by a technique or a convention, the longer they needed to be interviewed. Combining shading and oblique CS provides pronounced 3D perceptions in which shading reveals more details about the components of a scene and CS defines their positions.

## 8. CONCLUSION

CS has the potential to be used in kinematic displays, by implementing continuous colour rescaling, and could be a valuable tool to visualise obscured scenes to facilitate operational work. Combining CS and other depth cues such as shading, relative size and perspectives projection technique would significantly augment the overall 3D perception. However, the restricted use of colour in CS may challenge some established cartographic conventions: this could one of the main obstacles to applying CS in some applications. The willingness to accept new techniques is a function of age, experience and familiarity.

## ACKNOWLEDGMENTS

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## **BIOGRAPHICAL NOTES**

Iman Abdel Hamid is a PhD researcher at the University of Plymouth in the UK. She has a Master of Science degree in Hydrography from the University of Plymouth, a Post Graduate Diploma in Topographic surveying from the University of Aleppo in Syria and a Bachelor Degree in Civil Engineering from the University of Tishreen in Syria. During her career she has worked as a Lecturer in Topographic Engineering at the University of Tishreen and a hydrographic surveyor in The North Sea. Her research interests are linked to Hydrography. A particular focus is visualising hydrographic data in 3D using Chromostereoscopy. She has presented her work about CS in two conferences: The Summer School of Cartographers 2009 in Southampton/ UK, and Hydro10 in Rostock/ Germany. She is also a committee member in The Hydrographic Society in the South-western region/ UK, a member in the Society of Cartographer/ UK, a member in The Syrian Engineers Association, and The Syrian Teachers Association.

Dr. Victor Abbott has a hydrographic survey experience went from dredging surveys to offshore positioning and from Ireland to China. After 10 years he took a lecturing post, first in London and then Plymouth - where he's been for twenty years. He has completed a course accredited by FIG/IHO at Category A and an MSc and PhD in Coastal Management. He has extensive experience with the professional institutions, undertaking accreditation visits and participating on working parties and local committees. He has successful accreditation applications for the Plymouth surveying courses. His current research supervision includes chromo-stereoscopy, the mitigation of the effects of seismic research noise on marine mammals, and coastal management/marine planning.

Dr Samantha Lavender has over 15 year's research experience, and is Honorary Reader at the University of Plymouth and Managing Director of ARGANS Limited. Her research interests are linked to Geomatics and include remote sensing, GIS and hydrography. A particular focus is the quantitative remote sensing of water bodies with research extending from the movement of sediments in the coastal zone to phytoplankton and salinity in the open ocean, with links to wider issues such as climate change. She is also vice chairman of the Remote Sensing and Photogrammetric Society and, at an international level, co-chair of the International Society for Photogrammetry and Remote Sensing Working Group VIII/9 (Ocean) and a committee member on the International Ocean Colour Coordinating Group.

Dr.Kenneth Kingston lectures in theoretical coastal morphodynamics in the School of Engineering and Ocean Science at the University of Plymouth. He completed his PhD on Complex Adaptive Systems applied to Coastal Morphodynamics in 2003. His primary areas of interest relate to understanding the daily to yearly evolution of sedimentary coastlines. This has focussed on the use of video remote sensing of beaches to achieve a better understanding of how waves and currents shape our coastline.

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