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Chromo-Stereoscopic Visualisation For Dynamic Marine Operations

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CHROMO-STEREOSCOPIC VISUALISATION FOR DYNAMIC MARINE OPERATIONS

by

IMAN ABDEL HAMID

A thesis submitted to the University of Plymouth
in partial fulfilment for the degree of

DOCTOR OF PHILOSOPHY

School of Marine Sciences & Engineering

Faculty of Science & Technology

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Iman Abdel Hamid

Date: …. 28 October 2012..…

Abstract

Chromo-Stereoscopic Visualisation in Dynamic Marine Operations

Iman Abdel Hamid

Chromo-Stereoscopy (CS) is a simple and cost effective 3D system that can easily deliver geospatial information. CS has been used in several scientific data presentations, including remote sensing, physical modelling and hydrographic applications. In some of these applications the 3D effect was solely CS-related, while others integrated CS with other methods of implementing 3D. CS has been mainly used in static visualisation, but no dynamic applications were found. Also, the restricted use of colour was acknowledged as a limitation for CS suggesting its unsuitability for applications where colour conventions are significant. This research focuses on CS for marine applications and aims to: (i) investigate user's perception to CS effect and its interaction with other depth cues, (ii) assess the acceptance of the potential users to the changes in conventional colouring systems, and (iii) evaluate the usability and practicality of CS as an additional visualisation system in dynamic marine applications. To address these, visual scenarios were developed and expert human participants were recruited and interviewed for the evaluation.

CS was well perceived among the participants. The interaction between different depth cues has advantages of increasing the depth perception and comprehending the 3D nature of the surrounding environment. For instance, from a certain view angle where two objects block each other, CS enhances the interposition effect, that indicates which object is in the front and gives a qualitative estimation of the spatial separation between them. Shading increases the realism of surface objects, and provides information for their undulation. It also dilutes the colours used in CS and increases the range of colours perceived and enhances the effect perceived from CS.

The advantage of using the colour coding system to indicate distance is a valuable and original outcome of this thesis. This coding improved the participants understanding of the behaviour of moving objects (whether vessels coming closer or drifting apart) and enabled users to locate them in reference to the surrounding topography. Such knowledge is important to attain safer operations in a 3D environment.

Accepting changes in colours in a visual presentation is linked to experience gained during interaction with the system, and the changes would be tolerated by the users in favour of improvements in situation awareness. Blind navigation and underwater operations are examples of where CS can be beneficial.

Table of Contents

List of Figures

List of Tables

Acknowledgments

This thesis marks an important period of my life in which I recognised that dedication and hard work are the key for success. First and foremost, I would like to express my deepest gratitude to my supervisory team Dr Abbott (Director of Studies), Dr Samantha Lavender and Dr Kenneth Kingston for their time and support throughout my PhD. Especial thanks goes to Dr Abbott who created an atmosphere with encouragement, faith, freedom, and motivation that energised research in this thesis. He has been a great source of inspiration even outside the scope of this thesis.

I would like also to acknowledge all the participants who generously give up their time to participate in my questionnaire, particularly, Dr Andrew Eccleston, Mr Paul Scoble and Ms Sue Syson for facilitating access to the relevant user groups. I also thank the MarCoPol research group, the staff of ARGANS Ltd Company and the members of the Hydrographic Society of the UK South West region for their support.

Last but not least, my deepest gratitude goes to my beloved family for their continuous love, support and consistent pressure to finish this thesis. To those who indirectly contributed in this research, your kindness means a lot to me. Thank you very much.

Author’s declaration

At no time during the registration for the degree of Philosophy has the author been registered for any other university award.

During the period of study relevant scientific seminars and conferences were attended. Conference papers workshop and publications presented during the period of study are listed on page 25.

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Iman Abdel Hamid

Date:... 28 October 2012 ....

List of Abbreviations

2D	Two Dimensions
3D	Three Dimensions
ANOVA	ANalysis Of VAriance
APO	American Paper Optics Inc.
AZ	Azimuth
CGS	Coast and Geodetic Survey
CIE	Commission International de l’Eclairage
CPA	Closest Point of Approach
CRT	Cathode Ray Tube
CS	Chromo-Stereoscopy
CVD	Colour Visual Deficiency
CYM	Cyan Yellow and Magenta
DTM	Digital Terrain Model
ECDIS	Electronic Chart Display and Information System
ENCs	Electronic Navigation Charts
ECS	Electronic Chart System
El	Elevation
FINS	Fishing Information Navigation System
GPS	Global Positioning System
GUI	Graphical User Interface
HD	High Definition
HMD	Head Mounted Display
IALA	the International Association of Lighthouse Authorities
IHO	International Hydrographic Organisation
IMO	International Maritime Organisation
LIDAR	LIght Detection And Ranging
MarCoPol	MARine COastal POLicy
NOAA	National Oceanic & Atmospheric Administration
NOS	National Ocean Service
NIMA	National Imagery and Mapping Agency
RADAR	RAdio Detection And Ranging.
RCDS	Raster Chart Display Systems

ROV	Remotely Operated Vehicle
RGB	Red, Green and Blue
SAR	Synthetic Aperture Radar
SIRDS	Single Image Random-Dot Stereograms
SPSS	Statistical Package for the Social Sciences
SSS	Side Scan Sonar
THS	The Hydrographic Society
TFT	Thin-Film Transistor
TV	Television
USCG	United States Coast Guard
VA	View Angle
VR	Virtual Reality

Chapter One

1 Introduction

For generations, Two-Dimension (2D) plane maps have been considered a well-established means to communicate geospatial information. To present the real (Three-Dimension) 3D world in a limited 2D medium, cartographers have had to apply some generalization and simplification for features. Only prominent elements are presented as representative icons. The third dimension has been displayed in plane maps through visual variables (size, colour, light and shading, contours). A successful understanding for the map's contents and reconstructing a mental image requires experience in decoding these visual variables. For non-expert users, there is a risk of misinterpreting a 2D map. Further progress introduced perspective view. Using different perspective images, a 3D mental image can be induced. The ability of humans to infer 3D objects or presentations of 3D objects is a life-long experience. Hence, 3D visualisations have been recognised as an efficient means to boost the geospatial comprehension for both trainees and experts.

The fact that humans naturally view the world as 3D increases interest in 3D displays. The transition from 2D to 3D becomes possible as a result of the technological revolution. The significant development in computer power with cost reduction has supported the generation of more realistic scenes and increased spatial resolution. Also, the availability of large quantities of geographic information and the progress in algorithms to move from static to dynamic scenes and to display (Four-Dimension) 4D scenes (space and time) have even introduced virtual reality (VR) applications (Rase, 2006).

In the marine realm, 3D was mainly implemented by monocular depth cues such as shading, with the first stereoscopic (binocular) application to visualise hydrographic data being time-multiplexing deployed by the company IVS 3D, in 'Fledermaus' visualisation software. A simpler and yet effective 3D visualisation was attained through Chromo-Stereoscopy (CS). First it was successfully applied in a 2D plane bathymetric Digital Terrain Model (DTM) to highlight the depth of the seabed (Lamplugh et. al., 1996). In a more recent work Ostnes (2005) combined the effect of CS with other depth cues such as shading, perspective view and interposition to visualise the seabed and objects in the water column. The results showed an enhancement in users understanding to these data. This positive application of CS in marine applications and the simplicity and the low cost of the techniques besides the interest of the author in marine and hydrographic activities was a motive to explore further CS usability in such applications. The 3D and dynamic nature for the marine environment provoked the need to investigate the advantages of CS in moving images. However, the oblique application of colours along the line of sight encounters the conventions of displaying bathymetric data. The common practice is colour coded vertically from red (shallow) to blue (deep). Such unconventional use of colour could affect the users' life-long experience of using colours as an effective method to learn, memorise and interpret objects. Hence investigating the reaction of potential users to altering pre-established rules of the use of colours in a marine context was another element to be tested.

1.1 Aim and objectives of the research

1.1.1 Aim

The aim of this study is to investigate the human and technical factors of applying CS in dynamic marine situations, by addressing the following questions:

- Is there an interaction of CS with other 3D depth cues? Is CS perception enhanced or degraded when combined with shading relief and seen via adjusted viewing angles?
- What are the consequences of changing the colour of predefined symbols in the marine representations?
- How could CS be useful in marine applications in general and in dynamic situations in particular?

1.1.2 Objectives

To achieve this aim the following objectives were identified

- To review and understand the concept of human 3D vision and assess 3D techniques available to implement 3D effect in a visualisation.
- To analyse the cartographic design (symbols and colours) of the presentations of marine data to identify the consequences of applying CS.

- To identify suitable scenarios demonstrate dynamic applications and change of conventions.
- To develop scenarios and to interview participants from the marine community.

The study commences by investigating how people perceive CS and what factors affect their perception. This leads into understanding what are the benefits and the limitations of CS as applied to the marine environment. It is envisaged that the research findings can be used to demonstrate whether CS could be deployed as an additional viewing approach in marine applications. The project consisted of a set of case studies and scenarios: case studies where individuals used the marine environment as professionals and/or in recreation; scenarios represented how CS can be applied in both static and dynamic situations. A mix of quantitative and qualitative approaches was used to analyse the output.

1.2 Thesis overview

The general design of this thesis is shown in Figure (1-1).

The research background is presented in chapters 2 and 3. Chapter 2 provides an overview of the diverse elements that interact with visualisation, e.g. participants, the environment, cartographic design, human factors, trends of 3D visualisation and colour perception. Also a detailed discussion about CS implantation is given and finally it analyses of the human factors in CS perception of a display and the possibility to apply it in a dynamic visualisation environment. Chapter 3 presents methods of displaying marine data and the cartographic design of these visualisations.

Chapters 4 and 5 describe the methodology identified to conduct the study. To answer the research questions, the opinions of potential users were needed and a prototype of visual stimuli was created. Significant time was spent developing the scenarios. It started with a basic model tested on a small sample user group, then correcting identified errors to reconstruct a new model. The process was repeated until a satisfactory outcome was accomplished. This work, together with comments from the users is described in Chapter 4.

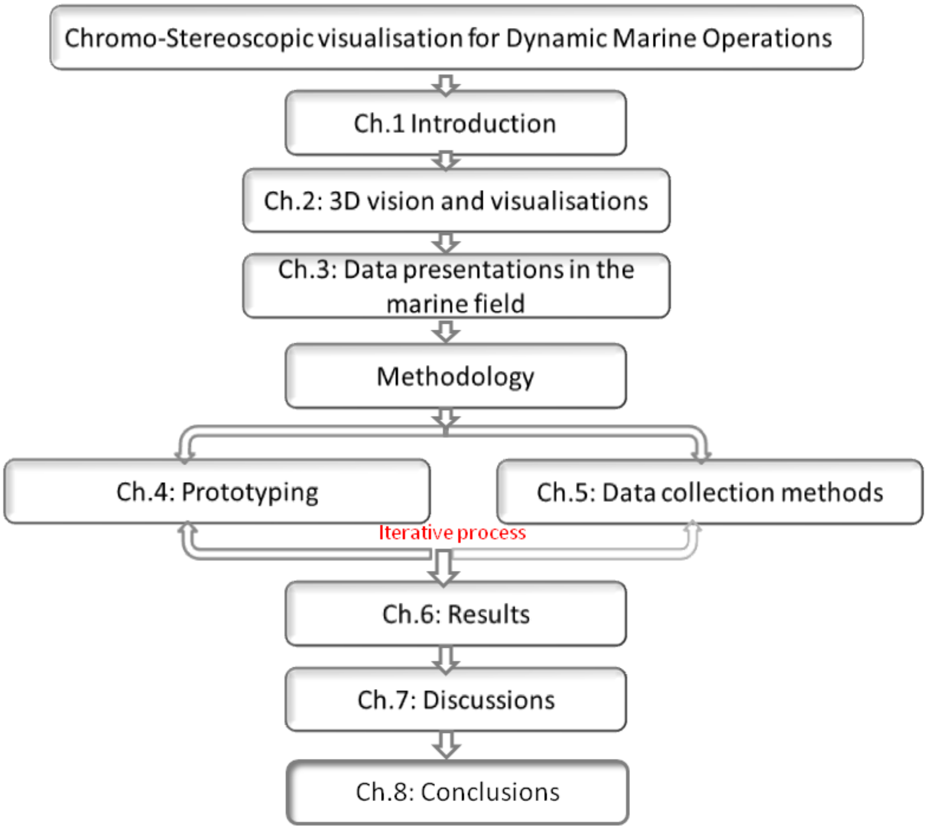


Figure 1-1 A flow chart of this thesis

Chapter 5 reviews the method used for data collection and the procedure of developing and designing the research questionnaires; group interviews and one-to-one interviews where used. The questions covered a range of aspects: demographics, 3D perception and the implication of CS on standard visualisations. Also users' evaluations for the usefulness of CS were obtained. It also presents the outcome of three sets of group interviews. These initial results were used to examine the participants' responses to CS and strengthen the design of the study. The feedback from each group was, as appropriate, incorporated into the design and tested on the next group. Several alterations were implemented to refine the models and the questionnaire until satisfactory stimuli and survey questionnaires were achieved, and the best method for data collection suited to this research was identified as a personal face-to-face interview.

The result of interviews and users' opinions about its usability in dynamic marine applications are presented in Chapter 6. Quantifiable answers are displayed in bar and pie charts, while the qualitative aspects of the users opinions are presented as themes. The data obtained from group and face-t o-face interviews where processed and entered into a Statistical Package for the Social Sciences (SPSS) database. All statistical analyses were considered significant at the 0.05 level. Nonparametric statistics, Chi-square test was performed to analyse questionnaire data. Statistically significant differences between the groups were analysed using within-group two-way Analysis of Variance (ANOVA) test.

Chapter 7 addresses issues in the tests, results and some concerns about risks with new technology and general problems with 3D viewing. On revisiting the research questions, conclusions about the research were drawn and finally recommendations for future opportunities in this field were presented in Chapter 8.

1.3 Conferences and workshops

This project has been presented in six conferences and workshops and two full papers were published. The content of these papers have been incorporated into the text and the full papers are appended separately after the references.

Abdel Hamid I, Abbott V, Lavender S and Kingston K, 2009, ‘Second Generation of Chromo-Stereoscopy in Marine Data’, Summer School of Cartographers, Southampton 6-9 September 2009. (Poster)

Abdel Hamid I, Abbott V, Lavender S and Kingston K, 2009, ‘Visualising Hydrographic Data in Chromo-Stereoscopy’, The Bulletin of the Society of Cartographers.

Abdel Hamid I, Abbott V, Lavender S and Kingston K, 2010, User Assessment of 3D Chromo-Stereoscopy for Hydrographic Applications (Oral presentation), Hydro08, Rostock, Germany.

Abdel Hamid I, Abbott, V, Lavender S and Kingston K, 2011, Chromo-Stereoscopy for Enhanced Viewing in Opaque Environment, Proceedings of the Conference of the FIG Working Week 'Bridging the Gap Between Cultures' Morocco: http://www.fig.net/pub/fig2011/papers/ts05j/ts05j_abdel_hamid_abbott_et_al_4895.pdf

Abdel Hamid I, Abbott V, Lavender S and Kingston K, 2012, CS for Dynamic Applications, Workshop, EIMR Conference, the Orkney 02-04th of May 2012.

Abdel Hamid I, Abbott V, Lavender S and Kingston K, 2012, ‘Developing a 3D Chromo-Stereoscopic Visualization for Real-Time Marine Operations’, GFG2 Summer School, Nottingham, 13-15 August 2012. (Poster)

Chapter Two

2 3D Vision and Visualisation

Human vision consists of two distinct processes: vision and imagery (Mathewson, 1999). Vision coincides with the use of the eye as a sensor to recognize position and think about objects and self-orientation in the world. Imagery is ‘the formation, inspection, transformation and maintenance of images in the “mind’s eye” in the absence of a visual stimulus’. Signals received from the eye are decoded in the eye/ brain system into three types of image components: pattern (shape, depth and texture), colour (hue, value and saturation) and movement (Hubel, 1988; Potegal, 1982; Rock, 1995).

The arrangement of these components to transform numerical data into a meaningful and displayable image requires cartographic and graphic visualisation guides. The word 'image' indicates a variety of representations, graphic displays and models. The term 'visualisation' in science and technology means computer-generated displays of data and numerical models, while the term graphics is donated to the technology of computer displays. Technological advances have offered new visualisation media (Kraak & Brown, 2001). Besides paper, visual presentations have been extended to encompass screns, projectors and televisions. Also media such as CD-ROMs and the world wide web have widened the viewing method to incorporate animated maps, multimedia, virtual reality, dynamic presentation and interactivity (Cartwright et al,1999).

Presenting a 3D dataset on 2D media (e.g. overheads, slides and computer screen) can cause a loss of sense of depth. Based on understanding human vision, several depth cues have been identified as the essence of seeing in 3D. The implementation of these depth cues in 2D visualisations become more accessible with technological advances. Numerous methods have been developed and seeing the third dimension in synthetic scenes becomes possible. This chapter reviews the different features of human vision and 3D perceptions, and their applications in both stereoscopic and auto-stereoscopic display systems.

2.1 Human vision: Seeing in 3D

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 (Dodgson, 2005).These depth cues can be classified into four different divisions:

- Oculomotor cues: the ability to sense the position of the viewer’s eyes from the tension in their muscles
- Monocular cues: work with a single eye
- Chromatic aberrations
- Binocular cues that require two frontal eyes

2.1.1 Oculomotor cues

These cues work in true three-dimensional space. They are known as convergence and accommodation of the eye as a consequence of the muscle expansion and contraction. When looking at an object, the eyes rotate toward the centre of interest either inward (close object) or outward (distant objects), the angle made by the two viewing axes of a pair of eyes is called 'convergence' (Figure 2-1, left). This rotation is associated with an adjustment of the focal length of the lens known as 'accommodation' (Figure 2-1, right). These cues interact in depth perception, but their effects are minimal unless combined with other binocular cues and with a viewing distance less than two metres (Okoshi, 1976). Except in holographic and moving-mirror displays, convergence does not match accommodation (Ternes et al., 2009). The discrepancy between the physiological feedback received from convergence and that received from accommodation causes the nausea effect.

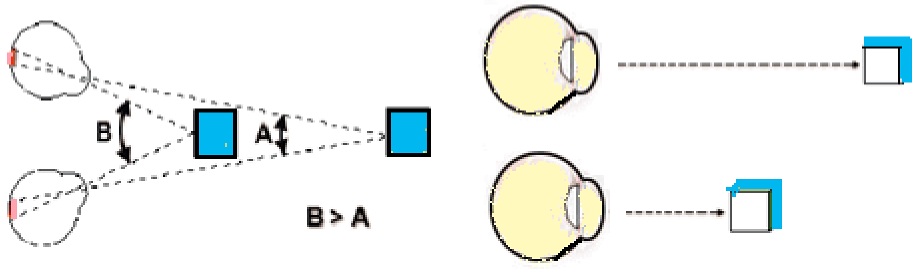


Figure 2-1: Convergence cue (left) and accommodation cue (right) Monocular cues

These include all depth information that can be derived from a 2D image by only one eye. A subset of monocular cues, called pictorial cues by some authors (Dodgson, 2005; Goldstein, 1989; Toutin & Vester, 2000) will be discussed.

2.1.1.1 Occlusion

Occlusion, overlapping (Toutin & Vester, 2000), interposition (Murray, 1994), and superposition (Michel, 1996) are different terms used in the literature to describe the partial blocking of a more distant object by a nearer object (Hershenson, 1999). Usually the impression of depth caused by interposition alone is not very strong. Figure 2-2 shows that the square occludes a portion of the circle which in turn partly blocks the rectangle, giving the impression that the square is the closest while the rectangle is the furthest away.

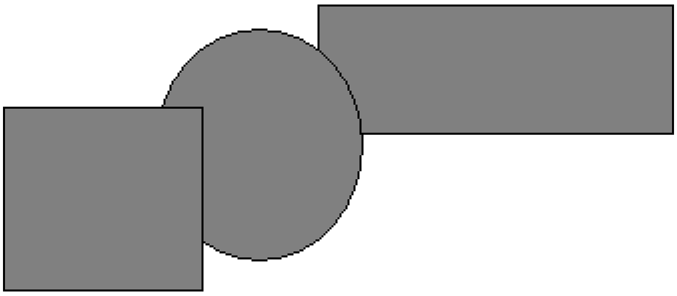


Figure 2-2: Occlusion as a depth cue. The square in the figure appears closer than the circle, while the rectangle is the furthest

2.1.1.2 Linear perspective

This depth cue is related to other two depth cues, namely relative size and texture gradient. The image size of an object is reduced gradually as distance from the object increases; in linear perspective, parallel lines that recede into the distance (Figure 2-3) appear to converge (Cutting, 1997).

Figure 2-3: The linear perspective as a depth cue. parallel objects appear to converge in the distance; and at a greater distance, objects appear to be of a reduced size

The rate of this convergence may vary in different parts of the scene. Retrieving a 3D effect from perspective drawings on 2D media depends on the viewer’s lifelong experience in recognizing and interpreting depth cues in images. The main limitation of using perspective drawings for cartographic applications is distortions in objects' dimensions that prevent uses to measure distances and directions from the picture (Rase, 2009).

2.1.1.3 Aerial perspective

The atmosphere causes light scattering, hence distant objects have lower luminance contrast and lower colour saturation causing slight blurring of distant objects (Figure 2-4). In computer graphics, this is called "distance fog", as the clarity and colour tinting of objects are affected by distance. Research into the human vision system revealed that colour gradient saturation indicates different depths (Faubert, 1995). Therefore, varying only the contrast between objects and the background is one of the techniques to perceive depth (O'Shea et al, 1994; Weiskopf & Ertl, 2002). It is a useful means to clarify distance differentials in a 3D map (Jenny, 2000).

Figure 2-4 Perception of distance differences with the help of aerial perspective (Terribrilini, 2001) has been removed for Copyright restrictions

2.1.1.4 Detail perspective/ texture gradient

This depth cue is related to relative size in some sense, but concerns the patterns and textures of materials and surfaces (Figure 2-5). These appear to become finer and look smoother as they get further away from the observer (Gibson, 1950). This cue is most effective with surfaces of deep structure (Michel, 1996).

Figure 2-5: Loss of texture with distance as a depth cue (Michel, 1996) has been removed for Copyright restrictions

2.1.1.5 Relative size and familiar size

The size of an object in the retinal image is linked to the separation distance between the object and the viewer; objects further away are smaller when projected on the retina. Familiar size is the pre-knowledge of the standard sizes of familiar objects. When two objects of standard but different sizes are presented in one image at the same size, the overall scale of the scene can be obtained (Murray, 1994).

2.1.1.6 Lighting and shadow

When objects are lit from one direction, they cast shadows (Figure 2-6) providing information about their orientations and relative position (Murray, 1994). The amount of light received by the object surface is inversely proportional to the square of the distance of this surface to the light source (McAllister, 2005), and hence the further away the object from the light, the less lit it is. Shadows provide depth information through different ways (Michel, 1996). The size of the object diminishes with distance, and so does its shadow. Hence, smaller shadows indicate distant objects. Depth information can be deduced from the difference in visible details inside and outside the shadows. Fewer details inside the shadow convey spatial depth of the scene.

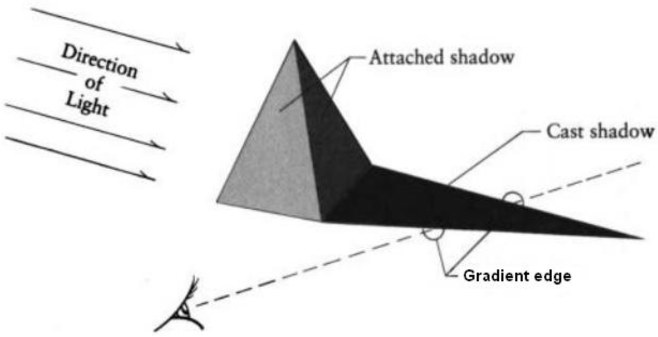


Figure 2-6: Light and shadow: determine the relative positions of objects to the light, objects in shadow are further away from light

2.1.1.7 Relative brightness

The amount of light reflected or emitted from an object is inversely proportional to the square of the viewer's distance from the object. It was experimentally demonstrated that viewers' interpretation for identical objects with different brightness was of varying distances, with the brighter the closer (Murray, 1994).

2.1.1.8 Relative height or plane height

The relative location of the object in the plane of view can aid in determining its relative distance. Generally, the closer to the horizon (middle of the scene), the further away objects appear (Dodgson, 2005).

2.1.2 Motion cues

All the previously discussed depth cues are used in a stationary image; however, a large proportion of human’s space perception comes from relative motion that is considered to be more important than stereopsis in helping viewers to understand the surrounding layout (Ware & Frank, 1996). This may have resulted from head motion causing motion parallax (Gibson et al., 1959) or from object rotation giving the kinetic depth of vision effect (Braunstemin, 1976; Bruno & Cutting, 1988). The motion in an animated flat image projected on a screen, produces a strong perception of 3D.

Motion parallax explains why distant objects appear to move slower than closer objects even when the speed of both objects is identical (Toutin & Vester, 2000). The same phenomenon explains why nearby objects blur when observed from a speeding train, but distant objects move slowly (Figure 2-7).

The direction of motion can be understood from where the picture seems to expand (Gibson, 1950). For a viewer sitting in the train, closer objects appear to move in the opposite direction.

Figure 2-7: Motion parallax: (left) the effect in animated flat image (Schwartz & Steinman, 2011), (right): the effect of close objects when they move in opposite directions relative to a moving observer (Wigmore, 2009) has been removed for Copyright restrictions

2.1.3 Chromatic aberration

Different wavelengths of light are reflected to varying extents. This finding is attributed to the transversal chromatic dispersion and the asymmetrical relation of the visual and optical axes (Figure 2-8) (Howard & Rogers, 1995). The fovea of the eye is about 5 degrees temporal to the eye's optical axis and the pupil of the eye is slightly decentred nasally (Cui & Campbell, 1994). This produces lateral chromatic aberration which causes differences in retinal location for different coloured objects. Light entering the eye is refracted in inverse proportion to its wavelength. Blue light has a shorter wavelength, and therefore it is refracted to a more distant plane when compared with red light. This causes the eye to refocus for differently coloured objects, providing potentially false cues about their relative positions known as chromo-stereopsis (Murray, 1994). The role of refraction may extend to objects located out of the focal length, creating a blurred image on the retina. For objects whose actual focal length is behind the retina, their blurred image will have reddish edges and bluish centres. The reverse will be applied for objects whose focal length is in front of the retina (Murray, 1994).

Figure 2-8: The asymmetrical relation of the visual and optical axes that cause chromatic aberrations (CCRS, 2010) has been removed for Copyright restrictions

2.1.4 Binocular cues

Binocular disparity is the spatial difference between the two retinal projections of the same object. As a result of the lateral separation between the eyes (about 6cm), they see slightly different images with a large overlap, but from different viewpoints (Qian, 1997). The magnitude of disparity between these images is a function of the convergence angle, which is inversely proportional to eyes' distance from the object. At a great distance, the convergence angle decreases and the depth perception becomes increasingly difficult. Hence binocular disparity is most effective over medium viewing distances (Toutin & Vester, 2000). The brain fuses the two images into one for the overall scene, and depth information obtained from the horizontal disparity (Figure 2-9) is called stereoscopic depth perception or stereopsis (Wheatstone, 1838). Based on this principle, several display systems, known as stereo displays, have been designed to generate depth perception (sensation of the third dimension).

Figure 2-9: The geometry of binocular projection (top), and the definition of binocular disparity (bottom) has been removed for Copyright restrictions

In the previous sections only the most common depth cues were briefly discussed. However, further explanations can be sought from numerous literature sources including (Blundell, 2008; Majumder, 2000; Michel, 1996; Murray, 1994; Okoshi, 1976).

2.2 Effectiveness of depth cues

The usefulness of depth cues to create the sensation of depth depends on the viewing distance. Figure 2-10 shows occlusion and relative size can be used in all depths, while aerial perspective and relative height are used only for distant objects. Also, disparity and motion cues can only be used for close objects (Majumder, 2000). The effectiveness of the depth cues varies according to the distance, and hence the realisation of the relative depth in the surroundings relies on the combined effect of the entire depth cues. Since the effects of depth cues are additive, the more depth cues used the easier for the viewer to obtain the depth effect. Nevertheless, the power of these cues is situation dependent, and some cues might override others and change the viewer's depth perception and interpretation of the scenes (McAllister, 2005). Occlusions, object and cast shadows as well as linear perspective information support the spatial perception. These effects are the most effective in 2D presentation (Hershenson, 1999).

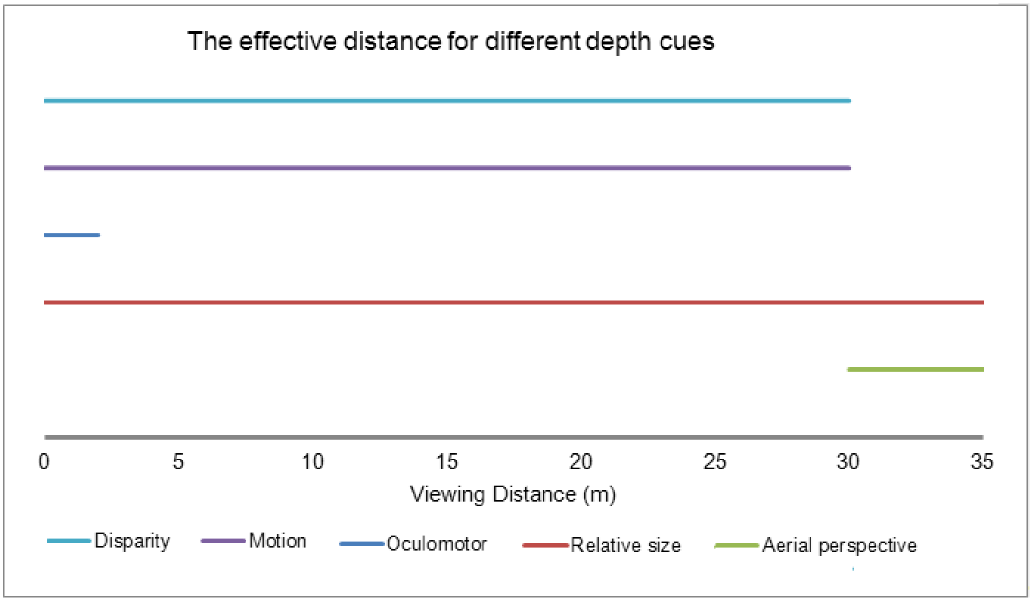


Figure 2-10: The effectiveness of depth cues to create a vivid sensation of depth

In complex spatial situations monocular depth cues may not be sufficient to explain the scene. For example, object overlap from a fixed view point (Figure 2-11, left), could mislead the interpretation of the scene (Figure 2-11, right) which shows that the scene has two successive different hills, not just one. Such a problem could be resolved by adding another depth cue to the image like chromatic aberration and changing point of view or complex 3D like virtual reality (VR).

Figure 2-11: Problem with occlusion when seen from a fixed view point (left), it is difficult to recognise the two separate hills in the right image has been removed for Copyright restrictions

From an application point of view, the employment of binocular and oculomotor cues is only feasible in the form of specialised hardware, such as shutter glasses (Weiskopf & Ertl, 2002), while monocular and chromatic aberrations are hardware-independent. Hence using monocular or chromatic aberration is beneficial to enhance 3D perception with a minimum cost.

2.3 Colour vision

Colour is the part of the visible spectrum of light with electromagnetic wavelengths between about 400 and 700 nm. Colours can be defined by three properties: hue, value and saturation (chroma) (Andrews, 1998; Robinson, 1995).

A hue refers to the name of pure colours (green, blue, red) found in the electromagnetic spectrum of the visible light (Figure 2-12, a). Value (known as brightness or lightness) refers to the lightness and/or darkness of a colour, and it measures the tendency of a colour to reflect light. For example, yellow is a light colour when compared to red which is dark. With the absence of colour, the typical lightness scale (Figure 2-12. b) starts with white, ends with black and has shades of grey in-between. The third dimension of colour, chroma is the perceived amount of white in a hue relative to the grey tone (Robinson, 1995). In some books, chroma, saturation and intensity are used equally. Saturation is the colourfulness of a colour relative to its brightness (Ramanath & Drew, 2008). Spectrally-pure colours are fully saturated, but when diluted with white light they produce de-saturated hues (i.e. pink can be considered as de-saturated red) (Butler et al., 1987).

a) hue scale

b) value scale in absence of hue

Figure 2-12: Representation of the colour dimensions (hue and value)

The human eye can only perceive colours associated with the spectral visible light. The recognised colour of any object matches the wavelength of light that is reflected from that object (Robinson, 1995). The human light perception depends on photoreceptors: cones and rods clustered in the retina with more density in one point called the fovea (where the eye’s lens focuses light and where colours are best perceived). Cones are mostly functional in bright light, while rods operate in dim light. Basically, there are three different types of cones that are more sensitive to different bands of wavelength (Figure 2-13): long (L), medium (M) and short (S), and sometimes are known as red, green and blue cones. These cones are responsible for colour detection in the human eye’s retina, while rods detect the intensity (Ramanath & Drew, 2008).

The human eye-brain system processes the light wavelength as a colour. This mental process has been explained in different physiological theories; the most important are the trichromatic theory and the opponent process theory, as the former explains colour perception at the level of photoreceptors, the latter explains the effects of neural interconnection among the photoreceptors on colour vision. The concept of human colour perception will be briefly explained, however for the detailed physiological concepts readers are referred to Hendee et al (1997).

Figure 2-13: The three types of colour perception cones in the human eye (Dowling, 1987) has been removed for Copyright restrictions

Trichromatic theory assumes that the messages from the three types of cones are sent directly to the brain, and the final perceived colour results from the additive sum of the ratios as each of these cones responds to light. For example, the colour purple is a ratio consisting of a strong "blue" response, weaker "green" response and an even weaker "red" response (Murch, 1983). Since the combination is based on additive and linear proportionality, any colour is defined by tristimulus (three dimensional vector) space (Weiskopf & Ertl, 2002). Trichromatic theory succeeds in explaining colour matching that considers the origin of many colours is the combination of three fixed primary colours However, it does not explain the perception of yellow despite the absence of yellow cones (Wyszecki & Stiles, 1982).

The opponent process theory proposed by Hering in 1800s (Jain & Healey, 1998) states that the signals from the rods and the three cones are not directly sent to the brain through the optic nerve, but to nerve cells that continuously transmit signals to the optic nerve (Robinson, 1995). There are three types of nerve cells, BY (Blue-yellow), RG (red-green) and WBK (white–black). WBK cells are excited by impulses from L, M and S cones. The excitement is proportional to the signal strength. RG cells are excited by impulses from L cones and inhibited by impulses of M. Strong and weak signals are sent to the brain, the strong one indicates red, while the weak is green. The signal will be only red or green, not both, as red and green are opponent colours. BY cells, are excited with impulses from both L and M, and inhibited by impulses from S.

The message sent to the brain is a strong signal for yellow and weak signal for blue (Dacey & Packer, 2003).

2.3.1 Individual Colour Perception

Among individuals colour perception is not uniform due to physiological differences. In a normal eye, the peaks of the three types of cones (S, M and L) are approximately sensitive to 430nm, 530nm and 560nm respectively (Dowling, 1987). A shift in the sensitivity of these cones or the absence of any of them as a result of genetic and non-genetic factors (including. accident and chemical poisoning) will cause a colour visual deficiency (CVD). In the white race, about 8% of men and 0.4% of women suffer CVD. They, consequently, cannot differentiate between colours of specific combinations.

Endsley et al (2003) studied the effectiveness of cartographic designs that are based mainly on colour in communication with red-green colour blind users. In comparison to how normal viewers perceive the spectral colours, red-green blind users can differentiate many fewer colours (Figure 2-14). Besides malfunctioned cones, vision disorders (short-sightedness and far-slightness) can degrade colour perception.

Figure 2-14: The visible spectrum as perceived by the normal viewer (top) and by those with red-green vision impairment (bottom) (Endsley et al, 2003) has been removed for Copyright restrictions

2.4 3D cartography & 3D display systems

Based on understanding the mechanism of human 3D vision, identifying depth cues and the advances in technology, implementing these depth cues in 2D visualisations becomes feasible. Numerous techniques have been developed and as a result seeing the third dimension in a scene becomes possible. This section evaluates these techniques.

3D display systems can be broadly classified as stereoscopic and autostereoscopic systems. Stereoscopic displays require the user to wear special glasses or some kind of headgear to ensure that each eye sees its matching view. In contrast, autostereoscopic systems allow unaided free viewing as all optical components needed to correctly reproduce 3D objects and scenes are integrated into the display device (Halle, 1997; Pastoor & Wöpking, 1997; Son & Javidi, 2005).

2.4.1 Stereoscopic displays

Stereoscopic displays use the natural ability to generate a 3D mental image from two slightly different pictures, one taken by each eye. 3D images may be built with binocular viewers, shutter glasses, lenticular and barricade displays. They can also be derived by monocular optical effects, such as single image random-dot stereograms (SIRDS) or Chromo-Stereoscopy. Table 2-1 summarises 3D visualization systems available in the market.

3D technique	The basis	Devices
Anaglyph	Colour multiplexed	Anaglyph glasses red & green/ blue/ cyan lenses & Two unnaturally colourer images
Chromo-Stereoscopy	Chromo aberration	ChromaDepth glasses & One an unnaturally coloured image
Linear or circular polarization	Polarisation multiplexed	Polarised glasses & Orthogonally polarised screens or One screen with interlaced images on the display by row or column
Shutter glasses	Time multiplexed	Electro-optical shutter glasses
Time sequentially controlled polarisation	Time and Polarisation multiplexed	Shutter glasses & Stereo image generator and System for synchronizing the components
	Localisation multiplexed	Stereoscope or Head Mounted Displays (HMD) or Virtual Reality boom

Table 2-1: Techniques available to create depth illusion in a 2D medium

2.4.1.1 Stereoscopes

The illusion of depth in stereoscopes relies on the binocular disparity cue. The first stereoscope was invented by Wheatstone (1838) who found that two images taken from two slightly different points of view can be fused visually through a mirror or lens system (Figure 2-15) to produce a representation of space and depth. Normally these two images are placed side by side with the same distance of the retinal disparity to be viewed through a stereoscope (Ohara et al., 2009).

Figure 2-15: Simple Stereoscope (left) & Mirror Stereoscope (right) (Carboni, 1996) has been removed for Copyright restrictions

2.4.1.2 Anaglyph techniques

The stereopsis in this viewing system is achieved by deploying colour-separation techniques. Each view in the stereo pair is presented in complementary or near complementary colours, red/ blue or red/ green yellow/ blue, but with red/cyan being the most commonly used (Woods & Rourke, 2004) on a single display device. The observer’s glasses (Figure2-16) direct an appropriate image to each eye through lenses corresponding to the colours of the two images. Littlefield (1982) considers the effectiveness of this 3D vision relies greatly on how well the colour between the glasses and the images are matched. The colour and contrast of 3D anaglyph representation is limited to a relatively low quality (Bailey, 2006).

The main limitation of this system is that being dependent on two differently coloured-filters causes retinal rivalry. Furthermore, despite the source images being displayed monoscopically in colour (Blundell, 2008; Burder, 1984), the system cannot accurately depict full-colour images (Sabine et al., 1997). Ghosting or crosstalk (the leaking of an image to one eye, when it is intended exclusively for the other eye) is another factor that can degrade the quality of the 3D image in most stereoscopic displays at different levels, but it is more evident in anaglyphs (Woods & Rourke, 2004). Solutions to reduce ghosting are presented in Wimmer (2011). Using colour coding in this technique restricts the use of the range of colours in depicting images, hence colours cannot be reproduced (Doneus & Hanke, 1999). Images normally are dual-coloured only and even the choice of these colours is very limited (Blundell, 2008).

Figure 2-16: Red and blue anaglyph glasses filter the coloured image and direct each colour to one eye (Bailey, 2006). Anaglyphic image and green /red glasses (Toutin & Vester, 2000) has been removed for Copyright restrictions

2.4.1.3 Polarized displays

Although polarization methods have been known for over a century, it was just recently exploited, almost exclusively in 3D cinema production such as Avatar in 2009, Alice in Wonder Land and Shreck 4 in 2010). The method uses either plane or circular polarising filters that are placed before the observer’s eyes and oriented at right angles to each other (Figure 2-17), to separate the visual information provided to each eye (Huffman, 1954).

Figure 2-17: a) the principle of light polarization (Murphy et al, 2010). b) Stereoscope using polarized glasses: the horizontal plane polarizer in front of the right image passes only horizontal waves of light, while the vertical polarizer in front of the left eye passes vertical waves of light (Ohara et al., 2009) has been removed for Copyright restrictions

Typically, on a non-depolarizing screen, the stereo-pairs are projected through filters oriented correspondingly to angles of the filters worn by the viewers (Shurcliff, 1954). In another configuration of the system the stereo pairs are displayed on two CRTs arranged at right angles (Figure 2-18) with a partially silvered mirror arranged at 45 degrees between them. Polarisers are placed directly on the screens while filters are oriented at right angles to each other. Plane polarizer systems suffer from loss of light intensity, in addition to image ghosting due to the incorrect position of a viewer's head. Circular polarisers can alleviate the effect of ghosting, but with a significantly increased loss of intensity (Sexton & Surman, 1999).

Figure 2-18: Left, the principle of polarized 3D glasses (Bailey, 2006). Right, screens oriented at right angles to each other (Petrie, 2001) has been removed for Copyright restrictions

Faris (1994), proposed a practical application of a technique that requires only one display screen and a spatially multiplexed image using micro-polarisers. The technique uses an array of microscopically small polarisers with a resolution of up to 1000 lines/ cm; these are arranged in horizontal lines of alternative polarization and aligned with a spatially multiplexed image (Figure 2-19). Viewing the image requires passive polarized glasses (Pulfrich, 1922).

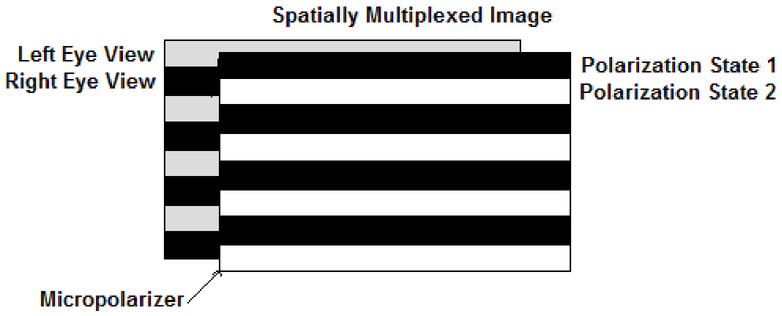


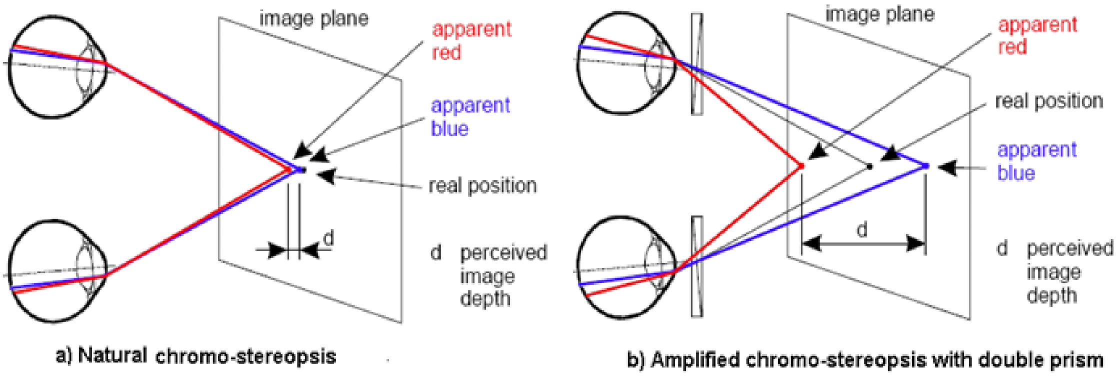
Figure 2-19: Image consisting of alternate strips of left and right eye views

The polarisation passive technique is used in RealD technology that is currently deployed in 3D cinemas. And it has been commissioned by Toshiba and Panasonic to produce 3D TVs. However, the technology would be significantly expensive compared to the active shutter glasses despite the cheap cost of the passive glasses (Radar 3D, 2011).

2.4.1.4 Chromo-Stereoscopy (CS)

This technique is based on the chromatic aberration depth cue (Section 2.1.5) that is naturally perceived but with a minimal effect (Figure 2-20.a). This effect can be exaggerated using the physical properties of refraction. Kishto (1965) designed a single prism optic that performs a chromatic dispersion of the colour in the image, but also deviates the line of sight to the image resulting in an unpleasant effect on the viewer. Steenblik (1987) established modern CS (Bailey & Clark, 1999; Petrie et al., 2001) by introducing the super-chromatic prism that amplifies chromo-stereopsis (Figure 2-20. b) and minimises the strain on the viewer's eye. The prism is made of a very thin cost effective clear diffractive micro-optic film (Steenblik, 1987).

The Steenblik's system uses a pair of prisms attached back to back and pointing in opposite directions (Steenblik, 1993; Verwichte, 2006). One prism is highly dispersive for colour while the other has low dispersion characteristics (Toutin & Vester, 2000). The high diffractive prism separates the colours, and the low dispersive prism ensures the rays reach the eye (Verwichte, 2006).



a) Natural chromo-stereopsis

b) Amplified chromo-stereopsis with double prism

Figure 2-20: Natural and amplified chromo-stereopsis

2.4.1.5 ChromaDepth glasses

Steenblik's invention has been commercialised through American Paper Optics (APO) Inc. The company is the exclusive producer for 3D ChromaDepth glasses, and its website provides useful guidelines on how to use colour to produce CS images (APO Inc, 2009) There are two types of ChromaDepth glasses: C3DTM glasses (formerly named standard) for printed displays and the HoloPlayTM (high definition (HD) glasses) for electronic displays (APO Inc., 2009). The main difference between the two types relies on the number of gratings used in each lens, which in turn influences the depth effect (Ucke, 1998). In the C3DTM glasses, each lens has a grating therefore the depth effect is larger, but the images are less sharp. Another limitation occurs when viewing Cathode Ray Tube (CRT) images. Colours on a CRT result from a combination of the three primary colours: red, green and blue (section 3.4.3.3). When any small region of a composite colour, such as yellow, is displayed on a CRT and viewed with ChromaDepth 3D glasses optics, it might be separated into its primary components causing blurring.

To solve this problem and provide a high definition, the optical power was concentrated in one eye, where the grating is used in the left lens, leaving the other eye to see the image clearly through a transparent film in the right lens (McAllister, 2005). Consequently, a sharp crisp image becomes possible, but at the cost of the depth perception, which is halved (Ucke, 1998).

A cross-section in the left part of the grating (Figure 2-21) shows a saw-tooth profile with a groove spacing of $g \approx 32 \mu m$. In this specification light of wavelength $\lambda = 560$ nm (yellow) appears under an angle of $\Phi = 1^{\circ}$ (where $\sin \Phi = \lambda / g$) on both sides of the normal of the grating.

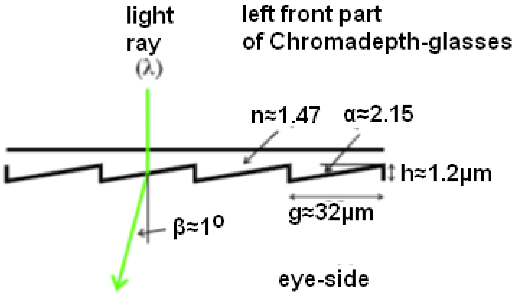


Figure 2-21: A cross-section in left part of ChromaDepth glasses: illustrates the saw-tooth profile of the grating adapted from Uck (1998)

2.4.1.6 Chromo-stereoscopic images

An unusual feature of CS is that, in contrast to all other stereoscopic techniques, the user does not have to use a stereo pair of images; only a single coloured-image is required (Steenblik, 1993). The image (Figure 2-22) contains the dimensions X and Y, while the third dimension Z is expressed by colours that are highly contrasted with the background (Bailey & Clark, 1999). The resulting apparent stereoscopic effect is created by the passive optics in the 3D ChromaDepth glasses that decode the colour-coded image (Verwichte, 2006).

Figure 2-22: ChromaDepth image presents the Tijuana River Watershed (Bailey, 2010). (The reader can use the glasses bound into the front cover) has been removed for Copyright restrictions

2.4.2 Field/ Frame sequential displays: active and passive glasses

These systems consist of three components: shutter glasses, a display with stereo image generator and a system for synchronizing the components (Roese & Khalafalla, 1976). The principle of these displays is to present images on the display using odd and even fields of the television interface. The screen is viewed with special glasses with Lanthanum-modified Lead Zirconate Titanate and recently liquid crystal (LC) lenses that alternate the viewing eye, hence each eye only sees one of the images (Sexton & Surman, 1999; Travis, 1997). The main drawback of these systems is bad flicker. However, with a sufficiently high frame rate, the viewer can see a flicker-free image (Travis, 1997). Passive systems have a lower dynamic range than active eyewear systems. The phosphor afterglow on the CRT causes ghosting, or image cross talk.

2.4.3 Shutter glasses

This technology (Figure 2-23) uses a pair of battery-powered, wireless liquid crystal display (LCD) shutter glasses combined with a special, 3D-vision-ready, high-refresh-rate (120 Hz) display screen. The lenses in active shutter glasses are normally transparent, but each one becomes dark when voltage is applied. They alternately darken over one eye then the other while the display is changing the perspective view for each eye. This alteration is synchronized with the refresh-rate of the monitor and controlled with the built in infrared signal (Boulos & Robinson, 2009).

The technique is credited with its ability to present all colours. In contrast, besides the high cost of shutter glasses compared with anaglyph and polarised glasses, problems associated with minimum refreshing screen rate (100Hz), confine their usability to CRT screens, since the modern TFT (Thin-Film

Transistor) monitors do not offer the required rate. Also, being not completely dark, the displays of shutter glasses allow some light to pass, resulting in a blurry image or some users may experience “ghost” images from the alternate channel (Fauster, 2007). Active shutter glasses are one of the essential components for the more sophisticated 3D visualisation method, virtual reality.

Figure 2-23: Components of 3D active shutter glasses (Sherwood, 2007) has been removed for Copyright restrictions

2.4.4 Virtual Reality (VR)

VR has been defined as “an advanced human-computer interface that simulates a realistic environment and allow participants to interact with it” (Latta & Oberg, 1994). It provides an immersive and a navigable 3D medium with a real time response for action (Whyte, 2002). The synthetic world created by VR increases participation and understanding, it enables the user to navigate around and interact with virtual objects. These attributes enhance the human awareness of complex situations and improve the quality of decision making.

There are various approaches to implement VR systems, and they can be classified according to their degree of immersion and interaction as:

- Immersive systems: absorb and involve the viewer by covering the user’s field of view through the use of a large screen or head mounted displays.
- Non-immersive systems: do not cover the user’s full field of view (i.e. small displays).
- Augmented systems: superimpose the virtual display over the visual field as the users view the real world.

The head mounted display (HMD) and CAVE approaches are two of the best VR methods known, so they will be briefly discussed.

2.4.4.1 Cave Automatic Virtual Environment (CAVE)

The scene of immersion is created by surrounding a user inside a cube consists of six display screens (Figure 2-24). On each screen 3D computer graphics are projected. To perceive stereo, users wear three-dimensional shutter glasses. Multiple users can step into the CAVE and share an experience, although only one of them is tracked, and therefore controls the viewpoint for everybody. A wand with a six-degrees-of-freedom tracker and several buttons are used to interact with the virtual scene.

Figure 2-24: CAVE: a 3D stereoscopic system that offers complete immersion of the user by projecting images on a cube screen (Fake Space Systems Inc, 1999) has been removed for Copyright restrictions

2.4.4.2 Head Mounted Displays (HMDs)

HMDs consist of two displays one in front of each eye. The displays can be CRT, LC or OLED (Organic Light Emitting Diode) screens that are mounted on a helmet or a glass frame structure. The HMD can be binocular showing the image to both eyes, or stereoscopic exposing each eye to a different image. Showing different images can be perceptively used to produce a 3D interaction, or 3D presentation (Fauster, 2007). The suitability of HMDs for any specific task can be influenced by several factors such as a display size, weight and adjustability of physical and visual settings. The high cost of head-mounted displays that are both high resolution and wide field of view is a major factor, added to potential health problems associated with hygiene (the possibility to transfer infections from one user to another).

2.4.5 Autostereoscopic systems

These devices are free viewing systems that display the 3D spatial image of an object to an observer without the use of any external viewing aids. These systems consist of three components: image reproduction unit (flat panel display or projectors), lenticular or parallax barriers for stereo image separation, and a head tracking system to enable the viewer to move his/ her head (Bo¨rner, 1999). Current virtual 3D displays are achieved by different systems based on a number of images. These include motion parallax systems based on single images, stereo and alternating pair systems using two images, varifocal mirror and holographic systems using more than two images (Hodges, 1992; Kraak, 1988; McAllister, 2005).

Autostereoscopy has been successfully achieved in 2D display screens by using two techniques: parallax stereograms and lenticular sheets. A brief description for these methods will be presented. For a detailed comparison among all variations and applications of these methods can be sought from Bergmann & Dynamic (2009).

2.4.5.1 Parallax stereograms

The autostereoscopy in these systems is known as the parallax barrier method in which a very finely striped grating is located before a specially created image. The grating contains a sequence of parallel transparent gaps separated with opaque lines. Each gap reveals a specific vertical column or strip of the image positioned behind it. This image integrates two sets of interlaced and alternating vertical segments obtained from the two images of the stereo-pair. The arrangement of this striped image and the slits of vertical grating redirect light from odd and even pixel columns to the viewer's left and right eyes respectively, to create the illusion of three dimensions. Sharp's autostereoscopic displays use this method in the switchable 2D-3D displays. The filter can be toggled, allowing the display to return to its 'normal' 2D state (Figure 2-25).

Figure 2-25: The principle of the parallax barrier system used in Sharp's switchable 2D-3D displays (Patker, 2009) has been removed for Copyright restrictions

While systems based on the barrier filter method are cost effective, they have limitations. The viewer has to stay in a fixed position to perceive the projected image in 3D. To enable the users to move, a head tracking device has been introduced. The device will adjust the angle of the array according to the user's current positions (Figure 2-26). The method used to manufacture this technology, may cause a significant degradation in the resolution. This can be clearly seen in the 2D-3D switchable Sharp TV. Although the standard resolution of such displays is1024x768, only half this resolution will be available when the 3D mode is activated as the monitor directs only half the columns of the pixel to each eye. To overcome this significant loss of resolution, Philips launched its HD 3D TV, the first quad full auto-stereoscopic high definition TV. Quad-full TVs increase the rate of data to the extent that the resolution of the display's screen increases to (3840 ×2160), four times the number of pixels of the highest HDTV standard.

Figure 2-26: Parallax barrier in eye tracking system (Petrie, 2001) has been removed for Copyright restrictions

2.4.5.2 Lenticular sheets

The basic concept is similar to a parallax-barrier, but it involves replacing the grating with a set of parallel gaps with a lenticular sheet (Figure 2-27). This comprises an array of long parallel cylindrical lenses or lenslets that are made from a transparent plastic material using a special mould. Each cylindrical lens in the array takes the place of an individual slit. The system reduces the significant loss of light caused by the opaque lines of the grating used in the previous system and provides a much improved image. The main application of autostereoscopic displays is TV production.

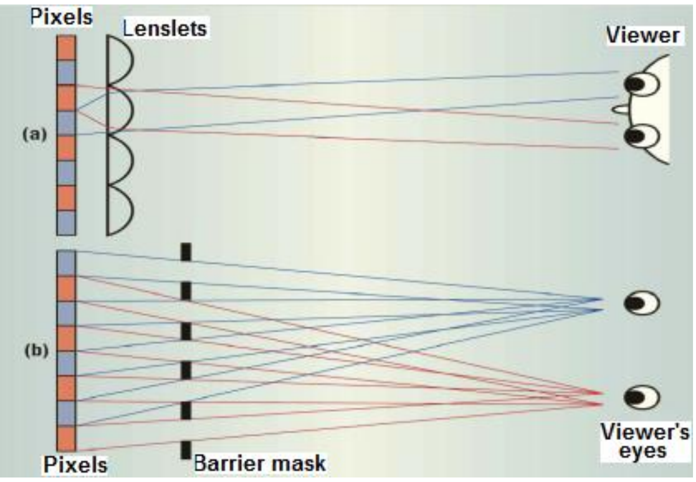


Figure 2-27 the principles of autostereoscopic displays

2.4.5.3 Holography

Holography is the only true 3D photograph. It can be perceived by all users using their human spatial/perceptual abilities (Hilaire et al., 1990). Holography is the first spatial imaging method that uses the accommodation cue (Gabor, 1948). Besides accommodation, this image deploys a range of depth cues that are associated with true 3D viewing, namely binocular convergence, motion parallax, and occlusion (Sexton & Surman, 1999). Holographic displays record both phase and amplitude information of the light reflected from the scene (Fauster, 2007). They provide high quality 3D images that can be seen with multiple viewers without restricted position of viewing. However, the quality of the images relies on the data rate which in turn is a function of the image size. For a high-quality full colour desktop monitor-sized display, the data rate is of order of 100 Tb/s. Such extremely high data rate restricts the application of holography for displaying realistic, dynamically computer-generated images in real time (Benton et al., 1993).

2.4.5.4 Volumetric displays

In contrast to all other 3D displays, this type is used to generate volumetric images (i.e. to occupy a space) and does not rely on flat displays (Sexton & Surman, 1999). Volumetric displays create 3D imagery via the emission, scattering or relaying of illumination from well-defined regions in x, y, z space (Fauster, 2007). There are two types of volumetric displays (Figure 2-28): moving screens (or swept-surface) and static volumetric 3D display (Fauster, 2007; Sexton & Surman, 1999). The differences between these systems are described in Langhans et al. (2002).

Volumetric display supports multiple users; the images are located within the physical world of the viewers. Each viewer can observe the picture from a different perspective, and it uses a range of depth cues, oculomotor and motion parallax. This makes the viewing experience very natural. Users can interact with the display in different ways as reviewed in Favalora (2005). To produce true volumetric images in high resolution, the system requires significantly high data rates which can be a challenge (Langhans et al., 2002).

Figure 2-28: Examples of the two types of volumetric 3D displays: a static display (left) and swept surface display (right) (Favalora, 2005) has been removed for Copyright restrictions

2.5 Chapter summary

The chapter reviewed the process of seeing in 3D, and the depth cues implemented in 2D visualisations to retrieve third dimensions of a scene. Also it presented the wide range of 3D systems developed and applied for various applications including entertainment and scientific field. Some 3D systems require wearing simple or sophisticated eye-wears and the others do not need any additional wear.

The application for each system is more dominant in one field than the other. In geo-physical mapping, 3D is mainly implemented by using techniques based on colours and shading. This includes anaglyph, Chromo-Stereoscopy and hill shading. This is due to the simplicity and cost effectiveness of such techniques. Although visualisation is applied in a range of scientific and entertainment fields, the limited space in this thesis and the author’s interest in marine science, it was decided to review the visualisation methods in marine field.

Chapter Three

3 Data presentation in marine field

This chapter presents the different methods of presentation used for marine operations. It begins by reviewing nautical charts that are primary marine visualization and their design conventions. A review of sonar images and digital terrain models is also provided; finally principles used to implement 3D visualisations in marine applications are discussed.

The data gathered to produce a graphical representation of the seabed and other geospatial information went through different stages. It started with manual measurements using lead lines, and then exploited the advances in acoustic survey technologies to map the seafloor more efficiently. The improvement in Lidar and lasers to satisfy hydrographic applications made them an alternative, even a unique option to map some areas where acoustic systems cannot be operated. Such a variety of techniques enabled the production of a significant amount of high resolution geo-data. Accordingly, display methods have been advanced and the cartographic conventions have been extended. These developments are evident in the evolution of nautical charts and other hydrographic survey products.

Digital cartography has provided an appropriate means to gain an understanding and insight into data (Emmel & Hersch, 2000) and to prepare more effective descriptions and interpretations for the surrounding environment (Monmonier, 1981). Häberling (2002) introduced the term of 3D maps to refer to presentations of spatially-arranged phenomena that possess cartographic characteristics and have a 3D illusion despite being presented in a 2D media.

3.1 Nautical charts

Navigating through water bodies is one of the first attempts to exploit the marine environment. To plan and document a safe navigation route, nautical charts were produced. Nautical charts are the essential tools for mariners to navigate in waterways. Nowadays charts are displayed in paper and electronic media. Regardless of the display medium, charts show critical information for navigation such as water depths, navigational hazards, positions of natural and man-made aids to navigation, information on tides and currents, natural features of the seabed, areas of restricted activities, details of the coastline, man-made structures, local details of the Earth's magnetic field, and man-made structures such as harbours, buildings, and bridges (NOAA, 2011). Such information is depicted on the charts by numbers and contour lines to represent the depth of the area and symbols for aid to navigation to indicate areas of recreational activities.

3.1.1 Paper charts

Paper chart production used to be a simple but tedious manual process, where the soundings of lead line and/ or single beam echo sounder were corrected then contoured (Figure 3-1). The advances in cartographic technology made the process semi-automated and the nautical chart has become more sophisticated.

Figure 3-1: Mariveles Harbour from a 1970 nautical chart: Sackett's hand drawn war time plan at a scale of 1:30,000 (Mariveles Harbor, 2010) has been removed for Copyright restrictions

In 1862, the Coast and Geodetic Survey (CGS) introduced colours to its charts to emphasize shallow water and hazardous underwater obstacles (NOAA, 2007). In nautical charts, colour signifies different features (Larkin, 1993). The colour coding system is conventional and may vary between publishing entities (USCG & Wooldridge, 2004). For instance, Admiralty charts use five colours yellow, white, and green, magenta and black each with different levels of intensity (Figure 3-2). Yellow refers to land, with the pale yellow representing normal land, while the darker shade infers more urban areas. Dark blue is used for shallow water, light blue for intermediate depths and white used for safe water areas. Green represents areas that are submerged at some stage of the tide. Magenta is a multi-purpose colour, as it can be clearly read under different illuminations on the vessel’s bridge. Magenta is used to highlight recommended routes, show danger messages, compass roses, and red and daylight buoys, and identify lighted buoys.

Most symbols and printed information are displayed in black. Although some aids to navigation buoys are coloured red and green to facilitate interpreting their meaning, they are most often drawn in black, as green does not appear clearly under red light (the main source of illumination at night used to preserve ‘night vision’ capability). In charts produced by the National Imagery and Mapping Agency (NIMA), the land may be presented with a grey shade. Other information on the charts is iconized according to international norms.

Figure 3-2: An example of colour use in Admiralty nautical charts (Johnson, 2009) has been removed for Copyright restrictions

3.1.2 Navigation buoys conventions

The standard usage of navigational buoys is defined by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) (formerly the International Association of Lighthouse Authorities (Khalique, 2009) and known as the IALA buoyage system. The system defines the characteristics and the meaning of all navigation marks (buoys and beacons). The buoys are differentiated with shapes, top marks, colours, and sometimes with characteristic lights. The five shapes used are pillar, spar, can, cone and spheres. Can and cone buoys indicate the sides of navigation channels while the other shapes have significance variety of meaning. The top marks of buoys are normally appropriate to the buoys’ shapes (i.e. can buoys carry a can top mark). Additionally, x-shape is intended for special buoys, two back spheres indicate isolated danger, while a combination of cones are used for cardinal buoys (Khalique, 2009).

The conventions of these marks are used worldwide with an exception in the colour of lateral buoys and their lights. Accordingly, the world is divided into two regions, Region A, and Region B (Figure 3-3). Region A covers the entire world excluding the Americas and a part of Far East from Philippines to South Korea, while Region B include Americas, Japan, Koreas and Philippines (Johnson, 2009).

Figure 3-3: The regions of IALA A and IALA B in the world (Sailing systems, 2012) has been removed for Copyright restrictions

The main difference between the two regions is the colour of the lateral buoys and the light used to signify port and starboard sides of a navigation channel when entering from seaward (Figure 3-4). In Region A: the channel will be marked with red cone-shaped buoys lit with a red light on the port side of the channel and the starboard side with green can-shaped buoys lit with a green light in Region B, the port and starboard markers maintain their shapes as in Region A as cones and cans respectively (Figure 3-5), but they have opposite colours: green port and red starboard. Despite the change of colours, port and starboard buoys can be clearly distinguished on the chart with their distinct symbols (Figure 3-6).

Figure 3-4: Navigation channel marking buoys in IALA A region; where the port buoy is red can-shaped while the starboard buoy is green cone-shaped

Figure 3-5: A schematic representation for IALA buoyage system region A (left) and region B (right) in the real world where the lateral marks have the same symbols, but the opposite colours, red can-shaped buoy for port-side of the channel in region A, while port-side is marked with a green can-shaped in region B (IALA, 2012) has been removed for Copyright restrictions

Figure 3-6: IALA buoyage system in Region A and Region B. As it appears on a chart, symbols are black and their actual colours represented by a letter (NOAA, 2007) has been removed for Copyright restrictions

There are four cardinal marks (North, South, East and West) with yellow and black colours. These marks indicate shallow water, and the name of cardinal mark specifies the safe area for navigation. For instance, south cardinal implies that safe navigation is to the south of that mark. There are other marks which are less frequently used to indicate safe water and isolated danger as their names imply: safe water and isolated danger marks these marks are normally red and white or black and white (Figure 3-7). Nevertheless, when these marks are presented on a chart, they appear as back symbols and the colour is described by small letters (Figure 3-8).

Figure 3-7: The use of colours for cardinal and Safe water marks to indicate safe water: (from left to right) keep to the: North, South, East and West. Red and white colour indicate safe navigation and isolated danger mark (Black on red) (Admiralty, 2005) has been removed for Copyright restrictions

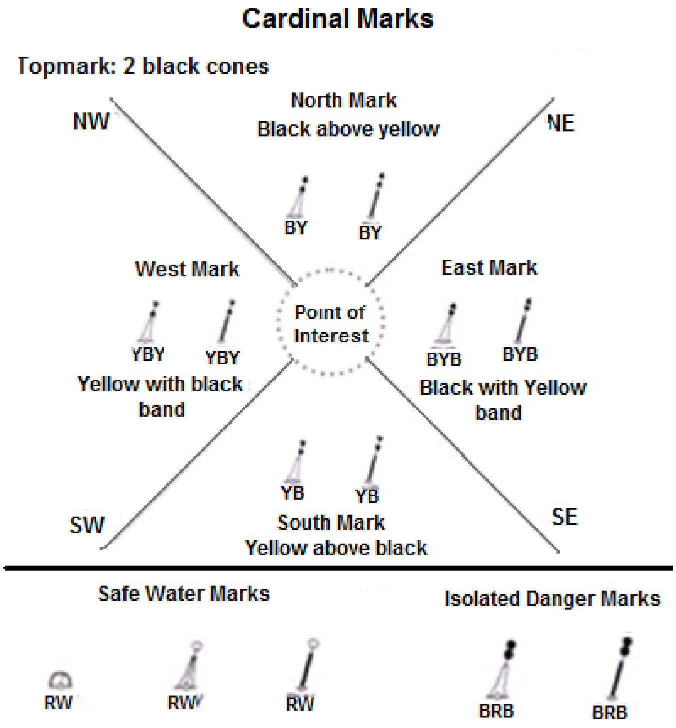


Figure 3-8 The symbols of cardinal marks and safe marks used on Admiralty Charts adapted from Admiralty (2005)

3.1.3 Electronic charts

With the development of computers and the 3D positioning system GPS, the need for electronic charts has arisen. In 1976 NAVASHLS was presented as the first electronic chart produced from digitised paper charts (Ward et al, 2000). Currently, there are two types of electronic charts: raster and vector. Raster charts are scanned copies of paper charts. They serve as an information layer on the online navigation system (Figure 3-9) to plan and perform the survey. The survey lines can be plotted on the screen and the vessel direction can be heads up.

Vector charts use mathematical algorithms to define the shapes and symbols of the coastal features. The positions and characteristics of all features are saved digitally in a layer format database (Khalique, 2009). Unlike raster charts, vector charts enable users to select which information to keep on the screen or to switch off (Figure 3-10). Also they maintain a good quality of image while zooming. Charts produced and authorised by the National Hydrographic Offices are known as official charts. There are two types of official charts Electronic Navigational Charts (ENC) and Raster Navigational Charts (RNC).ENCs use vector data that conform to the IHO chart data transfer standard S-57, while RCSs are digital raster copies of official paper charts conforming to IHO Product Specifications RNC S-61(IHO, 2010).

Figure 3-9: NOAA raster navigational chart to be used primarily as a backdrop display for plotting vector data, and for interpretation and analysis (NOAA, 2008) has been removed for Copyright restrictions

Figure 3-10: Illustration of ENC flexibility to display different levels of information: top: basic display, and bottom: full display (IHO, 2010) has been removed for Copyright restrictions

These charts are used in ECDIS package to enables the mariner to access more geospatial data on board by integrating chart information, global positioning data, radar data and tidal currents. Also, all electronic displays use two different colour schemes RGB and CYM (As required by IMO) (Figure 3-11) to accommodate the light difference between day and night time and preserve the skipper natural vision.

Figure 3-11: RNC display daytime (left) and night time (right) (IC-ENC, 2007) has been removed for Copyright restrictions

3.1.4 3D charts

The successful adoption of ENCs in hydrographic survey and navigation and the 3D nature of these operations led to developing 3D charts. Ford (2002) introduced the first 3D chart where he removed the sea surface and showed only the topography of the bathymetry (Figure 3-12) to promote safer and more efficient transportation on water. Gold et al. (2004) found 3D charts beneficial for training and navigation. Using another approach Porathe (2006) and Ternes et al (2009) created 3D charts based on VR. In their prototypes, they regenerated the view from a vessel bridge mimicking the real-world; including the water surface, surrounding topography and surface navigation marks (Figure 3-13).

Figure 3-12: The first 3D chart, where a peel off sea surface technique was used to reveal the seabed topography that is presented as a DTM in 3D perspective (Ford, 2002) has been removed for Copyright restrictions

Figure 3-13: A simulation of 2D chart features (top) into a 3D view (bottom) as seen from a vessel bridge view (Porathe, 2006) has been removed for Copyright restrictions

3.2 Digital Terrain Model (DTM)

A DTM is a continuous surface connecting many points defined in 3D space by x, y, z coordinates, where x and y define the position of the point in a 2D plane while z represents the height. Besides the height above seabed, a DTM provides information about the topography such as the slope (Podobnikar, 2005), and it forms the basis of displaying images on the screen. Figure 3-14 illustrates DTM examples derived from Lidar data. DTMs are normally coloured utilising a linear application of the colour map according to depth. Red is assigned to the highest part of the DTM and blue for the lowest part.

Figure 3-14: Bathymetric LIDAR is used to acquire data in areas with complex and rocky shorelines to establish water depths and shoreline elevations (USOCS, 2012) has been removed for Copyright restrictions

The advantages of 3D visualisation have been recognized for other operational activities carried out in 3D for example in fishing and remotely operated vehicle (ROV) operations. As a result, the conventional 2D DTM has been transferred into a 3D presentation using perspective view (Figure 3-15).

This presentation was used in 3D charts for navigation and in fishery navigation systems.

Figure 3-15: Three-dimensional bathymetric map image courtesy of Tombolo Institute (Washington State Seafloor Mapping Committee, 2008) has been removed for Copyright restrictions

Using a depth colour coding, DTMs enhance understanding of the seabed topography and highlight non co-planar objects. For instance, in Figure 3-16, a shipwreck can be easily detected and recognised through a multibeam bathymetric survey, while achieving that with a single beam survey would be very difficult unless accompanied with a side scan sonar survey.

Figure 3-16: The shipwreck Herbert D. Maxwell (sunk on May 16, 1910, east of Annapolis, Maryland) depicted by side scan sonar (left), and a (DTM) generated from M data (right). (NOAA, 2006) has been removed for Copyright restrictions

3.3 Side Scan Sonar (SSS) images

Side scan sonars uses acoustics to derive images either sides of a towed body the resulting swathes are stitched together to produce an image of the survey site. The intensity of the backscatter is used to examine the structure of the seabed and any objects on it. High intensity returns infer hard objects or rocks, while low-intensity indicates soft materials like silt or organic objects. A side scan only give a degraded image on an analogue trace (Figure 3-16), images can be hard to read and cannot be enhanced (Clough, 1999).

3.4 Fishery systems

All fish-finders operate using a sonar pulse that insonifies a cone of the water column. The system varies in range and display characteristics according to manufacturers and the fishery type. Most fish finders present the reflected signals in 2D (Figure 3-17).

Figure 3-17 FURUNO CH37, Data display modes:(left), semicircle scanning window, horizontal scan, left, vertical scan with 3D graphic overlay useful for trawlers, sounding beams directed from starboard to port (FURUNO, 2011) has been removed for Copyright restrictions

However, to optimise fishers' use of resources, the Canadian company ICAN, produced the fishing information navigation system (FINS) with a 3D module. The module (Figure 3-18) uses 3D perspective to show the fishing vessel and the towed gear, and the bathymetry as a DTM colour coded according to depth. To reference the water depth a drop line from the vessel centre to the seabed is used.

Figure 3-18: The 3D display of the Fishing Information Navigation System, showing the fishing vessel and the towed gear in perspective view with a DTM for the seafloor (FINS, 2011) has been removed for Copyright restrictions

3.5 Visualisations for Remotely Operated Vehicle (ROV)

The complexity of the underwater environment makes ROV operations difficult. The success requires a skilful pilot and a clear 3D view of the surroundings to aid the pilot to identify the exact spatial location of the ROV. Normally, ROV operators rely on video images in black and white grey scale. The relationships close to are very obvious, but the sense of perspective over greater distances is difficult to estimate.

In their research, Qingping and Chengi (2001) reviewed several proposals to enhance ROV operations, and concluded that VR (section 2.5.1.6) would be an appropriate solution. Hence they developed a VR-based application for tele-operation and pilot training. For a mission within underwater installations, a 3D model of any structure is created (Figure 3-19).

Figure 3-19: Sample screen capture of the virtual telepresence system, with camera view, profile view, bird's eye view, and historical path display. The safety domain is displayed as a white box wrapping the robot (Qingping & Chengi, 2001) has been removed for Copyright restrictions

3.6 Chromo-Stereoscopic visualisation

The initial use of CS in marine applications was to enhance estimating depth from a 2D birds-eye view DTM for hydrographic applications (Lamplugh et al, 1996). Lamplugh et al. applied the colour map proportional to depth. Allocating the number of colours used based upon a histogram analysis of the depths produced a balanced colourful image (Figure 3-20).

Figure 3-20: An image of seafloor generated from EM1000 multi-beam data collected on the FG Creed by the Canadian Hydrographic Service -Atlantic. (Lamplugh et al, 1996) has been removed for Copyright restrictions

The image is very striking. It highlights sea floor features and accelerates the viewer's understanding of the geomorphology of the ocean floor. This sort of rendering was deemed to be of enormous use for visualising and planning the coverage of a survey, also for checking erroneous data and showing the general nature of the seafloor.Recent use of CS for hydrographic applications incorporated CS with perspective 3D DTM to enhance the understanding the seabed topography. By colour coding objects according to their distances from the virtual viewing points, the 3D perception of a scene is augmented, and the interposition effect was easily perceived (Figure 3-21, top). Also CS was applied as a means to facilitate presenting and reading the tidal current in different layers in the water column (Figure 3-21, bottom). The advantage of CS was obvious especially in the 2D vertical view (Ostnes, 2005).

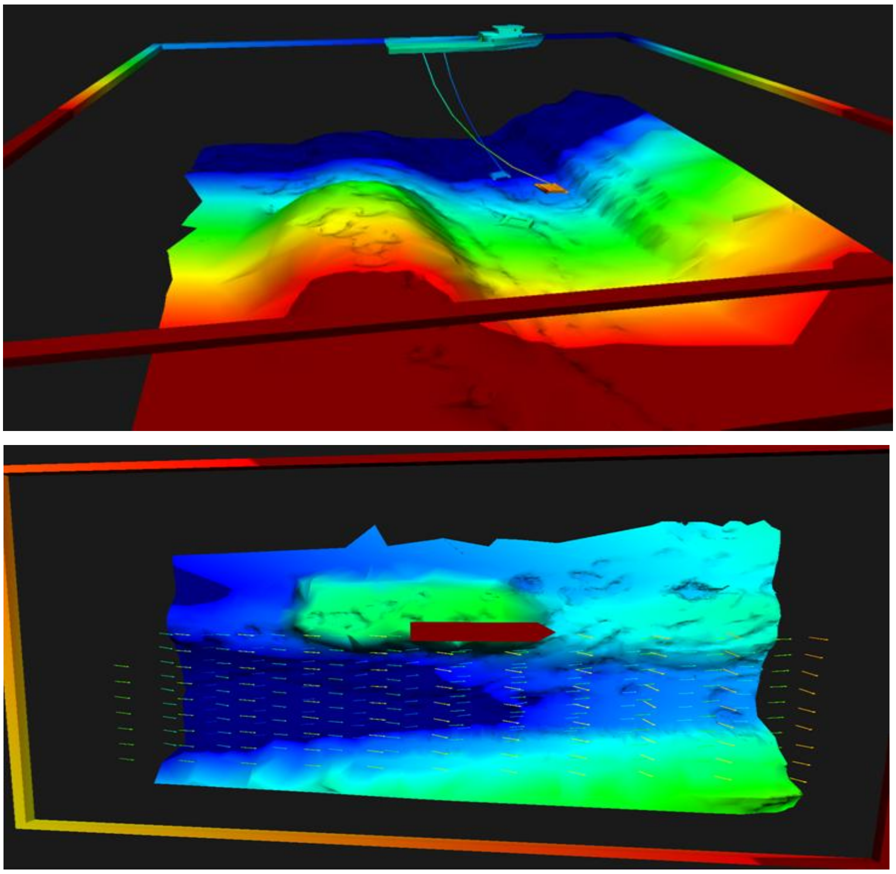


Figure 3-21: CS application with perspective 3D DTM and interposition (top), CS for representing tidal currents in the water column (bottom) (Ostnes, 2005)

Before proceeding with the study, some perception factors that are associated with CS are discussed.

3.7 Further discussion on CS

3.7.1 Advantages of Chromo-Stereoscopy

CS is colour-dependent, and the role of colour to present information has been well established (Tufte, 1990). Colour can express multidimensional data (Ware & Beatty, 1988) and significantly enhance the users' perceptions of information (Judd & Eastman, 1971). Colour is additionally important in many applications of 3D imaging. Colour is used in segmenting the images, allowing the viewer to distinguish between objects in the image and between objects and their background. It is also important in distinguishing types of objects or their status e.g. in medical applications (Batavia & Singh, 2001; Siegal & Akiya, 1999).

Although obtaining the chromo-stereoscopic effects requires an image coloured specifically to the application, the process of this operation is simple and affordable. This image can be seen naturally as a 2D flat image and transformed into 3D image when 3D ChromaDepth glasses are used (Bailey & Clark, 1999). In contrast to other stereoscopic techniques that require two images, Chromo-Stereoscopy offers a stereoscopic coloured-image without this additional cost, expenses that may result from increasing the raw data to be transmitted in the channel between the two colour cameras and the displays, and the cost of using two recording colour cameras as a part of the display configuration. ChromaDepth contains depth information in one image, which eliminates the ghosting seen in other schemes when one attempts to view them without 3D glasses.

Also, CS is compatible with all display media: the printed images, monitors, overhead projectors and the web (Steenblik, 1993; Wallisch et al., 2001). chromo-stereoscopic depth can be perceived by colour-blind people since it depends on the position of the projected wavelength on the retina not on colour recognition (Fauster, 2007; Wallisch et al., 2001). Most importantly, CS uses the chromatic aberration cue, which is one of the depth cues that does not rely of on specific hardware, thus it can be used to improve depth perception in computer-generated images (Weiskopf & Ertl, 2002).

3.7.2 Applications of Chromo-Stereoscopy

Figure 3-22 Image gallery for different applications of CS in applied science has been removed for Copyright restrictions

Since the introduction of Chromo-Stereoscopy, it has found wide applications in laser shows, print, video, television, computer graphics, photographic slides and internet images. Many areas of research have benefited from the use of CS (some example of these applications are presented in Figure 3-22.

In remote sensing, Toutin (1997) and Petrie. (2001) investigated the application of CS to improve spatial perception of data by colour coding of elevation variances in 3D maps. Verwichte and Galsgaard (1998) utilised 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 a different approach, Wallisch et al. (2001) applied CS to highlight abstract information where the priority of the objects are mapped linearly to a perceived depth. a recent use of CS, was in the medical sector to create illustrative rendering framework for enhancing depth perception on the renditions of complex vascular structures (Alan et al., 2008).

3.7.3 Positive and Negative CS

The general principles of CS (Section 2.4.1.4) and chromatic aberration (section 2.1.4) have emphasised how red colour is normally perceived in front of blue. However, this effect can be reversed in some circumstances producing different types of CS. Accordingly, there are two types of chromo-stereopsis: positive and negative. Most observers naturally experience a positive chromo-stereopsis (see red in front of blue). However Hartridge (1947) and Howard and Rogers (1995) suggest that minority of observers see a reverse effect (blue in front of red) known as negative chromo-stereopsis.

In CS glasses, these two effects are subject to the order in which the chromatic prisms are positioned. When the high dispersive prism is placed before the low dispersive prism, red colours appear closer than blue colours (Verwichte, 2006) resulting in positive chromo-stereopsis (Toutin & Vester, 2000), while, the opposite arrangement of the prisms reverses the colour order producing negative chromo-stereopsis (Figure 3-23). The commercial glasses produce a positive chromo-stereopsis (red in front).

Figure 3-23: Chromo-Stereopsis according to the interchangeable positions of the prisms in the super-chromatic prism: negative when the low dispersion prism is before the high dispersive prism (Left) and positive when this is reversed (Right) (Verwichte, 2006) has been removed for Copyright restrictions

An additional factor that can create depth reversal in images is the colour of the surrounding background. Dengler & Nitschke (1993) tested the effects of changing the background colour from black to white in images containing blue and orange stimuli. The study demonstrated that a reversed depth relation between the two colours coincides with the instant changes in the background from white to black or vice versa. This colour depth reversal was attributed to the changes in the border contrasts.

3.7.4 Viewing distance

Faubert (1994) suggested that the effectiveness of Chromo-Stereoscopy is viewing distance related. Andrienko et al (2003) and Akiyoshi et al (2006) found that stronger effects can be obtained from a viewing distance greater than one metre. This was confirmed by Yamauchi (2004), who tested this distance effect on both positive and negative chromo-stereopsis. The result of the test (Figure 3-24) demonstrated an increment in the chromo-stereopsis effect with a viewing distance up to 2 metres in both positive and negative states.

This effective distance of viewing CS images matches the IMO requirement for designing all electronic equipment to be readable within 2 m on the vessel bridge. This is beneficial for implementing CS in the navigation suit if it was proved useful for navigation.

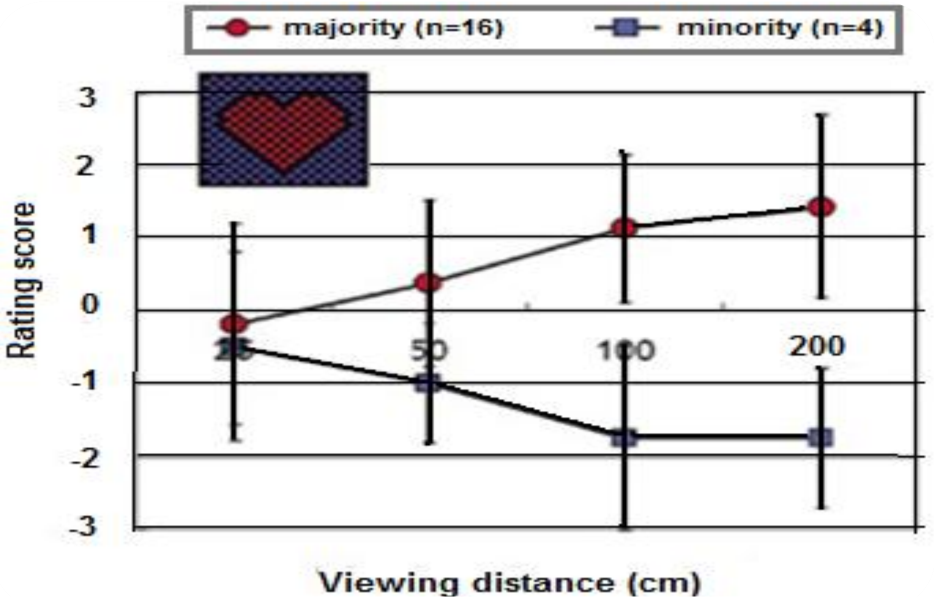


Figure 3-24: Figure 3-25: Chromo-Stereoscopy as a function of viewing distance adapted from Yamauchi, (2004). The red dots and blue squares respectively represent positive (the majority of observers who usually see red in front of blue) and negative stereopsis (the minority of observers see blue closer than red). The rating score ranges from -3.to +3. The strongest chromo-stereopsis effect scores 3 for the positive stereopsis, and -3 for the negative one, while 0 indicates the absence of a chromo-stereopsis effect. For both groups the longer the viewing distance the stronger the effect

3.7.5 Colour gamuts and colour reproduction

CS is a colour-based 3D system; hence the usability of this technique can be affected with differences in human-colour perception and the technical implementation of colours in electronic displays. The capacity of electronic devices to present a range of colours is defined by their colour gamuts. When the gamut of potential output devices (i.e. monitors, projectors and printers) are smaller than the gamuts of the input devices, the output device cannot reproduce colours equivalent to those of the input device. Figure (3-25) illustrates that a colour printer cannot regenerate all the colours perceptible on a colour monitor.

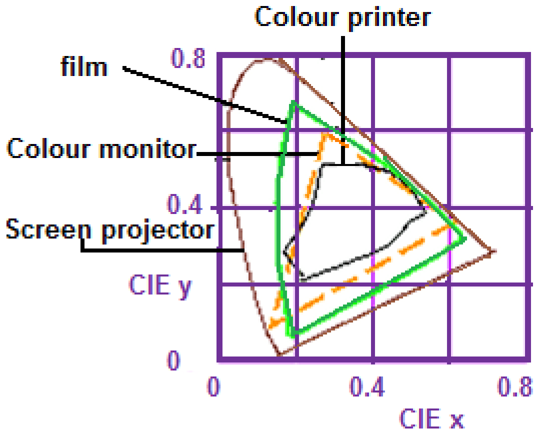


Figure 3-26: A schematic representation of colour gamuts for different devices

3.8 Discussion on 3D visualisation in the marine field and the research motive

3D has been successfully implemented to serve several purposes: data collection, monitoring and operational situations. Even for navigation, one of the most conservative sectors, 3D has been successfully introduced. The design of any visualisation is always based on cartographic conventions. These conventions dictate the layout, the symbols for abstract elements and the generalisation methods. Sophisticated 3D methods (e.g. VR) can follow these conventions and even replicate the natural surroundings. The latter would be very useful methods to adopt, but the high costs of specialised hardware may prohibit their use by individual users.

The availability of a simpler and a cost effective 3D technique like CS could be an option to support operational applications and enhance spatial awareness. The hydrographic models which were created by Ostnes (2005) demonstrated some applications of CS application in hydrography. The 3D effect was impressive and aided the test-user to understand the spatial relationship among the different element of the scenes. Nevertheless, in Ostnes' models the depth of field perceived was attributed to the compound effect of CS and other depth cues. Being obliquely presented in some views, the models had clearly used superposition and perspective view to convey 3D perception. Also illuminating the surface is an additional depth cue. There is a question on the extent this interaction between cues influenced the CS effect. From a cartographic aspect, the application of colour in CS has superseded the conventional colouring for DTM bathymetry, learning the potential users' reactions has to be studied. Finally all demonstrations were applied for static presentations while hydrography is a dynamic world: would CS support dynamic applications?

3.9 Chapter summary

There is a diverse range of methods to display marine data. Being a 3D environment, the representations tried to convey the sense of 3D using different techniques. Traditional displays are simple 2D representations with some pictorial depth cues like shading. With the advance of technology and computers more sophisticated technique become available, such as perspective view. In a later stage, mimicking the real surrounding becomes available through VR and flythrough. Despite the big advantage of these techniques, they are limited in use due to the high cost and high technical level. A cheaper and simpler method CS has introduced for hydrographic applications. Reviewing the principle of CS and the nature of marine applications and presentations revealed some gaps to be investigated. These include users respond to change in conventions, the interaction between CS and other depth cues and the use of CS for dynamic applications. The next chapter presents the methods used to conduct this study.

Chapter Four

4 Methodology: 1- Prototyping

Studying the users’ acceptance for the impact of CS on marine visualisation and its use for dynamic operations required producing visual stimuli to present to potential users. This chapter covers the programming work undertaken to create the study stimuli. Due to the difficulty of conveying movement on paper, the reader is advised to refer to the electronic display (available via the CD Rom provided at the back). There is an advantage in playing the electronic display. This will give an improved appreciation of the prototype development.

4.1 Programming tool: Matlab

Scenario developments require a programming tool. This tool was selected on the basis of supporting a novice programmer to create complex scenes with 3D objects and spatially move them and alter their colours according to their new locations from the viewing point. From the available programming languages (such as IDL, C++, openGL, and Matlab) Matlab was chosen. Its popularity in the academic sector and the availability of extensive support resources were advantageous. It has a huge number of built-in functions and for an extra cost it provides additional tool boxes, among which is the image processing toolbox. This toolbox facilitates creating different colour maps which are essential for CS, and controlling the viewing parameters (camera position, target position, view angle) which are of great significance in applying a simple interactivity for the visualisation. Finally, Matlab supports building a graphical user interface (GUI) either with programming or through the GUIDE (Graphical User Interface Development Environment) module, and is available on a wide range of computer platforms.

4.2 Stimuli design

The purpose of the programming work was to construct 3D models of marine applications to which the CS effect can be added. These visualisations were displayed to different user groups to assess the implications of CS on conventions and its application in dynamic situations. Additionally, the interaction between CS and other depth cues was considered.

By reviewing the marine activities and visualisation (Chapter 2), the researcher selected three types of scenario to show dynamic visualisation, alter colour conventions and demonstrate potential applications for marine users. These scenarios were a perspective DTM, surface navigation within a busy navigation channel and underwater operation. Table 4-1 summarises the basic elements for each scenario and its purpose.

Scenario	*Elements*	*Purpose*
Bathymetric DTM	Bathymetry and 3D vessel on the surface	Clarify changes in colour conventions
Surface Navigation	Two vessels and a navigation channel marked with lateral buoys	Demonstrate CS application in a dynamic situation (sea surface) Clarify changes in colour conventions in more restricted representations (buoyage system)
Underwater ROV	Bathymetry, two manifolds and a pipeline	Demonstrate an application of CS in dynamic situation (underwater operation)

Table 4-1: A summary of the three scenarios designed for this study

The design was based on Häberling (2002) guides for 3D map design. The process as illustrated in Figure 4-1 involved three steps: modelling, symbolisation and visualisation. In data modelling, the raw data are analysed and converted to an appropriate format and structure to be the base for the 3D models. For the following step, symbolisation, the graphic appearance for the DTM and topographic objects are defined. Although the final outputs of this programming work are visual scenarios to demonstrate the CS application, they can be considered to be map-related representations.

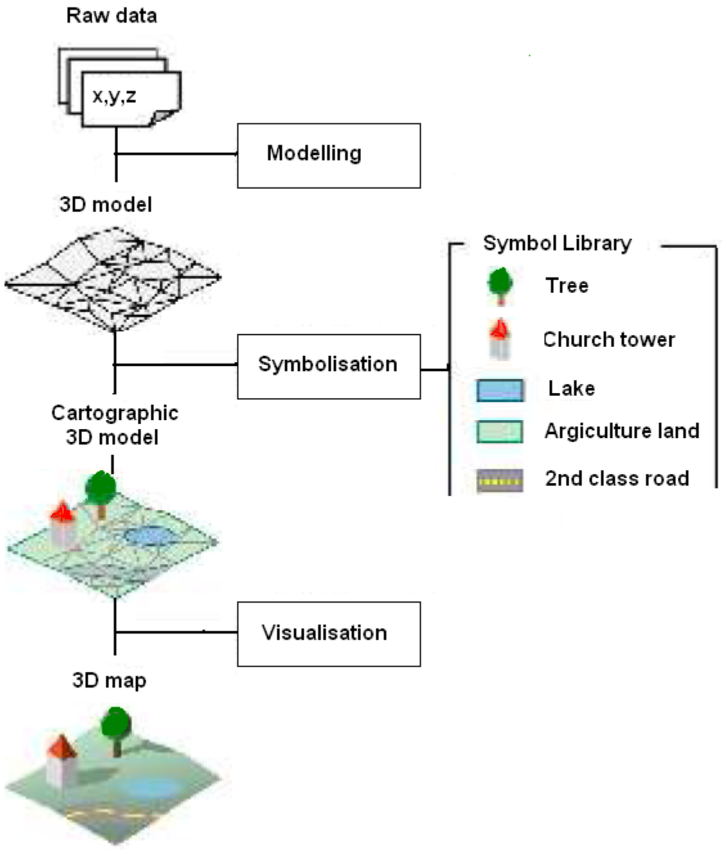


Figure 4-1: Schematic design process for 3D maps adapted from Terribilini (2001)

4.3 Stages of scenarios programming

The interaction with different test-groups (see Chapter 5), throughout the programming work has polished the final stimuli used for data collection. The following sections detail the programming steps for each scenario.

4.3.1 Scenario 1: Bathymetric DTM

The visualisation (Figure 4-2) represents a DTM for the seabed and a vessel floating at the sea surface. The sea surface was referenced with a frame only; in order not to obscure the seabed underneath it. The scenario demonstrates the concept of CS when applied to a bathymetric visualisation, and how the various parts of the DTM will be coloured differently according to the view point from which the scene was displayed. Hence, a series of snap shots from viewpoints scattered around the scene were used; each shot was presented for 20 seconds on the screen.

Due to the limited space in this thesis, only one snap shot taken from the angle defined by azimuth: az= 20 and elevation: el=30 is presented (Figure 4-2). The reader can refer to the accompanying CD to see the full scenario.

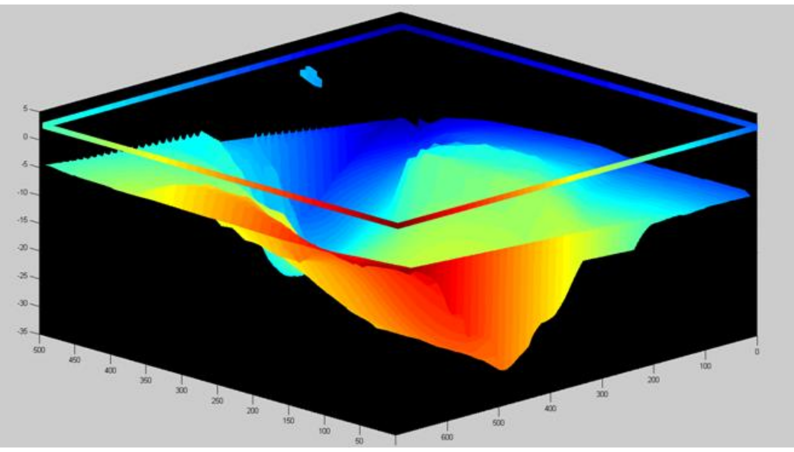


Figure 4-2: A first version of the bathymetric DTM scenario: the components are DTM bathymetry, a floating vessel and a frame marking the sea surface.

During the first assessment by the Marine Costal Policy (MarCoPol) Research group, the participants found the frame redundant and even confusing, so it was deleted from the scenario. Also, the respondents reported that the discontinuous transition from one view angle to another distracted their attention and understanding of the CS effect, and the time allocated for each scene was not sufficient to adjust and follow the changes. As a result, a smoother transition between the consecutive views was achieved by rotating the scene 360o with 1o increments.

In the second stage, it was noted by the participants, that the scenario did not provide a visual reference to compare to and hence comprehend the consequences of applying CS where colours applied along the distance from the view point. Therefore, this scenario was replicated using the conventional display for bathymetric data; where colour is assigned along the z axis (depth or height). Figures 4-3 and 4-4 are snapshots from the rotating model showing conventional colouring and CS colouring respectively. Both views are shown from a camera at 30o above the horizontal plane.

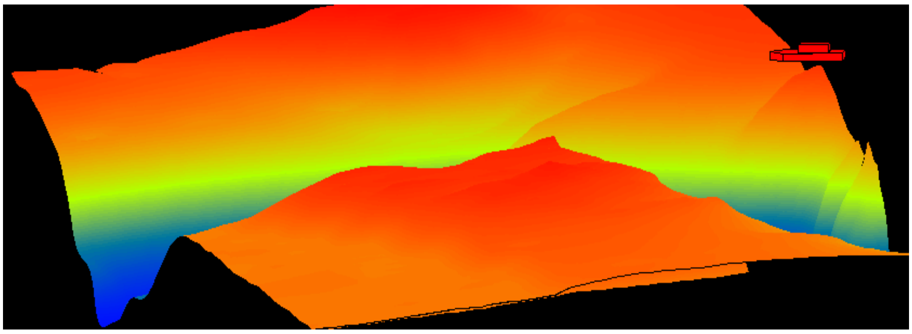


Figure 4-3: Scenario 1: bathymetric DTM (without a frame) in a conventional colour coding along the Z axis.

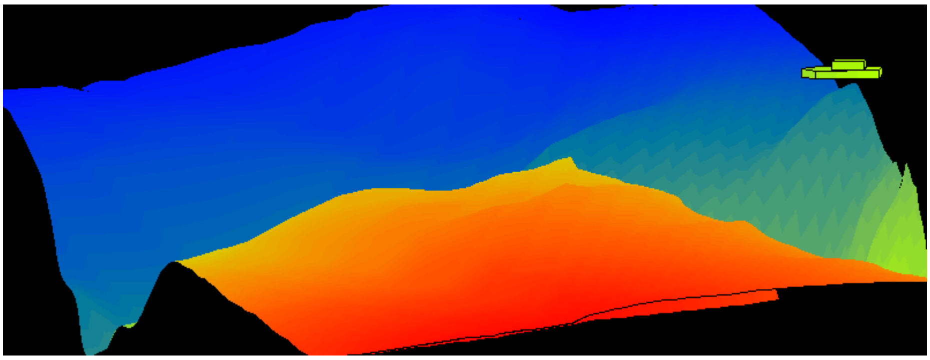


Figure 4-4: Scenario 1: bathymetric DTM (without a frame) in CS (colour coded along distance).

4.3.2 Scenario 2: Surface navigation

This scenario represents a navigation channel marked with two sets of buoys (port and starboard. At the sea surface level there are two vessels: one vessel acts as a reference vessel (from which the channel markers and the other vessel are observed) heading towards the land, while the other vessel is heading in the opposite direction. The goal of the scenario is to evaluate users' acceptance to the changes of international conventions used in a specific task and the usefulness of CS in dynamic situations (i.e. surface navigation).

The colours of the model components are changing according to their distance from the reference vessel. To differentiate this vessel in the model, its colour was fixed to grey; the choice of the colour was important as it affected their perceived location. With the ChromaDepth glasses on, when the main vessel was coloured white (Figure 4-5), it appeared as if it was positioned deeper into the screen even below the seabed and the other objects. This can be attributed to the CS effect of chromatic aberration (Section 2.1.4).

The navigation buoys were initially represented by spheres. However, their relatively small size compared to the bathymetry and the vertical exaggeration in the drawing scale distorted the shapes. To overcome this distortion, the spheres were replaced with dots (Figure 4-6) as the size of these dots can be fixed to a finite value suitable for the visualisation.

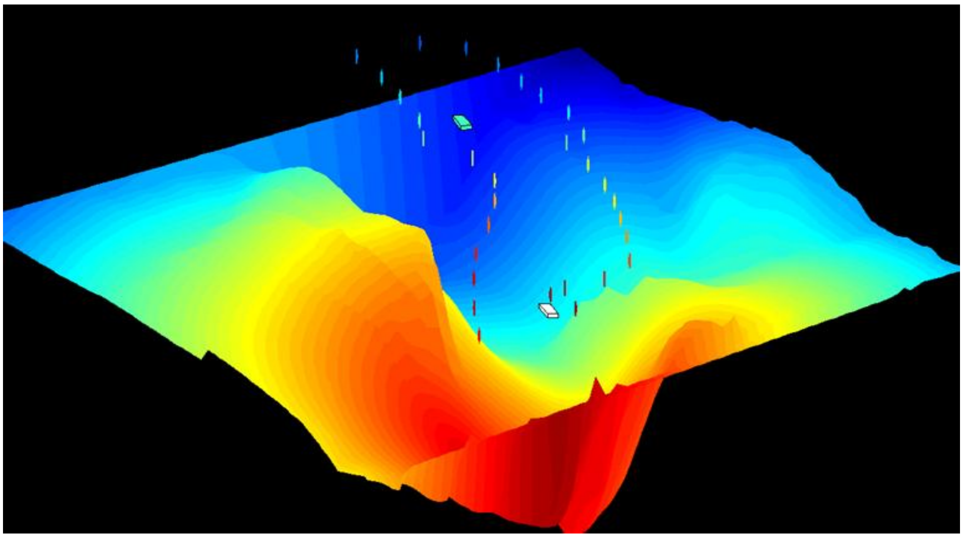


Figure 4-5: Initial design of the navigation scenario includes fully coloured bathymetry, channel marker buoys and two vessels.

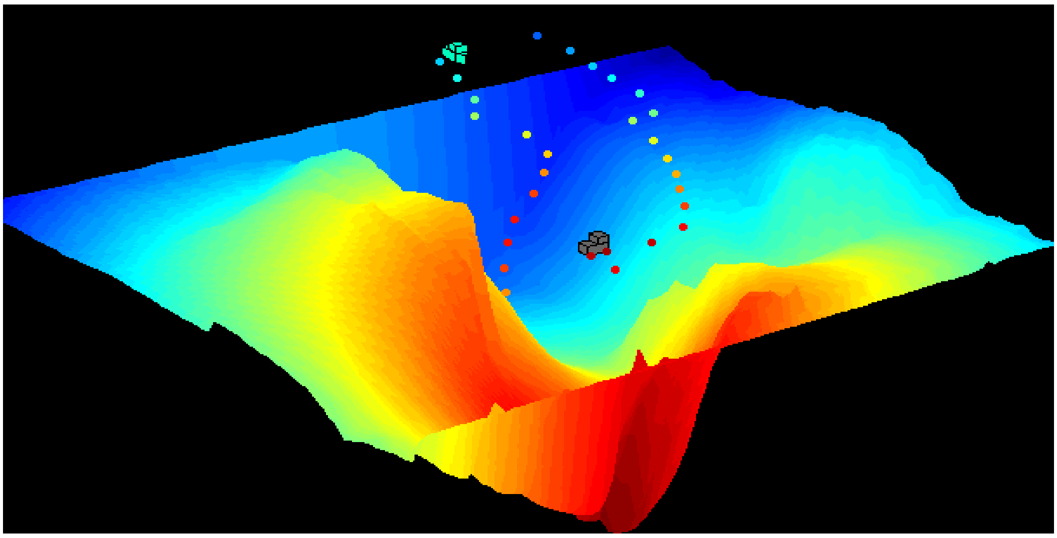


Figure 4-6: Improved visualisation of surface navigation scenario, the channel marker buoys are larger rounded objects and the vessels are ship-shaped; the reference vessel is grey.

Again, when this scenario was presented to the first focus group, they commented on how the coloured bathymetry dominated the scene (Figure 4-6), and made it difficult to recognise the difference in the buoys' colours. Hence, the colourful seabed was replaced with a grey mesh (Figure 4-7).

Comments from the second user-group, The Southern West Branch of Hydrographic Society UK (THSUK), highlighted the fact that both port and starboard buoys were similarly iconized, and not being coloured according to navigation conventions made them meaningless for navigation. Therefore, the channel markers where symbolised in two different shapes: squares and triangles (Figure 4-8); using the Matlab built-in function ‘scatter3’. These two shapes were considered the best simple representations for the can (port) and conical (starboard) buoys respectively as they conform to chart symbols (Section 3.1.1.1).

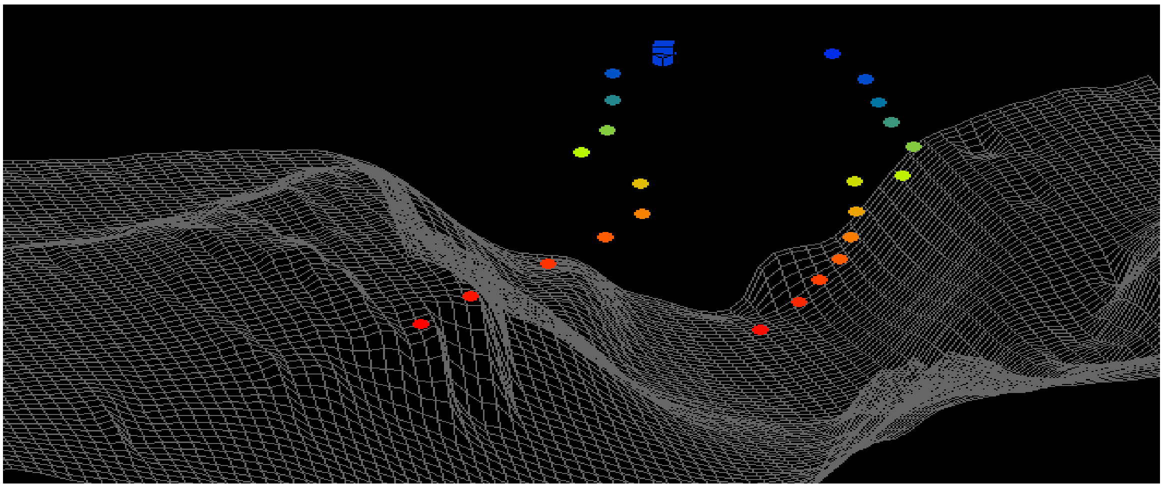


Figure 4-7: Stage 3 of surface navigation scenario; the bathymetry is represented with a grey mesh only

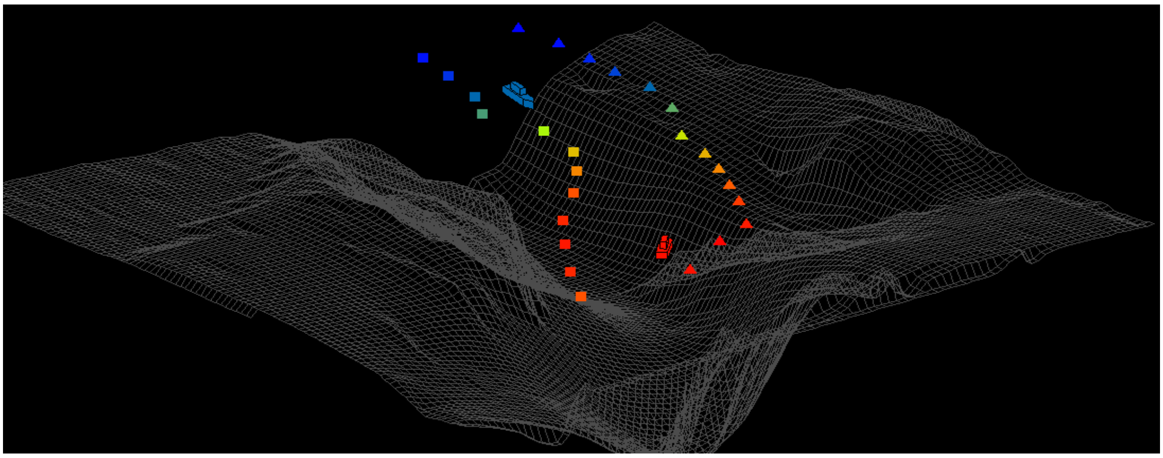


Figure 4-8:Navigation scenario: representing the navigation buoys according to chart symbols (can for port and conical for starboard), the reference vessel is static and red, while the other vessel is approaching and changing colour according to its distance from the reference vessel.

4.3.3 Dynamic navigation

In this scenario the reference vessel is moving and only objects in front of the updated position of the vessel are displayed in each scene, and the colour of each object is updated accordingly. Figure 4-9 shows two screenshots where the vessel leaving the land has changed position and colour.

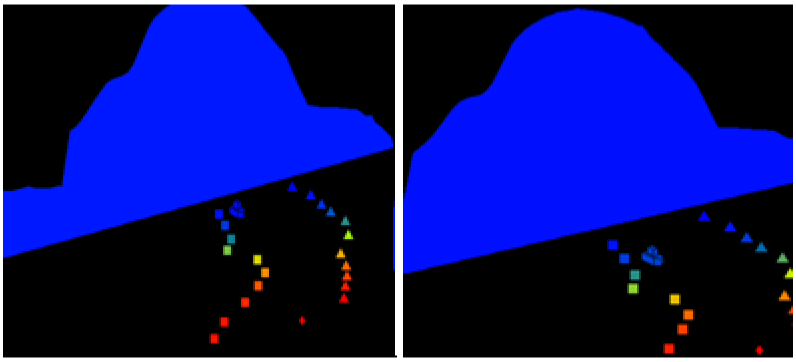


Figure 4-9: Dynamic navigation scenario where the reference vessel was replaced with a dot to indicate its new location in the scenes

4.3.4 Scenario 3: Underwater operation

This scenario is designed to demonstrate the application of CS in dynamic situations where a ROV is inspecting a pipeline, and to investigate whether CS can aid underwater operators understand the topological relationships between objects and the seabed. The scene (Figure 4-10) includes a bathymetric DTM, two manifolds (represented by cube-shaped objects), and a pipeline (symbolised by a cylindrical object) stretching between the cubes.

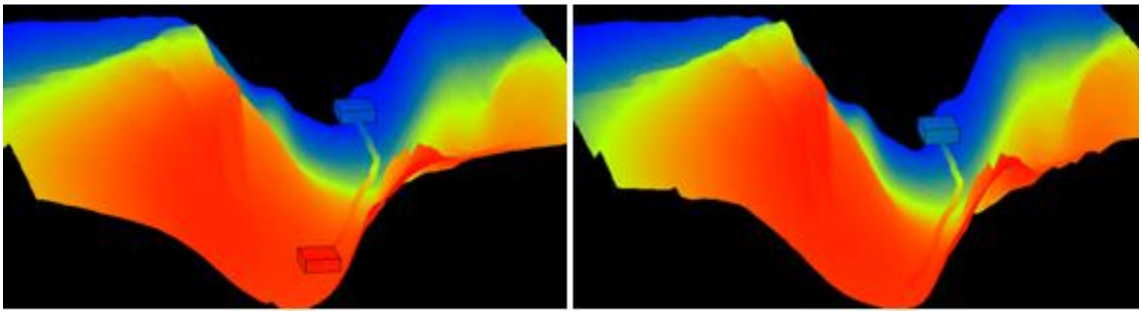


Figure 4-10: Underwater operation scenario illustrates the scene in front of an ROV inspecting a pipeline (Left) and show the scene update (Right) including displayed objects and colour from the new position.

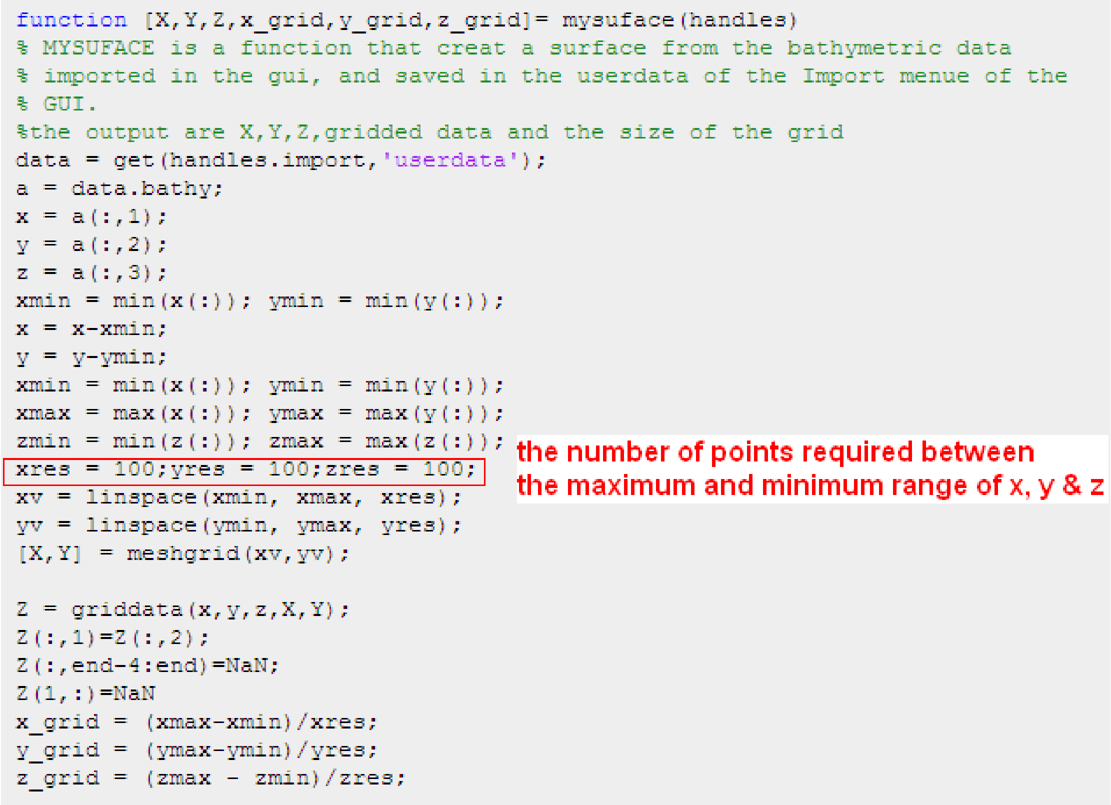
4.4 Scenarios’ construction

The main dataset used to build the scenarios is bathymetric data for Plymouth Sound. The data was retrieved from the Hydrography course archive (S drive) that is freely available for all students in the course. The accompanied survey report indicated that the survey was conducted in 2005 using a RESON Seabat 8125 multibeam with 455 kHz frequency to produce a (0. 5m x 0. 5m) gridded DTM data.

4.4.1 Generating a DTM

The typical output of multibeam sonar is a dense cloud of points. Visualising these points as a DTM requires interpolating the data into a regular grid (Robinson & Metternicht, 2005). Hence, the data file was imported into Matlab and a script ‘mysurface’ was written to grid the data. For the first DTM all data points (7 millions) were used, but the processing was slow and often prematurely ended due to a lack of memory. Therefore, the data had to be thinned to a manageable size that enabled smooth running for the gridding script. A range of interpolation algorithms were available, but there are no definite rules to specify where to use each algorithm (Erdogan, 2009). Therefore, the researcher experimented with different grid sizes and interpolation methods until a relatively small file size (10,000 points) and a realistic representation for the navigation channel bathymetry were achieved. The final gridding method used was linear interpolation based on Delaunay triangulation.

The DTM forms the basis of building synthetic visualisations to project the concept of CS, but not to create a 3D model for the authentic world. Therefore the DTM accuracy, in this research, was not essential. An extract of the code to grid the data and create the bathymetric DTM is (Figure 4-11):



```
function [X,Y,Z,x_grid,y_grid,z_grid]= mysuface(handles)
% MYSUFACE is a function that creat a surface from the bathymetric data
% imported in the gui, and saved in the userdata of the Import menue of the
% GUI.
%the output are X,Y,Z,gridded data and the size of the grid
data = get(handles.import,'userdata');
a = data.bathy;
x = a(:,1);
y = a(:,2);
z = a(:,3);
xmin = min(x(:)); ymin = min(y(:));
x = x-xmin;
y = y-ymin;
xmin = min(x(:)); ymin = min(y(:));
xmax = max(x(:)); ymax = max(y(:));
zmin = min(z(:)); zmax = max(z(:));
xres = 100;yres = 100;zres = 100;
xv = linspace(xmin, xmax, xres);
yv = linspace(ymin, ymax, yres);
[X,Y] = meshgrid(xv,yv);

Z = griddata(x,y,z,X,Y);
Z(:,1)=Z(:,2);
Z(:,end-4:end)=NaN;
Z(1,:)=NaN
x_grid = (xmax-xmin)/xres;
y_grid = (ymax-ymin)/yres;
z_grid = (zmax - zmin)/zres;
```

the number of points required between the maximum and minimum range of x, y & z

Figure 4-11: Matlab code written to grid the data and create a bathymetric DTM

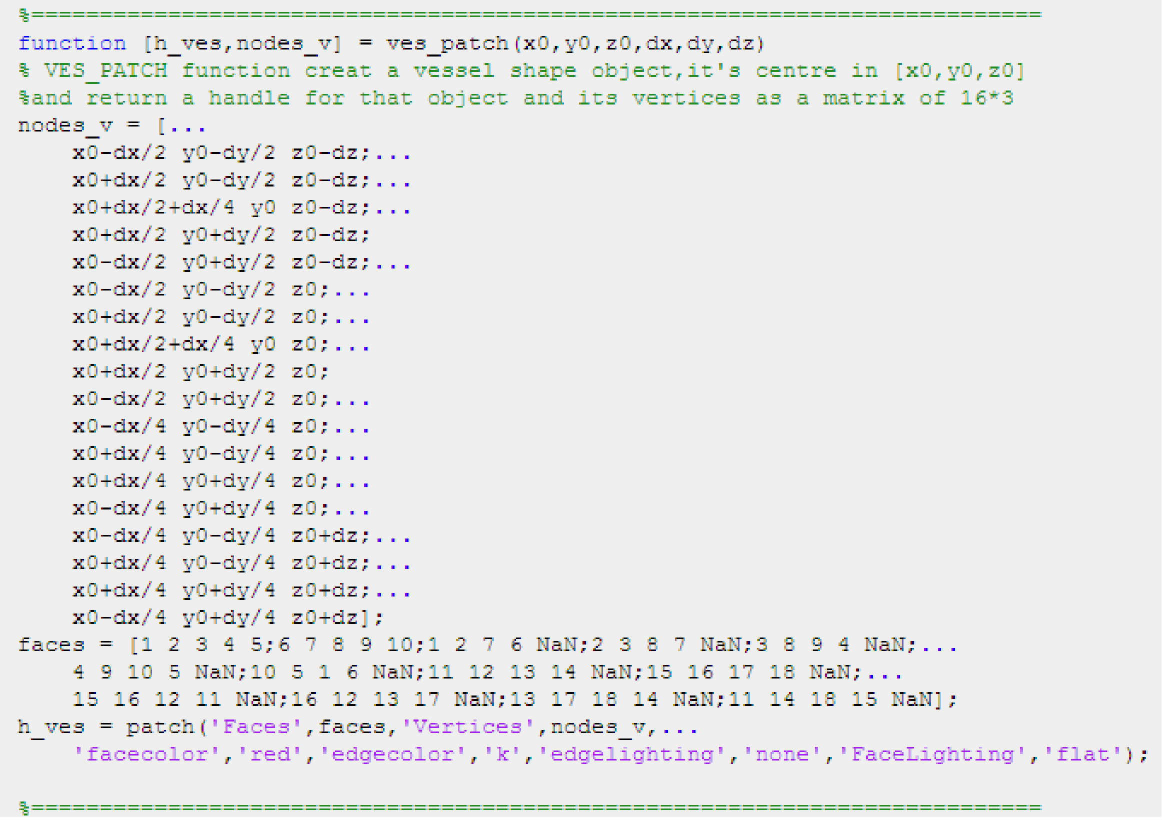
4.4.2 3D objects' positions

The DTM depicts the navigation channel in the Plymouth Sound. Following the undulation of the scene, the coordinates of the channel edges were graphically captured by exploiting the 'ginput' function in Matlab. Using the mouse as an input device and clicking on the grid to mark the edges of the deepest water, the appropriate positions for channel marking buoys were generated and saved for later use.

For the underwater scenario the positions of the ROV, manifolds and the pipeline in the middle of the channel were defined by the 'ginput' function and saved. Similarly, two navigation paths running above the channel and in two opposite directions (toward and away from the land) were specified and saved as 'ves1' and 'ves2' variables. Finally the raw bathymetric data, vessel's navigation paths, buoys' positions, manifold positions and the pipeline were saved in one data structure that can be called by the Graphical User Interface GUI to compose the final scenarios.

4.4.3 Building 3D object

Matlab supports a range of functions to build 3D objects, such as spheres, cylinders and patch. The ‘patch’ function creates multifaceted objects from predefined objects, with the possibility to alter the colour of faces and edges at any stage of construction. The function ‘ves_patch’ was written to create a simple vessel-shaped object (Figure 4-12).



```
%==========================================================================
function [h_ves,nodes_v] = ves_patch(x0,y0,z0,dx,dy,dz)
% VES_PATCH function creat a vessel shape object,it's centre in [x0,y0,z0]
%and return a handle for that object and its vertices as a matrix of 16*3
nodes_v = [...
    x0-dx/2 y0-dy/2 z0-dz;...
    x0+dx/2 y0-dy/2 z0-dz;...
    x0+dx/2+dx/4 y0 z0-dz;...
    x0+dx/2 y0+dy/2 z0-dz;
    x0-dx/2 y0+dy/2 z0-dz;...
    x0-dx/2 y0-dy/2 z0;...
    x0+dx/2 y0-dy/2 z0;...
    x0+dx/2+dx/4 y0 z0;...
    x0+dx/2 y0+dy/2 z0;
    x0-dx/2 y0+dy/2 z0;...
    x0-dx/4 y0-dy/4 z0;...
    x0+dx/4 y0-dy/4 z0;...
    x0+dx/4 y0+dy/4 z0;...
    x0-dx/4 y0+dy/4 z0;...
    x0-dx/4 y0-dy/4 z0+dz;...
    x0+dx/4 y0-dy/4 z0+dz;...
    x0+dx/4 y0+dy/4 z0+dz;...
    x0-dx/4 y0+dy/4 z0+dz];
faces = [1 2 3 4 5;6 7 8 9 10;1 2 7 6 NaN;2 3 8 7 NaN;3 8 9 4 NaN;...
    4 9 10 5 NaN;10 5 1 6 NaN;11 12 13 14 NaN;15 16 17 18 NaN;...
    15 16 12 11 NaN;16 12 13 17 NaN;13 17 18 14 NaN;11 14 18 15 NaN];
h_ves = patch('Faces',faces,'Vertices',nodes_v,...
    'facecolor','red','edgecolor','k','edgelighting','none','FaceLighting','flat');

%==========================================================================
```

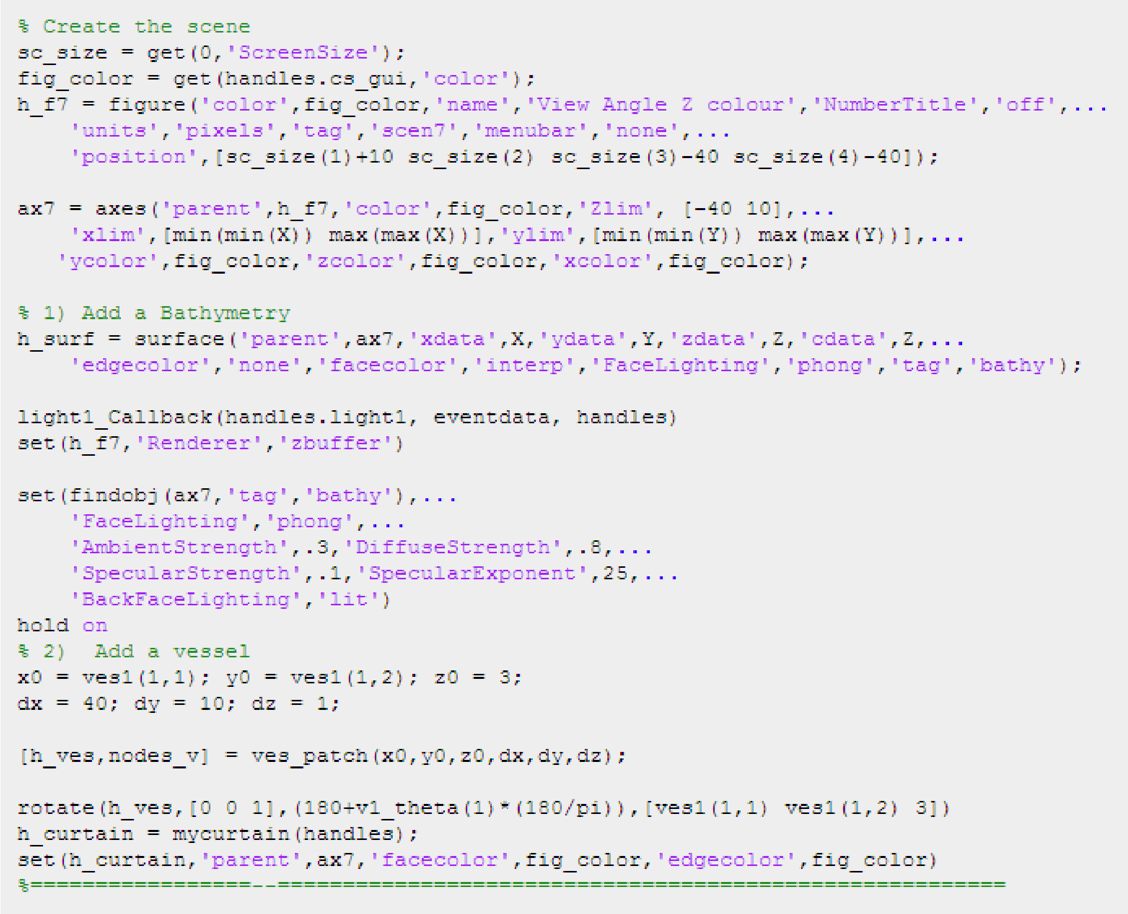
Figure 4-12: Matlab script written to create a vessel-shaped object using the patch function

4.4.4 Colour table

The generation of the chromo-stereoscopic image requires a special colour ramp that can be derived from Chromatek guidelines for the use of Chromo-Stereoscopy known as open “CyberHolographicTM” standard (APO, 2009) In this research the colour map is produced through linear interpolation between two extremes, red [1 0 0] and blue [0 0 1], for the RGB system and magenta [1 0 1] and cyan [0 1 1] for the CYM system.

4.4.5 Scenario compiling

In all scenarios, the size of all objects was fixed regardless of their relative distance from the viewing point. Although this would negate the effect of the relative size depth cue (Section 2.2), and the viewers may notice the absence of this cue, it was intended to clearly identify the CS contribution to the depth perceived in the scene. To render the final scenes, setting the right renderer was required. A renderer is the software that processes graphics data (such as vertex coordinates) into a form that Matlab can use to draw the figure. Matlab supports three renderers: Z-puffers, painters and OpenGL. A comparison between the capabilities of these renderers showed Z-buffer as the best for the current work, as it supports speed rendering of the scenes with lights, and accurately produces the expected colours. This is an essential requirement for CS. Figure 4-13 illustrates the Matlab script written to compile the rotating bathymetry scenario and display it in a separate figure.



```
% Create the scene
sc_size = get(0,'ScreenSize');
fig_color = get(handles.cs_gui,'color');
h_f7 = figure('color',fig_color,'name','View Angle Z colour','NumberTitle','off',...
    'units','pixels','tag','scen7','menubar','none',...
    'position',[sc_size(1)+10 sc_size(2) sc_size(3)-40 sc_size(4)-40]);

ax7 = axes('parent',h_f7,'color',fig_color,'Zlim', [-40 10],...
    'xlim',[min(min(X)) max(max(X))],'ylim',[min(min(Y)) max(max(Y))],...
   'ycolor',fig_color,'zcolor',fig_color,'xcolor',fig_color);

% 1) Add a Bathymetry
h_surf = surface('parent',ax7,'xdata',X,'ydata',Y,'zdata',Z,'cdata',Z,...
    'edgecolor','none','facecolor','interp','FaceLighting','phong','tag','bathy');

light1_Callback(handles.light1, eventdata, handles)
set(h_f7,'Renderer','zbuffer')

set(findobj(ax7,'tag','bathy'),...
    'FaceLighting','phong',...
    'AmbientStrength',.3,'DiffuseStrength',.8,...
    'SpecularStrength',.1,'SpecularExponent',25,...
    'BackFaceLighting','lit')
hold on
% 2)  Add a vessel
x0 = ves1(1,1); y0 = ves1(1,2); z0 = 3;
dx = 40; dy = 10; dz = 1;

[h_ves,nodes_v] = ves_patch(x0,y0,z0,dx,dy,dz);

rotate(h_ves,[0 0 1],(180+v1_theta(1)*(180/pi)),[ves1(1,1) ves1(1,2) 3])
h_curtain = mycurtain(handles);
set(h_curtain,'parent',ax7,'facecolor',fig_color,'edgecolor',fig_color)
%=================--========================================================
```

Figure 4-13: A script written to compile the scenario of a rotating bathymetry. The scenario was presented in a separate figure window, and it included bathymetric surface and a floating vessel

4.5 Cartographic elements

Shading is one of depth cues that are well exploited in cartographic designs to infer undulation details of surfaces. This effect is produced by illuminating the scene and it affects how colours appear and consequently it may impact CS perception. The influence of shading on CS is simulated by adding a light source into the bathymetric DTM and underwater scenarios. Another element tested was the impact of using different colour schemes on CS presented by deploying RGB and CYM. The choice of these two colour schemes conforms to the IMO recommendations for electronic displays (IMO, 2002). Figure 4-14 illustrates the visualisations displayed to the participants to assess CS observed from two colour schemes, RGB (a & e) and CYM (c and g), and the impact of shading on CS in both colour schemes (b, d, f and h).

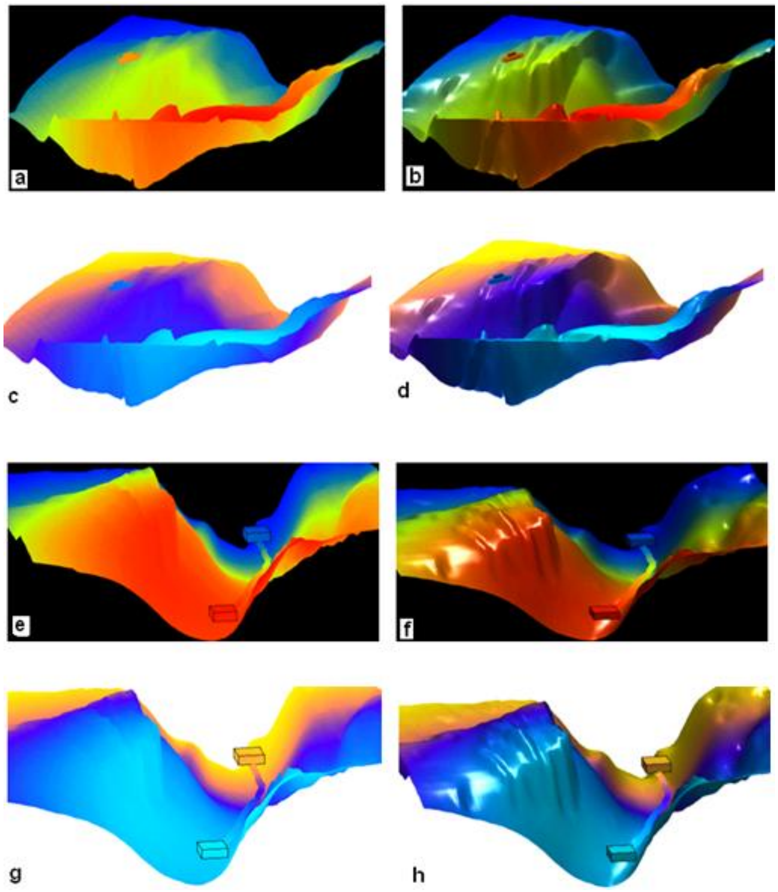


Figure 4-14 Stimuli scenarios used to demonstrate the difference between the CS effect perceived from RGB and CYM colour schemes (images a, c, e and g) and the shading effect on CS in both colour schemes (images b, d, f and h

4.5.1 CS with view angles

The view of the bathymetric DTM scenario was set up to be seen obliquely not from vertically; hence the 3D shape of the bathy was obtainable. The 1 degree increment in the camera azimuth erected smooth changes that made it difficult for the eye to spot the interaction between depth cues, chromatic aberration and the view point. Five static snap shots were taken from different distinct view points of the CS-coloured view were presented to the participants (Figure 4-15). Therefore whether the 3D effect that the participants perceived was merely because of the camera position set up or because of CS contribution can be tested.

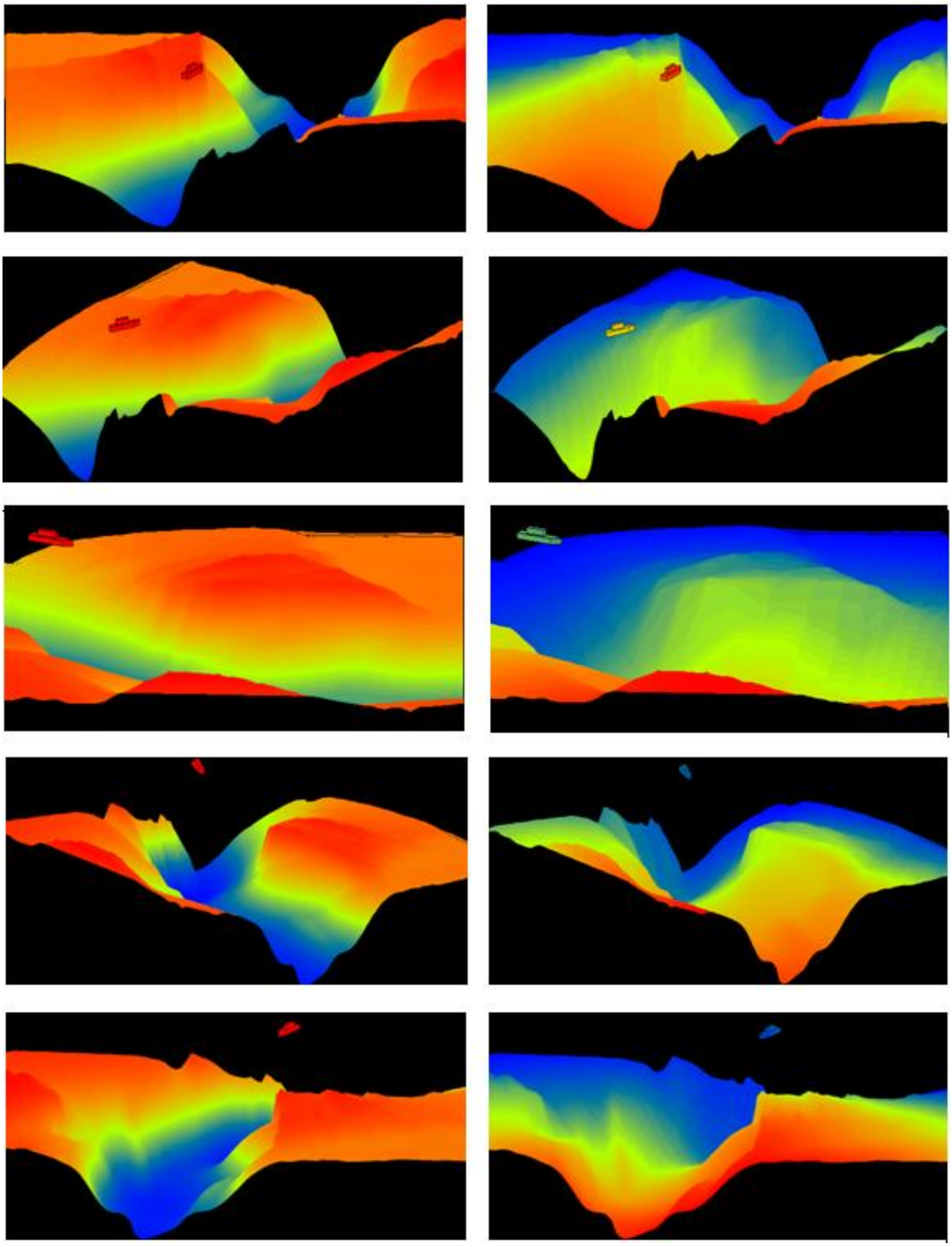


Figure 4-15 A set of images shown to the participants to identify the advantages of CS in understanding this complex topography. The images to the left represent five snapshots of the same bathymetry conventionally coloured along the Z-axis, while the images to the right show replicas of the left images, but with the CS scheme.

4.6 GUI for stimuli display

To give users a tool to interact with the visualisation and gauge their responses for the usefulness of CS in hydrographic applications and ensure a smooth running for the test, all scenarios and the additional effects were applied in a GUI. A GUI is defined as 'those aspects of the system that the user comes into contact with’ (IJsselstejn, et al., 1998).

4.6.1 GUI design

The GUI was designed to reduce the intellectual efforts to use the system through exploiting the computer’s capabilities. The technical phases of the design involve choosing the form of the visualisation, selecting the method of mapping data to that form, and defining the process of users' interaction with the system (Vos, 2008). Another decision to be made was what updating mode could be used to view changes in the parameters (Robert & Sluter, 2001). Also, aspects of good user interface design, such as visibility (indicates the location of the control) and affordances (the controls refer to their functionality) were considered. All controls were visible to the users and named according to their functions.

Robert and Sluter (2001) define three updating methods for a view: ‘replace’, ‘replicate’ and ‘overlay’. 'Replace' method allows new information associated with parameter changes to overwrite old information, whereas 'replicate' generates a new display window to present new information while the old information is preserved in its original window. 'Overlay' method merges both new and old information in the same display window. The initial GUI aimed to help users to switch between three different hydrographic presentations for some hydrographic data, conventional colouring along the Z axis and CS colouring along the line of sight using RGB or CYM colour systems. To facilitate comparing between the conventional colouring system and a CS system, a replicate method was used (Z display in the top axis and CS display in the bottom axis) (Figure 4-16).

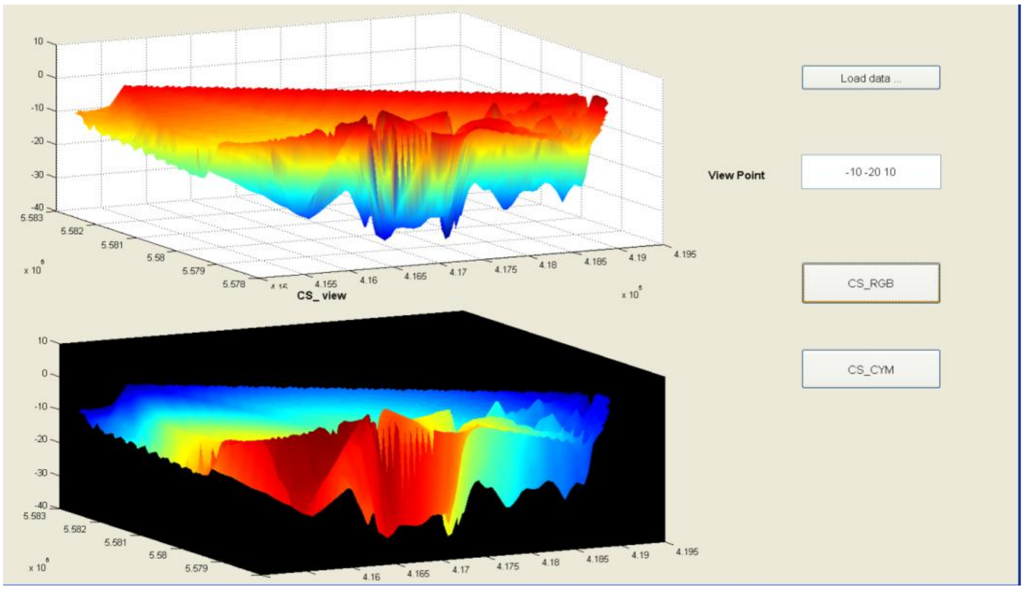


Figure 4-16: The initial GUI design using replicate method to compare the conventional colouring along Z axis (top) and chromo-stereoscopic colouring along the line of sight (bottom).

When only the RGB colour scheme was applied for conventional and CS visualisations, the GUI functioned properly. However, when the CYM colour scheme was deployed in the CS display, Matlab did not support using two different colour-maps to the same GUI window. This problem was solved by merging RGB and CYM colour-maps into one colour-map that was assigned to the GUI window, and then only the relevant part of this colour-map was assigned to the relevant axis.

Initially, having both the standard visualisation and the CS visualisation presented simultaneously was useful for evaluating the difference. However, from an application point of view, this was useful when only the RGB colour scheme was used for conventional and CS views. In that case, the only difference between the views was how the colour was applied along the Z axis or along distance. Nevertheless, when the standard view was presented in RGB colours and the CS view was CYM coloured it seemed to confuse the viewers; they could not easily comprehend that they were still looking at the same data set.

Additionally, IHO (2004) requests from manufacturers of electronic displays to use two colour schemes, RGB for daylight illumination condition CYM night illumination settings (to avoid any light distraction). Therefore, simultaneously displayed models one with conventional colours (RGB along Z axis) in the upper axis and the other with CS CYM in the lower axis would be distracting in the night time. Thus, it was decided to use the ‘replace’ method to show only a single view in the GUI window (Figure 4-17).

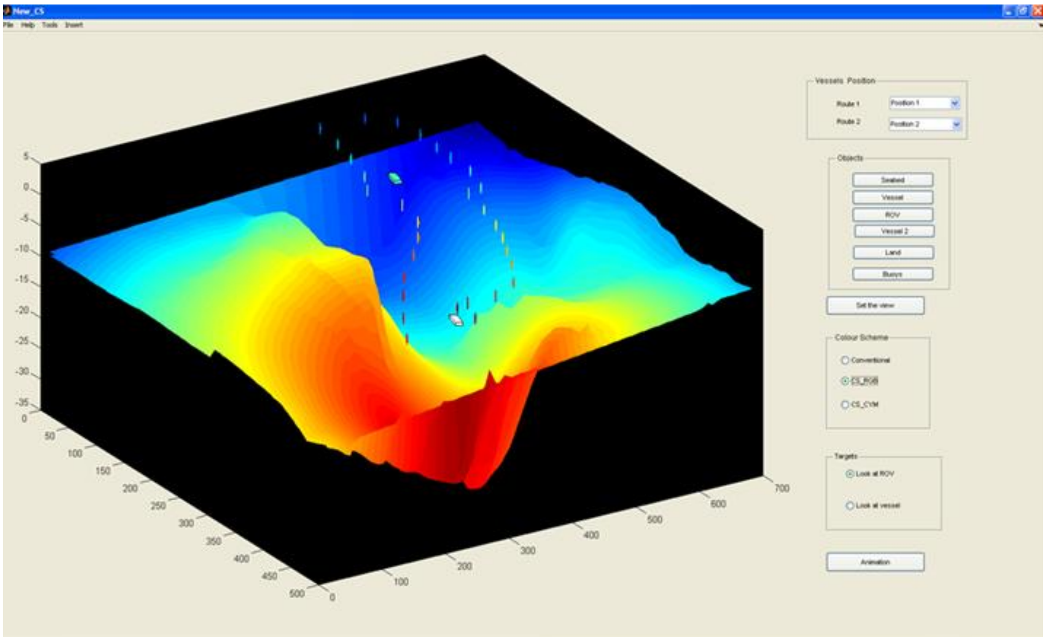


Figure 4-17: Second GUI design with only one display axis, and other buttons to add objects and change view parameters

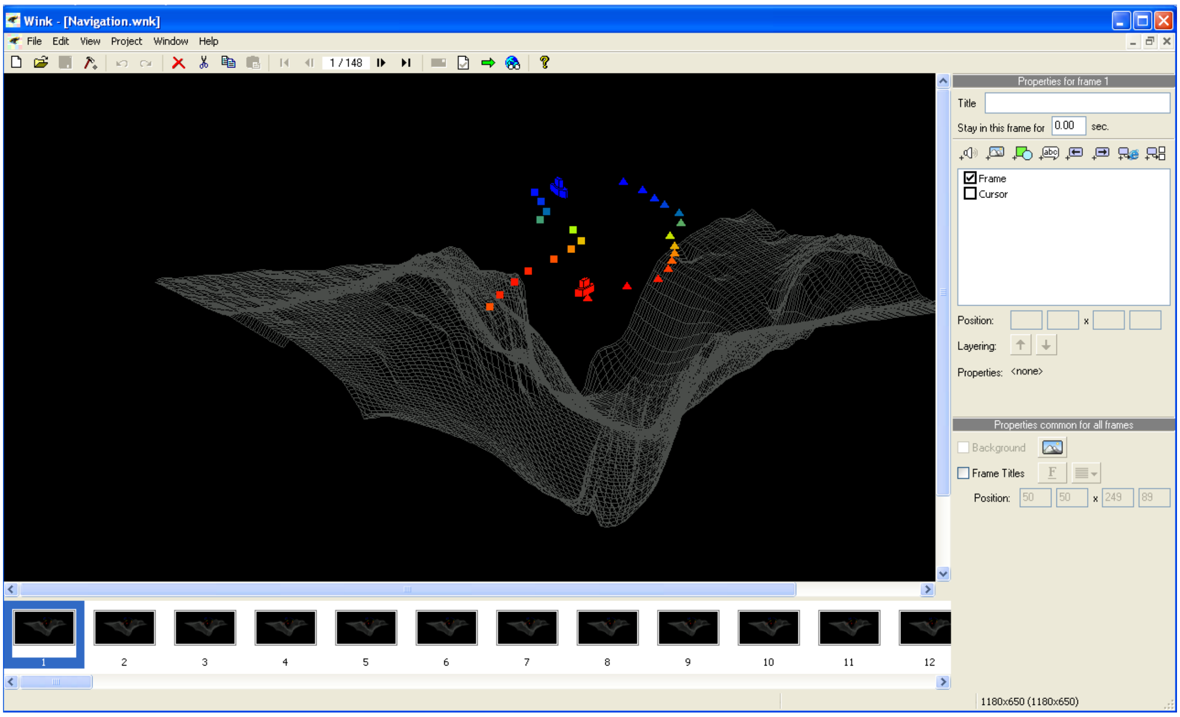
The final GUI (Figure 4-18) was designed to allow users to interact with the visualization without using the command window in Matlab. The GUI consists of four discrete components: menu, push buttons, drop-down menu and check box. The functionality of these elements was set up according to the usual method of using them in other interfaces. For instance, normally an import function is located as a sub object in a menu object, while a tick box is used for accepting or rejecting options etc. Hence, the push buttons were used to navigate between the scenarios by pressing the relevant ‘button’. The drop-down menu offers two options of colour schemes; RGB and CYM. Finally, adding or removing a shading effect was designated to a check-box. Programming the GUI components was significantly different from running the script in the Matlab command window. All variables needed to be identified and saved in the GUI environment to become accessible for the different functions. Each component has a unique handle and an allocated storage space. This space was used to store different types of data (variables, data structures). Whenever these data were needed in other functions, they could be called by specifying the handle of the object in which the data have been stored.

Although the scenarios could be run in any order, operating the GUI and testing the cartographic effects required the following steps. After running Matlab in the background, data must be imported into the GUI elements by using the 'File' menu then import. This would save the data within the GUI and activate the functionality of the components (the name of each component will change from grey to white). This step ensures that all variables needed to run the scenarios are identified, and no errors would occur if the participants accidentally pressed any other buttons. To apply a specific colour scheme or to add the shading effect in a scenario, the correct options must be selected before running that scenario otherwise it will not be updated.

Figure 4-18: The final design of the GUI used to run the test scenarios. The main dataset has to be imported first (in the left image) to activate the buttons in the right image

Finally to enable distributing the survey through the internet to reach a wider range of expertise and to demonstrate the scenarios in conferences and workshops, a backup Matlab-independent version of the scenarios was created. This was possible by using Matlab compiler but for additional cost. The alternative option was using freeware called 'Wink' available to download from the web. The software can capture consecutive snapshots of a whole screen

(Figure 4-19) or only a specified window. Then the static snap shots can be converted into a movie file and played using the same software or any other common movie player software.



Title
Stay in this frame for 0.00 sec.
☑ Frame
☐ Cursor
Position:
Layering:
Properties: <none>
☐ Background
☐ Frame Titles
Position: 50 50 x 249 89

Figure 4-19: A snapshot of Wink software used to produce Matlab-independent movie based on capturing a series of screen shots and rerun it on a specified rate of frames per seconds.

4.7 Chapter summary

This chapter reviewed the practical work undertaken to create the test scenarios using the programming language Matlab. The scenarios conveyed the principle of applying CS in dynamic marine applications such as surface navigation and underwater operations. To run the test a GUI was designed and programmed. The GUI provided an easy method to apply other cartographic elements such as light and changing colour schemes in the scenarios.

Chapter Five

5 Methodology-2: Data Collection: Group and Individual Interviews

This chapter presents the stages of data collection. It covers the process of selecting and designing the research questionnaire. Also it shows the preliminary results of group interviews conducted in the first stage. Finally it justifies the need for face-to-face interviews to obtain more credible data in the second stage.

5.1 Questionnaire design

Questionnaire and interviews are the best source of information for this research since the research subject is new to be found in the literature. To collect people's opinions about the use of CS in marine applications, the researcher had to select the appropriate data collection method between interview-administered and self-administered survey (Figure 5-1).

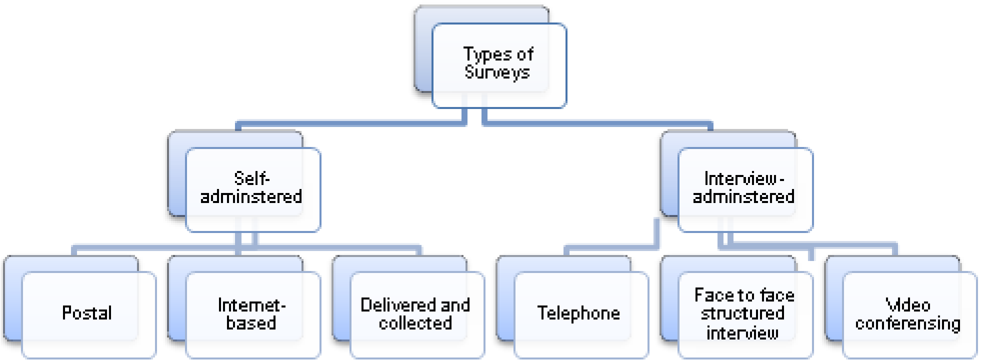


Figure 5-1:Types of research surveys

Based on the different characteristics of these methods, interview-administered face-to-face interviews were considered the most suitable for this study. They support presenting visual stimuli to the participants and interacting with them and allow the collection of the respondents' explicit opinions about the stimuli and observing their behaviour and impressions. Other methods using internet distribution and video conferencing were considered, as they could provide wider distribution and relatively easier and cheaper method to access participants. Nevertheless these methods might introduce uncertainty about the data collected as a result of technical issues in presenting colours in different medium.

5.1.1 Questions style

Survey questions have different styles depending on the type of information needed. For qualitative research, open questions as why, who and what require participants to reflect and describe their own thoughts openly. For quantitative research, when the interest is focused on the frequency that the population agree or disagree about one aspect, multi-choice questions and rating questions are used. This survey mixes the qualitative and quantitative approaches. The qualitative approach enabled the researcher to obtain real meanings that individuals allocated to an event, and the complexity of their attitudes, behaviours and experiences to build a complete picture of their perspectives (Weiss, 1994).

The quantitative approach deployed rating questions which were based on the Likert scale; this scale measures the intensity of the respondents' feeling, agreement and evaluation for a statement (Bryman, 2001). The level of preference is a 5-point scale, where 1 indicates the least preferred item and 5 represents the most preferred. Multi-choice questions covered a range of possible answers, including as a midpoint category 'not sure' that is positioned at the end of the options. This encouraged the participants to respond and avoided the pressure of answering awkward questions.

5.1.2 Survey structure

Before commencing the project, the researcher gained Human Ethics Committee approval of the Faculty of Science and Technology/ University of Plymouth for the use of human subjects in this study, following the appropriate procedures. The committee was provided with the “Application for Use of Human Participants”, an abstract of the proposed study, a copy of the proposed questions, the informed consent form and the procedures of advertising and other materials used during the research

The survey questionnaire commenced with a purpose statement. This statement is used to introduce the participants to the study and to keep both the researcher and reader concentrated on the fundamental aims of the study (Creswell, 2003). The final study (Appendix A) included 29 quantitative questions which provided demographic information as well as data on marine experience, sight problems, previous 3D experience and the preference of colour scheme. In addition, the topics of cartographic conventions (the colour of buoys, and bathymetry) and CS application were explored qualitatively in greater detail and in conjunction with prepared scenarios.

Since the test stimuli integrate different depth cues, it was essential to test the contribution of CS to the participants’ 3D perceptions in each scenario. As a criterion of testing whether CS has contributed to the 3D effect perceived by participants, after each scenario, the participants were asked to assess which colour was perceived closer while they were wearing the glasses.

The potential of CS applications in the marine field was assessed through the suggested scenarios and the participants’ suggestion for other applications. Cartographic issues with CS addressed the implication of changing the conventions of colour use in the bathymetric display, and the colours of navigation buoys. Also graphic design and the interaction between CS, colour schemes, shading and different view angles were explored.

5.1.3 User group selection

The evaluation of computer-generated applications is normally accomplished through usability testing (Endsley et al, 2003; Hackos & Redish, 1998). The usability test can be limited by the availability of resources (i.e. time and money) (Nielsen, 1993) and may potentially be affected by several factors such as age, culture, knowledge, skill, expertise, role or responsibility (Nivala, 2007). Hence, the best feedback can be gained from participants who match as closely as possible to the real end users, and are not involved with the product design and the development process (Nivala, 2007).

The study was conducted in two stages. Fist stage used group interviews. Three groups were recruited to pilot the questionnaires, identify users' perception to CS and improve the design of the scenarios. The second stage used the improved scenarios questionnaires to individually interview a sample of marine environments users. The results from this stage formed the findings of this research

5.2 Stage one: Pilot study group interviews and preliminary results

The aim of the pilot study was to evaluate and improve both the scenarios and the questionnaire and get the insight of participants' perception of CS. Three test-groups were used in this stage of evaluations as such method is cost-effective. The layout of test setup varied according to the space that was available to each session (Figure 5-2).

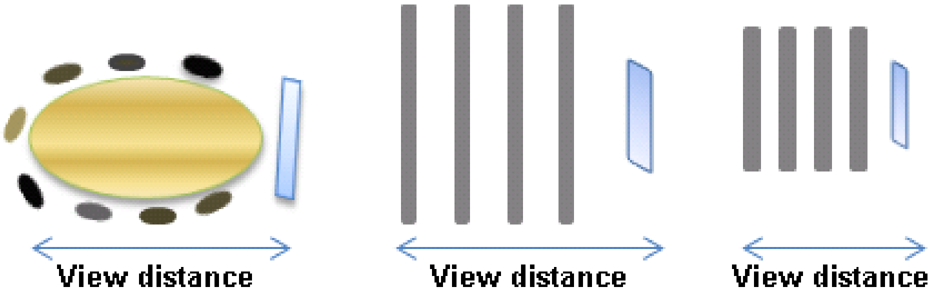


Figure 5-2: A schematic description of the seating arrangements for the participants in the group questionnaires. The viewing distance varied between participants

In total the survey was piloted on 45 respondents Table 5-2. For each session, participants were provided with a copy of the questionnaire and a pair of HD ChromaDepth glasses (Section 2.5.1.4) each. The researcher introduced the research objectives and the test structure and then ran the scenarios and requested the respondents to answer the relevant questions. All questionnaires were completed anonymously.

Test date and length	*Group description*	*Group size (ni)*	*Test settings*
28. 09. 10 (1 hour)	MarCoPol members Marine scientists/ Plymouth University	n1=8	Participants seated around an oval table within 1-3 m from an image projected on a screen
05. 10. 10 (1 hour)	The Hydrographic Society (THS) members: Navigators and Hydrographers (experienced & students)	n2=24	4 rows of chairs within 1-5 m from an image projected on a screen
11. 10. 10 (1 hour)	Argans Ltd employees (geophysical scientists and software engineers)	n3=13	3 rows of chairs within 1-3 m from an image projected on a screen

Table 5-1: Summary of user groups used in the pilot survey and the test parameters

5.2.1 MarCoPol group

The first exposure of this study to users was to the MarCoPol research group in Plymouth University. Being a member in this group, the researcher presented the study and encouraged the participants to project their views about the application, and provide constructive feedback about the questionnaire design. The attendants were (n1=8), 3 females and 5 males being doctoral students and academics in marine policy; their ages ranged from 28 to 55 years. All participants were correct-sighted. The study was conducted in the university campus. In the meeting room, the group was seated around an oval table, and the scenarios were projected on the wall. The viewing distance between the observers and the wall ranged from 1-3 m. The participants' observations and comments were presented in the general discussions of group interviews.

5.2.2 The Hydrographic society group

In the second assessment, the scenarios were presented to the members of The Hydrographic Society UK of the Southern West Region. The meeting was conducted in the Royal Plymouth Corinthian Yacht Club. The meeting room was spacious with low lighting. The scenarios were projected on a wide screen. The participants were seated in 4 rows, within 2-5 m from the screen. The sample size: n2=24 participants. This sample was 79% male and 21% female. The participants were in three different age groups; 21% were under 30 years old, 25% were in their fourth decade and the rest were above 40 years old. Also they had sight conditions: 57% had correct sight, 13% were short-sighted, 26% were longsighted, and 4% were red-blue colour-blind. They were mainly hydrographers and navigators of various levels of experience; ranging from students level to experts of 40 years of experience.

5.2.2.1 CS perception

Responses collected through questionnaires (Figure 5-3) showed that 71% of participants perceived 3D based on colours, while 8% were unsure about that. However, at the end of the test, participants were asked which colour appeared closer to them. The majority of those who responded to the question reported seeing red closer than blue. This answer was coded as “positive” effect (Figure 5-4).

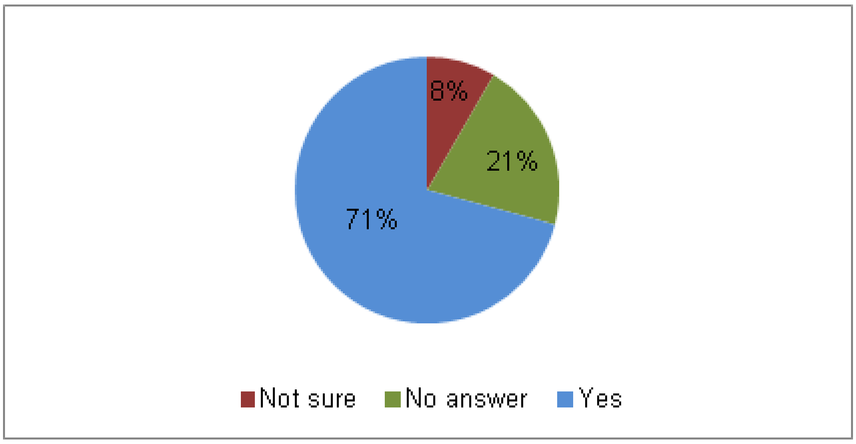


Figure 5-3: CS perception for THS group at the beginning when they answered whether they can see any difference in colour position on the screen (n2=24)

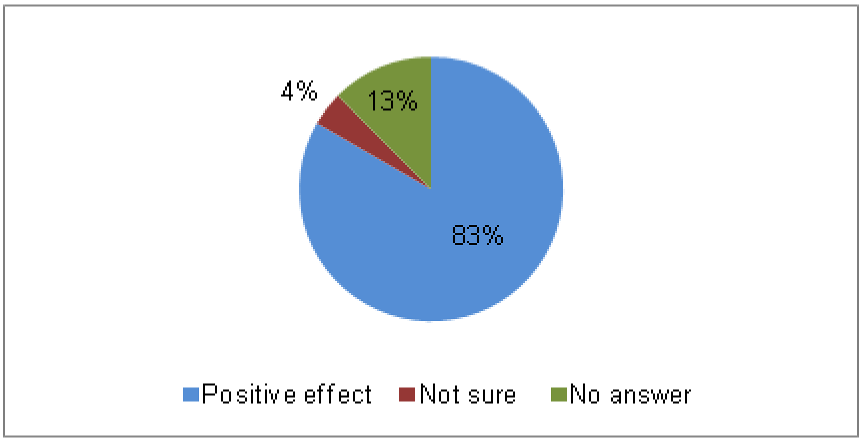


Figure 5-4: Participants response about CS effect perceived at the end of the test (n2=24)

The comparison between the two figures shows that by the end of the test, the rate of response increased and the majority perceived red closer than blue, so they were categorized as a positive CS, Also the number of undecided participants was halved. This seems a positive change, it can be explained by participants becoming more used to the concept of CS after viewing several scenarios. However, there is no evidence or any comments from users to support this conclusion.

5.2.2.2 Shading effect

Participants' responses to the interaction between CS and shading (Figure 4-14) were diverse. Figure (5-5) shows that 40% found shading has a positive effect on the 3D perceived stating that the edges of the scene become more defined with the effect of light. 24% thought shading degraded the 3D effect, reporting that the shiny surface shifted their attention to the smooth effect instead of the colour, and the surface looked flat. 8% reported that CS was not influenced by shading.

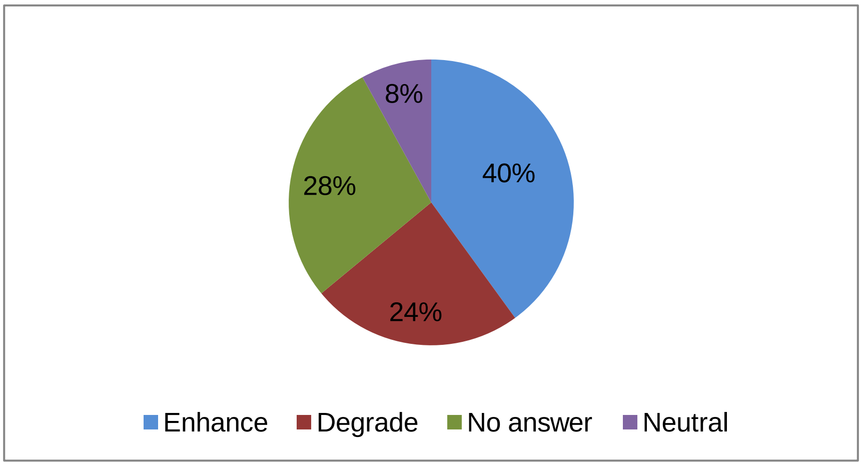


Figure 5-5: The Hydrographic Society group evaluation for shading effect on CS perceived from RGB colour scheme (n2=24)

5.2.2.3 Colour scheme

The participants were asked to evaluate the 3D perceived from CYM colour scheme and compare it to that perceived from RGB (Figure 4-14). Their answers were presented in Figure 5-6. 65% of the responses stated that RGB produced more effective 3D than CYM, while 4% of participants attained a better 3D effect from CYM scheme. Besides, 4% of respondents were undecided about the impact of these colour schemes on 3D perception. Few comments explained that the 3D effect was significantly reduced when the colour scheme switched from RGB to CYM. Also it was slightly confusing to see blue deeper in RGB and closer in CYM.

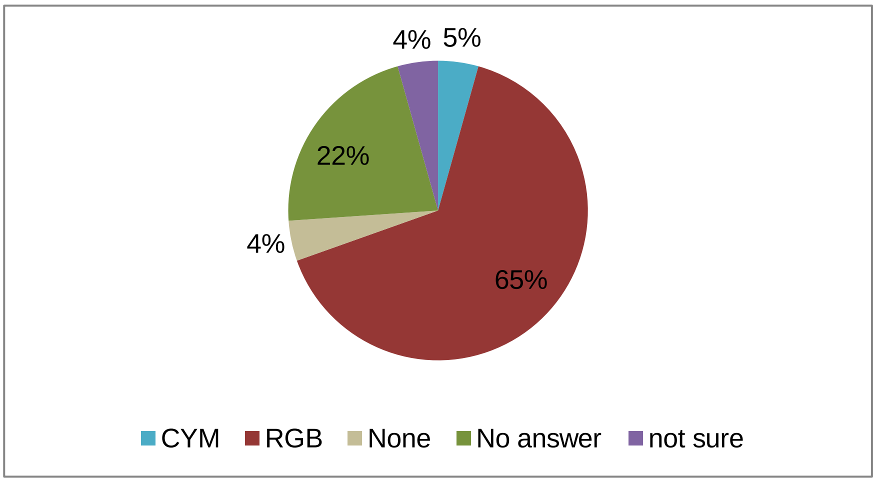


Figure 5-6: The Hydrographic society group evaluation of 3D perceived from RGB and CYM colour schemes (n2=24)

5.2.2.4 Evaluating CS application

In terms of the proposed scenarios for using CS, participants were conservative about the use of CS for navigation and more supportive for using it for underwater operations. The navigators showed a clear objection and suspicion about the benefit of CS in navigation. Some suggested CS can add significant complications to bridge operations without adding greatly to navigational data. Bridge crew might be unprepared to learn a new system after they had to learn ECDIS and ENCs. Also they reported that distance from or to objects is not always a controlling factor. For safety navigation, navigators prefer to see colours associated with depths “red = shoal = danger”.

While some participants did not see the advantage of estimating proximity in the scene and especially making everything closer to the viewing point red, others stated a vessel changing colour as it approaches would simply act as a colour coded proximity alarm “The redder is the closer”, and support collision avoidance and relative movement to ship or underwater docking. Nevertheless, CS should be applied with reservation and a lot of education. And it was suggested to be good for new generation of mariners, and possibly for navigation in fog.

A strong response acknowledged the benefit of CS for remotely controlled systems, and that should consider the ability to change scale in the ROV operation. The participants also proposed the use of CS for representing information on multifunction display, visualising layers of seismic data, such as 3D chirp and side scan data as well.

5.2.3 ARGANS group

In the third group interview, the researcher was invited to test CS with geophysical scientists and software engineers. The test was run with 13 participants, however during analysing the questionnaires; it was found that one of the participants could not perceive any 3D throughout the test. The respondent declared that he had a lazy left eye; so his responses were omitted from the sample. Consequently, the following results were based on sample size (n=12). 67% of the respondents were males and 33% females. 85% of them had sight impairment (self-ranked) among which 70% short-sighted and 30% long sighted. This was corrected using glasses.

5.2.3.1 CS perception

When participants were asked which colour was closer all reported red appeared closer. This was an indicator of positive CS. In a later question, when the participants were showed the first scenario, 5 snap shots taken for bathymetry (Figure 4-4), the majority evaluated the 3D effect as neither good nor poor, but neutral. Only one participant confirmed perceiving a good CS from the projected image by saying*" the effect of red near/ blue far is perceivable, but not sufficient detail for the bathymetry to give better impression"*. However, two respondents who saw the scenarios from the projected image and directly from the laptop screen found the 3D effect more pronounced, and classified it as good. This is illustrated in this quote

> *"[from the projected image] did not perceive any difference whether wearing the glasses or not, but once saw the PC image I could see depth projected".*

In the same scenario, 4 respondents mentioned that the scene appeared 3D in some views more than others. The best 3D was associated with the view that displays the shape of the channel clearly. This is confirmed in the following quote *"if the vessel is toward the front of the presentation, my brain perceived more depth in the image, this is enforced by the glasses"*, which also acknowledged the contribution of CS to the overall perceived depth by that participant. Another participant agreed with that view but reasoned that to the range of colours used in that image: *“The 3D effect was clear as long as I could see the full range of colours”.*

5.2.3.2 CS in different colour schemes

The first scenario (CS colour) was presented to the participants again but in CYM colour scheme instead of RGB Figure (4-14). Their responses to whether any 3D was perceived were presented in Figure 5-7, top. Despite 17% were uncertain about seeing depth in the CYM image, and 8% did not answer, 42% of participants perceived 3D. Whether this effect is CS related or not could not be confirmed. In comparison, in the RGB scheme (Figure 5-7, bottom) the participants did not report any total loss of 3D; instead 33% of them reported seeing good 3D. The 17% who reported a fluctuation in the 3D effect from good to neutral, their evaluation was based on the effect of the view angle.

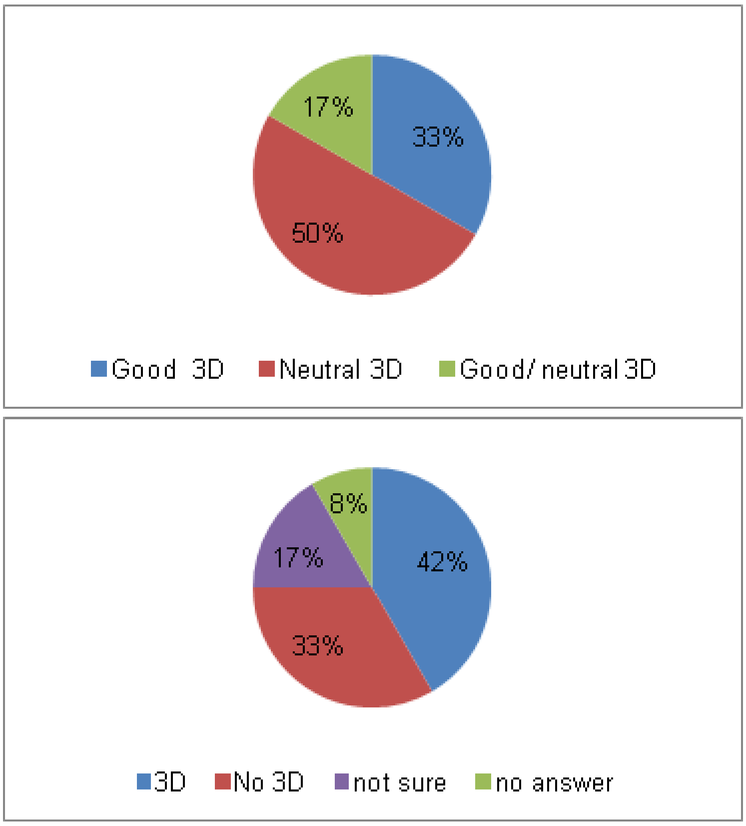


Figure 5-7: ARGANS group evaluation for 3D perceived in scenario 1, when displayed in RGB colour scheme (top) and in CYM scheme (bottom) (n3=12)

The remaining half of the sample declared that they had a neutral perception of 3D. Although this choice does not particularly indicate good 3D, it assumes the existence of some 3D perception; otherwise, participants could have ranked the 3D of the scenario as poor. Therefore it was inferred that the

RGB scheme has a better 3D effect than CYM. When the respondents were asked directly which colour scheme provided better 3D, 67% thought RGB was better than CYM scheme while only 8% favoured CYM over RGB (Figure 5-8).

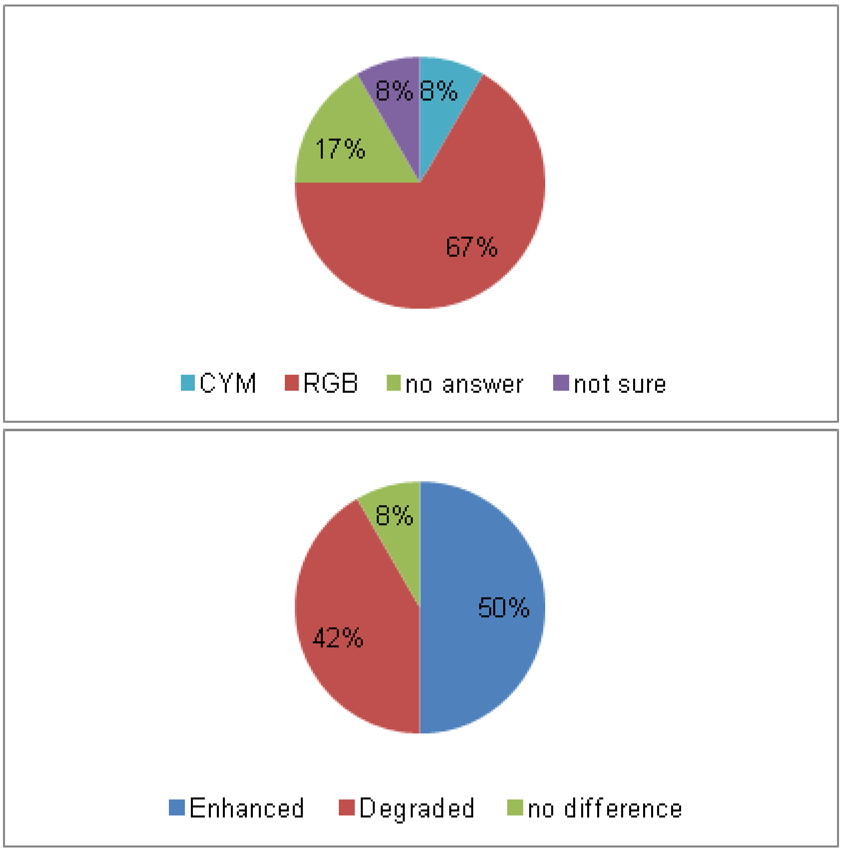


Figure 5-8: ARGANS group evaluation of 3D perceived from RGB and CYM schemes (top) and the effect of shading on RGB CS (bottom) (n3=12)

5.3 General discussion from group interviews

The small size of the group samples did not allow investigation of the significance of these results. Also, using a self-administrated questionnaire, did not allow any follow up question to clarify any ambiguous results. The results of analysing data collected from each group were used to iterate the scenarios and the questionnaires. Comments from these three groups (presented in the following sections) significantly crystallized the data collection method and visualisation designs. Accordingly, the final questionnaire (Appendix A. 3) and displays (Figures 4-2, 4-7, 4-8 and 4-9) were achieved. This mandatory and important phase of the research helped to eliminate many factors that may reduce the perception of CS. This, consequently, may affect participants' responses about the usefulness of this technique in marine applications. Also, this stage suggested recreational sailors and fishermen as potential users for CS.

5.3.1 Recommended changes in scenarios and questions

While showing the concept of applying CS in bathymetry and how colours were applied along the line of sight (Figures 4-3 & 4-4) the majority of participants reported that the quality of the 3D effect varied according to the view angle from which the scene was displayed. Such a statement necessitated clarifying whether the perceived 3D was CS-based or related to the amount of information revealed from each scene. Therefore, a new question was formulated (View angle Z vs CS) in the final questionnaire.

Another change recommended by participants was to create a visualisation that illustrated smooth transitions in the bathymetric view to allow enough time to adjust and recognize the meaning of the new colour application. Hence, the static images of bathymetry taken from specific view angles (Figure 4-15) were turned into a revolving bathymetry where the DTM was rotated 360^{o} at 1^{o} interval in the final GUI (See Z colour and CS colour scenarios on the CD),

The inclusion of bathymetry in the navigation scenario was a discussion point for the different group interviews. The MarCoPol users found the colourful bathymetry detracted from the buoys and the vessels, so it was replaced with a mesh surface. When the scenario was assessed by the THS members, some of them found the bathymetry irrelevant to surface navigation and should not be included. Hence, a new version of the scenario was created in which the bathymetry was substituted with a flat sea surface (Figure 4-9). When the ARGANS subjects were asked to compare the two versions of the scenario (Figure 4-8 and Figure 4-9), they stated that the presence of the bathymetry gave better context and reference than the flat sea surface did.

Being more acquainted with the real world situation and conventional use of colours to represent depth and navigation buoys, the ‘THS’ subjects assessed the scenarios on the basis of their knowledge and expectations. They raised issues about the consequences of applying CS obliquely and how it overrides the conventions especially in the buoyage colours. Changing both the colour and the shape simultaneously (Figure 4-5) made the objects meaningless for navigation. Therefore, the icon shapes for channel marking buoys were restored to match the conventions of IALA Region A (Section 3.1.1.1), i.e. cans and cones for port and starboard sides respectively (Figure 4-8).

5.3.2 Additional sampling

Analysing early questionnaires revealed new concepts about who should be included in the study to obtain a greater variety of responses about CS such as usability and users' acceptance. The following example demonstrates how sampling was based on an idea emerging from the data. In the early stages of interviewing, the need to differentiate between the natures of different work backgrounds was identified. Some participants stated that professional (merchant) navigators are conservative about any changes due to the rules that they must abide to. This may make them reluctant to accept or even refuse any changes in the way they perform their jobs. However, fishermen and recreational sailors are more open to new technology and gadgets' lovers. Evaluating some responses focused the attention on the attitudes of navigators towards new technology and whether their denial or approval of CS could be attributed to their experience or the international restrictions on rules of navigation.

5.3.3 Technical issues for CS perception

The group interviews showed that the perceived effect of CS was influenced by the viewing distance and colour reproduction between display devices. Viewing distance is the distance between the viewer position and the display system. Participants reported a significant loss of 3D effect when they were more than 3m distant from the display (a projected image on the wall) when compared with the effect they perceived from a closer viewing distance.

Also, images seen directly from the computer monitor showed a dramatic 3D effect compared to their projected copy. This could be attributed to the difference in colour gamuts between the projector and the computer. The three tests carried out with three different groups of participants and with three different projectors demonstrated significant differences among the colours perceived from these devices. This indicates that colour reproduction is an issue that has to be considered when CS is used on different platform

5.4 Stage two: Data collection method based on face-to-face interviews

Responses from the stage one highlighted the need for one-to-one interviews in a more controlled environment to obtain more realistic results. The tests were run at each participant's own pace allowing sufficient time to adjust to the visualisations, and to freely express their opinions without interference from others (as was the case in the group test). Also, this method unified the test set up (display method and viewing distance) using the same laptop screen that was located one metre from the participant.

5.4.1 Sample size and recruitment

To assess the potential of CS in a dynamic marine environment and to identify the implications for cartographic conventions, the participants were chosen from maritime users. Their interests reflected different activities; above and under water surface (Figure 5-9).

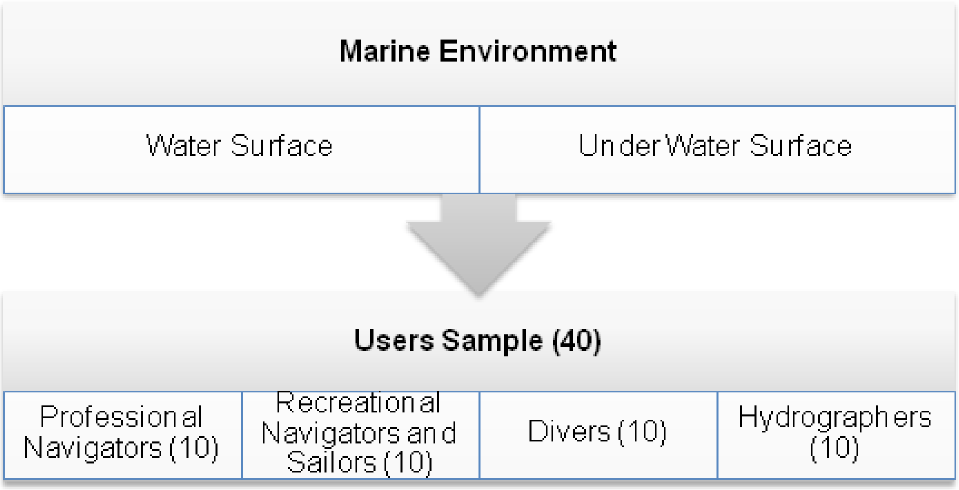


Figure 5-9: Breaking down the sample size used for face-to-face interviews

For navigation both professional navigators and recreational navigators were chosen, to evaluate the attitude of their acceptance. Hydrographic surveyors were suitable to evaluate the usability of the application. For underwater operations, divers and fishermen were considered for their knowledge about that environment. Unfortunately, fishermen were not represented in this research. Despite several attempts to contact fishermen through different fishery representatives, the nature of their jobs made it extremely difficult to find a mutual time to meet.

The first stream of participants was recruited during the ‘Hydro 10’ conference in Germany. The research was promoted during an oral presentation. Then the researcher spoke to different delegates to identify the relevance of their marine experience to the scope of the study. As a result 5 hydrographers and 2 sailors were interviewed. The researcher network within the Marine Institute in Plymouth University was a useful tool for ‘Snowballing’ and ‘Gatekeeping‘ to recruit interviewees (Flowerdew & Martin, 2005). The scope and the nature of the research were clearly explained in an invitation e-mail (Appendix B) that was sent to the leaders of the diving centre, the sailing club and the MSc Hydrography programme and to the head of the navigation section. In addition to providing contact details of their colleagues (divers, navigators and sailors), these ‘gatekeepers’ volunteered to participate in the study and promoted their experience to the others. This had a great advantage in encouraging people who were uncomfortable to participate in the study. Also it facilitated obtaining respondents’ consent. ‘Snowballing’ was a useful method to recruit more participants. For example, one of the interviewees, an expert sailor, pointed out that two of her friends are expert sailors and would be able to help in this research, and so on. ‘Snowballing’ could lead to a biased sample, as the researcher could be directed to a certain group, and exclude the other groups (Jacobson & Landau, 2003). However, this was unlikely to be the case in this research, because the study was designed and directed for certain groups and the participants who were recruited through snowballing met the requirements.

Participants were contacted and designated a time slot according to their availability and were invited to the university campus. Divers from the diving centre were interviewed in their work place, while the first group of participants were obviously interviewed in the conference venue. As an appreciation for their time and help, some refreshments were provided. Stating clearly in the information sheet that all answers are correct and appreciated and promising anonymity for respondents were important to gain unbiased data. These reassured participants who were concerned about the correctness of their answers and encouraged them to freely express their own views about the study.

In behavioural research the sample size should be 10% size of the parent population (Alreck & Settle, 1995) and within 30 and 500 is recommended. This applies to both studies with a target population and with a sub-categorized target population (Roscoe, 1975). An experimental group of 40 subjects associated with the marine environment was used; this group was subdivided into four groups of 10 participants. The groups represent underwater users (divers), professional navigators, recreational sailors, and hydrographers. The sample size was limited to 40 based on factors such as time and budget, considering the validity of this sample size to draw statistical conclusions, but taking in account that the sub-categories' sizes must meet a minimum of 30 to have a statistical validity (Roscoe, 1975). However with a sub-categorised target of ten, this small size sample is acceptable for interview-based studies where each individual participant offers huge amounts of qualitative data to answer research questions (Isaac & Michael, 1995).

5.5 Data analysis

The interview was designed to be approximately 1 hour in length. In a few cases, the interviews lasted for 3 hours. It was necessary to offer the interviewees sufficient time to develop their answers based on their own thoughts and experiences (Easerby-Smith, et al., 2008). Listening to their explanations and views about CS and their long experience in the marine field highlighted comments of great importance to the research topic (Torrington, 1991). This also allowed the researcher to probe meanings in depth. The interviews were conducted and recorded, producing 45-hours' worth of material to be transcribed. All audio files were transcribed in order to be coded; each one hour of recording needed three hours of transcribing.

To keep the anonymity of participants and to reduce the potential bias of the researcher by over quoting one or other participant, a coding system was developed to refer to each participant; each category was presented with the initial of the category's name, hence N was donated for professional navigators, S for sailors (recreational navigators), H for hydrographers and D for divers. Then the members of each class were numbered from 1 to 10 according to the interviewing order. For example, D1 refers to the first interviewee among divers and H10 represents the tenth hydrographer and so on. This division relayed the recent marine activities in which the participants were involved.

Qualitative data that were based on the participants' descriptions of the technique and its usefulness were reduced to categories and connections to develop themes using QSR Nvivo9 package. Data from open-ended survey questions were quantified and converted into meaningful, quantitative statistics. Supplementing the rich qualitative results with quantitative statistics, may cooperatively deliver a richer answer to the research question being studied.

Theme	Associated elements
CS interaction with other depth cues	Different colour schemes View angles Shading
CS usefulness	Proximity Colour coding Cognitive offload
CS applications	Navigation proximity alarm for blind navigation situation awareness Underwater pre-trip for divers Flythrough for real-time ROV operators Simulator navigation suits and interpreting Radar
Confusion	Change in conventions Buoyage colour Colours from z to distance
Design factors	Object size Colour range Contrast between background and foreground
Requirement for real time application	Colour scale Speed update
Human factors	Sight impairment and CS Visual power Coping with an additional screen Attitude
CS Learnability and acceptance	Experience Age and attitude Training
Practicality for application	Glasses The setup of use

Table 5-2: Themes extracted from the qualitative data

Quantitative data, such as participants' opinions about shading, the level of 3D perceived and the overall evaluation for the scenarios were imported to the statistical package SPSS and analysed using appropriate statistical tests. The Chi-square test was used to derive any significant difference between the responses about 3D perceived from CS and conventional visualisations of the bathymetry. This is a non-parametric test that does not make assumptions about the sample distributions. It is recommended for nominal and ordinal data and for small samples (Pallant, 2011). The ANOVA test with two parameters was used to evaluate the interaction between the view angle and CS on the perceived depth.

5.6 Methods Critique

5.6.1 The use of Matlab

With the progress achieved in learning Matlab, the author realised that having a high level language made the prototyping task more difficult and time consuming. Despite the extensive range of readily available functions, a considerable amount of time and effort were spent to understand the default setting for each function and then try to modify it to achieve the desired output. As a result, the scenarios were kept in the simplest forms that could deliver the proposed concept. For future work, low level programming languages would provide more control for the design. Another drawback of Matlab is its restricted capacity to handle large datasets. The programme ‘crashed’ frequently, when the full set of bathymetric data was used to create a DTM.

5.6.2 Scenario and visual stimuli

The selected scenarios demonstrate several elements. Firstly, they present a simple concept of some dynamic operations where the viewing point of the scene is changing/ or the observed objects are moving. They allow integrating CS effect with two other depth cues shading and interposition that are continuously used in most visualisations. This helps estimating the contribution of CS to users’ 3D perception and the compatibility of these cues with each other. Finally, the scenarios represent two established colour conventions in the marine environment buoyage colour and DTM bathymetry colour, hence testing users’ acceptance for the implication of CS on conventions is possible.

5.6.3 Data collection

A questionnaire could have reached a wider geographic range and obtain a significantly larger number of respondents, and less biased data. Interviews were identified more useful for this research to explore users' reactions and attitudes. The method allows presenting the scenarios, observing participants' behaviour and clarifying their opinions, especially as the scenarios incorporated a number of depth cues, and it is important to clarify what is the CS contribution to the perceived depth. Also, face-to-face interviews helped to make the interviewees tolerate the one-hour interview.

Some personal interviews were in-home interviews. This may have had an effect on the test set-up, particularly the viewing distance. The researcher visited the interviewees in their offices and had to use the available space to set-up the test environment. Moreover, to reduce the source of bias in the data, the researcher tried to present the questions with minimum cues that might influence participants' opinions, and also tried to encourage the participants to speak freely and assure them that all answers are correct and important. This was an important reminder as some respondents were concerned about giving wrong answers or contradicting others' opinions. The study is not intended to generalise to a wider population using a statistical significance, but to explore ideas and generalise these ideas to a wider concept. Ideas were supported with quotes. Miles and Huberman (1994) stated that *"words, especially organized into incidents or stories, have a concrete, vivid, meaningful flavour that often proves far more convincing than pages of summarized numbers".*

5.6.4 Sampling

Most participants are based in Plymouth, and some of them were colleagues, so it might not give a realistic representation of the full spectrum of users. However, they came from many different backgrounds. They were unified in the work place but they spoke from their own experience, which mainly related to their origins.

5.7 Chapter summary

This chapter presented the process of designing the research questionnaire for administrated interview, and justify the number of participants used. The survey was conducted in two stages: in the first stage three group-interviews were performed. The result of each group used to iterate the questionnaires and the stimuli. The participants’ evaluation of CS, its interaction with shading and colour schemes and its potential applications was presented for each group. Moreover, this essential phase of the research identified several elements that have a direct effect on CS perception, most importantly, viewing distance and colour reproduction between devices. Eliminating these influential factors and improving the designs of scenarios were essential to obtain more credible and representative data for this research. Individual face-to-face interviews were identified as the best solution. A sample of marine users was interviewed using the final stimuli and questions to obtain a credible evaluation for CS usability.

Chapter Six

6 Results

This chapter summarises the principal outcomes of the second stage of the research obtained from 40 face-to-face interviews. The results include quantitative and qualitative outcomes. The quantifiable factors such the interaction between viewing angle and CS and the preferences of colour scheme were statistically identified. The statistical elements were supported with the words and voices of the people involved. The qualitative explanations for those people about the factors that influenced their perception of the CS effect and the potential applications in the marine realm are presented under themes; each theme is supported with quotations referenced to the relevant respondent by a coding system that maintains anonymity. Within the text, all quotes were reproduced in italic.

6.1 Overview of participants

In this stage 39 participants were interviewed. Originally 40 participates were recruited; however the data obtained from one of the participants was dismissed as he could not the 3D effect from RGB scheme. The respondents were involved in the marine environment in different activities. The interviews revealed that respondents' experiences in the marine environment were not restricted to one activity. For instance some navigators were divers as well, or worked in hydrography. Some hydrographers were expert sailors and professional divers and so on. Although this blurs the boundaries between categories, it provided a comprehensive evaluation for the usability of CS in the marine environment. Also it was noted that under recreational sailing, dingy sailors differed from yacht sailors in terms of the level of navigation activities in which they are involved. The level and length of experience varied among participants from all categories. Some respondents had a little experience (up to 2 years), while others had an extensive experience (up to 40 years) and acted as instructors in their field. This was useful to test the correlation between experience and acceptance of new technology. To describe the length of experience for the members of each group, the actual years of experience was collapsed into four categories, less than 2 years, 3-5 years, 6-10 years and more than 10 years. Figure 6-1 illustrates that in each activity subgroup some participants had a relatively short experience while at least two thirds of them had an experience of 6 years or more.

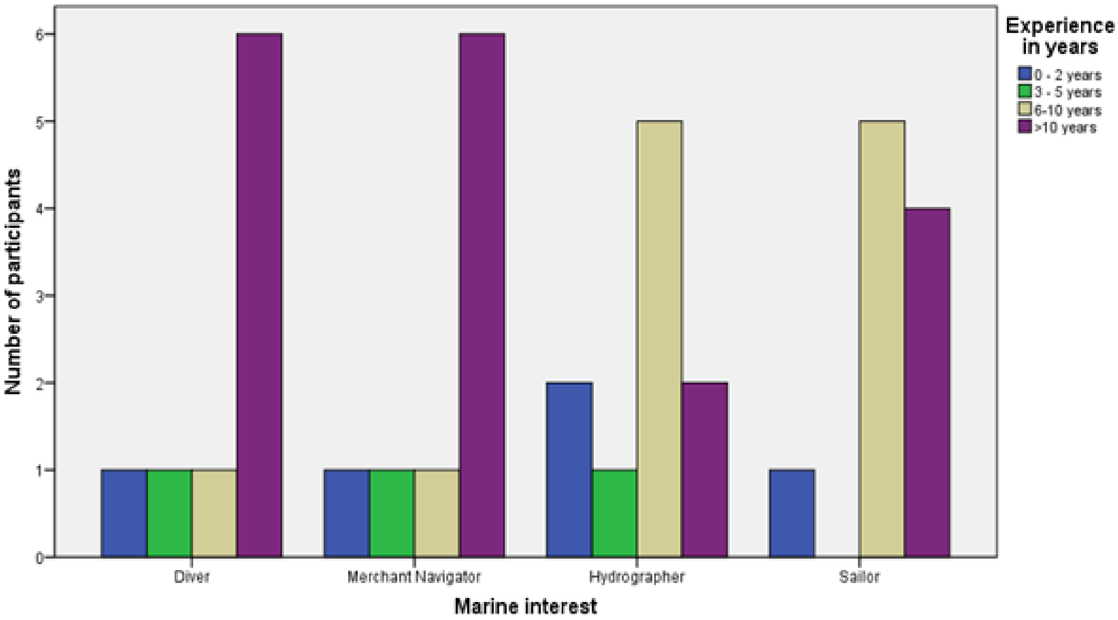


Figure 6-1: A summary of participants' length of experience in the different marine activities

The sample group consisted of 68% males and 32% females. The distribution of females and males in each marine activity is presented in Figure 6-2. This sample was dominated by males. This imbalanced proportion in gender was partially due to the difficulty to recruit participants, and to the fact that one of the targeted activities, i.e. navigation, is principally undertaken by males. The variables of this study can be reviewed from the complete test records in appendix 9.3.1.

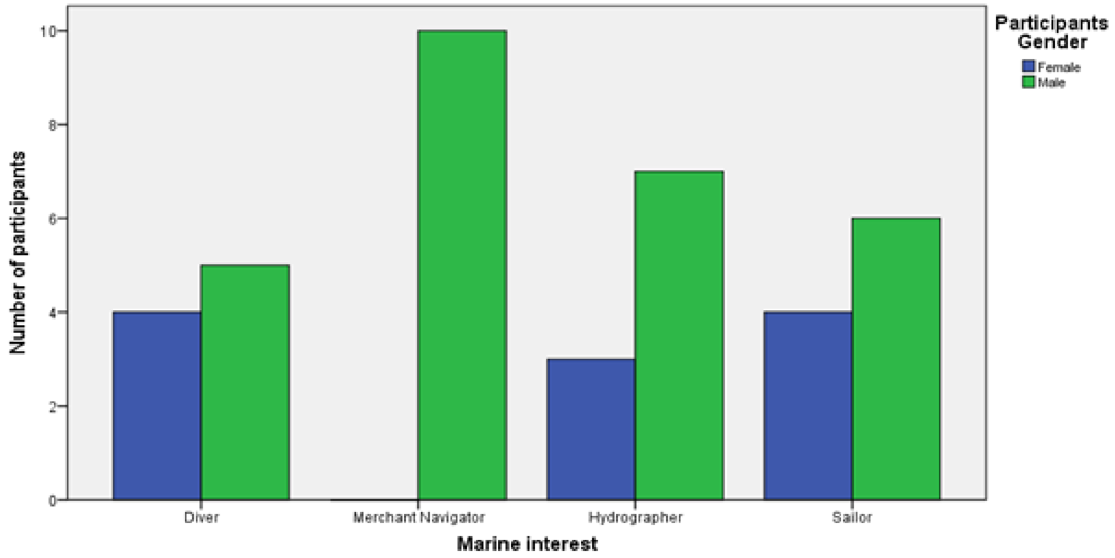


Figure 6-2: A summary of gender distribution among the different marine activities for the test sample

Among the 39 participants different sight conditions were spotted (Table 6-1). Only 35% had a naturally correct sight, while the others had different types of sight impairment. Short sightedness was a common problem as it was reported by 41% of the participants. The rest of participants declared to be either longsighted (12.8%), had a lazy eye (7.7%) or colour-blind (2.6%). 75% of short sighted participants had their sight corrected either using glasses or contact lenses (Figure 6-3). Only 40 % of long-sighted people were correcting their sight using glasses. In total 25% of sight impairments were not corrected including eye laziness.

Sight impairment	Participants' Gender				Total	
	Female		Male			
	Number	% females	Number	% males	Number of participants	all participants
Colour blind	0	0.0	1	3.6	1	2.6
Short sighted	4	40.0	12	42.9	16	41.0
Long sighted	2	20.0	3	10.7	5	12.8
Lazy eye	0	0.0	3	10.7	3	7.7
None	5	40.0	9	32.1	14	35.9
Total	11	28.2	28	71.8	39	100

Table 6-1: Sight impairments between participants and each gender

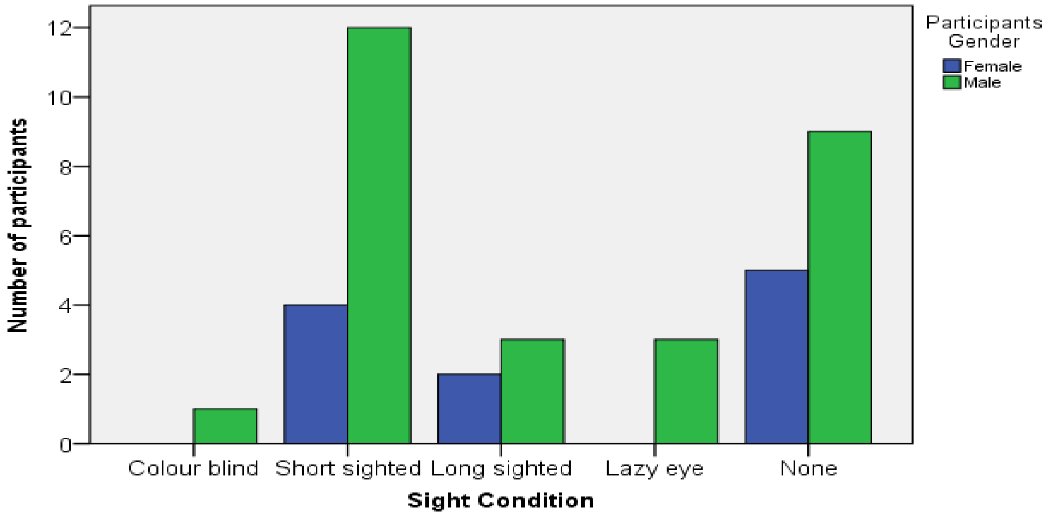


Figure 6-3: Types of sight imparity between participants from different genders

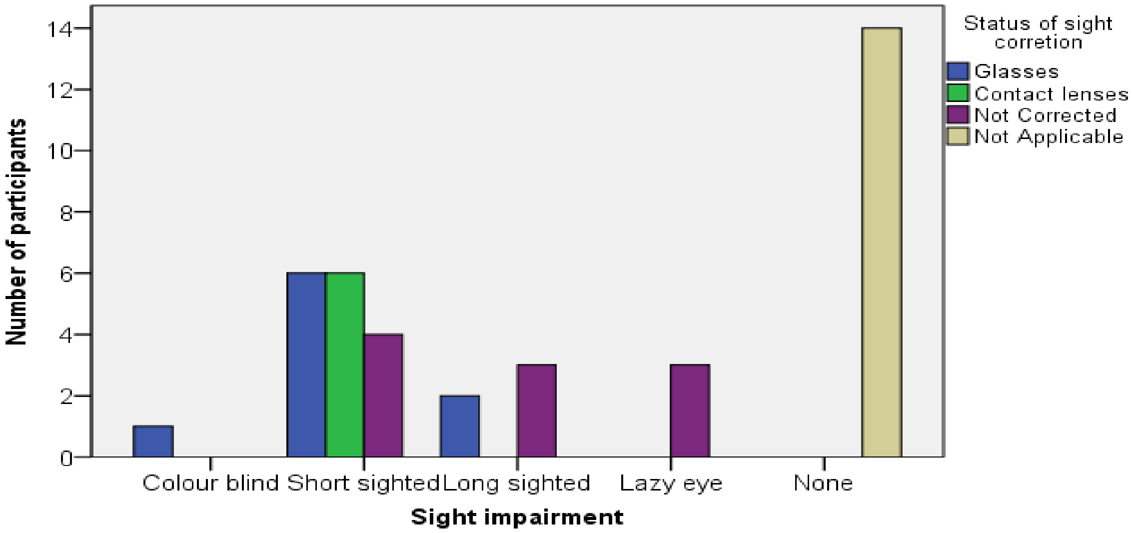


Figure 6-4: The correction status for the participants' sight impairment

6.2 Participants' prior knowledge of marine visualisations

6.2.1 Charts and DTMs

Responses about previous experiences with charts and DTM bathymetry were analysed. Figure 6-5 shows that in total 85% of participants were familiar with charts symbols, 42% were familiar with DTM display of a bathymetry. While 8 % of participants lacked to any experience of charts and DTM, over a third of participants were familiar with both visualisations. A cross referencing between the background of participants and the visualisation method they used is performed. Figure 6-6 shows that charts were used by all merchant navigators and by the majority of other groups. Bathymetric DTM was known among the participants from different groups to varying extent, best known by divers and hydrographers and least known by merchant navigators. Only one hydrographer and two dinghy sailors were not familiar with the visualisations in question.

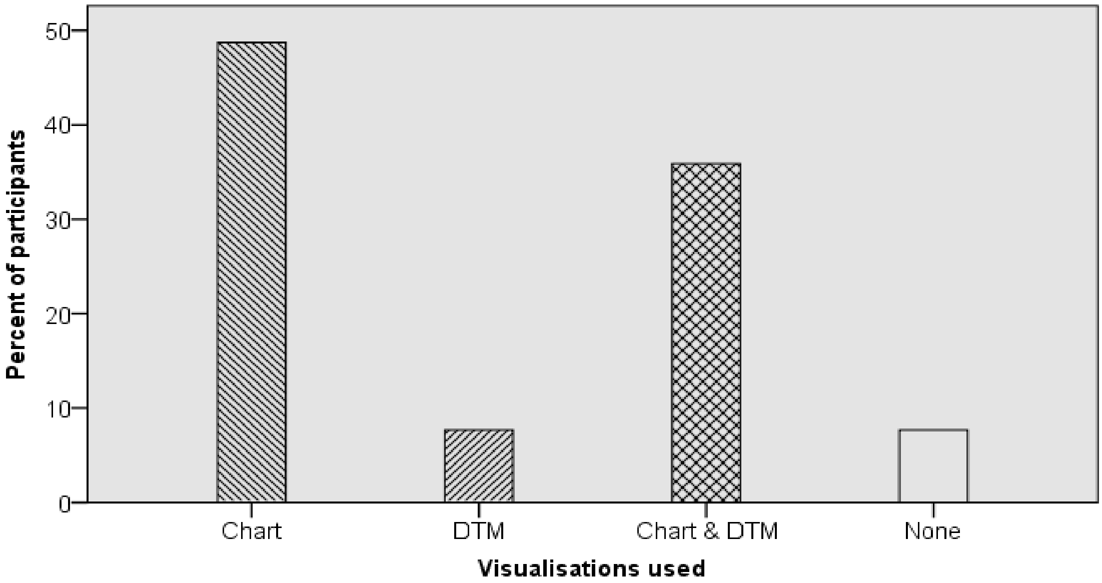


Figure 6-5 Types of marine visualisations that the participants used

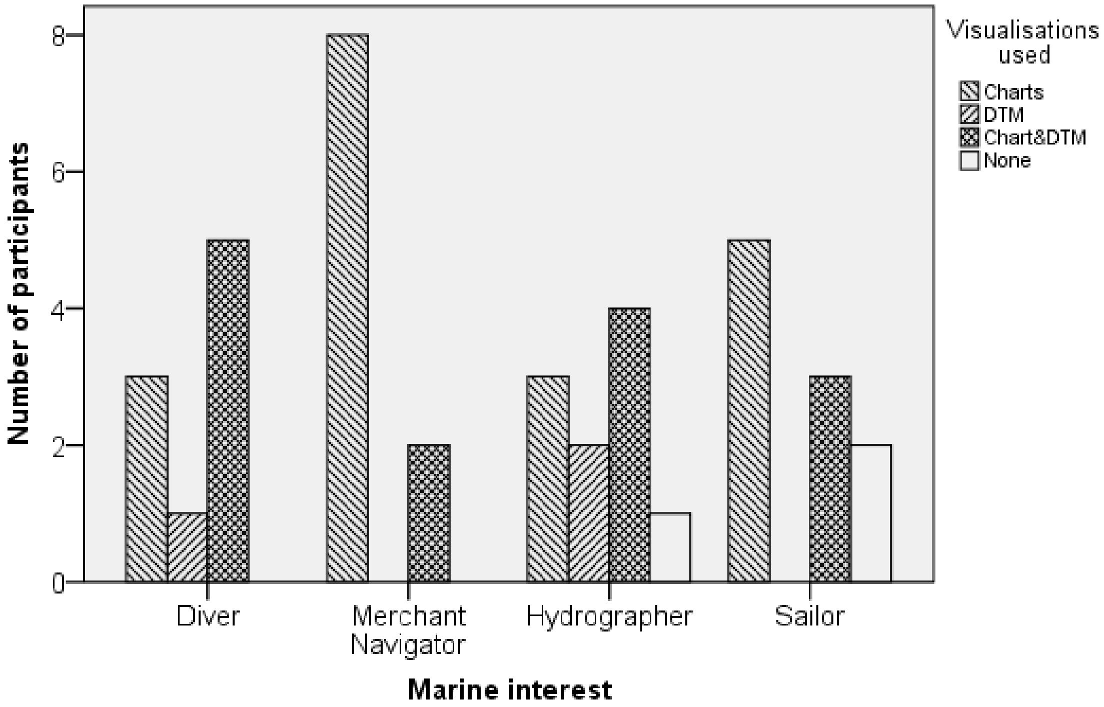


Figure 6-6: Types of visualisations used by each group of participants

6.2.2 Buoyage systems

When the participants were asked about their knowledge about the buoyage conventions, all participants were aware of the descriptors of navigation buoyage. Predictably, the knowledge of buoyage systems among merchant navigators was superior to other groups. This knowledge was equally shared between navigators, regardless of the level or the origin of their experience. For instance, a Belarusian navigator with less than two years of experience described navigation practice and the buoyage system exactly the same way that a British navigator with 40 years of experience did. Navigators talked about the buoyage system, the use of symbols, top mark, colours and light for identifying navigation aids and the existence of IALA A and B. Also they described the special requirement and technical details of navigation, the restriction imposed on their work, the problems they face and expectations.

One of the terms used by navigators and sailors was ‘situation awareness’. Constructing situation awareness in navigation depends on the visual side, navigation aids, radar and charts. Navigators are window watching focused. Objects appearing on the radar will be checked on the chart and observed with binoculars before any interpretation. Merchant navigator participants stressed that window watching is their main source of reality to which they verify the situation.

> *‘As a navigator I will prefer to see the real thing. I used to distrust everything you see until it is right, and query the way it interpret it’ (N5).*

Beside window-watching, charts and radar provide the main stream of information for spatial awareness. These visual resources are distributed around the vessel’s bridge, and it is the navigator’s task to correlate this information and create a mental image that accurately reflects the situation and to act according to navigation rules imposed by the International Maritime Organisation (IMO). This process requires skills that include reading charts, and interpreting radar and a high degree of alertness. All navigators admitted that radar is a difficult and unfriendly tool for non-expert users and even for some experts.

The danger of collision with any observed target is measured by the CPA (closest point of approach) that is not only how distant the object is, but how quickly it will approach the vessel as explained by this navigator:

> *”looking at two ships one 8 miles away and the second 5 miles away, but the one of 8 miles away is travelling with twice the speed of the second one, so you are more interested in the one further” (N2).*

For coastal navigation, navigators referred to the buoyage systems used in the world (Section 3.1.1.1). They described how the process of identifying the buoys is based on four elements (colour, shape, top-mark and the pattern of flashing light). This information was not known for all sailors. Yacht sailors who had extensive experience in sailing were more knowledgeable about the different descriptors of navigation buoys and navigation rules. However, for dinghy sailors these rules were almost ambiguous even for those of 10 years of experience. They knew about the difference in colours, but could not recall exactly which colour referred to the port or starboard side of the channel. Although they had been frequently reminded about navigation rules, dinghy sailors were less interested in memorising such information. This was justified by several reasons. Dinghies are shallow drafted and not liable to ground.

For divers, the operation starts from the office were the diving area is studied on the chart, and then the divers are transported to that area. Once they are in the water, the only sense of direction they have is based on the mental image they created from the chart. However the magnifying effect of the water makes vision harder and operations more difficult.

> *“When you are diving, things always appear closer and bigger” (D2). “It gets difficult because of magnification, you think closer to things than you really are (D3).”you might look and think I can swim there and start and after many hours you are still trying” (S6).*

However, magnification becomes less problematic through experience.

6.2.3 CS perception

The ability of participants to perceive a 3D effect from CS was tested at the beginning of and through the test. While watching the ‘spider and fish’ video clip, all participants but one confirmed seeing a 3D effect. They reported seeing red objects closer than blue ones as quoted.

> *“There is an element of 3D in this scenario, and I think this is based upon colours, blue being darker further away and red being closer” (H1).*

This type of colour perception was confirmed during the test. After each scenario participants answered the CS question test about the position perceived for different colours on the screen. All respondents confirmed that objects looked at different positions on the screen based on their colours. Red seemed closer than blue all the time. They noted that the ChromaDepth glasses significantly enhanced this perception as illustrated in this citation,

> *"With the glasses I see some 3D effect in the green as well. They enhance the effect. I feel that I can use a ruler to measure where the buoys are from the screen" (N5).*

In a later stage, the respondents' CS perception in CYM colour scheme was evaluated. The result showed two different types of CS: positive and negative. In the former the cyan colour was perceived closer than yellow by 92% of respondents, while 8% of responses reported a reverse effect. Figure 6-7 presents the overall classification of CS effect reported by the interviewees. Further discussion about CS in different colour schemes is presented in Section 6-3-2-3.

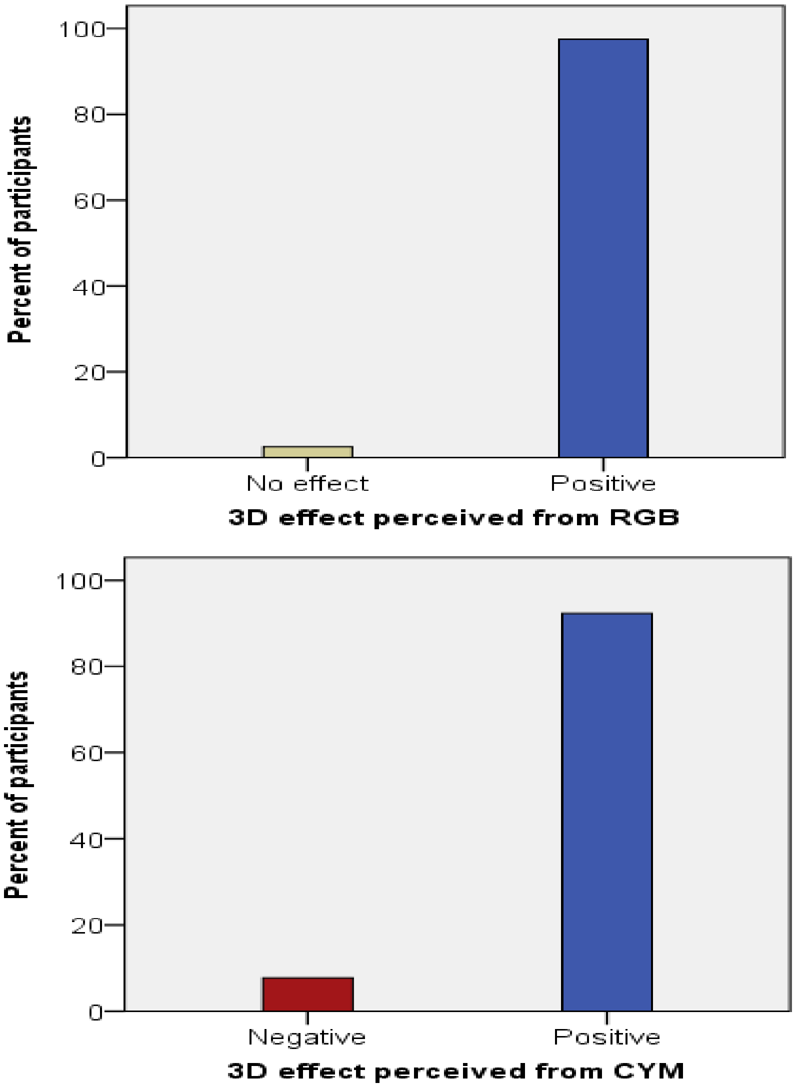


Figure 6-7 Classification of participants' perception in RGB and CYM colour schemes (n=39)

6.3 Factors influence CS perception

This section investigates the effects of several elements that could influence CS effects. These elements include human factors (such as sight impairments and gender) and cartographic factors (such as the contrast between foreground and background produced from different colour schemes, shading and interaction with view angles).

6.3.1 Human factors

6.3.1.1 Gender

To check any association between gender and 3D perception for CS, a Chi-square test for independence was used. The results indicated no significant association between gender and 3D perception from CS in either colour schemes as the values were $\chi 2$ (1, n = 39) = .4, p = 0.52, phi = –1for RGB, and $\chi 2$ (1, n = 39) = 0.04, p = 0.84, phi = - 0.03, for CYM.

6.3.1.2 Sight impairment and method of sight correction

A factor that could influence CS perceptions is sight impairment; short sightedness, long sightedness or eye laziness may cause a fuzzy vision which reduces the 3D perceived from CS. Information collected about sight impairment and the method of sight correction was used to assess the association between these two variables and the CS effect perceived by participants in RGB and CYM colour schemes.

Figure 6-8 shows that one of the short-sighted participants did not notice any 3D effect from the RGB colour scheme, while most of them perceived red closer than blue; hence they had a positive CS. For the CYM scheme, all participants reported that different colours appeared at different distances. The majority perceived cyan closer than yellow, but for 3 participants this effect was reversed. Interestingly, one of these participants was short-sighted and the other two had naturally correct vision.

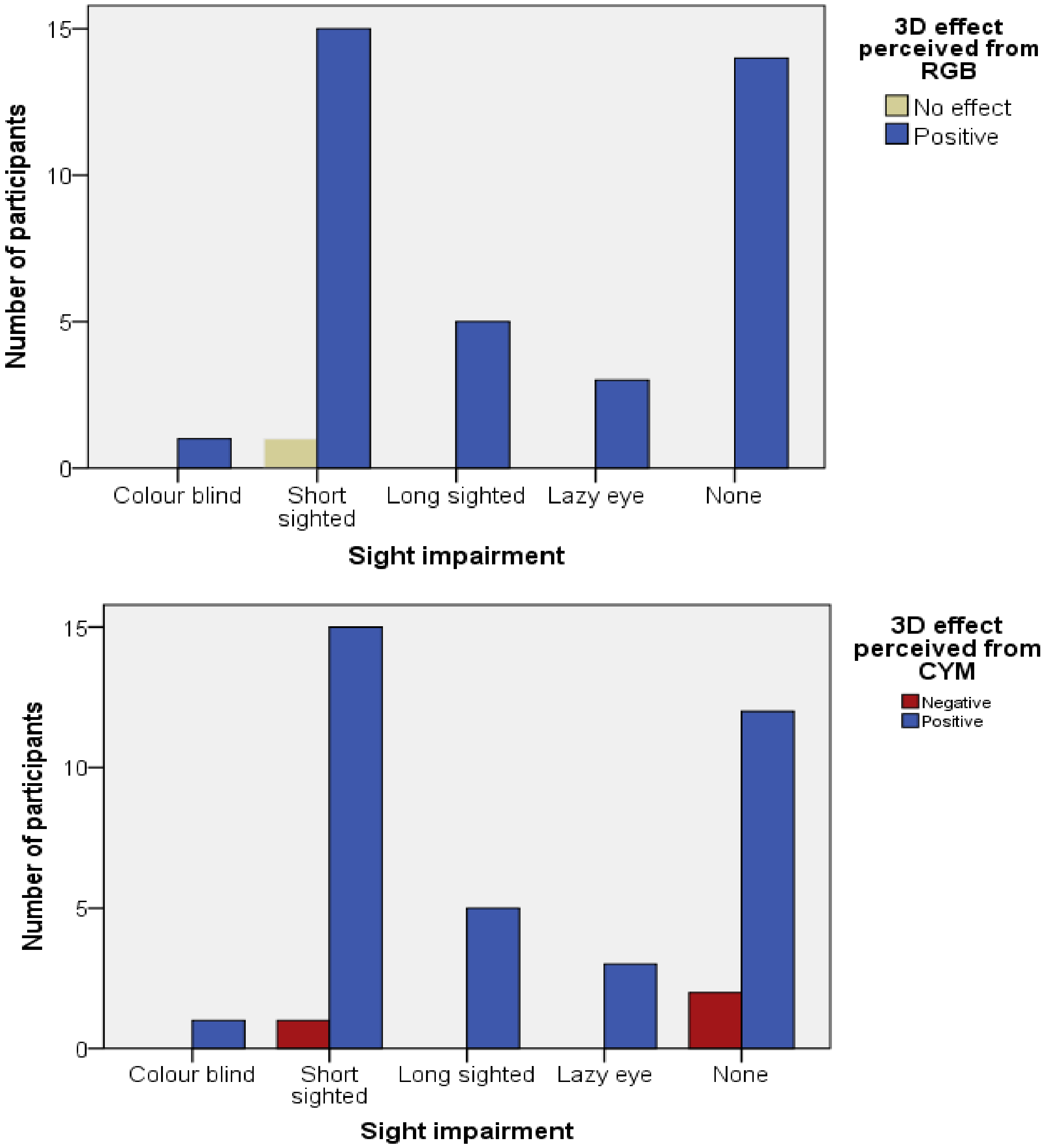


Figure 6-8: The interaction between different sight impairments and CS perceived in RGB colour scheme (top) and CYM scheme (bottom)

In a quick test, participants who were correcting their vision with glasses were asked to use ChromaDepth glasses only without prescription glasses. This showed that participants' 3D perception was slightly lowered or disappeared due to blurry vision. Further investigation tested the influence of the status of sight correction and the CS effect perceived from RGB and CYM schemes. The initial results presented in Figure 6-9 showed that in RGB colour scheme, the participant who could not perceive any 3D effect was one of those who had uncorrected sight impairment.

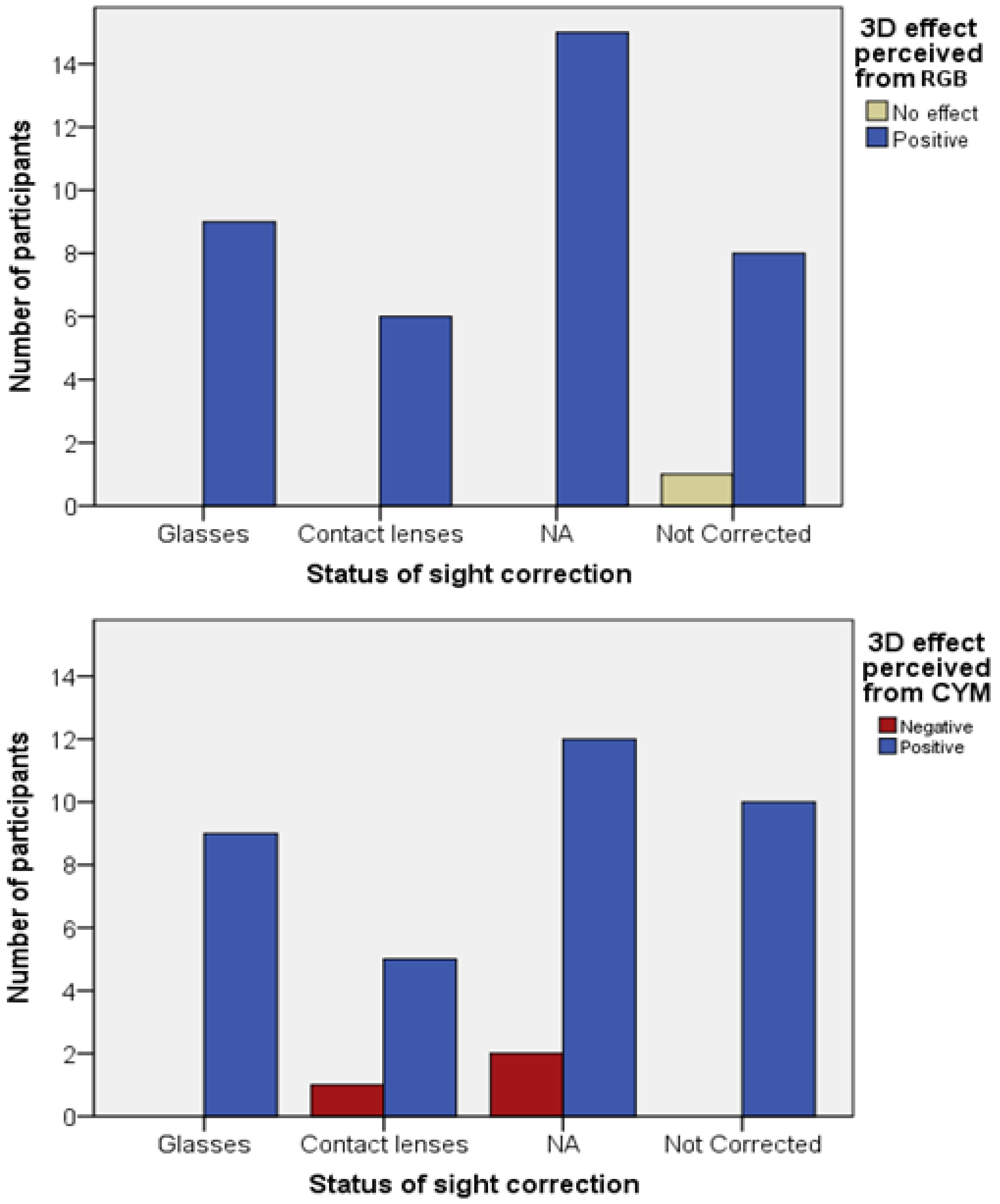


Figure 6-9: The interaction between the status of sight correction and CS perceived in RGB colour scheme (top) and CYM scheme (bottom)

The potential effect of different sight impairments or the method used for sight correction on 3D perceived in CS was assessed. Chi-square test for independence (with Yates Continuity Correction) was run for RGB and CYM schemes. The results for the test are presented in Table 6-2 where P-value for all tests was larger than 0.05%. This indicated that neither the type of sight impairment, nor the correction method had any significant effect on CS perceived by participants.

Sight impairment	*Chi-squared*	*P*	*phi*
RGB (n=39)	1.475	0.83	–0.19
CYM (n=39)	1.654	0.78	0.21
Corrected sight	Chi-squared	P	phi
RGB (n=39)	4.42	0.33	–0.3
CYM (n=39)	3.121	0.37	0.28

Table 6-2: The results of Chi-squared test used to compare the relation between CS (in both RGB and CYM) and different conditions of sight impairments (top table) and CS and different status of sight corrections (bottom table)

In the crosstabs the effect size statistics for 2 by 2 tables is measured by the phi coefficient, with higher values indicating a stronger association between the two variables. In these tests the phi coefficient values were between (-0.19 and -3), the effect is 'medium' according to Cohen's (1988) criteria of 0.10 for small effect, 0.30 for medium effect and 0.50 for large effect

6.3.2 Familiarity, experience and acceptance

Understanding the CS application needed some time as it encountered new conventions and familiarity. Familiarity has clearly played a significant role in the way individuals look at new software or a visualisation. Participants' facial and verbal expressions reflected a state of confusion once they were exposed to CS and an unexpected application of colours.

Some participants required a longer time to recognize the difference in the bathymetry when displayed in the same colour scheme (RGB), but applied differently once in the conventional way along Z axis and later along the line of sight.

> *"It is confusing as I am trying to put the standard interpretation for the colour, because I am used to other colour ranging being used" (S1).*

And they found it difficult to adopt the new colouring system despite recognising its effect.

Experience has a clear impact on participants' evaluation for CS application. Participants who were used to see a certain visualisation in a specific format in the same context for a long time found it difficult to accept.

> *"When your journey started a long time ago, and you always remember what you start it with. I started with paper charts, and you always think about what you know until now" (N5).*

Nevertheless, participants' familiarity with the conventional use of red to signal danger was one of the reasons which made CS appealing. On the other hand, the lack of experience in conventions helped some participants to evaluate CS independently. Also, previous experience of visualising data in different ways and colours was deemed useful to accept the changes in convention and interpret the different application of colours. This was suggested by a diver whose modelling background helped him to accept the changes and agreed by a sailor whose programming and visualisation experience has trained his eyes to perceive and interpret different colours.

6.3.3 Cartographic factors

6.3.3.1 Shading effect on CS

Responses about the interaction between shading and CS in both RGB and CYM schemes were grouped according to its effect (Figure 6-10). 33% of participants found shading did not affect both colour schemes. 54% of respondents thought that shading increased the 3D effect in RGB colours, while 13% stated that CS was negatively influenced by shading. For the CYM scheme, 62% of participants found shading enhanced the 3D effect perceived from CS, while only 5% found it diminished

Based on participants' comments, shading had two effects on the general 3D effect and on CS in particular. The observers reported that shading assisted them in recognizing the shape of the bathymetry and the orientation of the different parts; the image became more realistic and easier to interpret and the overall 3D perception for the scene was significantly enhanced.

> *"[Shading] augmented 3D. The light effect makes the contours sharper, it is more natural" (S9).*

This general improvement in the scene aided some participants to focus their attention on CS and understand its effect. This opinion was shared between four respondents and was clearly stated by one of the hydrographers

> *"The sun illuminated view helps to understand the bathymetry, this understanding helps to get better, faster or easier 3D view from colours" (H5).*

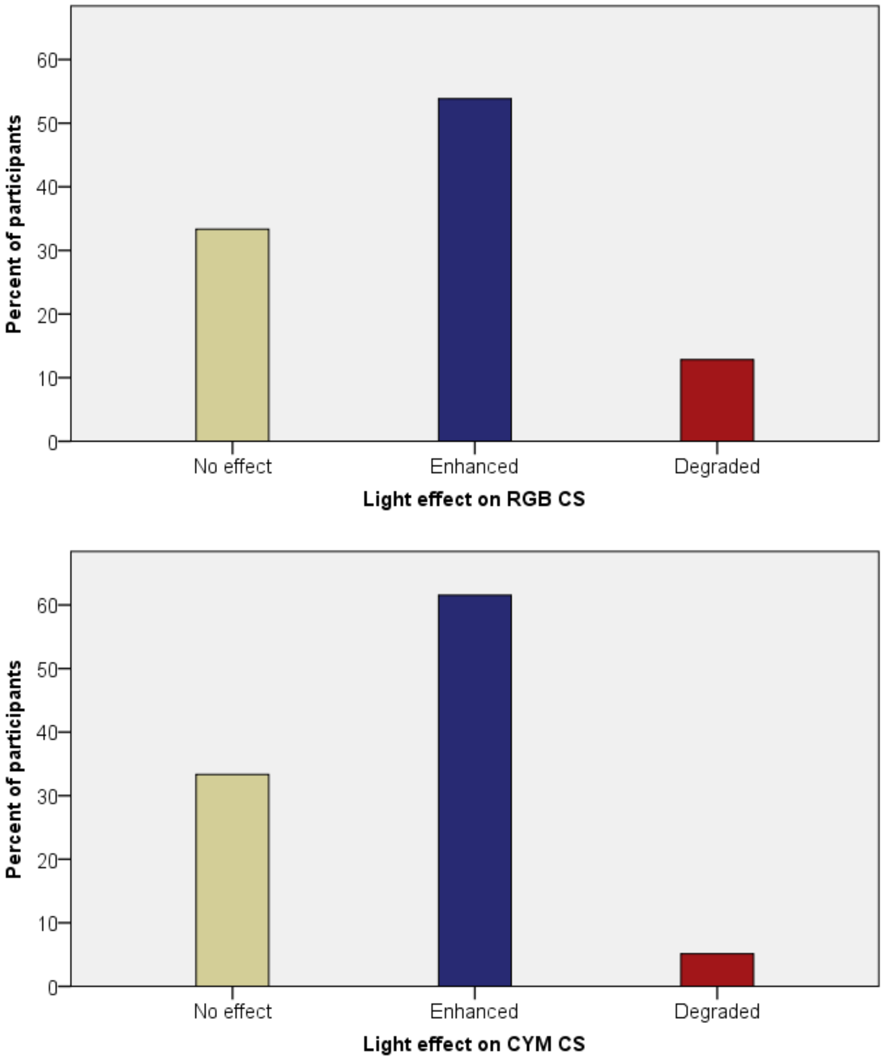


Figure 6-10: Comparison sets between CS effects perceived from two different colour schemes RGB and CYM

In contrast, for participants with no previous experience in interpreting shading, the additional details were confusing so they concluded that shading reduced the CS effect. Some participants found the 3D effect from shading took over the CS effect as they could easily infer 3D from shadow. An experienced navigator who could perceive CS effect only from CYM described the actual impact of shading on CYM by saying

> *"In CYM, it is much more interesting; you get more information, more variation of light and shade. Without shading, the image is so plain" (N10).*

6.3.3.2 CS from different view angles

The 3D effect perceived from different view angles for bathymetry coloured along the Z axis and with distance (CS) was evaluated by the participants, by scoring each view from 1 to 5; 1 for the least 3D and 5 for the best 3D. The influence of the view angle on the score of 3D perceived from conventional and CS displays is presented in Figures 6-11 and 6-12 respectively.

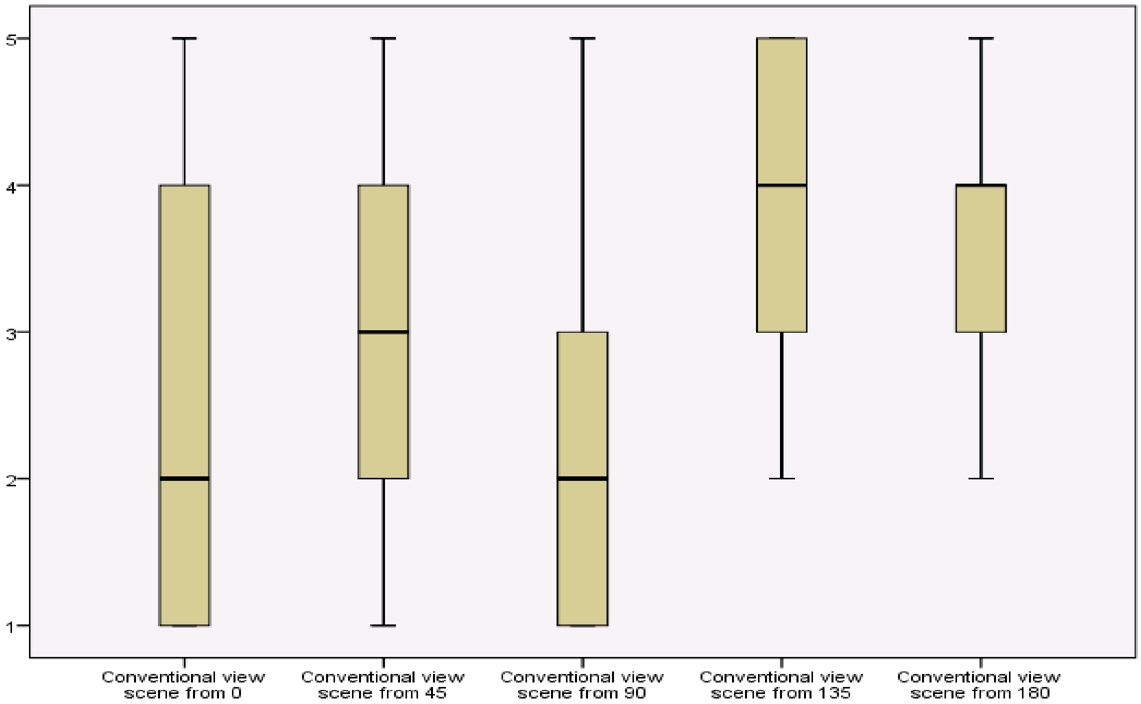


Figure 6-11: Boxplot of the data for z with view angle (n=39)

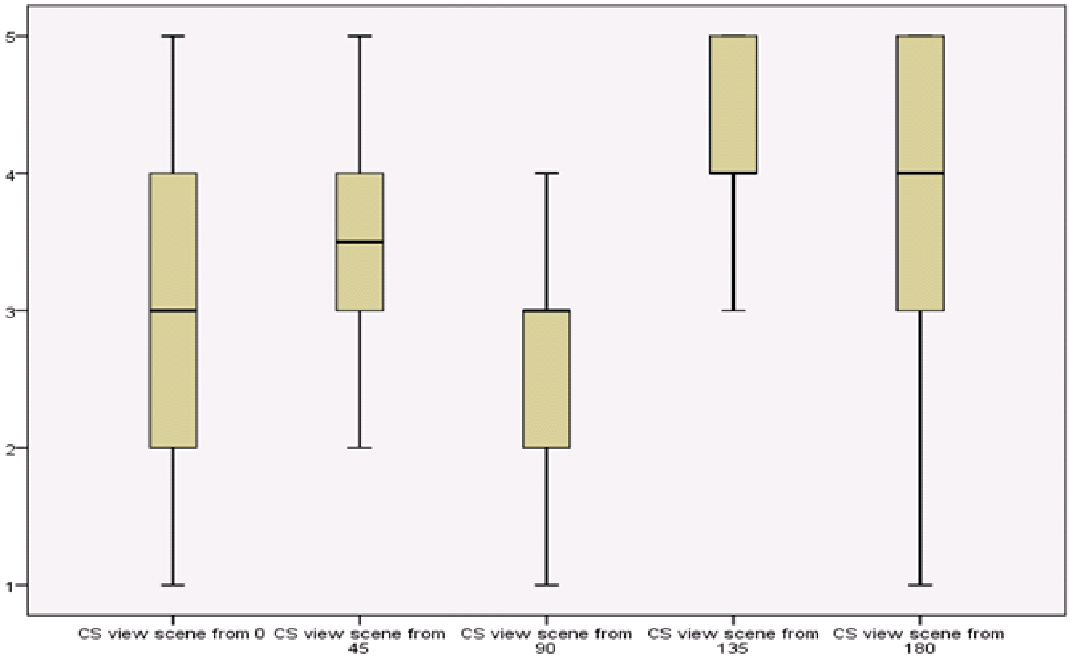


Figure 6-12: Boxplot of the data for CS with view angle (n=39)

Each figure is a clustered boxplot, in which the distribution of all participants' scores for each nominated view angle (variable) is represented by a box and 'whiskers' (protruding lines). The whiskers define the minimum and maximum value of the scores, while the length of the box contains the score of 50% of cases and represents each variable's interquartile range. The median is displayed as a line across the inside of the box.The figures indicate that the distribution of scores on the 3D effect perceived from a different view angle is different in both the Z and CS colouring system and this suggests that the best 3D was perceived from view angles of between 135 and 180 degrees. Also, Figure 6-13 indicates a higher score (better 3D) was achieved in the CS system.

To assess the significance of these differences between Z and CS colouring, two-factor within-groups analysis of variance (ANOVA) statistical test was conducted. Table 6-3 summarises the test factors. The test investigates the relationship between different angles, and effects of the colour scheme on each angle. The scientific hypothesis is CS enhances 3D perception from different view angles. The null hypothesis is CS makes no difference to 3D effect perceived from view angles.

View Angle (VA)	1 (00)	2 (450)	3 (900)	4 (1350)	5 (1800)
Dependent variable	ZVA0	ZVA45	ZVA90	ZVA135	ZVA180
	CSVA0	CSVA45	CSVA90	CSVA135	CSVA180

Table 6-3: Two-Factor within-groups ANOVA variables

Table 6-4 shows that the ‘view angle’ factor is significant F(1, 29) = 28.880; P = 0.000. Similarly the colour application (Conventional and CS) is a significant factor, F(1,29) = 21.870, P = 0.003. Also, the interaction between view angle and colour application is significant F(1,29); p = 0.003. These factors are significant beyond the 1% level since their p-values are less than 1%.

	F	Sig. (P-value).
View Angle	28.880	0.000
Colour Application (Z vs CS)	10.817	0.003
View Angle * Colour Application	10.310	0.003

Table 6-4: The edited ANOVA summary table for Within-Subjects Effects

The profile plots for the colouring application across the different view angles (Figure 6-13) demonstrate how CS colouring has increased the participants’ ability to perceive 3D better. The advantage of CS was more noticeable in the scenes viewed from ‘VA = 0^{o}’ and ‘VA = 90^{o}’ from which little information were revealed about the shape of the bathymetry.

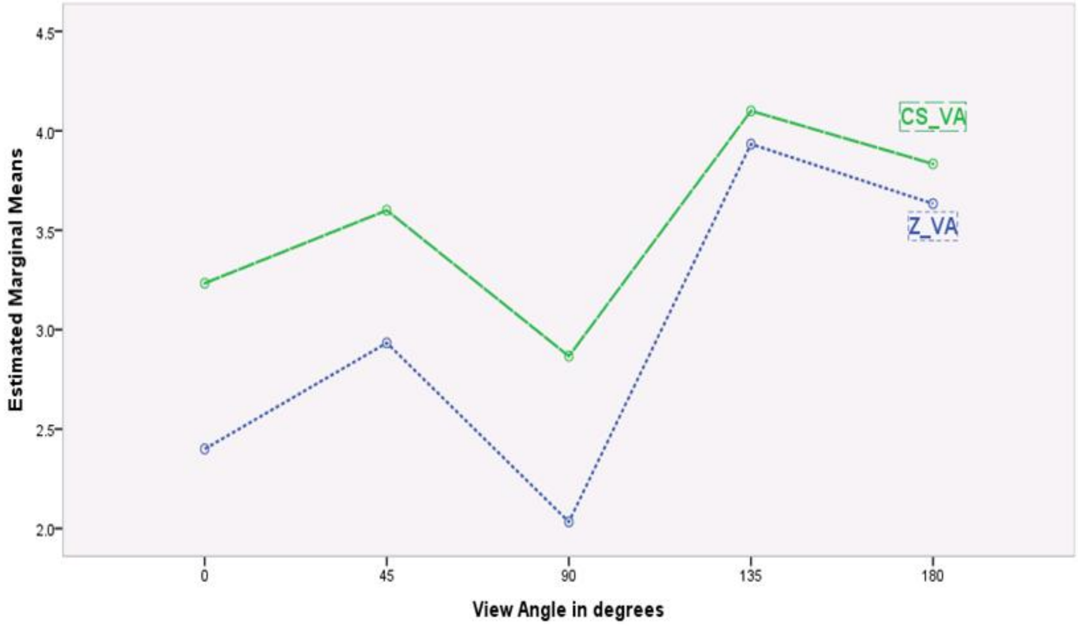


Figure 6-13: The profile plots of the two levels of colouring across the five view angles (n=39)

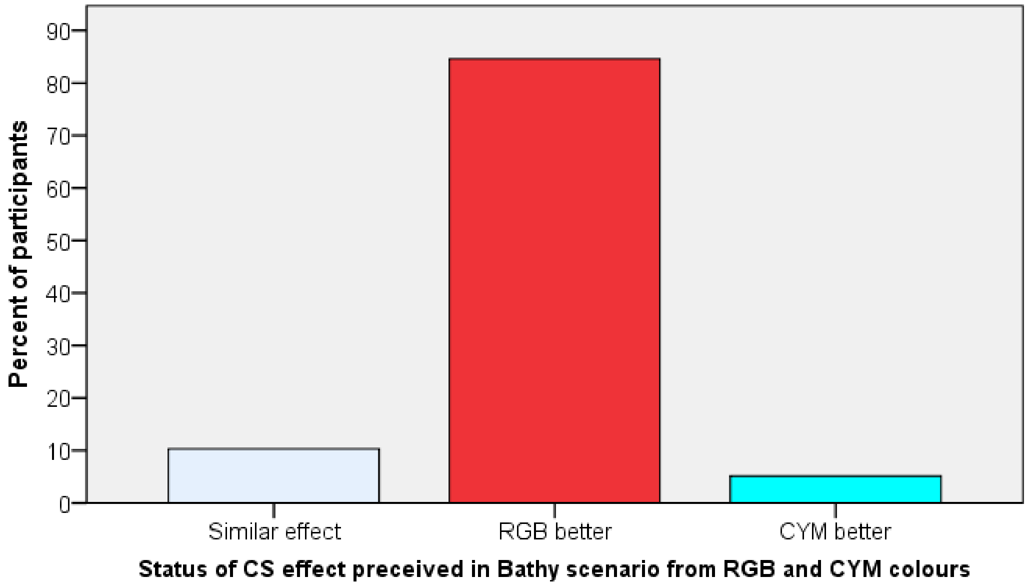
6.4 A comparison between RGB and CYM colour schemes effects

After viewing the scenarios in two different colour schemes, respondents were asked to evaluate which colour scheme provided a better 3D effect. The responses differentiated between the effects according to the scenario. Hence the results for bathymetry and underwater scenarios were presented separately in Figure 6-14. They show that in both scenarios the RGB scheme provided a better 3D effect than CYM.

Apparently, the advantage of 3D perceived from the CYM scheme was more valued in the underwater scenario than in the bathymetry scenario. The percentage of responses which favoured CYM over RGB rose by 15% between the two scenarios. This was explicitly stated by participants for example

> *“Cyan is closer; underwater with CYM is better than RGB one, the depth is slightly heightened over the previous one” (S8).*

Nevertheless, 11% of respondents reported that both RGB and CYM schemes generated an equally effective 3D.



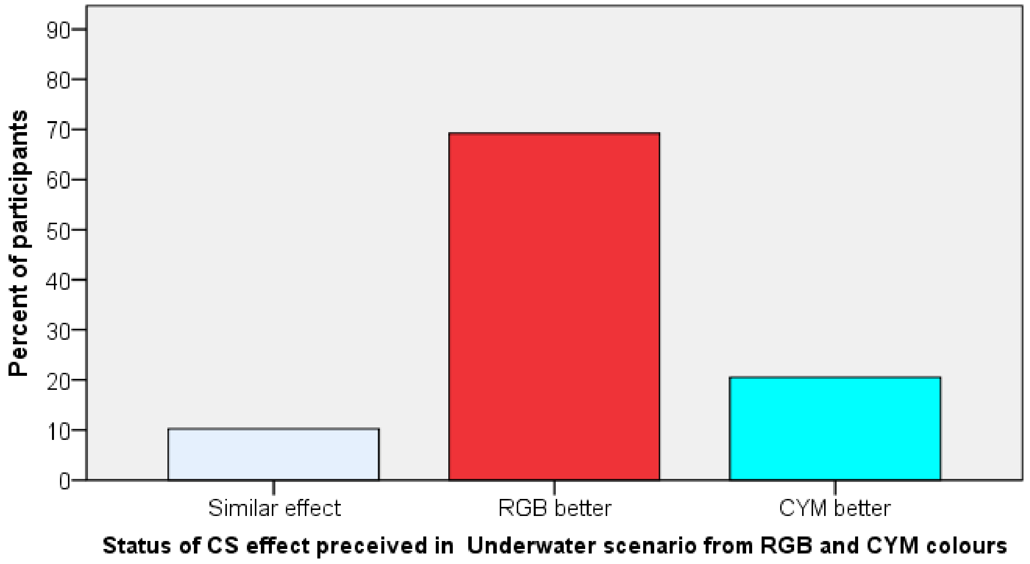


Figure 6-14: Participants evaluation for CS perceived from RGB and CYM colour schemes in bathymetry and underwater scenarios

Referring to the interviewees' comments about the scenarios and their impressions about switching from RGB to CYM, three main points were extracted. The colour scheme has affected the amount of field depth perceived from CS. RGB has more lively colours. The edges of each colour were clearly defined and had good contrast with the black background. On the other hand, CYM used less intensive colours, that did not provide a good range of colours, and with a white background the contrast was not as good as RGB. Nevertheless, it was noted that the respondent who could not see the 3D effect from the RGB scheme found the effect in the CYM scheme by saying

> *“OK that is good, I can definitely see 3D related to colour, cyan is much closer, and the yellow is in the deep background” (N10).*

Some participants preferred the use of CYM over RGB despite stating that they perceived more 3D in the latter. They reasoned this to the difference in intensity of colours in both schemes.

> *“CYM is better than RGB because the colour is friendlier, the RGB is more 3D effect, but less comfortable. CYM is less intense and more relaxing to the eye” (H7).*

6.5 Implication of CS (Change in conventions)

The main challenge of applying CS is the constrained use of colour, which overrides any previous conventions. The scenarios that were used in this research altered two traditional uses of colour. The first is the custom of layering the colour spectrum along the z axis starting with red for the highest value and blue for the lowest value. The second convention is the buoyage colouring system which is more restricting and imposed by international organisations to maintain safe navigation. These conventions are implemented in the design of charts and commonly produced DTMs. Remarks made by participants about these two conventions were summarised and presented in the following themes.

6.5.1 Bathymetry in CS vs Z colouring

In bathymetry: 2D with z scaled according to depth colours are stratified from red for shallow to blue for deep. This convention was well known for most participants either because they used charts and DTMs (Figure 6-5), or from their knowledge about the use of colours to indicate heat distribution in the water; deep water is cold (blue) and shallow water is warm (red). Users with extensive experience of seeing bathymetry coloured along the Z axis, found it more difficult to adjust to a CS colouring scheme and were reluctant to accept and interpret the new colour scheme. Participants were more comfortable to see the conventional display that meets their expectations. Unconventional display needed some time to be accepted.

6.5.2 Buoys convention: The importance of colours and shapes

The importance of navigation conventions (shapes and colours of the buoys) were discussed with all participants. Then, the possibility of dismissing colours from this convention and relying on symbols for identification was examined. The majority of participants stated that colours are the first thing they look at to define the navigation channel and buoys, but not exclusively

> *"I relate more to the colour than the symbol on the top. I think most people are naturally looking at the colour and not even bother with the shape" (S5).*

Colours are more eye-capturing and easier to remember. However, in some real situations such as looking from a distance and sailing "into the sun" colours become less significant and difficult to be recognised. Colour is not the only or the most important indicator for the buoys' meaning. It can be dismissed as long as other indicators were used, and in this research shape was suggested to be the most important descriptor for buoys.

Some participants stated that colours are less important than shapes citing the fact that most buoys are represented in black symbols on a chart and their actual colour is referred to by a letter (Section 3.1.1). After viewing the navigation scenario, the respondents managed to easily distinguish between port and starboard buoys of the channel based on the shapes only. This was certified in this diver's quote

> *"I did not have a problem to guess that is a port and that is starboard channel, because I am used to starboard cone and port can" (S7).*

And they concluded, in concept, shapes can be used to define the navigation channel without the need for colours. This will be possible only if the shapes match the conventions of the Chart 5101 (Myres, 2008), as confirmed by a diver "It has to have a link in to the convention already in use so it is easy to interpret" (D1). This concept was also enforced by another diver by saying

> *"People spend so long time looking at charts and navigating. They subconsciously recognise them as cardinal marks. Just to have cans and cones made like the charts" (D5).*

This was further supported by a navigator:

> *"Colour in navigation always require thinking IALA A and B, and leaving coming port, so you can learn and accept colour change in CS" (N7).*

It was noted that the design of the scenario and having the buoys seen simultaneously made it easier to recognise the channel in-between based on shapes only.

6.6 CS use for marine applications

6.6.1 Aspects of CS usability

In terms of participants' evaluation of the usability of CS, two elements were identified: the 3D effect and the colour coding. The 3D effect provided proximity appreciation through exaggerating the difference in distance between colours. The oblique application of colours in correlation with the perspective view provides a qualitative scale of the distribution of objects within the scene on 'A longitudinal scale' and to understand the details of the scene.

> *"The proximity to the viewer is much easier to see and it brings out a lot of details much more clearly than just having a flat display'' (D7)," Distance is always useful because it puts objects in perspective" (S1).*

The advantage of CS in presenting distance was discussed by 22 participants from different marine backgrounds (Figure 6-15).

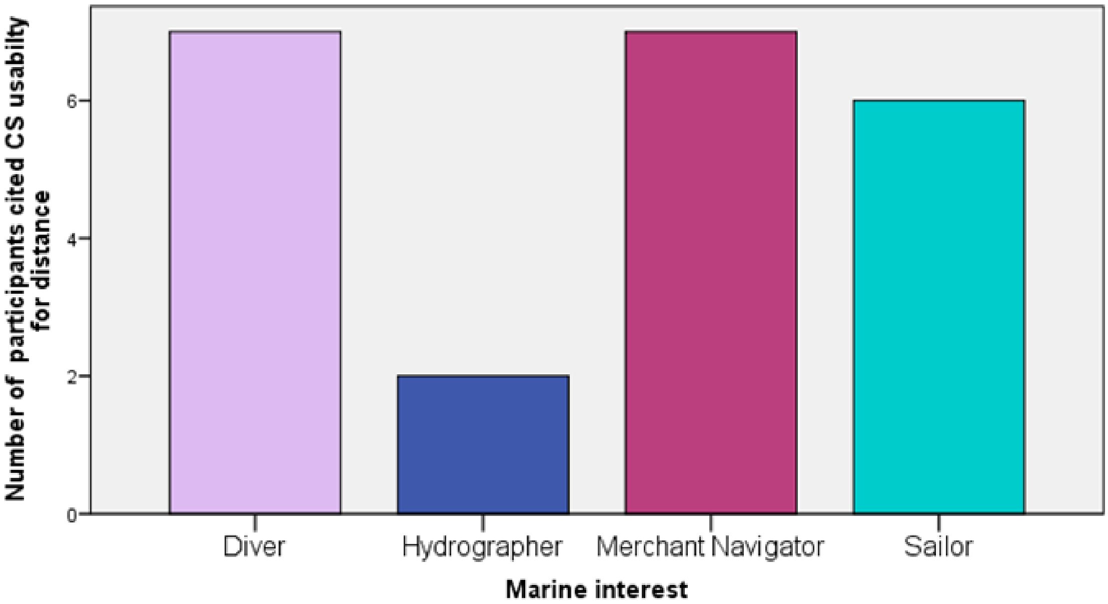


Figure 6-15: Number of participants from each group who linked the usability of CS to the distance perceived (n=22)

Also CS aided understanding the relative positions among objects, and objects and the surrounding environment. Participants evaluated the rotating bathymetry and underwater scenarios. The general response can be summarised by the following quotes,

> *"The most noticeable part for me is that the CS colouring improved my ability to position the boat in the screen" (S2. "[With CS] I had awareness where that boat was, that was definite more than z view" (S7).*

The novel colour coding system of CS was recognised as another useful element. With the first exposure to the concept of CS, the participant's interpreted the 3D effect as a distance then they learnt to associate colours with distance. This information was used to interpret the dynamic situation presented in the navigation scenario as it was described by one of the divers

> *"Because you see the depth perception from the buoys that are constants, while you see the vessel is changing colour in correlation to the buoys, you know that it getting more and more imminent" (D5).*

Applying RGB colours along distance was counted as a useful addition for marine applications *"The colour banding is very useful, instead of the 3D bit" (H7).* This is particularly relevant as CS uses red for close objects and red is a colour associated with danger, and can be used as an additional method for early alarm;

> *"CS having red is near to you, so the closer it gets to you, the more red it gets, the more danger represents" (N9).*

6.6.2 CS for surface navigation

Navigation involves several skills: reading radar, interpreting the critical approach point, reading charts and integrating all this information in a mental image to depict the real world. This task is daunting and so CS can help

> *"It is a lot easier to flash interpret that [CS] instead of flash interpret a radar screen" (D1).*

Navigators stated that the proximity and distance appreciation with CS could be a useful tool for surface navigation in a busy environment. CS may help increasing situation awareness in situations of low visibility and blind navigation. Changing colours could be useful as a quick visual alarm method. This will help the navigators to lessen the amount of effort and aid quick thinking and decision making.

> *"Without processing information too much, you can see which vessel is closest to you, and which one is further in a very busy environment. It facilitates transferring the mental image that we had created from the radar to a physical representation on the screen" (N7).*

Even in the bathymetric display, the proximity perceived from CS is advantageous to understanding the scene and recognising danger.

> *"With CS if you see seamounts and cliffs you can see how far you are away from them, even not necessarily knowing the depth, you can still see that you have to watch them" (S1).*

CS can be a useful additional function for navigation using both the 3D effect and the colour coding. It can increase situation awareness for the mariners in dynamic applications, such as surface navigation. The colour coding on the screen would provide a useful and quick visual alarm to avoid collision. Some merchant navigators suggested that, in conjunction with radar, CS can highlight aspects of vessels, e.g. in which direction they are heading and their speed according to their colours and perceived distances. For instance, if two vessels appeared from a distance, the mariner could identify whether the vessels were approaching his vessel from its colour. If the vessel colour remained in the green-blue band, it is going further away.

> *"This can be by gauging distance and defining the aspects of other vessels by the colour coding, instead of relying only on the relative size. If the colour of the vessel on watch is changing along the colour scheme from blue or yellow toward red or cyan, that means the vessel is approaching and must be watched to define if it may cause a risk" (N7).*

6.6.3 Underwater operation

There was a general agreement between participants that CS would be a very useful addition to underwater operations where resources of information are very limited. The proximity perceived in CS and the 3D effect may help both divers and underwater operators in understanding their position relative to the surrounding environment and avoid risks. *"In isolation, like a submarine it will be a great tool to understand proximity of targets" (N2).* Having distance perception helps to create a clear mental image about the situation underwater where visual acuity can be reduced by the clarity and magnification effect of the water.

> *"I can feel where I am in relation to objects. It will be nice to have it on the screen to look at from time to time whenever 3D is needed in conjunction with other tools" (N2).*

Divers perceived CS as a useful tool for training new divers. It also can be very useful for experienced divers as 'a pre-diving trip' preparation when diving for the first time in completely new areas.

> *"CS would be useful for ROVs when you need to be moving through or you need to have a good idea what is there, or you need to visualise something before you did it a kind of virtual run through" (D8).*

6.7 Further applications

According to the participants CS potentially could be very useful for several tasks. In real time dynamic applications, CS would be beneficial to enhance conducting tasks based on a computer virtual environment like remote piloting of ROVs, and USVs (unmanned surface vehicles). Hence the scene is synthesised on the screen by integrating data from all sources of information, and the effect of altering conventions could be minimal. Also integrating CS with flythrough visualisation can support obstacle avoidance tasks and augment situation awareness. For military contexts, a threat identification target is another area where CS and particularly the colour coding system were suggested to be useful. It can help for rapid targeting. Also the use of colour coding can increase the amount of information displayed on one screen. Several layers of information can be presented on a 2D screen at different depth by colouring them from red to blue according to priority.

CS can be used for cleaning data collected horizontally from terrestrial laser scanning. For training, CS can be used in simulators (navigation and ROV) to augment trainees' experience and understanding and facilitate interpreting radar. It provides a good visualisation effect that could be a valuable tool for marketing.

6.8 Remarks about CS

6.8.1 Factors that influence the design of CS-based application

This section summarises some graphic design features that were identified by the participants as a source of potential influence on CS.

The proximity perception from CS was subject to the range of colours deployed in the scene. A wider range of colours enhanced the ability to estimate distance. Participants cited the example of the rotating bathymetry where in some views only two colours were displayed and compared it to the view from which the whole spectrum of colours was apparent. They declared that the continuity and the smooth transition of colour were essential for the CS perception. *"More range of colours reflects better CS" (S10).* The continuity also strengthens the accuracy of estimating distance between objects. The lack of a clear and smooth transition in colours in the CYM scheme compared to that in the RGB scheme was also one of the reasons why RGB provided better CS.

The type (dots, lines or surface) and the size (small or large) of the objects displayed in CS can potentially affect the 3D perception. Reponses evaluating 3D perceived from scenarios with a surface object (bathy) and the one with small sparse objects like buoys and vessels (navigation scenario) varied. Some participants found CS is very effective when small objects are differently coloured and scattered on a black background (Navigation scenario). This setup provided a distinct contrast between the foreground and the background and improved CS perception. As one of the navigators cited;

> *"When you get a greater contrast of colours, then the depth perception is improved. As the black becomes in the background then you get that greater perception going from light to dark to darker colours" (N6).*

However, seven participants reported a ghosting effect in the navigation scenario. The following quote accurately described the artefact in the scenario and referred to the partial reason of its occurrence

> *"Buoys are so small. It makes it slightly blurry. It is difficult to focus on 3D. I experience displacing and double vision" (D7).*

This double vision is attributed to the way that colours are produced on computers and applied for a small object (Chapter 2). Also, unlike surface objects, scattered objects lacked the connection between perspective and the colour appeared as different blocks that does not allow *"gauging the interpolated feel"* (S2) that actually exists in real life.

6.9 The practicality of CS

Issues related to the Chroma Depth glasses and the practical settings of the task were raised. Users were concerned about the cumbersome nature of the 3D glasses and that they have to be worn to perceive 3D effect. The design of the glasses looks silly and uncomfortable; besides the glasses are not wearable with prescription glasses. As a response to the question of whether the glasses had any negative influence on their eyes (Figure 6-16), 11 participants from all four categories acknowledged feeling tired of using the ChromaDepth over the test period. Among those people five had no sight impairment, two had uncorrected sight impairment, while the rest were correcting their sight by contact lenses and glasses (3 people and 1 person respectively) (Figure 6-17). Such a distribution indicated the absence of any correlation between tiredness and the method of sight correction. This result was confirmed in a Chi-square test (the value was 3.428 with the associated significance level of (p = 0.33 >0.05).

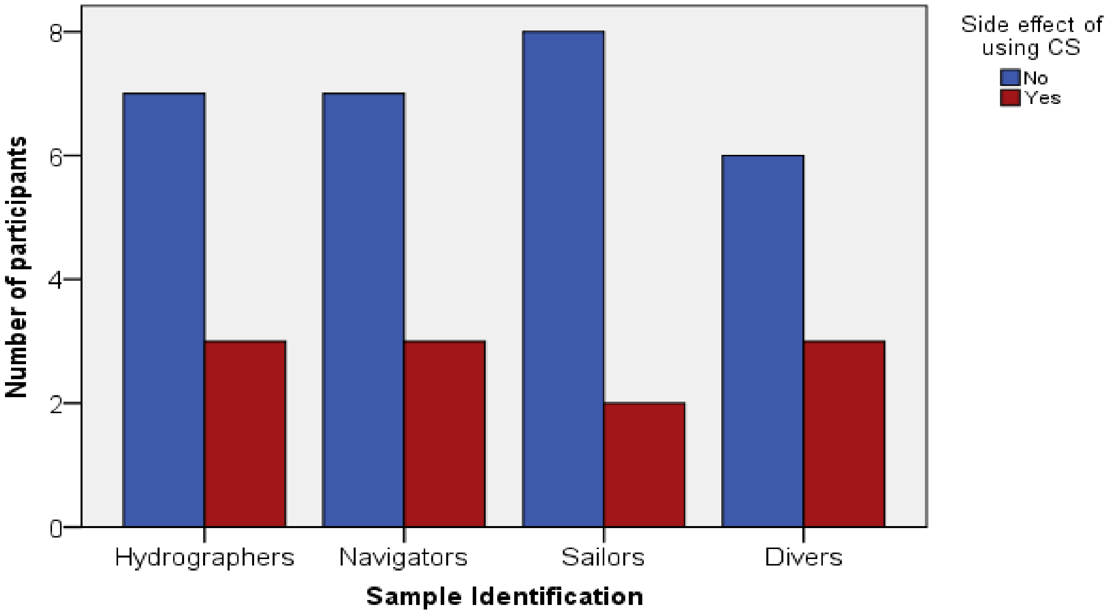


Figure 6-16: Side effect of using ChromaDepth glasses as reported by participants from all categories; yes indicates tiredness

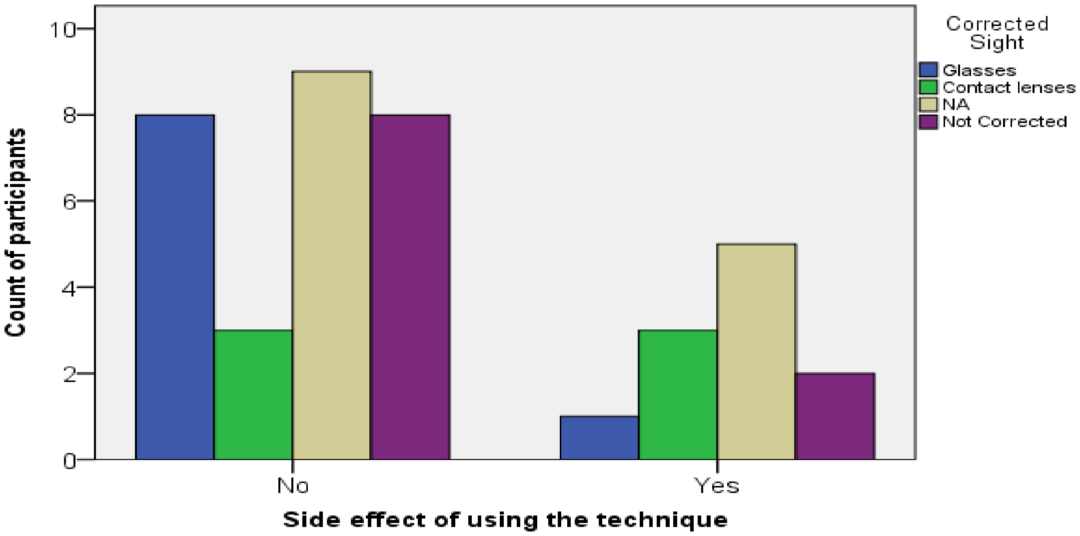


Figure 6-17: A cross linking between the side-effect of wearing the ChromaDepth glasses and the condition of sight corrections of the participants

Also, the setup of each marine operation could influence the use of CS. For instance in navigation, the pilot needs to move between and check different resources of information (window, radar, and chart) so refocusing the eye would be difficult;

> *”From a navigation context: changing the eye focus from the screen to look out the window and the translation between the screen and the real world maybe challenging” (N 2).*

Not being able to wear the glasses permanently while conducting other tasks could be challenging for navigators. And it increases the risk of losing them on the vessel bridge in the dark. However, in ROV operations where limited information is available and the pilot performs the operation from the piloting seat, CS would be more beneficial and applicable.

> *”If you are an ROV operator, you do not have any other source of information so you put on the glasses and concentrate on what is going on” (N3).*

Finally the capability of coping with an additional visualisation screen was suggested as daunting.

6.9.1 Visual power

Concerns about the visual power of CS as an electronic visualisation was a key issue raised by navigators. CS can potentially capture the attention of a navigator with limited experience and become the exclusive source of situation awareness.

> *“The visual side of situation awareness is very powerful” (N5). “The problem is if you show a 26 year old the image on a screen they will believe the screen” (N2).*

Concentrating on a single display and ignoring other resources of situation awareness sources (radar and window watch) can be extremely dangerous for a master. This problem was also raised by navigators when Ternes (2009) proposed a 3D chart for navigation.

6.10 Requirement of implementing CS

An effective application of CS in future software requires the consideration of several elements, including viewing distance, colour production and the size of objects on the screen. Additional factors were raised by participants who suggested the need for a colour scale and the display mode.

6.10.1 Scale

For real time application, it is important to quantify colours. This requires identifying the distance associated with each colour.

"As long a scale is possible to say that red will be 0-1000 ft, and orange from 1000-1500 ft so it is a useful addition" (S1).

This scale should be changeable according to the task. A generic scale could serve for flying something to a more immediate distance, while for a smaller scale task (e.g. lift an inspection hatch cover on a manifold), the colour scale should be redefined. This is possibly applicable for surface navigation. Also the rate of adjusting colours in dynamic situations should match the speed of data update of other sensors, GPS and sonar. *"When you have a visualisation on the board, it must be current" (D1).*

6.10.2 Display mode

The display mode should consider the users' abilities to interpret the difference in the colour application, which may cause an initial confusion. CS can be implemented in future software as a complementary function to the conventional colouring scheme, either by enabling the user to switch between CS and a conventional scheme, or to display them side by side. Figure 6-18 illustrates that 62% of participants found "switching" mode between a conventional and CS display useful, as they complement each other by providing different approaches to understand bathymetry.

> *"Yes it is useful from a navigation point of view, to switch between 2 scenarios on the screen, if you are worried about how deep things are, and how much water you have below you so you go for z, but if you want better appreciation I would switch between them but I would favour CS to visualise what is around me" (N8).*

22% of the respondents suggested that presenting CS and conventional colouring views side by side would be better for assurance purposes and comparing different information. 15% preferred to have only a CS display to benefit from the proximity aspect in navigation. Having one display only helps to avoid any potential of misinterpreting the scene when switching between CS and a standard visualisation.

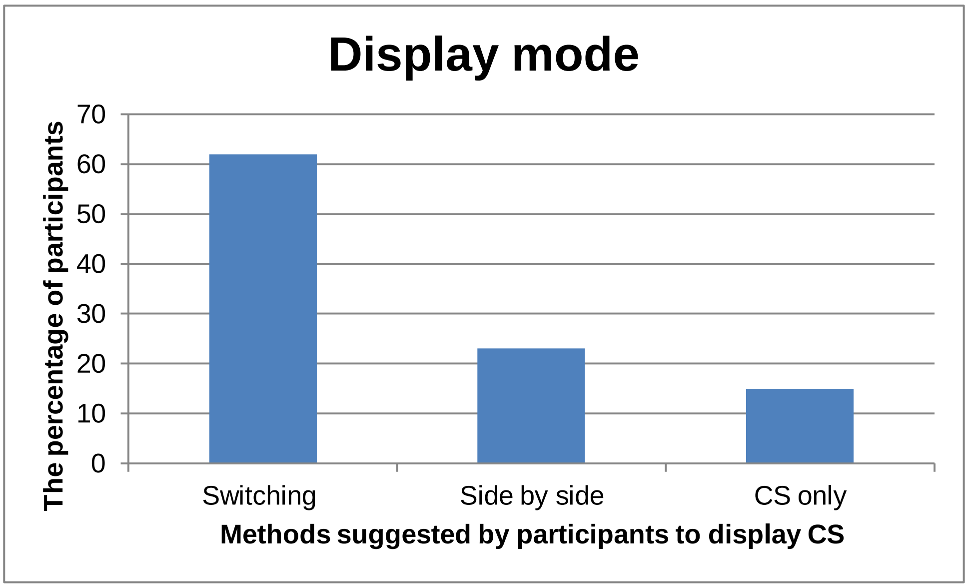


Figure 6-18: Participants' suggestions for the display mode of CS in future software

6.11 Attitude among different groups

It was interesting to see how navigators referred to underwater operators and sailors as the people who need or might be interested in the technology, while the other groups of sailors, divers and hydrographers anticipated that navigators will have trouble to accept CS as they have a strong attitude against change. This attitude was attributed to either the importance of conventions or reluctance to learn new technologies as explained by a diver

> *"A lot of people in marine environment know what they know and that what they want to do. Even for example, for VHF licensee, a lot of people do not do even they are supposed to do. They are stuck in what they do, and they do not care" (D2).*

This was confirmed by navigators themselves. Citing this navigator with 40-years of experience *"My attitude is rather typical of sea farer generally; when new technology comes along we are very sceptical about it" (N5).* For navigators, because of the time they spend learning and mastering navigation skills and devices, they avoid learning new concepts, unless they would add significant advantages for their daily tasks. This was well demonstrated in the response of a few navigators. Some of them stated if a future CS application will be based on radar that they already know how to interpret, CS is not needed.

In contrast, recreational sailors were considered the people who 'love gadgets' and would be more open to changes. Even sailors were perceived by one of the hydrographers, who is involved in technology marketing, as the best customers for new technologies, as they would adopt them even for fun regardless of their practical value.

> *"For the hobby sailing, recreational sailors who love things like this, they would love it. Does not necessarily actually give them any benefits in reality but because it is graphics" (H7).*

Yacht sailors themselves admitted their interest in gadgets and new technologies.

> *"It will be something interesting for a sailor and I would like to have it. As a gadget my dad [an old experienced sailor] will love it. And if it can work alongside radar will be better, and with GPS even better" (S1).*

This attitude toward technology is not based on fun only, but because of its potential practicality. CS would be very useful in blind navigation in fog to provide a quicker sense of distance than relying on the chart.

> *"If you are sailing on your own, it will be an extra pair of eyes, so you can see that the buoys are getting closer. For shipping, it is invaluable" (S4).*

6.12 Getting used to CS and overcoming confusion

The willingness to adopt a new technique relies on the advantages provided, previous experience and personal attitudes toward new technologies. 26% of the participants had previous knowledge of the concept of CS. Some of them were used to seeing the effect on the screen while the knowledge of the rest was limited to the theory. After conducting the test, 90% of the interviewees reported a significant enhancement in perceiving CS *"I see the 3D effect emerging the more I look at it" (S9)* and in interpreting the use of that effect. This in turn helped them to recognise the advantage of CS without the influence of their previous expectations.

> *"When I saw Z first and then CS, it took me a couple of seconds to let my head catch up, and then loading up others [scenarios] was a slower time period to adjust to it. So it became clearer" (S1).*

Participants who did not recognise any enhancement in CS perception stated that the 3D effect was quite good from the start. Whether the previous knowledge of CS helped the participants to understand the effect was tested using contingency tables. Figure (6-19) shows that understanding CS was augmented throughout the test for most participants including those who had previous knowledge of CS. Such a result indicates that with all the consequences of applying CS, training would be helpful even essential to promote its use among potential users. This was also suggested by the participants i.e. to overcome the confusion of changing conventional colours in navigation buoys.

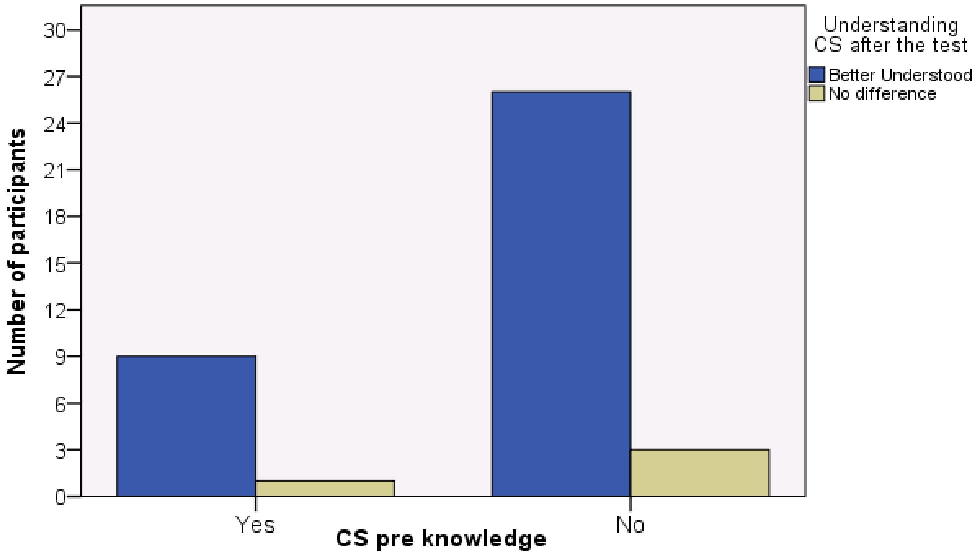


Figure 6-19: The association between participants' pre-knowledge of CS before and after the test

6.13 Chapter summary

This chapter presented the results of interviewing a sample of the users of the marine environment. The users' reaction for this technique were extracted and formed. In light of the research objectives, themes of the benefits of CS in marine operations and its implications to conventions were derived.

Chapter Seven

7 Discussion

7.1 Human factors

The evaluation of CS was a multifaceted process. It involved assessing the visual perception of the participants and their attitude toward adopting CS as an additional visual aid. Perception relies on knowledge, skills, cognition, or the system of symbols for individuals. Barat (2007) acknowledged the complexity of perception saying *"It is a complex process. It begins with sensation, but after that visualization becomes quite individualized. This process is an explicit, multilevel and symbolic work of the mind".*

CS was a novel 3D technique for the majority of the participants. It challenged their previous knowledge and altered the conventions of using colours. Hence the key method to assess the usability of CS is measuring participants' attitude. *"Attitude is an important concept that is often used to understand and predict people's reaction to an object or change and how behaviour can be influenced" (Fishbein & Ajzen, 1975).* The individuality of analysing the scenes was clear throughout the test. The elements which were selected from each scene differed between individuals, even when they inferred similar conclusions.

7.2 CS perception

On first exposure to a CS view, participants reported seeing 3D. The description they gave about the difference in the position of colours being more apparent with glasses was a clear indicator of the CS effect. However, most participants (especially those who were not acquainted with the concept of CS) denied any contribution of colours to the 3D perception. They were convinced that any 3D perception was related to motion parallax or perspective, but not colour. For instance in the navigation scenario, participants thought that the moving vessel looked to be getting closer because it was getting bigger, not because it is changing colour. Since the size of the vessel was fixed by design, the participants were given additional time to see the scenario and to realise the contribution of CS. Once they discovered that the size was the same all the time, they accepted the effect of CS, and reflected on their experience stating that they were relying on their expectations more than their vision.

Previous knowledge and experience were heavily relied on to accept or decline the new concept. For instance, when CS was presented in the RGB scheme, some participants accepted the order of colours from red for nearness to blue for farness because they knew that colour intensity decreases with distance and in paintings cooler colours (i.e. blue) are used to convey distance.

7.3 Conventions and attitudes

Familiarity issues related to previous experience and conventions. In some settings conventions are restrictive and must be obeyed, especially those which are related to safety and become international obligations. Others are related to prolonged use of a colour scheme that has been suggested once and has gained familiarity through usage despite the lack of scientific or logic reasons behind it.

Having professional navigators whose profession is constrained by restricted rules and conventions, and recreational sailors who are using the navigation environment but less restricted to rules, enabled the researcher to test how users will tolerate changes to navigation conventions. Also, it shows how experience and familiarity plus other subjective issues may limit the use of CS.

Adopting a new technology is a subjective and background-related issue. Some users are open to any changes like sailors who love gadgets, while others would prefer to hold to what their original knowledge. Their rational for this is being unwilling to spend additional time to learn new methods of perceived marginal benefit to what they already know.

Although the scenarios and the test were intended to explore the potential application of CS in marine applications, the research revealed that navigators welcome some ideas that facilitate their tasks, and so tried to find the positive points linked to their job. Despite some not being used to 3D DTM bathymetry, they showed interest in seeing both the sea surface and seabed in the same visualisation.

> *“We are changing the way we perceive the world; we are all moving to 3D representation of the world. I think conceptually we accept that we will be more comfortable with it, but this is early days” (N4).*

The changes in predefined characteristics of navigational aids in the visualisation were a controversial issue. Despite being reluctant to accept changes in colour conventions for navigation aids (buoys), recreational navigators found it acceptable to some extent to change colours provided that the symbols kept intact. This restricted use of symbols is attributed to the fact that each symbol represents an object, and any changes in the symbol would indicate different objects

Conventions related to risk avoidance are normally more respected and particularly by those who can be affected with this risk. Buoy conventions are more important for merchant navigators than yacht sailors, being least used by dinghy sailors. The latter normally sail in local areas with which they are familiar and can easily define their position and direction without any visual aids such as charts. They can define the hazardous areas even without knowing the depth, as dinghies float almost on top of the water.

CS is counter intuitive to users, due to the unconventional use of colour. However, it seems that its familiarity can be improved by practice. Within a one hour interview the difference was significant in the participants’ acceptance to this change. Also, even if CS was argued as confusing to visualise bathymetric data for some it was seen as promising e.g. for divers and sailors. The unique element is providing a visual gauge for proximity, which seems of great need for marine operations.

Being based on colours, CS is an appealing technique. Colours are always interesting and attractive to people, can be easily learnt and associated with meanings. They are useful as an alarm system in dynamic busy environments and a situation awareness booster in restricted visibility conditions.

7.3.1 Colour scheme

The purpose of using RGB and CYM colours was merely to provide colour schemes appropriate to IMO requirements. It proved to be useful as an optional choice for people who cannot stand colour of high intensity that in turn disturbs their 3D perception, but found CS of high value for application. It was interesting to find that some participants highlighted the effects of colour intensity on their experience, and the strain it causes on the eye. This point was raised in the earliest stage of the research. A 'printer' in the Summer School of for Cartographers mentioned the intensity of RGB colours may cause discomfort and distraction. Some participants stated they would favour a more comfortable colour scheme to use over an effective 3D. And they reported the intensity of these colours CYM is more relaxing to their eyes. As a result CYM could be a good alternative for RGB, even if it was not used for night conditions, but as a personal preference. Some people find it more appealing with an acceptable 3D effect.

> *"I prefer the night time colours ok, that is interesting , in my GPS car I have day and night colours and I do prefer the night mode even in day time, so I think this something to do with my eyes" (N10).*

Such behaviour would not be exclusive to CS only, but is a part of human practice. The observers admitted that they tend to use what suits them in terms of familiarity and ease instead of following the regulations and guidance.

> *"We do preserve the natural vision, by changing the colour scheme to CYM, but in practice no one do that, we only deem the light" (N7).*

7.4 Observations

Users were more comfortable to see conventional Z colouring bathymetry than CS one. Interesting observations were noted when the participants were shown the conventional colour scheme followed by the CS scheme. Most of them tended to tilt their heads 90o left then right, trying to restore the original colour application and comprehend the scheme. Also, they tried to reach the screen with their hands to gauge the apparent 3D effect. Interestingly, their fingers never touched the physical screen, but were left hanging in the air at different distances from it. This was a good indicator that CS was actually sensed by the participants at different levels.

The diversity of applications of CS suggested by participants reflected their interest in the technique and its potential use in their fields. Some of these applications have already been implemented in previous research. For instance a proposal to colour code different layers on the radar screen for different types of data and coding objects according to risk or the current situation conforms to Wallisch et al (2001) application of CS for prioritizing importance. Hence, integrating these functions into software could produce an effective and useful system.

7.5 Scenario evaluation

An indirect evaluation of the scenarios affectivity was possible. The participants' description of the scenarios was sufficiently close to the design idea. That mitigated the researcher's initial concerns about the simplicity of the visualisations, in comparison to readily available commercial ones (which might have undermined the evaluation process). In general the scenarios successfully delivered the purposes of their design. Nevertheless, fixing some design problems such as clipping, enlarging the size of the scene, and using more sophisticated imagery could reduce the time needed to understand the scene and focus the attention on CS.

The absence of scale and legends made it difficult for some observers to comprehend the meaning of colours. These cartographic elements were considered in the prototyping process, however they were intentionally removed. This approach has two advantages;

a) It reduced the cognitive load on the screen and focused the participants' attention on the application only by seeing the scenario itself and not distracted by legends

b) It also allowed the users to freely interpret the view and the colours on the screen.

Creating a visualisation is a sensitive task. It requires considering the effects of any elements in the design on the observer's understanding. The human brain uses all elements in a visualisation as cues to maximise understanding the scene. The concept of CS was a completely new technique for most of the participants, and it was definitely a novel application for navigation. Hence they tried to find some cues to assist them to assess the new visualisation. For instance, in the navigation scenario, the existence of a set of two lateral buoys coloured according to distance served as a reference for how distant the approaching vessel was.

Running the test within Matlab environment and not using the readily made videos proved to be advantageous during data collection. This allowed the researcher to change some elements in the scenarios, e.g. to eliminate the participants' doubts about whether the depth perceived was a result of CS or other depth cues. For instance, removing the buoys in the navigation scenario demonstrated that neither the constant colour coding of the buoys nor a change of the vessel size was responsible for depth perception but CS.

Also, it seems that participants from different backgrounds have different preferences and perceptions. On viewing the navigation scenario bathymetry was considered to be redundant, even confusing for some merchant navigators, because in deep seas the closest point to the vessel could be thousands of metres below the vessel. Other merchant navigators found it a useful progress in visualisation to be able to see both surface objects and the seabed simultaneously. For remote sensing scientists, bathymetry was important for understanding the context of the scene. For sailors, both sea surface objects and the bathymetry are needed to be represented in CS colouring, to provide better spatial awareness.

7.6 Remarks about results

Despite all the psychological influences in the process and conservative attitude, CS was demonstrated as being promising as both an additional and a complementary function for visualisation software. There is a need for a 3D element to enhance users' perceptions in the dynamic environment. The combination of the colour effect with a perspective view is beneficial to lessen the cognitive load and accelerate decision making. In an operational situation, where situation awareness is important, CS would provide a useful tool to reconstruct the surrounding scene in conjunction with radar that would be useful for blind navigation, diving and underwater operations.

The validity of the qualitative research was assessed through consistency checks and stakeholder checks. These are common methods to test the validity of research (Patton, 2002). For a consistency check, a coding list was created for a sample of raw interviews, and all interviews were reduced according to the coding criteria. After a period of time, the researcher re-coded the raw data independently. The comparison between the two coding systems showed minor difference. This proves consistency. For stakeholder checks, the interpretation and explanations extracted from the raw data was checked by the participants who produced it. The participants were asked to evaluate whether the summary of their answers reflected their experience and that was approved.

Chapter Eight

8 Conclusions and future work

The marine environment is a dynamic, three dimensional one. A review of the literature reveals that methods to produce a 3D effect have been extensively studied and marine data have benefited from some of it among which is Chromo-Stereoscopy (CS). On the other hand the literature shows an increasing interest in using CS to present geospatial data. However that it overrides the conventional colouring system in any cartographic visualisation was a well-known drawback of this technique. The power of conventions in cartographic designs is well established; hence it was essential to investigate the users' attitudes toward changes in conventions alongside the potential application of this 3D technique.

In order to investigate the human factors of interacting with changes in cartographic conventions and to explore the application of CS as an affordable 3D technique in the dynamic marine environment, visual stimuli were created and user groups were sampled. The stimuli reflect scenarios of dynamic operations at sea including surface navigation and underwater operations. They also present cases of interaction between CS and other traditional depth cues including shading and perspective view. The user sample was selected from the marine domain and represents different activities and different levels of experience.

The interview process successfully captured the impact of human and cartographic factors on CS, and the result highlighted the difficulty of this assessment due to the complexity of visual perception and the diversity of people's attitudes.

- The objectives proposed in this thesis were successfully achieved and the main conclusions are:
- CS coupled with perspective view can be a promising addition to marine visualisation methods. It has the potential to support navigation and underwater operations. In dynamic presentations,

the 3D effect enhances understanding the 3D nature of the operations and clarifies the relative positions and distances between moving objects. Changing the colour of moving objects relative to a fixed point could act as a useful visual alarm, and highlight the aspect of the moving objects; whether it is moving towards or further away from the reference point.

- Conventions are important for visualisations and variations could cause confusion. This confusion can be mitigated by training and practice. Also, conventions vary in importance. In situations where different visual indicators represent the same element, colours could be the least important factor and so changed as long as other indicators, such as shape, are kept.
- The 3D effect coupled with the proximity and relative position perception obtained from CS is very useful, and in comparison changing colours can be trivial and overlooked.

CS was used with other depth cues to augment the 3D perception. This helped to partly solve the visual ambiguity where some features were obscured behind others in the perceptive view of people are trying to grasp a spatial situation.

8.1 Future Work

Observations and statements collected from the research participants and contacts made through different conferences and workshop indicated that there is a real interest in CS. Maritime users acknowledged the usability of CS in an industrial context and are looking forward to use in real-time dynamic visualisation. Hence future work should focus on integrating CS into functional software where real-time data can be streamed from forward looking sonar, high precision real-time GPS and radar. A future test should be conducted in a navigation simulator or at sea in a more realistic setting and operational environment.

Appendices

1. Invitation letter to participants
2. A copy of questionnaire used in the study
3. Research variables and data
    - SPSS variables code book
    - Summary of general information about participants
    - Summary of participants' visualisation experience
    - Evaluation of 3D perceived from CS
    - Summary of the interaction between CS and the view angle

8.2 Invitation letter to participants

Dear Participant,

I would like to invite you to participate in a research project that I am undertaking for my PhD. My name is Iman Abdel Hamid, and I am being supervised by Dr Victor Abbott, Dr Samantha Lavender and Dr Kenneth Kingston, who are academic staff at the School of Marine Sciences and Engineering, University of Plymouth.

I am doing a research on the usefulness of 3D Chromo-Stereoscopy to visualise data in Marine Environment. The aim for my current study is to assess users' perception and acceptance for the consequences of applying this technique, which would be used further in my research.

I am looking for volunteers of different marine experiences Academic, industrial and recreational, for example (divers, navigators/ recreational sailors, fishermen, hydrographers, and underwater operators) to interview them. The interview should last approximately one hour. During the interview you will view different scenarios using 3D glasses. You may, of course, withdraw from the study at any time. All of the information revealed in this interview will be strictly confidential.

If you are interested to know more about the studies, please do not hesitate to contact me through my email at: iman.abdelhamid@plymouth.ac.uk.

Some refreshments tea/ coffee and biscuit will be provided

Thank you very much for your time and cooperation.

Iman Abdel Hamid

PhD candidate

8.3 Interviews Questions

Study on the Usefulness of Chromo Stereoscopic 3D Technique in Visualising Hydrographic Data

Thank you for agreeing to help in this research. There are no right or wrong answers, but any comment will be helpful and all your data are anonymous and confidential.

The research is built on previous work undertaken between 2002 and 2005, where the potential benefits of using the natural response to colour to aid 3D viewing in the marine environment was established. The work I have undertaken is to semi-automate the system by developing scripts in the software package, Matlab. Although not to a commercial operating standard, I hope to ascertain the views of a specific user group on the advantages of 3D viewing using colour in a more mature Chromo-stereoscopic (CS) system.

Survey's goals: Obtain subjects' opinions about CS depth effect and to examine the wider potential of CS to other hydrographic applications, ROV operators, mariners, and others as may be identified.

There are three elements to the testing process:

- To establish the volunteer's ability to distinguish 3D imagery using CS and whether the colour scaling needs to be positive or negative
- To gather opinions on the contribution of this 3D technique to the suite of navigation aids
- To establish whether there are other applications of this technique where such a 3D aid can help understanding

NOTE: Participants need to wear the 3D glasses when they are running the test and looking at the screen

First I would like to ask you few questions about you

1. What is your gender? ☐ Male ☐ Female
2. Do you have any type of sight impairment?

   ☐ No ☐ Yes ☐ Do not want to answer

3. If yes choose one of the options

   ☐ Colour blindness what type: …..

   ☐ Long sighted ☐ Short sighted ☐ Others

   If others: please specify: ……………………………………………………………

4. During the test are you correcting your natural vision?

   ☐ No ☐ Yes

5. if yes, are you wearing ☐ Glasses ☐ Contact lenses

About your occupation

6. Do you have experience in marine industry?

……………………………………………………………………………………

Which part of the industry?

………………………………………………………………………………………

7. What is your work; what does it involve?

………………………………………………………………………………………

How many years of experience you have?

………………………………………………………………………………………

About 3D

8. Have you watched any movie with 3D glasses? ☐ No ☐ Yes

If yes, approximately, how many?

9. Are you familiar with a 3D technique known as Chromo-Stereoscopy?

☐ No ☐ Yes

10. If yes, where did you hear about it?

………………………………………………………………………………………

After viewing the short clip of a spider and a fish with ChromaDepth 3D glasses,

11. Please describe your 3D perception

………………………………………………………………………………………

12. Can you see any difference in the position of colours on the screen

☐ No ☐ Yes ☐ Not sure

13. Which colour, if any, appears closer?

☐ Red ☐ Blue ☐ Neither

CS/ Z colour Rotating bathy: this scenario includes bathymetric data with one vessel; the view is rotating 360 degree about Z-axis, with 1 degree steps.

14. Describe what you are seeing on the screen

………………………………………………………………………………………

15. Tick the appropriate box (you can tick more than one

The bathymetry and the vessel in the same level on the screen ☐

The bathymetry and the vessel appear at different levels ☐

View Angle Z: Five images taken from 5 distinct viewing angles

16. Rate the 3D quality of each image from 1 – 5

		No 3D effect			Very good 3D	
Image one view angle	0^{o}	1	2	3	4	5

Image two view angle	45°	1	2	3	4	5
Image three view angle	90°	1	2	3	4	5
Image four view angle	135°	1	2	3	4	5
Image five view angle	180°	1	2	3	4	5

View Angle CS: Five images taken from 5 distinct viewing angles

17. Rate the 3D quality of each image from 1 – 5

		No 3D effect				Very good 3D
Image one view angle	0 °	1	2	3	4	5
Image two view angle	45°	1	2	3	4	5
Image three view angle	90°	1	2	3	4	5
Image four view angle	135°	1	2	3	4	5
Image five view angle	180°	1	2	3	4	5

Change the colouring scheme, using the drop down menu, from RGB to CYM

18. Can you see any difference in the position of colours on the screen

☐ No ☐ Yes ☐ Not sure

19. Which colour, if any, appears closer?

☐ Cyan ☐ Yellow ☐ Neither

20. Can you perceive any 3D effect?

☐ No ☐ Yes ☐ Not sure

21. Which of the colour schemes provide better 3D

☐ RGB ☐ CYM ☐ Neither

Check the light effect box and rerun the scenario.

22. When the view is illuminated, describe how this affects your understanding of the view?

………………………………………………………………………………………

23. If your answer for Q. 16 was yes, does the light influence colours perceived from previous views

☐ Enhance ☐ Degrade ☐ Other

24. Please describe your observation

………………………………………………………………………………………

25. After running this scenario, how do you describe the effects of changing the colour and using the glasses?

………………………………………………………………………………………

26. Do you have any suggestions to enhance this scenario?

………………………………………………………………………………………

Navigation1Scenario: represents a bathymetry of navigation channel, marked with buoys, and a vessel navigating towards you. Describe what you are seeing on the screen

………………………………………………………………………………………

27. Is there any difference in the position of colours on the screen
☐ No ☐ Yes ☐ Not sure
28. Which colour, if any, appears closer?
☐ Red ☐ Blue ☐ Neither
29. Can you perceive any 3D effect?
☐ No ☐ Yes ☐ Not sure
30. If yes, is there any additional value of using this effect to understand the position of the vessel?

………………………………………………………………………………………

31. Which of the colour schemes provide better 3D
☐ RGB ☐ CYM ☐ Neither

Tick the 'light effect' box and rerun the scenario

32. When the view is illuminated, describe how this affects, if it does, your understanding of the view?

………………………………………………………………………………………

33. Do you have any suggestions to enhance this scenario?

………………………………………………………………………………………

34. Does CS aid you to highlight the potential hazard of the passing vessel? Please explain

………………………………………………………………………………………

35. Navigation buoys are mainly represented by symbols and colours. Does the change in the shape of the navigation buoys affect your understanding of what they represent?

………………………………………………………………………………………

36. Do you mainly rely on the colours of buoys to recognize the safe navigation area?

………………………………………………………………………………………

37. What are the consequences of changing the colour convention of the buoys?

………………………………………………………………………………………

Navigation 2 Scenario: represents a bathymetry of navigation channel marked with buoys, and a vessel navigating towards you.

38. Run this scenario and compare its visualisation to that from navigation1, which one, if any, gives clearer presentation for navigation, and why?

………………………………………………………………………………………

Underwater Scenario: shows a view from a Remotely Operated Vehicle (ROV) inspecting a pipeline extending between two manifolds

39. Describe what you are seeing on the screen:

…………………………………………………………………………………

40. Change the colouring scheme from the drop down menu from RGB to CYM. Can you perceive any 3D effect?

☐ No ☐ Yes ☐ Not sure

41. Which colouring scheme is more effective ☐ RGB ☐ CYM

42. Tick the ‘light effect’ box and rerun the scenario. When the view is illuminated, how does this affect 3D perception?

☐ Enhance ☐ Degrade ☐ Other

Please describe your observation

…………………………………………………………………………………

43. Describe the effect of using the glasses on your understanding of the surrounding environment of an ROV on the move

…………………………………………………………………………………

44. Do you have any suggestions to enhance this scenario?

………………………………………………………………………………..

45. How do you feel after wearing the glasses for a period of time?

…………………………………………………………………………………

46. Do you find the 3D effect of CS become clearer throughout the test

☐No ☐ Yes ☐ Not sure

47. Which colour, if any, appears closer? Tick only one box for CYM, and one box for RGB

☐ Cyan ☐ Yellow ☐ Neither

☐ Red ☐ Blue ☐ Neither

48. How effective were the scenarios in showing the potential applications, if any, of a 3D effect by CS for hydrographic applications? Select one number.

	Not effective			Very effective	
Scenario 1:	1	2	3	4	5
Scenario 2:	1	2	3	4	5
Scenario 3:	1	2	3	4	5

49. From your experience, do you think that 3D CS has the potential to be usefully adopted as an additional visualising system on the bridge of a vessel? Give reasons for your answer

…..……………………………………………………………………………

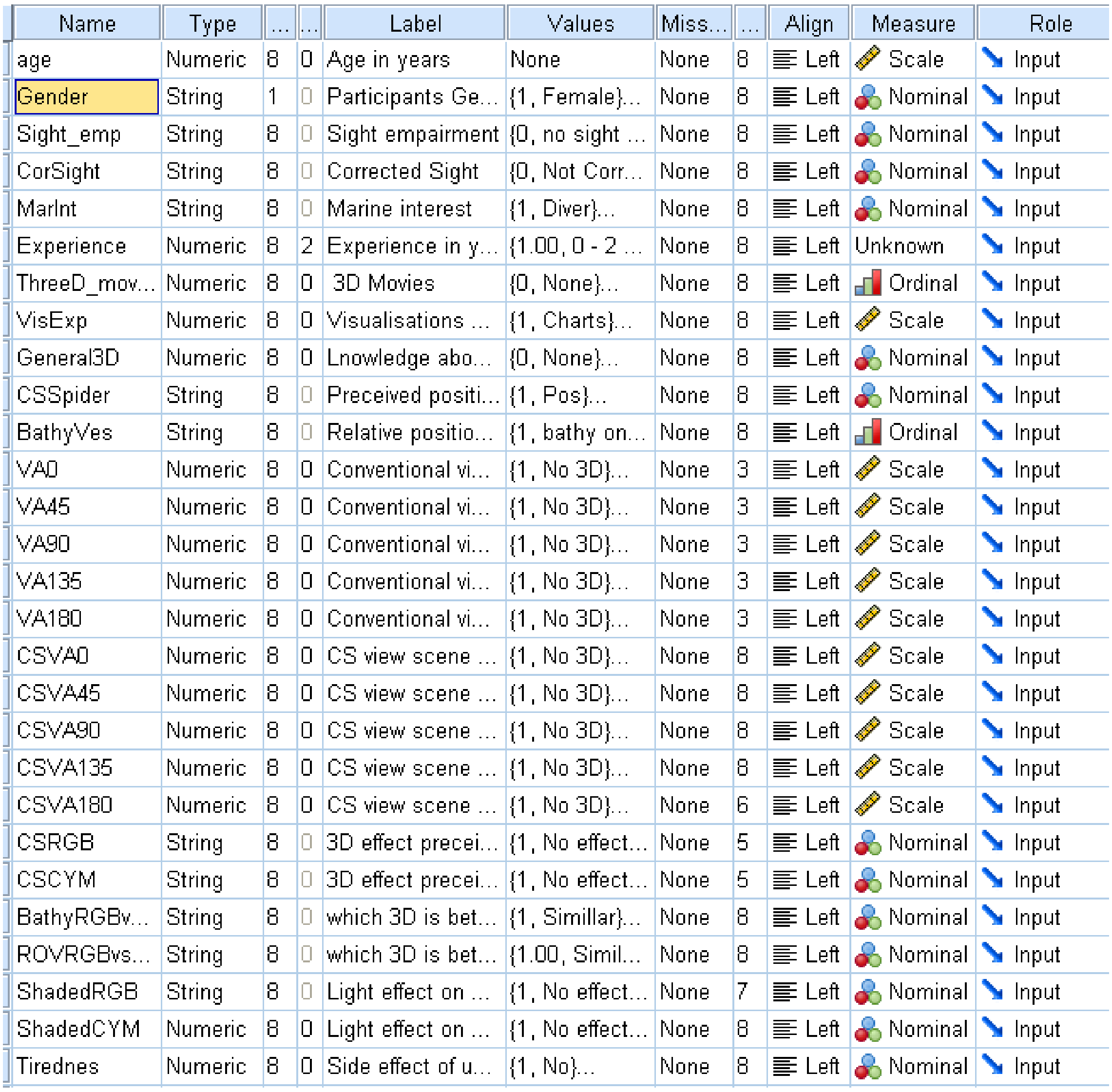
50. Could you think of further applications of CS in the marine environment?

…………………………………………………………………………………

Many thanks for your time and your contribution to this research.

8.4 Research variables and data

8.4.1 SPSS code book



Name	Type	…	…	Label	Values	Miss…	…	Align	Measure	Role
age	Numeric	8	0	Age in years	None	None	8	Left	Scale	Input
Gender	String	1	0	Participants Ge…	{1, Female}…	None	8	Left	Nominal	Input
Sight_emp	String	8	0	Sight empairment	{0, no sight …	None	8	Left	Nominal	Input
CorSight	String	8	0	Corrected Sight	{0, Not Corr…	None	8	Left	Nominal	Input
MarInt	String	8	0	Marine interest	{1, Diver}…	None	8	Left	Nominal	Input
Experience	Numeric	8	2	Experience in y…	{1.00, 0 - 2 …	None	8	Left	Unknown	Input
ThreeD_mov…	Numeric	8	0	3D Movies	{0, None}…	None	8	Left	Ordinal	Input
VisExp	Numeric	8	0	Visualisations …	{1, Charts}…	None	8	Left	Scale	Input
General3D	Numeric	8	0	Lnowledge abo…	{0, None}…	None	8	Left	Nominal	Input
CSSpider	String	8	0	Preceived positi…	{1, Pos}…	None	8	Left	Nominal	Input
BathyVes	String	8	0	Relative positio…	{1, bathy on…	None	8	Left	Ordinal	Input
VA0	Numeric	8	0	Conventional vi…	{1, No 3D}…	None	3	Left	Scale	Input
VA45	Numeric	8	0	Conventional vi…	{1, No 3D}…	None	3	Left	Scale	Input
VA90	Numeric	8	0	Conventional vi…	{1, No 3D}…	None	3	Left	Scale	Input
VA135	Numeric	8	0	Conventional vi…	{1, No 3D}…	None	3	Left	Scale	Input
VA180	Numeric	8	0	Conventional vi…	{1, No 3D}…	None	3	Left	Scale	Input
CSVA0	Numeric	8	0	CS view scene …	{1, No 3D}…	None	8	Left	Scale	Input
CSVA45	Numeric	8	0	CS view scene …	{1, No 3D}…	None	8	Left	Scale	Input
CSVA90	Numeric	8	0	CS view scene …	{1, No 3D}…	None	8	Left	Scale	Input
CSVA135	Numeric	8	0	CS view scene …	{1, No 3D}…	None	8	Left	Scale	Input
CSVA180	Numeric	8	0	CS view scene …	{1, No 3D}…	None	6	Left	Scale	Input
CSRGB	String	8	0	3D effect precei…	{1, No effect…	None	5	Left	Nominal	Input
CSCYM	String	8	0	3D effect precei…	{1, No effect…	None	5	Left	Nominal	Input
BathyRGBv…	String	8	0	which 3D is bet…	{1, Simillar}…	None	8	Left	Nominal	Input
ROVRGBvs…	String	8	0	which 3D is bet…	{1.00, Simil…	None	8	Left	Nominal	Input
ShadedRGB	String	8	0	Light effect on …	{1, No effect…	None	7	Left	Nominal	Input
ShadedCYM	Numeric	8	0	Light effect on …	{1, No effect…	None	8	Left	Nominal	Input
Tirednes	Numeric	8	0	Side effect of u…	{1, No}…	None	8	Left	Nominal	Input

8.4.2 Summary of general information about participants

Sample Identification			articipants’ Gender	Sight impairment	Corrected sight	Marine interest	xperience in years
Hydrographers	1		Female	None	NA	Hydrographer	6-10 years
	2		Male	Short Sighted	Glasses	Hydrographer	3 - 5 years
	3		Male	None	NA	Hydrographer	6-10 years
	4		Male	None	NA	Hydrographer	>10 years
	5		Male	None	NA	Hydrographer	6-10 years
	6		Male	Long Sighted	Glasses	Hydrographer	6-10 years
	7		Male	Short Sighted	Glasses	Hydrographer	>10 years
	8		Male	None	NA	Hydrographer	6-10 years
	9		Female	Long Sighted	Not Corrected	Hydrographer	0 - 2 years
	10		Female	Short Sighted	Glasses	Hydrographer	0 - 2 years
	Total	N	10	10	10	10	10
Navigators	1		Male	None	NA	Merchant Navigator	>10 years
	2		Male	Colour Blind	Glasses	Merchant Navigator	3 - 5 years
	3		Male	Short Sighted	Not Corrected	Merchant Navigator	0 - 2 years
	4		Male	Lazy Eye	Not Corrected	Merchant Navigator	6-10 years
	5		Male	Short Sighted	Glasses	Merchant Navigator	>10 years
	6		Male	Long Sighted	Not Corrected	Merchant Navigator	>10 years
	7		Male	Long Sighted	Glasses	Merchant Navigator	>10 years
	8		Male	None	NA	Merchant Navigator	>10 years
	9		Male	None	NA	Merchant Navigator	>10 years
	10		Male	Short Sighted	Not Corrected	Merchant Navigator	>10 years
	Total	N	10	10	10	10	10
Sailor	1		Female	Short Sighted	Not Corrected	Recreational Navigator	>10 years
	2		Male	Short Sighted	Contact Lenses	Recreational Navigator	6-10 years
	3		Male	Short Sighted	Contact Lenses	Recreational Navigator	6-10 years
	4		Male	Lazy Eye	Not Corrected	Recreational Navigator	>10 years
	5		Female	Long Sighted	Not Corrected	Sailor	6-10 years
	6		Male	Short Sighted	Contact Lenses	Recreational Navigator	>10 years
	7		Male	None	NA	Sailor	>10 years
	8		Male	Short Sighted	Glasses	Sailor	0 - 2 years
	9		Female	None	NA	Sailor	6-10 years
	10		Female	Short Sighted	Contact Lenses	Sailor	6-10 years
	Total	N	10	10	10	10	10
Diver	1		Female	Short Sighted	Contact Lenses	Diver	>10 years
	2		Female	None	NA	Diver	0 - 2 years
	3		Female	None	NA	Diver	>10 years
	4		Male	Short Sighted	Not Corrected	Diver	>10 years
	5		Male	Short Sighted	Glasses	Diver	>10 years
	6		Male	Short Sighted	Contact Lenses	Diver	6-10 years
	7		Female	None	NA	Diver	>10 years
	8		Male	Lazy Eye	NA	Diver	>10 years
	9		Male	None	NA	Diver	3 - 5 years
	Total	N	9	9	9	9	9
Total	N		39	39	39	39	39

8.4.3 Summary of participants' visualisation experience

Sample Identification		Visualisations Used	3D Movies	Knowledge about 3D Techniques	S Pre- Knowledge
Hydrographers	1	Chart & DTM	None	None	yes
	2	Chart & DTM	<=3	Polarized	no
	3	Chart & DTM	None	None	no
	4	Charts	<=3	Polarized	no
	5	Charts	<=3	Polarized	no
	6	Chart & DTM	<=3	Polarized	yes
	7	Charts	None	Anag & Polar	no
	8	none	<=3	Anag, Polar	yes
	9	DTM	>3	Polarized	no
	10	DTM	<=3	Polarized	yes
Navigators	1	Charts	>3	Polarized	no
	2	Chart & DTM	>3	Polarized	no
	3	Charts	<=3	Anaglyph	yes
	4	Charts	<=3	Polarized	yes
	5	Charts	>3	Polarized	yes
	6	Charts	<=3	Polarized	no
	7	Charts	<=3	Polarized	no
	8	Charts	>3	Polarized	no
	9	Chart & DTM	<=3	Polarized	no
	1 0	Charts	<=3	Anag & Polar	no
Sailor	1	Chart & DTM	>3	Anag & Polar	no
	2	Charts	<=3	Anag & Polar	no
	3	Charts	<=3	Polarized	no
	4	Charts	<=3	Anag & Polar	no
	5	Charts	<=3	Anaglyph	no
	6	Chart & DTM	<=3	Polarized	no
	7	Chart & DTM	>3	Anag & Polar	no
	8	none	<=3	Polarized	no
	9	none	<=3	Polarized	no
	10	Charts	<=3	Polarized	no
Diver	1	Charts	>3	Polarized	yes
	2	Charts	>3	Polarized	no
	3	DTM	<=3	Polarized	no
	4	Chart & DTM	<=3	Anag & Polar	no
	5	Charts	None	None	no
	6	Chart & DTM	<=3	Polarized	yes
	7	Chart & DTM	None	None	yes
	8	Chart & DTM	<=3	Polarized	no
	9	Chart & DTM	<=3	Polarized	no
Total	N	39	39	39	39

8.4.4 Evaluation of 3D perceived from CS

Sample Identification		erceived position of colours	D effect perceived from RGB	D effect perceived from CYM	Vhich 3D is better n Bathy scenario	Vhich 3D is better in ROV scenario	Light effect on RGB CS	Light effect on CYM CS	Shading 3D
Hydrographers	1	Positive	Positive	Positive	RGB better	RGB better	No effect	Enhanced	Enhance
	2	No effect	Positive	Positive	RGB better	RGB better	No effect	No effect	Enhance
	3	Positive	Positive	Positive	Similar	Similar	Enhanced	Enhanced	Enhance
	4	Positive	Positive	Positive	RGB better	RGB better	Enhanced	Enhanced	Enhance
	5	Positive	Positive	Positive	Similar	Similar	Enhanced	Enhanced	Enhance
	6	Positive	Positive	Positive	RGB better	RGB better	Enhanced	No effect	Enhance
	7	Positive	Positive	Positive	RGB better	RGB better	Enhanced	Enhanced	Enhance
	8	No effect	Positive	Positive	RGB better	RGB better	No effect	No effect	Enhance
	9	Positive	Positive	Positive	Similar	Similar	Enhanced	Enhanced	Enhance
	10	Positive	Positive	Positive	RGB better	RGB better	No effect	No effect	Enhance
Navigators	1	Positive	Positive	Positive	RGB better	CYM better	No effect	Enhanced	Enhance
	2	Positive	Positive	Positive	RGB better	RGB better	No effect	No effect	Enhance
	3	Positive	Positive	Positive	RGB better	RGB better	No effect	Enhanced	Enhance
	4	Positive	Positive	Positive	RGB better	RGB better	Degraded	Degraded	Enhance
	5	Positive	Positive	Positive	RGB better	RGB better	Enhanced	Enhanced	Enhance
	6	No effect	Positive	Positive	RGB better	RGB better	Enhanced	No effect	Enhance
	7	Positive	Positive	Positive	RGB better	RGB better	Enhanced	Enhanced	Enhance
	8	Positive	Positive	Positive	RGB better	RGB better	No effect	No effect	Enhance
	9	Positive	Positive	Negative	RGB better	RGB better	Degraded	Enhanced	No effect
	10	No effect	No effect	Positive	CYM better	CYM better	Enhanced	Enhanced	Enhance
Sailor	1	Positive	Positive	Positive	RGB better	RGB better	Enhanced	Enhanced	Enhance
	2	Positive	Positive	Positive	RGB better	RGB better	Enhanced	Enhanced	Enhance
	3	Positive	Positive	Positive	RGB better	RGB better	Degraded	Enhanced	Enhance
	4	Positive	Positive	Positive	CYM better	CYM better	Enhanced	No effect	Enhance
	5	Positive	Positive	Positive	RGB better	RGB better	No effect	No effect	Enhance
	6	Positive	Positive	Positive	RGB better	CYM better	Enhanced	Enhanced	Enhance
	7	Positive	Positive	Positive	RGB better	CYM better	Enhanced	No effect	Enhance
	8	Positive	Positive	Positive	RGB better	CYM better	No effect	No effect	Degrade
	9	Positive	Positive	Positive	RGB better	RGB better	Degraded	Degraded	Enhance
	10	Positive	Positive	Positive	RGB better	RGB better	Enhanced	Enhanced	Enhance
Diver	1	Positive	Positive	Positive	RGB better	RGB better	Enhanced	Enhanced	Enhance
	2	Positive	Positive	Negative	RGB better	RGB better	Enhanced	Enhanced	Enhance
	3	Positive	Positive	Positive	RGB better	RGB better	Enhanced	Enhanced	Enhance
	4	Positive	Positive	Positive	Similar	Similar	Enhanced	Enhanced	Enhance
	5	Positive	Positive	Positive	RGB better	CYM better	No effect	No effect	Enhance
	6	Positive	Positive	Negative	RGB better	RGB better	Degraded	Enhanced	No effect
	7	Positive	Positive	Positive	RGB better	RGB better	No effect	Enhanced	Enhance
	8	Positive	Positive	Positive	RGB better	RGB better	Enhanced	No effect	Enhance
	9	Positive	Positive	Positive	RGB better	CYM better	No effect	Enhanced	Enhance
Total	N	39	39	39	39	39	39	39	39

8.4.5 Summary of participants' answer about the interaction between CS and the view angle

Sample Identification		Conventional view from 0	CS view from 0	Conventional view from 45	CS view from 45	Conventional view from 90	CS view from 90	Conventional view from 135	CS view from 135	Conventional view from 180	CS view from 180
Hydrographers	1	No 3D	Moderate 3D	Slight 3D	Moderate 3D	No 3D	Moderate 3D	Moderate 3D	Good 3D	Slight 3D	Good 3D
	2	Slight 3D	Moderate 3D	Slight 3D	Moderate 3D	Slight 3D	Slight 3D	Good 3D	Good 3D	Good 3D	Good 3D
	3	Slight 3D	Good 3D	Slight 3D	Moderate 3D	No 3D	No 3D	Good 3D	Slight 3D	Slight 3D	Moderate 3D
	4	Moderate 3D	Good 3D	Slight 3D	Good 3D	Slight 3D	Moderate 3D	Moderate 3D	Good 3D	Moderate 3D	Very good 3D
	5	Slight 3D	Good 3D	Moderate 3D	Good 3D	No 3D	Moderate 3D	Good 3D	Good 3D	Good 3D	Moderate 3D
	6	No 3D	Moderate 3D	Slight 3D	Good 3D	No 3D	Moderate 3D	Good 3D	Very good 3D	Good 3D	Very good 3D
	7	Moderate 3D	Good 3D	Moderate 3D	Good 3D	No 3D	Moderate 3D	Good 3D	Very good 3D	Very good 3D	Very good 3D
	8	Slight 3D	Moderate 3D	Good 3D	Moderate 3D	Slight 3D	Slight 3D	Very good 3D	Very good 3D	Good 3D	Good 3D
	9	Slight 3D	Good 3D	Good 3D	Very good 3D	Moderate 3D	Good 3D	Good 3D	Very good 3D	Moderate 3D	Very good 3D
	10	Moderate 3D	Moderate 3D	Slight 3D	Slight 3D	Slight 3D	Slight 3D	Very good 3D	Moderate 3D	Very good 3D	Moderate 3D
Navigators	1	No 3D	No 3D	Slight 3D	Moderate 3D	Moderate 3D	Moderate 3D	Good 3D	Slight 3D	Slight 3D	Moderate 3D
	2	Moderate 3D	Good 3D	Good 3D	Good 3D	Slight 3D	Moderate 3D	Very good 3D	Good 3D	Good 3D	Moderate 3D
	3	Very Good 3D	Good 3D	Good 3D	Good 3D	Slight 3D	Moderate 3D	Very good 3D	Very good 3D	Very good 3D	Very good 3D
	4	No 3D	Moderate 3D	Slight 3D	Moderate 3D	Moderate 3D	Good 3D	Good 3D	Very good 3D	Very good 3D	Good 3D
	5	Slight 3D	Slight 3D	Good 3D	Good 3D	No 3D	Slight 3D	Good 3D	Good 3D	Slight 3D	Moderate 3D
	6	No 3D	Slight 3D	Good 3D	Slight 3D	No 3D	No 3D	Very good 3D	Very good 3D	Very good 3D	Good 3D
	7	Good 3D	Good 3D	Moderate 3D	Good 3D	Slight 3D	Good 3D	Good 3D	Good 3D	Good 3D	Good 3D
	8	Slight 3D	Moderate 3D	Moderate 3D	Moderate 3D	Slight 3D	Moderate 3D	Moderate 3D	Good 3D	Moderate 3D	Moderate 3D
	9	Slight 3D	Slight 3D	Moderate 3D	Moderate 3D	No 3D	Slight 3D	Slight 3D	Good 3D	Slight 3D	Good 3D
	10	Good 3D	No 3D	Good 3D	Moderate 3D	Slight 3D	No 3D	Good 3D	Moderate 3D	Good 3D	No 3D
Sailor	1	Slight 3D	Moderate 3D	No 3D	Good 3D	No 3D	Moderate 3D	Slight 3D	Good 3D	Slight 3D	Good 3D
	2	Good 3D	Very good 3D	Good 3D	Very good 3D	Moderate 3D	Very good 3D	Good 3D	Very good 3D	Good 3D	Very good 3D
	3	Slight 3D	Slight 3D	Slight 3D	Moderate 3D	No 3D	Moderate 3D	Good 3D	Very good 3D	Moderate 3D	Good 3D
	4	No 3D	Slight 3D	Slight 3D	Moderate 3D	Slight 3D	Slight 3D	Moderate 3D	Good 3D	Very good 3D	Very good 3D
	5	No 3D	Moderate 3D	Moderate 3D	Good 3D	No 3D	Slight 3D	Good 3D	Very good 3D	Good 3D	Very good 3D
	6	Good 3D	Very good 3D	Very good 3D	Very good 3D	Very good 3D	Very good 3D	Very good 3D	Very good 3D	Very good 3D	Very good 3D
	7	Slight 3D	Good 3D	Moderate 3D	Moderate 3D	No 3D	Slight 3D	Moderate 3D	Good 3D	Slight 3D	Moderate 3D
	8	No 3D	Slight 3D	No 3D	Moderate 3D	Slight 3D	Slight 3D	Moderate 3D	Good 3D	Slight 3D	Good 3D
	9	Slight 3D	Good 3D	Slight 3D	Good 3D	Moderate 3D	Moderate 3D	Good 3D	Good 3D	Good 3D	Very good 3D
	10	Slight 3D	Slight 3D	No 3D	Moderate 3D	No 3D	Slight 3D	Good 3D	Slight 3D	Moderate 3D	No 3D
Diver	1	Very Good 3D	Good 3D	Very good 3D	Moderate 3D	Good 3D	Moderate 3D	Very good 3D	Moderate 3D	Good 3D	Moderate 3D
	2	Slight 3D	Moderate 3D	Moderate 3D	Good 3D	Slight 3D	Good 3D	Very good 3D	Moderate 3D	Good 3D	Moderate 3D
	3	Slight 3D	Very good 3D	Slight 3D	Very good 3D	Slight 3D	Moderate 3D	Slight 3D	Very good 3D	Good 3D	Good 3D
	4	Good 3D	Very good 3D	Good 3D	Very good 3D	Moderate 3D	Very good 3D	Very good 3D	Very good 3D	Good 3D	Very good 3D
	5	Good 3D	Very good 3D	Moderate 3D	Good 3D	No 3D	Moderate3D	Good 3D	Good 3D	Good 3D	Good 3D
	6	Slight 3D	Slight 3D	Moderate 3D	Moderate 3D	No 3D	Slight 3D	Slight 3D	Good 3D	Slight 3D	Good 3D
	7	No 3D	Moderate 3D	Slight 3D	Moderate 3D	No 3D	Moderate3D	Moderate 3D	Good 3D	Slight 3D	Good 3D
	8	No 3D	Moderate 3D	Slight 3D	Moderate 3D	Moderate 3D	Good 3D	Good 3D	Very good 3D	Very good 3D	Good 3D
	9	No 3D	No 3D	Slight 3D	Moderate 3D	Moderate 3D	Moderate3D	Good 3D	Slight 3D	Slight 3D	Moderate 3D
Total	N	39	39	39	39	39	39	39	39	39	39

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