Making 3D Work: A Classification of Visual Depth Cues, 3D Display Technologies and Their Applications

Mostafa Mehrabi, Edward M. Peek, Burkhard C. Wuensche, Christof Lutteroth
Graphics Group, Department of Computer Science
University of Auckland

mmeh012@aucklanduni.ac.nz, epee004@auckland.ac.nz, b.wuensche@auckland.ac.nz,
lutteroth@cs.auckland.ac.nz

Abstract

3D display technologies improve perception and interaction with 3D scenes, and hence can make applications more effective and efficient. This is achieved by simulating depth cues used by the human visual system for 3D perception. The type of employed depth cues and the characteristics of a 3D display technology affect its usability for different applications. In this paper we review, analyze and categorize 3D display technologies and applications, with the goal of assisting application developers in selecting and exploiting the most suitable technology.

Our first contribution is a classification of depth cues that incorporates their strengths and limitations. These factors have not been considered in previous contributions, but they are important considerations when selecting depth cues for an application. The second contribution is a classification of display technologies that highlights their advantages and disadvantages, as well as their requirements. We also provide examples of suitable applications for each technology. This information helps system developers to select an appropriate display technology for their applications.

Keywords: classification, depth cues, stereo perception, 3D display technologies, applications of 3D display technologies

1 Introduction

The first attempts for creating 3D images started in the late 1880s aided by an increasing understanding of the human visual perception system. The realization that the visual system uses a number of depth cues to perceive and distinguish the distance of objects in their environment encouraged designers to use the same principles to trick the human brain into the illusion of a 3D picture or animation (Limbchar 1968).

Moreover, the realism 3D display techniques add to images dramatically improved research, education and practice in a diverse range of fields including molecular modelling, photogrammetry, medical imaging, remote surgery, pilot training, CAD and entertainment (McAllister 1993).

This success motivated researchers to develop new 3D display techniques with improved performance and for new application fields (Planar3D 2012). This process continues as more complex and more realistic display techniques are being researched (Favalora 2005).

Different 3D display technologies are suitable for different applications depending on their characteristics and the depth cues that they simulate (McAllister 1993, Okoshi 1976). Therefore, a developer must be familiar with these techniques in order to make an informed choice about which one to use for a specific application. Characterizing 3D display techniques in terms of which applications they are suited for is not easy as the information regarding their limitations, constraints and capabilities is much dispersed.

Earlier contributions (Pimenta and Santos 2010) have categorized depth cues and 3D display technologies; however there is no information provided about the significance of each of the depth cues, and the advantages, disadvantages and constraints of display techniques are not discussed. Furthermore, no guidelines are provided about which display technology is most suitable for a specific use-case.

In this paper, we address the following two research questions:

1. What are the limitations of the depth cues of the human visual system?
2. What applications is each 3D display technology suitable for?

To answer question 1, we have analysed the seminal references in that area (McAllister 1993, Okoshi 1976), in addition to references from art and psychology, and used them to build a new classification of depth cues. To answer question 2, we have analysed the most common display technologies (Planar3D 2012, Dzignlight Studios 2012) and the common characteristics of the applications they can be used for. The result is a classification of 3D display technologies in terms of their depth cues, advantages and disadvantages, and suitable application domains.

Section 2 describes the classification of depth cues. Section 3 describes the classification of display technologies. Section 4 establishes a link between the display technologies and the applications they are appropriate for. Section 5 concludes the paper.

2 Depth Cues

Depth cues are information from which the human brain perceives the third visual dimension (i.e. depth or

---

distance of objects). Each display technique simulates only some of the depth cues. Thus, evaluating their usability for a specific application requires knowing the importance of depth cues with respect to that application.

Visual depth cues can be classified into two major categories: *physiological* and *psychological* depth cues. Both are described in the following, and summarized in Table 1 (McAllister 1993, Okoshi 1976).

2.1 Physiological Depth Cues

The process of perceiving depth via physiological depth cues can be explained using physics and mathematics. That is, it is possible to calculate the depth of objects if the values for some of the important physiological depth cues are available (e.g. using triangulation for binocular parallax values). For this reason, phys. depth cues are used for applications that simulate human 3D perception, such as in robotics to estimate the distance of obstacles (Xiong and Shafer 1993, Mather 1996).

Physiological depth cues are either binocular (i.e. information from both the eyes is needed for perceiving depth) or monocular (i.e. information from only one eye is sufficient to perceive depth). In the following we describe different phys. depth cues.

Accommodation. The focal lengths of the lenses of the eyes change in order to focus on objects in different distances. This depth cue is normally used in combination with convergence as it is a weak depth cue. It can only provide accurate information about the distance of objects that are close to the viewer (Howard 2012).

Convergence is the angle by which our eyes converge when focusing on an object. This depth cue provides accurate information about the distance of objects. However, the convergence angle gets close to zero as an object moves further away, eliminating the cue for large distances (i.e. convergence angle is asymptotic to distance) (Howard 2012).

Binocular Parallax. Our eyes are positioned approximately 50-60mm away from each other (Oian 1997). Thus, they see images with slightly different perspectives. Two slightly different images are fused in the brain and provide 3D perception. Every 3D display system must simulate this depth cue, as it is the most important one (McAllister 1993).

Monocular Movement (Motion) Parallax. Objects that are further away in the scene appear to move slower than objects that are closer. This depth cue can consequently provide kinetic depth perception which is used by the brain to estimate the time to clash/contact (TTC) (McAllister 1993, Okoshi 1976, Mikkola et al. 2010).

Depth from Defocus. Our brain can estimate the depth or distance of objects by the blurring in the perceived image, where objects with different amount of blurring have different depths. The depth of field of an optic (e.g. an eye lens) is the distance to an object that stays clearly and sharply focused while the objects behind it are blurred (Mather 2006). The human brain uses it together with depth from focus (accommodation) to improve the results of the latter (Mather 1996, Mikkola et al. 2010). Some artificial vision systems, e.g. in robotics, use this cue alone to calculate depth (Xiong and Shafer 1993).

2.2 Psychological Depth Cues

All of the psychological depth cues are monocular. In the following we briefly describe all of them (McAllister 1993, Okoshi 1976, Howard 2012, Bardel 2001).

Retinal Image Size. If our brain is familiar with the actual size of an object, it can estimate its distance by considering its perceived size with respect to its actual known size.

Linear Perspective. In a perspective projection parallel lines appear closer as they move towards the horizon and finally converge at infinity. This depth cue is one of the most frequently used ones to express depth in computer graphics renderings.

Texture Gradient. Details of surface textures are clearer when the surface is close, and fade as the surface moves further away. Some psychologists classify linear perspective as a type of texture gradient (Bardel 2001, Mather 2006).

Overlapping (Occlusion). Our brain can perceive exact information about the distance order of objects, by recognizing objects that overlap or cover others as closer, and the ones that are overlapped as farther (Gillam and Borsting 1988).

Aerial Perspective. Very distant objects appear hazy and faded in the atmosphere. This happens as a result of small particles of water and dust in the air (O'Shea and Blackburn 1994).

Shadowing and Shading. Objects that cast shadow on other objects are generally perceived to be closer (shadowing). Moreover, objects that are closer to a light source have a brighter surface compared to those which are farther (shading). However, many psychologists do not consider this as a depth cue because shadows only specify the position of an object relative to the surface the shadow is cast on, and additional, more accurate estimations of distance are needed from other depth cues (e.g. texture gradient) (Bardel 2001).

Colour. Different wavelengths are refracted at different angles in the human eye. Thus, objects with different colours appear at different distances. Therefore, the results obtained from this depth cue are not reliable (McAllister 1993).

3 3D Display Technologies

3D display techniques are typically classified into two main categories: *stereoscopic* and *real 3D*. In the following we describe the most important technologies (McAllister 1993, Okoshi 1976); a summary can be found in Table 2.

3.1 Stereoscopic Display

Stereoscopic techniques are mainly based on simulating *binocular parallax* by providing separate images for each of the eyes. The images depict the same scene from slightly different viewpoints. Stereoscopic displays are not considered as real 3D displays as users cannot find more information about the image by moving their head around. In other words, *motion parallax* is not simulated and the *look around* requirement is not satisfied.

However, in some of the new techniques *motion parallax* is simulated by adding a head tracking system (e.g. HCP). In all of the stereoscopic displays, *convergence* and *accommodation* are disconnected as viewers observe all the images from the same image plane (i.e. planar screen). These types of images are called *virtual*, and not everyone is able to perceive a 3D vision from them (Media College (2010) stated that 2-3% of the population are stereo blind). Stereoscopic displays are divided into two subclasses: *stereo pair* and *autostereoscopic* displays.

3.1.1 Stereo Pair

Stereo pair displays are based on blocking each eye from seeing the image corresponding to the other eye. This is usually achieved via glasses using various technologies. In some of the classic techniques, placing the pictures close to each lens prevents the other eye from seeing it.

In more efficient techniques, the right and left images are polarized and projected onto a single screen in order to provide for more than one viewer. Viewers wear polarized glasses that separate right and left images. All polarizing glasses darken the perceived image as they only let a fraction of the emitted light pass through. Stereo pair displays can be classified into two categories: *non-polarized* and *polarized*.

Non-Polarized Displays are described below:

Side-by-Side. In this technique users wear stereoscopes as their glasses, and stereoscopic cards are placed close to the stereoscopes' lenses, providing a different image to each eye. Although this is an old technique, it is still used in some schools for educational purposes (ASC Scientific 2011, Prospectors 2012).

Transparency Viewers. This technique is an enhanced version of side-by-side. The images can be illuminated from behind, and therefore provide a wider field of view. These viewers are mostly used as toys (e.g. Fishpond Ltd. 2012).

Head Mounted Displays. Each eye receives its own image via the magnifying lenses. The head tracking system has been added to this technique to enable motion parallax. HMDs are used for many AR applications. However, one of their drawbacks is their limited field of view (Fifth Dimension Technology 2011).

Polarized (Coded) Displays. There are two different ways of projecting left and right images onto the screen. Either both of the images are projected at the same time (time parallel), or sequentially (field sequential). Passive polarized glasses are worn for time parallel projection. In contrast, in field sequential projections active shutter glasses actively assign each image to its corresponding eye by blocking the opposite eye.

A disadvantage of active glasses is that they have to be synchronized with the screen every time the viewer attempts to use the display. Moreover it is not easy to switch between screens as glasses need re-synchronization. In both parallel and sequential projection, images must be projected with at least 120 Hz frequency to avoid image flicker. Polarized displays are described as following.

Anaglyph. In this technique images are polarized by superimposing additive light settings. On the viewers' side coloured anaglyph glasses (normally red and green) take each image to its corresponding eye by cancelling the filter colour and reconstructing the complementary colours (Southern California Earthquake Centre, n.d.).

Some people complain from headaches or nausea after wearing anaglyph glasses for long time periods (ESimple, n.d.). Moreover, if glasses do not filter colours appropriately and part of an image is observed by the opposite eye, image ghosting occurs. Anaglyph photos are widely used for entertainment, educational and scientific applications (Joke et al. 2008, 3DStereo 2012).

Fish Tank Virtual Reality. This technique increases the immersion by adding a head tracking system to stereoscopic images. For this purpose a stereo technique (Li et al. (2012) use Anaglyph) is incorporated with a head tracking system to provide a cheap approach for higher immersion.

Li et al. demonstrate that the technique is reasonably efficient in providing realistic 3D perception, as it simulates three depth cues (retinal size, binocular parallax and motion parallax). Its low cost gives it a great potential as a replacement for more expensive techniques with similar functionalities (e.g. ImmersaDesk).

Vectograph Images. This technique includes printing polarized images that are formed by iodine ink on the opposite sides of a Vectograph sheet. It can provide excellent results, but creating an image requires time consuming photographic and dye transfer. Therefore it was quickly replaced by a new method called StereoJet. Vectographic images were used in the military to estimate the depth of an enemy's facilities and by optometrists to test the depth perception of patients (especially children) (Evans et al. n.d.).

StereoJet. In this method fully coloured polarized images are printed on Vectograph sheets with high quality (Friedhoff et al. 2010). StereoJet images are widely used in advertisements, entertainment, government and military imaging. The advantage of this technique is that the images are high quality and the projectors do not need to polarize the images as they are already polarized before being printed (StereoJetA 2012, StereoJetB 2012).

ChromaDepth. In this technique the colours used in the image depict the depth and the glasses are double prism-based. Therefore, the glasses impose different offsets on each specific wavelength and form the stereo pair images. Small regions of composite colours might be decomposed into their base colours and create some blurring regions that are called colour fringe. ChromaDepth images are used in amusement parks, and educational cases (ChromatekB, n.d.).

The advantage of this technique is that only one image is required. However, images cannot be arbitrarily coloured as the colour carries information about depth. In some stages of designing the ChromaDepth pictures, the adjustments have to be done manually while the animators are wearing prism based glasses, which is a demanding job (ChromatekA, n.d.).

Interference Filter Technology. In this technique the glasses can be adjusted to pass only one or more specific wave lengths and reflect the rest; therefore image ghosting is avoided. The glasses do not require non-depolarizing silver screens and are more durable and accurate compared to other polarized glasses.

The main advantage of these glasses is the selective wavelength filtering. However, this technique requires trained personnel to adjust the wavelengths of colours on the projectors; which increases costs (Baillard et al. 2006, Laser Component ltd. n.d.). This technique is used for analytic chemistry, physics, life science, engineering, communication, education and space science (SCHOTT 2008).

Fake Push Display. This technique is consisted of a stereo display box that is mounted on sensors with 6 DOF to simulate moving in the virtual environment. The display technique is normally used for laboratory research (e.g. molecular modelling).

Eclipse Method (Active Shutter Glasses). This method is based on field sequential image projection. It has been used in the gaming and entertainment industry for a long time. Recently other companies have experimented incorporating this technique into their products as well (e.g. Nintendo and Samsung smart phones). Although this method is popular, it becomes expensive when more than a few viewers use it. Moreover, active shutter glasses darken the image more than other polarizing glasses (Perron and Wolf 2008).

ImmersaDesk. In this technique a big screen projects polarized images and fills the fields of view for up to four people. ImmersaDesks are designed to have the same applicability of fully immersive CAVEs in addition to offering smaller dimensions and portability. Unlike fully immersive CAVEs, ImmersaDesks do not require synchronization between the images of multiple walls. The screen is tilted to allow user interaction with the floor as well. One of the limitations of ImmersaDesk is that it can only track the position of one viewer (DeFanti et al. 1999).

Fake Space System Display (CAVE). This is normally used for studying human reaction and interaction scenarios that are expensive or impossible to implement in the real world.

CAVEs require processing and synchronizing eight images (left and right images for three walls and the floor) in a high speed. Nearly seventy institutes are currently using sixty ImmersaDesks and forty CAVEs for their researches (Academic Computing Newsletter of Pennsylvania State University 2006).

3.1.2 Autostereoscopic

Autostereoscopic images do not need glasses to be worn. These techniques are described in the following section.

Autostereograms (FreeView). In this technique left and right images are encoded into a single image that appears as a combination of random dots. The viewer has to be positioned in front of the picture and move it back and forth. The right and left images are merged in the brain using transverse (crossed) or parallel (uncrossed) viewing. However, some viewers are not able to perceive 3D images from autostereograms. Autostereograms are used for steganography and entertainment books (Tsuda et al. 2008).

Holographic Stereogram. Images are stored on a holographic film shaped as a cylinder, and provide motion parallax as a viewer can see different perspectives of the same scene when moving around the cylinder (Halle 1988).

Holographic stereograms are normally used for clinical, educational, mathematical and engineering applications and in space exploration. The method has some constraints that limit its usage. For example, if viewers step further away from Holographic stererograms with short view distances the size of the image changes or distorts (Watson 1992, Halle 1994, ZebraImaging 2012).

Parallax Barrier. In this technique left and right images are divided into slices and placed in vertical slits. The viewers have to be positioned in front of the image so that the barrier conducts right and left images to their corresponding eyes (Pollack, n.d.).

Forming the images in a cylindrical or panoramic shape can provide motion parallax as viewers are able to see different perspectives by changing their position. However, the number of images that can be provided is limited, so horizontal movement beyond a certain point will cause image flipping (McAllister 1993).

Lenticular Sheets. Lenticular sheets consist of small semi cylindrical lenses that are called lentics and conduct each of the right and left images to their corresponding eyes. Because its mechanism is based on refraction rather than occlusion, the resulting images look brighter (LenstarLenticular 2007).

Alternating Pairs (VISIDEP). This method is based on vertical parallax. Images are exposed to the viewer with a fast rocking motion to help viewers fuse them into 3D images. This method avoids image flicker and ghosting because of vertical parallax.

VISIDEP was used in computer generated terrain models and molecular models. However, not all the viewers were able to fuse the vertical parallax images into a 3D image. This method was limited in terms of implementation speed and quality of images, thus it is not in use anymore (Hodges 1985).

3.2 Real 3D Display

In real 3D displays, all of the depth cues are simulated and viewers can find extra information about the observed object by changing their position (this type of image is called *solid*). Real 3D displays can be classified in three main categories: *Swept Volume Display*, *Static Volume Displays* and *Holographic 3D Displays*. One motivation for creating real 3D displays is to enable the direct interaction between human and computer generated graphics thanks to finger gesture tracking systems (Favalora 2005).

3.2.1 Swept Volume Displays

In this method microscopic display surfaces such as mirrors or LCD displays sweep a specific volume with a very fast speed (900 rpm or 30Hz). Software applications are used to decompose a 3D object into small slices and processors compute which slices must be projected onto the display screen considering its position in the volume.

Because of visual persistence in the human brain, and the fast rotation of the display screen, the displayed points seem consistent in the volume; therefore a 3D illusion appears in the human brain. The projected lights have to decay very fast to avoid the appearance of stretched light beams (Matteo 2001). Swept volume displays can be classified as follows:

Oscillating Planar Mirror. In this method the microscopic mirror moves backward and forward on a track perpendicular to a CRT which projects the light beams (Favalora 2005).

Varifocal Mirror. In this method a flexible mirror which is anchored on its sides is connected to a woofer. The woofer changes the focal length of the mirror with a high frequency. Therefore the light beams projected on the mirror appear at different depths.

Rotating Mirror. In this method a double helix mirror or a LCD display rotates at the rate of 600 rpm and an RGB laser plots data onto its surface (Dowing et al. 1996).

3.2.2 Static Volume Display

This is a new area of research in which some projects are focused on intangible mediums that reflect light as the result of interaction with a specific frequency of infrared beams. Other projects investigate using a set of addressable elements that are transparent on their *off* state and emit light on their *on* state (Dowing et al. 1996).

Moreover, a volume space has been proposed in which fast infrared pulses that last only for a nanosecond, appear as consistent points. Therefore the display surface does not need to sweep the volume and is static (Stevens 2011, Hambling 2006).

3.2.3 Holographic Display

In Holographic Displays or Computer Generated Holography a holographic interference pattern of an object is collected and stored. Initial systems required a physical object, but recently algorithms were developed for enabling the use of computer simulated scenes, by calculating light wavefronts through complicated mathematical processes (e.g. Fourier Transform Methods) (Slinger et al. 2005).

4 Applications of 3D Display Technologies

3D applications exploit different display techniques depending on their requirements. We found that applications can be classified into eight key categories presented below. A classification of the most common display technologies and the application domains that they are most suitable for is found in Table 3.

Geospatial Studies. 3D display techniques are utilized for exploring digital elevation models (DEM) of terrains. Applications include monitoring coast erosion, predicting river levels, visual impact studies, and civil defence simulations, e.g. preparing for possible disasters such as tsunamis or tornados. Moreover, DEMs are used by the military for simulating and planning operations, and in astronomy for studying planet surfaces.

In geospatial studies, latitude, longitude and altitude of geographical points are factors of interest. In other words, only the surface of a terrain is studied and depth is the only information required to be added to normal 2D images. For this purpose, binocular parallax is simulated using anaglyph or passive polarized imaging (Li et al. 2005, Planar3D 2012)

Discovery of Energy Resources. Oil and gas drilling operations are very expensive. Therefore, seismic sensors are used to gather information from underground seismic explosions in order to prepare subterranean maps that can identify the accurate location of resources (Planar3D 2012). Unlike geospatial studies, this type of data needs to be inspected in a volumetric approach. This is because clusters of different information are mixed and form data clouds that need to be inspected manually to distinguish different features (CTECH 2012).

The Mining Visualization System (MVS) is an example of a non-stereo visualization of subterranean maps (CTECH 2012). It allows users to rotate the 3D-visualized graphs to gain exact information about the density of different substances in each point in addition to their x, y and depth coordinates. There are new applications that try to provide precise information about oil and gas reservoirs by rendering stereo 3D maps using simulated binocular parallax (Grinstein et al. 2001).

The provided information can be displayed via passive polarized techniques to preserve the brightness and the colour of the maps. For example, Fish Tank VR is a promising technology as it allows users to look around the stereoscopic map and calculate even more accurate estimations about where exactly drillings should be conducted (Planar3D 2012, Li et al. 2012).

Molecular Studies. Understanding the complex structure of biomolecules is the first step towards predicting their behaviour and treating disease. Crystallographers need to have a precise knowledge about the location of molecular constituents in order to understand their structure and functioning.

For this reason, molecular modelling has always been an application domain for 3D display technologies, and some techniques such as VISIDEP were specifically developed for this purpose. These types of applications require motion parallax and look around feature in addition to binocular parallax to enable a thorough inspection of molecular structures (Hodges 1985).

Therefore, 3D volumetric displays are the best option for molecular studies; however the volumetric applications are not practically usable yet, and normal stereo displays such as passive polarized and parallax barrier are used instead. Fish Tank VR has a potential for replacing the current stereo methods as it provides motion parallax (Pollack n.d., Planar3D 2012).

Production Design. Obtaining a realistic view of a design is essential for fully understanding a product and facilitating communication between different stakeholders such as designers, developers, sales people, managers and end users. Using a suitable display technique is critical in this field, as the quality of a presentation influences the success of product development and sales (Penna 1988).

For example, for interactive scenes such as videogames and driving and flight simulations, a 3D display with smooth and continuous vision is most suitable. Thus, an active polarizing system is preferred; however for demonstrating an interior design of a house, illumination and colour contrast must appear appealing. Therefore, a display technique with passive polarization, which better preserves the resolution of the image, is more appropriate.

Furthermore, demonstrating different parts of a design separately would provide a better understanding about the final product for the stakeholders and the end users. Therefore, using display techniques that allow inspecting the designed parts from different angles (such as volumetric displays, Fish Tank VR, ImmersaDesk) before the assembly stage can benefit all stakeholders (Planar3D 2012, Penna 1988). Also, Fish Tank VR can be used for applications that require reasonable immersion as well as cheap costs (Li et al. 2012).

Medical Applications. 3D display techniques (MRI, Ultrasound and Computer Tomography) have been used by radiologists, physiotherapists and physicians for a long time in order to gain a better understanding of patients' conditions and to provide more accurate diagnosis and interventions. In addition, minimally invasive surgery (MIS) applications widely take advantage of stereo displays. MIS reduces the risk of complications and reduces recovery time by using small incisions (keyhole surgery). In MIS miniature cameras are slid through patients' body to let surgeons monitor the process of an operation. Recently stereo 3D displays have been exploited to provide binocular parallax for helping surgeons with better recognition of body organs and their depth, and performing more accurate operations. Passive polarized techniques are most popular for this purpose as most operations take long and require wearing glasses for extended time periods (Planar3D 2012, Wickham 1987).

Simulation and Training. Many scenarios are impossible or expensive to simulate in the real world. For example, training novice pilots is very risky as small mistakes can have catastrophic consequences. Fully immersive display techniques are used to simulate these scenarios as realistically as possible (McAllister 1993, Planar3D 2012).

Cheaper stereo 3D displays (such as stereoscopes, StereoJet) are used for educational purposes in schools to increase the understanding rate in students by providing comprehensive 3D charts and diagrams where only binocular parallax is required (Watson 1992, ASC Scientific 2011).

Entertainment. The entertainment industry is one of the biggest users of 3D displays. The employed display technologies vary depending on requirements such as quality of colour and brightness, smoothness of animation, whether polarizing glasses are to be worn (if yes, how long for?), whether the display is for more than one viewer etc. (Dzignlight Studios 2012). For example, in the gaming industry smooth and continuous animation has the first priority and brightness can be compensated. Moreover, in movies wearing glasses for long time periods and brightness of the images must be taken into consideration, and the display technology should be reasonably cheap, so that it can be provided for large number of viewers (Penna 1988, Dzignlight Studios 2012).

In amusement parks such as haunted walkthroughs the combination of colours must provide the excitement and psychological impression that the images are supposed to impose on the viewers. Therefore, ChromaDepth images are used which are mainly formed by a combination of red, green and blue colours on a black background and the glasses are reasonably cheap (ChromatekA, n.d.).

Informative Displays. 3D display techniques are also used for better and more attractive public displays. Autostereoscopes have recently become popular in this application domain, as the information can be displayed in public to a large audience in a fast, affordable, and convenient way (e.g. advertisement billboards and posters) (Chantal et al. 2010).

Parallax barriers are used in airports security systems to provide a wider field of view for the security guards (BBC News 2004). In the vehicle industry new display screens use parallax barriers or lenticular sheets to direct different images to different people in the vehicle such that GPS information is provided for the driver while other passengers can watch a movie (Land Rover 2010).

Some of the new smartphones and digital cameras use parallax barriers for their screens to attract more consumers to their brands. For the same reason new business cards, advertisement brochures and posters use 3D display techniques such as lenticular sheets or anaglyph images (LenstarLenticular 2007, Dzignlight studios 2012).

5 Conclusion

In this paper we presented the following contributions:

- A classification of depth cues based on a comprehensive literature review, highlighting their strengths and limitations.
- A classification of 3D display technologies, including their advantages and shortcomings.
- A discussion of 3D application domains and guidelines about what 3D display technologies are suitable for them.

The classifications provide the information that a developer needs to make an informed choice about the appropriate 3D display system for their application. Based on constraints, limitations, advantages and costs of different display technologies, we have provided guidelines about the common characteristics of applications that utilize a specific 3D display technique.

As a future work we will develop benchmark scenarios that allow us to evaluate the suitability of different 3D display systems for common application domains experimentally. This would help to address the lack of quantitative guidelines in this area.

Depth Cues	Strength	Range	Limitations	Static/ Animated
Accommodation	Weak (McAllister 1993)	0-2m (McAllister 1993)	1. Not perceivable in a planar image (Mather 2006) 2. Only works for less than 2 meters (Mather 2006)	S & A (McAllister 1993)
Convergence	Weak (McAllister 1993)	0-10m (McAllister 1993)	1. Not perceivable in a planar image (Mather 2006) 2. Only works for less than 10 meters (Mather 2006) 3. Convergence is tightly connected with Accommodation (Mather 2006)	S & A (McAllister 1993)
Binocular Parallax (Stereopsis)	Strong (Kaufman et al. 2006)	2.5-20m (Kaufman et al. 2006)	1. The variations beyond 1.4 meters becomes smaller (Mather 2006)	S & A (McAllister 1993)
Monocular Movement (Motion) parallax	Strong (Ferris 1972)	0-∞ (Mikkola et al. 2010)	1. Any extra movement of the viewer or the scene create powerful and independent depth cues (Mather 2006) 2. Does not work for static objects (McAllister 1993)	A (McAllister 1993)
Depth from Defocus	Strong for computer (Xiong and Shafer 1993) Weak for human (Mikkola et al. 2010)	0-∞ (Mather 1996)	1. Depth of field depends on the size of pupils as well. The estimated depth may be inaccurate (Mather 2006) 2. Human eyes cannot detect small differences in a blurry scene (Mather 2006)	S (Mather 1996)
Retinal Image Size	Strong (Howard 2012)	0-∞ (Bardel 2001)	1. Retinal size change for distances over 2 meter is very small (Mather 2006)	S & A (McAllister 1993)
Linear Perspective	Strong (Bardel 2001)	0-∞ (Bardel 2001)	1. Works good for parallel or continuous lines that are stretched towards horizon (Mather 2006)	S & A (Mather 2006)
Texture Gradient	Strong (Howard 2012)	0-∞ (Bardel 2001)	1. Only reliable when the scene consists of elements of the same size, volume and shape. And texture Cues vary slower for a taller viewer compared to a shorter (Mather 2006)	S & A (Mather 2006)
Overlapping	Strong (Bardel 2001)	0-∞ (Bardel 2001)	1. Does not provide accurate information about the depth. Only ordering of the objects (McAllister 1993)	S & A (McAllister 1993)
Aerial Perspective	Weak (TAL 2009)	Only long distance (Bardel 2001)	1. Large distance is required (Mather 2006) 2. Provides unreliable information as it highly depends on weather, time of the day, pollution and season (TAL 2009)	S & A (Mather 2006)
Shadowing And Shading	Weak (Bardel 2001)	0-∞ (Bardel 2001)	1. The perception depends on illumination factors (Bardel 2001)	S & A (McAllister 1993)
Colour	Weak (McAllister 1993)	0-∞ (McAllister 1993)	1. Objects at the same depth with different colour are perceived with different depths. 2. Brighter objects appear to be closer (McAllister 1993)	S & A (McAllister 1993)

Table 1: Table of Depth Cues ▨ Binocular ☐ Monocular

Display Technique	Category	Physical Depth Cues Exploited	Hardware/Software Requirements And Prices
Side by side images	Stereo pair Non-polarized	Binocular Parallax	1. Stereoscope (~ US$ 40) (ASC Scientist 2011) 2. Stereographic cards (ASC Scientist 2011)
Transparency viewers	Stereo pair Non-polarized	Binocular Parallax	1. View masters (~ US$ 25) (Fishpond ltd. 2012) 2. Translucent films (Fishpond ltd. 2012)
Head Mounted Displays	Stereo pair Non-polarized	Binocular Parallax& Motion Parallax	1. Helmet or pair of glasses (US$ 100-10,000) (TechCrunch 2011) 2. Powerful processors with HDMI interfaces (TechCrunch 2011) 3. Software (Vizard VR Toolkit) to render stereo graphics and process head tracking data (WorldViz, 2012)
Anaglyph	Stereo pair Time parallel Polarized	Binocular Parallax	1. Anaglyph glasses (less than $1.0) (Southern California Earthquake Centre, n.d.) 2. Anaglyph photos software programs such as OpenGL, Photoshop, Z-Anaglyph (Rosset 2007)
Fish Tank VR	Stereo pair Time parallel Polarized	Binocular Parallax& Motion Parallax	1. A pair of cheap passive glasses (Anaglyph) (Li et al. 2012) 2. Head Tracking system using home webcams (~ $30) (Li et al. 2012)
Vectographs	Stereo pair Time parallel Polarized	Binocular Parallax	1. Vectograph sheets in the rolls of two-thousand feet length for ~US$ 37,000 (Friedhoff et al. 2010)
StereoJet	Stereo pair Time parallel Polarized	Binocular Parallax	1. Vectograph sheets(Friedhoff et al. 2010) 2. StereoJet printers such as Epsom 3000 inkjet with four cartridges of Cyan, Magenta, Yellow and Black. StereoJet inks are ~US$ 50 for each cartridge (StereoJetA 2012)
ChromaDepth	Stereo pair Time parallel Polarized	Binocular Parallax	1. Double prism-based glasses (C3D^{TM}) (ChromatekB, n.d.) 2. ChromaDepth image design applications. Micromedia Shockwave Flash 3.0 is specific for web based ChromaDepth animations (ChromatekA, n.d.)
Fake Push Displays	Stereo pair Time parallel Non-polarized	Binocular Parallax& Motion Parallax	1. A box shaped binocular mounted on sensors to simulate movement in the virtual world (depending on their degrees of freedom their prices vary from US$ 10,000 to US$ 85,000) (McAllister 1993)
Eclipse Method (Active Shutter System)	Stereo pair Field-sequential Polarized	Binocular Parallax	1. Stereo sync output (Z-Screen by StereoGraphics Ltd.) (McAllister 1993) 2. Normal PCs can use an emitter to enhance their screen update frequency and a software program to convert left and right images into an appropriate format for normal displays. The price for emitter is approximately US$ 400

ImmersaDesk	Stereo pair Field-sequential Polarized	Binocular Parallax & Motion Parallax	1. A big LCD mounted on a desk 2. Motion tracking system 3. Shutter glasses 4. Software libraries for processing and rendering graphical data (OpenGL). ImmersaDesk sells for US$ 140,000 (Academic Computing Newsletter of Pennsylvania state university 2006)
Fake Space System Display	Stereo pair Field-sequential Polarized	Binocular Parallax & Motion Parallax	1. A walkthrough cave 2. Fast processors for synchronizing the images on the walls and the floor 3. Shutter glasses 4. Gloves for interacting with environment 5. Software libraries for processing and rendering graphical data (OpenGL, C and C++) 6. Motion tracking system Fully immersive CAVE are worth US$ 325,000 - 500,000 (Electronic Visualization Laboratory, n.d.)
Interference Filter Technology	Stereo pair Time parallel Polarized	Binocular Parallax	1. Interference glasses (Dolby3D glasses) (SCHOTT 2008) 2. White screen for projecting image (SCHOTT 2008) 3. Display projectors with colour wheels that specify the wavelengths of the colours of interest Infitec Dolby 3D glasses are ~US$ 27.50 (SeekGlasses 2010)
Lenticular Sheets	Auto stereoscopic	Binocular Parallax & Motion Parallax if panoramic	1. Lenticular Sheets (LenstarLenticular 2007) Ordinary sizes of Lenticular Sheets are worth less than US$ 1.0 (Alibaba Online Store 2012)
Free View	Auto stereoscopic	Binocular Parallax	1. Autostereogram designing software applications (e.g. stereoptica, XenoDream which are priced US$ 15-120) (BrotheSoft 2012)
Holographic Stereogram	Auto stereoscopic	Binocular Parallax & Motion Parallax	1. A holographic film bent to form a cylinder (Halle 1994) 2. A set of stereo pair images from different perspectives of a scene to be stored on a holographic film. Colourful H.S worth US$ 600 - 2,500. Monochrome H.S worth US$ 250 - 2,000 (ZebraImaging 2012)
Parallax Barrier	Auto stereoscopic	Binocular Parallax & Motion Parallax if panoramic	1. Fine vertical slits in an opaque medium covered with a barrier. (Pollack, n.d.) Digital cameras with parallax barrier are priced US$ 100 – 200 (Alibaba Online Store 2012)
Alternating Pairs (VISIDEP)	Auto stereoscopic	Binocular Parallax	1. Two vertically mounted Cameras with similar frame rates and lenses (Hodges 1985)
Oscillating Planar Mirror	Multiplanar Swept olume	All Depth Cues	1. A microscopic planar mirror 2. A projector for projecting light beams on the mirror 3. A software program that decomposes the 3D object into slices (Perspecta, OpenGL) (Favalora 2005)
Varifocal Mirror	Multiplanar SweptVolume	All Depth Cues	1. A flexible mirror anchored on its sides 2. A woofer that changes the focal length of the mirror at the rate of (30 HZ) 3. A software platform (McAllister 1993, Matteo 2001,)
Rotating Mirror	Multiplanar Swept olume	All Depth Cues	1. A double helix mirror rotating at the rate of 600 rpm 2. RGB Laser projector 3. Software platform for decomposing 3D objects (Downing et al. 1996, Matteo 2001)
Static Volume Displays	Static Volume	All Depth Cues	1. A transparent medium 2. Laser or Infrared Projector (Stevens 2011, Hambling 2006)

Table 2: Table of 3D Display Technologies

▨ Non Multi-User ☐ Multi-User

Display Technique	Main Characteristics of The Display Technique	Common Characteristics of Applications Utilizing the Display Technique	Application Examples	References
Anaglyph	1-Very cheap 2-Can be viewed on any colour display 3-Doesn't require a special hardware 4-Most of colour information is lost during colour reproduction process 5-Long use of anaglyph glasses cause head ache or nausea 6-Does not provide head tracking feature 7-Most of the times image cross talk occurs 8-Ghosting is possible if colours are not adjusted properly	1-Colour does not denote information 2-Do not include wide range of colours 3-Do not require wearing anaglyph glasses for long time periods 4-Do not require head tracking feature 5-For more than one viewer 6-Limited budget (passive polarized can have the same use with better quality, but more expensive)	1-Advertisements 2-Post Cards 3-3D comics 4-Scientific charts 5-Demographic Diagrams 6-Anatomical studies	(McAllister 1993) (Okoshi 1976) (Planar3D 2012) (Jorke et al. 2008)
Head Mounted Display	1-Can provides head tracking feature 2-Fills the field of view of the viewer 3-Guarantees crosstalk-free display 4-Provides display only for one viewer 5-May be slow in presenting quick movements if it uses field sequential 6-Fairly expensive	1-Time parallel 2-Not for more than one user 3-May require head tracking system 4-Immersive environments that do not require direct interaction with virtual elements 5-Interaction is done via additional controllers	1-Augmented Reality 2-Video games	(McAllister 1993) (Okoshi 1976) (Dzignlight 2012)
Active Polarizer	1-High stereo resolution 2-Preservation of colour 3-Extra darkening of images 4-Possible image flickering (not in LCD shutter glasses any more) 5-Does not require non-depolarizing silver screens 6-More expensive than passive polarized	1-Field sequential 2-Do not require very high screen refreshment rate 3-High 3D resolution 4-Smooth and fast motion 5-Can compensate on factors such as image flickering and light complexities 6-For more than one viewer	1-Video games 2-Movies 3-In digital cameras and smart phones (Since LCD shutter glasses are being produced)	(Penna 1988) (Farrel et al. 1987) (Perron and Wolf 2008)

Passive Circular Polarized	1-Cheap 2-Less possibility for image cross talk as the result of tilting viewer's head (while in Linear Polarized is highly possible) 3-Provides continuous image without flicker 4-Requires polarized projectors 5-Cross talk possible (especially in Linear Perspective) 6-Darkens the images 7-Requires non-depolarizing silver screens	1-For more than one viewer 2-Colour and illumination is important 3-Require wearing glasses for long time periods	1-Most popular for movies 2-Geological and astronomical studies 3-Government/Military information and security photography 4-Interior and exterior designs 5-Mechanical designs 6-Oil and Gas discovery 7-Recent medical images 8-Molecular modeling and crystallography 9-Minimally invasive surgery 10-Radiology 11-Eye surgery and optometry 12-Amusement parks] 13-Educational applications	(ASC Scientific 2011) (Planar3D 2012) (Penna 1988) (Dzignlight 2012) (StereoJet 2012) (Chromatek A, n.d.) (McAllister 1993)
Fully Immersive **CAVE**	1-Requires wearing shutter glasses 2-Requires gloves for interacting with virtual environment 3-Simulates binocular parallax and motion parallax 4-Provides head tracking system 5-Fully immersive 6-Expensive (in terms of graphic rendering and processing tasks as well as price)	1-Study circumstances that are impossible or expensive to implement in real world (serious games)	1-Flight simulation 2-Pilot training] 3-Studies on human interaction with specific conceptual environments	(McAllister 1993) (Planar3D 2012)
Volumetric Display	1-Simulates all depth cues 2-Provides all view perspectives of an object 3-The graphical object is a bit transparent	1-Detailed investigation of complex structures 2-Provides accurate information about three dimensional structure of objects 3-Resolution of colour is not important	1-Molecular modeling 2-Crystallography 3-Radiology 4-Product design	(Planar3D 2012) (Penna 1988) (McAllister 1993)
Autostereo scopic **Displays**	1-Does not require wearing glasses 2-Can direct different images to different positions 3-Reduces resolution and brightness (Parallax Barrier) 5-Image cross talk is highly possible] 6-Image flipping may occur 7-Cheap	1-Do not require wearing glasses 2-Can compensate on image resolution 3-May require providing different images for viewers at different positions 4-Limited budget 5-Can provide panoramic view	1-Security systems of airports 2-Display screen of vehicles (show GPS data to driver and movie to passengers) 3-Display screen of smart phones 4-Business cards 5-Post cards 6-Decoration ornament 7-Panoramic images 8-Molecular modeling 10-Educational applications 11-Advertisements	(LandRover 2010) (Planar3d 2012) (BBC News 2004) (Chantal et al. 2010) (Watson 1992)

Table 3: Table of Common 3D Display Technologies and Their Applications

References

3Dstereo, November 2012, *Stereo 3D Equipment Supplies*, accessed on 21st August, http://www.3dstereo.com/viewmaster/gla.html

Academic Computing Newsletter of Pennsylvania State University, 2006, I*mmersaDesk*, accessed on 21st August 2012, http://www.psu.edu/dept/itscss/news/nlsp99/immersadesk.html

Alibaba Online Store, 2012, *Lenticular Sheets*, accessed on 22nd August 2012, http://www.alibaba.com/showroom/3d-lenticular-sheet.html

Alibaba Online Store, 2012, *Parallax Barrier Glasses*, accessed on 22nd August 20120, http://www.alibaba.com/showroom/parallax-barrier.html

ASC Scientific, 2011, *Stereoscopes plus Stereo Photographs and 3D Software*, accessed on 17th August 2012 http://www.ascscientific.com/stereos.html

Baillard, X., Gauguet, A., Bize, S., Lemonde, P., Laurent, Ph., Clairon, A., Rosenbusch, P. (2006): *Interference-filter-stabilized external-cavity diode lasers, Optics Communications*, Volume 266, 15 October 2006, Pages 609-613

Bardel, H. (2001): *Depth Cues For Information Design*, Master Thesis, Carnegie Mellon University, Pittsburg, Pennsylvania

BBC News, 2004, *Easy 3D X-rays for Air Security*, accessed on 22nd August 2012, http://news.bbc.co.uk/2/hi/technology/3772563.stm

BrotherSoft, 2012, *Stereogram software programs*, accessed on 22nd August 2012, http://www.brothersoft.com/downloads/stereogram-software.html

Burton, H. E. (1945): *The optics of Euclid*, Journal of the Optical Society of America,

Business dot com, 2012, *Head Mounted Displays Pricing and Costs*, accessed on 19th August 2012, http://www.business.com/guides/head-mounted-displays-hmd-pricing-and-costs-38625/

Chantal, N., Verleur, R., Heuvelman, A., Heynderickx, I. (2010): *Added Value of Autostereoscopic Multiview 3-D Display for Advertising in A Public Information*, Displays, Vol. 31, page 1-8

ChromatekA, *Applications of ChromaDepth*, accessed on 21st August 2012, http://www.chromatek.com/applications.htm

ChromatekB, *Print Friendly Primer*, accessed on 21st August 2012, http://www.chromatek.com/Printer_Friendly_Reference/ChromaDepth_Primer/chromadepth_primer.html.

CNN TECH, 2011, *LG unveils world's first 3-D smartphone*, accessed on 22nd August 2012, http://articles.cnn.com/2011-02-15/tech/lg.optimus.3d_1_google-s-android-smartphone-nintendo-s-3ds?_s=PM:TECH

CTECH, 2012, *Mining Visualization System*, accessed on 29th August 2012, http://www.ctech.com/?page=mvs

DeFanti, T., Sandin, D., Brown, M. (1999): *Technologies For Virtual Reality, Tele immersion application*, University of Illinois an Chicago

Downing, E., Hesselink, L., Ralston, J., Macfarlane, R. (1996): *A Three-Colour, Solid-State, Three-Dimensional Display*

Dzignlight Studios, 2012, *Stereoscopic 3D at Dzignlight Studios*, accessed on 28th August 2012, http://www.dzignlight.com/stereo.html

ESimple, *3D Anaglyph – A life of red/blue glasses*, accessed on 21st August 2012, http://www.esimple.it/en/pageBig/3D-Anaglyph-apps.html

Evans, H., Buckland, G., Lefer, D., *They Made America: From the Steam Engine to the Search Engine: Two centuries of innovators*

Farrell, J., Benson, B., Haynie, C., (1987): *Predicting Flicker Threshold for Video Display Terminals*, Hewlett Packard, Proc. SID, Vol. 28/4,

Favalora, E. (2005): *volumetric 3D displays and applications*

Ferris, S. H. (1972): *Motion parallax and absolute distance*, Journal of experimental psychology

Fifth Dimension Technology, 2011, *Virtual Reality for the Real World*, accessed on 19th August 2012, http://www.5dt.com/products/phmd.html

FilmJournal, 2009, *The best is yet to come: 3D technology continues to evolve and win audience approval*, accessed on 21st August 2012, http://www.filmjournal.com/filmjournal/content_display/news-and-features/features/technology/e3i8fb28a31928f66a5faa6cce0d6b536cc?pn=2

Fishpond ltd. 2012, *New Zealand's Biggest Toy Shop*, accessed on 17th August 2012, http://www.fishpond.co.nz/c/Toys/p/Viewmaster

Friedhoff, R. M., Walworth, V. K., Scarpetti, J. (2010): *Outlook For StereoJetTM Three-Dimensional Printing*, The Rowland Institute for Science, Cambridge, Massachusetts

Gillam, B., Borsting, E. (1988): *The role of monocular regions in stereoscopic displays*, Perception, 17, 603-608.

Grinstein, G., Trutschi, M., Cvek, U. (2001): *High Dimensional Visualizations*, Institute of Visualization and Perception, University of Massachusetts

Halle, W. (1994): *Holographic Stereograms as Discrete Imaging Systems*, MIT Media Laboratory, Cambridge, USA

Halle, W. (1988): *The Generalized Holographic Stereogram*, S.B. Computer Science, Massachusetts Institute of Technology, Cambridge, Massachusetts

Hambling, D. (2006): *3D plasma shapes created in thin air*

Hodges, F. (1985): *Stereo and Alternating-Pair Technology for Display of Computer-Generated Images*, IEEE-Computer Graphics and Applications

Horii, A. *Depth from Defocusing*, Computational Vision and Active Perception Laboratory (CVAP), Royal Institute of Technology, Stockholm, Sweden,

Howard, I. (2012): *Perceiving in Depth. New York*, Oxford University Press

Jorke, H., Simon, A., Fritz, M, (2008): *Advanced Stereo Projection Using Interference Filters*, INFITEC CmbH, Lise-Meitner-Str.9, 89081 Ulm, Germany

Kaufman, L., Kaufman, J., Noble, R., Edlund, S., Bai, S., King, T. (2006): *Perseptual Distance and Constancy of Size and Stereoptic Depth*, Spatial Vision, vol. 19, No. 5, 23 January 2006

Land Rover, 2010, *The Range Rover Catalogue*, accessed on 22nd August 2012 http://www.landrover.com/content/me/english/pdf/me-en/rr-ebrochure.pdf

Laser Components (uk) Ltd , *Interference Filters*, *Optometrics Corporation*, accessed on 21st August 2012 http://www.lasercomponents.com/de/?embedded=1&file=fileadmin/user_upload/home/Datasheets/optometr/interference-filters.pdf&no_cache=1

LenstarLenticular, 2007, HomePage, accessed on 22nd August 2012, http://www.lenstarlenticular.com/

Limbchar, J. (1968): *Four Aspects of The Film*

Li, I., Peek, E., Wunsche, B., Lutteroth, C. (2012): *Enhancing 3D Applications Using Stereoscopic 3D and Motion Parallax*, Graphics Group, Department of Computer Science, University of Auckland, New Zealand

Li, Z., Zhu, Q., Gold, C. (2005): *Digital terrain modeling: principles and methodology*

Mather, G. (1996): *Image Blur as a Pictorial Depth Cue*, Proceedings: Biological Sciences, Vol. 263, No. 1367

Mather, G. (2006): *Foundation of Perception and Sensation*, Psychological Press

Matteo, A. (2001): *Volumetric Display*, 16th March 2001

McAllister, David F. (1993): *Stereo Computer Graphics and Other True 3D Technologies*, Princeton U. Press, Princeton, NJ

Media College, 2010, *Stereo-Blind: People Who Can't See 3D*, accessed on 30th August 2012, http://www.mediacollege.com/3d/depth-perception/stereoblind.html

Mikkola, M., Boev, A., Gotchev, A. (2010): *Relative Importance of Depth Cues on Portable Autostereoscopic Display*, ACM

Nagata, T. (2012): *Depth Perception from Image Defocus in a Jumping Spider*, Science Vol. 335 no. 6067 (27 January 2012) pp.

Okoshi, T. (1976): *Three Dimensional Imaging Techniques*, Academic Press, New York

O'Shea, R. P., Blackburn, S. G., & Ono, H. (1994): *Contrast as a depth cue*, Vision Research,

Penna, D. (1988): *Consumer Applications for 3D Image Synthesis*, Phillips Research Laboratories Surrey, U.K.

Perron, B., Wolf, M. (2008): *Video Game Theory Reader*, Taylor and Francis Group Publisher, ISBN 0-415-96282-X

Pimenta, W., Santos, L. (2010): *A Comprehensive Classification for Three-Dimensional Displays*, WCSG

Planar3D, 2012, *3D Technologies*, accessed on 28th August 2012, http://www.planar3d.com/3d-technology/3d-technologies/

Planar3D, 2012, *Planar3D applications*, accessed on 28th August 2012, http://www.planar3d.com/3d-applications

Pollack, J. *3D Display Technology from Stereoscopes to Autostereo Displays*, VP Display Business Unit, Sharp Microelectronic of Americas.

Prospectors, 2012, *Online shopping*, accessed on 17th August 2012, http://www.prospectors.com.au/c-103-stereoscopes.aspx

Qian, N. (1997): *Binocular Disparity and the Perception of Depth*, *Neuron*

Rosset, 2007, *Z-Anaglyph*, accessed on 21st August 2012, http://rosset.org/graphix/anaglyph/zanag_en.htm

SCHOTT, 2008, *Interference Filters Catalogue*, accessed on 21st August 2012, http://www.schott.com/advanced_optics/german/download/schott_interference_filter_catalogue_july_2008_en.pdf

SeekGlasses, 2010, *News for Infitec 3D Dolby glasses*, accessed on 21st August 2012, http://www.seekglasses.com/news_2010-8-24/60053.html

Slinger, Ch., Cameron, C., Stanley, M. (2005): *Computer-Generated Holography as a Generic Display Technology*, Computer (IEEE)

Southern California Earthquake Centre, *Making Anaglyph Images In Adobe Photoshop*, accessed on 21st August 2012, http://www.SCEC.org/geowall/makeanaglyph.html

StereoJetA, 2012, *The Leading Technology For Stereo Images - applications*, accessed on 21st August, http://stereojetinc.com/html/applications.html

StereoJetB, 2012, *The Leading Technology For Stereo Images – technology*, accessed on 21st August 2012, http://stereojetinc.com/html/technology.html

Stevens, T. (2011): *3D fog projection display brings purple bunnies to life, just in time to lay chocolate eggs*, 17 March 2011

TAL. (2009): *5 Factors That Affect Atmospheric Perspective*, November 19, www.arthints.com

TechCrunch, 2011, *Sony's Head-Mounted 3D OLED Display Is World's First*, accessed on 19th August 2012, http://techcrunch.com/2011/08/31/sony-3d-oled/

Tsuda, Y., Yue, Y., Nishita, T. (2008): *Construction of Autostereograms Taking into Account Object Colours and Its Applications for Steganography*, CyberWorlds, International Conference on Digital Object Identifier

Tyler, C., Clarke, M., (1990): *The Autostereogram*, Proc. SPIE: Stereoscopic Display and Applications, Vol. 1256, pp 187

Watson, F. (1992): *Contouring. A Guide to the Analysis and Display of Spatial Data (with programs on diskette)*, In: Daniel F. Merriam (Ed.); Computer Methods in the Geosciences; Pergamon / Elsevier Science, Amsterdam; 321 pp. ISBN 0-08-040286-0

Wickham, J. (1987): *The New Surgery*, December 1987, Br Med J 295

WorldViz, 2012, *Head Mounted Displays*, accessed on 19th August 2012, http://www.worldviz.com/products/peripherals/hmds.html

Xiong, Y., Shafer, A. (1993): *Depth from Focusing and Defocusing*, The Robotics Institute, Carnegie Mellon University, Pittsburgh

ZebraImaging, 2012, *3D Hologram Print Prices*, accessed on 22nd August 2012, http://www.zebraimaging.com/pricing/