Autostereoscopy

Putting Things in Perspective

Final Thesis Project

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Table of Contents

1: Introduction

1.1: Topic

When thinking about the future, 3D is a reoccurring concept, which comes to mind. However, 3D films, 3D printing and 3D TV are already available to the public these days. It gives people an extra dimension and gives films, series and objects so much more detail. There is a future in 3D, while 3D is a thing of the future as well. However, 3D is still in a fairly early stage. It is not yet affordable for a large part of the Western society. Stereoscopy (a fancy name for 3D), is only available using special technology, including glasses. These glasses are often considered a nuisance, which is why companies are looking for ways to watch stereoscopic images without glasses. This will increase the immersion of the experience of watching stereoscopic images. The concept is called autostereoscopy (a fancy word for no-glasses 3D). There are several techniques to create autostereoscopic setups, but most of them are still in a very early stage of production. No-Glasses 3D will be an important addition to the future digitalised world, which is why we think it's a great topic for our final thesis.

1.2: Motivation

Besides it being such an important element in the digitalisation, we also chose 3D as our topic, because we both like going to the theatre. We don't only like them for the great plots and famous actors, but we are both very interested by the techniques implemented to give us an immersive movie experience. These techniques include surround sound, IMAX and, of course, three-dimensional images. However, we both agree that those 3D-glasses, that you get to watch the films in 3D, are a massive nuisance. They either don't fit properly or they hurt your eyes, but you can't take them off, as you will see a blur instead of a visually optimised film. This is why we wondered: Is there an option to get this immersive experience WITHOUT the glasses? Yes, there is, and its name is autostereoscopy. Throughout the last few years autostereoscopy has been a revolutionary technique, but it was still in a theoretical stage. We knew that it was there, but we didn't yet know how it worked, so there was much more to learn about autostereoscopy. This is to us the perfect characterisation of a final thesis topic. At least, that is what we thought.

1.3: Research Question

Our main research question is as follows:

> *Is it possible to recreate a prototype autostereoscopic setup, and if so what are its dependent factors, limits and possibilities?*

In order to answer such a complex question, we decided to create a number of sub-research questions:

- Which techniques to achieve displaying an autostereoscopic image already exist?
- Which of these techniques lie within our capabilities and (financial) means?
- How do these techniques work? Which factors do they depend on?
- Can these factors be influenced or changed?
- What are the limitations to this technology?
- What are the drawbacks of using a particular autostereoscopic setup when comparing it to other forms of autostereoscopy?

Our intention was to find answers for these questions through in-depth literary research, expert interviews with companies involved with autostereoscopy and through our own experience in the practical stage of our final thesis, which involved creating a prototype setup.

We also set up some hypothetical variables based on our pre-existing knowledge, which we thought might be important for our prototype:

- Viewing distance
- Viewing angle
- Applied technique(s)
- Content modification(s)
- Monitor(s) used and its (their) specifications

To give a small hypothesis:

We believe we will be able to create an autostereoscopic prototype with a limited 3D effect, based on pre-existing knowledge. The possibilities, limitations and dependent factors are what we hoped to discover in our background and in-depth research.

1.4: Background Research

In the background research we looked towards 3D-imaging techniques in general (both stereoscopy and autostereoscopy) and the way in which the human eye and brain perceived this. We used this general research to help direct us to a more specific and narrowed down topic within the field of 3D imaging.

1.4.1: Stereoscopy

Stereoscopy is the technique used to create an illusion of depth in a 2D image by taking advantage of the fact that humans have binocular vision (two eyes with a distance between them) and that the brain therefore receives a slightly different image from each eye, which it merges into a 3D image with height, width and depth.

The majority of stereoscopic methods present two offset images separately to the left and right eye of the viewer. The brain combines these 2D images creating the illusion of depth in the image.

To determine the depth and the relative distances between objects in a perceived scene, the brain uses a number of cues (hints/giveaways):

Stereopsis

Stereopsis means receiving different visual information from each eye

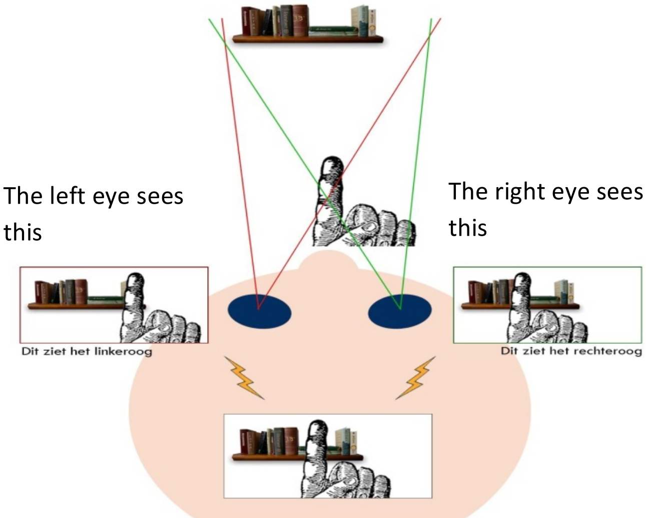


FIGURE 1.1

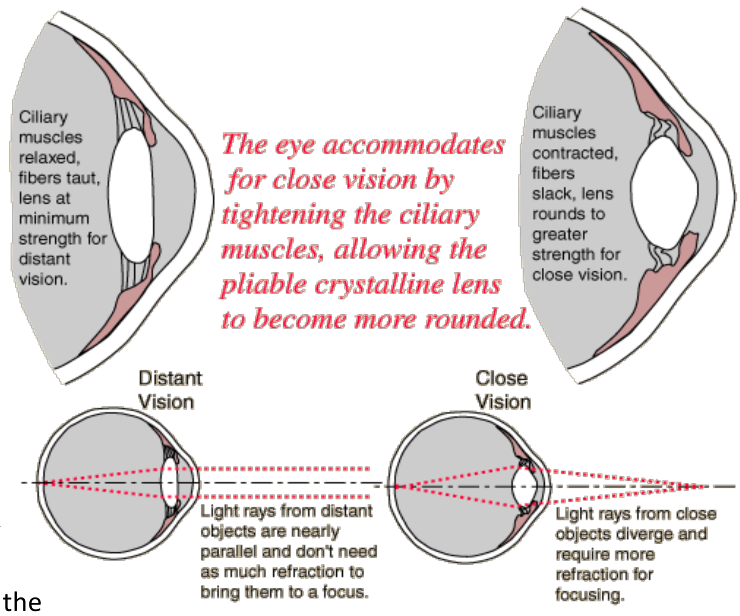


FIGURE 1.2

- Accommodation of the eye: The ability of the human eye to change power to maintain a clear image or focus of an object as the distance between the eye and the perceived object varies. It generally acts as a reflex but can also be consciously controlled. This shift in focus is achieved by the contracting and relaxing of the ciliary muscles, which in turn changes the shape of your eye's lens and ultimately increasing or decreasing the level of refraction by the lens to maintain a clear image.

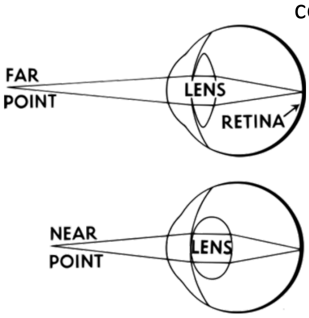


FIGURE 1.3

Subtended Visual Angle of an Object of Known Size

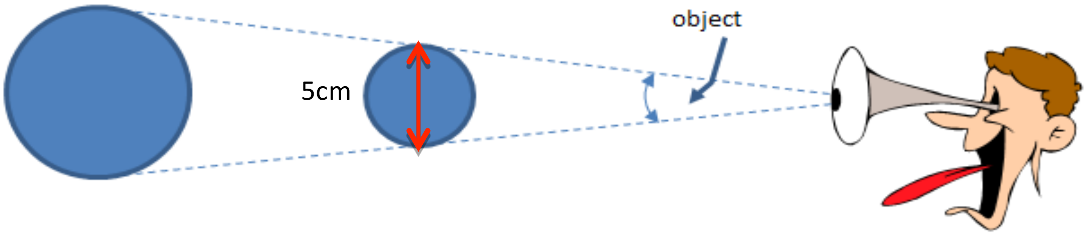
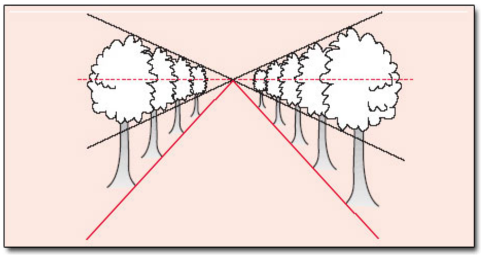


FIGURE 1.4

Linear Perspective



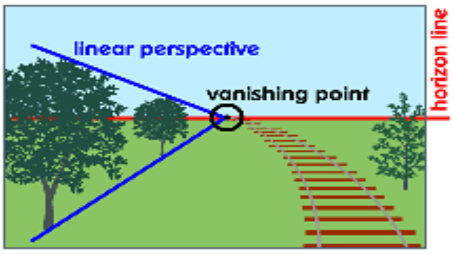


FIGURE 1.5 FIGURE 1.6

As can be seen in figures 1.5 and 1.6, distant objects appear smaller than objects that are closer. By drawing lines along the top, bottom & centre of these objects you can determine a so-called vanishing point along the horizon. This is a point in which lines that are actually parallel to each other appear to converge and vanish.

Vertical Position

Objects higher in the scene generally are seen as further away

Haze, Desaturation, and Blueshift/Redshift

Haze/blurriness is caused by a lack of focus as the distance between the eyes and the perceived object grows too far or too small (blind spot). Desaturation is the reduction of colour saturation (colours become less bright and distinguishable from one another). Blueshift and redshift is the decrease and increase of wavelength respectively as the source of the light moves towards (blueshift) or further away from (redshift) the viewer. Figure 1.8 shows a simplified diagram of the light source moving away from the viewer causing an increase in light wavelength and a decrease of wavelength as the source of light moves towards the viewer. Figure 1.7 shows an example of desaturation (loss of colour brightness).

FIGURE 1.7

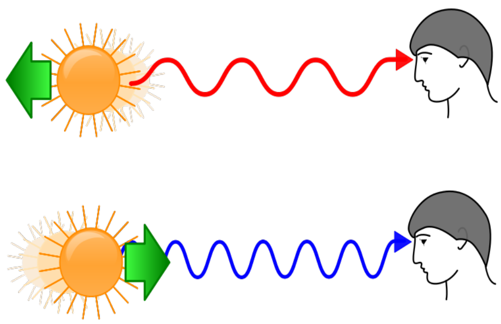
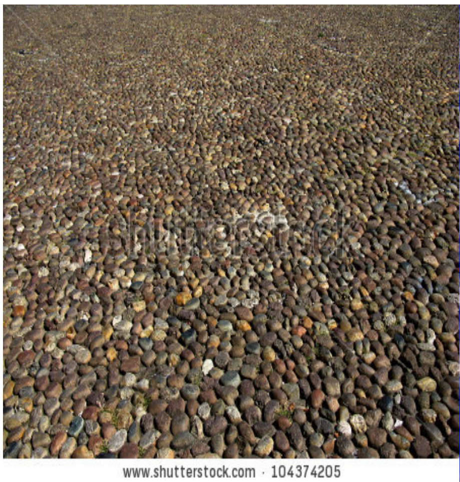


FIGURE 1.8

Change in Size of Textured Pattern Detail

The size of the texture patterns in the images below changes as one shifts gaze from the front of the image to the back (the horizon) Figures 1.9, 1.10 and 1.11 are clear examples: The texture patterns become smaller and seem to converge towards the horizon.



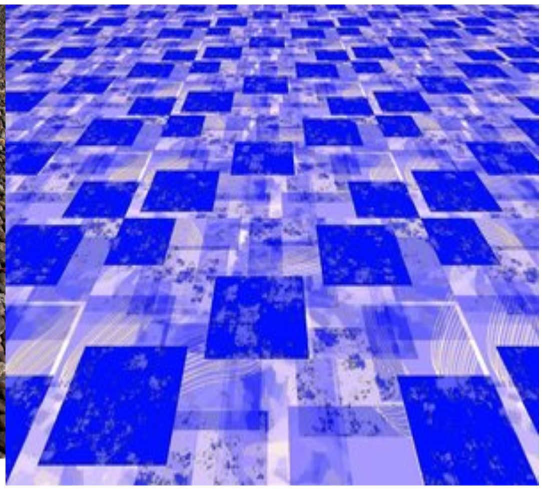


FIGURE 1.9

FIGURE 1.10

FIGURE 1.11

1.4.2: Stereoscopic Content

Stereoscopic Film

A 3D, 3-D film or S3D (Stereoscopic 3D) film is a motion picture that enhances the illusion of depth perception. Derived from stereoscopic photography, a regular motion picture camera system is used to record the images as seen from two perspectives or compute-generated imagery generates the two perspectives in post-production. Special projection hardware and/or eyewear are used to provide the illusion of depth when viewing the film. 3D films are not limited to feature film theatrical releases; television broadcasts and direct-to-video films have also incorporated similar methods, especially since the start of 3D television and Blu-ray 3D.

3D films have existed in some form since 1915, but had been largely relegated to a niche in the motion picture industry because of the costly hardware and processes required to produce and display a 3D film, and the lack of a standardised format for all segments of the entertainment business. Nonetheless, 3D films were prominently featured in the 1950s in American theatres, and later experienced a worldwide resurgence in the 1980s and 1990s driven by IMAX high-end theatres and Disney themed-venues. 3D films became more and more successful throughout the 2000s, culminating in the unprecedented success of 3D presentations of *Avatar* in December 2009 and January 2010.

1.4.3: Stereoscopic Technology

Stereoscopic TV's and Screens

3D television (3DTV) is television that brings depth perception to the viewer by employing techniques such as stereoscopic display, multi-view display, 2D-plus-depth, or any other form of 3D display. Most modern 3D television sets use an active shutter 3D system or a polarised 3D system, and some are autostereoscopic (without the need of glasses). This will be explained more thoroughly in "Forms of Stereoscopy."

There are several techniques to produce and display 3D moving pictures. The following are some of the technical details and methodologies employed in some of the more notable 3D movie systems that have been developed.

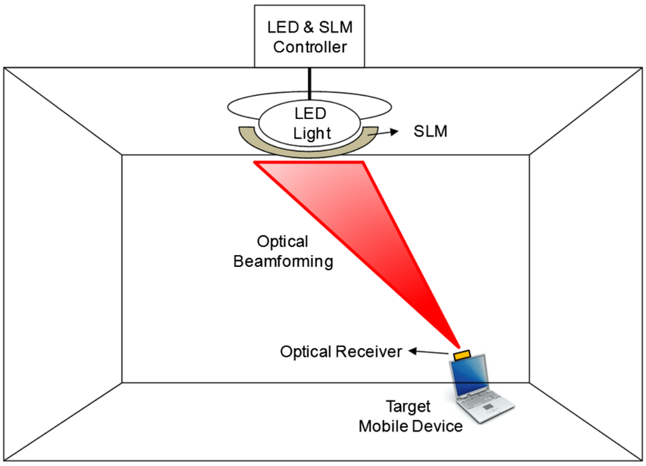


FIGURE 1.12

As time progresses, the potential of 3D television for widespread use in various industries becomes more evident. New technology like Window Walls (wall-sized displays) (see figure 1.13 on the next page) and Visible Light Communication are being implemented into 3D television as the demand for 3D TV increases. Scott Birnbaum, vice president of Samsung's LCD business, says that the demand for 3D TV will skyrocket in the next couple of years, fuelled by televised sports and gaming. One might be able to obtain information directly onto their television due to new technologies like the Visible Light Communication (VLC) that allows for this to happen because the LED lights transmit information by flickering at high frequencies. The working of VLC can be seen in figure 1.12, where data input goes from the flickering LED to the optical receiver on the electrical device. This can be done at very high speed and accuracy, which makes it ideal for giving digital information from 3D-TV's to 3D-glasses.

FIGURE 1.13 (WINDOW WALL)

The basic requirement is to display offset images that are filtered separately to the left and right eye. Two strategies have been used to accomplish this: have the viewer wear eyeglasses to filter the separately offset images to each eye, or have the light source split the images directionally into the viewer's eyes (no glasses required). Common 3D display technology for projecting stereoscopic image pairs to the viewer include:

With filters/lenses:

- Anaglyph 3D - with passive colour filters
- Polarised 3D system - with passive polarisation filters
- Active shutter 3D system - with active shutters
- Head-mounted display - with a separate display positioned in front of each eye, and lenses used primarily to relax eye focus

Without lenses:

- Autostereoscopic displays, sometimes referred to commercially as **Auto 3D**.

The forms of 3D imaging above will be explained further in "Forms of Stereoscopy".

1.4.4: Forms of Stereoscopy

In this part we will be explaining most forms of stereoscopy more thoroughly.

Colour Anaglyph Systems

One of the earliest forms of artificial stereoscopy was the colour anaglyph system. It was first tested in the United States in 1915 and is still in use today, although its use is no longer widespread. In order to create an illusion of depth, two superimposed images are shown on top of each other (one for each eye). The images are given a different colour to filter out the correct image for each eye. These colours must be complementary. That is to say that the one colour must be able to filter out the opposite colour. The most commonly used set of colours is red and blue. The viewer, in order to experience the illusion of depth, must wear a pair of glasses with lenses in the same complementary colours as the images. Each lens shows one colour and filters out the other colour, showing it as black. The brain's visual cortex then combines the two images into a single 3D image. Figure 1.14 shows how this works.

The advantage of this system is that it is universally applicable, requiring only a coloured television.

The biggest disadvantage is that a lot of colour detail is lost through the filters of the glasses, so certain colours must be avoided during the production of a film.

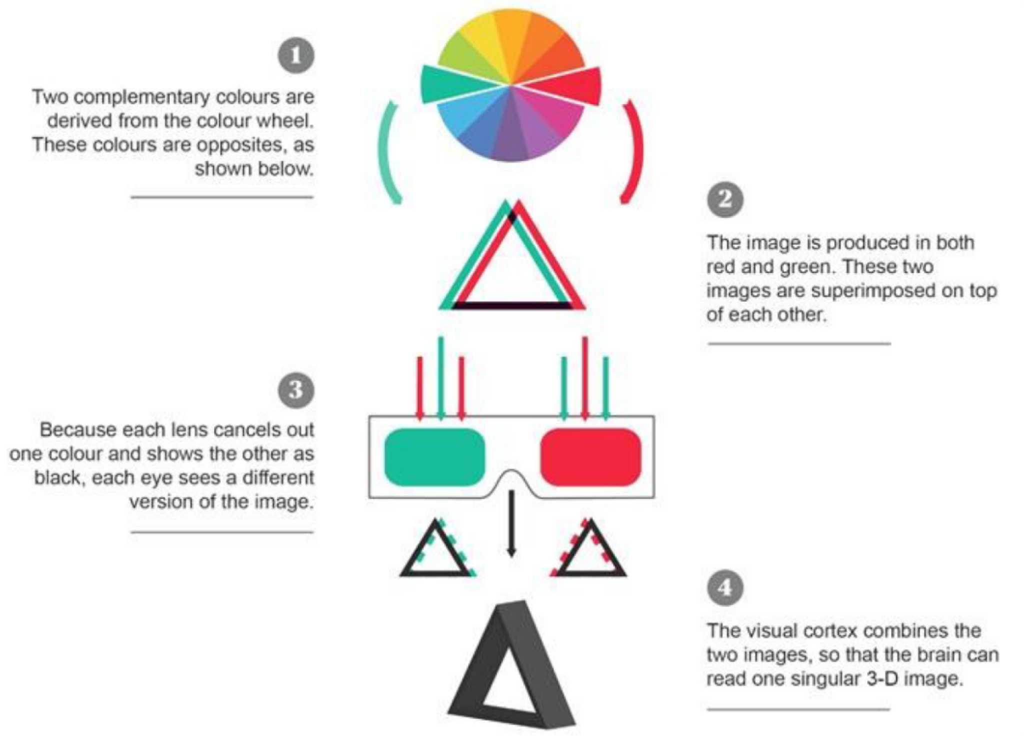


FIGURE 1.14

Linear and Circular Polaroid

Polaroid 3D, similarly to colour anaglyphs, uses two different images. However rather than colouring the images, which leads to a loss of colour detail, the two images are polarised in a different way. Light travels in waves and oscillates in all directions away from its source, polarisation cuts down a certain amount of directions the light can travel in.

There are currently two types of polarisation that used in 3D television and for 3D films in cinemas.

The first type is linear polarisation. This method is used by IMAX, and basically means that the light can only travel in one direction (towards the viewer). When the light hits one of the lenses on the viewer's glasses, the light is either let through or blocked by the polarised filter on the lens. This depends on the angle of polarisation, if the light and filter are polarised in the same direction, the light can pass through the lens, but if the light is polarised in a perpendicular direction to the filter, the light is blocked out. Figure 1.15 shows a linear polarised light wave passing through a filter.

The advantage of this system is that although some light intensity is lost through the filter, the colour detail is not lost.

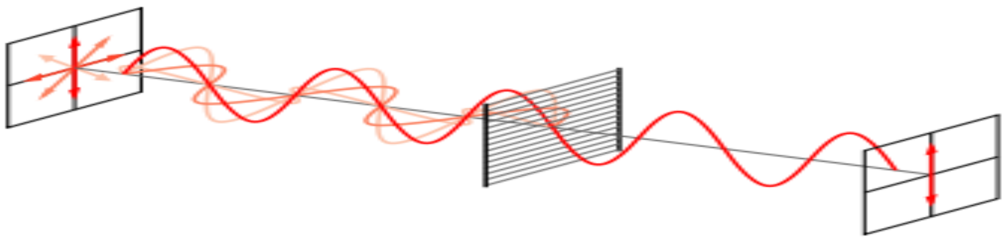


FIGURE 1.15

The second type of polarisation is circular polarisation. This is more complicated and involves polarising the light in a clockwise and anti-clockwise direction. RealD uses this method. In order to achieve circular polarisation, light must pass through two filters, as shown in the image below (Figure 1.16).

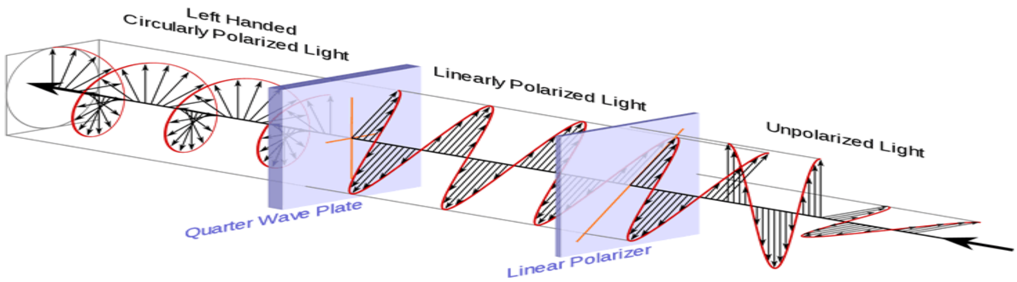


FIGURE 1.16

Unpolarised light passes through a linear polariser so that the light can only travel in one (linear) direction. A second filter called a quarter wave plate then polarises the light in two directions: clockwise and anti-clockwise. The filters on the glasses are then polarised so that each lens only lets in one direction of light: either the clockwise waves or the anti-clockwise waves. The advantage of this type of polarisation over linear polarisation is that the viewer can tilt his or her head slightly more before the image becomes distorted.

Shutter System

Shutter 3D systems are, in contrast to the previous systems/methods, a form of active 3D. This system requires battery-operated shutter glasses, that literally open and close shutters on one of the lenses to block out the image intended for the other eye, this means that left lens is "blacked out" when the image for the right eye appears on screen and vice versa, as can be seen in the images below (Figures 1.17 and 1.18). This happens at such high speed that the eye doesn't notice the shutters opening or closing. The only requirement on the screen side of the system is the ability to refresh the images fast enough to provide each eye with 60 frames a second.

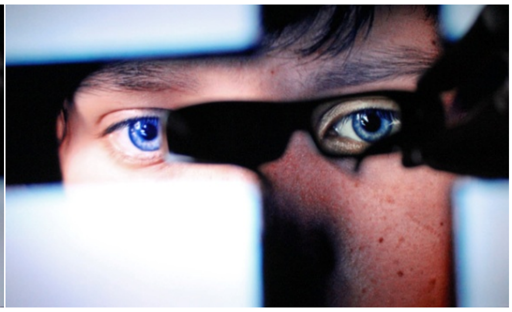


FIGURE 1.17 **FIGURE 1.18**

Chromadepth

Chromadepth is a relatively new method of creating the illusion of 3D. Contrary to all previous methods artificial stereoscopy, chromadepth creates a 3D image out of one single image, rather than two separate images.

The glasses (Figure 1.20) are equipped with lenses that are made out of prism-like holograms. The lenses diffract the colours so that the red appears closest and blue appears furthest away, with the whole visible light spectrum in between. (Figure 1.19)

Due to the fact that this method requires only one image rather than two and has no other requirements screen-wise, it is probably the most universally applicable method of watching 3D to date. The only disadvantage of this is that the image only can be viewed in the colours of the rainbow, as the different colours are very important to create the 3D effect. Therefore no colour is lost, but the image is only available in the bright colours.

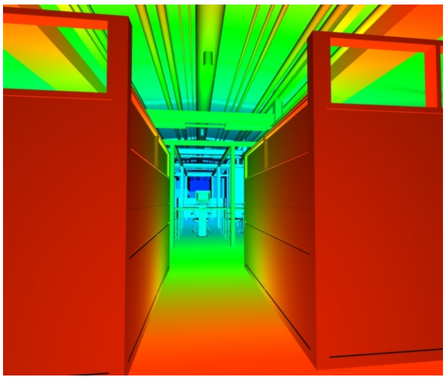


FIGURE 1.19

FIGURE 1.20

EXAMPLE OF A "CHROMA" IMAGE THAT REQUIRES CHROMADEPTH GLASSES

Pulfrich Method

Pulfrich 3D is one of the least known methods of stereoscopy. It is named after its inventor, the German physicist Carl Pulfrich. The method uses a pair of glasses with one dark and one transparent lens. The human brain responds to visual information more slowly at lower light levels and therefore, light passing through the dark lens is processed slightly later by the brain than the light passing through the transparent lens. The glasses to create this effect can be seen in figure 1.21. The brain therefore receives two separate images with a delay between them. It then perceives the differences and the delay as depth and objects appear to move closer together. This process can be seen schematically in figure 1.22. When this process is reversed, the lenses shorten the brain's response time and objects seem to move further away from each other.

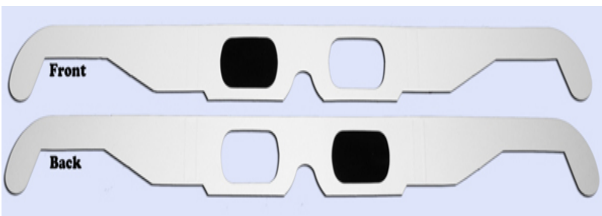


FIGURE 1.21

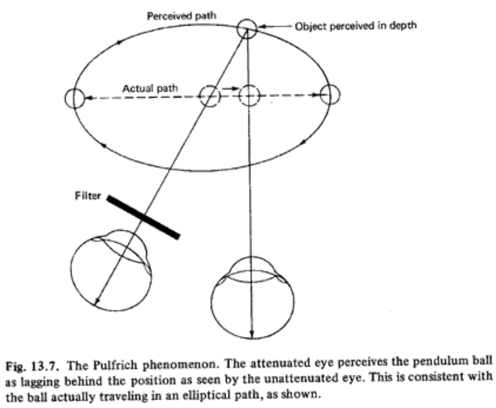


FIGURE 1.22

Over-Under Format

Over-under 3D is a format of 3D in which each frame is dived into to two sub-frames directly on top of each other. Normally a High Definition Television has a screen resolution of 1920x1080 or 1280x720 pixels. With the over-under format, the vertical resolution is halved in order to fit two images onto the frame (figure 1.23). The sub-frame labelled L is intended for the left eye and the sub-frame labelled R is intended for the right eye. A 3D television then extracts each sub-frame and scales it back to a full HD (1920x1080) frame, and displays the images in sync with active shutter 3D glasses (figure 1.24). This technique is often used and referred to as the Shutter 3D technique, seen in "Stereoscopic Technology".

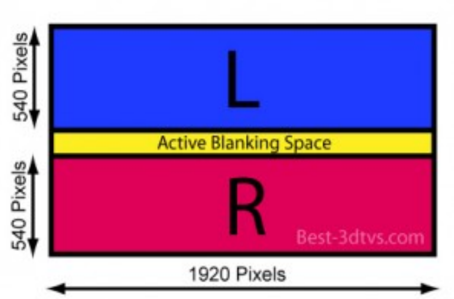


FIGURE 1.23

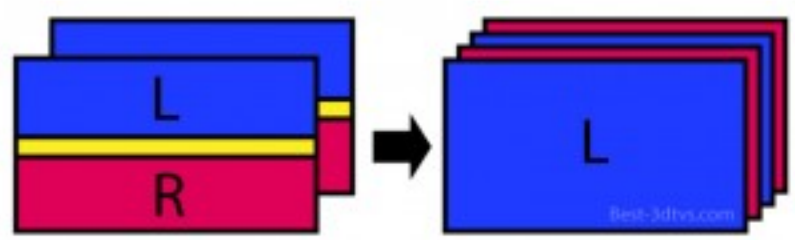


FIGURE 1.24

Autostereoscopy

Autostereoscopy is the technology used to create an illusion depth in a 2D image without the use of 3D glasses. Although certain forms of autostereoscopy have been around since the 1960s, developers have more recently been looking into the technology, as a crucial step in making 3D imaging for entertainment purposes mainstream, i.e. in the form of 3D televisions. The implemented techniques of autostereoscopy will be explained more in the in-depth research.

1.4.5: Companies

In this section we will give some background information on the companies, which were very important in our research process.

Philips

Philips is a Dutch company, famous for the invention of the light bulb. They originated in Eindhoven, which is called the 'City of Light' thanks to Philips. Philips has grown to become a company involved in almost all other fields of technology. They also are involved in 3D Technology, cooperating with Dolby to compete with other multinationals in the field of stereoscopic images and displays. A few years ago Philips discontinued the autostereoscopy production project, because of the financial crisis, according to one of their employees in that field, Patrick Vandewalle. They now only focus on licensing the techniques used for the autostereoscopic displays.

Dimenco

Dimenco is a Dutch company founded by four ex-Philips employees, who wanted to continue the producing of autostereoscopic 3D-displays, which was discontinued by Philips. With licensed Philips 3D-techniques and a good cooperation with Philips and Dolby, they have a good base to sell 3D-TV's on the market. They are very important for the Asian television giants (Sony, Samsung, etc.), as no autostereoscopic TV could be made without the techniques of Dimenco, according to their CTO, Jan van der Horst.

Dolby

Dolby is a British company, founded in London, which main focus is on audio programming and converting. They also have projects, together with other companies, to improve film experiences by optimizing the total package (audio, video and content). They also have a separate branch called Dolby 3D, which main focus is on three-dimensional audio and video. They have licensed certain techniques, seen in the White Paper, which is in the appendix.

2: In-Depth Research

2.1: Expert Interviews

To further increase our knowledge on the field of autostereoscopy and to have a better understanding of the companies involved we wanted to arrange a few expert interviews. It turned out that we were incredibly fortunate to be living in the Eindhoven area, as both Philips and Dimenco were situated here. Through electronic correspondence and a number of phone calls we were able to arrange an interview with Patrick Vandewalle, a Philips employee working on signal processing for autostereoscopic TVs in the Dolby-Philips collaboration and Jan van der Horst, Chief Technical Officer at Dimenco. A summary of both interviews can be found below and the audio files of the full interviews can be found in the appendix.

2.1.1: Philips (Patrick Vandewalle) PHILIPS

What does Mr Vandewalle do at Philips?

Mr Vandewalle started working at Philips in 2007. His interest in 3D and desire to create, improve and optimise an immersive 3D experience is what drew him to Philips and autostereoscopy.

He works on the "signal processing" side within the collaboration between Philips and Dolby. This involves converting 2D and stereoscopic 3D images to a format that can be displayed on autostereoscopic (also referred to as Glasses-Free 3D) displays. This includes adding more views to the 2D- or stereoscopic 3D-image, to give a more pleasing, sharp image for the viewer of the autostereoscopic image.

How did Philips move into the World of stereoscopy?

The idea of autostereoscopy is fairly old, with the earliest examples being holograms (late 1950s – early 1960s).

Philips started working on autostereoscopy in the late 1990s. At that time, Philips was the only large television manufacturer doing research in this field. The company was a pioneer and has contributed a lot to the development of autostereoscopic technology by building lenticular displays, constantly improving and refining them, tackling the loss of resolution caused by the blocking of certain (sub-) pixels to each eye and balancing the resolution loss between vertical and horizontal resolution.

Later Philips's TV department struggled to continue to perform well on the market due to the increase in competition, forcing Philips to discontinue its glasses-free 3D venture.

However this wasn't the end for autostereoscopy at Philips. The company now collaborates with Dolby to develop both autostereoscopic technology for displays and 3D content both real-time (for live events) and non-real-time. They then licence this technology to external parties who implement this for the production of autostereoscopic displays.

What's the status of the market for autostereoscopic displays and how will it develop according to Mr Vandewalle?

At the moment the market for autostereoscopic displays is in its early stages. None of the big TV manufacturers currently have a model on the market, but this is expected to change by 2015-2016. Despite being in its infancy, the market is already highly competitive, as every company involved in this field wants to be the first and the best.

Glasses based 3D (stereoscopy) has proved fairly unsuccessful in home use and therefore autostereoscopic displays are seen as a crucial step towards success for 3DTV at home.

A few obstacles that still need to be overcome in order for autostereoscopic TV to become mainstream are:

- Loss of resolution caused by the blocking of certain (sub-) pixels to each eye
- Loss of brightness as light passes through the lenticular layer
- “Chicken and Egg” dilemma: If there is no 3D content available, then nobody will buy an autostereoscopic television and companies won’t want to invest in their production, but if there are no autostereoscopic televisions available, then nobody will want to make 3D content.
- A lot of people still need convincing that this technology will actually add to and improve their film experience at home. The poor reception that 3DTVs have had so far makes it harder to convince people.

However the technology isn’t that far away from becoming available to consumers and once that happens, it can gradually become mainstream. One idea could be to start making it available for application in gaming and to slowly expand to other purposes as well.
The TVs might start in the high end of the market price range but autostereoscopic displays probably won’t be twice as expensive as 2D models currently available. The production cost of autostereoscopic displays is only slightly higher, the additional cost mainly being attributed to the addition of a lenticular sheet. Offering a decent and pleasant 3D experience to multiple people will also be possible with the displays generating a minimum of 9-28 different views.

What can autostereoscopic 3D bring to us in the future, according to Mr Vandewalle?
The technology has a lot of potential and could be used not only for entertainment purposes, but also for medical application and remote communication. However it is still a long way away from being used in cinemas, as the large screens require a much higher resolution of 3D content and more views.

Tips for the practical part of our final thesis:
Adding a lens (lenticular rays) on a display will probably be too difficult to realise with our budget, capabilities and time. A possible option will be to simulate the effect of the parallax barrier. You have to make an open space an open space between the pixels and the barriers. From each place you can see a different pixel area and you can make two different pixel areas have a different image. This will make a recognisable 3D-image. This is also realisable with limited budget, time and capabilities.

The autostereoscopic 3D-prototype-room:
After the interview, Mr Vandewalle took us to the prototype room. We walked in and we saw what seemed to be regular monitors, with some computers behind them. However, when we got closer, a lens sheet was visible on top of the display. Mr Vandewalle then asked us to go and sit on a table right in front of one of the displays. He started a film on the desktop and the first thing we both thought was: WOW! A clear 3D-image was visible, without us wearing glasses. Things actually came out of the screen. Our eyes had to get used to the image, which temporarily caused some discomfort, but after a minute or two it turned faded. Then Mr Vandewalle showed us some Disney-trailers in 3D, and it really gave a more immersive experience then a regular display, which was very cool to see. The gaming-section was also implemented, as he showed us a bit of a shooter-game. This

was made in an earlier stage, so the 3D-element wasn't very good yet. However you could see some bushes coming out of the screen when you walked past it. This was a very cool and interesting experience to give us a view of what autostereoscopic 3D was like.

2.1.2: Dimenco (Jan van der Horst)

What does Dimenco do regarding autostereoscopy?

Dimenco actually makes the displays. Dimenco made most of the prototypes that Philips and other companies own. While Philips owns the patents for autostereoscopic technology, Dimenco has the know-how on applying this technology to create high quality displays. They have created displays ranging from 4.5" to 105" for various applications varying from smartphones to television sets. One of Dimenco's specialties is the "switchable" screen, which allows the viewer to choose between a 2D and glasses-free 3D viewing experience.

Apart from creating prototypes, Dimenco provides services to other companies to share their knowledge and practical experience with them and to teach these companies how to make displays themselves. This is also the role that Dimenco envisions for itself in the future: providing the technology and know-how to large television manufacturers, rather than making displays themselves, these companies will, in turn, produce the displays that will become commercially available.

How did Dimenco get involved with autostereoscopy?

Dimenco was founded in 2010 after Philips stopped funding research on autostereoscopy due to the economic crisis, a year earlier. They started as a small four-person company on the High Tech Campus but soon moved to the Run business park in Veldhoven. As interest in autostereoscopy grew, so did the turnover and number of employees at Dimenco. Thanks to Dimenco's research, the quality and resolution of autostereoscopic displays improved greatly. Dimenco also discovered that by adding a Liquid Crystal layer between the pixels and the optical sheet, they could switch between 2D and 3D viewing by running an electric current through the LC layer.

What is Dimenco's current position on the market?

Dimenco could be considered as a major competitor, companies wanting to produce autostereoscopic displays need Dimenco's technology to do so. Dimenco provides this technology through business deals, securing the company's future.

What were/are the main obstacles/challenges for making auto stereoscopy commercially mainstream?

Some of the previous main obstacles were the unequal distribution of image quality and resolution across the different views generated by the display. Particularly the viewers, who are furthest away from the central viewing cone, had a very poor image. Through constant research and fine-tuning and the discovery of ultra-HD, this has improved the distribution of resolution considerably.

Another previous issue was the inability to switch between 2D and glasses-free 3D, a freedom and choice, which was considered to be vital for autostereoscopic displays to become a success. The development of the technology, which allows a viewer to switch between 2D and 3D, is one of Dimenco's main contributions to the field of autostereoscopy.

The balance between cost of production/price and the image quality and quality depth was also a challenge. This balance was particularly skewed towards the cost side at first, but over the years, the balance has become more favourable and it is expected that it will continue to do so, once mass production takes off.

The three main issues, that still present a challenge, are:

- The quality of depth is not always as prominently visible as desired, especially in content not originally intended for autostereoscopic displays.
- There isn't enough 3D content available at the moment for autostereoscopic displays to take off commercially, but without the production of these displays, companies won't be interested in making 3D content. A lot of steps still need to be made in this particular area, especially for the generation of real-time 3D content.
- People will probably need convincing, that autostereoscopic TVs are worth spending money on, seeing is believing, so the only way for people to truly get a sense of how immersive the experience can be is for them to actually see it for themselves.

So how far away is auto stereoscopy from becoming commercially available?

Dimenco is currently negotiating with a number of television manufacturers in Asia and the United States and we expect that the first models become available with 1-2 years. They expect that autostereoscopic televisions will take off first in Asia, while autostereoscopic smartphones and tablets will probably take off in the United States before spreading to the rest of the world, which shouldn't take too long either.

How does Dimenco envision a future with autostereoscopy?

So far, autostereoscopic displays have only been used for billboards at airports and train stations. However the first televisions, smart phones and tablets should become available by next year and high-end car producers are also working on applying this technology into car dashboards. We believe that the technology has the potential not only to create an even more immersive viewing experience for entertainment purposes, but also for companies to create even more powerful commercials and advertisements and the technology might even have potential for medical applications as well.

2.2: Literary Research

In “Literary Research” we will explain most forms of autostereoscopy, which was the topic we decided to focus on, after researching stereoscopic techniques in “Background Research”.

2.2.1: Holography

Holography is the oldest form of autostereoscopy. The development of the laser in the late 1950s allowed the Soviet physicist Yuri Nikolaevich Denisyuk and American physicists Emmett Leith and Juris Upatnieks to create the world’s first optical holograms in 1962.

The setup required to create a hologram is fairly simple. The following tools are needed:

A laser: Red helium-neon lasers are commonly used in holography. Holograms can also be made with lasers that produce different colours of light as well. With certain types of lasers, a shutter may also be necessary to control the level and duration of exposure. It is important to use a laser rather than any source of white light because lasers produce monochromatic light (light with one wavelength and one colour). The light produced by a laser is also coherent: each photon moves in step with the others forming wave fronts that launch in unison. The laser light is very strong and concentrated in a tight beam.

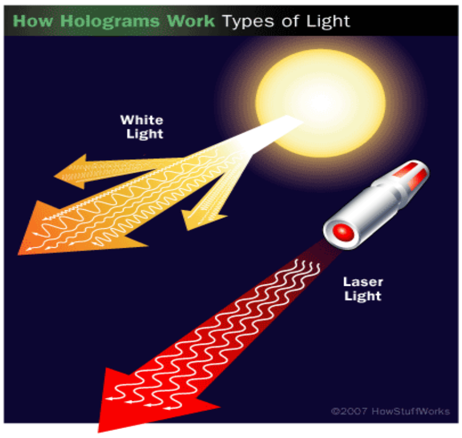
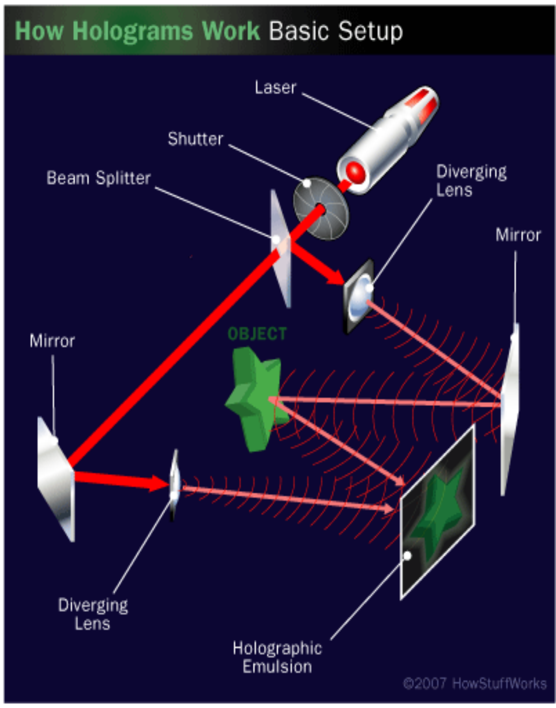


FIGURE 2.1

- At least two divergent lenses: although holography is sometimes called “lensless photography”, it does in fact require lenses. The difference is that photography uses convergent lenses to focus light while holography uses divergent lenses.
- A beam splitter: a device consisting of prisms and mirrors to split a beam of light into two.
- Mirrors: to direct the beams of light in the right directions to reach the intended location.
- Holographic film: a layer of highly light-sensitive compounds (e.g. silver-halide) on a transparent surface. Holographic film is capable of recording minute changes in light over microscopic distances. If a red laser is used, compounds especially sensitive to red light may be used

The laser is pointed at the beam splitter and light passes through the shutter. When the beam of light hits the beam splitter it is split into two (one will become a reference beam, while the other one will be directed at the object). The reference beam bypasses the object and hits a mirror. The light reflects of the mirror and passes through a diverging lens. The diverged beam of light then hits the holographic film. The other beam, the “object beam”, is sent through another diverging lens and directed to the object with a mirror. The light reflects from the object and hits the holographic film (of course, some of the light is absorbed by the object). (Figure 2.2) The holographic film records the pattern in which the object beam intersects and interferes with the reference beam. When a laser identical to the one used to record the hologram is shone on the holographic, the light is diffracted by the hologram's surface pattern, producing a light field identical to the original field scattered onto the hologram. This produces a virtual image. Because the surface of any object is rough and uneven on a microscopic scale, light is reflected of every part of the object in every direction and reaches every part of the holographic plate. This is why every fragment of a hologram shows the entire picture, albeit from one particular perspective. (Figure 2.3)



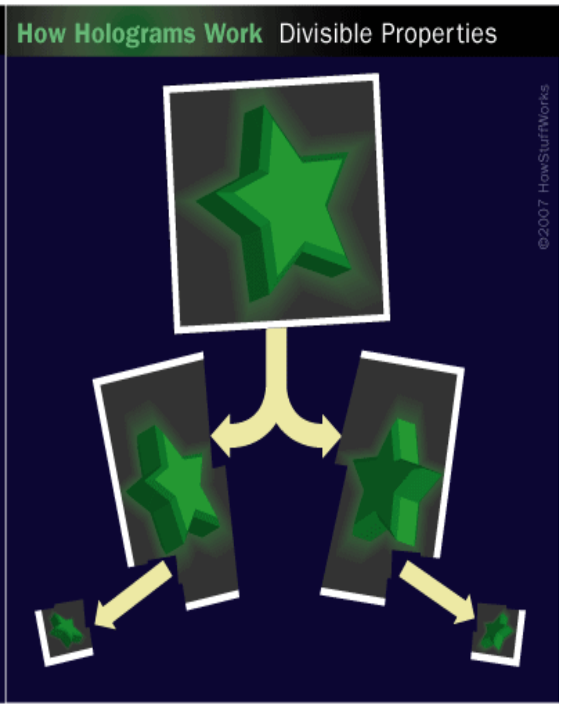


FIGURE 2.2 **FIGURE 2.3**

There are two types of holograms, reflective holograms and transmission holograms. Reflective can be viewed with white light. They can be easily and cheaply produced en masse (in big numbers), by coating the surface of a hologram with metal and stamping the pattern onto a developed a holographic surface.

This type of hologram can be found on credit cards, driver's licences and on bank notes, as seen in the following figures.

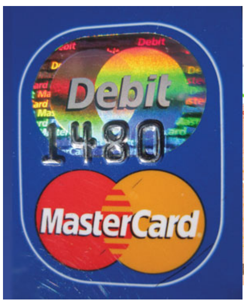


FIGURE 2.4 **FIGURE 2.5**

The other type is the transmission hologram. This hologram can only be viewed by shining a laser identical to the one used during recording through the hologram. One can then see a reconstructed image of the object suspended in space. This can be seen in figure 2.6.

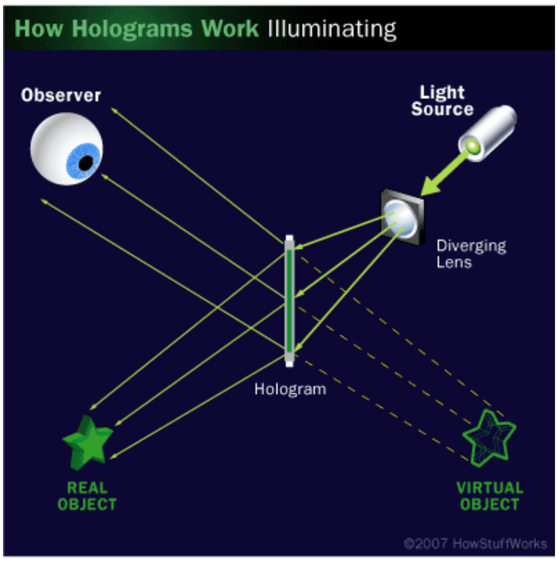
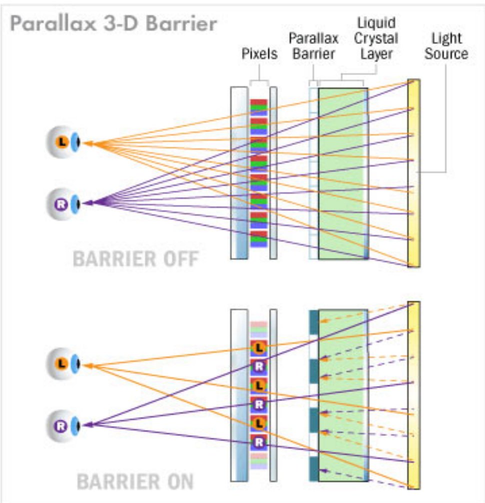


FIGURE 2.6

2.2.2: Parallax Barrier

A parallax barrier is a way of creating an autostereoscopic image. As its name suggests it involves a barrier, which is positioned between the liquid crystal layer of an LCD screen and the screen. The barrier consists of number of precision slits that direct and block light so that each eye sees a different set of pixels and essentially two different images. By using a liquid crystal material for the parallax barrier, the option to switch between 2D and 3D becomes possible. In 2D mode, the liquid crystal slits of the barrier are clear and therefore allow light to pass through them. An electrical current can cause the slits to become opaque, blocking some of the light and creating a left and a right image.



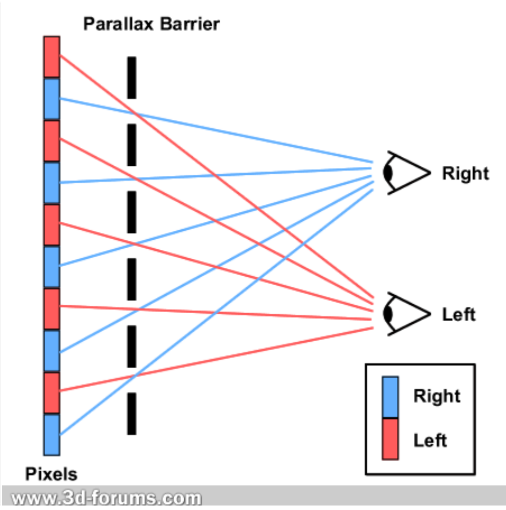


FIGURE 2.7

FIGURE 2.8

A disadvantage of this technology is that the viewer needs to be in a precise position to experience the 3D effect, which is why the technology is limited to single view, screens on handheld gaming consoles such as the Nintendo 3DS. Another disadvantage is that the resolution is reduced because each eye effectively only sees half the amount of horizontal pixels.

In order for the slits in a parallax barrier to effectively direct light from specific (sub-) pixels to each eye they need to be positioned in a specific way with respect to one another, the screen and the viewer/intended viewing position. The most important parameters one has to keep in mind to achieve an optimal effect are: the pixel-parallax barrier separation [d] (distance between the pixel layer and the parallax barrier), the parallax barrier pitch [f], the pixel aperture [a] and the slit width [b].

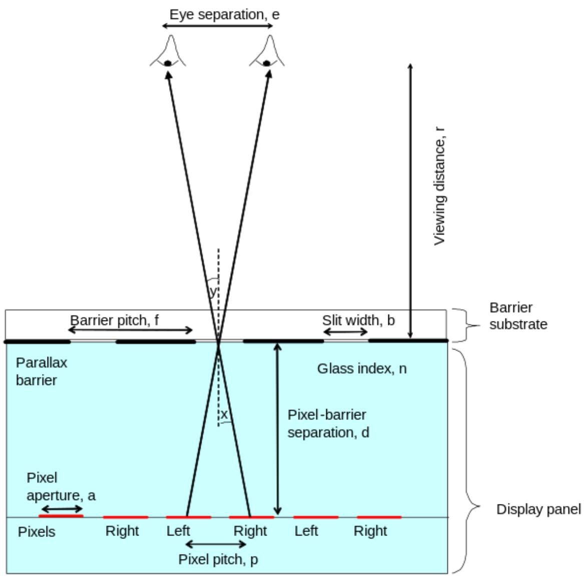


FIGURE 2.9

Pixel Separation

The distance between the parallax barrier and the pixels influences the angle of separation between the left and right images. The closer barrier is to the pixels, the wider the angle between the images becomes. In order to create a stereoscopic image, both the left and right image need to reach the intended eye. Therefore, the angle of separation between the images needs to be small.

Through the Snell-Descartes law or law of refraction the formula for the pixel-barrier separation can be derived:

$$\frac{\sin(i)}{\sin(r)} = \frac{n_2}{n_1}$$

In which:

i = the angle of incidence

r = the angle of refraction

n_1 = the refractive index of the medium from which the light came ·

n_2 = the refractive index of the medium the light is travelling towards

In the case of the parallax barrier $n_2 = n_{air} \approx 1.000$ therefore → → → → → →

$$\frac{\sin(i)}{\sin(r)} = \frac{n_{air}}{n_{glass}} = \frac{1}{n_{glass}}$$

so

$$\sin(r) = n_{glass} \cdot \sin(i)$$

$$\sin(i) \approx \frac{p}{2d}$$

$$\sin(r) \approx \frac{e}{2r}$$

$$\frac{e}{2r} = n_{glass} \cdot \frac{p}{2d}$$

$$\frac{e}{2r} = \frac{n_{glass} \cdot p}{2d}$$

$$2d \cdot e = 2r(n_{glass} \cdot p)$$

$$d \cdot e = r(n_{glass} \cdot p)$$

$$d = \frac{r(n_{glass} \cdot p)}{e}$$

In which:

e = eye separation
r = the viewing distance (distance between eyes and the screen
p = the pixel pitch (distance between two sub-pixels of the same colour on the inside of the display
d = pixel-parallax barrier distance

Parallax Barrier Pitch

The Parallax barrier pitch should be approximately twice the pixel pitch, while the optimum design should be slightly less than the parallax barrier pitch. This deviation of the barrier pitch compensates for the fact that the edges of the display are viewed at a different angle than the centre of a display, enabling the left and right images to target the eyes properly from anywhere on the screen. For an optimum design, the barrier pitch is therefore approximately 0.1% smaller than twice the pixel pitch.

Pixel Aperture & Barrier Slit Width/Reducing Crosstalk

Reducing crosstalk (interference between the left and right views) (Figure 2.10) while maintaining a bright image is very hard to do. If the slit width of the parallax barrier is small, and the light passing through is diffracted heavily, a lot of crosstalk is caused. The brightness is also reduced. If the slits are wider, more light passes through and is not diffracted as much. However due to light's tendency to travel in a straight line in a homogenous medium, the wider slits still create crosstalk (even more than the narrower slits do). Therefore, it is necessary to compromise between increased brightness and reduced crosstalk. Crosstalk can be measured with the following formula:

$$crosstalk_{pixel} = \frac{part\ of\ pixel\ seen\ by\ the\ incorrect\ eye}{pixel\ area}$$

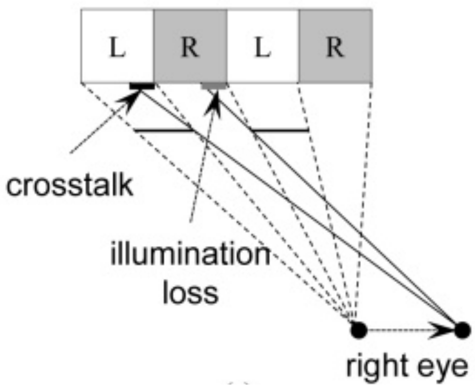


FIGURE 2.10

Switching Between 2D & 3D

The greatest disadvantage of the parallax barrier is that the horizontal resolution of an image is halved. It could therefore be considered desirable for a viewer to have the ability to switch between 3D and full resolution 2D at his/her own liberty. This will double the resolution of the horizontal image and, whenever the person's eyes are tired of watching the 3D-image, switching to 2D will most likely be less exhausting for the eyes. The most practical method to achieve this switching is by forming the parallax barrier from a liquid crystal material. This allows the barrier to switch between a transparent and opaque state. (Figure 2.11)

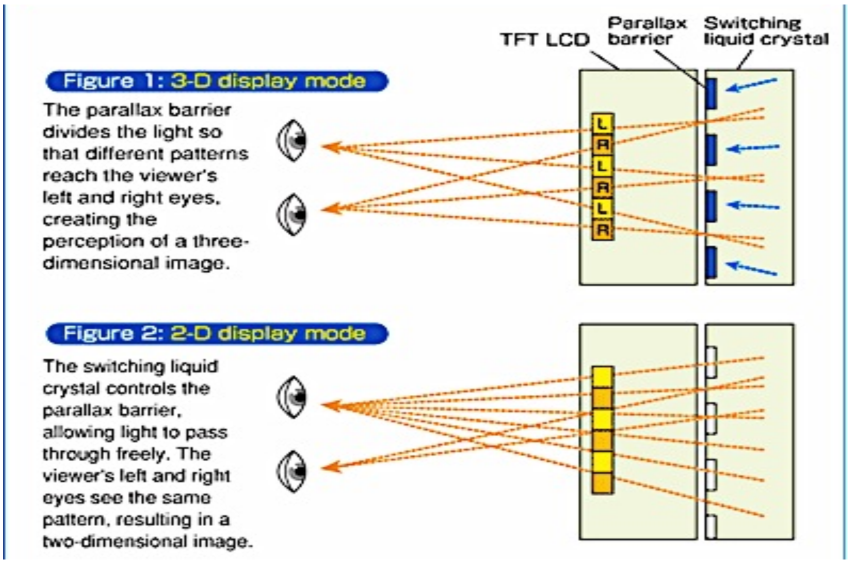


FIGURE 2.11

Time Multiplexing

Another solution for the loss of resolution, but one that maintains an autostereoscopic image is time multiplexing. This essentially works in a similar way to the active shutter glasses. By using a parallax barrier in which the slits can change position like a shutter, the (sub-) pixels that were blocked out for either the left or right eye can be revealed to that particular eye. If this switching happens fast enough, that the user doesn't notice the image swapping around each frame (approx. 20 ms), the user is given the illusion that he/she is seeing an image from all the pixels, so with a full resolution.

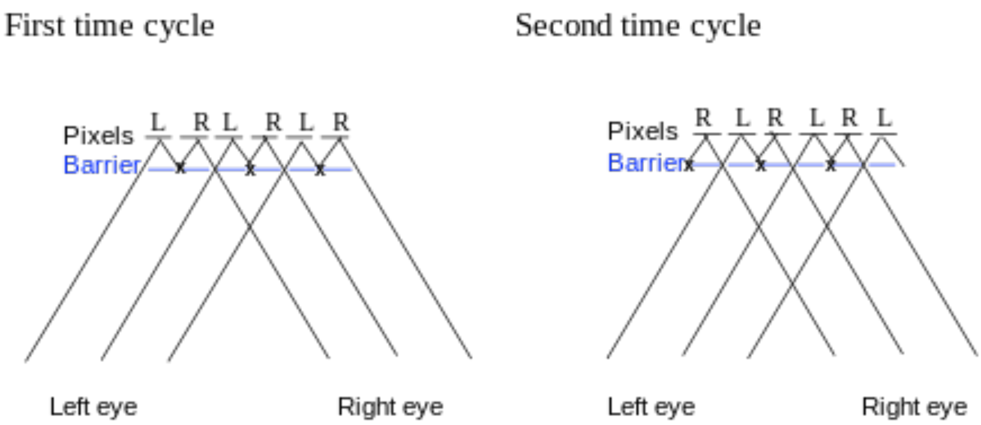


FIGURE 2.12

Tracking Barriers

A tracking barrier is a solution for the limited viewing freedom of a parallax barrier. By using a front facing camera, capable of recognising and tracking a viewer's head, the user's position with respect to the screen can be tracked and the barrier can be adjusted (either mechanically or electronically) to direct the light towards the user's eye.

2.2.3: Integral Photography and Lenticular Lens

Integral Photography

Integral photography is one of the earliest forms of autostereoscopy and in essence one of the first holographic methods. The method was first proposed by physicist Professor Gabriel M. Lippmann in 1908. Integral photography basically involves using an array of small, spherical convex lenses (commonly known as a fly's-eye lens array) (figures 2.13 & 2.14) to both record and display the image. Each lens captures a unique image from a unique angle and records this on a photographic film. This results in a series of sub-images (each taken from a different angle). When viewing the photograph, the reverse happens: light reflects off each of the sub-images and is diffracted by the different lenses, reconstructing an image in which each of the recorded vertical and horizontal positions can be seen, thus creating a 3D image. The position of the viewer's eyes with respect to the screen determines which sub-image the viewer sees and thus at which angle the viewer perceives to be viewing the 3D image from. (Figures 2.15 & 2.16)

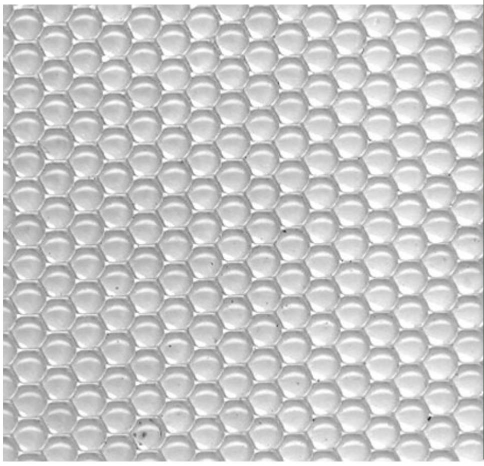


FIGURE 2.13

FIGURE 2.14

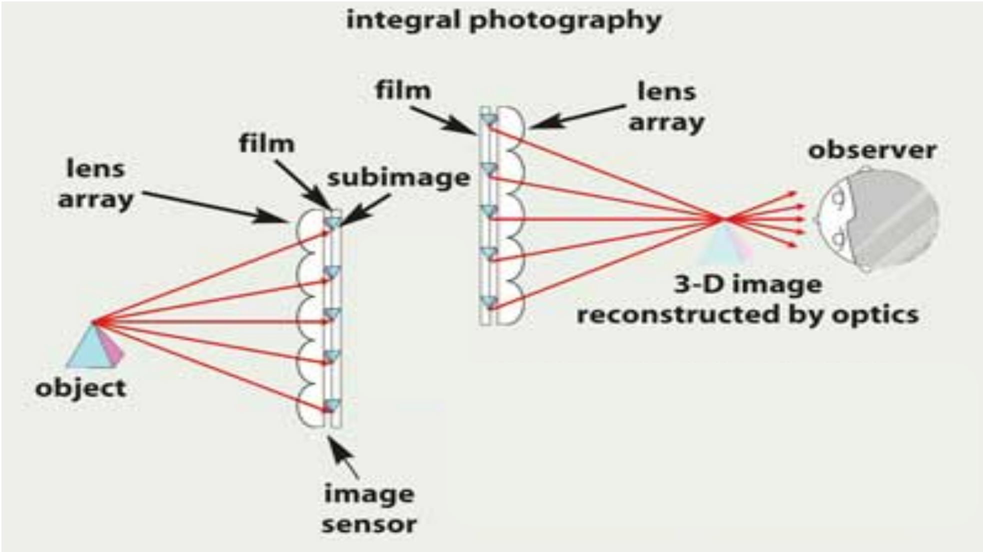


FIGURE 2.15

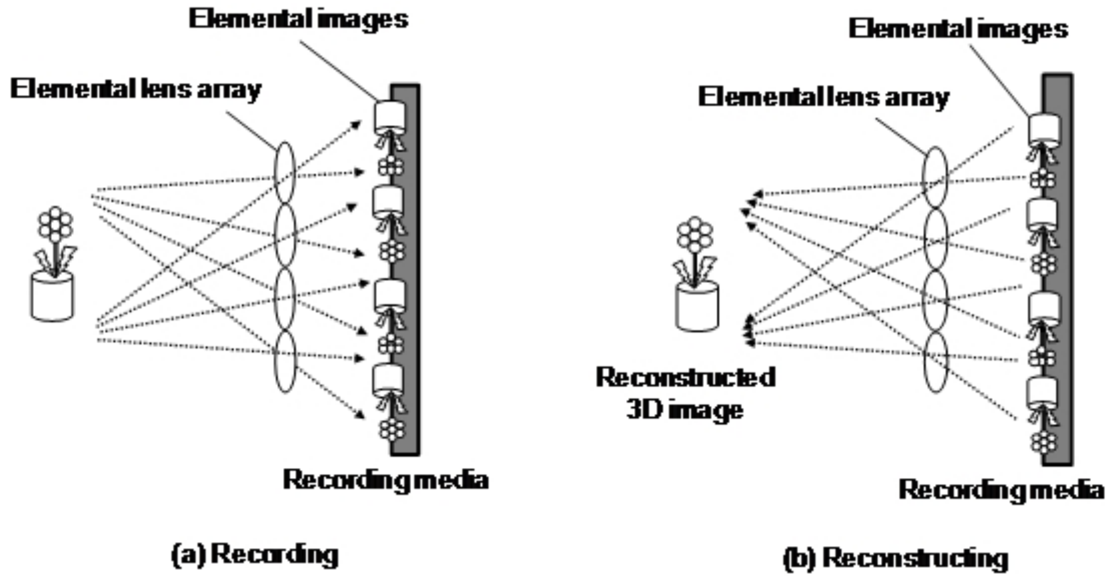


FIGURE 2.16

Decades later, in the 1970s 80s and even 90s, attempts have been made to apply the techniques used in integral photography to HD colour television, with digitally interlaced images. Although this in itself hasn't led to a commercial success, it did inspire a similar technology: Lenticular lens arrays, the technology, which is hailed as the future of autostereoscopy.

Lenticular Lens

Lenticular lens arrays work in a similar way to the parallax barrier. However rather than blocking light from specific sub-pixels with a physical barrier, an array of magnifying cylindrical lenses (lenticules) refracts the light in such a way that certain sub-pixels will only reach one of the eyes. (Figure 2.17) This barrier can be placed either directly over the pixel layer or in front of a 2D (LCD) screen. (Figure 2.18)

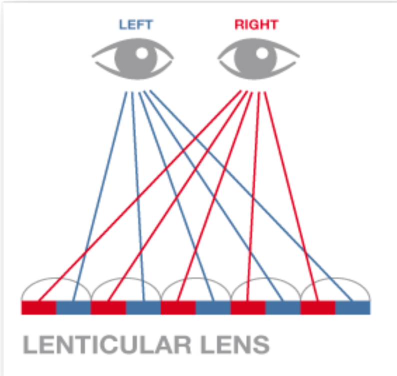


FIGURE 2.17

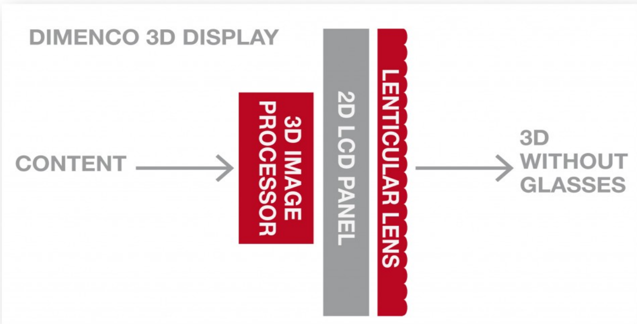


FIGURE 2.18

Light from each of the sub-pixels is project/refracted in a certain direction depending on the pixel's position with respect to certain lenses, which form a lenticular sheet. Pixels shining light in the same direction form a single view. Combining all the single views creates the viewing cone (Figures 2.19 & 2.20). Outside this central viewing cone the views are repeated to create a wider viewing area. (Figure 2.20) Typically the best 3D-image and illusion of depth can be seen in the central viewing cone, but technological advancement has allowed a reasonable perception of depth to be maintained throughout the entire viewing area.

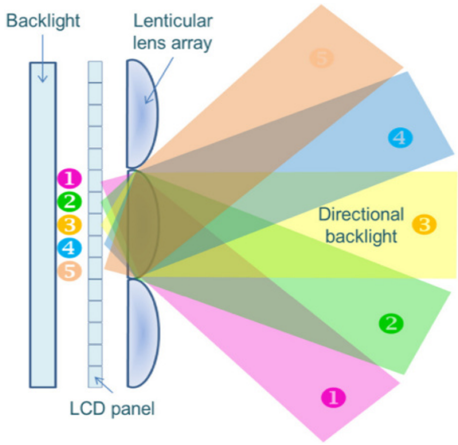


FIGURE 2.19

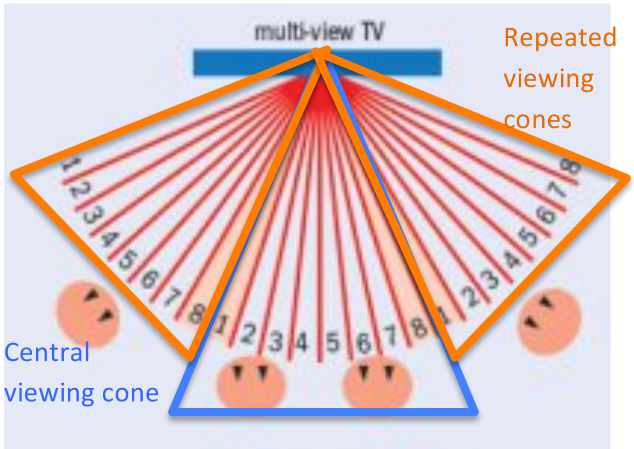
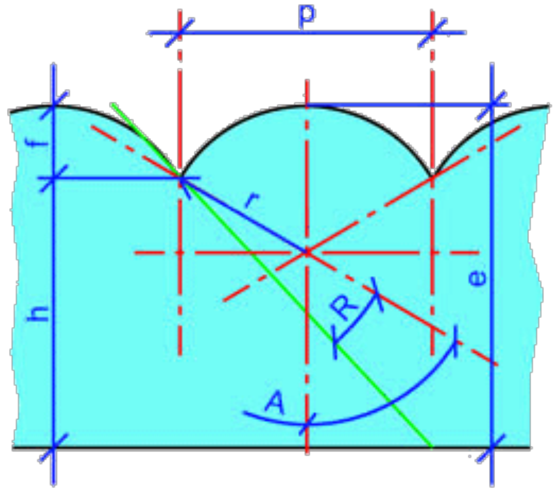


FIGURE 2.20

The advantage of an array of lenticular lenses over parallax is that the loss of brightness is far lower and it therefore doesn't require such a strong backlight as a parallax barrier would. Another advantage is that the lenses refract the light in different angles therefore allowing a far greater number of views at different angles to see a 3D image, greatly increasing the viewing freedom. Viewing the image onscreen from different angles will allow the viewer to see different images magnified each time. As with the parallax barrier the pixels need to display an image with left and right views interlaced.

The range of angles in which a viewer can still see the entire image is determined by the maximum angle at which a ray of light can leave the correct lenticule. The ray that leaves the lenticule at the maximum angle is also called the extreme ray.

The angle between the extreme ray and the normal can be calculated with the following formula:
R = the angle between the extreme ray and the normal through the point where the ray exits/intersects the lens
p = width of the lenticular lenses (pitch)
r = is the radius of the curvature of the lenses
e = is the thickness of the lenticular lens
h = the thickness of the substrate below the curved surface of the lens
f = the thickness of the lenticular lens minus the thickness of the substrate below the curved surface of the lens (e − h)



n = the lens's index of refraction

FIGURE 2.21

A = the angle between the normal through the centre of the lens's curvature and the normal through the point of intersection of the extreme ray and the lens.

$$R = A - \tan^{-1}\left(\frac{p}{h}\right)$$

$$A = \sin^{-1}\left(\frac{p}{2r}\right)$$

e=h+f ➔ h = e – f

$$f = \sqrt{r^2 - \left(\frac{p}{2}\right)^2} \text{ (Figure 44)}$$

$$R = \left(\sin^{-1}\left(\frac{p}{2r}\right)\right) - \left(\tan^{-1}\left(\frac{p}{\left(e - \left(\sqrt{r^2 - \left(\frac{p}{2}\right)^2}\right)\right)}\right)\right)$$

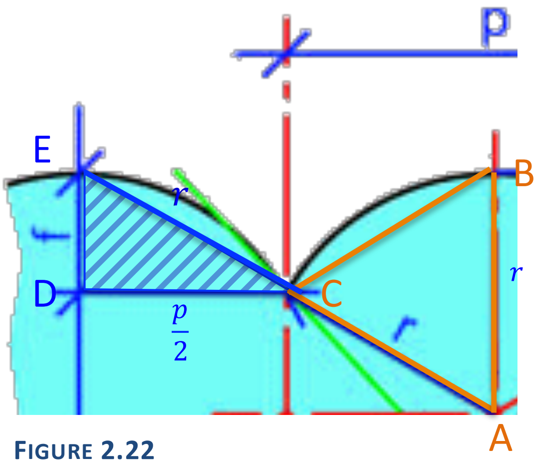


FIGURE 2.22

AC = AB = r ➔ ΔABC is an isosceles triangle

∠ABC = ∠ACB (isosceles Δ)

∠BAC = 60°

So ∠ABC = ∠ACB = $\frac{180° - 60°}{2}$ = 60° = ∠BAC ➔

ΔABC is an equilateral triangle ➔ BC = AC = r

Therefore CE = r

In ΔCDE

$ED^2 + CD^2 = EC^2$ ➔ $ED^2 = EC^2 - CD^2$

2.2.4: Autostereoscopic Content Conversion

Autostereoscopic content conversion is a fancy word for changing 2D images into 3D images, which can be seen without glasses. A key factor for autostereoscopic images is undoubtedly the precise acquisition of depth information, which is needed to reduce the huge bandwidth requirements of 3DTV transmission. A technique that is frequently used for content conversion is DIBR, Depth Image Based Rendering. This technique represents 3D images by dividing them into colour and depth images. This is used to create more views in a 3DTV.

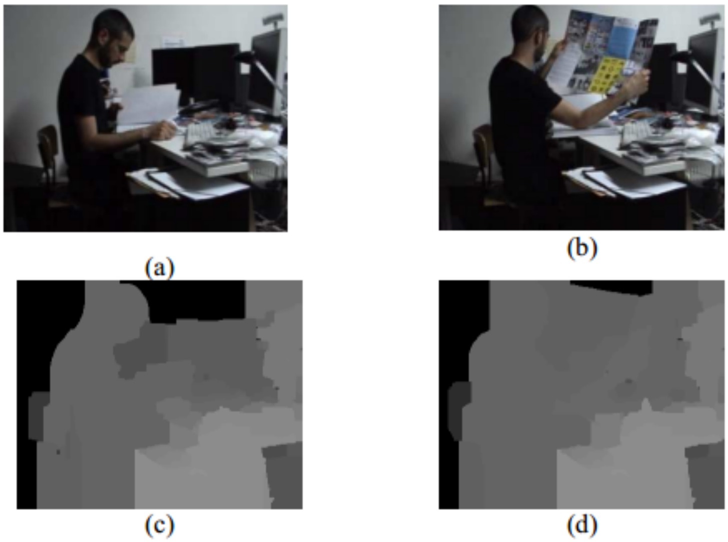


FIGURE 2.23: PICTURES A AND B WITH THEIR CORRESPONDING DEPTH MAPS C AND D

Most semiautomatic methods of stereo conversion use depth maps and depth-image-based rendering. The idea is that a separate auxiliary picture known as the "depth map" is created for each frame or for a series of homogenous frames to indicate depths of objects present in the scene. The depth map is a separate grey scale image having the same dimensions as the original 2D image, with various shades of grey to indicate the depth of every part of the frame. While depth mapping can produce a fairly potent illusion of 3D objects in the video, it inherently does not support semi-transparent objects or areas, nor does it allow explicit use of occlusion, so these and other similar issues should be dealt with via a separate method.

The major steps of depth-based conversion methods are:

- Depth budget allocation - how much total depth in the scene and where the screen plane will be.
- Image segmentation, creation of mattes or masks, usually by rotoscoping, which is a technique in which separate pictures are put in a certain sequence that repeats itself. For example, when you put 8 pictures of a man (see figure 2.24) behind each other you'll see that the man is walking. This technique can be used to split pictures of real people or spaces into segments, so that mattes or masks can be created. Each important surface should be isolated. The level of detail depends on the required conversion quality and budget.

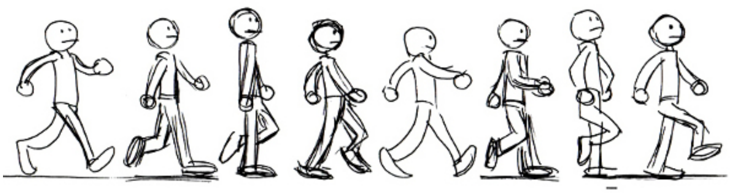


FIGURE 2.24

- Depth map creation. Each isolated surface should be assigned a depth map. The separate depth maps should be composed into a scene depth map. This is an iterative process requiring adjustment of objects, shapes, depth, and visualisation of intermediate results in stereo. Depth micro-relief, 3D shape is added to most important surfaces to prevent the "cardboard" effect when stereo imagery looks like a combination of flat images just set at different depths.
- Stereo generation based on 2D+Depth with any supplemental information like clean plates, restored background, transparency maps, etc. When the process is complete, a left and right image will have been created. Usually the original 2D image is treated as the centre image, so that two stereo views are generated. However, some methods propose to use the original image as one eye's image and to generate only the other eye's image to minimize the conversion cost. During stereo generation, pixels of the original image are shifted to the left or to the right depending on depth map, maximum selected parallax, and screen surface position.
- Reconstruction and painting of any uncovered areas not filled by the stereo generator.

Stereo can be presented in any format for preview purposes, including anaglyph.

Time-consuming steps are image segmentation/rotoscoping, depth map creation and uncovered area filling. The latter is especially important for the highest quality conversion.

There are various automation techniques for depth map creation and background reconstruction. For example, automatic depth estimation can be used to generate initial depth maps for certain frames and shots.

3: Method

In this section we will discuss the necessities for our prototype setup. These include the materials, calculations, applied techniques and considered variables.

3.1: Technique

To make an autostereoscopic display, we had to choose between all the techniques discussed above. We researched the price tag and difficulty of every technique on the Internet and asked the people we interviewed, which technique would be the best. The result was that we actually had to choose for the parallax barrier technique, because this is the most affordable and the most efficient way to make an autostereoscopic display. The other techniques are nearly impossible for students with our level and budget.

3.2: Materials

- Figure 3.1: A HP W19 (41x26cm) 19” Display
- Figure 3.2: A Samsung SyncMaster 943NW (41x26cm) 19” Display*
- Figure 3.3: A MacBook Pro 13” (Mid-2012)
- Figure 3.4: 5STAR A4 Transparent Paper for Inkjet Printers
- Figure 3.5: HP Photosmart 5525 Inkjet Printer (4800 x 1200 dpi)
- Figure 3.6: A Steel Ruler
- Figure 3.7: A Stanley-knife
- Figure 3.8: Photoshop Elements 2014 Software
- Figure 3.9: iPhone5 (8 Mega Pixel Camera)
- Figure 3.10: Fujifilm FinePix AX200
- Various Objects for Pictures

*For use in the presentation only

Figures of the materials can be found on the next page.

Material Figures

FIGURE 3.1

FIGURE 3.2

FIGURE 3.3

FIGURE 3.4

FIGURE 3.5

FIGURE 3.6

FIGURE 3.7

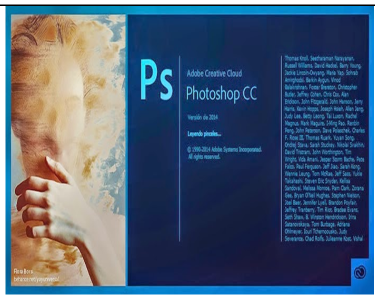


FIGURE 3.8

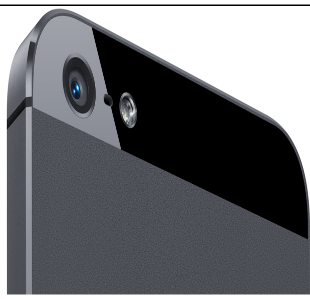


FIGURE 3.9

FIGURE 3.10

3.3: Calculations

In this section we will be making the required calculations for the model, as well as discussing the variables we intend to investigate.

3.3.1: General Calculations

Hypothetical Viewing Distance

The figure below (taken from the theory) shows the formula for calculating certain factors concerning parallax barrier, including the viewing distance.

i = the angle of incidence

r = the angle of refraction

n_1 = the refractive index of the medium from which the light came

n_2 = the refractive index of the medium the light is travelling towards

In the case of the parallax barrier $n_2 = n_{air} \approx 1.000$ therefore

$$\frac{\sin(i)}{\sin(r)} = \frac{n_{air}}{n_{glass}} = \frac{1}{n_{glass}}$$

so

$$\sin(r) = n_{glass} \cdot \sin(i)$$

$$\sin(i) \approx \frac{p}{2d}$$

$$\sin(r) \approx \frac{e}{2r}$$

$$\frac{e}{2r} = n_{glass} \cdot \frac{p}{2d}$$

$$\frac{e}{2r} = \frac{n_{glass} \cdot p}{2d}$$

$$2d \cdot e = 2r(n_{glass} \cdot p)$$

$$d \cdot e = r(n_{glass} \cdot p)$$

$$d = \frac{r(n_{glass} \cdot p)}{e}$$

In which:

e = eye separation
r = the viewing distance (distance between eyes and the screen
p = the pixel pitch (distance between two sub-pixels of the same colour on the inside of the display
d = pixel-parallax barrier distance

To calculate the hypothetical viewing distance, the formula has to be rewritten:

$$d = \frac{r(n_{glass} \times p)}{e}, therefore\ r = \frac{d \times e}{n_{glass} \times p}$$

The result is hypothetical, as n_{glass} differs per glass and light colour and e differs per human. p and d are given, but the possibility exists that these numbers are slightly off.

Barrier Pitch

To calculate the barrier pitch, the following formulas have to be used:

$$Pixels\ per\ barrier\ =\ pixel\ pitch\ *\ dpi_{printer}$$
$$Barrier\ slit\ width = pixels\ per\ barrier \times pixel\ width$$
$$Barrier\ pitch\ (in\ mm) = (barrier\ slit\ width\ x\ 2) \times 0.99$$
$$Barrier\ pitch\ (in\ pixels) = (pixels\ per\ barrier \times 2) \times 0.99$$

3.3.2: HP W19 Monitor

Hypothetical Viewing Distance

We used the following formula to calculate the viewing distance:

$$d = \frac{r(n_{glass} \times p)}{e}, therefore\ r = \frac{d \times e}{n_{glass} \times p}$$

$e = 65\ mm = 65 \times 10^{-3}\ m$

$r = ?\ m$

$n_{glass} = 1.52$

$p = 0.285\ mm = 0.285 \times 10^{-3}\ m$

$d = 0.9\ mm + 0.7\ mm = 01.6 \times 10^{-3}\ m$

$$r = \frac{d \times e}{n_{glass} \times p} = \frac{(1.6 \times 10^{-3}) \times (65 \times 10^{-3})}{1.52 \times (0.285 \times 10^{-3})} \approx 0.240\ m \approx 24.0\ cm$$

Barrier Pitch

$pixel\ pitch = 0.285\ mm = 0.0112204724\ inches$

$dpi_{printer} = 1200\ dpi$

$Pixels\ per\ barrier = pixel\ pitch \times dpi_{printer} = 0.0112204724 \times 1200 = 13.46456688\ px \approx 13\ px$

$Barrier\ slit\ width = pixels\ per\ barrier \times pixel\ width = 13.46456688 \times 0.285 \approx 3.84\ mm$

$Barrier\ pitch\ (in\ mm) = 3.84 \times 2 \times 0.99 = 7.5981\ mm \approx 7.60\ mm$

$Barrier\ pitch\ (in\ pixels) = (pixels\ per\ barrier \times 2) \times 0.99 = 13.46456688 \times 2 \times 0.99 \approx 26.65984226\text{px} \approx 27\ \text{px}$

3.3.3: MacBook Pro 13' (Mid-2012)

Hypothetical Viewing Distance

$$d = \frac{r(n_{glass} \times p)}{e}, therefore\ r = \frac{d \times e}{n_{glass} \times p}$$

$e = 65\ mm = 65 \times 10^{-3}\ m$

$r = ?\ m$

$n_{glass} = 1.52$

$p = 0.2188\ mm = 0.2188 \times 10^{-3}\ m$

$d = 0.9\ mm + 0.7\ mm = 01.6 \times 10^{-3}\ m$

$$r = \frac{d \times e}{n_{glass} \times p} = \frac{(1.6 \times 10^{-3}) \times (65 \times 10^{-3})}{1.52 \times (0.2188 \times 10^{-3})} \approx 0.313\ m \approx 31.3\ cm$$

Barrier Pitch

$pixel\ pitch = 0.2188\ mm = 0.00861417323\ inches$

$dpi_{printer} = 1200\ dpi$

$Pixels\ per\ barrier = pixel\ pitch \times dpi_{printer} = 0.0112204724 \times 1200 = 10.337007876\ px \approx 10\ px$

$Barrier\ slit\ width = pixels\ per\ barrier \times pixel\ width = 10.337007876 \times 0.2188 \approx 2.262\ mm$

$Barrier\ pitch\ (in\ mm) = 2.262 \times 2 \times 0.99 = 4.4782\ mm \approx 4.48\ mm$

$Barrier\ pitch\ (in\ pixels) = (pixels\ per\ barrier \times 2) \times 0.99 = 10.337007876 \times 2 \times 0.99 \approx 20.46727559\text{px} \approx 20\ \text{px}$

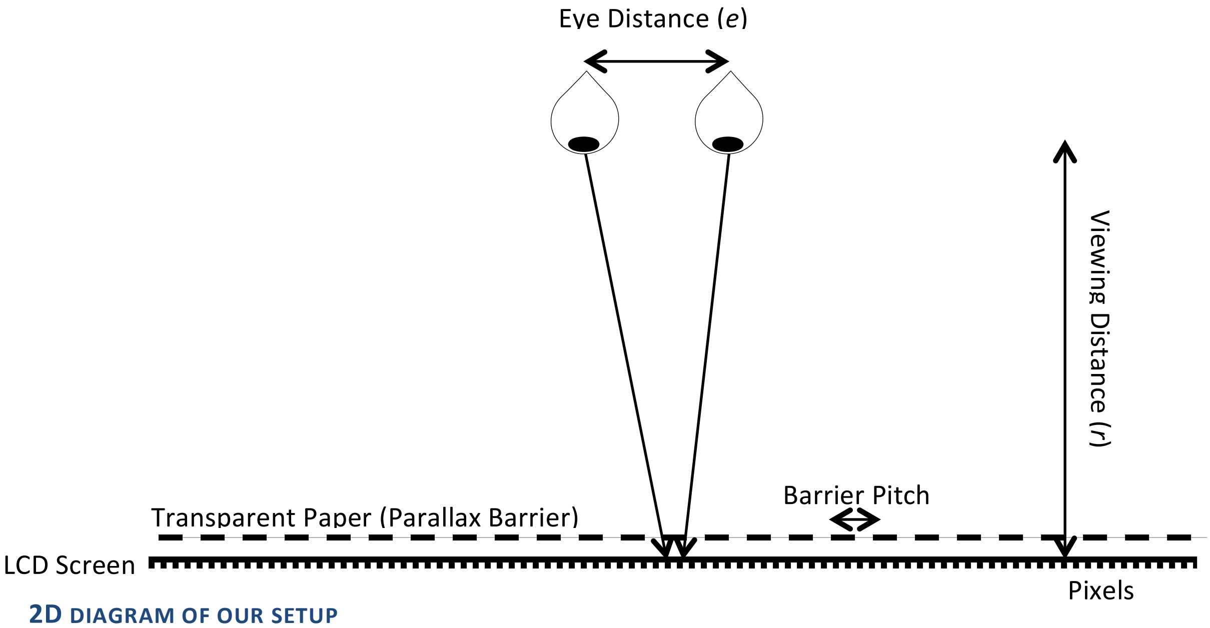
3.3.4: Variables

In the calculations, which apply to the model, these variables can play a big role:

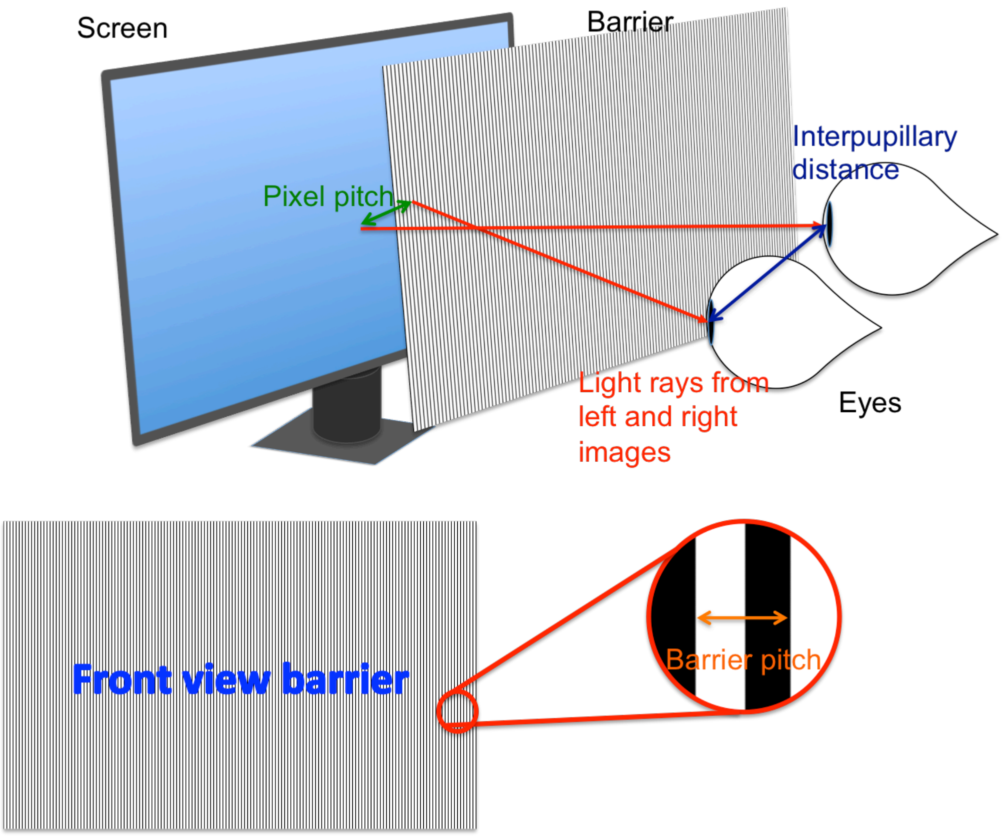
- Eye distance *(e)*: This is a variable because every human face is different. The pupillary distance can vary between 61 and 69 mm. That is why we took 65 mm as the average pupillary distance into our calculation. When the eye distance becomes longer, the viewing distance also becomes longer.
- The refractive index of glass (n_{glass}): This is a variable as the refractive indices of glass differ when exposed to a different colour of light. This can vary between 1.4 and 1.6, however the most common used value is 1.52. Therefore we took 1.52 into our calculation. However, when the refractive index becomes larger, the viewing distance becomes shorter. This is why it is an important factor in the calculation.
- The pixel pitch (*p*) is given in the specifications of most monitors. Therefore it can't be off that value very much. For most monitors this value is in between 0.25 and 0.30 mm. Whenever the pixel pitch becomes smaller, the viewing distance becomes longer and the barrier pitch becomes smaller.
- The pixel-barrier distance (d) is given in most specifications of most monitors. For most monitors this value is between 1.5 and 2 mm. The pixel-barrier distance is separated into two components: the screen depth and the pixel-screen distance. The barrier distance is not of any influence, as it's too thin and directly attached to the screen.
- The dpi-value of a printer ($dpi_{printer}$) is the amount of dots a printer can print every inch horizontally. The printer we used had a horizontal dpi-value of 1200 dots per inch. This dpi-value was recommended to us by various sources, as it would be the most suitable dpi-value for parallax barriers.
- What also has to be kept in mind is that certain values have to be calculated using the metric system, while other values should be calculated in inches.

3.3.5: Scheme

This is a basic schematic representation of our setup, drawn from above, including some of the terms we mentioned in the calculations. This is just an overview of the situation of the setup, including the variables from the calculations. <u>Note that this is not drawn to scale.</u>



2D DIAGRAM OF OUR SETUP



3D DIAGRAM OF OUR SETUP. PLEASE NOTE THAT THE DISTANCE BETWEEN THE BARRIER AND THE SCREEN IS ACTUALLY NEARLY 0 MM AND HAS BEEN PLACED FURTHER AWAY FROM THE SCREEN IN THE DIAGRAM FOR THE SOLE PURPOSE OF MAKING THE DIAGRAM CLEARER

4: Model

In this section we will include the setup, the phases for creating a working parallax barrier prototype and specifications of the final model. Pictures and screenshots of our findings and models can also be found in this section.

4.1: Setup

4.1.1: Barrier Creation

In order to create the parallax barrier, we used a trial of Photoshop CC 2014. With our calculations for the slit width and barrier pitch, creating the pattern was quite simple.

The first step was to create the pattern. When opening a new file, we filled in the following:

Width: 27 pixels for the HP W19 monitor and 21 pixels for the MacBook Pro Screen. (Barrier pitch)

Height: 1 pixel

Resolution: 1200 pixels/inch ($dpi_{printer}$)

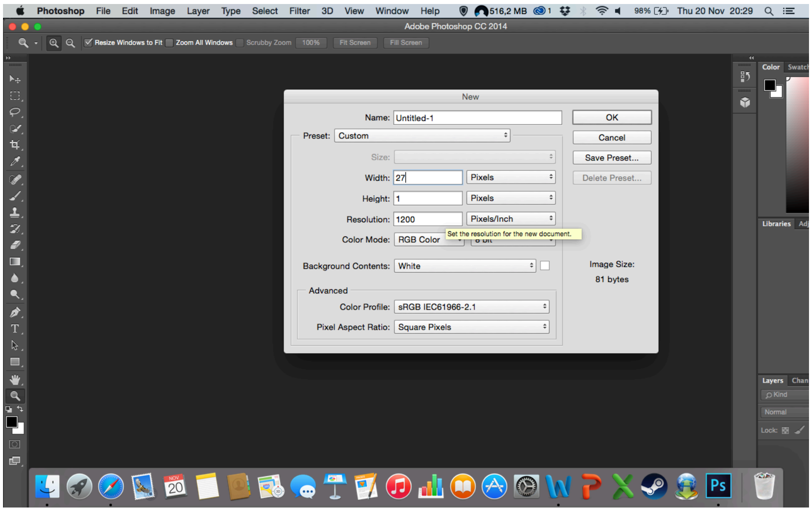


FIGURE 4.1

This created a single row of white pixels. Using the select tool, we selected the slit width in pixels (13 pixels and 10 pixels for the HP monitor and the MacBook Pro screen respectively.) and deleted these, leaving blacked out pixels behind (Figures 4.2 & 4.3).

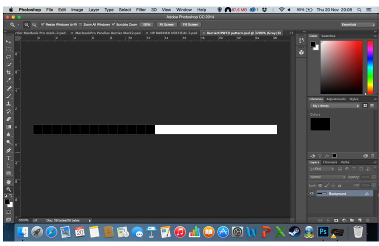


FIGURE 4.1

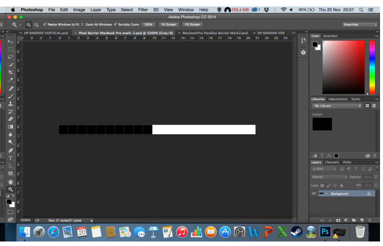


FIGURE 4.3

In a new file, we opened a blank A4 size page (21.0cm x 29.7 cm) (Figure 4.4). Next, to open the pattern in our new file, we clicked on the *fx* button and selected the *pattern overlay* option (Figure 4.5). From the pattern overlay menu we selected the appropriate pattern. (Figure 4.6), thus creating our parallax barriers (Figures 4.7 & 4.8)

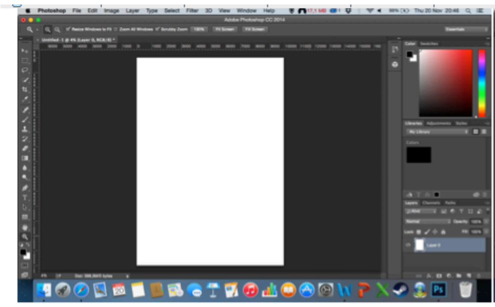


FIGURE 4.4

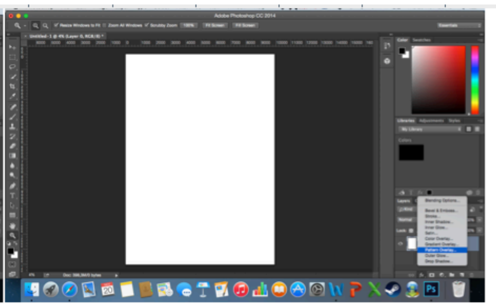


FIGURE 4.5

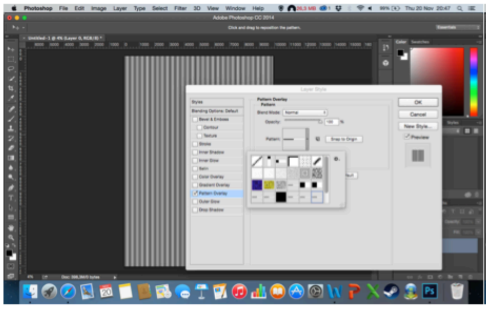


FIGURE 4.6

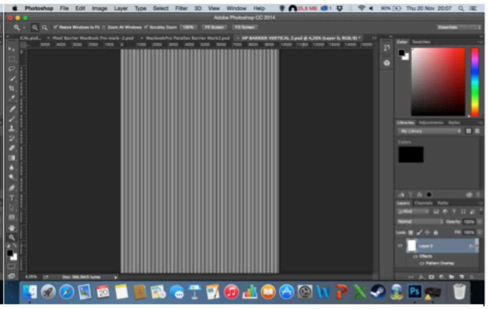


FIGURE 4.7

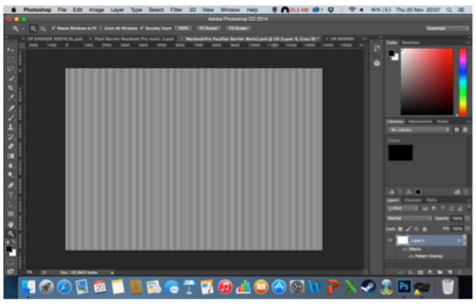


FIGURE 4.8

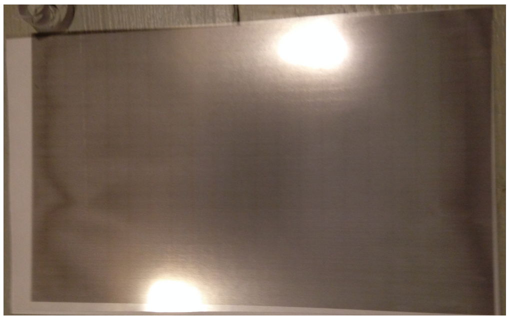


FIGURE 4.9

All that remained was to print these barriers on transparent A4 paper suitable for inkjet printers. We printed barriers for the HP monitor, but also for the MacBook Pro, so that we didn't have to carry the monitor around every time we wanted to work on the setup, barriers or content. Figure 4.9 shows an example of a printed barrier. Due to the larger screen size, we needed to print a barrier in portrait across two transparent sheets for the HP monitors, as opposed to printing the barrier in landscape on a single sheet for the MacBook Pro.

When printing it is important to be aware which side one must print on. Our paper had a smooth and a rough side. Printing on the smooth side resulted in a pattern that was easily smudged out and far from accurate. The rough side turned out to have a special layer on which Inkjet printers could print properly, without the ink smudging.

4.1.2 Interlacing Images

In order for a parallax barrier to work, we also require suitable content. As explained before, a parallax barrier requires the content for the left and right eye to be interlaced.

We used Photoshop CC 2014 to interlace our images.

First of all, we defined how many images we wanted to interlace; this corresponded with the number of views we wanted to create.

For the 2-view image, we decided to take the average slit width of 13px to interlace our image. In other words, we wanted to alternate between 13-pixel-wide columns of either image. For the 4-view image we decided to halve the amount of pixels and round off to the nearest integer (7 pixels). For the 8-view image we first tried halving the pixels again and rounding off to 3 pixels but this led to an overly bright and very blurry image. We therefore decided to stick with 7 pixels for the 8-view image as well.

We started by opening a new document in Photoshop 15cm x 15 cm in size and added all the images we wanted to use, one per layer. We then opened an additional layer for each of the images we wanted to interlace.

In order to create the pattern itself, we opened a new document 1 pixel in height and the (number of views*desired image column width) in width, i.e. 4 views * 7 pixels = 28 pixels wide. Then using the select tool, we created the patterns for the different views in the same way we did for the barriers.

The first pattern was the first **Right view** (**NOT** the left view).

7 pixels	7 pixels	7 pixels	7 pixels

RIGHT I IN A 4-VIEW SETUP

7 pixels	7 pixels	7 pixels	7 pixels
7 pixels	7 pixels	7 pixels	7 pixels
7 pixels	7 pixels	7 pixels	7 pixels

FROM TOP TO BOTTOM: RIGHT II, LEFT I, LEFT II IN A 4-VIEW SETUP

This is because you always start interlacing from left to right and when looking to the far left of your screen, your right eye will see the first column of pixels, as the figure below demonstrates (Figure 4.10).

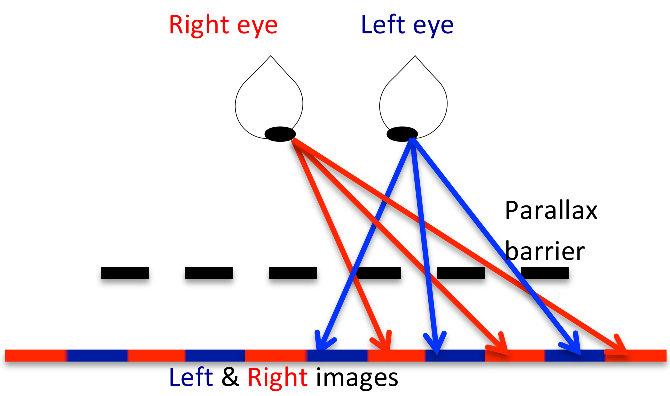


FIGURE 4.10

Having created and saved all the required patterns, we went back to the file containing the images, and added the patterns to the blank layers (**NOT** the layers containing the images).

After all the blank layers had been given a *pattern overlay,* we carefully selected each of these layers and did the following:

For each layer we clicked on *select* and then on *colour range*. From this menu we chose *shadows*, causing Photoshop to select all of the black columns. Then, with the columns still selected, we went to the image that corresponded with the particular pattern and clicked on *layer* → *layer mask* → *reveal selection* in the menu bar. This resulted in a pattern of columns of the image and blank columns in an identical pattern to the black on white columns.

Once we had done that for all the images, all we had to do was move around the images until we had a properly interlaced image, in which the separate views weren't placed to far apart and in which no black or white lines were visible, thus creating an interlaced image (Figure 4.11)

FIGURE 4.11

4.1.3: Barrier Test & Fine-Tuning

In order to create good content for our autostereoscopic setup, we had to take pictures from different views. The amount of views had to be at least 2, representing the right and the left eye.

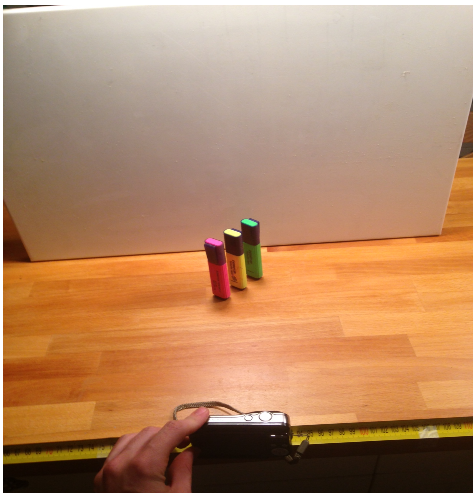
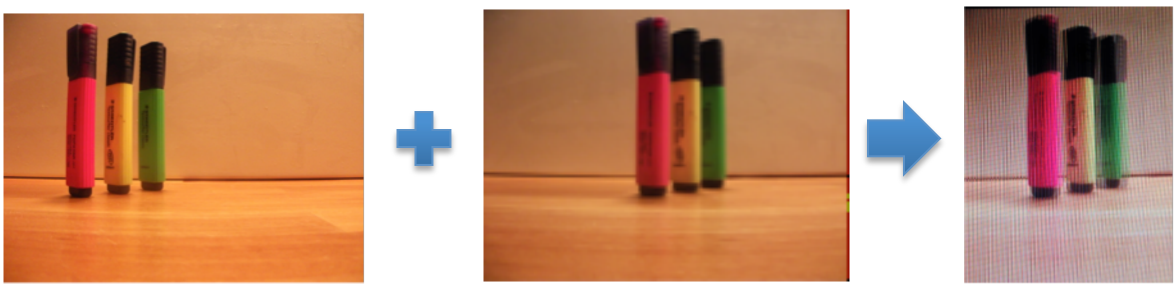


FIGURE 4.12

More views can be added to create a better 3D effect, but this also has to be taken into account while interlacing the images, as even more of the resolution is lost. The barrier can be adjusted to the number of and separation between the views, but it's easier to adjust the views to the barrier. This is what we did to find a good pattern for the next barrier test.

We started off with a simple setup, consisting of three markers in front of a plain white background, measuring tape and a camera. The setup can be seen in figure 4.12.

In order to test the barrier, we needed a test image. This image had to consist of at least two different views of an object (left and right views) interlaced into one image, or in other words split into columns of pixels and combined with the other view in alternating order (Left, Right, Left, Right…). By placing the barrier over the screen and properly aligning it with the image, the blacked out pixels of the barrier should block out certain columns of pixels for each eye, thus creating an illusion of depth. Figure 4.13 shows pictures of two views and their corresponding interlaced image.



LEFT VIEW RIGHT VIEW INTERLACED IMAGE

FIGURE 4.13

We used the interlaced image to test and align our barrier. By placing the barrier with the rough printed side against the screen and carefully shifting it horizontally, we were able to determine the optimal position for the barrier, while restricting the barrier distance to the pixel – front of screen distance. Otherwise we would have had to take the thickness of the paper into account. This was the position in which the barrier actually blocked parts of the image from a certain viewing angle. Only by shifting angle, can one see these blocked out parts, while subsequently causes other parts, in turn, to be blocked by the barrier.

The barrier that we first created, however, was not accurate enough to create a proper illusion of depth. What we did manage to achieve with this barrier was a “flipbook” effect: by shifting the barrier horizontally across the screen, the text on the highlighters in our test image changed in such a way, that certain segments of text appeared and disappeared from view as the barrier shifted over the image. Pictures of this setup are seen in figure 4.14, but the “flipbook” effect isn't very clear. This was heartening, as we knew that this was a step in the right direction.

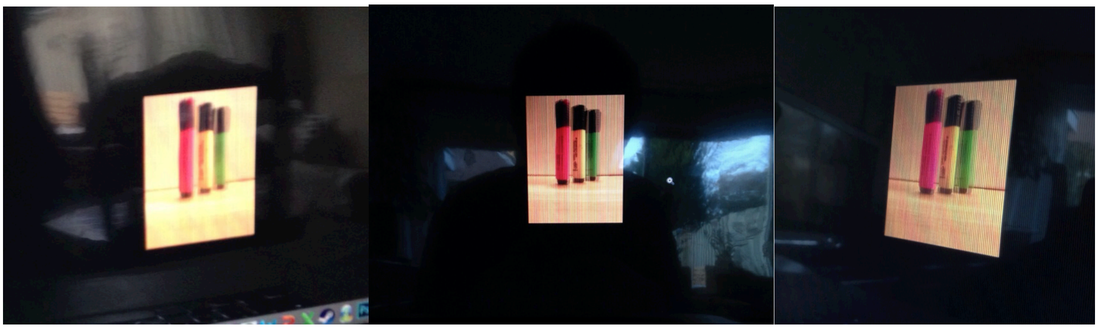


FIGURE 4.14

Further research, using some of the sources that we already had, gave us an indication as to how we could make our barrier more accurate. Our calculations showed that the barrier pitch for the HP and monitor's barrier and the MacBook Pro's barrier was approximately 27 pixels and 21 pixels, respectively. However as the first test showed, this was nowhere near accurate enough to create a 3D effect.

The barrier pitches were actually closer to 26.65984226 pixels and 20.46727559 pixels, respectively. This was due to the fact that according to the calculations, the respective barrier slit widths were 13.46456688 pixels and 10.33700788 pixels. As Photoshop doesn't allow creating patterns with fractions or decimal numbers of pixels, we had to be a little more creative with our pattern.

Rather than creating a pattern with 13 blacked out pixels and 14 white pixels (for the HP and Samsung monitors) or a pattern with 10 blacked out and 11 white pixels, we decided to extend the pattern as follows:

<u>For the HP monitor:</u>

$$\frac{13px\ (black) + 14px(white)}{2} = 13.5px\ average\ (barrier)\ slit\ width$$

$$\frac{13px\ (white) + \ 13\ px(black) + \ 14\ px\ (white)}{3} \approx 13.33px\ average\ (barrier) slit\ width$$

$$\frac{10\times\ 14px\ (white) + \ 11\times 13px(black) + \ 1\times 13\ px\ (white)}{22} \approx 13.454545\ px\ average\ (barrier) slit\ width$$

13.4545px is considerably closer to 13.46456688 than 13.5px

By finding the mathematical limits of the borders, a more accurate slit width can be found.

For the MacBook Pro:

$$\frac{10px\ (black) + 11px(white)}{2} = 10.5px\ average\ (barrier)\ slit\ width$$

$$\frac{10px\ (white) + \ 10\ px(black) + \ 11\ px\ (white)}{3} \approx 10.33px\ average\ (barrier) slit\ width$$

10.33px is considerably closer to 10.33700788px than 10.5px

Schematic example of MacBook Pro pixel patterns for the barrier:

10	B	L	A	C	K	P	X	11		W	H	I	T	E		P	X	

10		W	H	I	T	E		P	X	10	B	L	A	C	K		P	X	11		W	H	I	T	E		P	X	

Another reason why we weren't able to achieve a 3D-effect was the fact that distance between the left and the right views was too large and the distance between the camera and the objects was too small. Objects that appear in the foreground change too much to create a smooth 3D effect, when shifting views. The large distance between the photos (approx. 6cm or an average interpupillary distance) also made it hard to interlace the images properly. All in all, this taught us that creating an interlaced image required a lot more precision than we first expected. So we went decided to try again with a new image.

We tested the improved barrier MacBook Pro again, using a different image, which we interlaced using photos of a soup can we got off the internet (seen in figure 4.15) and the result was much closer to a 3D setup than the previous one, because our barriers were much more accurate than the ones used in a previous setup. We also experimented with shades of grey, to test whether it would influence the 3D effect but it did not.

FIGURE 4.15

This interlaced image resulted into the following setup, seen in figure 4.16:

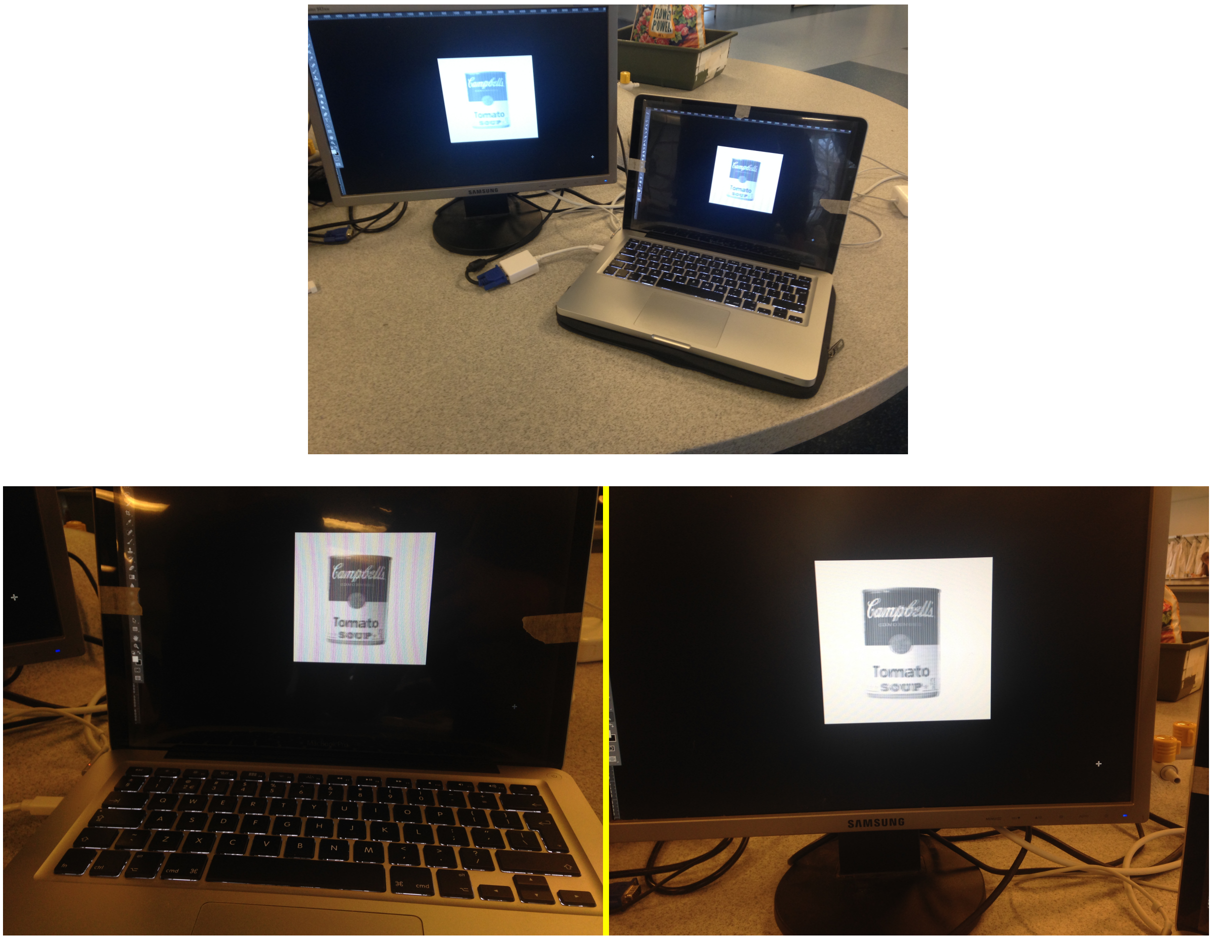


FIGURE 4.16

The interlaced image on the MacBook screen (left) was placed behind a parallax barrier, while the interlaced image on the Samsung monitor (right) was shown without a barrier. This resulted in a clear contrast between the two images. The interlaced image without a barrier had vertical lines running through it, appeared flat and did not change in any way when shifting views from left to right. The interlaced image with a barrier, however, appeared to have a rounded surface and actually seemed to have depth. Furthermore, the text on the can shifted position when moving our heads from left to right, as one would expect to see when looking around an actual soup can.

Having finally gotten the hang of interlacing images, we decided to make another interlaced image, the setup of which can be seen in figure 4.17. The setup consisted of a gas tap in front of a brownish background, a steel ruler and a camera. This time we decided to make 4 photos: 2 right views and 2 left views. We tried taking pictures with 3cm, 2cm and 1.5 cm between one another, but all of these distances were still too large. Through trial and error, we finally came to the right distance between the photos: 1cm. We first tried

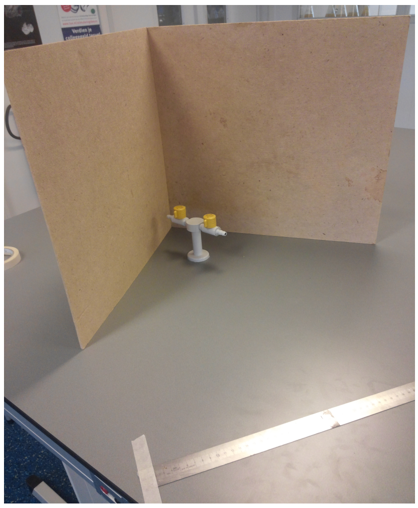


FIGURE 4.17

experimenting with various objects at different distances, but whilst interlacing we found out that the closest objects (<30 cm) moved too much when seen from different views. Therefore we decided to make the photos of the gas tap at approximately 35 cm distance, with one of the taps pointed to the camera, in order to create enough depth in the view. Having learnt from these mistakes, we were able to successfully interlace pictures we had taken ourselves, rather than just using images off the Internet.

After interlacing these pictures and editing them to fit the MacBook Pro barrier, we finally created our first successful 3D image. The results can be seen in figure 4.18, in which you can clearly see the different positions of the tap when viewed from left to right. One disadvantage however was the blurriness of the interlaced image, because 4 interlaced pictures have more overlap than 2 interlaced images. Nevertheless we were very pleased with the image we got and we decided that this would be the image to use on the prototype, as the 3D effect of this image was much more visible than in the previous tests. We still needed to get the same 3D effect on a monitor though, as this was more suitable for the prototype and a future presentation.

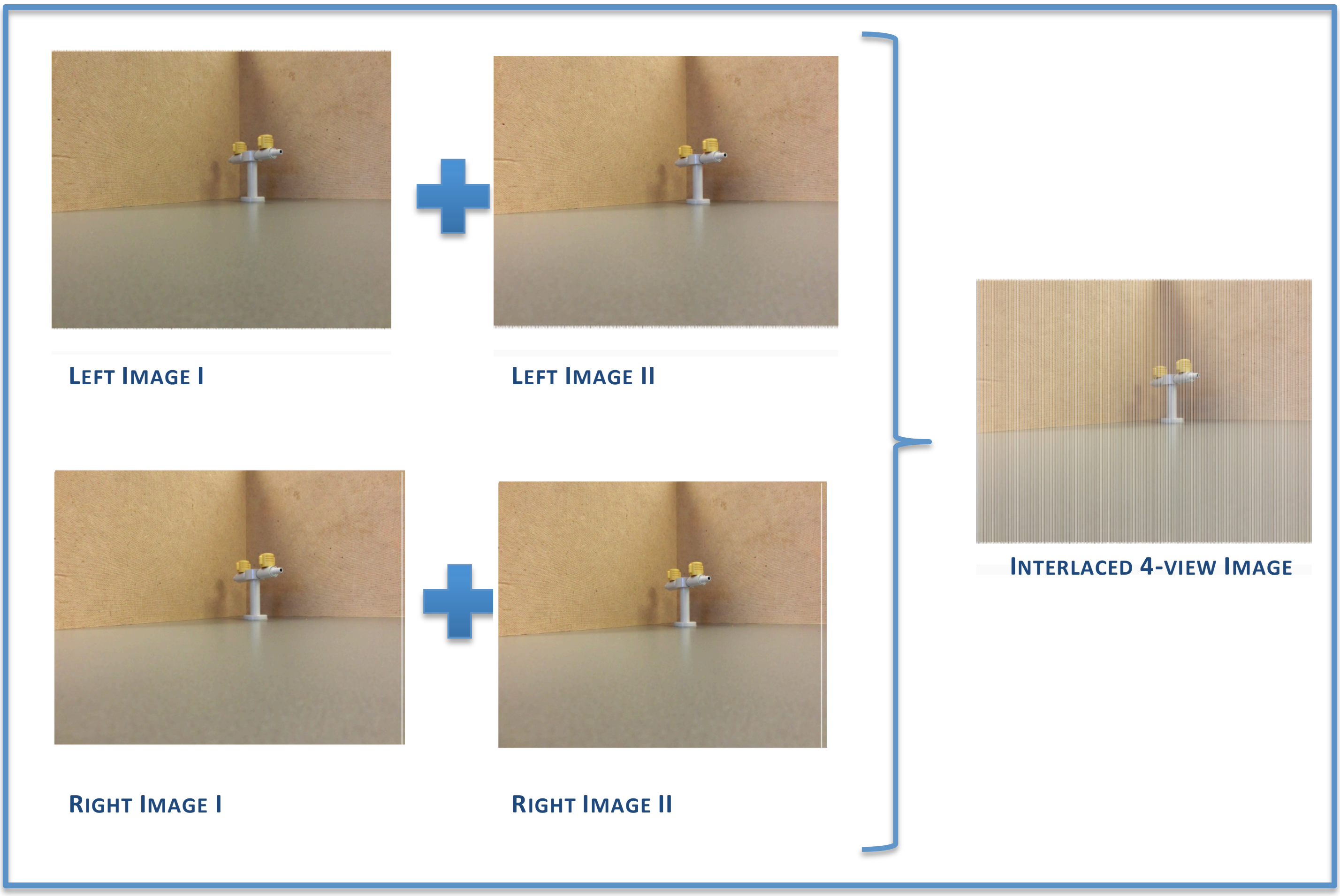
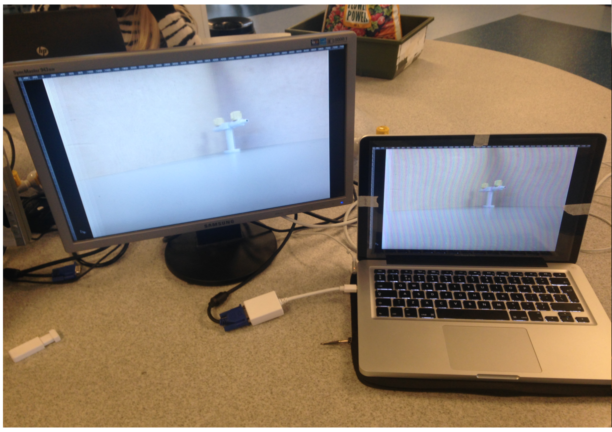


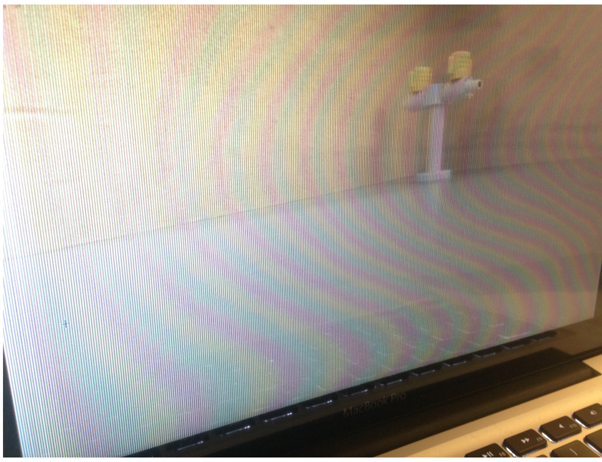
FIGURE 4.18

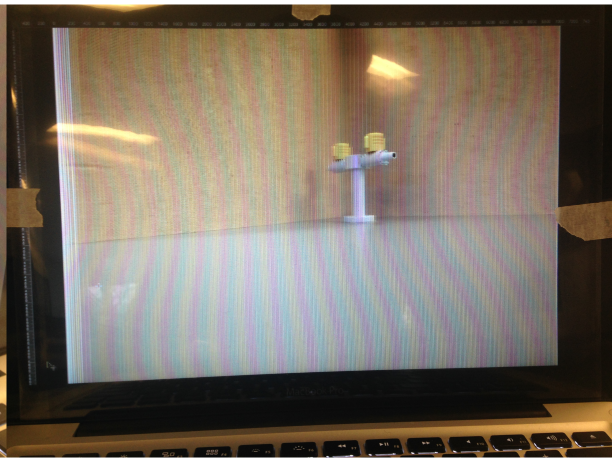
We displayed the interlaced image on a monitor, resulting in the setup seen in figure 4.19. We decided to show two images: one consisting of 4 views and the other consisting of two views to show a contrast in the illusion of depth that each of these images created. Furthermore a clear difference can be seen in the images, when viewed through a parallax barrier when viewed without a parallax barrier.

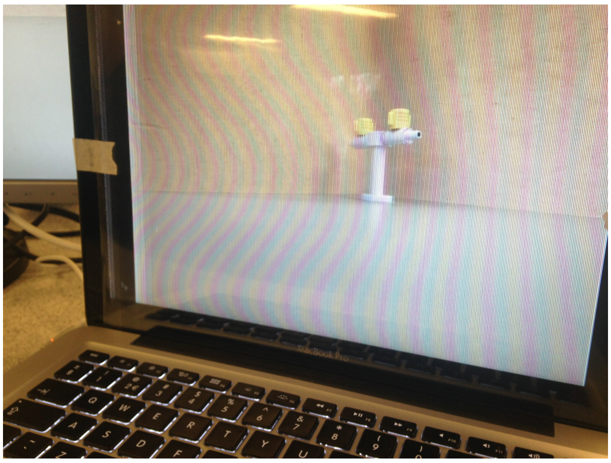


4 VIEW GAS TAP, WITH AND WITHOUT BARRIER

WITHOUT BARRIER







WITH BARRIER, VIEWED FROM DIFFERENT ANGLES

FIGURE 4.19

The tap really appears to shift when looking through the barrier at different angles, the illusion of depth is especially apparent in the front tap. When shifting one's head from left to right, the parts of the tap appear and disappear from view. This effect would be impossible without the parallax barrier. Therefore the image without the barrier appears flat and shows no difference when viewing it from different angles.

4.2: Prototype

As we mentioned in the previous section, we used the interlaced 4-view image of the gas tap (seen in figure 4.17) as content for the prototype. However we had to adjust the image to suit the HP monitor(s) instead of the MacBook Pro, for practical reasons regarding our presentation. To make the difference even more clear, we tried to implement different amounts of views on the two monitors, to make the prototype show the differences between images with more or less views. We used the following setup (see figure 4.20) to make an 8-view image of another object.

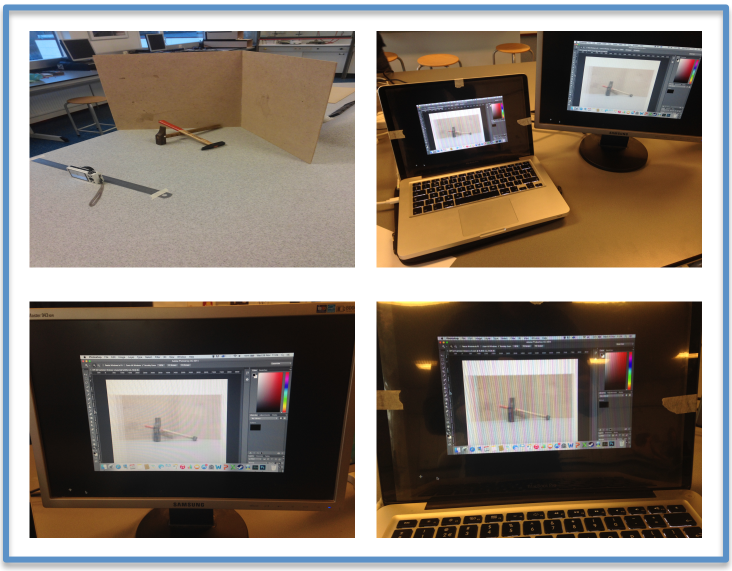


FIGURE 4.20

The pictures from the photo shoot and the interlaced image can be seen in figure 4.21 below:

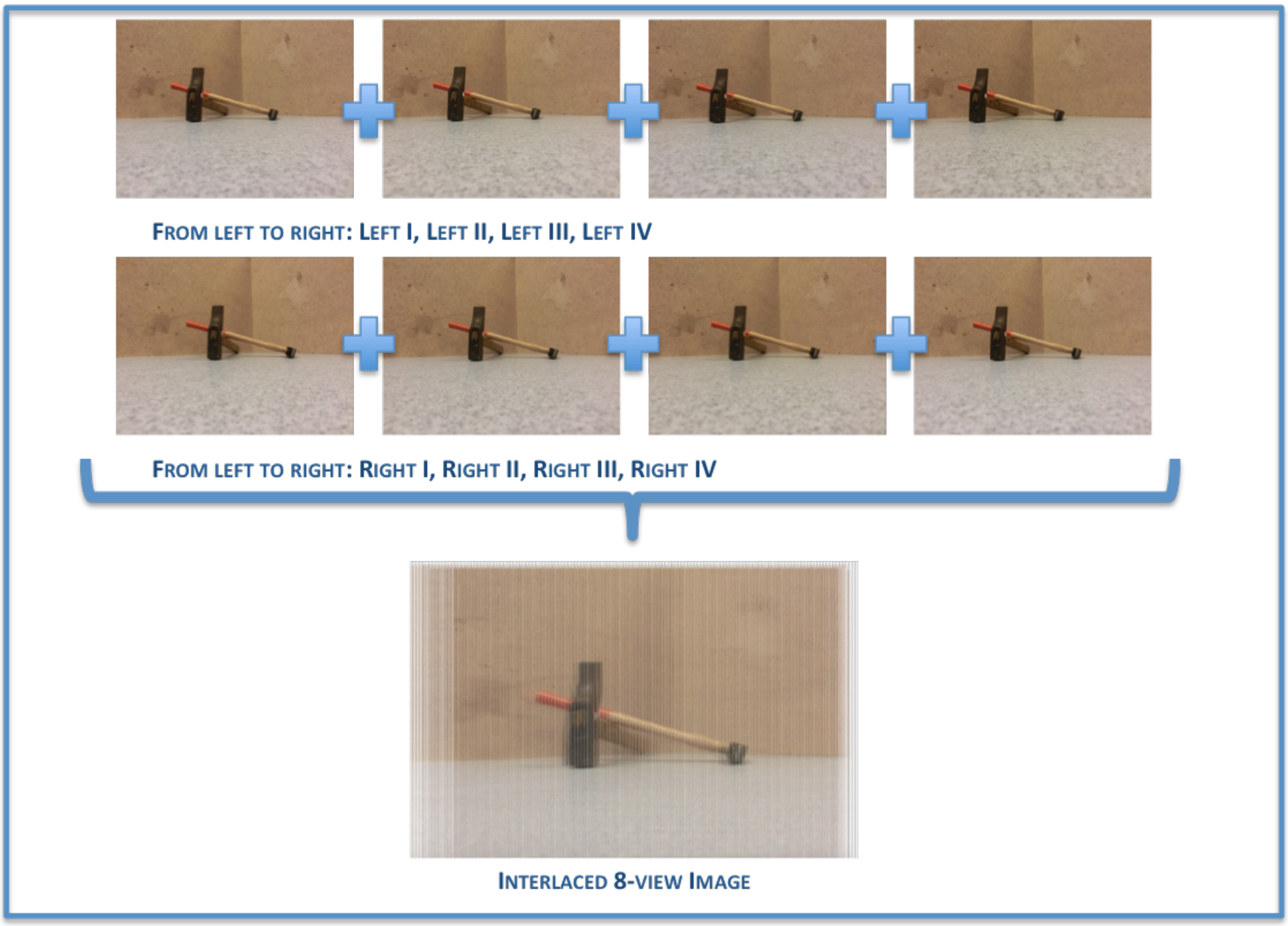


FIGURE 4.21

The 8 views were interlaced in 7 pixel-wide columns to create as clear an image as possible. This still resulted in a slightly blurry image but also created a much smoother 3D effect when switching from one view to another.

Figure 4.22 shows an overview of the different number of views that we experimented with:

As can be seen in the figure, the image becomes less and less sharp as more views are added. Meanwhile the illusion of depth and the ability to look around the object becomes more prominent. More views mean more viewing freedom and more potential viewing angles, thus creating a better 3D illusion, in real life, we have unlimited viewing angles and viewing freedom so more views brings the image closer to reality. However more views also mean more images that need to be interlaced which results in less of the individual images appearing in the interlaced image. This is what causes the increase in loss of resolution. Figure 4.23 shows the 4-view gas tap setup vs. the 8-view hammer setup, both with and with out the barrier.

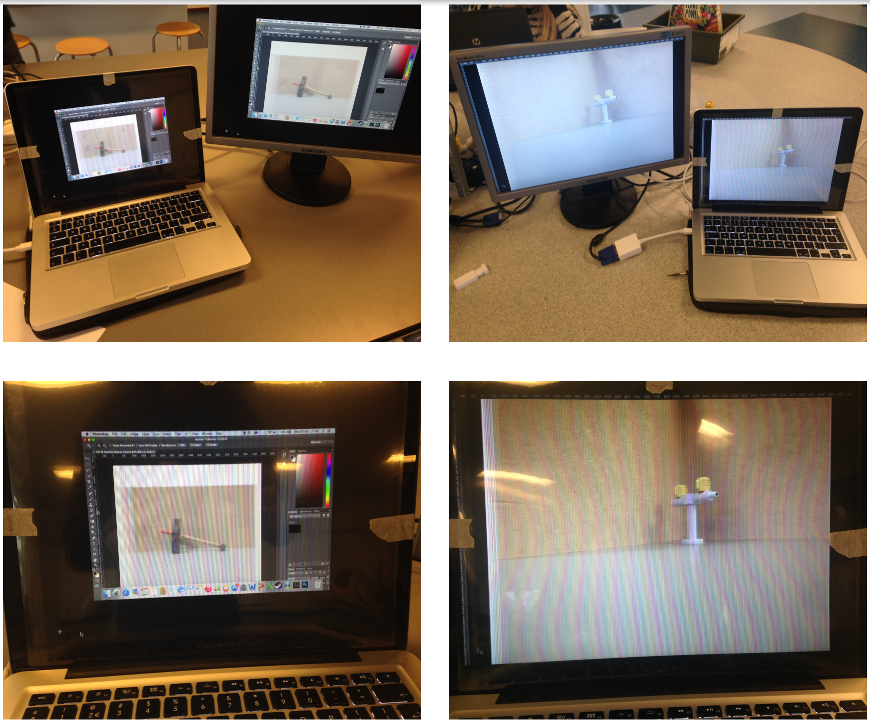
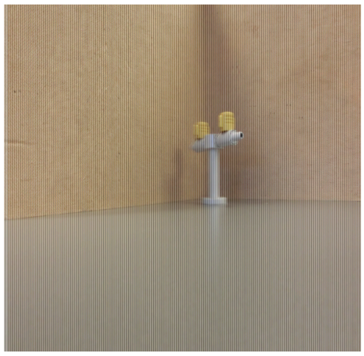
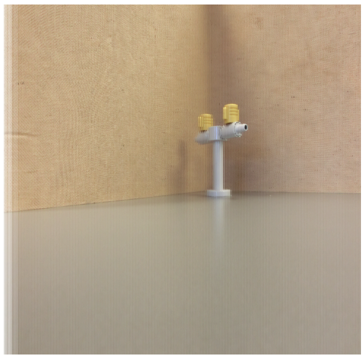


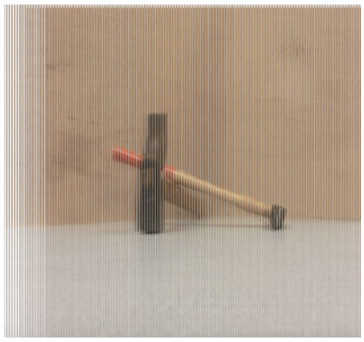
FIGURE 4.23



2 VIEWS



4 VIEWS



8 VIEWS

FIGURE 4.22

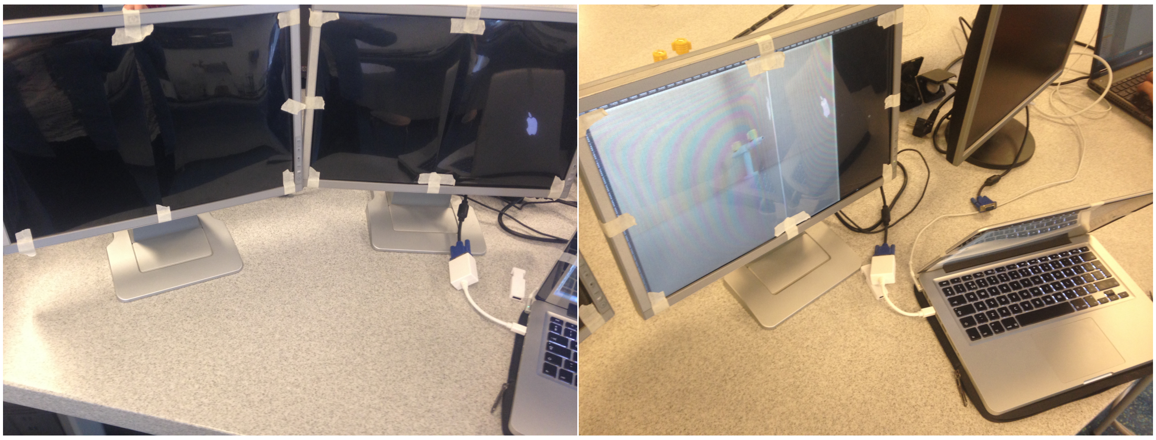


FIGURE 4.24

Figure 4.24 shows our complete model: two identical 19" HP w19 LCD monitors which we used interchangeably. Both provided with a parallax barrier printed across two transparent sheets of A4 inkjet paper. We connected the monitors to the MacBook Pro to provide a video signal for the images we wished to display. An overview of the various 3D images we displayed with our model can be seen in figure 4.25

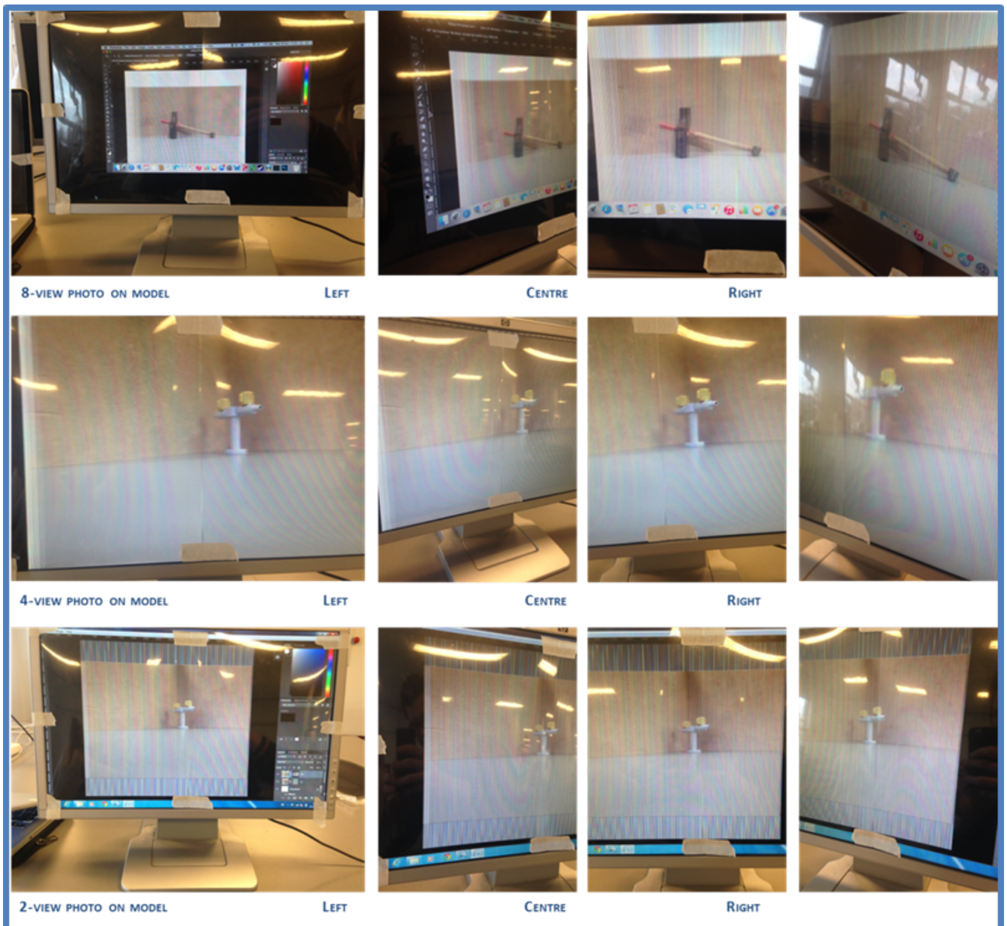


FIGURE 4.25

4.3 One last check: getting a second opinion

To make absolutely sure that our own will to make this project succeed wasn't clouding our judgement and that we weren't trying too hard to see the 3D effect, we asked a number of fellow students on the science floor to view the various interlaced images with our prototype.

Whilst showing them the images, we asked them whether they thought they saw depth, whether or not anything changed when shifting from left to right and if they saw differences in quality as the number of views increased.

The majority of the students stated that there was indeed an illusion of depth and that this was most prominent in the 4-view image. The 8-view image had a remarkably lower resolution, but a more subtle 3D effect, while most people didn't see much of a 3D effect in the 2-view image at all.

This reassured us, that we had indeed created a successful prototype and weren't just fooling ourselves into seeing 3D.

5: Finalisation

In this section we will evaluate and reflect on our work during the final thesis project. We will also round up the project and discuss a suitable way to present our findings and model to those who are interested. To end the thesis a small afterword will be included.

5.1: Conclusion

Our research question was:

> *Is it possible to recreate a prototype autostereoscopic setup, and if so what are its dependent factors, limits and possibilities?*

Before answering the research question, we will first go over the sub-research questions, their answers and how we came to those answers.

- *Which techniques to achieve displaying an autostereoscopic image already exist?*

In our in-depth research we found that autostereoscopy has developed quite a bit over the past 5 decades. This gave birth to a number of new techniques to create a 3D image without the need of glasses. The most relevant techniques are: integral photography and lenticular lenses, parallax barrier and holography. These techniques can all be used for autostereoscopic setups, but differ in price, quality and difficulty.

- *Which of these techniques lie within our capabilities and (financial) means?*

We found that the parallax barrier and the lenticular lens techniques were the most suitable for a setup meeting our capabilities. However, further research and expert interviews pointed out that the lenticular lens technique was way too expensive for us. Luckily the parallax barrier technique provided a cheaper alternative, which made it the most suitable technique for our setup, concerning its price tag and our capabilities.

- *How does this technique work? What factors does it depend on?*

The parallax barrier technique works with a transparent sheet in front of the (LCD) screen, on which a pattern of black and transparent slits is printed. The black slits block certain pixels for each eye allowing each eye to see different pixels. Interlacing two or more images and editing them to fit the barrier can, with the barrier combined, create a 3D effect. The left eye sees the pixels that form the left image and right eye sees the pixels that form the right image. The brain then combines these two images and converts it into one stereoscopic image, which completes the optical illusion. We discovered this during our in-depth research and our expert interviews with Dimenco and Philips. The technique depends on various factors, including the interpupillary distance, the viewing distance, the pixel pitch, screen-barrier distance and the refractive index of the screen. The setup also requires a lot of accuracy, as pixels are only micrometres long, which means accuracy is crucial whilst making a parallax barrier and its 3D content.

- *Can these factors be influenced or changed?*

Not all the factors discussed in the previous paragraph can be influenced or changed. The refractive index of glass, to start off with, is a given value, which cannot be changed manually. The pixel pitch is a specific for every screen/monitor and therefore cannot be influenced. This also counts for the screen-barrier distance, as we can't make the screen much thicker and the barrier has to be attached directly to the screen. The interpupillary distance or eye distance is another given value, which is different for any other human. There is, however, one factor we can change is the viewing distance. This value can be adjusted to the barrier and the content, as there is a large range of possible viewing distances.

- What are the limitations to using this technology?

During the practical phase we found that one of the disadvantages of parallax barriers is that half of the resolution is lost for each eye, as the black lines on the barrier cover half of the pixels on the screen. Another disadvantage is that a lot of light is lost, because not all the light can get through the transparent sheet. Besides the disadvantages of the sheet, the technique also has some general disadvantages, such as a short viewing distance and a limited amount of views. These two are closely related to each other, as a larger viewing distance gives more viewing angles and options. Furthermore, the 3D image isn't of very high quality, but as it was the only available option for our capabilities and budget, it was a very good way of creating an autostereoscopic setup. We knew about all these limitations beforehand, and we were very aware of these limitations during the practical phase. Luckily, in spite of our limitations, we were successful in creating a 3D image.

- What are the drawbacks of using a particular autostereoscopic setup when comparing it to other forms of autostereoscopy?

When comparing our setup to the prototype screens we saw at the companies we visited, we can easily say that the parallax barrier is not an optimal technique, when one desires a high quality autostereoscopic image. The lenticular lens technique is far more suitable for customers, as it does not suffer as much from loss of light, loss of resolution, short viewing distances and limited viewing freedom. Moreover, the 3D effect is far more immersive. Therefore it also has much more potential for future applications in various industries than the parallax barrier does, but its potential is reflected in the price tag and difficulty of the technique and its materials. This is why the parallax barrier was a quite good, cheap, and solid technique to use for our autostereoscopic setup, even though it's not the best technique available.

To repeat our research question one last time:

> *Is it possible to recreate a prototype autostereoscopic setup, and if so what are its dependent factors, limits and possibilities?*

Yes, it definitely is possible to recreate a prototype autostereoscopic setup, but depending on your financial means and capabilities, is has its limits. Parallax barriers have a fairly restricted amount of viewing freedom and a relatively small viewing distance, they halve the horizontal resolution of an image and the 3D effect isn't as sharp and clear as it would be with glasses or when using a lenticular lens sheet. However, the parallax barrier certainly has some possibilities as well, as it can clearly show a moderate 3D effect, when compared to regular pictures shown without a barrier. During the research we found that the amount of views can be increased, but this will reduce the resolution. This difference in resolution could be clearly seen, but the 3D effect is subtler. This factors had to be kept in consideration, while making the model.

5.2: Evaluation

On the very first day of the project, we told each other two things. The first thing was that we were not going to do this project just before the deadline and the second thing was that we had to find a topic which suited us and had something to do with our common interests. This should not be too hard, we thought. Therefore we started looking for new technical phenomena, which we were interested in, to find a good topic for our final thesis. We almost instantly thought of films, as we both enjoyed watching them. From this we moved on to cinemas, from which we got our first concept: 3D. We knew this would be the topic for our final thesis, as it is a thing of recent decades We dug deeper and deeper into the topic of 3D and by chance, we stumbled upon something totally new to us: Glasses-free 3D. To us, this was a new phenomenon, but we quite quickly agreed that it would be an even better topic for our final thesis. We also knew what we wanted to do with the topic: to use our technical capabilities to recreate an autostereoscopic prototype. This brainstorming phase did not take too long, and we believe it helped us to find a very good topic, which is why we feel this was a good first step.

Through further research we found out that certain companies in our area were specialised in making autostereoscopic LCD-TV's and doing further research into the development of its technology. With the help of our supervisor we contacted these companies with a request for an expert interview. We continued to do research on the topic, but we did not get any response from any of the companies. When we had completed a large part of the research, our supervisor told us that we should try to phone them over and over again until we received a response. Had we not done that, we might have missed out on the amazing opportunity to get these interviews and to get a sneak preview of some amazing autostereoscopic prototypes. The theoretical part was almost complete before the summer holidays. The interviews took place during the summer holidays themselves. We were very pleased with the answers and fresh insights we were given during the interview. However, we still had some background research to finish, as the deadline came closer and closer. It was nearly October when we finished the theoretical part and sent it to our supervisor for a first evaluation. The time and effort we had put into it paid off. Our supervisor was very pleased with the documentation of the theoretical stage. However, in the future we had to be keener to get a response from someone to avoid missing out on amazing chances. The time costliness of theoretical phase, did infringe on our plans for the practical phase, which may have resulted in a compromise in depth and quality.

We decided quite quickly which technique we were going to use. We believe we made the right choice, keeping our capabilities and financial resources in mind and based on the advice given by Dimenco and Philips. There was a slight unintended overlap between the theoretical and the practical stage, but this was due to the fact that we were running out of time. We started enrolling the first testing ideas at the end of October, which was quite late (we had planned to start early October). We gathered the required materials, but we were unable to start testing the barriers until mid-November. Realising that we had only two weeks left, we started printing the barriers right away. Unfortunately we could not use the Science Floor printer, as it was not compatible with Photoshop Elements. In the first test we learned much about the barriers, but we were not quite able to make a successful autostereoscopic setup. As the last week of the project commenced we realised that we had to come up with a working prototype very soon. Thankfully, only five days before the deadline, we achieved a successful autostereoscopic setup, allowing us to answer our research question positively. However, having updated the report real-time, we felt like we had some time left to enhance and fine-tune the prototype, as we did not have to write an entire report towards the very end. All that remained was the Prototype, Conclusion and Finalisation sections, which we could easily finish in the last week. We enhanced the prototype, which we believe adds value and depth to our final thesis and our presentation later on. The practical stage was a very stressful one, because we were running behind on schedule. Nevertheless, we enjoyed working on it and being able to show what we were able to do with our findings. We are very proud to have made this prototype, especially since we spent so much time and effort making it, and we nearly missed the deadline.

All in all, we were very happy with our ten-month cooperation. Dividing the tasks was always relatively painless and we both put a considerable and equal amount of effort into the project. We shared the same view on the thesis and on the process, which helped things to run smoothly. We believe we complemented each other in the theoretical and the practical stage, as we both have different qualities but common interests. We definitely put more time in it than the required 80 hours, as we were intrigued by our topic and model. Despite a slight difference in working hours, we were rather satisfied with one another's input. We thought the cooperation and communication with each other, as well as with our supervisor, Mr Van de Klundert, went quite well and we never had too much trouble meeting up with each other. We enjoyed our cooperation with each other and our supervisor and we appreciated the useful feedback and tips we were given. To conclude, we believe that our final thesis project can be considered quite successful and we are content about our model, report and project in general. A successful end to a ten-month adventure.

5.3: Presentation

Although our Final Thesis research has come to an end, there is still an upcoming presentation in January. For this presentation it is important that we select on information we want to talk about during the presentation and that we decide how we want to present our topic to the audience. We decided to keep the prototypes we have and show them during the presentation, so that the audience can take a close look at the differences between the different images and barriers. This consists of two parallax barrier monitors, one with 4-view content and one with 8-view content, to show the differences when changing the amount of views. We also decided to add a stereoscopic monitor, to show the difference between 3D with and without the need of glasses. Our prototype setup for the presentation will therefore consist of:

- One monitor with a parallax barrier (4-view autostereoscopic content of gas tap)
- One monitor with a parallax barrier (8-view autostereoscopic content of hammers)
- One monitor without a parallax barrier (colour anaglyph content) + corresponding colour anaglyph glasses
- Three laptops (for the interlaced images without a barrier)

We believe this setup will contribute the most to our presentation, as the differences we talk about can be proven by showing the different images. It therefore will visualise the core of our presentation, giving a clearer idea to our audience of how an autostereoscopic setup with a parallax barrier works.

5.4: Afterword

Our final thesis would not have been what it is now without some help, and we therefore want to thank Mr Van de Klundert for supervising us during the process and helping us to get the best out of the project. We also want to thank Mr Vandewalle and Mr Van der Horst for their time, interest and answers to the interview. We hope that you have enjoyed reading our report and that you will think about our report in the near future, when autostereoscopic 3D TV's will be available for customers. And while you are watching sports or playing your favourite video game, you realise that even you can make a basic autostereoscopic setup.

6: Bibliography

6.1: Literature

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Visual Angle	http://en.wikipedia.org/wiki/Visual_angle
3D TV	http://www.3duniversity.net/page.aspx?page=233 http://www.3dtvtechnology.org.uk/passive-3d
Chromadepth	http://www.thebrainfactory.com/learn-chromadepth.html
Pulfrich	http://www.3dglasses.net/Pulfrich%203D%20Glasses.htm http://www.thebrainfactory.com/learn-pulfrich.html
Autostereoscopy	http://www.dotztech.com/how-3d-without-glasses-works-autostereoscopy-technology-in-3d-vision/ http://www.outstanding-3d.com/3d-principles/autostereoscopy/
Holography	http://en.wikipedia.org/wiki/Holography
Parallax Barrier	http://en.wikipedia.org/wiki/Parallax_barrier http://www.opticsinfobase.org/oe/fulltext.cfm?uri=oe-19-24-24762&id=224479
Lenticular Lenses	http://www.outeraspect.com/history_lenticular.php http://www.lenstarlenticular.com/Lenstar/lenticular.htm http://www.dimenco.eu/our-technology/ http://en.wikipedia.org/wiki/Lenticular_lens http://physicsforme.com/2011/06/03/3d-tv-without-glasses/
Integral Imaging	http://en.wikipedia.org/wiki/Integral_imaging
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Content Generation	http://www.3duniversity.net/page.aspx?page=12]
Calculations & Specifications	http://h10032.www1.hp.com/ctg/Manual/c00661319.pdf http://www.unitconversion.org/typography/pixels-x-to-millimeters-conversion.html http://www.mtbs3d.com/phpBB/viewtopic.php?f=26&t=1467&start=191 http://h10010.www1.hp.com/wwpc/pscmisc/vac/us/product_pdfs/HP_Ofice jet_Enterprise_ColorMFP_X585series.pdf

6.2: Figures

Figure 1.1	http://telescript.denayer.wenk.be/2012-13/b4/public_html/fotogrammetrie.shtml
Figure 1.2	http://en.wikipedia.org/wiki/Accommodation_of_the_eye http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel_pre_2011/electrical/thenervoussystemrev4.shtml
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Figure 2.12	https://www.flickr.com/photos/macheophotos/5856411655/?rb=1
Figure 2.13-14	http://www.photonics.com/images/Web/Articles/2009/3/8/Figure10_1.jpg
Figure 2.15-16	http://www.ecti-thailand.org/assets/user_files/fck/Untitled(1).jpg
Figure 2.17-18	http://www.dimenco.eu/our-technology/lens-technology/
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Figure 3.1	http://h10025.www1.hp.com/ewfrf-JAVA/Doc/images/940/c00655675.jpg

Figure 3.2	http://cdn.clubafaceri.ro/clients/16/82634/80/monitor-lcd-samsung-943nw-s-19-inch-wide-5ms-854439_big.jpg
Figure 3.3	http://content.hwigroup.net/images/products/xl/165122/3apple_macbook_pro_md213na.jpg
Figure 3.6	http://ecx.images-amazon.com/images/I/314-JohhtiL._SY300_.jpg
Figure 3.7	http://www.londongraphics.co.uk/netalogue/zoom/knife-stanley.jpg
Figure 3.8	http://2.bp.blogspot.com/-qM1cu8GrlfY/VCTVzcFCB6I/AAAAAAAABik/dU4mBJpGaYE/s1600/Add152.jpg
Figure 3.9	http://lifeinlofi.com/wp-content/uploads/2012/09/iphone-5-camera.jpg
Figure 3.10	http://s3.amazonaws.com/nl.hub.foobar/images/original/1076/fujifilm-finepix-ax200.jpg?1318235257

The figures that aren't mentioned in the bibliography were of our own making and therefore didn't need any reference.

7: Appendix

Appendix A (Dolby White Paper)

Dolby White Paper on Dolby 3D® for Glasses-Free TV and Devices

http://ewh.ieee.org/r6/scv/ce/meetings/DOLBY_3D_GlassesFree_WhitePaper_WEB_Final.pdf

Appendix B (Interview Audio Files)

Digital Audio Files of our interviews with Patrick Vandewalle, employee at Philips and with Jan van der Horst, CTO at Dimenco. Also includes a link to the official site of Dimenco.

Interview Philips: http://vocaroo.com/i/s1948PVzG5sj

Interview Dimenco: http://vocaroo.com/i/s171iSkpmZdB

Dimenco Site: http://www.dimenco.eu/

Appendix C (Log and Website)

The first link is one to the log we kept during the final thesis. The second links to the home page of the personalised Google website we used for documentation and log keeping during our final thesis.

Log: https://sites.google.com/a/spvozn.com/pws-3d_imaging/time-tracker

Website: https://sites.google.com/a/spvozn.com/pws-3d_imaging/home