MAXIMIZING USER COMFORT & IMMERSION

A GAME DESIGNERS GUIDE TO 3D DISPLAYS

Jens Ogniewski
Information Coding Group, Linköpings University
581 83 LINKÖPING, Sweden
jenso@isy.liu.se

One of the key elements of game development is to heighten the immersion of the user, i.e. all means that increase the experience of perceiving the game as reality. This can be done by e.g. using realistic graphics, whose effect can be heightened further by using a 3D display solutions. Recent months have seen the introduction of several such solutions like NVIDIAs 3DVision, Nintendos 3DS, and Sony's enhancement of the Playstation 3. Although many reports have been done concentrating on the more technical aspects of these display systems (see (NVIDIA), (Schneider and Matveev, 2008), (Flack et al., 2009) and (Sony) for examples), guidelines on more subjective aspects like user comfort have yet to be developed. This report is meant as a first step to close this gap.
Many different 3D displays are available, however this report concentrates on autostereoscopic and glasses (both polarization and shutter)-based displays, since these share common problems and all systems available to the customer fall in these categories. All these systems have in common that they create the illusion of three-dimensional images by showing each eye a slightly different image. Thus the eyes of the user are tricked to see objects in places were they are not, which can however confuse the human focusing system and ultimately lead to eye-strain. Reducing the discomfort for the eyes of the beholder while at the same time maintaining a vivid 3D effect is the main challenge a modern game designer faces in this regard. As will be shown, immersion and user comfort are not always contradicting goals.
Although only few studies have been conducted on 3D quality in computer games (see (Häkkinen et al., 2006) or (Ogniewski and Ragnemalm, 2011) for examples), the problem is much better researched by the video society, and much can be learned from their results. For example, Lambooij et al. (2009) and Kalva et al. (2006) examined stereoscopic systems for video applications in regards to user comfort, while Meesters (2004) presented an overview of different artifacts that can occur in stereoscopic image systems. Finally, Konrad and Halle (2007) suggested different solutions to overcome some of these shortcomings. Although most of the results apply to video games as well, a few problems do not arise there (like e.g. blocking artifacts due to the video compression), while others might be introduced (e.g. problems due to incorrect depths or occlusion).

1. MOTIVATION

Over the years, many different 3D solutions have been developed. One should note that early systems go back as far as 1838, i.e. they even outdate photography. However, only recently the quality and the pricing of the systems became good enough to allow entrance to the consumer market. Still many critics expect the current developments to be a temporary craze, but it seems that the technologies are finally mature enough to find general exception. Also, most TV-sets that are sold nowadays are at least 3D-ready, so that there will be a 3D capable display in most homes soon. The only downside is the limited content, in form of the available videos. Most computer games contain already elaborate 3D scene geometry, which could be easily used to generate stereoscopic images. However, as we shall see, it is unfortunately not as easy as simply rendering a second image from a different viewpoint. There are already many good stereoscopic computer games available (showing that modern 3D displays are up to the task), but sadly just as many bad examples as well. It just goes to show, how good (or painful) a stereoscopic game is depends on the skill of its developer. Therefore, a few points on what one have to think about while developing a computer game for a stereoscopic display should prove useful.

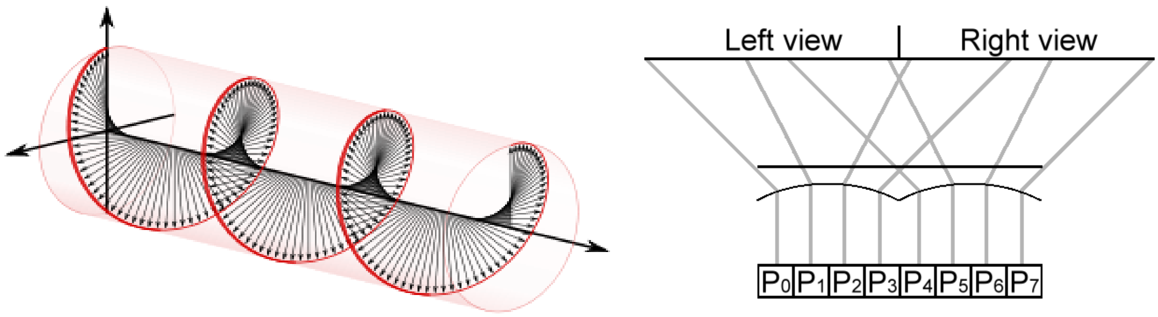

Figure 1: a) (left) polarized light wave as used in polarized-glasses-based 3D displays, taken from (wikicommons)
b) (right) lenticule-based autostereoscopic display: P0..P7 donate different pixels on the display, the grey lines are the light rays emitting from these

2. 3D DISPLAY TECHNIQUES

Of the many different 3D displays available, only three different will be considered here (see (Ogniewski, 2009) for a more complete overview): shutter-glass-based, polarized-glass-based and autostereoscopic. These systems show common characteristics, and furthermore all displays available to the consumer fall in one of these categories.

Shutter-glass-based systems are probably the most ubiquitous at the moment of this writing[1]. They work by showing different images for the right and the left eye alternatively, while the two glasses switch between transparent and nontransparent, thus allowing only one eye to see the actual image (thus it can be seen as a time-multiplex stereoscopic display). Crosstalk (light leakage between the right eye and the left eye image) can exist due to inaccurate synchronization between the glasses and the display, or due to the speed with which the display can switch between different colors. To minimize these effects, guardbands are introduced, which are basically periods where both glasses are nontransparent. On the plus-side, these displays are comparably cheap and many modern displays are already able to show images fast enough for this kind of solutions. However, the glasses needed are expensive, heavier than polarized glasses and need batteries to run. Furthermore, due to the shuttering these solutions are susceptible to flickering.

Polarized-glass-based system use the polarization of the light to separate the two different images. The polarization of a wave is the direction in which it oscillates. For example, a sine-wave in a three-dimensional space might be contained in a plane. If a filter is constructed which is perpendicular to this plane, the sine-wave will not be able to pass it. Constructing a 3D display using this principle is possible (and has been done since the late 1930s), however it will lead to problems if the beholder tilt his/her head (thus effectively inverting the stereo image). Therefore, modern polarization-based systems are circular multiplexed. The light rays are giving a spin, i.e. they change their polarization clockwise or counter-clockwise (see also figure 1a)). Thus, the two different swinging directions can be assigned to the two different images. This technique has been successfully used in 3D cinemas for several years, however only few displays using this technology are available for the consumer. The main reason is that such displays need the double resolution, which is more difficult and expensive to produce than a higher frequency. These displays are prone to crosstalk as well, which is introduced by imprecise manufacture of the optical components or light leakage of the diodes[2].

Only few autostereoscopic displays have arrived on the consumer market. Autostereoscopic displays work by using optical filters like lenses or lenticules (or even simple slits; see also figure 1b)) to direct the light in different directions. On the plus-side, the beholder doesn't need to wear glasses, however they have to be sitting in the sweetspot – straining from this spot will lead to increasing crosstalk and eventually stereo-inversion. This is one of the main reasons why most available autostereoscopic systems are actually handheld systems – keeping the user in the sweetspot is easier since it can be assumed that they will be approximately one arm-length away and holding the system parallel to their eyes. Like polarized-glass-based systems autostereoscopic systems will need the double of the resolution as each of the two images.

All these systems have further in common that they direct only part of the light to each eye, thus decreasing the illumination level of the display.

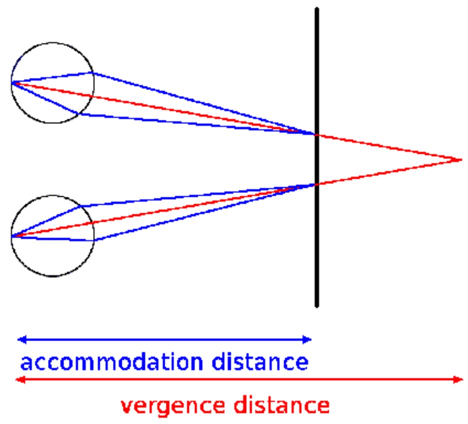

Figure 2: accommodation and vergence conflict introduced by an stereoscopic display; the virtual placement of the object is where the two red lines meet

3. SHORTCOMING OF CURRENT STEREOSCOPIC DISPLAYS

The main problem of stereoscopic displays is that they force the human eye to perceive objects in other places than where they are actually located, thus introducing an accommodation problem since the vergence distance and the focal distance are not the same (see also (Shibata et al., 2011) and figure 2). This effect can lead to severe eye strain if the display is observed over a longer time. The effect and its strength is very different from user to user, a certain percentage of the populace is even not able to see such images in 3D at all.

Note that eye strain is not limited to 3D displays and in fact occurs even if using 2D displays. However, due to the unnaturalness of the presented images in the case of 3D displays and the higher stress this induces on the eyes, 3D displays are more prone to lead to user discomfort.

4. BASIC DESIGN RULES

As mentioned, the main drawback of stereoscopic 3D displays is the problem they can cause for the human visual system. Reducing its workload should therefore be the main task for the game designer regarding 3D displays, especially easing the focusing. Flack et al. (2009) suggested an auto-focus procedure which could help with that. In any case, it should not be made more difficult by e.g. introducing focus blur (as is unfortunately still done in many 3D movies).

Apart from that the game designer should oblige to the following basic rules: 1. keeping the scene as realistic (in terms of using correct depths and occlusion) and 2. as simple (i.e. including as less objects and depth variation) as possible (both to lessen the burden on the user eyes) and 3. to give the user possibilities to adjust settings, thus accommodate to the fact that the perceived 3D effect and the discomfort it causes varies from user to user. In many cases the display supplier already provides these settings which can easily be incorporated in an application.

One example for keeping the scene simple is to tread motion carefully. Speranza et al. (2006) showed that movements towards to resp. away from the user (i.e. in depth or the z-direction) can increase the eye strain. Although it is often assumed that all kinds of motion heighten the stress on the users eyes, the author could not find a study which confirmed this.

Furthermore, the game designer should not overdo the depth effect by e.g. enhancing the perceived depth artificially or placing objects as far in front or behind the screen as possible. Instead, it is better to adhere to the comfort zone described by Wopking (1995), i.e. the zone in which the scene can be virtually placed while minimizing the eye-strain. Also, Chen (2011) developed rules on how the two cameras should be correlated, while Jones et al. (2001) described how the perceived depth can be controlled.

 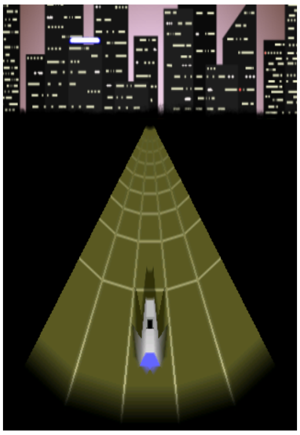 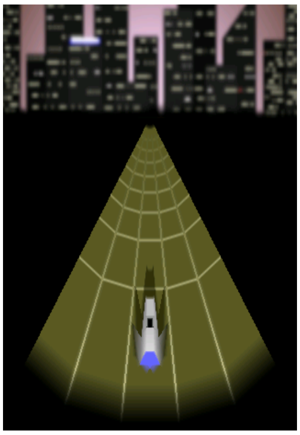

Figure 3 (left): Example for depth cues used in art: painting in the sistene chapel, taken from (vatican)
Figure 4 (middle, right): Different depth cues used in a computer game:
a) (middle) without distance blur, b) (right) with distance blur

5. DEPTH CUES

Depth cues are basically all measures which heightens the perceived depth of an image. They have been used by artists for centuries, see figure 3 for an example. As one might have guessed, stereoscopy itself is a depth cue, too, but not the only one which is of interest for the game designer. Other important depth cues are occlusion, motion parallax (as explained later) and distance blur, see also figure 4. It is of high importance to get these depth cues correct, i.e. in accordance with the stereoscopic effect, or otherwise the immersion of the user will be lessened while at the same time increasing their discomfort. Especially occlusion should be handled correctly, whose importance was already shown in (Cutting and Vishton, 1995).
On the other hand, correct handling of the depth cues can aid the visual system to determine the correct depth, thus minimizing its workload.
Of these depth cues motion parallax shall be explained further, since its concept is not as commonly known as the others. Basically motion parallax is the change of the viewpoint in accordance to the movement of the user, and is easily introduced by user tracking, either using optical tracking or a gyroscope or accelerometer (see also (Ogniewski and Ragnemalm, 2011)). It is possible to produce 3D displays relying on motion parallax alone, as shown in (Suenaga et al., 2005) and (Uehira et al., 2007). See also (Lee) or (Francone et al.) for examples.

 

Figure 4: truncation of objects by the image borders: a tree (left) and the same tree truncated by the image border (right)

6. IN FRONT OR BEHIND THE SCREEN?

Although objects “popping out” of the screen are more eye-catching, many individual statements indicate that they lead to higher eye-strain as well than. A study proving this has still to be conducted, but looking at the maximum distance the objects can be placed in front / behind the screen in the comfortable zone according to Wopking (1995), it can be noticed that this zone stretches farther behind the screen than in front of it. Or, to put it in another way, an object placed at a certain distance in front of the screen causes higher eye strain than an object placed at the same distance behind the screen.

Furthermore, placing objects in front of the screen can lead to problems where objects are cut by the edge of the screen thus introducing unnaturalness to the scene which both decreases the immersion and increases the discomfort (see also figure 4), especially if the object is only truncated in one of the two views.

Another problem occurs if the screen in question is a touchscreen which is used as an input device as well. The control elements should then be placed on the same plane as the screen itself, because any other placement (above or below the screen) would lead to confusion of the user and at least to a decreased immersion. In the worst case it hinders the user of making correct inputs. Placing objects in front of the control elements would either hide them or lead to an unnatural scene where objects farther away occlude nearer objects, which of course heightens user discomfort and lessen their immersion. It is therefore the recommendation of the author to place objects behind the scene rather than in front.

That said, in a few circumstances objects could be placed in front of the screen, in which case they should be placed in the middle to avoid the problem of truncated objects. If used sparsely, the pop-out effect will be even more spectacular and effective and is thus best saved for shock effects. An example could be a pole penetrating the windshield after the user crashed with their car in a racing game.

7. TECHNICAL ASPECTS

Although autostereoscopic displays have the advantage that no glasses are needed, they inhibit problems if the user does not reside in the “sweetspot” in front of the display, in which case crosstalk and even stereo inversion may appear. These problems occur especially if the display contains an accelerometer or gyroscope which is used as input device, which therefore should better be avoided if the different user positions cannot be treated appropriately. This can be done by detecting the user via e.g. headtracking and adjusting the image accordingly, (which can also be used to introduce motion parallax), i.e. calculating the stereoscopic image based on the viewpoint of the user. Autostereoscopic display exists which can adapt to the user position by moving either the optical filter (e.g. the lenticules) or the display itself. However, it is as easily possible to determine dynamically which pixel of the display should be used for which of the two images, see (Ogniewski and Ragnemalm, 2011) for an example. In this case, it is beneficial to even look at the different colors of each pixel since they are in most cases produced by different optical elements like e.g. LEDs.

Autostereoscopic displays are using irregular masks which can introduce aliasing artifacts, which the game designer should deal with (for more on that see (Konrad and Halle, 2007)). However, even in the case of glasses-based display systems anti-alias is desirable, since the effects of the alias may vary between the two different images – in extreme cases fine structures may even only be visible in one view, but hidden in the other thus leading to a very artificial looking scene and higher discomfort and lesser immersion of the user. Since most of these artifacts are introduced by fine structures far away from the beholder, distance blur might be used to lessen this effect.

Autostereoscopic and polarized-glass-based display both needs to blend the two images on the screen. This blending step can be combined with an anti-alias-filter, thus decreasing the computational overhead introduced by anti-aliasing.

Finding out which effects work only in 2D and which are possible in 3D as well is another important part of game design for 3D displays. A list of popular techniques and suggestions how they could be implemented if using 3D displays can be found in (NVIDIA). One important point should be noted here: all objects need to be rendered at the correct depth and using the same depth range since otherwise the scene will look unnatural. Thus effects using wrong depths, like e.g. billboarding (except possibly billboard clouds), bump-mapping, and skyboxes, should better be avoided. In the case of skyboxes, this might be compensated by placing them as far from the user as possible. Again, distance blur might help as well. 2D-filter effects like HDR bloom or particle effects are better avoided as well.

Furthermore, high contrasts are more prone to lead to ghosting artifacts, i.e. that part of the image, which is destined for one eye can be seen by the other one as well. Ghosting artifacts are introduced by crosstalk between the different views, but are more visible if the contrast between the two different views on the position of the artifact is high. If the display system is known in advance, ghosts can in many cases be treated by calculating an anti-signal. For more information on that see (Konrad and Halle, 2007)).

8. CONCLUSION

As might have become clear, not every game is suited for a stereoscopic display. The game designer should make sure that their game works on a 3D displays if one should be used. Furthermore, a game should not depend on being played with a 3D display. Instead, the 3D display should be used merely as a mean to heighten the immersion. In fact, Nintendo issued a statement that they will make no game which makes the use of the autostereoscopic display on the 3DS obligatory (Nintendo 2011). Bearing that in mind, there are games which can profit from the added depth (apart from the higher immersion), like platformer or racing / flying simulators. Also, the 3D effect is more impressive in slow-paced games, giving the user the possibility to really observe it. This furthermore helps avoiding the problems with rapid motions as mentioned earlier.

3D displays can considerably heighten the immersion of the user, but can also lead to severe discomfort. Therefore, content for such displays has to be creatded carefully to both heighten immersion and decrease discomfort. This report gives guidelines to which a game designer should adhere if designing games for stereoscopic displays. Keeping the scene simple yet realistic and giving the user possibility to adjust settings like perceived depth all work towards minimizing the discomfort the user might experience due to the unnaturalness of the display system.

Even though only limited studies have been conducted on the usage of 3D displays in computer games, their application in video systems is much better researched, and many of the results can be directly applied to computer games as well. The game designer should therefore make use of these publications to optimize the usage of 3D displays for their computer games.

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[1]Obviously, the author is not counting anaglyph (or color-multiplex).

[2]Most diodes do not send a concentrated light beam, therefore some of the light might leak to one of the sides where a different polarization filter is used.