Fundamentals of Stereoscopic 3D Game Design

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Abstract. Stereoscopic 3D (S3D) has (re-)emerged as a major technological trend [12]. Hence, many game designers are challenged to avoid S3D pitfalls whilst creating innovative and entertaining gameplay experiences. We analyze the challenges and opportunities of S3D game design. Based on a review of related findings in the fields of perceptual psychology and 3D movie making, we propose a catalogue of fundamental and innovative concepts for S3D game design that shall lead to new and differentiating game developments.

Keywords: Stereoscopy, game design, S3D, 3D gaming, stereoscopic vision.

1 Introduction

Current S3D products enable stereoscopic viewing for existing games (e.g. Nvidia 3D Vision, Sony Playstation 3, Nintendo 3DS). Such games often provide the same gameplay but with S3D graphics, sometimes at the cost of reduced visual quality (e.g. shadows, bloom, depth of field effects, reflections) [16]. Only little academic research on S3D games is available: Zachara and Zagal reviewed the failure of Nintendo's Virtual Boy. They describe a lack of focused design and emphasize a need for S3D game mechanics [25]. A game that is unplayable without stereoscopy is needed. Rajae-Joordens found that S3D creates an additional value for playing Quake III: Arena [17] but gives no indication for how such value can be deliberately created.

This paper systematically explores challenges and opportunities in S3D game design. We review physio-psychological and technological literature in 3D movie making to formulate requirements for designing a pleasurable experience. Based on this analysis, we propose a list of possible future innovations in S3D game design.

2 Requirements in Stereoscopic Perception and Imaging

According to Tam et al., S3D image sequences are preferred over non-stereoscopic versions; perceived depth is rated greater for S3D sequences than that for non-stereoscopic ones; perceived sharpness of S3D sequences is rated same or lower compared to non-stereoscopic sequences [21]. S3D provides additional information about spatial location, size, shape, or orientation of 3D objects [9]. Virtual scenes experienced in S3D induce an increased perceived presence [10]. Binocular vision on most current display solutions differs from real-life stereopsis: In natural viewing, the

J. Anacleto et al. (Eds.): ICEC 2011, LNCS 6972, pp. 155–160, 2011.

two major visual cues accommodation and convergence always coincide. On a flat screen display, however, the eye lenses accommodate on the display plane while the two eyes converge on other planes, depending of the current parallax. This separation, called accommodation/convergence mismatch, can cause visual discomfort [5]. Human vision has limited abilities to provide eye vergence in a certain range around the accommodated depth, related to the depth of human focus and depth of field (DOF). The resulting area of tolerance is called comfortable viewing range (CVR) and originally based on Panum's fusion area [14]. A tolerance of up to one degree around the accommodated convergence angle is recommended. Tolerance decreases with visual spatial frequency [13]. As a result, blurred objects in the foreground or in the far background may contain parallaxes beyond the recommended CVR. Movie makers even recommend using diverging parallaxes for background layers if the viewer's attention is locked to comfortable depth layers [15]. The effects are assumed to be stronger with prolonged viewing and shorter viewing distances [14].

Effectively, the CVR of a regular display is only a few centimeters behind and in front of the screen. Mapping a whole virtual scene into that range requires scaling of depth. Jones et. al presented an algorithm to calculate parameters for automatically mapping a virtual depth range into physical screen space [11]. Holliman later proposed a multi-pass rendering approach for non-linear mapping of three different depth regions into screen space [7; 8]. Dynamic depth mapping allows to dynamically fit the respective depth of scene into the comfortable range of the used display [20].

The currently focused depth layer is also called Depth-of-Interest (DOI) and providing DOF effects around this region has proven to reduce visual discomfort [2]. DOF can also cause problems, when the player focuses on a blurred object. Thus to create a dynamic and realistic DOF effect, the game needs to know what the player looks at [14]. In movies this can be achieved through direction and cinematic storytelling [20]. In a game, where the camera is controlled by the player, automatic selection of the correct DOI puts up new challenges for camera artificial intelligence.

Obviously, game mechanics of S3D games could put up game design challenges related to depth perception. Performance in precision of depth perception, or stereoscopic acuity, depends on human factors (interocular distance (IOD), accommodation ability, maximum pupil size) and external factors (distance to target, spatial frequency and luminance of target, distance from fixation, observation time).

The human factors are strongly affected by aging. While the average IOD is reportedly at 63 mm [4], it may vary between 50 and 75 mm among most adults, and down to 40 mm for 6 year old children [3]. It has significant impact on depth perception: an increased interocular distance causes hyperstereoscopy: the depth we are used to perceive within arm's range stretches into the far landscape, creating a model-like impression of large buildings [16]. Artificially reducing the IOD below normal creates a hypostereo effect, often used for close-ups and macro footage. Accommodation ability and the maximum pupil diameter decrease dramatically from 14 diopters for ten year old children down to 2 diopters among elderly people [18]. Given optimal luminance and a fixation distance of 65 cm (typical for computer displays), the authors report a minimum detectable depth difference of 0.3 mm.

Depth precision is affected by the used 3D display (driver, electronics), correlating with individual physiology of the user [6]. The resolution limits the number of perceivable depth layers, causing depth aliasing. In effect, depth resolution decreases with distance to the display plane. Slowly moving game objects might look jerky in far away depth layers on low resolution displays.

The benefits of S3D only apply if it is free of noticeable distortions [21]. Those might occur from exaggerated disparity, cross-talk, binocular rivalry, blur, compression artifacts, noise [24], or are related to geometric errors [23]. For objective assessment, 2D image quality metrics are not appropriate; 3D quality metrics are not available yet [24]. If distortions occur, viewers might experience visual discomfort that leads to decreased visual performance, called visual fatigue, often accompanied by headache, eye strain, and other symptoms [14]. Theoretically, children of age six and under are physically endangered, because their visual system still has a high degree of plasticity [19].

In conclusion, there are currently no absolute measures for ensuring visual comfort in interactive games. Thus, S3D game development always requires evaluation of visual comfort with the target group on target displays.

Table 1. Catalogue of S3D game design concepts and related considerations.

Cat.	S3D game design concepts	Perceptual considerations and possible benefits
Camera	Depth-promoting camera perspectives	Speed perception, better distance estimation, more immersive experience
	Camera interaxial adjustment	Hypostereo, hyperstereo, playing as big monsters or tiny creatures
	Non-linear depth mapping	Depth perception of both fore- and background, e.g. in racing games both track and cockpit
	Dynamic depth mapping	Maintaining stereovision comfortable and spectacular between perspectives/scene transitions
Game Challenges and Design Ideas	Depth-estimation tasks	Unbalancing depth cues e.g. texture gradient, lighting, shadows, transparency, or relative position can create optical problems, solvable through S3D
	Balancing towards easy tasks	High contrast, complex texture, bright colors, close depth ranges
	Balancing towards difficult tasks	Low contrast, simple homogeneously colored textures, far away depth ranges
	Memory tasks	No impact from S3D expected
	S3D game scenarios	Mapping real world stereo applications for gaming tasks: bullet casings, diamond reflections, etc.
	Depth-based level design	Possible impact on flow due to specifically designed variety of depth ranges in level design
Game GUI	Depth-positioning of context information and system control	Still unsolved, requires smart dynamic placement to reduce depth jumps and avoid depth cue conflicts
	Text-directed attention	Text can draw attention towards certain depth layers
Extreme S3D	Deliberate double-vision	Simulating gun-sights, image comparison tasks, simulation of drug effects
	Abusive gaming	Putting up physical strain on purpose to simulate sick characters and push towards finding a remedy

3 Stereoscopic Game Design Opportunities

Based on the aforementioned findings, the following section proposes a list of game design opportunities for S3D games (summarized in Table 1).

Interactive S3D Camera Effects: S3D can be effectively used by choosing depth-promoting camera perspectives. Super Street Fighter IV 3D Edition on the Nintendo 3DS offers an additional view from over the shoulder. Reportedly, this view may be unplayable without S3D vision, as depth perception supports judging the distance to the other character [1]. Nevertheless many current games feature over-the-shoulder-perspectives perfectly playable in monoscopic view. Further evaluation is necessary. In addition to perspective, adjusting the interaxial distance of the two virtual cameras for effects of hypo- or hyperstereoscopy (see Section 2) can be used to simulate other creatures' visual perception: hypostereo lets the player experience the world through the eyes of tiny creatures, so everything seems gigantic; hyperstereo could apply to simulate the visuals of a big monster, for which the world looks small and crushable.

The camera should keep the depth range always within CVR, e.g. through depth mapping. In racing games, for example, the best experience is distributing the depth range across the whole landscape, to maximize perceived speed. However, in in-car view, the cockpit would be rendered too closely, causing visual discomfort. Non-linear depth mapping could help to render both cockpit and the far landscape in both comfortable and entertaining depth ranges, but at an unrealistic scale. Still, interactive changes in perspective can easily alter the depth range. Cuts and scene transitions may cause depth jumps [15]. One solution could be dynamically adjusted depth mapping, which may result in unnatural morphing effects when an interactive scene dynamically switches between large depth ranges and close-up visuals. Overall, we need to find new methods for automatic adjustments of S3D cameras in games.

Stereoscopic Game Challenges and Design Ideas: Effective game effects can be achieved by deliberately creating cognitive conflicts of depth cues. Texture gradient, lighting, shadows, transparency, or relative position can be used to create optical problems, solvable through S3D. Balancing depth precision tasks depends on the target group (children, adults, elderly). Easy tasks should involve brightly textured objects close to the screen plane. Difficult tasks should present dark, homogeneously colored objects at far away depth. Despite such abstract tasks, S3D game scenarios can be found in the real world: crime scene investigators examine bullet casings using stereo microscopes; diamonds cause reflections in both eyes slightly differently, which is used to estimate value. Other game scenarios can be enhanced using depth-based level design. Similar to varying difficulty, varying the depth budget across level design might increase the flow a player experiences. In 3D movie making, depth charts are created that give an overview on the applied depth budgets over time [15].

S3D Game GUI and Information Visualization: Generally, games display status information (score, items, resources, etc.) on the image plane and world information (mission, name, properties of NPCs, etc.) spatially next to its referencing entity. Dialogues and subtitles are found in either position. In S3D, both positioning methods can cause problems: Overlaid visuals positioned in screen space conflict with out-of-screen effects and result in contradicting depth cues of occlusion and disparity. If the player's attention is directed towards distant depth planes, switching back to screen space requires eye convergence and takes effort. Also, if object-related information is displayed at object depth, other objects might occlude the text. Event alerts popping up during game play draw attention towards them and thus to their depth layer. New solutions should automatically reduce depth jumps and avoid depth cue conflicts.

Extreme S3D: Double Vision and Abusive Effects: If the two S3D views differ too much, the brain cannot fuse them anymore, leading to double vision. Games could offer two different images for the two eyes: the overlay effect could allow for comparison tasks; a character rendered in both images could be part of two worlds, each putting up different challenges; GUI elements like gun-sights could be rendered in one view only; double vision can be used to simulate drug effects. These possibilities have to be assessed upfront for possibly causing visual discomfort. A large difference in two pictures can increase ghosting effects depending on the used display technology. A user tutorial may help first-time players with such irritating effects. Such negative effects might occur on purpose, as part of abusive game design [22]. In FarCry 2, the protagonist suffers from malaria, shown through blurred and deformed 3D visuals. Wrong S3D could be used to emphasize this effect, directly causing eye strain, to push the player towards finding a remedy.

4 Conclusions

In this paper, we have analyzed previous findings on stereoscopic vision in perception and movie making. Our contribution is a list of opportunities how S3D games potentially can make a difference beyond a short-term novelty-based fascination (see Table 1). Interactive or intelligent S3D cameras, depth-adaptive GUI systems, depth-based game challenges and level design, or new visual effects need further research and case studies that demonstrate applicability and lead to innovative solutions. To ensure entertaining qualities, S3D game production requires intensive balancing of perceptual constraints and ergonomic requirements against new and innovative game design. To conclude, we strongly propose to apply S3D vision as a differentiator in game design, provided that perceptual issues are worked out. The presented list is incomplete, offering a first direction to other researchers and to the games industry. Hopefully, we can see some of these concepts applied in future S3D games.

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