Evaluation of a Multi-Layer 2.5D display in comparison to conventional 3D stereoscopic glasses

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Abstract: In this paper we propose and evaluate a custom-build projection-based multi-layer 2.5D display, consisting of three layers of images, and compare performance to a stereoscopic 3D display. Stereoscopic vision can increase the involvement and enhance game experience, however may induce possible side effects, e.g. motion sickness and simulator sickness. To overcome the disadvantage of multiple discrete depths, in our system perspective rendering and head-tracking is used. A study was performed to evaluate this display with 20 participants playing custom-designed games. The results indicated that the multi-layer display caused fewer side effects than the stereoscopic display and provided good usability. The participants also stated a better or equal spatial perception, while the cognitive load stayed the same.

Keywords: stereoscopic vision, multi-layer display, 3D interfaces

1 Introduction

Stereoscopic, standalone displays are a quite well-spread technology when it comes to 3D interfaces. Nevertheless, they can have several side effects, e.g. motion sickness [SLM12]. Also, the need for stereoscopic glasses can restrict the comfort and usability of those 3D interfaces. In this paper we propose a custom multi-layer 2.5D display and evaluate its suitability as a 3D display that could avoid these side effects and obviate the need for stereoscopic glasses. Furthermore, the multi-layer display utilizes real depth while displaying images on the different layers. Our multi-layer display has two acrylic glass panes with a holographic foil to display partially transparent images, and a conventional LC-display as a third layer. Each layer is using perspective rendering.

A challenge for multi-layer displays to compete with stereoscopic displays is to present 3D environments in an adequate manner. Although the multi-layer display consists of multiple 2D images, it is considered a 2.5D display. Instead of displaying objects in a continuous depth this method displays all contents on discrete depth-levels - users have to focus deliberately on the layers to perceived their content. A further challenge for the display is that it can just show one perspective. Furthermore, there is a discrepancy between the perspective of the left and right eye. As such, the user will see a gap in between the contents of adjacent

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layers. We tried to tackle this problem by visually overlapping the contents of these adjacent layers.

A study was performed to compare the multi-layer display with its stereoscopic counterpart. The goal of this study was to show whether multi-layer displays can compete with stereoscopic glasses in spatial perception and usability. Additional goals were to evaluate potential side effects and influence on game performance. For the use in this study two gaming applications were developed. 20 participants played these games in stereoscopic mode and multi-layer mode and answered a questionnaire after each play-through using a *within*-subjects design. The questionnaire is based on a mixture of well-established standard questionnaires to evaluate the aforementioned aspects. Additional in-game measurements were performed to analyze game performance.

2 Related Work

Besides stereoscopic glasses there are several technologies for displaying 3D content, e.g. auto-stereoscopic displays, stacked layers of polarizers, volumetric displays, and so-called "holograms". Auto-stereoscopic displays show multiple views at once for different viewing angles and therefore do not need any glasses or HMD. [HSS17] developed pixel-mapping algorithms to increase the resolution of the individual views up to large-scale displays. The Company Looking Glass Factory Inc. developed an auto-stereoscopic display that uses a special glass-block to refract the light of multiple compressed images in different directions. As such, the user sees different images from different view angles. The depth cube uses polarization of light to project images in multiple depth-layers [JSM11]. A compressed image is projected in a stack of selective scattering polarizers. With this selection it is possible to project images into different depths. Volumetric displays can be realized with various technologies, e.g. a fog display[LCLH14]. Volumetric displays show their contents as volumes and can be used by multiple users, but they do not show surfaces with occlusions. 2D "holograms" (augmentations) are used quite frequently for automotive head-up-displays by [WZCT18]. These augmentations are created by one laser and therefore are mono-colored, but have a high brightness. [LXW15] are summarizing their progress in holographic displays, including full-color holograms and 3D holograms. Principally, these systems make use technology similar to the so-called *Peppers Ghost* [Bur15] display. In this type of system an image is projected on a semi-transparent glass pane, which reflects the image (on top of a real object) to the eyes of the audience. [SIM+17] used this principle of reflections in a pyramid-structure (often called virtual showcase [Bim01]) to create an interactive and educational system.

The benefits of 3D displays using stereoscopic 3D are investigated in several studies. [SLM12] performed a study with three games to compare the game experience, spatial presence, simulator sickness, attention, and cognitive involvement. Their results indicated an increased immersion, spatial presence, and simulator sickness when using stereoscopic 3D vision. In a further study [SJM14] showed similar results. Additionally, gameplay strategies where investigated. Analysis showed that players did choose different gameplay strategies when using stereoscopic 3D and monoscopic vision. They suggested more general examinations with other technologies. Finally, [RJ08] investigated the game-play of users in the game Quake III: Arena with a lenticular display (a type of autostereoscopic display) for 2D and with a stereoscopic display. The users showed a higher involvement, emotions and feeling of presence using the stereoscopic display. The gaming performance was also investigated, but the stereoscopic display showed just initially better performance, indicating an adaptation over time.

3 Research Questions

The study reported here after addressed the following two research questions.

RQ1: How does the usability and the spatial perception of the multi-layer 2.5D display relate to its stereoscopic alternatives? The restricted depth representation could hurt the spatial perception of a 3D environment, because the multi-layer display shows objects in discrete and quantized depth-levels and not in a continuous depth. We try to overcome this disadvantage by applying perspective rendering on each single layer. The multi-layer display uses real depth and the user has to focus "manually" to the desired depth. This could also give the user a better feeling of the spatial environment and we expect it to match up in spatial perception. Also we expect the multi-layer display can profit in usability, because the user does not have to wear any glasses, like shutter glasses or polarizing glasses.

RQ2: Does the multi-layer 2.5D display suffer from issues with motion/simulator sickness? Stereoscopic 3D applications can be prone to symptoms related to simulator sickness. Those issues can arise through contradictory perceptions of the visual and vestibular systems [RB75]. When users suffer from any of these symptoms the system exhibits limited usability.

4 System

We constructed a custom multi-layer display to investigate the usage of stacked image projections as a semi-3D (2.5D) display system. As a side-effect of the used projectors, this system also supports stereoscopic glasses. As such we were able to compare both display methods in one system.

4.1 Hardware Setup

The multi-layer display is constructed inside a cuboidal aluminum frame. Two aluminum mountings (front and middle) retain acrylic glass panes with holographic foil affixed. The width of each pane is $100cm$ and the height is $60cm$. The projectors are placed behind the acrylic glass panes (cf. figure 1). The projectors used are the LG PH450U ultra-short-throw projectors They support stereoscopic projection through DLP-link. The distance between both acrylic glass panes is $23cm$. Therefore, another $23cm$ behind the last acrylic glass pane

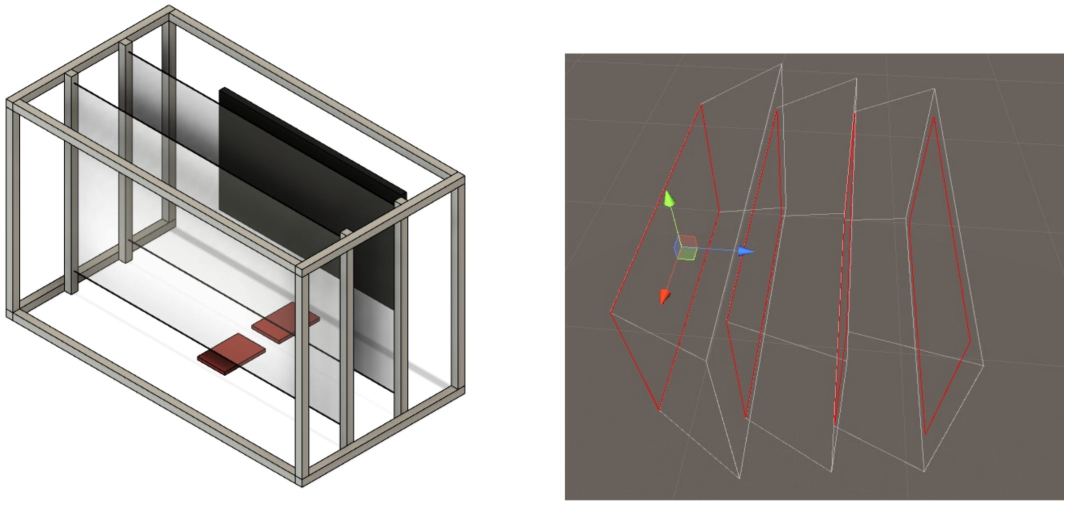

Figure 1: Left: A technical drawing of the multi-layer display. The black box at the back shows the placement of the LC-display. The red boxes show the placement of the ultra-short-throw projectors. Right: Rendering configuration of the multi-layer display inside the editor. Notice the truncated viewing pyramids (white).

a LC-display is placed. For eye and head tracking the Tobii Eye Tracker 4c was placed on the bottom of the mounting of the first acrylic glass pane.

All three displayed images need to be placed such that the images are aligned and of the same size(*67cm x 38cm*). A 30-inch LC-display is used at the back of the system. The distance between the panes can be measured and configured in the code. The projectors are placed so the projected images have the same horizontal and vertical padding on the acrylic glass panes. The LCD screen is placed horizontally centered between the vertical rods. The height of the LCD screen is defined by the distance to the bottom of projected images on the acrylic glass panes. The emitted light of the displayed images (projections and LCD screen) is scattered by each acrylic glass pane and therefore the displayed images need to be brighter with each pane they have to pass, so the same brightness reaches the user's eye. This is also the reason for using the front pane for stereoscopic vision, so the light does not get scattered or blocked by the other panes.

4.2 Implementation

Stereoscopic displays provide a 3D vision by showing two different images to the eyes of the user. In our system we used shutter glasses to achieve this. Perspective rendering adjusts the position and view-frustum of the rendering camera according to the position of the user's head relative to the position of the display. The content of the displayed image appears to be three dimensional behind the screen, because of the parallax between the varying perspectives. For implementation Unity version 2019.1.1f1 was used. We implemented a module named *gamebox* to realize our rendering techniques. For the multi-layer mode there are three sections to display and each one uses perspective rendering. In figure 1 the *gamebox* is displayed. The white lines show the view-frustum of the cameras. The clipping planes of the cameras separate the sections, visualized by the red rectangles. Through eye tracking the

Figure 2: In this pictures the multi-layer display is shown. Left and Middle: The SideScroller. Right: SpaceInvaders

position of the users head is broadcasted into the virtual world. The position of the user's head relative to the displayed image defines the spatial relationship between the image plane and the camera. The property *Lens Shift* of the virtual camera shifts the image plane horizontally and vertically and realizes this relationship. For the *stereoscopic display* just the first projector is displaying an image on the pane in front, while the other projector and display is turned off. Two cameras, with a rendering range along the complete *gamebox*, are horizontally shifted and the view-frustum adjusted to the gamebox. This realizes the different perspectives of each eye of the user. Since the projected images in multi-layer mode are transparent and overlapping, the stereoscopic mode needs to take account for this by rendering objects semi-transparent.

5 Applications

We developed two applications to be used in our user study. Both applications utilize the system properties by dividing content into the three sections (the three display panes). This can be seen in figure 2.

The first application is an adaptation of the classic game *Space Invaders*[1]. In this application the player can move a figure at the bottom of the screen horizontally and shoot one shot at a time upwards. In this version the game is split into three layers, so the player can also switch from layer to layer. At the top of each screen there is a 5X4 grid of enemy figures that move from left to right and back. Each time they reach one side of the screen they also move one row downwards. At random times one of the enemy figures shoots straight down. If the player is hit by the enemy, the game continues. The application is meant to investigate the effects of the player's movements in a steady environment and evaluate the spatial awareness of the user in this fixed setting.

The second application is a *SideScroller*. The player controls a red space ship and can move left, right, up, and down inside the middle screen layer. All other objects automatically move from right to left to simulate a steady movement. The player has to dodge asteroids and rockets, which slowly pursue the player. The player can collect bonus-points by flying through rings of green flares. While the player's figure moves in the middle section, there are

[1] https://de.wikipedia.org/wiki/Space_Invaders

also asteroids in the first and the last layer. Those asteroids do not interact with the player or other object, but give additional motion clues. With this application we want to inject more motion into the gameplay and confront the user with a dynamic scene that changes over time.

6 Study

This study started with a questionnaire asking for demographic data and rating the interest in the topic of 3D interface technologies and the spatial perception of the participants. We used the 4-item scales of *Domain Specific Interest (DSI)* and *Visual Spatial Imagery(VSI)* of the *MEC-Spatial Presence Questionnaire (MEC-SPQ)* [VWG+04]. The study deployed a *within-subjects* design [DE13][BM16] - the participants played both games in both display modes (multi-layer or stereo). To prevent training and adaptation effects in the four play-throughs, the games and modes were alternated. While playing Space Invaders the participants had no time limit. The game finished when all enemies were hit. The time needed to hit all enemies and the number of hits on the player were measured. Afterwards, the participants played the SideScroller for 5 minutes straight. The player did not die when hit, but got visual feedback through an explosion animation. While playing, the collisions with asteroids and enemy-rockets as well as the collections of bonus-points were counted.

After each play-through (stereoscopic and multi-Layer) the participants answered a questionnaire. In this questionnaire, the participant first rated the usability of the system and game with the *System Usability Scale (SUS)* [JTMW96]. Here the user had to rate his approval of 10 statements, 5 positive and 5 negative. With these information we can see, how the usability is affected by the different systems and especially if the omitting of the stereo glasses has a positive effect. After that the participant rated spatial perception and cognitive load by answering the *Spatial Situation Model (SSM)* and *Higher Cognitive Involvement(HCI)* 4-item-scales of the *MEC-SPQ* [VWG+04]. The *SSM* questionnaire asks the user about the spatial perception of the 3D environment, whereas the *HCI* asks the user about the cognitive load they felt while playing the games. Finally, the participant was asked to rate side effects with the *Simulator Sickness Questionnaire (SSQ)* [KLBL93]. In this part the participant had to rate 16 different symptoms of simulator sickness and motion sickness on a scale from 0 to 3, which may indicate if the other questionnaire's results are influenced by side effects. At the end an open interview was held.

7 Results

20 people participated in this study, 3 women and 17 men. The average age was 27 with a range from 21 to 42. Except for one participant, participants were playing video games on a regular base. Further on the following coding is used for the games and modes: HG1 -> SpaceInvaders in multi-layer mode || SG1 -> SpaceInvaders in stereoscopic mode || HG2 -> SideScroller in multi-layer mode || SG2 -> SideScroller in stereoscopic mode. In this paper

we only report the most salient results and therefore omit some results. The DSI and VSI scores of the MEC-SPQ questionnaire are omitted in section 7.1. In section 7.3 the SSQ just lists symptoms that showed informative results. Section 7.4 omits the results of the SpaceInvaders measurements.

7.1 MEC-SPQ

Table 3 shows the mean and the standard deviation of the SSM and HCI scales of the MEC-SPQ for each game and mode. Both scales deploy the same hypothesizes but with different factors (reflecting spatial perception and cognitive load differences between stereo and multi-layer 3D vision).

The Kolmogorov-Smirnov-test is used [HS18] to test the MEC-SPQ-results for a normal distribution. In table 3 the result of the Kolmogorov-Smirnov-test indicates, data did have a normal distribution.

Kolmogorov-Smirnov-test (MEC-SPQ SSM and HCI, normal dist.)								
X	SSM				HCI			
parameter	HG1	SG1	HG2	SG2	HG1	SG1	HG2	SG2
mean	4.42	3.96	4.39	3.04	3.54	3.49	3.60	3.45
std. dev.	0.46	0.84	0.56	0.74	0.90	0.75	0.88	0.89
Kolmo.-Smir. Z	0.89	0.64	0.85	0.60	0.82	1.06	0.92	0.99
sig.	0.411	0.810	0.469	0.858	0.512	0.200	0.372	0.275

Figure 3: Results of the Kolmogorov-Smirnov-test of the results of the MEC-SPQ-questionnaire

Two-sample t-test for MEC-SPQ					
samples	mean	std. dev.	t	df	sig.
HG1-MEC-SSM + SG1-MEC-SSM	0.46	0.96	2.15	19	0.044
HG2-MEC-SSM + SG2-MEC-SSM	1.35	0.77	7.83	19	0.000
HG1-MEC-HCI + SG1-MEC-HCI	0.05	0.52	0.43	19	0.674
HG2-MEC-HCI + SG2-MEC-HCI	0.15	0.49	1.37	19	0.186

Figure 4: Results of the two-sample t-test for the scales SSM and HCI of the MEC-SPQ. The games (G1 SpaceInvaders and G2 SideScroller) are compared separately.

There was a significant difference in the MEC-SPQ-SSM-scores for SpaceInvaders and also for SideScroller in multi-layer mode (SpaceInvaders: M=4.42, SD=0.46, SideScroller: M=4.39, SD=0.56) and stereoscopic mode (SpaceInvaders: M=3.96, SD=0.84, SideScroller: M=3.04, SD=0.74) conditions; SpaceInvaders: $t(19)=2.15$, $p = 0.044$, SideScroller: $t(19)=7.83$, $p = 0.000$. On the other hand, there was no significant difference in the MEC-SPQ-HCI-scores for SpaceInvaders and also for SideScroller in multi-layer mode (SpaceInvaders: M=3.54, SD=0.90, SideScroller: M=3.60, SD=0.88) and stereoscopic mode (SpaceInvaders: M=3.49, SD=0.75, SideScroller: M=3.45, SD=0.89) conditions; SpaceInvaders: $t(19)=0.43$, $p = 0.674$, SideScroller: $t(19)=1.37$, $p = 0.186$. The SSM scale of the MEC-SPQ shows a significant difference in favor of the multi-layer display. The HCI scale does not show a statistical significant different.

7.2 SUS

Results - SUS					Kolmogorov-Smirnov-test (SUS, normal dist.)				
Game+Mode	Mean	Std. Dev.	Min	Max	parameter	HG1	SG1	HG2	SG2
HG1	85.13	10.65	65.00	100.00	mean	85.13	82.50	82.88	62.25
SG1	82.50	9.67	55.00	100.00	std. dev.	10.65	9.67	13.63	16.44
HG2	82.88	13.63	55.00	100.00	Kolmo.-Smir. Z	0.66	0.68	0.62	0.34
SG2	62.25	16.44	30.00	95.00	sig.	0.778	0.741	0.834	1.00

Figure 5: Left: Results of the SUS-questionnaire for each game and mode. Right: Results of the Kolmogorov-Smirnov-test of the results of the SUS questionnaire.

In table 5 the results of the SUS-questionnaire are listed for each game and mode. The SideScroller in the stereoscopic mode has a noticeable low mean rating of 62.25.

The Kolmogorov-Smirnov-test is used to test for a normal distribution. In table 5 the result of the Kolmogorov-Smirnov-test indicates, data did have a normal distribution. The games are analyzed separately and a two-sample t-test can be used[VB99]. In table 6 the results of the two-sample t-test are listed.

Two-sample t-test for SUS					
samples	mean	std. dev	t	df	sig.
HG1-SUS + SG1-SUS	2.63	14.54	0.81	19	0.43
HG2-SUS + SG2-SUS	17.63	16.45	4.79	19	0.00

Figure 6: Results of the two-sample t-test for SUS. G1 : SpaceInvaders, G2 : SideScroller.

There was a no significant difference in the SUS-scores for SpaceInvaders in multi-layer mode (M=85.13, SD=10.65) and stereoscopic mode (M=82.50, SD=9.67) conditions; t(19)=0.81, p = 0.43. But there was a significant difference in the SUS-scores for SideScroller in multi-layer mode (M=82.88, SD=13.63) and stereoscopic mode (M=62.25, SD=16.44). conditions; t(19)=4.79, p = 0.00. The usability of the SideScroller has a statistical significant difference in favor of the multi-layer display. Whereas the usability of the SpaceInvaders had no statistical significant difference.

7.3 SSQ

In table 7 just the informative results of the SSQ-questionnaire are listed. Each cell of the table shows the number that answer has been given for each game and mode in the following order: HG1 | SG1 | HG2 | SG2. Just fatigue, eye strain, difficulty focusing and blurred vision did occur multiple times. Fatigue has an equal distribution among both games and modes and is therefore not meaningful.

Eye strain, difficulty focusing and blurred vision are the most noticeable symptoms here. All are related to the visual perception and are stronger represented in the stereoscopic mode when comparing between play-throughs of the same game.

Results - SSQ				
symptom	None	slight	moderate	severe
2 Fatigue	18 , 18 , 18 , 18	1 , 1 , 1 , 1	1 , 1 , 1 , 1	0 , 0 , 0 , 0
4 Eye strain	19 , 17 , 17 , 11	1 , 3 , 2 , 7	0 , 0 , 1 , 2	0 , 0 , 0 , 0
5 Difficulty focusing	19 , 19 , 17 , 16	1 , 1 , 2 , 4	0 , 0 , 1 , 0	0 , 0 , 0 , 0
11 Blurred vision	19 , 18 , 19 , 17	1 , 2 , 1 , 3	0 , 0 , 0 , 0	0 , 0 , 0 , 0

Figure 7: Results of symptoms with informative outcomes of the SSQ questionnaire. Each cell of the table shows the number that answer has been given for each game and mode. The games and modes are listed in the following order: HG1 | SG1 | HG2 | SG2

7.4 In-game measurements

Table 8 shows the results of the in-game measurements for SideScroller. The results of the in-game measurements for SpaceInvaders showed no notable results.

In-game measurements SideScroller				
measurement	mean	std. dev.	min	max
Deaths	26.55 , 60.85	14.52 , 23.84	6 , 32	113 , 41
Deaths by Asteroids	18.70 , 48.55	11.38 , 21.30	1 , 16	60 , 94
Deaths by Rockets	7.85 , 12.30	5.47 , 6.10	0 , 4	32 , 25
Bonus-Points	34.20 , 32.30	7.48 , 5.59	18 , 32	48 , 40

Figure 8: Results of the in-game measurements in the game SideScroller. Each cell of the table shows on the left the value of the multi-layer mode and on the right the value of the stereoscopic mode

8 Discussion

The most notable results are the results of the MEC-SPQ-SSM and the SSQ. The result of the SSM scale in section 7.1 showed a significant difference in favor of the multi-layer display for both applications. In the results of the SSQ in section 7.3 the stereoscopic display struggled with symptoms that relate to the eye. The three major symptoms were *eyestrain, difficulty focusing*, and *blurred vision*. These symptoms indicate that the users had difficulties using stereoscopic glasses.

RQ1: How relates the usability and the spatial perception of the multi-layer display to the use of stereoscopic alternatives?

In section 7.1 the results of the SSM-scale in the MEC-SPQ questionnaire showed a better spatial perception in the both applications for the multi-layer display, while the HCI-scale did not show a higher cognitive load. Here we expected the multi-layer display to match the stereoscopic display, but it also outperformed the stereoscopic display, but this may due to the side effects of the stereoscopic glasses. As mentioned in chapter 3 we expected the multi-layer display to exceed in usability since it does not need any glasses. This expectation is met partially since the usability in section 7.2 of the multi-layer display differs from the stereoscopic display just for the SideScroller, but not for the SpaceInvaders. This is backed up by the increased occurrence of side effects in the SSQ in section 7.3. The SUS-score for the SpaceInvaders is matched between both modes. This shows that usability is dependent on the application. While [SLM12] results showed a better spatial presence with stereoscopic

3D vision compared with monoscopic vision, our results indicate better spatial presence with the multi-layer display compared with stereoscopic 3D. But it is to mention that our worse results for the stereoscopic 3D could be altered by the side effects of the stereoscopic glasses, similar to what is reported in [RJ08].

RQ2: Does the multi-layer display suffer from issues with motion/simulator sickness?

The simulator-sickness questionnaire showed the participant had more often symptoms of eye stain, difficulty focusing and blurred vision when using the stereoscopic display, meeting our expectations of the stereoscopic glasses causing more side effects.[SLM12] presented also increased symptoms of simulator sickness. However, the impact of these side effects was stronger than expected and damaged the gaming-performance seen in the in-game measurements in section 7.4 and the spatial presence in section 7.1. Multiple participants also stated after all play-throughs that they had problems to see in which layer the asteroids flew. [SJM14] also showed with their study the different gameplay strategies users choose when using stereoscopic 3D vision or monoscopic vision. [RJ08] found better initial gaming performance for stereoscopic 3D indicating an adaption over time. In our study the performance adaption overtime was not investigated. The occurrence of the mentioned symptoms when using stereoscopic glasses are also most likely responsible for the worse results in the MEC-SPQ-SSM scale. The results of the study could change when using different stereoscopic technologies.

9 Conclusion

The study showed that the multi-layer display did not restrict the users spatial perception within our particular applications and in one application outperformed the stereoscopic display in usability. But this could be influenced by the design of the applications. The disadvantages of the discrete depth of the Multi-Layer 2.5D display were overcome in this study. Also the multi-layer display showed fewer side effects (eye strain, difficulty focusing and blurred vision) than the stereoscopic display. These side effects caused by the stereoscopic glasses impacted the spatial perception and could vary when using different stereoscopic devices. An examination with different stereoscopic glasses could give further insights about the effects of the glasses themselves. To draw more general conclusions about the multi-layer display, applications can be studied that use of continuous depth. Changes in the hardware setup can improve the spatial perception and could provide the ability to render 3D volumes with less noticeable artifacts, e.g. increasing the number of layers, reducing the distance between layers and varying the size of the layers. A further aspect that was not covered in this study are the effects of a longer usage time of the multi-layer display. When using this system for a longer time than in this study, the low brightness could cause more side effects, e.g. eye strain.

Overall the custom multi-layer 2.5D display showed a good performance in spatial perception and usability in this study when compared to a stereoscopic display. Furthermore the side effects of the stereoscopic display harmed the gaming-performance for one of two applications. Results indicate that the 2.5D multi-layer display is capable of showing environments with depth information and profit from omitting stereo-glasses, but it remains to be seen if it also is usable with continuous 3D volumes.

References

[Bim01] Fröhlich B. Schmalstieg D. Encarnação M. Bimber, O. The virtual showcase. *Journal IEEE Computer Graphics and Applications, 21(6), November/December 2001, pp. 48-55*, 2001.

[BM16] Regina Bernhaupt and Florian Mueller. Game user experience evaluation. In *Game User Experience Evaluation*, pages 940–943, 05 2016.

[Bur15] Russell Burdekin. Pepper's ghost at the opera. *Theatre Notebook*, 69:152–164, 01 2015.

[DE13] H. Desurvire and M. S. El-Nasr. Methods for Game User Research: Studying Player Behavior to Enhance Game Design. *IEEE Computer Graphics and Applications*, 33(4):82–87, July 2013.

[HS18] J. Hedderich and L. Sachs. *Angewandte Statistik: Methodensammlung mit R*. Springer Berlin Heidelberg, 2018.

[HSS17] Y. Huang, M. R. Swash, and A. Sadka. Innovative 3D pixel mapping method for LED holoscopic 3D display. In *2017 4th International Conference on Signal Processing and Integrated Networks (SPIN)*, pages 330–333, 2017.

[JSM11] Jung-Hun Jung, Byoung-Sub Song, and Sung-Wook Min. Depth cube display using depth map. *Proceedings of SPIE - The International Society for Optical Engineering*, 7863, 02 2011.

[JTMW96] Patrick W Jordan, Bruce Thomas, Ian Lyall McClelland, and Bernard Weerdmeester. *Usability evaluation in industry*. CRC Press, 1996.

[KLBL93] Robert S. Kennedy, Norman E. Lane, Kevin S. Berbaum, and Michael G. Lilienthal. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, 3(3):203–220, 1993.

[LCLH14] M. Lam, B. Chen, K. Lam, and Y. Huang. 3d fog display using parallel linear motion platforms. In *2014 International Conference on Virtual Systems Multimedia (VSMM)*, pages 234–237, 2014.

[LXW15] J. Liu, G. Xue, and Y. Wang. Recent progress on holographic 3d display at beijing institute of technology. In *2015 IEEE 13th International Conference on Industrial Informatics (INDIN)*, pages 742–745, 2015.

[RB75] James T Reason and Joseph John Brand. *Motion sickness.* Academic press, 1975.

[RJ08] Rosemarie Rajae-Joordens. Measuring experiences in gaming and tv applications. 8:77–90, 01 2008.

[SIM+17] C. V. Siang, M. I. M. Isham, F. Mohamed, Y. A. Yusoff, M. K. Mokhtar, B. Tomi, and A. Selamat. Interactive holographic application using augmented reality educard and 3d holographic pyramid for interactive and immersive learning. In *2017 IEEE Conference on e-Learning, e-Management and e-Services (IC3e)*, pages 73–78, 2017.

[SJM14] Jonas Schild, Joseph Jr, and Maic Masuch. Altering gameplay behavior using stereoscopic 3d vision-based video game design. *Conference on Human Factors in Computing Systems - Proceedings*, 04 2014.

[SLM12] Jonas Schild, Joseph LaViola, and Maic Masuch. Understanding user experience in stereoscopic 3d games. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, page 89–98, New York, NY, USA, 2012. Association for Computing Machinery.

[VB99] Dirk Vorberg and Sven Blankenberger. Die auswahl statistischer tests und masse. *Psychologische Rundschau*, 50(3):157–164, 1999.

[VWG+04] Peter Vorderer, Werner Wirth, Feliz Gouveia, Frank Biocca, Timo Saari, Lutz Jäncke, Saskia Böcking, Holger Schramm, Andre Gysbers, Tilo Hartmann, Christoph Klimmt, Jari Laarni, Niklas Ravaja, Ana Sacau, Thomas Baumgartner, and Petra Jäncke. Mec spatial presence questionnaire (mec-spq): Short documentation and instructions for application. *Report to the European Community, Project Presence: MEC (IST-2001-37661)*, 06 2004.

[WZCT18] W. Wang, X. Zhu, K. Chan, and P. Tsang. Digital holographic system for automotive augmented reality head-up-display. In *2018 IEEE 27th International Symposium on Industrial Electronics (ISIE)*, pages 1327–1330, 2018.