Depth Perception and Visual After-effects at Stereoscopic Workbench Displays

T. Alexander, J. Conradi, C. Winkelholz
Research Institute for Communication, Information Processing and Ergonomics (FKIE)
Neuenahrer Str. 20
53343 Wachtberg, Germany
{alexander, conradi, winkelholz}@fgan.de

Abstract
The vivid and clear way of virtual scene presentation in Virtual Environments (VE) is nearly exclusively accomplished by stereoscopic displays. Depth perception with these displays differs from the viewing conditions in reality and causes usability problems. For this reason three important aspects of visualization at a stereoscopic workbench display were analyzed. The results of three experiments with terrain data as an example application show a significant increase of depth perception when using stereoscopy, while map texturing causes a significant decrease. For additional wireframe texture and head-tracking no significant effects were found. With regards to the upper and lower bounds of stereoscopic visualization a linear relationship between the maximum elevation of single objects and the distance between fixation and projection plane was specified by regression analysis. Finally, it is shown that ½ hour activity at such a display does not result in negative after-effects for the visual system, including visual acuity, phoria, fusion, and stereoscopy. These results suggest the use of stereoscopic workbench displays for presentation of three-dimensional terrain data. In contrast, deficits of depth perception are verified resulting from overload of visual information, or from using too large parallax for the presentation.

1. Introduction
In real environments, depth cues like perspective, size difference, occlusion, shadow, accommodation, convergence and disparity facilitate a very exact depth perception in near, medium, and far range. However, depth perception in VE differs from this [1].

Main differences have their origin in characteristics of the tracking and rendering system (e.g. latency, inaccuracies), the display itself (e.g. resolution, update rates), or even in visual deficits of the user (e.g. amblyopia, contradicting depth cues). They may lead to limited or impossible depth perception in VEs and introduce additional ocular stress.

2. Experiments
Existing shortcomings and problems of stereoscopic visualization led us to the analysis of three important aspects. Therefore, experiments were carried out to determine the effect of different types of rendering on visual performance, the upper and lower display bounds and after-effects for activities on a stereoscopic workbench display.

2.1. General experiment: Participants and apparatus
The experiments were performed in a three weeks period at our institution. 27 members of the institute volunteered as subjects. The average age of the subjects was 43.9 years (s=11.8). The sample consisted of 22 male and 5 female subjects. 22 subjects wore glasses. Interrogation proved that all subjects were well motivated. In advance of each experiment, a standardized visual screening test was performed.

For the three experiments a proprietary VE framework was used. The stereoscopic workbench display connected to this system had a size of 1.95 x 1.24 m. For picture separation Stereographics CrystalEyes™ shutterglasses were used. Head-tracking was processed by the optical Advanced-Realtime-Tracking (ART™) system with 4 cameras.
Subject's inputs, including first reaction input and a time-separated selection of the answer, were performed on a commercial PC-mouse. Subject's inputs and reaction times were measured and recorded for later analysis.

2.2. Experiment 1: Rendering and depth perception
The first experiment was performed to analyze the effect of rendering on visual depth perception. As not all aspects of rendering could be included, four types of rendering, respectively display types were specified in advance of the experiment. The intended application of terrain visualization led to the consideration of wireframe and map texture. Head-tracking (motion parallax) and
stereoscopy (binocular sight) were added as further display options. For the experimental design a 2 (wireframe on/off) x 2 (map on/off) x 2 (tracking on/off) x 2 (stereoscopy on/off) design with repeated measures was chosen. In the experiment different terrain reliefs with four mountains served as virtual scenes. The elevation of one of the mountains was larger than the elevation of the three others. Subjects were instructed to identify this mountain as fast as possible, press the reaction button, and identify/enter the number of the mountain afterwards.

2.3. Experiment 2: Upper and lower bounds

Due to stimulus thresholds for depth perception different bounds for stereoscopic depth perception exist. The goal of this experiment was to determine these bounds of a stereoscopic workbench in a display-fixed coordinate system.

The experimental procedure for determining the display bounds followed the method of constant stimuli, which is frequently used for stimulus threshold analysis. The experimental virtual scene setup consisted of five objects in the same fixation plane. One of these objects was prominent to the others. As a second factor, the distance between fixation plane and projection plane varied. Subjects were instructed to react as soon as they detect the prominent object and afterwards to enter the result. This result was taken as measure for depth perception performance under the specific experimental condition.

2.4. Experiment 3: After-effects of ½ hour activity

For activities at stereoscopic workbench displays a high ocular stress is expected, possibly resulting in serious negative after-effects on the visuals system of the user. For this experiment subjects processed a visual screening test before and after the two experiments described before. These experiments took about ½ hour and were characterized by difficult stereoscopic viewing tasks close to depth perceptual thresholds. Due to this, a high visual workload resulted. The viewing screening test used in this experiment has been standardized by DIN 52880 and G37 respectively [2, 3]. The first part comprises visual acuity, and the second part several tests of binocular sight.

3. Results and Conclusion

For analyzing the effect of rendering type on depth perception the individual depth separation was determined by selecting the first correct detection. A subsequent four-way ANOVA with repeated measures shows significant effects of stereoscopy (F=13.6, p<0.01) and map texture (F=11.4, p<0.01) on depth separation. Stereoscopy improves (minimizes the perceivable distance) and map texture reduces depth perception (enlarges perceivable distance). The additional wireframe structure affects minimum separation distance significantly (F=5.6, p=0.03) and increases depth perception. For head-tracking no significant effect is found (F=0.06, p=0.81). With regard to reaction time, a second 4-way repeated measures ANOVA revealed significant effects of texturing (F=7.8, p<0.01), head-tracking (F=5.7, p=0.03) and stereoscopic rendering (F=5.1, p=0.03). For wireframe no significant effect is detected (F=0.16, p=0.69).

These findings prove the benefits of stereoscopic data presentation in contrast to an accumulation of 2D-displays with elevation information (e.g. by color coding). This is especially important in case of presenting complex additional textural or color-coded information. In this case stereoscopy brings benefits for depth perception and helps to prevent perceptual overload.

For determining the lower bound of the display the results of the second experiment were analyzed. A one-way ANOVA confirms a significant effect of the distance between fixation plane and projection plane on the minimum perceivable distance (F=30.6, p<0.01), and a subsequent trend analysis specifies a linear relationship (F=74.6, p<0.01). With regard to the maximum distance before desegregation of the picture, a second ANOVA determines a significant effect as well (F=5.4, p<0.01). A subsequent trend analysis shows a linear relationship as well (F=29.3, p<0.01).

For fixation plane meeting projection plane a maximum bound of x=0.43 m (s=0.06 m) for object elevation is found. At a maximum fixation plane elevation of 0.96 m above projection plane no depth separation is possible. The minimum distance of the prominent object to the fixation plane deviates between x =0.08 m (s=0.04 m) and x=0.17 m (s=0.09 m), dependent on the distance between fixation and projection plane.

Based on the measured values of the last experiment, performed ANOVAs show no negative visual after-effects for ½ hour of activity at stereoscopic workbench displays. A slight improvement of visual acuity in the near range is found, which cannot be interpreted. But as it is only slightly significant, it can also be caused by random error.

These findings support the usability of stereoscopic workbench displays for the visualization of geographic information, as long as special display bounds are considered.

References