Stereo Vision and Acuity Tests within a Virtual Reality Set-Up

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Abstract: The provision of stereo images to facilitate depth perception by stereopsis is one key aspect of many Virtual Reality installations and there are many technical approaches to do so. However, differences in visual capabilities of the user and technical limitations of a specific set-up might restrict the spatial range in which stereopsis can be facilitated. In this paper, we transfer an existent test for stereo vision from the real world to a virtual environment and extend it to measure stereo acuity.

Keywords: Virtual Reality, Perception, Immersion

1 Introduction

Tests for stereo vision are commonly made at opticians and a well-known standard test is the Lang-Stereotest [LSA82]. This test uses a Random-Dot-Stereogram where two layers contain random noise dots but in a specific area the dots are placed in such a way that two corresponding points have a specific horizontal disparity. A human with normal stereo vision is then able to detect an emerging shape. A cascade of such tests with different disparities can be made to assess stereo acuity.

In a virtual reality (VR) set-up, it is commonly relevant to detect, whether users have stereo vision. Testing stereo acuity, however, is not that common. In addition, while the results of a cascaded Lang-Stereotest describes the stereo acuity of the user in the real world, technical constraints of the VR set-up may affect the practical stereo acuity of the user in the VR simulation. Knowledge about stereo acuity is especially important in a range of empirical studies. Thus, testing the stereo vision of new users is a common task.

The idea followed in this paper is to test stereo vision and acuity within the system using the system's technical capabilities. This way, we measure the expected performance of the user in the simulation and not the potential performance the user may achieve under optimal conditions in the real world.

There are multiple depth cues which support depth perception in the visual context. Many factors only require monocular vision such as parallax scrolling or pictorial cues like shadows, accommodation, occlusion and relative size. Binocular factors are retinal disparity and convergence. Retinal disparity describes the fact that because of their differences in position, two slightly shifted pictures are projected onto the retina. The eyes' rotation towards each other is called 'convergence' and the focus at a specific distance is known as 'accomodation'. In this paper we will focus on the binocular cues. In the projection system we use, accomodation will always focus on the projection layer and not onto observed objects.

2 Related Work

Abdeldjallil Naceri et al.[NC12] made a similar study to explore depth perception in virtual reality against the real world. Participants were seated 2.2 m in front of a 3D projector screen while wearing passive polarized glasses. They had to quantify distances of spheres shown to them. The spheres were either blue (which was the standard, always 7 cm in diameter and presented at 1.9 m from the participant) or red (which were the comparisons and displayed with radial distance ranging from 1.4 m to 2.4 m) while the spheres' sizes were varied to always hold the perceptual size constant to the subject. There was a 1 sec. pause between every presentation and the order of presentation was randomized. Participants had to verbally indicate which of the spheres appeared closer by pointing out that sphere's colour. The results of the study showed that the proportion of correct answers increases in the distances from 1.4 m to 2.4 m. Even though the results were splitted into two groups because of different fittings - as the results of group 1 could be fitted into a psychometric function and the other group's results were fitted to a linear function - the groups' shared statement was, that in VR the recognition was getting better in the range between 1.4 m and 2.4 m. Also both groups had a similar turn in recognition at the distance of ∼1.8 m where the proportion of correct responses crossed the 50% mark.

Other studies have shown that stereo acuity is higher in peripersonal space and lower in extrapersonal space. The limits Cutting et al. [CV95] or Previc [Pre98] found in their studies were either 1 m or less. Others found 5 m to be the limit like Nagata [Nag91].

These varying results leave it unclear, what the exact operational range of spatial discrimination of differences based on stereo vision is in a specific technical set-up. We present a first study in which we evaluate our within-system test for stereo acuity. The idea is to develop a test procedure that can easily be used to assess stereo acuity of users.

3 Stereo Acuity Study

We conducted a study with ten participants aged 19 to 27 years (median: 24) with normal stereo vision capability and experiences in virtual worlds. The participants were standing in front of a stereo projection screen (circular polarized light, 1280x1024 px) at our standard interaction distance of 1 m. In this set-up, one pixel has the width of 1.9 mm (visual angle $\sim 0.11°$). The maximum distance a human eye can distinguish pixels of that size is at about 6.33 m [Kie02], so this imposes one potential technical limitation. Each participant was presented disc-targets at varying depth (0.5 m, 1 m, 1.5 m, 3 m, 5 m, 7 m, and 10 m), a large background disc with four smaller discs in front. As experimental condition either none or one of the smaller discs was elevated (see the left example in Figure 1(a)). We excluded other

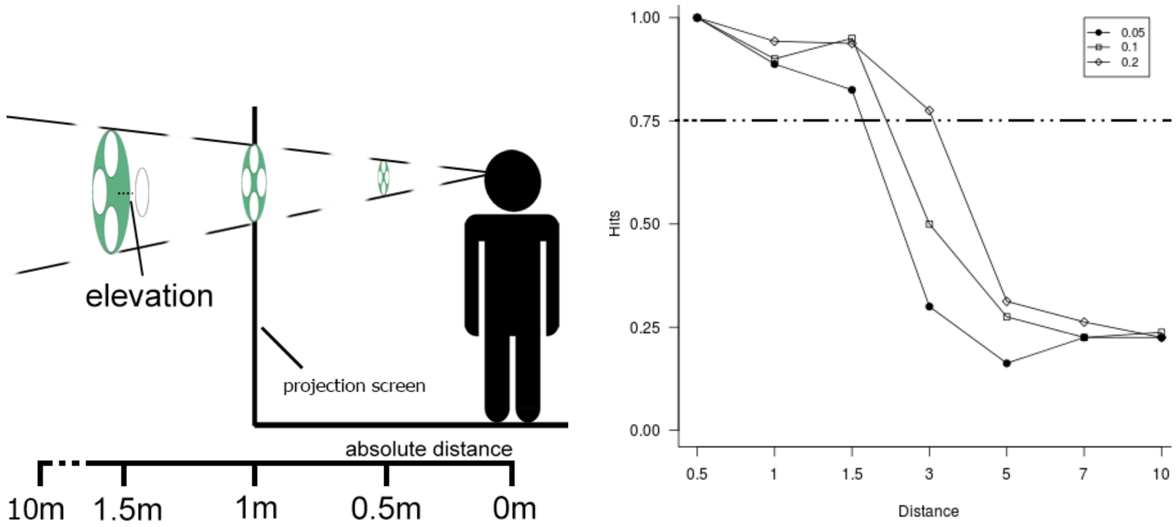

Figure 1: (a, left) Schematic diagram of the set-up with distances and discs used as stimuli with elevation example of the right disc elevated. (b, right) The mean success rate of all participants for the different distances.

depth cues such as size, shadows or environmental references and motion parallax effects (by locking the discs to head shifts). All discs were scaled to remove effects of relative size. The set-up was verified in a baseline test in which participants had to rate the stimuli with eye distance set to 0, thus eliminating effects of disparity. In this baseline test, the success rate was 25%, which is slightly above chance. In the study, each participant had to rate 167 configurations, each shown for 2 sec with a 1 sec blank inter-stimulus interval. For every stimulus, the participant had to decide which if any of the discs were elevated.

3.1 Results

Figure 1(b) shows the mean success rates for the three elevation distances. The performance is decreasing significantly between 1.5 meters and 3 meters (tested with Student-T test). According to the recognizable differences between discs we found our results to be affected primarily by the pixel width of the projection plane, due to the projection of points of different depths onto the same physical pixel. For example, a viewer can only distinguish a background object at 10 m distance from a foreground object at a distance of at least 5,95 m. These relative distances are getting smaller in proximity to the user. To give another example, to distinguish an object at 0,5 m from a closer object, this object would have to be at least two centimetres closer to the user. These distance values are only valid for our set-up and would increase or decrease depending on pixel size.

4 Conclusion

The results of our study are in line with the findings of Naceri et al. [NC12], but we could not replicate those of Cutting [CV95] or Previc [Pre98]. All participants were able to discriminate differences in depth within the default interaction space of 1 m, but not much beyond the distance of the projection screen. The limiting factor in our set-up is pixel size. Thus a simple stereo vision test is sufficient for our users. Individual differences in stereo acuity might become relevant if a higher resolution display would be used. In this paper we presented work on a stereo test for virtual reality environments that works within-system. The results achieved with our test are in line with results from real world tests, but are affected by technical limitations. In particular, we found that stereo acuity in our virtual reality set-up for differences of 20 cm and up is stable only for distances below 3 m. Smaller distances can only be differentiated in the closer proximal area around the user. Because of the low stereo acuity at distances beyond 3 m, stereo images would only have to be generated for objects within this area. Such knowledge could be used to optimize rendering performance. At the moment, the stimulus set is quite large and not adapted to the expected range of operation. It could be significantly improved by sampling the interesting area or by adapting it on-line to the performance demonstrated by the user (e.g. to not frustrate users without stereo vision). A decrease of perceived pixel size would push the limits of technology beyond the limits of individual users, which would make systematic tests of stereo acuity more important. Retina-like displays for HMDs, 4K resolution projectors or multi-projector systems should allow us to facilitate stereo vision close to the limits of the human eyes.

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