The Impact of Stereo Rendering on the Perception of Normal Mapped Geometry in Virtual Reality

Martin Mišiak
TH Köln, Computer Graphics Group
University Würzburg, HCI Group
Köln, Germany
martin.misiak@th-koeln.de

Niko Wißmann
TH Köln, Computer Graphics Group
Köln, Germany
niko.wissmann@smail.th-koeln.de

Arnulph Fuhrmann
TH Köln, Computer Graphics Group
Köln, Germany
arnulph.fuhrmann@th-koeln.de

Marc Erich Latoschik
University Würzburg, HCI Group
Würzburg, Germany
marc.latoschik@uni-wuerzburg.de

ABSTRACT

This paper investigates the effects of normal mapping on the perception of geometric depth between stereoscopic and non-stereoscopic views. Results show, that in a head-tracked environment, the addition of binocular disparity has no impact on the error rate in the detection of normal-mapped geometry. It does however significantly shorten the detection time.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; • **Computing methodologies → Perception**.

KEYWORDS

Virtual Reality, Normal Maps, Binocular Disparity, Motion Parallax

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1 INTRODUCTION

3D depth perception emerges as a result of various depth cues, and is a prominent and important feature of most Virtual Reality (VR) applications. Generating depth cues at interactive frame rates is one central goal of the field of real-time rendering. Although a broad spectrum of techniques for accelerating real-time rendering exists, the extent of their applicability to VR is not entirely clear.

Normal maps [Kilgard 2000] are widely used to reduce the geometric complexity of a model. By explicitly storing its normals in a texture, the underlying geometry can be extremely simplified, yet retains its shading properties [Cohen et al. 1998]. While this approximation works well on a monoscopic screen, the lack of geometry based depth cues is more noticeable in VR. Although some general guidelines for using this technique in VR have been established [Vlachos 2015], no precise evaluations have taken place.

Binocular disparity and motion parallax are important depth cues in VR applications. While both cues have a positive impact on user performance, their individual contribution depends strongly on the performed task [Faubert 2001; Norman et al. 1996; Ragan et al. 2012; Ware and Mitchell 2005]. In this context, we evaluate the influence of binocular disparity on the perception of normal mapped geometry in a head-tracked environment.

2 EXPERIMENT

A total of 24 subjects (21 males, 3 females), aged 20 - 36 ($M = 25.1, SD = 3.8$) were equally divided into two test groups - mono (motion parallax only) and stereo (motion parallax + binocular disparity). In 14 trials, participants were shown 2 models of a coin (Figure 2) side by side. One model represented the geometric reference, while the other coin was flat and had its minting solely represented by a normal map. The relative position and minting strength of both models was varied in a randomized order across each trial, ranging from 0.4 mm to 7.0 mm. The experiment was designed as a 2AFC, with the goal of identifying the "flatter" normal mapped model. Response time and correctness were noted for each trial. Participants were seated 1.3 m from the monitor screen and were encouraged to perform swaying movements during the trials to engage motion parallax.

To mitigate geometric masking effects [Rushmeier et al. 2000] and to strengthen the perception of 3D shape [O'Shea et al. 2008], a white frontal light source position without cast shadows and a homogeneous diffuse color were used to shade the models. Furthermore to reduce the negative influence of display resolution, a fish tank VR setup (Figure 1 (a)) was used. It consists of a 27″, 2560×1440 stereoscopic monitor with shutter glasses and a positional tracker. Using this setup a resolution of 95 pixels per degree was achieved when placing the observer at a distance of 1.3 m from the monitor screen.

3 RESULTS

Figure 1 (b) shows the average of correct responses given by the participants for each comparison pair. No statistically significant

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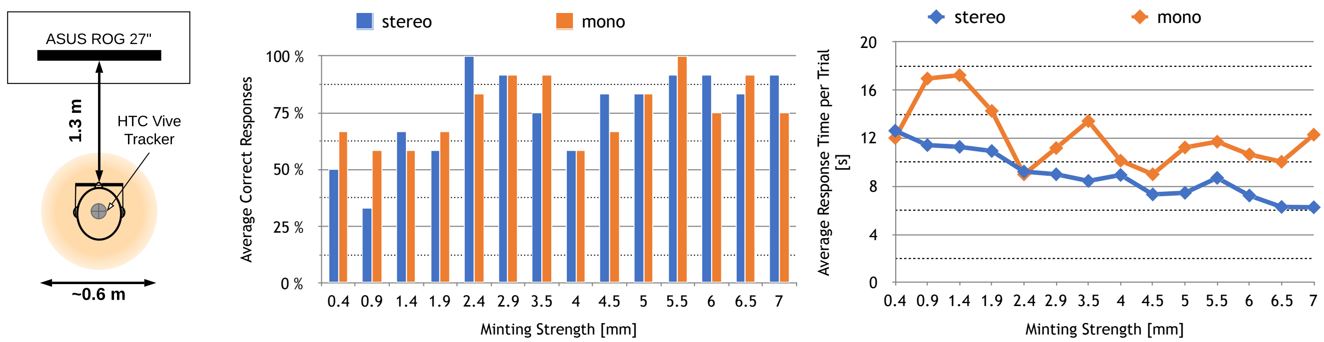

(a) (b) (c)

Figure 1: (a) Setup of the user study. The light orange area defines the subject's allowed movement radius during the study. Results of all trials, for both conditions: (b) Average response correctness (c) Average response time

Figure 2: Left: Side by side comparison of 2 coins as seen in each trial. Right: Oblique view of both coins to emphasize the differences. Top right: Geometry reference coin with a minting of 5 mm. Bottom right: Corresponding flat coin with applied normal map.

difference was found (Mann-Whitney-U = 67.5; $p = 0.799$) in the number of correct responses between both test groups. However, there are significant differences in the completion time. While the stereo group has an average total completion time of 125.1 s ($SD = 24.0\,s$), the mono group took longer with 169.1 s ($SD = 53.2\,s$) (Welch's $F(1, 15.3) = 6.82, p = 0.019$). We can also observe, that average response times in both viewing conditions decrease towards larger depth differences (Figure 1 (c)). While the response times for the stereo group decrease linearly, the mono group exhibits larger variances, which can be explained by the active nature of motion parallax as a depth cue.

4 CONCLUSION

To our surprise, the addition of binocular disparity did not decrease the error rate for detecting normal mapped geometry. The presence of motion parallax alone yielded the same results. However, we found significant differences in the measured task execution times between both conditions. Participants in the stereo group decided on average 25% faster, than participants in the mono group. The viewing condition was found to have a large effect size on the measured times (Cohens $d = 1.066$). In the literature, similar findings have been reported for spatial adjustment [Ragan et al. 2012] and path tracing tasks [van Beurden et al. 2010]. Participants of the stereo group also displayed more consistent response times. This suggests, that in a real-world time-constrained scenario, the addition of binocular disparity could lead to an increased detection probability for normal mapped geometry.

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