Utility of Gaze-contingent DOF Blur for Depth Perception

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Abstract

Depth-of-Field blur is a by-product of optical systems and its recreation can enhance the realism of images and convey information about size and distance. In this paper we present an approach to create a gaze-contingent DOF blur using pre-rendered scenes created with ray-tracing techniques. The approach has been evaluated in a user study and been shown to increase perceived realism and the perception of depth.

Author Keywords

Gaze-contingent display; depth-of-field; depth perception; eye tracking

ACM Classification Keywords

H.1.2 [Models and Principles]: User/machine Systems; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

General Terms

Human Factors

Introduction

Depth-of-field (DOF) describes an effect of complex optical systems that causes parts of a projected scene to be blurred based on their distance to a focus plane. DOF blur does not only appear in artificial camera systems, but it is also inherent to the human eye.

Blur has been identified as a cue that allows ordinal judgement of depth between texture regions with blurred borders [9] and also as a potential depth cue in the human visual system [10]. The interaction of blur with other depth cues has been investigated [11] and it has been shown to influence perception of distance and size (e.g., [4, 14]).

This suggests that DOF blur is not only useful for creating photo-realistic images, but also may be of benefit in the strife for "vision-realistic" rendering [1]: to create images that are not just mimicking simple camera models but depict scenes in the way that humans would actually perceive them. Towards this goal DOF blur has been used in virtual reality applications to create more realistic and more immersive environments (e.g., [5, 8]).

While most of these techniques relied on static placement or estimates (e.g., auto focus) to introduce blur in the scenes, the advent of more robust eye tracking and faster rendering techniques as well as more powerful hardware allow to implement DOF blur that is adapted to the user gaze-position as already proposed by Rokita in 1996 [13].

The use of eye tracking based gaze-adaptive systems (i.e., gaze-contingent displays) utilizing DOF blur have been investigated with the goal to to enhance immersiveness and realism of virtual environments (e.g., [2, 8, 12]), to reduce eye strain in stereoscopic displays (e.g., [3, 6, 7]) and to convey depth information [12].

Our goal is to expand on the existing research on blur with an in-depth investigation of the inherent properties of gaze-contingent DOF blur. We want to compare how this kind of perceptual adaptation can improve upon static display methods and map out its limitations and strengths.

This paper presents a first step in which a display rendering gaze adaptive DOF blur is implemented and a qualitative investigation and validation of the used approach and equipment is carried out.

Implementation

In order to simulate the DOF impression of commonplace viewing in a virtual scene we implemented a system that uses an eye tracker to detect the user's gaze location in the observed scene. Based this and the geometry of the scene parts of the image are blurred as they would be when recorded by a physical camera. This also means that the region the user is looking at will stay in focus and the overall image should appear sharp.

The gaze-contingent display is realised using an EyeLink 1000[1] and an analogue display with a resolution of 1280 px × 1024 px running at 100 Hz. The displayed scenes were pre-rendered using POV-Ray[2] and have a size of 1152 px × 864 px. Each scene was rendered with 30 different focal points. The application to display gaze-contingent images is written using Matlab[3] and relies on the use of OpenGL[4] to pre-load the scene images as textures for timely presentation.

[1] http://www.sr-research.com/EL_1000.html
[2] http://www.povray.org/
[3] http://www.mathworks.co.uk/products/matlab/
[4] http://www.opengl.org/

Figure 1: Kitchen scene with focus at front.

Figure 2: Kitchen scene with focus at back.

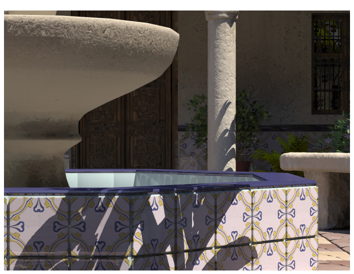

Figure 3: Patio scene.

To decide which focal image to display the eye tracking data is used to determine the current gaze position on the image. From there the depth of the attended point is looked up in the depth map. To avoid abrupt transitions the displayed image is not switched to the target image immediately. Instead a smooth transition function is used.

Experiment

To evaluate 3D impression and perceived realism of gaze-contingent DOF blur we conducted an experiment. The gaze-contingent display we used was created using the hardware and techniques described earlier with the addition of a keyboard for user input. 15 participants (seven female, age 19 to 31, all with normal or corrected-to-normal vision) took part in the experiment.

First each participant had to pass an acuity and stereo-vision test. Then they were seated in front of the display and an eye-tracking calibration was performed. During the main part of the experiment one of two scenes was presented: A kitchen scene (see Figures 1 and 2) or a patio scene (see Figure 3)[5]. During viewing the participant could use left/right ctr-key to switch between the gaze-contingent or static presentation. In the static condition the scene was shown completely in focus. The assignment to the keys was random and participants did not receive instructions on which key was mapped to which condition. After viewing both conditions participants were asked to rate a number of statements with regard to the displayed scenes (see Table 1 for a list of all statements). The order of statements varied between trials and participants. The first trial was followed by a second trial depicting the other scene.

[5]The models for both scenes are kindly provided by Jaime Vives Piqueres (http://www.ignorancia.org/) under a CC BY-SA 3.0 license

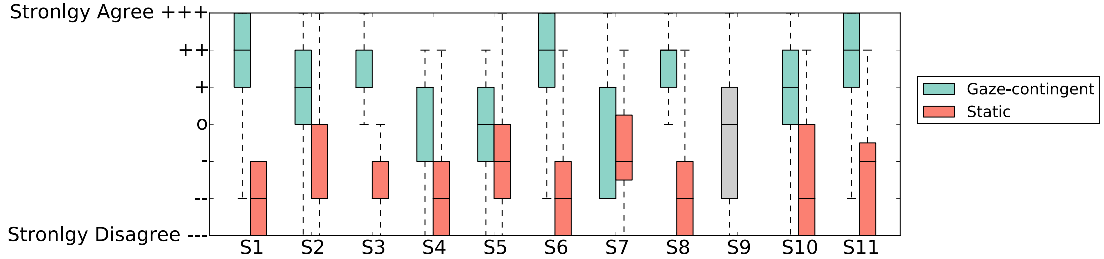

Figure 4: Results for each question of the questionnaire.

Results and Discussion

To asses the perceived 3D-effect and realism of the gaze-contingent blur participants rated the statements, which each either referred to the "Left" or "Right" condition. The statements were rated on a seven point scale from "Strong Agree" to "Strong Disagree". For the analysis we coded the statements according to whether they referred to the gaze-contingent or static condition (except for S9). In addition to relevant questions the list contained four catch-statements (S4, S5, S7 and S9) to asses whether participants are biased towards ascribing arbitrary properties to one of the conditions.

The results of the ratings can be found in Figure 4. We conducted an analysis using Bonferroni corrected MannWhitney U tests, which showed a significant ($p < .05$) difference between the two conditions for all statements that indicate a higher realism and 3D effect (S1, S2, S3 S6, S8, S10 and S11) but not for the catch trials S5 and S7. No test was performed for S9. This leaves only S4 as a catch statement that appears to differ between conditions. As it refers to "distortion" of objects this could indicate that participants picked up on the peripheral blurring.

S1	Depth is more defined and clearer in [L/R] condition
S2	In [L/R] condition it feels though you could reach out and touch things
S3	It feels more like looking at real objects than a picture of objects in [L/R] condition
S4	Objects appear distorted in [L/R] condition
S5	Objects appear larger in [L/R] condition
S6	Objects appear more 3-dimensional in [L/R] condition
S7	Objects appear more transparent and translucent in [L/R] condition compared to [L/R] condition
S8	Objects appear to stick out/come out of the screen in [L/R] condition
S9	The shape of objects is different between [L/R] and [R/L] condition
S10	There is a greater amount of separation between objects in [L/R] condition
S11	There is a more definitive sense of separation in [L/R] condition

Table 1: List of statements used to asses participants' perception of the displays

Conclusions and Future Work

In this paper we have presented an approach to display static scenes enhanced by gaze-contingent DOF blur. The proposed approach was evaluated for its capabilities to enhance the perception of depth and realism in the displayed scenes. The results of the conducted experiment confirm that the use of gaze-contingent DOF blur enhances perceived realism and the sense of depth.

This represents a first step in a larger analysis of the usefulness of DOF blur for depth perception. As a next step we will expand upon these findings with a quantitative analysis to evaluate to what extend gaze-continent DOF blur can convey depth information.

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