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Using a Graphics Turing Test to Evaluate the Effect of Frame Rate and Motion Blur on Telepresence of Animated Objects

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Abstract: A limited Graphics Turing Test is used to determine the frame rate that is required to achieve telepresence of an animated object. For low object velocities of 2.25 and 4.5 degrees of visual angle per second at 60 frames per second a rotating object with no added motion blur is able to pass the test. The results of the experiments confirm previous results in psychophysics and show that the Graphics Turing Test is a useful tool in computer graphics. Even with simulated motion blur, our Graphics Turing Test could not be passed with frame rates of 30 and 20 frames per second. Our results suggest that 60 frames per second (instead of 30 frames per second) should be considered the minimum frame rate to achieve object telepresence and that motion blur provides only limited benefits.

1 INTRODUCTION

Motion blur is heavily used in animated films to increase the visual realism. It is created based on the motion blur which occurs when recording real films (Potmesil, 1983). However, it can be argued that this way of creating motion blur is not optimal for creating realistic animations since it does not simulate the actual human visual system where processes like eye pursuit help deblurring the perceived image (Burr, 1980). We present a setup to determine the minimum requirements in terms of frame rate, object velocity and blur length to render realistic animations in virtual environments.

The specific aim of the work presented in this paper is to evaluate the relation between the frame rate and the velocity of an object in a virtual scene such that the displayed virtual scene is indistinguishable from a real scene. Also, it is tested whether or not simulated motion blur can compensate for low frame rates in order to obtain object telepresence which we define as the subjective experience that a virtual object is situated in the real world in the accordance with definitions of presence and telepresence by Slater and Usoh, Steuer and Witmer and Singer (Slater and Usoh, 1994; Steuer, 1992; Witmer and Singer, 1998).

Rather than, for instance, evaluating the pixel colour difference between different synthesised videos, test subjects assess object telepresence directly. The relation is evaluated through an experiment setup restricting the human visual system and taking into account the limitations of today's monitors — for example insufficient black levels and colour range. The setup used in the experiment hides these limitations and makes it possible to carry out the tests focusing solely on the comparison between the real and the virtual object in order to provide more reliable results.

Our main contribution is to determine under which conditions (in terms of frame rate and blur length) it is possible to create an animated scene which can pass a limited Graphics Turing Test as defined by McGuigan (McGuigan, 2006). In this context, the relation between the object velocity and the frame rate needed to pass the test with simulation of motion blur will be investigated. The setup is tested using a fixed motion pattern. However, the setup is also applicable for testing other motion patterns.

2 RELATED WORK

The persistence of the human eye has been shown to vary depending on several parameters, for instance intensity (Barlow, 1958), contrast (Bowling et al., 1979), proximal objects (Chen et al., 1995; Di Lollo and Hogben, 1987), duration (Efron, 1970), trajectory (Watamaniuk, 1992) and velocity.

A study by Watson et al. (Watson et al., 1986) has tested the relation between frame rate and velocity for moving lines with staircase and stroboscopic light. They used an experiment structure similar to the Graphics Turing Test and found that the critical sampling frequency starts at about 30 frames per second for very small velocities of the lines and increased linearly with the velocity. Others have tested the relation between the ability to distinguish between blur lengths at different velocities (Pääkkönen and Morgan, 1994) as well as how motion deblurring is affected by velocity (Hammett et al., 1998). In relation to object velocity Watamaniuk found that the persistence was reduced solely by step size, hence frame rate, rather than velocity with fixed-trajectory motion (Watamaniuk, 1992).

Common to all of these experimental methods is that they implicitly expect the test subject to compare to a simple pattern or a manufactured reality. The results might prove to work for simple patterns and videos but not necessarily in virtual reality systems where presence is essential.

We propose an experiment in the spirit of Alan Turing's artificial intelligence test (Turing, 1950) where the test subjects will compare a virtual representation of a scene to a genuine scene (McGuigan, 2006). We use a setup similar to the one proposed by Brack et al. (Brack et al., 2010) which is a modification of the experiment by Meyer et al. (Meyer et al., 1986), who made the test subjects watch the scenes through cameras with Fresnel lenses, and the experiment by McNamara et al. (McNamara et al., 2000), who focused on matching light intensities in real scenes, photographs and renderings.

3 EXPERIMENT SETUP

The setup consists of two boxes as seen in Figure 1. One box has a monitor at the end and the other has a small box containing a physical object. The monitor and the small box can be switched in order to present the virtual and genuine scenes in a randomised order. The monitor displays a virtual representation of the physical object, box and light. This setup allows the user to compare the two scenes which can be seen in Figure 2. The fronts of the boxes are covered by opaque plates with circular holes of 2.6 cm in diameter which make it possible to view the entire scene, as well as restricting the depth cues provided by occlusion, size, position, ocular accommodation, linear perspective, motion parallax, stereopsis and convergence (Borg et al., 2012). The box is 200 cm long and lined with black fabric in order to avoid reflections of the light emitted from the monitor. The experiment environment surrounding the boxes is well lit (≈70 lux) and the test subjects are asked to look through the hole at a minimum distance of 7 cm to prevent dark adaption. The physical scene is lit by a halogen lamp through a diffuse filter at an oval shaped hole in the top of the box. A luminosity of about 600 lux is measured just below the filter. Sufficient light is emitted by the spotlight in order to make the object easily visible.

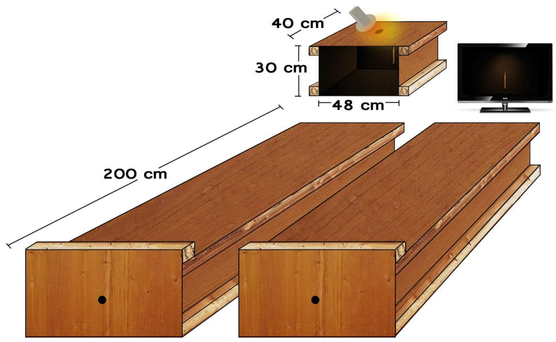

Figure 1: A graphic representation of the setup. This does not include the sheet preventing the user from viewing beyond the fronts of the boxes.

Before the test, the test subjects are informed about the experiment setup and asked to answer which of the two is the real scene — similar to a two-alternatives forced choice test. The test subjects can look into the boxes for as long as they want.

4 VIRTUAL SCENE

A 12 cm white plastic propeller is chosen for the experiment because of its simple shape, its rotating motion pattern and its high contrast relative to the background. A rotating pattern makes it possible to keep the trajectory inside the scene.

The experiment is executed on a Samsung SyncMaster 2233RZ 22" TFT monitor with a luminosity of 300 cd/m^2 and a dynamic contrast of 20,000:1. All videos are rendered and shown in 1680×1050 to preserve aspect ratio. The length of the propeller extends 2.87 degrees of the visual angle.

4.1 Modeling and Setup

The virtual scene is modeled in Autodesk 3ds Max to the exact measurements of the real scene in order to achieve realistic lighting. A photometric light source is set up with a temperature of 3400 Kelvin and an intensity of 14.4 cd. The light is emitted from a disc

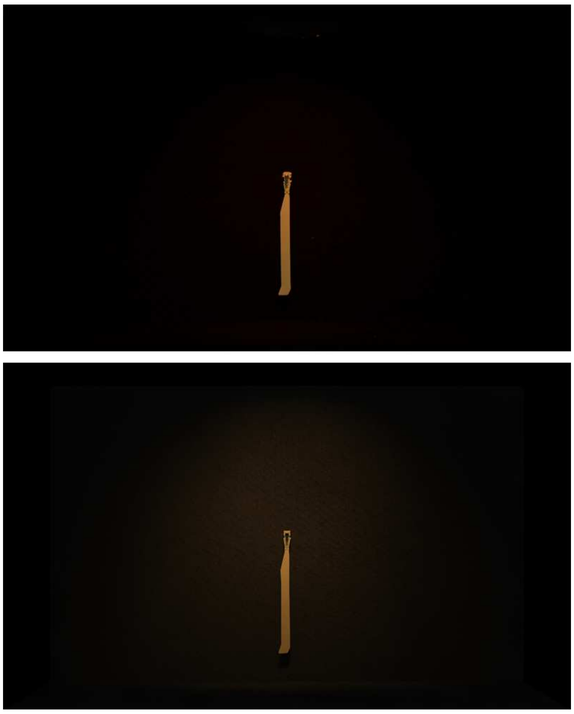

Figure 2: Top: The physical object captured with a 85 mm SLR camera — aperture of 4.5, shutter time of 1 second and ISO 100. Bottom: The virtual representation of the real object. The bright area on the back of the box gets darkened due to the dynamic contrast on the employed screen.

positioned equivalently to the halogen lamp. Subsampling is set to 4 and the shadows are rendered with 256 samples. Object motion blur is used for motion blur rendering.

4.2 Scene Compatibility

To prevent bias of the two scenes being distinguishable, an experiment testing a static version of the scene is conducted. Fifty answers were collected from ten male subjects in the age of 21–29 with normal or corrected-to-normal vision. The scenes are shown in a randomised order and with the propeller pointing either up, down, left or right. The test subjects provided 25 wrong guesses and 25 right guesses which is exactly the same ratio as would be expected at random chance.

5 RELATION BETWEEN FRAME RATE AND OBJECT VELOCITY

To determine whether or not previous findings (Watson et al., 1986) of relations between frame rate and object velocity apply to object telepresence tested by a Graphics Turing Test, four different propeller velocities of 2.25, 4.5, 9 and 18 degrees of visual angle per second (furthest from the center of rotation) are shown at three different frame rates — 60, 30 and 20 fps. The order of renderings is randomised.

	2.25°/s	4.5°/s	9°/s	18°/s
60 fps	15	17	8	8
30 fps	10	10	6	2
20 fps	5	3	2	1

Table 1: Incorrect answers provided out of 40 trials.

In the experiment, 40 people in the age of 17 to 47 participated, 7 females and 33 males where 33 had experience with computer graphics. All have normal or corrected-to-normal vision.

A criterion for successfully passing the Turing Test has been proposed (Borg et al., 2012) to verify whether or not the null hypothesis (that people can see which object is real) can be rejected. This method complies with true hypothesis testing of rejecting the null hypothesis. In order to pass the test, the probability that the test subjects incorrectly identify the virtual object as the genuine object must be greater than 19 % for a significance level of 5 %. This corresponds to the commonly used threshold of subjects guessing incorrectly at least 25 % of at least 100 trials (McKee et al., 1985). With 40 trials and p_{null} = 0.19, the corresponding threshold is slightly higher to compensate for lower samples sizes.

The probability for a specific number of incorrect answers, i, can be calculated by the probability mass function:

$$f(i|n,p_{null}) = \frac{n!}{i!\,(n-i)!}\,(p_{null})^i\,(1-p_{null})^{(n-i)}$$

where p_{null} is the probability for the null hypothesis and n is the number of trials. With this function, the critical value, i_c, of incorrect answers to pass the test can be found, such that the null hypothesis is rejected with a significance level of 5 %:

$$i_c(n,p_{null}) = \min\{i \mid \sum_{j=i}^{n} f(j|n,p_{null}) < 0.05\}$$

With 40 trials and p_{null} = 0.19, the critical number of incorrect answers is 13. The provided answers from the experiment can be seen in Table 1.

At low velocities shown at 60 fps, the Graphics Turing Test can be passed. This corresponds to previous findings of Watson et al., who suggests that a frame rate of at least 150 to 250 fps is needed to pass the test with the highest object velocity (Watson et al.,

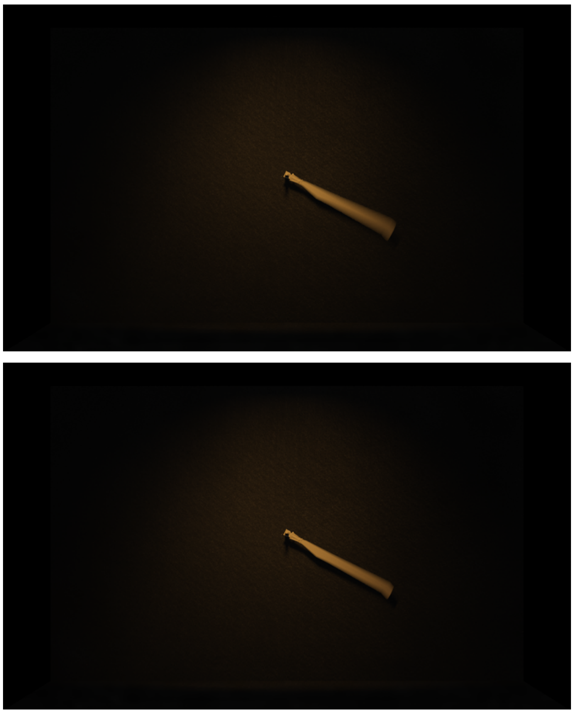

Figure 3: Top: Frame from 30 fps rendering with 1 frame blur length. Bottom: Frame from 60 fps rendering with 1 frame blur length. At low frame rates motion blur is more excessive.

1986). The results also correspond to Watamaniuk's findings that persistence is decreased solely by step size and not by object speed (Watamaniuk, 1992), i.e. the critical object velocity depends on the frame rate.

6 RELATION BETWEEN FRAME RATE AND MOTION BLUR

It might be possible to pass the test with simulated motion blur as it has been shown to increase acuity at high velocities and large separations, i.e. low frame rates (Fahle and Poggio, 1981; Hammett et al., 1998).

To determine whether or not motion blur can be used to compensate for low frame rates, two renderings with blur lengths corresponding to shutter times of 0.5 and 1 frame are compared to the three frame rates. The object velocity is kept fixed at 9 degrees of visual angle per second.

Ten male test subject in the age 21 to 27 participated in the experiment. Eight of them had experience with computer graphics and all had normal or corrected-to-normal vision. They compared each rendering twice, giving a total of 20 trials, which can be seen in Table 2.

	0.5 frame blur	1 frame blur
60 fps	5	8
30 fps	2	0
20 fps	2	0

Table 2: Incorrect answers provided out of 20, with a fixed object velocity of 9 degrees of visual angle per second.

A one-tailed Fisher's exact test between renderings with no blur and their corresponding renderings with blur reveals no significant difference with the addition of simulated motion blur for a significance level of 5 %. However, the critial value for 20 trials is 8 which indicates that long streaks of motion blur might be used to pass the Graphics Turing Test at higher object velocities than 9 degrees of visual angle per second for 60 fps.

For 30 fps and 20 fps, the addition of motion blur had either no effect (Hammett et al., 1998) or allowed all test subjects to identify the rendering based on excessive blur (see Figure 3).

7 CONCLUSION

The work in this paper tests the relation between object velocity and frame rate in a Graphics Turing Test and the influence of motion blur for various frame rates. The experiments showed that the only frame rate that facilitated movements up to 4.5 visual angles per second was 60 fps. In general, the results of the experiments point towards a tendency that higher object velocity makes the test subjects more likely to recognise the 3D model. More specifically, the amount of visual angles that the object moves from one frame to the next is roughly sought to be 0.075 visual angles. 0.075 visual angles only apply to 60 fps — and not 30 fps. This indicates that frame rate is predominant compared to object velocity.

A second experiment was carried out in order to clarify if it was possible to decrease the frame rate by adding various amounts of motion blur. In this experiment, the 60 fps rendering with 1 frame blur length was able to pass; the other renderings did not improve by the use of simulated motion blur. Although the 60 fps rendering with 1 frame blur length passed the Graphics Turing Test, the result may be due to the low number of test subjects as a Fischer's exact test proved that there was no significant difference between the renderings with motion blur and the renderings with no simulated motion blur. Based on the work presented in this paper virtual reality systems require at least 60 fps to pass the Graphics Turing Test if they include any kind of movement. This indicates that the previously assumed limit of 30 fps might not be sufficient (McGuigan, 2006). Also, motion blur is unlikely to help passing the Graphics Turing Test for the tested object velocities since humans perceive real objects at low velocities without much motion blur (as opposed to cameras with finite shutter times).

8 FUTURE WORK

The experiment for 60 fps and 1 frame blur length passed the Graphics Turing Test; however, no significant difference between this result and the result for the experiment without motion blur was found; thus, this result is worth further research. The results described in this paper show a tendency that higher object velocities as well as lower frame rates are less likely to pass a Graphics Turing Test. Therefore, it should be researched further whether a higher object velocity can pass the Graphics Turing Test with the use of simulated motion blur without having to increase the frame rate of the rendering as it is not realistic in terms of the limitations of today's consumer monitors. Lastly, we would also encourage more research in the area of other object trajectories and more complex scenes.

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