Cross-modal affects of smell on the real-time rendering of grass

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Abstract

Smell is a key human sense which can significantly effect our perception of an environment. Although, typically not as developed as our other senses, the presence of a pleasant or unpleasant smell can alter the way we view a scene. Such a cross-modal effect can be substantial with parts of a scene literally going unnoticed as the smell dominates our senses. This paper investigates the cross-modal affect on the perception of the real-time animation of a field of grass in the presence of the smell of cut-grass. Rendering the high level of detail of a close-up view of a field of grass is computationally very demanding. In the real world the smell of grass would be present, and especially strong if the grass had just been cut, for example in preparation for a sports event. By exploiting the cross-modal interaction between smell and visuals we are able to render a lower quality version of a field of grass at a reduced computational cost, without the viewer being aware of the quality difference compared to a high quality version.

CR Categories: I.3.0 [General]: Cross-modal, Olfaction, High-fidelity rendering—; I.3.3 [Picture/Image Generation]: Anti-aliasing—; I.3.7 [Three-Dimensional Graphics and Realism]: Animation, Color, Shading, Shadowing and texture, Virtual reality—;

Keywords: olfaction, scent, real-time, visual perception, grass-rendering

1 Introduction

Accurately modeling and rendering natural scenes is a major challenge for computer graphics. However, there are numerous applications which would benefit from such accurate representations of the real world. Although computer generated imagery of natural scenes has made significant progress in the last few years, for example figure 1, the computational requirements are still high precluding their exploitation in real-time settings on standard desk top machines.

A human's perception of an environment is not only through what we see, but is also significantly influenced by our other sensory inputs, including sound, smell, touch and even taste. The presence of one or more additional senses may dramatically alter the way we view the scene with our eyes, for example [Calvert et al. 2004]. Knowledge of how our eyes might view a scene when more than one sense is present has been exploited in computer graphics to selectively render images at a computationally lower cost without the viewer being aware of any drop in perceived quality [Ramic et al. 2006], [Mastoropoulou et al. 2005a], [Ellis and Chalmers 2006].

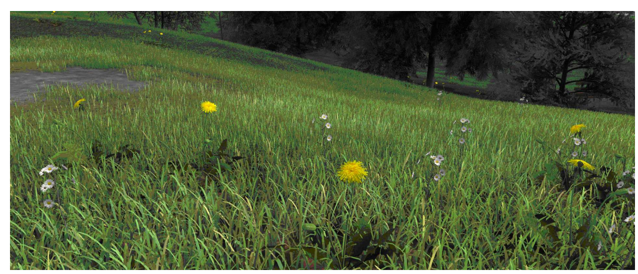

Figure 1: Real-time rendered grass blades

Smell, or *olfaction* is a key human sense. The sense of smell creates sensory experiences that are uniquely pleasurable and sometimes even sensual. For example, the smell of baked bread significantly enhances any visit to a bakery, and indeed, some bakeries vent their ovens out to the sidewalk, exploiting the aroma of fresh bread to attract customers inside [Winter 1976]. Smell can have a powerful emotional impact. It provides an important recognition function. Each of us has a unique scent [Jacobs 2007] and on the basis of smell alone we can distinguish whether a person is male or female [Wallace 1977]. Smell is also able to evoke old memories more strongly than any of our other senses [Jacobs 2007]. In addition to being pleasant or unpleasant, smell also provides us with crucially important information including alerting us to danger, although not, perhaps surprisingly, when we are deeply asleep [Carskadon and Herz 2004]. Smell is with us at all the time [Blake and Sekuler 2006].

In this paper we investigate whether the presence of a related smell could be used to significantly reduce the level of detail in a real-time rendering application without the user being aware of a reduction in quality. In particular we studied if viewers would notice a reduction in the quality of the rendering of a field of grass when the smell of cut-grass was present. Accurate, real-time rendering of grass has

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SCCG 2009 Budmerice, Slovakia, April 23 – 25, 2009.
© 2009 ACM 978-1-4503-0769-7/09/0004 $10.00

many application possibilities, especially for use in sports games.

2 Previous work

2.1 Real time rendering of grass

Apart from water, grass occupies the largest area of our planet. It can be found everywhere. A surface of grass is composed of a large number of grass blades. When viewed from afar, grass can be simulated by a simple “green texture”, but when examined close up, every blade of grass may need to be considered. In even a small field of grass this requires far too much memory and computational effort to be rendered directly [Boulanger 2008].

Overcoming the complexity of grass in order to render it in real-time has been a challenging problem for many years. Previous approaches either render grass in real-time but with coarse approximations ([Reeves and Blau 1985], [Perbet and Cani 2001], [Bakay and Heidrich 2002], [Pelzer 2004], [Shah et al. 2005]), or render grass in high quality but offline [Deussen et al. 1998].

In this paper we use a relatively novel approach to rendering of large surfaces of grass, using dynamic lighting, dynamic shadows and anti-aliasing. This method has three levels of detail, chosen depending on the distance from the camera: geometry rendering, volume rendering with per pixel lighting, rendering of 2D texture map with per pixel lighting. Our approach, however, allows rendering of very detailed grass with shadows in close proximity from the viewer, and far grass with per pixel lighting and with a convincing parallax effect [Boulanger et al. 2006].

Using a level of detail approach, provides a good compromise between lighting quality and rendering speed. Furthermore, this grass rendering algorithm allows us to render virtually infinitive number of grass blades [Boulanger 2008].

2.2 Cross-modal rendering

Despite the significant research into the limitation of the HVS within Computer Graphics, see good overviews in [O’Sullivan et al. 2004] and [Bartz et al. 2008], little work has been undertaken into the strong cross-modal interactions between visual and other sensory stimuli.

Research by Mastoropoulou et al. [Mastoropoulou et al. 2005a], [Mastoropoulou et al. 2005b], [Mastoropoulou 2006] demonstrated that sound can influence the visual perception using knowledge from psychology in combination with selective rendering algorithms. This research inferred that by exploiting the presence of sound it is possible to render animations with lower frame rates without perceived difference in animation smoothness.

It was also shown that observers are unable to perceive reductions in quality of animated sequences when selective rendering was used to render sound emitting objects in higher quality than the rest of the scene. Other research by Storms [Storms 1998] and Winkler et al. [2005] showed that using the high-quality audio stimuli increases the perceptual quality of video observed and that the quality of both of them contribute in the perceived quality, respectively. In addition Ellis and Chalmers showed that viewers also failed to notice a quality difference when motion was present [Ellis and Chalmers 2006].

Despite the importance of scent in our every day life, little work has been done to include smell in virtual environments. Recently smell has started to be introduced into virtual environments for training, for example [Wahburn et al. 2003], and therapy, for example [Barfield and Danas 1995] and [Chen 2006]. Results from preliminary studies have shown that the introduction of smell does indeed increase the user’s sense of ”presence” in the virtual environment [Zybura and Eskeland 1999]. In particular, the introduction of realistic smells, including the smells of burning rubber and flesh, have been used effectively to treat soldiers returning from Iraq with post-traumatic stress disorder [Fildes 2007], [Rizzo et al. 2007]. Most recently an interactive olfactory display was developed for a ”cooking game”, in which the duration and strength of a number of predefined smells was controlled and blended in real-time into a number of recipes by the game [Nakamoto et al. 2008]. Olfactory displays have been shown to enhance the sense of presence and add salient spatial cues in virtual reality (VR) environments [Tominaga et al. 2001], [Dinh et al. 1999]. Along these lines, olfactory displays have been used to enhance VR-based training systems for fire-fighters and emergency medical personnel [Carter 1994], [Krueger 1995].

In 2007, Ramic et al. [2006] showed that smell, in their case perfume, can be used to direct a viewer’s attention to the smell origin in the scene, a bowl of flowers. The area around the bowl of flowers was rendered at the highest quality, while it was possible to render the remainder of the scene at a much lower quality, and thus at a reduced computational cost, without the viewer being aware of this quality difference.

3 The Experiment

We hypothesized that viewers would fail to see the difference between a high quality and a lower quality rendered animation of a field of grass if they viewed the animations in the presence of the smell of cut-grass. We thus considered two conditions: no smell and smell.

3.1 Design

For our experiment we used an independent samples design. The dependent variable was the perceived relative quality of a rendered animation sequence in each test pair. The independent variables were the actual quality at which animations were rendered (either high quality or low quality) and the olfactory background (smell or no smell effect). The conditions tested are shown in Figure 2.

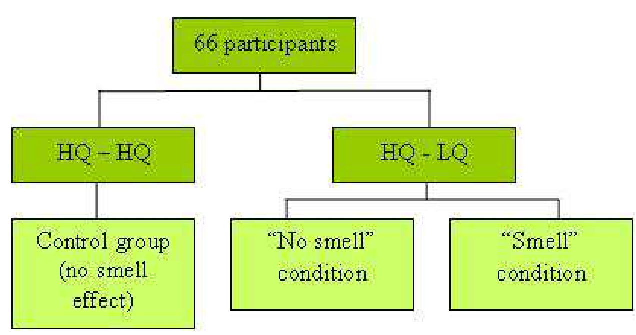

Figure 2: The conditions tested

During each session, subjects watched a pair of animations which showed a flyover of a grass terrain. They viewed the animations, one after the other and then had to judge which animation was of better quality. If they could not distinguish between two shown clips, they were asked to choose one (2-Alternative Forced-Choice method, 2AFC) [Abbey et al. 1999].

Both animations had the same visual content but were rendered at different qualities. The high quality animation, HQ - Figure 3, was rendered with eight time anti-aliasing for grass and with shadows. The low quality animation, LQ - Figure 4, was rendered with no anti-aliasing and no shadows. Both videos were rendered at 1280×800 pixel resolution using a GeForce 8600M graphic card.

The animations were recorded as fast as our hard drive could follow, which is around 2 frames per second. But, in order to have real timings, we measured the speed of the original program without recording. The rendering speed varies in this range as a function of the camera position and orientation.

- High quality (1280×800): 6-7 fps
- Low quality (1280×800): 9-11 fps

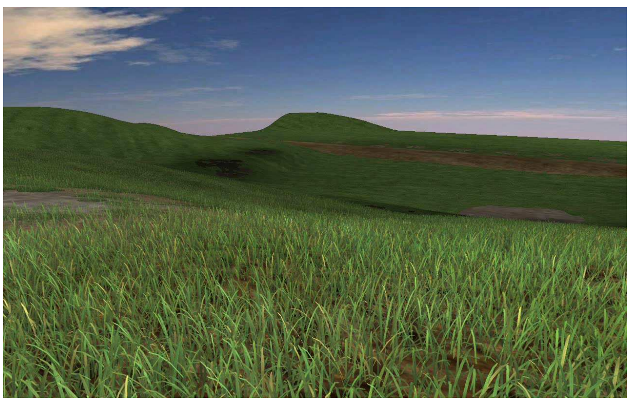

Figure 3: Frame from animation sequence rendered in high quality

Figure 4: Frame from animation sequence rendered in low quality

3.2 Participants

Sixty six participants, ages ranging from 18 to 57, mixed sexes (19 females and 47 male) from the postgraduate student population volunteered to participate in this study.

None of the participants reported any problem with their sense of smell, for example a cold or being pregnant. All of them reported normal, or corrected to normal vision. The majority of them had taken a course in computer graphics and were familiar with concepts such as image quality and, aliasing.

The participants were randomly divided in two groups across the two conditions. Members of each group were informed that they could withdraw at any point during the experiment and were naive about its purpose.

3.3 Equipment and materials

The test environment comprised a PC placed on a desk in an empty room, so that the subjects would not be distracted by surrounding objects. The subjects watched animations on a full screen on 17" monitor (resolution: 1280×1024 pixels). They were seated at a normal viewing distance from the monitor ($\approx 60cm$).

The scent of cut-grass was delivered using an off-the-shelf perfume atomizer. This commercial atomizer releases a small puff of scent automatically at a user defined time interval. The smell was created by mixing ethanol with cis-3-hexenol in ratio 9:1. This 10% solution of cis-3-hexenol was sufficiently strong to rapidly fill the environment with the smell, even with the small volume of release of the odor at each "puff".

3.4 Procedure

Each participant individually was shown two animations, one rendered in HQ and the other rendered in LQ. The order of showing was randomized to prevent any bias. The subjects in "Smell Effect" group were told that the animations would be accompanied by the smell of fresh cut grass which will be delivered through the use of smell delivery system. The smell is continually puffed during the experiment so the user is receiving different concentrations over time so will not get fully adapted and thus fail to notice the smell.

After seeing both animations, viewers were asked to answer the question: "Which of the two shown animations was of better quality taking into consideration only rendering quality?".

Each animation was prerendered in real-time and lasted for 12 seconds. The whole experiment took about 2 minutes for each subject as each one had to sign a consent form and anonymously supply some demographic information including details about their age, gender, eyesight, if they were having problems with smelling such as a cold or allergy, and their knowledge of computer graphics.

4 Results

The measure of performance in our experimental task was the percentage of times each subject correctly identified the animation rendered in high quality within the pair of displayed animations. For example, a performance of 100% within a certain condition means that all participants correctly identified the animation which was of the better quality. If the subjects could not distinguish the difference in quality, then we would expect a result of 50% as they were asked to guess if they were not sure.

A pilot study involving 6 participants was run, using the HQ animations both times. As expected a result of 50% was achieved.

Results for the "No smell" condition are presented in Figure 5. As we can see in the figure, 80% of our participants correctly identified the high quality animation.

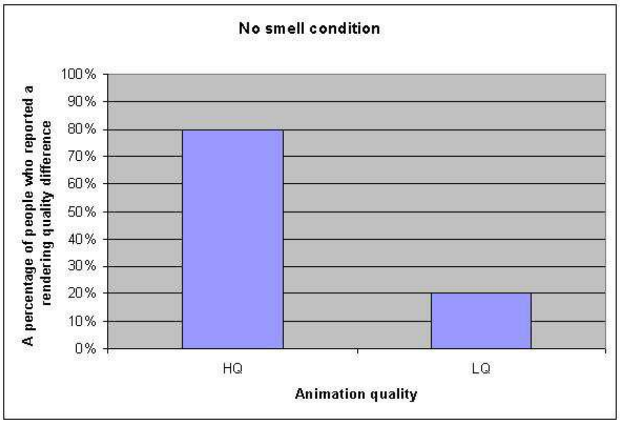

Figure 5: Results for ”No smell” condition

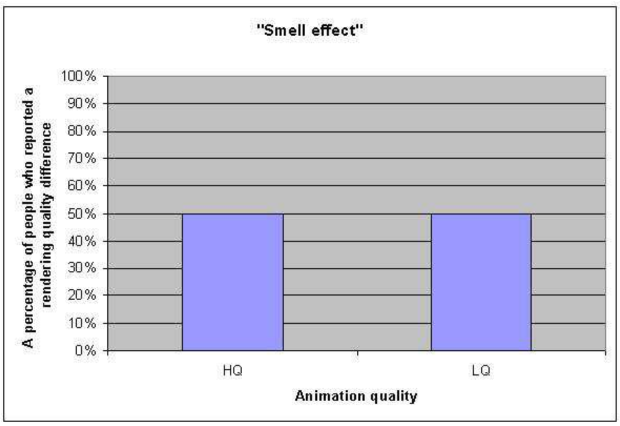

Figure 6: Results for ”Smell effect” condition

Figure 6 shows the results for the ”Smell effect” condition. In this case, only 50% of the participants correctly identified the higher quality animation. Figure 7 presents a comparison between two tested conditions. In order to see if there is a significance to our results we used a chi square two independent samples test since we have two conditions and two different set of subjects. For the degree of freedom 1, chi square value is $x^2 = 5.934$ and the level of significance is $p = 0.01$.

Therefore, the probability of rejecting the null hypothesis when it is true, in our case is equal to 1%. There is thus evidence that smell does indeed make a significant difference to a viewer’s ability to distinguish the quality difference in the renderings of the field of grass.

5 Conclusion

The results in this paper show that the smell of fresh cut grass can indeed distract viewers from correctly identifying animation quality. Only 50% could correctly identify the HQ animation, whereas without the smell, 80% of the subjects could successfully make the distinction. We are thus able to deliver a field of cut grass at approximately twice the speed (9-11fps vs 6-7fps) without the viewer being aware of a quality difference. Furthermore, all subjects, in the post-experiment questionnaire, felt that the presence of the smell of

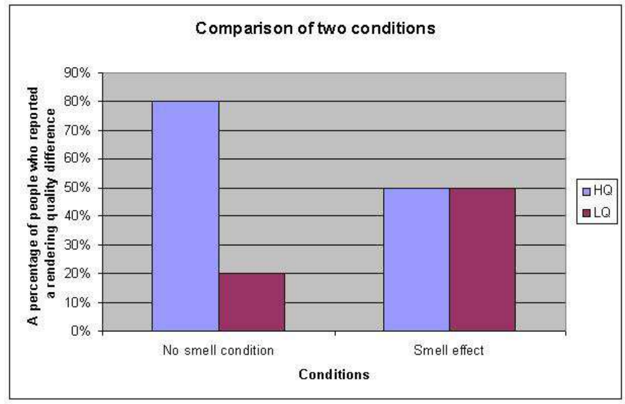

Figure 7: Comparison of the results for two conditions

cut-grass enhanced their viewing experience.

The smell of cut-grass, cis-3-hexenol, is a single smell molecule, easy to produce and which can be delivered in a straightforward manner using an off-the-shelf atomizer. Packaging such a “smell addition” to an existing computer game would enable perceptually higher quality grass rendering to be utilized and enhance the user experience.

Smell plays very important role in our perception of an environment and there is a strong connection between olfaction and human visual system. In future we will consider a far larger number of subjects to gain further confidence in our results. We will also investigate an even lower quality of grass rendering to achieve the 60fps requirement which is typical for most computer games, and the addition of more complex smells, such as perhaps the occasional smell of a hot-dog, another common feature at a sports match.

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