Simulation of HDR Displays on Standard Displays Using Eye Tracking

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Motivation

High dynamic range (HDR) is one of the most prominent areas of exploration and development in modern display technology. For many years, advances in screens and projectors focused on increasing resolution. While manufacturers still value HD quality, the craze of cramming ever-increasing numbers of pixels into screens has mostly subsided. This is likely because screens already possess a high enough pixel density that further improvements would barely be noticeable. The greatest remaining gap in realism of displays lies in available levels of contrast and dynamic range.

Although lots of progress has been made in manufacturing HDR displays, the technology is still prohibitively expensive. By emulating the effects of an HDR display in software, it could be possible to provide users a similar experience at only the cost of a standard display plus an eye tracker. Without great expenditure, users could experience digital media such as photography and video games with a much greater level of depth and realism.

Related Work

Many researchers have studied the specific ways in which the eye responds to differing levels of light. Sharpe et al. (2005) published an effective method for estimating the eye's response to specific wavelengths. In an attempt to preserve realism, I may need to reverse any adaptations encoded in some images or in the monitor. These functions can help me with this [1]. Additionally, I must account for the eye's differing sensitivities under bright light versus low light. This could involve separately modeling photopic vision (bright light in which cone cells dominate) and scotopic vision (dim light in which rod cells dominate) at some point in the future. Kalloniatis and Luu (2005) summarize a lot of the research that has been done on the perceptual differences of these methods of vision [2].

Ledda et al. (2004) proposed a model for the adaptation of rods and cones to differing light scenarios. In their paper, they account for the accommodation of the eye to different brightness levels, and account for the perceptual qualities at each level. Their model also accounts for time dependent scenarios, meaning that they examine how long photoreceptors take to adapt fully [3].

New Technique

I use an eye tracker to retrieve the position of the user's gaze on the screen, many times per second. I use high dynamic range images that are linear in their luminance scale, which affords full control of the processing pipeline. Every time a new gaze position is recorded, I re-calibrate the exposure of the image so the gaze point is well exposed. Knowing the dynamic range of the eye at this specific sensitivity level, other values in the image can be adjusted to be brighter and darker; pixels at the edge of the dynamic range could be blown out or fully dark.

In the preliminary implementation, I use a fixed dynamic range of 8 powers-of-two for the virtual eye. This ranges from four stops below the exposure of the gaze position to four stops above. This range holds under all lighting conditions. When the user shifts their gaze, I immediately adjust the pixels at that point to be perfectly exposed, and change other pixels to be over- or under-exposed. To calculate the correct exposure level, I average the lightness values of all the pixels within a small region of the gaze center (to smooth out small variations in luminance). I then set this value to be the center brightness value (128 on a 0-255 scale), and gamma correct all pixels within the decided dynamic range. The edges of the dynamic range define full white and full black.

I will expand this prototype to account for differences in the eye's sensitivity in different light levels. Ideally, a spot of the image in full sunlight will still appear a bit brighter than a spot in the shade, even after adaptation. The eye may also realistically have different dynamic range levels at different levels of accommodation. To create greater realism, adding a temporal component would be ideal. This would involve interpolating between old and new exposure levels over time every time the gaze changes. As an example, adjusting to bright light might happen almost immediately while adjusting to a lower light level could take several seconds. If time permits, I could expand the simulation further by adding additional effects the eye might experience in the real world. One possibility would be to model the color after-effects that one sees when staring at a bright object such as the sun.

Experimental Results

The results of this prototype are promising. The adaptation of the exposure to the user's gaze position proves to be a useful way to understand the full lighting qualities of an image. On a standard display, tone-mapped HDR images have no notion of light and dark areas, which results in an interesting but unrealistic aesthetic. Using eye tracking maintains many of the cues that the brain uses to understand the full luminance range.

There is still some work to do before this technique convincingly appears similar to an HDR screen. In order to fully create the sensation of high dynamic range, I will need to experiment with ways to reduce latency. Possibilities include pre-computing various exposure levels and making use of the GPU. I also believe that modeling characteristics of the eye more closely will greatly increase immersion.

Works Cited

[1] Sharpe, Lindsay T., et al. "A luminous efficiency function, V*(λ), for daylight adaptation." *Journal of Vision* 5.11 (2005): 3-3.

[2] Kalloniatis M, Luu C. Light and Dark Adaptation. 2005 May 1 [Updated 2007 Jul 9].

[3] Ledda, Patrick, Luis Paulo Santos, and Alan Chalmers. "A local model of eye adaptation for high dynamic range images." *Proceedings of the 3rd international conference on Computer graphics, virtual reality, visualisation and interaction in Africa*. ACM, 2004.