Gaze-Dependent Simulation of Light Perception in Virtual Reality

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Introduction

brightness range

tone mapping
Introduction
Introduction

- Perceptual algorithms necessary!
  - Medically based
  - Account for viewing direction, pupil size
Contribution

- Post-processing workflow
  - Accurate simulation of light perception in VR/AR
- Medically-based, perceptual effects
  - In real-time VR/AR
  - Following optometrist advice
- Eye tracking for measuring light incidence
- Pilot user study, comparison of
  - Real-world low-light situation
  - And VR simulation
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**Temporal Eye Adaptation**
- Visual adjustment to bright and dark
- Adaptation of rods and cones over time

**Perceptual Glare**
- Colorful patterns when viewing bright light sources
- Scattering of light in the eye

**Visual Acuity Reduction**
- Blurred details in low light scenes
- Rods not present in fovea (point of sharpest vision)

**Scotopic Color Vision**
- Color shift towards blue in low light scenes
- Rods more sensitive to longer wavelength light than cones

Based on Krawczyk et al., 2005 and Ritschel et al., 2009
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Temporal Eye Adaptation

\[ L_i = L_{i-1} + (Y - L_{i-1}) \cdot 
\left(1 - e^{-ft/\tau(Y)}\right) \]

- Target luminance Y
- Temporally filtered luminance \( L_i \) of frame i
- Photoreceptor adaptation times \( \tau \)
Perceptual Glare

Motivation ▫ Overview ▫ Methodology ▼ Adaptation ▼ Glare ▼ VA reduction ▼ Color shift ▼ Evaluation ▼ Conclusion ▼

Image adapted from commons.wikimedia.org/wiki/File:Eyesection.svg
Perceptual Glare

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Perceptual Glare

\[
M(x, y) = \frac{1}{(\lambda d)^2} \left| \frac{1}{N} \cdot \mathcal{F} \left[ P(x, y) \cdot e^{i \frac{\pi}{\lambda d} (x^2 + y^2)} \right] \right|^2
\]

After Ritschel et al., 2009
Perceptual Glare

Monochromatic PSF
Diffraction on the retina of a single wavelength light source

Spectral PSF
Combination of multiple wavelengths to simulate spectral light
Diffraction on the retina of a single wavelength light source

Monochromatic PSF

Spectral PSF

Combination of multiple wavelengths to simulate spectral light
Perceptual Glare

\[
(1 - \cdot (1 - )) + \cdot =
\]
Perceptual Glare

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Visual Acuity Reduction

- $\sigma(L) = \max(1 - L, 0)$
  - Gaussian variance $\sigma$
  - Pixel’s lightness $L$
Evaluation

Qualitative user study with 5 participants
Conclusion

Real-time VR/AR post-processing workflow
Using eye tracking
Based on medical research
Pilot user study

- temporal eye adaptation
- perceptual glare
- visual acuity reduction
- scotopic color vision

Related article: “CatARact: Simulating Cataracts in Augmented Reality”, Krösl et al., 2020
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Thank you for your attention!