Investigation of Image Perception Under Low Light Conditions

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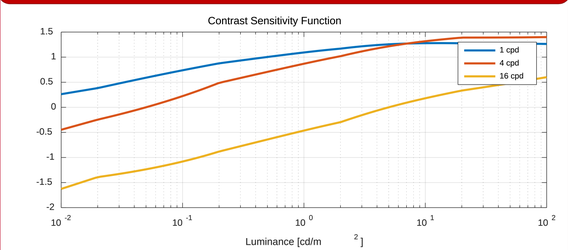
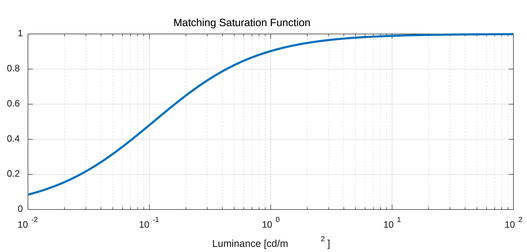
Motivation

Modern displays are used in different lighting conditions with the awareness of the ambient illumination levels. Automatic brightness adjustment can reduce energy consumption and eye fatigue. However, the display content is the same across the range of ambient illuminations even though human visual systems have different color and contrast response functions. Therefore, the image quality and viewing experience can be significantly different when the same picture is shown in a darker situation. It is the goal of this project to take a closer look at human perceptive models under low light conditions and examine different algorithms to adjust the image in order to create a constant perception.

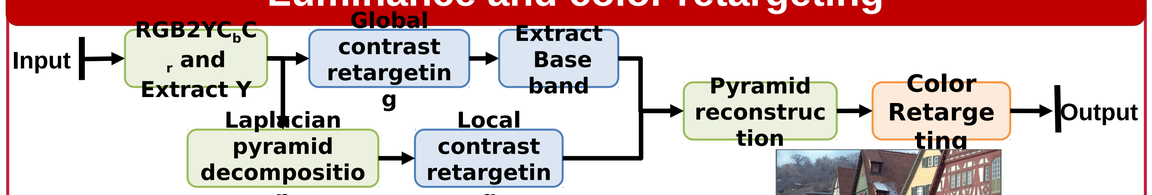
Human perceptive model

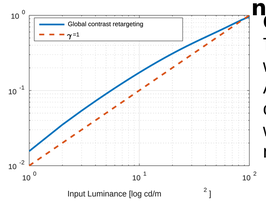




The Contrast Sensitivity Function (top) and the Matching Saturation Function (bottom) of human eyes depend on many factors such as distance, background, spatial and temporal frequency, age etc. [1,2] In the scope of this project, the effects of luminance is investigated and plotted above. The same pattern will appear different in terms of intensity and color saturation under different lighting conditions.

Luminance and color retargeting





Global contrast retargeting

Two contrast magnitudes match in their appearance when their supra-threshold contrasts match [3]: $M - M_t = \gamma(M_t - M_t)$

A tone-curve for global contrast retargeting from 100 cd/m² to 1 cd/m² peak luminance is plotted on the left with a γ=1 curve (simply dimming without retargeting) as reference.

Local contrast retargeting

Spatial frequency and contrast magnitude are addressed on a local level. The image is decomposed into frequency-selective bands (P_k) and reconstructed with different weights computed from the local contrast [5]: where $\bar{P}_k(x,y) = P_k \cdot g_{\sigma_k}$ is a Gaussian kernel with standard deviation σ_k and g_σ is a Gaussian kernel with standard deviation σ.

$$\frac{\sqrt{(g_\sigma * l)(x,y)]^2)(x,y) - G(M_t) + G(\bar{M}_t)}}{\sqrt{(g_\sigma * [l(x,y) - (g_\sigma * l)(x,y)]^2)(x,y)}}$$

Color retargeting

When luminance is low, the image loses color saturation, along with a hue shift. This is because of the varying contribution ratio between cones and rods. To reproduce the same perception, a conversion matrix is computed using the display/printer spectral functions, human cone and rod spectral absorption functions, and target luminance $\tilde{Y}$:

$$\begin{bmatrix}\tilde{R}\\ \tilde{G}\\ \tilde{B}\end{bmatrix} = \frac{\tilde{Y}}{Y}\left(M_c(\tilde{Y})M_E\right)^{-1} M_c(Y) M_E \begin{bmatrix}R\\ G\\ B\end{bmatrix}$$

. The color saturation is corrected by $\hat{R} = \left(\frac{\tilde{R}}{\tilde{Y}}\right)^{\frac{s(Y)}{s(\tilde{Y})}} \tilde{Y}$. where $s(Y) = \frac{Y}{Y+0.108}$.

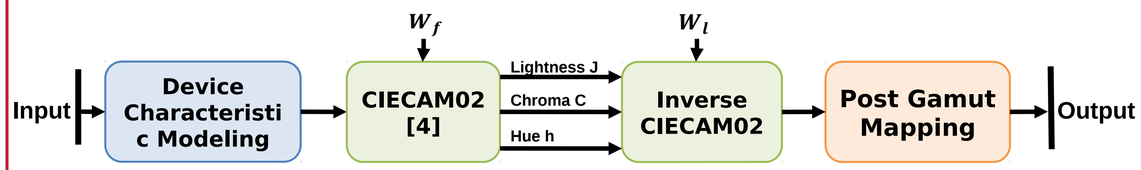
Original image

After global contrast retargeting

After local contrast retargeting

After color retargeting

Perceptual anchoring



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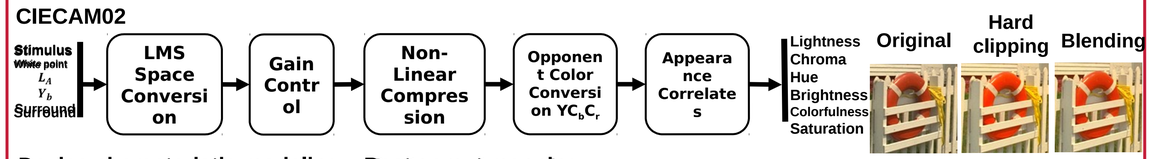
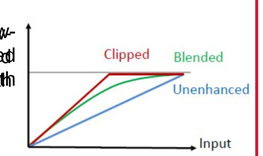


Device characteristic modeling

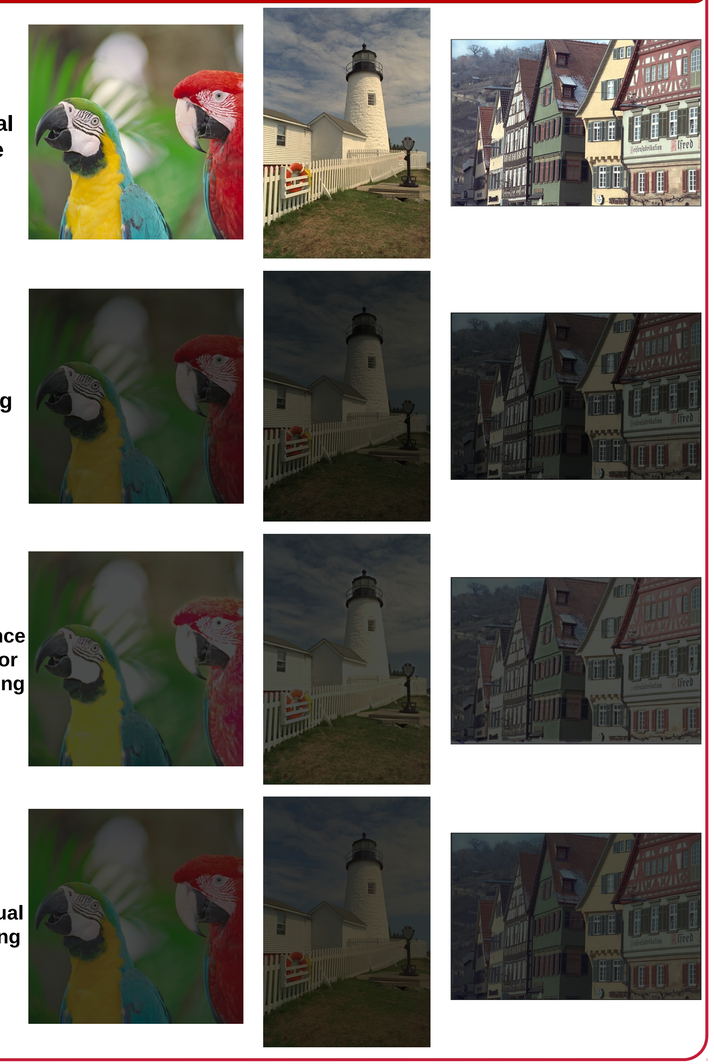
Pixels are converted from srgb to lrgb domain, with different gamma applied in each channel. RGB values then converted into XYZ domain by taking into account different display parameters.

Post gamut mapping

Some enhanced pixels are not displayable by the low-backlight display. Instead of hard clipping, the gamut mapped pixels are computed by blending the clipped pixel value with the original pixel value [5]: $\begin{bmatrix}\tilde{R}\\ \tilde{G}\\ \tilde{B}\end{bmatrix} = (1 - JC)\begin{bmatrix}R_c\\ G_c\\ B_c\end{bmatrix} + JC\begin{bmatrix}R_i\\ G_i\\ B_i\end{bmatrix}$



Simulated results comparison



Original image

Just dimming

Luminance and color retargeting

Perceptual anchoring

Conclusions

Both algorithms provide better visual experience than naively dim the image when ambient light is decreased. It is noticeable that the image obtained after luminance and color retargeting is more appealing to the eyes, providing visual perceptions that are closer to the original images. Fine frequency details are emphasized, and colors appear to be more vivid. However it also takes very long time to compute (16.2 min) comparing with perceptual anchoring method, whose process time is much shorter (0.94 s).

References

[1] Kim et al., *Proc. Of Human vision and Electronic Imaging XVIII, 2013.*
[2] Wanat et al., *Transactions on Graphics, 2014.*
[3] Kulikowski, *Vision Research, 1976.*
[4] Moroney et al., *IS&T: Tenth Color Imaging Conference, 2002*
[5] Shih et al., *IEEE Transactions on Multimedia, 2016.*