Display Adaptive Tone Mapping - Supplementary Materials

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Abstract

This document contains supplementary formulas and results for the paper *Display Adaptive Tone Mapping*, ACM Transactions on Graphics 27 (3) (Proc. of SIGGRAPH) 2008.

1 HVS Model Appendix

Most of the symbols used in the equations below are taken from the original papers and have no connection with the same symbols used in our paper. Function signatures and its parameters are consistent with the equations used in the main paper.

The HVS model introduced in Section 3.4 of the main paper rescales contrast using the transducer function $T(W,S)$ proposed by Wilson [1980]:

$$T(W,S) = \frac{a\left\{\left[1+(S\,W)^q\right]^{1/3}-1\right\}}{k[b+S\,W]^e} \tag{1}$$

where W is contrast given as the Weber fraction ($\Delta L/L$) and S is the sensitivity (as predicted by the CSF, described below). We use the fits of the function from the original paper (Fig. 4 in [Wilson 1980]) with the constants: $k=0.2599$, $q=3$, $a=3.291$, $b=3.433$, $e=0.8$.

The sensitivity S for the detection task is predicted by the contrast sensitivity function (CSF). We employ the CSF model from [Daly 1993]:

$$S = CSF(\rho, L_a, v_d) = P \cdot \min\left[S_1\left(\frac{\rho}{r_a \cdot r_c \cdot r_\theta}\right), S_1(\rho)\right], \tag{2}$$

where

$$\begin{aligned}
r_a = &\quad 0.856 \cdot v_d^{0.14} \\
r_c = &\quad \tfrac{1}{1+0.24c} \\
r_\theta = &\quad 0.11\cos(4\theta)+0.89 \\
S_1(\rho) = &\quad \left[\left(3.23(\rho^2 i^2)^{-0.3}\right)^5+1\right]^{-\frac{1}{5}} \cdot \\
&\quad \cdot A_l \varepsilon \rho e^{-(B_l \varepsilon \rho)} \sqrt{1+0.06 e^{B_l \varepsilon \rho}} \\
A_l = &\quad 0.801\left(1+0.7\,L_a^{-1}\right)^{-0.2} \\
B_l = &\quad 0.3\left(1+100\,L_a^{-1}\right)^{0.15}
\end{aligned} \tag{3}$$

The parameters are: ρ – spatial frequency in cycles per visual degree, θ – orientation ($\theta=0$ in our application), L_a – the light adaptation level in cd/m^2, i^2 – the stimulus size in deg^2 ($i^2=1$ in our application), d – distance in meters, c – eccentricity ($c=0$ in our application), ε – constant ($\varepsilon=0.9$), and P is the absolute peak sensitivity ($P=250$). Note that the formulas for A_l and B_l differ from the original publication and contain corrections.

As the spatial frequency ρ in Equation 3 we use the medium frequency of the band l in the Laplacian pyramid G_l (refer to Section 3.4 in the main paper). The medium frequency of a band can be found using the formula:

$$\rho_l = \frac{0.5\,n_{ppd}}{2^{l-1}}, \tag{4}$$

where n_{ppd} is the number of pixels per visual degree. The n_{ppd} depends on the viewing distance and the screen resolution. A convenient way of expressing a viewing distance is by multiples of the screen height (vertical size) n_h, so that n_{ppd} can be computed:

$$n_{ppd} = \frac{h_{res}\,\pi}{360\,atan(\frac{1}{2\,n_h})} \tag{5}$$

where h_{res} is the horizontal screen resolution in pixels. For example, a typical computer display is usually viewed from the distance of about twice its screen height, therefore for $n_h=2$ and $h_{res}=1024$, $n_{ppd}\approx 36$ $pixels \cdot deg^{-1}$.

2 LDR images and tone mapping

Tone mapping is quite often simplified to the problem of mapping high contrast (or high dynamic range) images to pixel values. Not only high dynamic range, but also images of arbitrary luminance range can benefit from tone mapping if a display characteristic is taken into account. Therefore, we do not restrict our test set to HDR images, but include also typical low dynamic range JPEG images. Low dynamic range images are commonly assumed to be represented in the sRGB color space [IEC 61966-2-1:1999 1999]. The sRGB color space assigns very low luminance levels for dark pixels (≈ 0.024 cd/m^2 for $(r,g,b)=(1,1,1)$), which are unrealistic for most of displays. Also the theoretical dynamic range that the sRGB encoded files can encode, which is $\approx 3.5\log_{10}$ units between pixel value 1 and 255, is usually larger than the contrast available on a display. We convert low dynamic range JPEG images from the sRGB color space to linear tri-chromatic values, and then apply our tone mapping to make the best use of the information that is stored in them.

3 Results: illumination and print

This section contains one more application scenario for the proposed algorithm, which was not included in the main paper. The display adaptive tone mapping can be also used to profile a print for ambient illumination. Paper and e-paper, unlike light-emitting displays, does not change its effective dynamic range (measured in photometric units) with ambient light and only the absolute luminance values of reflected light will differ between a dim room and sunlight. However, the sensitivity of the human eye changes with absolute luminance levels, and thus also changes the number of perceived just noticeable differences (JNDs). This is not an issue for printed text, as text is usually printed with the highest possible contrast to ensure maximum visibility in all conditions. However, for gray-scale images the differences between darker gray-levels can disappear when a print is seen under low light.

Figure 1 shows several examples of a print profiled for viewing in a dim room, a bright office and outdoors. When the ambient light

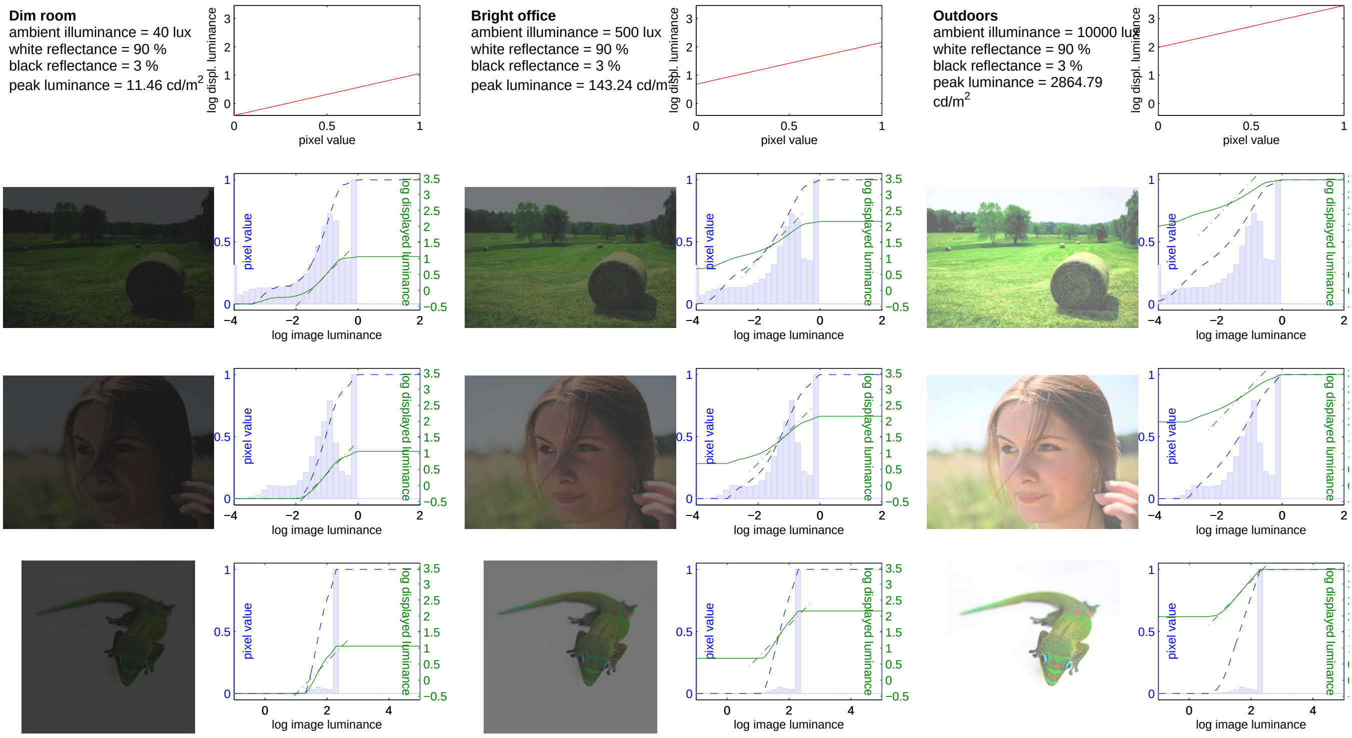

Figure 1: Images tone-mapped for a print under different illumination conditions. The top row describes the parameters of a display model and its luminance response in each scenario (dark room, bright office, outdoors). Each plot in the rows below contains two tone curves that map image log luminance factor to either pixel values (blue) or display log luminance levels (green). The dash-doted green line represents slope=1 (no contrast change). The light-blue bars show image histogram. The images depict simulated image appearance on a display, which however does not convey actual contrast or brightness due to print limitations. Please refer to the supplementary materials for the full resolution images and more examples.

is lowered to the levels at which the HVS sensitivity drops, the display adaptive tone mapping compensates for this effect by boosting image contrast (compare the tangent of the green solid lines for the first and last columns). Since the print sometimes does not offer sufficient dynamic range for the boosted contrast, some pixels, especially in darker regions, need to be clipped. The portrait image in the center shows how the algorithm clipped most of the dark details in the shadows to achieve higher contrast for brighter tones (compare the blue-dashed lines for the first and the last column in the third row). The result of tone mapping for this image is shown in Figure 3. The difference between images for the bright office and outdoors conditions is much smaller, since the change in the sensitivity of the visual system remains almost constant for the day-light (photopic) vision.

Although such an algorithm may have little application for a print, which cannot adaptively change its content, it can be used to control the tone-curve of e-paper displays.

References

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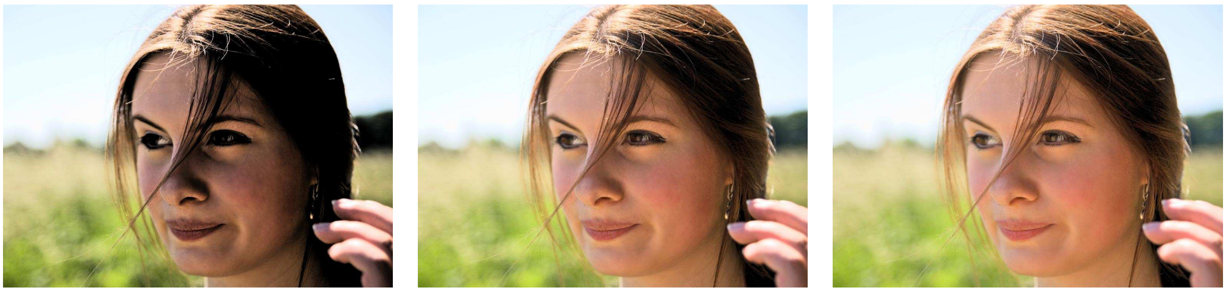

Figure 2: Tone-mapped images profiled for dim room, bright office and outdoors illumination (from left to right). The rightmost image is missing some details in the hair, but has the largest contrast, which compensates for the loss of sensitivity in low-light conditions.