Perceptual Uniformity of Contrast Scaling in Complex Images

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1 Introduction

In the recent years, we witness a significant progress in the display technology in terms of expanded color gamut, increased luminance dynamic range and physical contrast. Almost perfect black levels achieved on high dynamic range (HDR) displays motivate revisiting well-established image processing techniques, because for instance psychophysical experiments on the contrast perception demonstrate that the contrast sensitivity drops significantly for such low luminance levels. To account for such novel circumstances, we investigate the standard equation for contrast scaling in image processing [1991]:

$$L(c) = \bar{L} \cdot \left(\frac{L}{\bar{L}} \right)^c , \qquad (1)$$

where L denotes the luminance of a pixel, $\bar{L}$ is the luminance reference (mean luminance in the analyzed area), and c denotes *contrast factor*.

2 Perceptual Experiments

We conducted two psychophysical experiments to measure the perceptual change in contrast at four different luminance levels. First, *contrast scaling* was conducted as a two-alternative forced choice with 11 versions of the same image with different contrast magnitudes in each region and analyzed by Thurstone's Law of Comparative Judgment [1927]. Secondly, *contrast discrimination thresholds* were measured by the Parameter Estimation by Sequential Testing (PEST) [1967].

Figure 1: *Our test image and its masks for "very dark"/"dark", "medium", and "bright" regions (left to right). The average luminance levels are 0.3, 4.5, 28.8, and 158.5* cd/m^2*, respectively. It is a typical landscape image in black-and-white of 900×600 pixels.*

Our test image was segmented based on the luminance levels into three different regions: "dark", "medium", and "bright" (see Figure 1). Additionally, to reproduce "very dark" part, we reused "dark" region with reduced power of LED back-lights in HDR display. In all experiments, the selected regions were surrounded for a short while by a contour to focus the subject on the selected regions. The rest of an image was slightly blurred to maintain local luminance adaptation levels but not to distract the subject from the test area. 11 subjects participated in the *contrast scaling* experiment, and 6 of them continued the *discrimination thresholds* experiment.

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3 Results and Applications

From the experiments, we derived a model for a perceptually uniform contrast change in complex images. To rescale the results from *contrast scaling* experiment analyzed by Thurstone's Law in arbitrary units to JNDs, we firstly set origins to *contrast detection thresholds* computed by *contrast sensitivity function*. Then, the results of *contrast scaling* experiment were rescaled to match the results of *contrast discrimination threshold* experiment. After rescaling, the response curves are produced by fitting to power functions (see Figure 2 left). By interpolating those curves, we obtain a surface model with parameters of *contrast factors*, mean luminance levels, and JNDs as shown in Figure 2.

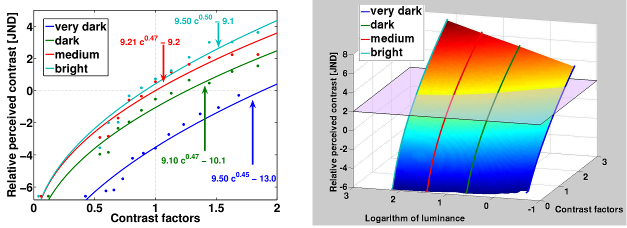

Figure 2: *Left: Relative perceived contrast in JNDs at different luminance levels for given physical contrasts. Dots represent the rescaled data for each luminance level shown in different colors. Right: A surface model of perceived contrast rescaled in JNDs.*

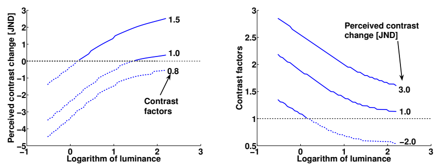

Figure 3: *Left: Influence of uniform physical contrast to perceived contrast. Right: Different* contrast factors *are needed to maintain perceptually uniform contrast change.*

We use the model to maintain perceptual uniformity of global and local contrast change. The gray plane in the surface model shows an example that the intersection curve between the plane (2 JNDs) and the surface depicts the *contrast factors* for different luminance levels to achieve perceptually uniform contrast. As seen in the plot, different physical contrasts (*contrast factors*) need to be applied for different luminance levels. If we apply the same change of contrast globally, it results in different perceived contrast depending on luminance level (Figure 3 left); therefore, to maintain the perceptually uniform contrast change, we apply different *contrast factors* for different luminance levels (Figure 3 right). The model proves to be particularly necessary for HDR displays where in dark regions below 3 cd/m^2 nonuniformity can exceed 2 JNDs.

References

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