Naturalness and Image Quality: Influence of Chroma Variation at Various Lightness Levels

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Abstract

The relation between perceptual image quality and naturalness was investigated by varying the colorfulness of natural images at various lightness levels. A systematic difference was found between quality and naturalness judgments. This difference, reflecting the subjects' preference for more colorful but, at the same time, somewhat unnatural images, was most noticable at the original lightness level and diminished with decreasing lightness, in particular at the lowest lightness level investigated.

Introduction

Naturalness is generally considered a decisive constituent of the perceptual quality of color images of natural scenes. The underlying, intuitively justifiable assumption is that appreciation-oriented images[1] of high quality should at least be perceived as 'natural', that is, they should be judged to possess a high degree of correspondence to (memorized) reality. Accordingly, naturalness plays an important role in optimizing color reproduction (both electronically and in print). But what exactly is the relation between naturalness and image quality? And, how does naturalness restrict the number of permissible color transformations?

In this paper, an experiment is described in which the relation between perceptual image quality and naturalness was investigated by varying the colorfulness of color images of natural scenes at various lightness levels. The variation of colorfulness was created by digitizing the images, subsequently calculating their color point distributions in the CIELUV color space[2] and finally multiplying the chroma value of each pixel by a constant. Overall lightness was manipulated by placing neutral density filters in front of the CRT-monitor on which the images were displayed.

Method

Subjects

Four male and two female subjects participated in the experiment. They had normal or corrected-to-normal vision. Their color vision was checked with the H-R-R Pseudoisochromatic Plates[3]. No color deficiencies were observed.

Stimuli

The colorfulness of four different kinds of natural images was manipulated using a Gould deAnza Image Processing System IPS8400. Pictures of the following four scenes were used: the portrait of a female model (WANDA01), a terrace scene with a yellow parasol in the foreground (TERRASGEEL), fruit displayed in front of a greengrocer's shop (FRUIT) and an abstract sculpture with bushes (STADHUIS). RGB signals obtained by scanning slides of these scenes were digitized with 8 bits/pixel on a grid of 512 by 512 pixels. Before describing these original images by their color point distributions in the CIELUV uniform color space, the size of each image was reduced to 456 by 450 pixels to avoid artifacts on the edges. Each color point corresponded to one pixel. Reference white was D_{65}[2]. New images were generated by multiplying the chroma value of each pixel by a constant. During the chroma transformation the lightness and hue-angle of each pixel were kept constant. For each scene this resulted in five images in which chroma decreased (multiplication factors ranging from 0.5 to 0.9) and five images in which chroma increased (multiplication factors ranging from 1.2 to 2.0). If, during the processing of the images, calculated values were out of the possible range for the grey values of the monitor, the nearest possible value of chroma was used (clipping). During the experiment, the original images were also included, creating an experimental set of 44 images.

Images were displayed on a 70 Hz Barco CCID7351B monitor placed in a dark room. The monitor was corrected such that the screen luminance was linearly related to the opticalxxx density of the original slides. The maximum attainable luminance for white was 60 cd/m^2. Using this luminance as a reference[4], the average lightness of the scenes was calculated to be 37.89 (FRUIT), 42.18 (STADHUIS), 43.54 (WANDA01) and 46.04 (TERRASGEEL). Overall lightness was decreased by placing neutral density (ND) filters (Cinemoid no. 60 Pale Gray) in front of the monitor. The transmission of this type of filter was measured to be the same for the three phosphors of the monitor. By placing one ND filter in front of the monitor, luminance decreased to 22 percent of its original value. Placing two of these filters in front of the monitor reduced the luminance to 5 percent of its original value. This produced new lightness

levels that were 46 and 17 percent of the original lightness level respectively.

Procedure

The experiment consisted of eight sessions. No ND filters were placed in front of the monitor during the first three sessions, two filters during the following three sessions and one filter during the final two sessions. In the course of a session all 44 images were displayed four times in a random sequence, except that the same scene never appeared on two consecutive trials. The images were presented for five seconds after which a 9 cd/m^2 adaptation field appeared on the screen. The luminance of this adaptation field was also attenuated by the ND filters. The subjects viewed the monitor at a distance of about 1.7 m. At this distance, the pixel size is about 1 min of arc. Per session, the subjects rated either the perceptual quality, the naturalness or the colorfulness of all images on a tenpoint numerical category scale ranging from one (lowest quality/naturalness/colorfulness) to ten (highest quality/naturalness/colorfulness). The instructions given to the subjects defined perceptual image quality as 'degree of excellence of the image', naturalness as 'degree of correspondence between the reproduced image and reality (that is, the original scene as it is according to the viewer)' and colorfulness as 'presence and vividness of colors in the whole picture'. Quality was assessed in sessions l, 4 and 7, naturalness in sessions 3, 6 and 8 and colorfulness in sessions 2 and 5. Before starting a session, subjects had to judge a training series of 12 images.

Results and Discussion

Colorfulness

Colorfulness always increased monotonically with average chroma. This implies that the subjects could perceive colors in the whole lightness range investigated. The results at the original lightness level agreed with those of an earlier study carried out by Fedorovskaya et al.[5]. For one scene (WANDA01) the relation between the colorfulness judgments and chroma was linear. For the other scenes this relation was found to be slightly compressive. Per scene, the colorfulness-chroma relation was independent of lightness level, provided the colorfulness judgments were plotted against the chroma values calculated for the original lightness level. Apparently, the subjects compensated for the perceived differences in overall brightness. This phenomenon can be represented in the CIELUV space by using saturation instead of chroma because the *CIE 1976 u,v saturation,* being chroma divided by lightness, is invariant with changes in luminance, whereas chroma scales with luminance[2].

Image Quality

Fedorovskaya et al.[5] and De Ridder et al.[6,7] have already shown that at the original lightness level the perceived quality of the transformed images is nonmonotonically related to the average chroma and that this relation can be described by an inverted-U-shaped function. Their results are confirmed in the present study and generalized to the other two lightness levels. In addition, it was found that, per scene, the functions at the different lightness levels are almost identical when the quality judgments are plotted as a function of saturation. Moreover, the optimum quality seems to occur at the same saturation level. An exception is TERRASGEEL because for this scene the quality function had the tendency to shift to higher saturation values when lightness decreased. To quantify these trends, second- to fourth-order polynomials were fitted to the quality ratings (r^2 >0.95). The saturation values at which these polynomials reached their maxima were (in order of decreasing lightness): 0.30, 0.32, 0.36 (TERRASGEEL); 0.43, 0.41, 0.44 (STADHUIS); 0.96, 0.97, 0.97 (FRUIT); 1.25, 1,25, 123 (WANDA01). These values are systematically higher than the saturation levels of the original images (TERRASGEEL: 0.29; STADHUIS: 0.29; FRUIT: 0.84; WANDA01: 1.08). Apparently, the subjects preferred more colorful images to the original ones.

Naturalness

In essence, the same results were obtained for the naturalness judgments as for the quality judgments. Again, polynomials were fitted to the naturalness judgments in order to determine the saturation levels at which the subjects judged the images to be most natural. The resulting values were (in order of decreasing lightness): 0.28, 0.31, 0.34 (TERRASGEEL); 0.37, 0.36, 0.41 (STADHUIS); 0.85, 0.87, 0.92 (FRUIT); 1.17, 1.18, 1.23 (WANDA01). In contrast with what was observed for the quality judgments, the saturation levels at which the images were judged to look most natural systematically increased with decreasing lightness.

Naturalness and Image Quality

A comparison of the maxima estimated for the naturalness and quality judgments shows that, in general, the qualitatively optimal images are more colorful than the images considered to be the most natural ones. Apparently, the subjects used different criteria to assess naturalness and image quality; the subjective preference in quality was biased towards more colorful images, although the subjects realized that these images looked somewhat unnatural. This difference between quality and naturalness judgments was most noticable at the original lightness level and diminished with decreasing lightness, especially at the lowest lightness level. This is mainly due to the naturalness function shifting towards higher saturation levels with decreasing lightness.

Conclusions

In this study, the relation between perceptual image quality and naturalness was investigated by varying the average chroma of color images of natural scenes at various lightness levels. Both naturalness and image quality were found to be nonmonotonically related to average chroma over a large range of lightness levels. The relation be-

tween the quality/naturalness judgments and average chroma could always be described by an inverted-U-shaped function. At the original lightness level, the inverted-U-shaped function for the quality judgments was always found to be shifted to higher chroma values relative to the function for the naturalness judgments. This suggests that subjects tend to prefer more colorful images, although they realize that these images look somewhat unnatural. This difference between naturalness and quality diminished with decreasing lightness. This is mainly due to the naturalness function shifting towards higher saturation levels with decreasing lightness.

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