An algorithm can enhance color for images illuminated with extremely low backlight.

Handheld electronic devices, such as smart phones, have become increasingly popular. However, their LCD backlight consumes a significant amount of energy. While reducing the backlight power prolongs battery life, it does so at the cost of degrading both luminance and chrominance image quality. Existing image-enhancement algorithms deal mostly with the luminance appearance, while color has been largely ignored. As a result, we are focusing our work on the chrominance-degradation problem.

We investigated the relation between perceptual attributes and backlight intensity, modeled the effect of backlight using a color appearance model, and plotted the chroma and saturation versus backlight intensity (see Figure 1). Chroma drops dramatically when we lower the backlight intensity. As a result, the gamut shrinks (see Figure 2).

This observation serves as the basis of our algorithm, which aims to preserve the image’s chroma. In the flowchart of our algorithm (see Figure 3), we mixed the two chroma layers using the following equation:

\[ C(x, y) = (1 - w_L)C_O(x, y) + w_L C_L(x, y), \]

where \( C(x, y) \) is the resulting chroma; \( C_O(x, y) \) and \( C_L(x, y) \), respectively, are the original and backlight-scaled chroma; and \( w_L \) is a weighting factor. The two problems to be solved are the imaginary color and the display gamut. The former occurs in the inverse International Commission on Illumination Color Appearance Model 02 (CIECAM02) block in Figure 3. The inverse appearance model generates false color in some dark regions: see Figure 4(a). We solved this by setting an upper bound on the variable \( t \) in inverse CIECAM02: see Figure 4(b).

The display gamut problem occurs because a visible color is not necessarily displayable. Therefore, we need to map all out-of-gamut colors back into the display gamut. A conventional clipping approach causes a hue shift. A better solution is to project the out-of-gamut pixels to the gamut boundary towards the white point (see Figure 5). Since the constant hue locus is a set of radial curves centered at the white point, our method preserves hue much better.

We carried out subjective tests to find the optimal weight in equation (1). For each of the 20 images in the test set, we generated 11 enhanced images using (1) with different weights. We performed two tests—preference and fidelity. In the preference test, subjects selected the image they liked the most without reference. In the fidelity test, eight subjects were asked to select one of among 11 enhanced images that best matches the full-backlight image.

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Figure 3. The color enhancement algorithm flow chart. CIECAM02: International Commission on Illumination Color Appearance Model 02. sRGB: Standard red-green-blue. LBL: Low backlight.

Figure 4. A demonstration of the imaginary color problem.

Figure 5. A demonstration of the display gamut problem. The magenta curves are constant hue loci. The red points are out-of-gamut. Their gamut-mapped results are in blue.

For both tests, we showed images using two HTC Desire smartphones, one with full backlight and the other with 10% backlight.

The averaged weights are shown in Table I, and some enhanced images are shown in Figure 6. For the unenhanced images, $w_L$ equals zero. The higher the $w_L$, the more the chroma is preserved. A negative $w_L$ corresponds to a desaturated image. We can see that almost all averaged $w_L$ are positive. This indicates that chroma preservation is indeed an effective approach for both faithful and pleasant reproduction.

To conclude, we investigated the effect of low backlight on perceptual attributes and presented a color-enhancement algorithm for images illuminated with extremely low backlight. Our results show that the algorithm effectively compensates for the chroma degradation. Currently, the algorithm involves subjective determination of a weighting factor. In the future, we plan to make the algorithm fully automatic by conducting a thorough analysis of the color perception subjectivity.

Table 1. The Optimal Weighting for Test Images

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Figure 6. A demonstration of the algorithm. Left column: 100% backlight. Middle column: 10% backlight, unenhanced. Right column: 10% backlight, enhanced.

Author Information

Homer Chen, Kuang-Tsu Shih, and Tai-Hsiang Huang
Multimedia Processing and Communications Lab
National Taiwan University
Taipei, Taiwan

References