A Quantitative Parameter of Nonlinear Tone Compression for HDR Color Reproduction

Jae-Hoon Jang, Sung-Hak Lee, and Kyu-Ik Sohng
School of Electrical Engineering and Computer Science, Kyungpook National University, Daegu, Korea

Abstract

High-dynamic-range (HDR) images were embodied by a lot of algorithms. This paper takes notice one of these algorithms, which is iCAM06. iCAM06 has worked color appearance prediction of HDR images based on CIECAM02 color prediction and incorporates the spatial processing models in the human vision system for contrast enhancement. We investigated the effect of user controllable factors of iCAM06 and tried to find the best factor which is correspondence with Breneman’s corresponding color data sets. Suggested model meet with good results, it improves color matching prediction for corresponding color data set in Breneman’s experiment.

Keywords: HDR images, iCAM06, user controllable factor

1. INTRODUCTION

High-dynamic-range imaging technology makes to change from broad dynamic range (up to 9 log units) of luminance, in real-world scene, to 8bit dynamic range which is a common output display dynamic range of luminance. It is a technology that gives a similar impression in comparison to an original scene, which is showed to our eyes, within limited dynamic-range of common output displays.

One of these algorithms is the iCAM06. It has a superior ability for making HDR rendering image and spatial filtering. But this model has several problems. User controllable factors are one of the problems. They have a big impact on output image, and users get into the difficulty because they can’t find an adequate solution how to adjust these factors. For example, when we take a photograph of original scene in dim surround, output rendering images are changed by setting values of user controllable factors, such as output images are too dark or too bright. This paper based on iCAM06 can be used useful tool with these conditions.

The purpose of this paper is to establish method which makes a rendering image considering adapting luminance of the input and output viewing condition, and it needs to take a photograph of an original scene. Thus this paper adds several equations and adjusts user controllable factor about a luminance for high performance images. Its performance has a well-defined character on a low luminance which is a dim surround. Also this paper suggests that users consider output display viewing condition as a factor of HDR rendering image for output image quality.

2. iCAM06

2.1 Overview of iCAM06

Fig. 1 presents the general flowchart of iCAM06. It can be divided into three big parts, such as the bilateral filter, chromatic adaptation process included tone compression process, and IPT color space. The goal of iCAM06 is to accurately predict human visual attributes of complex images [1].

![Flowchart of iCAM06](image)

The iCAM06 needs HDR file format (RGBe or XYZe) and three user controllable factor values, \( L_{\text{max}} \) (maximum luminance in the original scene), \( p \) (nonlinear exponent value depends on adapting luminance or surround luminance), and surround factor such as dark, dim, and average surround. These factors were selected by users due to original scene a physical measurement or user’s preference.

The input data of iCAM06 is CIE tristimulus values (XTZ) for the image or scene in absolute luminance units. Therefore HDR file format (RGBe, XYZe) which is produced by Photoshop CS3 has transformed into floating point RGB and it has transformed into XYZ by sRGB or specific camera characteristic equation [1]. it is assumed that transformed XYZ are linear value.

2.2 Bilateral filter
Because our eyes have an unusual sensibility for local contrast in the real world scene, bilateral filter is usefulness algorithms for preserving local contrast [6]. Thus iCAM06 selected a preserving local contrast filter which is a bilateral filter for output image quality. iCAM06 uses edge-preserving filter, the base layer is obtained using a edge-preserving filter called bilateral filter [6] and The detail layer is achieved by subtracting the base layer image from the original image. bilateral filter serves as preserving local contrast, avoid the "halo" artifacts [1].

### 2.3 Chromatic adaptation

Chromatic adaptation process of iCAM06 is similar to CIECAM02 [7]. However iCAM06 has some difference with CIECAM02, first because of IPT color space (IPT) using illuminant D65, thus it uses illuminant D65 instead of illuminant E.

Next step is the tone compression part. Equations (1)-(5) present tone compression equations in iCAM06 which are based on CIECAM02 [7]. The final output of tone compression function is \(R'_a, G'_a, B'_a\). \(R'_a, G'_a, B'_a\) has transformed into CIE tristimulus values again, because input data of a IPT color space [10] which is the next step of tone compression process is CIE tristimulus values (XYZ) which is adapted by illuminant D65. Thus iCAM06 model has worked inverse Hunt-Pointer-Estevez fundamentals using the CIECAM02 formula. \(L_f\) is 20% of white in the original image, \(R'_G'B'_a\) is a value after chromatic adaptation, \(Y_w\) is the luminance of the local adapted white point which is calculated local value, so it is locally different value in image.

\[
R'_a = \frac{400(F_L R'/Y_W)^\rho}{27.13 + (F_L R'/Y_W)^\rho} + 0.1 \\
G'_a = \frac{400(F_L G'/Y_W)^\rho}{27.13 + (F_L G'/Y_W)^\rho} + 0.1 \\
B'_a = \frac{400(F_L B'/Y_W)^\rho}{27.13 + (F_L B'/Y_W)^\rho} + 0.1 \\
F_L = 0.2k^4(S_Ld) + 0.1(1-k^4)(S_Ld)^{1/3} \\
k = \frac{1}{5L_d + 1}
\]

#### 2.4 IPT color space

In the IPT color space [10], this process has a input data of chromatic adapted XYZ. I from IPT unit is the lightness channel, P and T are color channel. IPT color space is used to apply Hunt effect and surround effect [3]. This effect has a power function, which has exponent value of 1, 1.25 and 1.5 for dark, dim, and average surround each other [1].

### 3. SUGGESTED EQUATION FOR USER CONTROLLABLE FACTORS

#### 3.1 Considering input and output viewing condition

HDR evaluation algorithms have carried out many experiments [2]. But all psychophysical experiments were performed limited conditions in a dark surround. But generally our viewing condition is from 10cd/m\(^2\) to 100cd/m\(^2\) in office environment. Therefore, in this paper, our discussion concentrates on a part of nonlinear tone compression in iCAM06. So this paper suggests that \(p\) (a factor of non linear tone compression function) in iCAM06 should change input and output viewing conditions from different luminance condition.

Fig. 2 presents that it compares original iCAM06 with modified iCAM06 which is added to suggested equations for two \(p\) factors which is different from input or output viewing conditions. Original iCAM06 model has fixed \(p\) value, but modified equations uses two \(p\) factors at input factor \(p_1\) and output factor \(p_2\) two values. Forward transform has been worked same original iCAM06 but inverse transform has been worked for using different factor \(p_2\).

#### 3.2 Parameter \(p\) (nonlinear tone compression exponent)

Original iCAM06 uses \(p\) factor which is defined by a range of \(p\) factor from 0.6 to 0.85. And, in indoor scene, it has a lower value than \(p\) factor in outdoor scene. Thus we can know that \(p\) factor is related to a Luminance of an image or a scene. This paper makes an equation which is dependent on luminance. Equation (6) is made by breneman’s corresponding color data sets [6] which are different luminance condition, same kind of color patch, and same kind of illuminant D55. (15cd/m\(^2\), 270cd/m\(^2\), 850cd/m\(^2\), 2120cd/m\(^2\), and 11,100cd/m\(^2\)).

\[
p = 0.391 + 0.114 \times \log(L)
\]

The \(p\) is nonlinear tone compression exponent factor, and \(L\) is an effective white level. If \(L_{\text{max}}\) is limited by 20000cd/m\(^2\), this function informs that a range of \(p\)
factor is from 0.585 to 0.854. Fig. 3 shows that if \( L \) is a low value, factor \( p \) has a sharp difference, but if \( L \) is a high value, factor \( p \) has a slight difference. In dim surround, this equation prevents color desaturation and almost never showing object in the dim area of image.

3.3 Single nonlinear gamma correction

Original iCAM06 used photoreceptor response functions. So it omits inverse tone compression process. This paper divides \( p \) factor into two values (input viewing condition and output viewing condition), so different tone compression equation is added to model. This paper adds simple nonlinear gamma correction [5] which adopts by flexible exponent factor and default value setting is 0.62. It can be changed by a user preference.

3.4 Parameter \( L_{\text{max}} \)

\( L_{\text{max}} \) is a user controllable factor, and Hunt effect is considerer by \( L_{\text{max}} \) [3]. Perceived colorfulness in color stimuli increases by Luminance level. If people don’t know \( L_{\text{max}} \)’s values, iCAM06 will set a default value which is 20000 cd/m². However if image is an indoor scene, dim area of an image is seen too dim. So users must select proper value, but it is difficult to choose value that matches up to an image, so several values are needed for an adequate value. However, in outdoor scene, a default value is a right choice. When \( L_{\text{max}} \) is 10000 cd/m² or 20000 cd/m², the user can’t detect a difference well, so \( L_{\text{max}} \) is an important part of image in dim surround and user must choose an adequate value for image’s performance.

4. TESTING THE PERFORMANCE OF SUGGESTED MODEL

4.1 Experimental Design

Worked experiment in this paper was similar to the iCAM06’s experiment [2], however experimental objects were limited to two algorithms which were iCAM06 and suggested model. This experiment had been worked by seven persons with normal color vision. Experimental setup was the same as the optimum viewing distance and angle of High-definition television (HDTV) [4]. The rendering result were displayed LCD display, on a gray background with a luminance of 20% of the adapting white point, and output viewing condition changed various luminance, for example from dark surround to 100cd/m².

Experimental method worked method of paired-comparison of used iCAM06’s performance experiment. Without viewing original scene, two simultaneously displayed images were presented one person who selected one preferred image based on overall impression on image, such as colorfulness, local or global contrast, and overall image impression, etc. In the next step, rendering image was compared with their corresponding real-world scenes, because original scene’s viewing condition was different from rendering image’s viewing condition, observer were taken of times at a least 30 seconds or 1 minute for adaptation. Fig. 4 and Fig. 5 present that One HDR image provides four rendering output image.

Fig. 3. Changes in \( p \) factor as a function of effective white level according to Breneman’s corresponding color data set experiments. Scare points represent experimental results and fitting curve represents function of newly suggested equation for \( p \) factor.

Fig. 4. Observers were asked to evaluate overall impression on these images, one HDR (RGBe) image was expressed to four or five rendering images which were worked by iCAM06 and suggested model from various factor values.

Fig. 5. In an average surround, four rendering images had an indistinct change each other.
Fig. 4 (a) picture was a rendering image of iCAM06. It set default setting, $p=0.7$, $L_{\text{max}}=20000\text{cd/m}^2$. (b) Picture was a rendering image of iCAM06. It set $L_{\text{max}}=20000$, $p=0.635$. (c) Picture was a rendering image of iCAM06. It set $L_{\text{max}}=600$, $p=0.635$. (d) Picture was a rendering image of a suggested model. Fig. 5 set same method of Fig. 4, one suggested model’s rendering picture was compared with three iCAM06 model’s rendering images that three user controllable factor had different values.

4.2 Evaluation of Experimental result

Table 1 provides color deference of color appearance models, such as CIECAM97s [8], CIECAM02, iCAM06, and suggested model. And the $\Delta u'v'$ in the equation 7 has a scale of color deference. Suggested model is prominently improved on previous models.

$$
\Delta u'v' = \sqrt{(u'_m - u'_p)^2 + (v'_m - v'_p)^2} 
$$

(7)

(u'_m, v'_m) is experimental value of Breneman’s corresponding data sets. (u'_p, v'_p) is a predicting value of chromatic adaptation model. And Ten HDR images were evaluated by observers about overall impression on image. Experiments were divided into two big parts in average surround and dim surround. In average surround, persons didn’t detect well the difference between two pictures, but in dim surround, used models showed a bigger difference than in average surround. Suggested model has a high performance than others models, especially overall luminance and colorfulness. Low luminance area of dim surround was seen too dark or too bright dependent on $L_{\text{max}}$ and factor $p$, thus suggested model adjusts user controllable factors by optimized equations and has a higher performance than original iCAM06

<table>
<thead>
<tr>
<th>Data set</th>
<th>Illuminant</th>
<th>Y [cd/m²]</th>
<th>CIECAM97s</th>
<th>CIECAM02</th>
<th>iCAM06</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breneman</td>
<td>D55</td>
<td>130-2120</td>
<td>0.0215</td>
<td>0.0206</td>
<td>0.0234</td>
<td>0.0100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>850-11100</td>
<td>0.0195</td>
<td>0.0191</td>
<td>0.0210</td>
<td>0.0076</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15-270</td>
<td>0.0212</td>
<td>0.0213</td>
<td>0.0232</td>
<td>0.0133</td>
</tr>
</tbody>
</table>

Table. 1. Color difference among chromatic adaptation models for different luminance levels of corresponding color data sets

5. CONCLUSIONS

User controllable factors of iCAM06 impact on images. But iCAM06 factor’s range is so wide, thus it is necessary to limit factor’s value. This paper suggested new equation for $p$ factor and adopted various $L_{\text{max}}$. Calculated over the equation has a better performance values than original iCAM06 in dim surround. Also $p$ factor divides two values into input and output viewing condition based on luminance. It is very important that luminance of output viewing condition has various values.

6. REFERENCES