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Considering Chromatic Adaptation in Camera White Balance

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Abstract

White balance is an important process in image signal processing (ISP) to adjust the overall tone of an image, which actually simulates the chromatic adaptation mechanism in the human visual system. A typical white balance always aims to completely remove the color cast of the illumination, so that the color appearance of the image appears as it is captured under daylight (i.e., D65 illumination). This assumes the human visual system can always achieve a complete chromatic adaptation under any illumination. In this study, we built a scene under 85 different light settings having a wide range of chromaticities. The human observers viewed the scene under each light setting, and then adjusted the color appearance of the scene image on a smartphone display to match that of the scene. A pipeline was designed to apply a chromatic adaptation transform to an image, which changes the color appearance of the image by changing its white point. The results clearly showed that it is not appropriate to always adjust the image white point to D65. Therefore, white balance should consider the effect of the scene illumination on the degree of chromatic adaptation, and adjust the image white point accordingly.

Introduction

In camera image signal processing (ISP) pipelines, white balance is an important step to correct the appearance of the neutral colors in the images, which affects the overall color tone of the captured scenes. White balance simulates the chromatic adaptation mechanism in the human visual system. It allows an automatic adjustment of the sensitivities of the three types of the cones based on the color of the illumination to remove the color cast of the illumination on the illuminated objects, maintaining a relative constant color appearance of the objects. In typical ISP pipelines, the color appearances of neutral colors are corrected to as if they are captured under the daylight illumination (i.e., D65 illuminants). This assumes that the human visual system can always achieve a complete chromatic adaptation under any illumination condition, with the perceived color appearance remain completely constant.

Both life experience and several recent studies suggest that the complete chromatic adaptation does not always happen. Under some circumstances, the human visual system cannot completely adapt to the illumination color, so that the color cast of the illumination cannot be removed completely and the color appearances of the objects are affected by the illumination color. For example, our previous studies [1,2] found that the degree of chromatic adaptation was jointly affected by the adapting correlated color temperature (CCT) of the illumination and the adapting luminance level. A higher adapting CCT was able to introduce a higher degree of adaptation, and the effect of the adapting luminance was more significant under the lower adapting CCT (e.g., 2700 and 3200 K). Moreover, even when the adapting luminance was extremely high (i.e., L_w of 3000 cd/m^2), a lower adapting CCT still did not introduce a complete adaptation. Also, Zhu et al [3] investigated how the luminance and CCT of the display white point affected the degree of chromatic adaptation through using a memory color matching method. Similarly, a lower CCT was found to introduce a lower degree of adaptation. Few study, however, investigated how chromatic adaptation should be considered in camera white balance, though it aims to simulate such mechanism for faithfully capturing the colors of objects and scenes.

In this study, the human observers viewed a scene under various illumination first, and then adjusted the color appearance of the image of the scene to match the color appearance of scene they just viewed. The color appearance of the image was changed through the change of the image white point, which was achieved by performing a chromatic adaptation transform in the image pipeline.

Apparatus

The experiment was carried out in two viewing booths, with dimensions of 60 cm (width) × 60 cm (depth) × 60 cm (height). The two booths were placed side by side, with the left booth for simulating a real scene and the right booth for the observers to adjust the color appearance of the image. Various neutral objects were placed inside the left booth, which was purposely designed to let the observers aware the overall color tone of the scene. A 45° viewing table was placed at the center of the right booth, with a smartphone placed on the table. Two 11-channel spectrally tunable LED devices were placed above the two booths to provide a uniform illumination. Two chin-rests were mounted just outside the viewing booths, so that all the observers experienced similar viewing geometries when viewing the two booths. Figure 1 shows the apparatus and setup of the experiment.

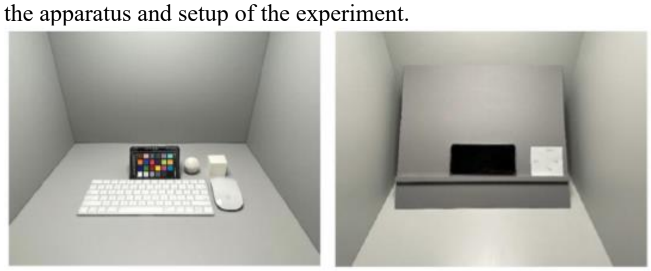

Figure 1 Photographs of the two viewing booths used in the experiment.

Light Settings

The intensities of the 11 channels were carefully adjusted to provide the desired light settings. In particular, 85 light settings were designed for the left booth, which covered a wide range of chromaticities in the chromaticity diagram, as shown in Figure 2.

The light settings were carefully calibrated, so that their illuminance levels were around 500 lx, which was the typical light level for general illumination. (Note: the illuminance of some light settings with the chromaticities close to the spectrum locus was little lower, due to the power of these chromatic LED channels). In contrast, the light setting of the right booth was fixed to have chromaticities around D65, with a diffuse white luminance around 300 cd/m^2. This was purposely designed to match the white point of the display for avoiding a mixed chromatic adaptation. All the calibrations were performed using a JETI Specbos 1211uv spectroradiometer and a Labsphere reflectance standard.

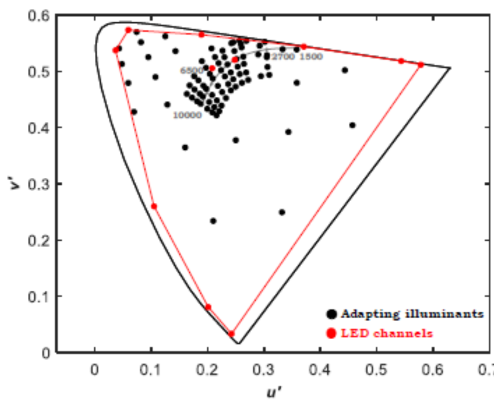

Figure 2 Chromaticities of the light settings in the left booth.

Image processing and control algorithm

We designed an algorithm to process the image of the left booth, which allowed to simulate the ISP pipeline and also the adjustment of the image white point through a chromatic adaptation transform, as briefly illustrated in Figure 3.

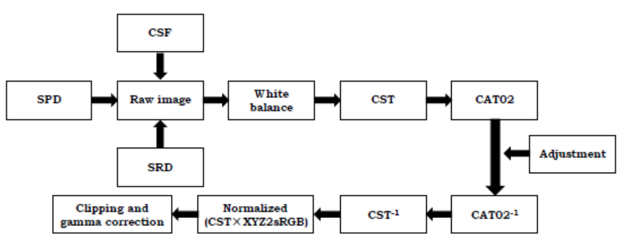

Figure 3 Illustration of the image processing pipeline, which adjusted the image color appearance through a chromatic adaptation transform (i.e., CAT02) through the adjustment of the image white point.

The left viewing booth was captured using a Specim hyperspectral camera, so that the spectral reflectance distribution (SRD) of each pixel can be captured. The spectral power distribution (SPD) of the light setting, SRD of each pixel, and the camera sensitivity function (CSF) can simulate a RAW image, with each pixel containing RGB values in the camera color space. White balance was performed using the RGB values of the ground truth illuminant, which can be obtained from the pixels at the white patch on the colorchecker. Color space transformation (CST) matrix can be derived based on the RGB values of the pixels of the 24 color patches and the CIE tristimulus values of these 24 color patches. Then we used CAT02 to apply a chromatic adaptation transform to the image based on the white point adjusted by the observers. In particular, the observers used four arrow keys (i.e., up, left, right, and down) to adjust the chromaticities of the image white point along the *u*' and *v*' axes in the CIE 1976 *u*'*v*' chromaticity diagram, with a step of 0.004 units, which adjusted the color of the entire image. Without any adjustment, the image white point was D65. Figure 4 shows the effect of the pipeline.

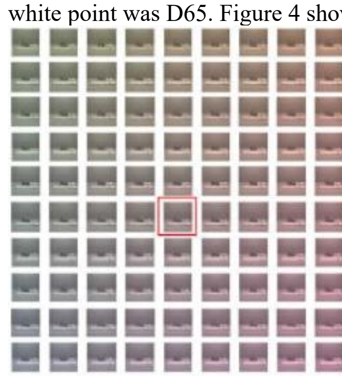

Figure 4 Illustration of how the pipeline changed the image color appearance of the image, with the red square highlighting the image with the D65 white point, which was the starting point of the adjustment.

Experimental procedure and observers

The observer always viewed the left booth under a certain light setting for 90 seconds, which helped to chromatically adapted to the light setting. The observer was reminded to view the overall color appearance of the light setting in the booth, instead of the specific color patches on the colorchecker. Then he or she moved to the right booth, and to adjust the color appearance image shown on the smartphone display to match the overall color appearance of the left booth using the four arrow keys. The observer was allowed to take as much time as he or she needed, and was instructed to press the enter key to confirm the adjustment. Then the observer moved back to the left booth for the next light setting. The order of the 85 light settings was randomized, and the observer completed all the light settings on three different days, and completed the adjustments under eight settings twice for evaluating the intra-observer variations. In total, ten observers completed the experiment.

Intra- and inter-observer variations

Both the intra- and inter-observer variations were characterized using the mean color difference from the mean (MCDM) in the CIE 1976 *u*'*v*' units. In particular, the intra-observer variations ranged between 0.001 and 0.036 units, with an average of 0.010 units; the inter-observer variations ranged between 0.010 and 0.036 units, with an average of 0.018 units.

Results and discusssions

The chromaticity shifts from each light setting in the left booth to the average white point adjusted by the observers to match the color appearance of the image to that of the left booth are shown in Figure 5, with Figure 6 showing those for the light settings with a D_{uv} between -0.03 and +0.03.

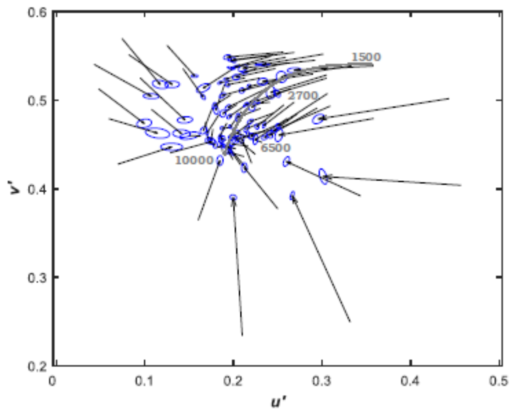

Figure 5 Chromaticity shift from the light setting in the left booth to the average white point adjusted by the observer to match the color appearance of the image to that of the left booth.

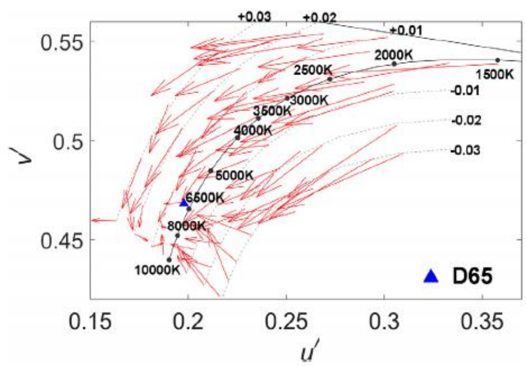

Figure 6 A close-up area around the blackbody locus, showing the chromaticity shifts for the white light settings (i.e., those having a D_{uv} between -0.03 and +0.03).

It can be observed that all the vectors generally converged towards an area around the blackbody locus with a CCT around 6500 and 10000 K, which was similar to several recent studies investigating chromatic adaptation. Moreover, only a small number of light settings resulted in the adjusted white point within such an area. These light settings actually introduced a similar degree of chromatic adaptation as D65, since the images were viewed and adjusted under the D65 illumination. For the light settings which did not result in the adjusted white point within such an area, the degrees of chromatic adaptation were generally low. In particular, the further the adjusted white point, the lower the degree of chromatic adaptation. As the image was viewed under the D65 illumination, we used D65 chromaticities as the baseline. Figure 7 shows the chromaticity distance Δu'v' between the adjusted white point and D65 versus that between the light setting and D65. It can be observed that the further the chromaticities of the light setting to the D65 chromaticities, the further the adjusted white point to the D65 chromaticities.

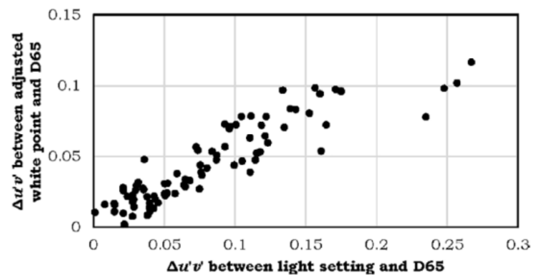

Figure 7 Chromaticity distance Δu'v' between the adjusted white point and the D65 and that between the light setting and the D65.

Conclusion

In this study, we aimed to investigate whether the white balance should always correct the image white point to D65 regardless of the illumination in a scene. We developed a pipeline to apply a chromatic adaptation transform to adjust the image color appearance by changing the image white point. The human observers viewed a physical scene under each of the 85 light settings, which covered a wide range of chromaticities, and adjusted the color appearance of the image by changing the image white point, so that the color appearance of the image matched to that of the scene. Such a result clearly suggested that it is not appropriate to always adjust the image white point to D65. The further the chromaticities of the illumination to the D65, the further the adjusted white point to the D65. The proposed pipeline can be used as a method to adjust the image white point based on the chromaticities of the illumination in the scene.

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Author Biography

Minchen Wei received his BEng from Fudan University, China (2009), his MSc and PhD from The Pennsylvania State University, USA (2011 and 2015). Since then he has worked at The Hong Kong Polytechnic University, Hong Kong. His work has mainly focused on color science, color management, imaging science, and illuminating engineering. He is an associate editor of the Journal of the Optical Society of America A (JOSA A) and Color Research & Application.

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