Preferred Color Correction for Mixed Taking-Illuminant Placement and Cropping

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Abstract

The growth of automatic layout capabilities for publications such as photo books and image sharing websites enables consumers to create personalized presentations without much experience or the use of professional page design software. Automated color correction of images has been well studied over the years, but the methodology for determining how to correct images has almost exclusively considered images as independent indivisible objects. In modern documents, such as photo books or web sharing sites, images are automatically placed on pages in juxtaposition to others and some images are automatically cropped. Understanding how color correction preferences are impacted by complex arrangements has become important. A small number of photographs taken under a variety illumination conditions were presented to observers both individually and in combinations. Cropped and uncropped versions of the shots were included. Users had opportunities to set preferred color balance and chroma for the images within the experiment. Analyses point toward trends indicating a preference for higher chroma for most cropped images in comparison to settings for the full spatial extent images. It is also shown that observers make different color balance choices when correcting an image in isolation versus when correcting the same image in the presence of a second shot taken under a different illuminant. Across 84 responses, approximately 60% showed the tendency to choose image white points that were further from the display white point when multiple images from different taking illuminants were simultaneously presented versus when the images were adjusted in isolation on the same display. Observers were also shown to preserve the relative white point bias of the original taking illuminants.

Introduction

Recently, color science research has shifted its focus from uniform patches to spatially complex images. Due to improvements in image-based applications, the ability to make automated judgments about images has increased in importance. This research is part of a program that hopes to provide valuable improvements to image appearance models for use in image-processing algorithms applied to still and moving images placed in the complex arrangements that new and evolving multimedia demand.

Part of the motivation for the current investigation is to begin to develop an understanding of how presence of images captured under different illumination impact the preference for color settings for a first image so that the set of images appear cohesive when viewed together. Some examples of applications where collections of images are viewed would include brochures, annual reports, photo books, image sharing websites and even junk mailers. High quality examples of such output generally involve professionals manually manipulating the pages. Alternatively, in many cases, images are manipulated in isolation to remove any original color bias. While the result of this latter approach does make the images "look the same," this research sets out to determine if it will be optimal. Both options are costly and when they fail, compilations can be highly objectionable even though individual images might have high quality when seen outside the grouping.

Today's growth of digital printing enables consumers to create personalized documents without much experience or the use of professional image and layout software. Self-publishing websites such as Lulu are examples of companies profiting from this technology and business model [1]. Much of their success is attributed to the quality they produce. In this type of application the quality of the output is highly dependent on any automated enhancement available within the publisher's workflow. Therefore adding image processing that improves the appearance of image cohesiveness of sets of images could improve the quality of the output. Already image processing techniques are designed to take advantage of preferred image reproduction, albeit in isolation. What is missing is the ability to take into consideration multiple images on a single page.

Chromatic adaptation uses cognitive and physiological mechanisms of the human visual system to map object colors to alternative white points [2]. Cognitive mechanisms take into account knowledge of scene content. Physiological mechanisms take into account a change in sensitivities of the photoreceptors and the neurons first few stages in the visual pathway. Chromatic adaptation occurs when prolonged exposure to a colored stimulus reduces awareness of that color while viewing an environment. Imaging systems do not innately have either group of mechanisms. Thus, they require image processing to produce reproductions that have apparent matches to the original scene. White balancing algorithms within digital cameras apply image processing that somewhat mimics the physiological mechanisms.

The current recommendation by the International Color Consortium is to adapt the measured colorimetry to the profile connection space (PCS) to account for differences in white point chromaticities and luminance [3]. Proper estimation of the white point of the taking illumination is crucial to the acceptability of the final output. A simple von Kris-like transformation is typically used to convert from the estimated colorimetry to the standard condition. This method is computationally inexpensive and predicts a majority of chromatic adaptation phenomena. But, it does have some limitations. Jameson and Hurvich found that this method is inaccurate and inadequate for predicting the appearance of color patches [4]. Developments of better models have taken place, but these models tend to be computationally cumbersome and require knowledge of the scene that cannot be collected via a camera. It is important to note that these corrections are based on image processing research done on images in isolation.

A second motivation for this research is to collect information useful for automatic cropping techniques. Artists have been painting grand landscapes for hundreds of years. It is known that perspective is enhanced with the use of color. Stelmack explored the effect of hue and chroma on apparent distance [5]. He found that with small solid patches there was a significant effect on apparent distance with changes in hue and chroma where brighter hues with more chroma appeared closer. Unlike Stelmack, our research looked at images. We also wish to understand how apparent distance impacts color appearance.

Through a series of experiments, the two questions outlined above were explored: how does apparent distance affect color preference and how does the presence of other images taken under different illumination conditions impact color preference. For the multi-image portion of the experiments, we focus on image processing applied to images viewed simultaneously, which is the way many images are normally presented. Within a single compilation of images, it is often the case that different taking illuminants are represented. In this research, we explored how images captured under different illuminations are color adjusted when viewed in isolation compared to simultaneous presentation. Our hypothesis was that when adjusted for simultaneous view the white points would move closer to the original taking illuminants than when adjusted for isolated view. The effect of apparent distance of the subject on chromatic content was also investigated. We hypothesized that when objects are apparently closer to a camera within a scene, observers would prefer to set them to a higher chroma than when the same objects appear further away from the point-of-view

Experimental Method

Image generation

We characterized a Nikon D40 with an 18 to 55 millimeter lens [6]. The camera was used to capture the images under three different illuminations: daylight, fluorescent and tungsten. Measurements of the radiance of the illuminations were made using the PhotoResearch 650 spectroradiometer and pressed polytetrafluoroethylene powder (Halon) as a prefect reflecting diffuser as a part of the characterization [7].

The changes in the apparent distance were made in Photoshop by cropping out a portion of each image [8]. These images will be referred to as the zoomed images. The original images will be referred to as the long shots. To create the zoomed images, the long shots were cropped to 399 by 600 pixels. Then the long shot was down sampled in Photoshop using the bicubic sampling method so that both the zoom and the long had the same pixel count. Figure 1 contains the experimental images.

Display characterization

A 30" flat-panel Apple HD Cinema liquid crystal display was characterized and used in this experiment [9]. A Power Mac G5 controlled the display through a DVI connection. It was set to maximum brightness using the buttons on the side of the display. The LCD is thin film transistor (TFT) active matrix display with 2560 x1600 pixel resolution. This monitor has 178° viewing angle and an antiglare coating. All surrounding illumination was turned off to provide a black background that allowed observers to completely adapt to the display's white point (D65) [10].

The maximum absolute radiance of the image capture illuminations differed greatly between the three taking environments. Great care was taken to ensure that all the images were transformed to within the gamut of the display while preserving the original white point. A maximum luminance value for all potential white points was chosen by running an optimization that looked at a range of potential white points along the Planckian locus. For each white point, the maximum luminance of white was derived. Smallest of all qualifying white point maximum luminances was chosen as the limiting maximum luminance for all white points.

Figure 1. Test images included the experiments (a) daylight long shot (b) daylight zoom shot (c) fluorescent long shot (d) fluorescent zoom shot (e) tungsten long shot (f) tungsten zoom shot

Experiment details

All the observers had normal color vision. Two experimental modalities were designed: a single image experiment where only one image was presented to users at a time; and, a double image experiment where two images were presented to users at a time. 29 observers participated in the single image experiment. The double image experiment included 28 observers. There were 21 males and 8 females ranging in age from 21 to 65 years old.

The interface for the experiment was written in MATLAB R2007b (7.5.0.338) using PsychToolbox (3.0.8) [11,12]. Each observer ran the experiment three times with random presentation of the images. The three trials were then averaged within observer for analysis.

Single image experiment

The single image experiment had three parts where the observers are given different controls to adjust the image to their preferred reproduction. The three control scenarios were white point adjustment alone, chroma adjustment alone and white point and chroma adjustments together. The specific instruction were:

> You will be presented with several images and captions which are to be included in a photo book you are creating. Using the slider bar(s) provided adjust images to your preferred reproduction. There are three different control scenarios for which you will be able to adjust the images: white point alone, chroma alone and both white point and chroma together. When the preferred reproduction is reached press the space bar to proceed to the next image. Typically this experiment will take 15 to 20 minutes.

A diagram of the white point and chroma adjustments together portion of the single image experiment is shown in Figure 1a.

Double image experiment

The double image experiment had two parts. In both, only the white point control was used. In part one, only the image on the right was adjusted and part two, both images could be adjusted. The observers' were given the following instructions:

> You will be presented with several pairs of images and captions within a page layout, which are to be included in a photo book you are creating. In the first part of this experiment, you will use a white point slider to adjust the image on the right (point to screen) so that the entire page layout including both images is your preferred page layout. In the second part of this experiment, you will have two sliders one for each image (point to screen). Please adjust both images to your preferred page layout. When the preferred page layout is reached, press the space bar to proceed to the layout. Typically, this experiment will take 15 to 20 minutes.

A diagram of part two (both images are adjusted) of the double image experiment is shown in Figure 1b. For part one, where the observer could only adjust the right image, the control was located beneath the center of the images.

User controls – white point

The white point control was not a typical slider bar. The white point control was designed with the requirement that observers' be able to keep their attention on the image while making white point decisions. Holding the mouse button down on the control and moving to the right caused white point to shift toward blue, moving to the left caused the white point to shift toward red and moving to a mid point caused the white point to stop changing. Also, the control design prevented observers from easily returning to an earlier setting simply through a geometric relationship on the control itself helping to guarantee that white points were set through observing the images themselves.

The Planckian locus was used to calculate the new white point in reaction to observers' manipulation of the control. The actual taking illuminations were not located on the Planckian locus, indicating that they were not blackbody radiators.

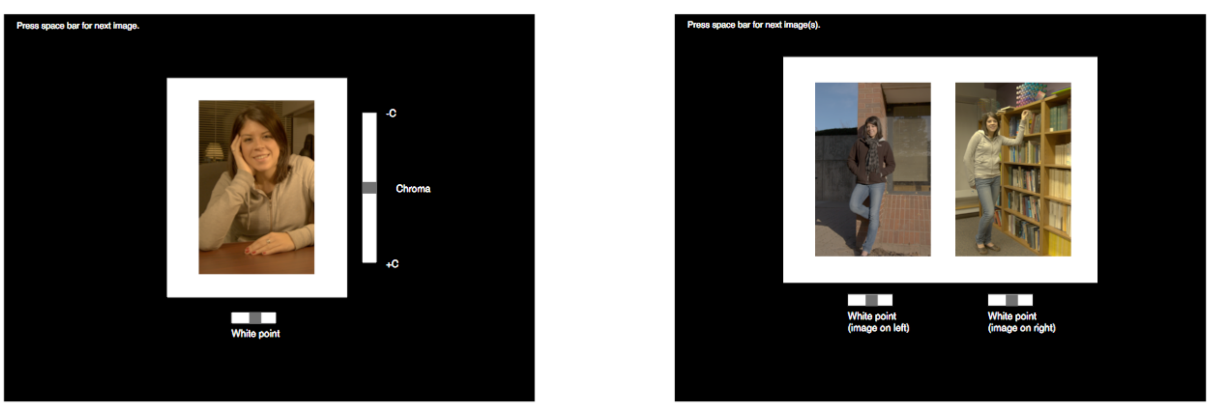
Results and Discussion

Apparent distance and chroma

Table I contains the results for chroma adjustment using the white point and chroma controls together in the single image experiment. Results for chroma control-only were unreliable because observers felt that they could not adjust the image to an acceptable reproduction. Observers' results for chroma control combined with white point control will be the basis of the following analysis.

Table I. Apparent distance percentage results for chroma for each illuminant.

	Long > Zoom	Long = Zoom	Long < Zoom
Daylight	38%	7%	55%
Fluorescent	59%	0%	41%
Tungsten	17%	3%	79%
Total	38%	3%	59%



(a) (b)

Figure 2. (a) Single image experiment with both user controls (b) double image experiment with two white point controls.

Table I shows a tendency for increased chroma to be preferred for the zoom shot over the long. These results follow the same trends as previous work related to chroma [5]. The long shots included would be considered a middle distance compare to the previous work. Fluorescent, which did not follow the trend, had artifacts that were more apparent in the zoom shot and thus observers may have been attenuating the artifact by reducing the zoom shot chroma.

The images in this experiment are classified in the semantic category of images with people [13]. Extrapolation of these results to other image classifications may not be appropriate. Further work on all image content classification should be preformed to form a more complete conclusion.

White point adjustment

Observers adjusted the white point on all the illuminations toward the white point of the display when presented in isolation. Table II contains the CIEDE2000 values for the measured and average adjusted white points calculated with the display white point as the standard. The ordering of the illuminations in terms of CIEDE2000 units was preserved after white point adjustment.

Table II. CIEDE2000 between the display white point and the illuminant white point for both the measured and average adjusted white point.

	Measured	Avg.of adjusted	Meas. - Adj.
Daylight	17.0	8.2	8.8
Fluorescent	23.3	12.0	11.3
Tungsten	28.0	16.0	12.0

Noise was inherent in this data because observers' were unable to perfectly replicate their previous results each time. Rank order per observer was used to analyze the data due to this inherent noise.

The analysis for the double image experiment contains a combination of the results from the two experiments using the single image experiment results as a baseline. In the double image experiment part one adjustments were made to the same image twice once with each of the other two illuminants. Signed CIEDE2000 between the display white point and the observer adjusted white point was used to order the results. The results from the double image experiment were compared to the results from the single image experiment (standalone image).

Images presented in isolation and simultaneously both maintained the same order as their initial white points, shown in Table III. Based on the tests concerning a population proportion the percentage required for significance was 59% [14]. The close proximity of daylight and fluorescent white points caused fewer occurrences of maintaining order, this was true for both isolation and simultaneous presentations. When initial white points are further apart, then the order is more clearly preserved. A higher percentage was observed for tungsten with daylight compared to tungsten with fluorescent.

The largest difference in initial white point was between daylight and tungsten, which influenced the percentage of observations that maintained order to be the highest at 75%. Daylight and fluorescent had the smallest difference leading to 50% of the observations maintaining their order.

Table III. Percentage of observer responses maintaining relative order of adjusted white points for Isolation presentation and Simultaneous presentation and percentage of observer responses increasing the average white point distance from the display white point when comparing Isolation presentation to Simultaneous presentation.

	Isolation maintain order	Simul. maintain order	Distance increase in simul. case
Population	64%	61%	60%
Tungsten vs Daylight	75%	75%	54%
Tungsten vs Fluorescent	68%	64%	68%
Daylight vs Fluorescent	50%	43%	57%

Table IV contains the categories into which the rank order data were sorted. S is isolated presentation, D is presented simultaneously with the daylight image, F is presented simultaneously with the fluorescent image and A is presented simultaneously with the tungsten image. The left column under each illuminant is the condition with the largest CIEDE2000 from the display white point. The third column is the smallest. The thick borders represent equality among illumination conditions.

Table IV. The 13 rank order categories.

Category	Daylight			Fluorescent			Tungsten		
1	S	F	A	S	D	A	S	D	F
2	S	A	F	S	A	D	S	F	D
3	A	S	F	A	S	D	F	S	D
4	A	F	S	A	D	S	F	D	S
5	F	S	A	D	S	A	D	S	F
6	F	A	S	D	A	S	D	F	S
7	S	F	A	S	D	A	S	D	F
8	A	S	F	A	S	D	F	S	D
9	S	F	A	S	D	A	S	D	F
10	S	F	A	S	D	A	S	D	F
11	F	A	S	D	A	S	D	F	S
12	S	A	F	S	A	D	S	F	D
13	F	S	A	D	S	A	D	S	F

Table V contains the adjustment conditions causing the smallest CIEDE2000 adjustment difference from the display white point. The symbols in the first column relate to those in Table IV with the gray squares representing all the possible combinations that end in the same symbol. The majority of the observations were included in categories that ended with the image in isolation (S) for all three-illumination conditions. This means that a majority of the images adjusted in isolation were closer to the display white point than those adjusted simultaneously. This supports our hypothesis that color adjustments differ when the image is viewed in isolation and the image is view in a pair.

Table V. Adjustment conditions causing the smallest CIEDE2000 adjustment difference from display white.

White point of other image being presented simultaneously	White point of image being adjusted		
	Daylight	Fluorescent	Tungsten
S	68%	46%	50%
D	-	39%	25%
F	14%	-	21%
A	14%	14%	-
Ties	4%	1%	4%
Total	100%	100%	100%

Table VI contains the adjustment conditions causing the largest CIEDE2000 difference from display white. The symbols are the same in this table as they were in Table V. Daylight and fluorescent images adjusted with tungsten and tungsten adjusted with daylight had the largest CIEDE2000. When the white point of the image to be adjusted was most dissimilar the image it was paired, the adjusted white points were the furthest from display white.

Table VI. Adjustment conditions causing the largest CIEDE2000 adjustment difference from display white.

White point of other image being presented simultaneously	White point of image being adjusted		
	Daylight	Fluorescent	Tungsten
S	14%	25%	21%
D	-	14%	43%
F	29%	-	32%
A	54%	61%	-
Ties	3%	0%	4%
Total	100%	100%	100%

From tends shown in the tables adjusting images in the presence of other images does effect the white points. White points were set somewhere between where they started and the display white point. This enabled the image to differentiate itself from the display illumination and the other displayed image.

Conclusions

Our results for apparent distance and chroma adjustment indicate that there is a tendency to prefer increased chroma for apparent short distances and decreased chroma for apparent longer distances. This is consistent with previous research and adds to it since the longer shots here are not as far in distance as previous work looked at. Further experimentation should be done with a larger number of stimuli that contains diverse content and multiple apparent distances to fully establish the trends.

Images viewed in isolation were, as expected, preferred with white points that were modified from the original taking illuminant toward that of the display. When the images were adjusted in the presence of other images that were captured under different taking illuminants, the preferred white points migrated back toward the original taking illuminants. This preference phenomenon may be in place to allow the images to maintain some of sense of their original lighting condition.

Trends found through this work need further exploration. Comparison of these results to those predicted by current image appearance models must be preformed. This research and those that follow should point toward modifications of image appearance models that will be of value to the new publication and presentation modalities such as picture books and image sharing websites.

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