Determination of Adapted White Points for Various Viewing Environments

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Abstract

Adapted white points were visually determined for four environments using a CRT-based, neutral-point selection, psychophysical method called MIND. Three of the environments simulated the common viewing condition of a CRT illuminated by an overhead source. The chromaticity and luminance of the monitor and its ambient illumination were varied. The fourth environment was a CRT monitor viewed in a dark surround and was used as the null case. For the sRGB environment, the adapted white point was found to be similar to D65. For all environments empirical AWP's are given. A model is proposed for predicting AWP in mixed-mode viewing environments based directly on monitor and ambient illumination influences. The authors describe the next steps in testing this model with images.

Introduction

The introduction of CIECAM97 is a significant advancement in digital color imaging. After many years of research, there is finally a CIE-recommended color appearance model that can reasonably predict a number of color appearance phenomena and attributes. However, there are some unresolved questions about how the model can be applied to certain common viewing conditions. For example, it is unclear what the adapted white point is for a stimulus in a mixed-mode, or multiple source, viewing environment.

Two of the input parameters for CIECAM97s are the D factor and the adapted white point or AWP. The D factor specifies the degree of adaptation to the white point and has been used to account for incomplete adaptation. The AWP is the chromaticity and luminance to which one is adapted. It is unclear how to set these parameters when there is more than one source in a viewing environment. It is not uncommon for the white point of a monitor to be different from the white point of the ambient illumination. For instance, the sRGB standard is based on a D65 monitor under D50 ambient illumination. It is therefore critical to understand if the AWP of such an environment is the monitor white point, the white point of the ambient illumination or some other white point. Once the AWP is known, D can be set to one, indicating complete adaptation to the mixed-mode environment.

Furthermore, based on recent findings,[1] it is essential to accurately know the AWP for a given viewing environment. Small difference in the AWP can result in large deviations in the resulting CIECAM97s predictions. For example a change of only 250°K CCT in AWP input of CIECAM97s causes an average 1.2 ΔE in the prediction of an IT8 target. While apparently small, remember that this error will be propagated through any other transforms.

The first step in determining the AWP in mixed-mode viewing environments was to develop a method to collect visual data using psychophysical techniques. As in past research,[2] we employed a multiple-stimuli, interactive, neutral-determination method, called MIND, to accurately and precisely determine the AWP. The next step was to select various mixed-mode environments and collect data on the corresponding perceived adapted white points, as well as measure the physical characteristics of the environments. Finally we used this data to create a model that predicted AWP based on environmental factors.

The basic assumption was that observers would chromatically adapt to the adapting field. When using MIND, the adapting field is an achromatic random dot pattern that fills the monitor screen. This is called the background. The RGB values specified for the background are determined through the monitor white point characterization. The background is equivalent to projecting an L* 60 gray from the monitor. However, what the observer actually sees as the background includes both the luminances from the projected RGBs and the reflection of the ambient illumination. This measurement is referred to as the background measurement.

As stated above, the measurement of the background includes the effect of ambient illumination. Previous research[3,4] has shown that the AWP is closer to the white point of the monitor than the ambient illumination white point. However, there has been limited research as to how these results could be applied to setting the input parameters for CIECAM97s. Our goal in this research was to devise a model that would allow the AWP to be determined for any typical viewing condition, and thus provide an easy way to apply the CIECAM model to everyday situations.

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Experimental

Four mixed-mode illumination environments, representing typical office conditions, were investigated. Approximate values for these viewing conditions are listed in Table 1. Note that the first environment, where the CRT is viewed in the dark, corresponds to the null condition. The only difference between the Office I and the Office II conditions is the monitor white point; the ambient illumination remained the same for both these conditions. Note that in Table 1. the Office ambient white point illuminance values are measured on the desktop.

Table 1. The four viewing environments studied.

	CRT White Point		Ambient White Point	
	CCT	Luminance	CCT	Illuminance
Dark	D65	80 cd/m^2	-none	0 lux
sRGB	D65	80 cd/m^2	D50	64 lux
Office I	D65	80 cd/m^2	3920	840 lux
Office II	D93	80 cd/m^2	3920	840 lux

The monitor was a Sony GDM2000TC monitor and was characterized and calibrated periodically (twice a day) during the observations. A PR650 spectroradiometer was used to measure the CRT white point. The ambient sources were fluorescent bulbs in overhead housings with plastic diffusers, a setup typical for many offices. The ambient illumination was measured with the PR650 by placing a halon tablet at the monitor faceplate. The room was painted gray and the observers wore a black shirt.

The visual experiment employed an interactive, multiple stimuli, achromatic selection method called MIND, an improvement upon methods described in earlier research. The background of the visual field was a random-dot achromatic pattern with an average L* of 60 in reference to the monitor white point. The observer began the experiment by adapting to this background for 60 seconds. Next, 16 color patches were displayed and the observer was instructed to select the one that appeared most neutral.

The test patches were displayed along four hue vectors. Upon selecting a patch, the program processed the response and computed the step size for the next set of patches to be displayed. Over time the observer selections converged to a set of stimuli in which most samples appeared to be achromatic. After four consecutive achromatic selections agreed to within 0.25 $\Delta E^*_{ab,}$ the process would stop and the average of those four selections would be called the observer's AWP. This process was repeated for a total of five estimates of the AWP. For each repetition, a new set of starting stimuli was randomly generated.

Chichilnisky and Wandell[5] have shown that the relationship between the lightness of the stimuli and the lightness of the adapting field affects overall adaptation. Therefore, the entire experiment was repeated three times using lightness levels of L* = 50, 65 and 80 for the test stimuli, while keeping the lightness of the background constant. Additionally, each observer completed the testing process for all four test environments.

Due to temporal instability of the monitor, measurements of the achromatic-appearing stimuli determined by the observer and of the background were made immediately after each observation session. This background measurement included the influence of the monitor white point and the ambient illumination of the viewing environment. Individual measurements were also made of both the monitor and the ambient illumination every four hours. The monitor and ambient illumination were adjusted accordingly and remeasured in order to keep the adapting stimuli as consistent as possible across observation periods

Originally a population of 20 naive, color normal observers were slated to participate in the experiment. However, the results from the first group of 11 observers were very consistent and it was decided not to increase the observer pool. Intra-observer noise was low, with typical standard errors of 0.7 ΔE^*_{ab}. The inter-observer standard error was 0.6 ΔE^*_{ab}. Observers' ages ranged from 25 to 63, with the median age being 41. There were 4 male and 7 female observers.

Results and Discussion

The results of the experiment are discussed in three parts. First is the examination of the trends across observers. Second the trends across viewing conditions are analyzed. Third, the overall trends for predicting AWP are explored.

The data were processed in CIECAM space in order to compare and average color differences in a color uniform space. Although CIECAM has not been specifically recommended for this use, investigations by Moroney[6] show that CIECAM color differences are equivalent to CIELab color differences. CIECAM calculations were performed using the monitor white point measured under the ambient illumination as the white point. It should be noted that the analysis offered here has also been carried out in CIELab space, and those results are very similar to the CIECAM results. We will however present only the CIECAM analysis here for the sake of consistency.

The AWP was calculated in CIECAM for each observer under each test viewing condition, resulting in 44 averaged AWP's. The calculation was achieved by averaging the 5 repetitions of each luminance level, as well as the 3 luminance levels themselves, for a total of 15 data points for each observer's AWP. Although differences were seen between the luminance levels, they were averaged together on the principle that typical computer usage encompasses a range of luminances.

One impressive finding is that all of the observers exhibited the same trend across all of the test environments. Figure 1 shows the change along the b-axis as a function of the slight individual changes in each observers' viewing condition. The data are plotted relative to each observer's experimentally-determined AWP. The results show that on a whole, observers' AWPs (equivalent to 0) are always closer to the background than the monitor measurement, which are both always closer to AWP than the ambient illumination. The same trend is found in Δa, but is not as pronounced.

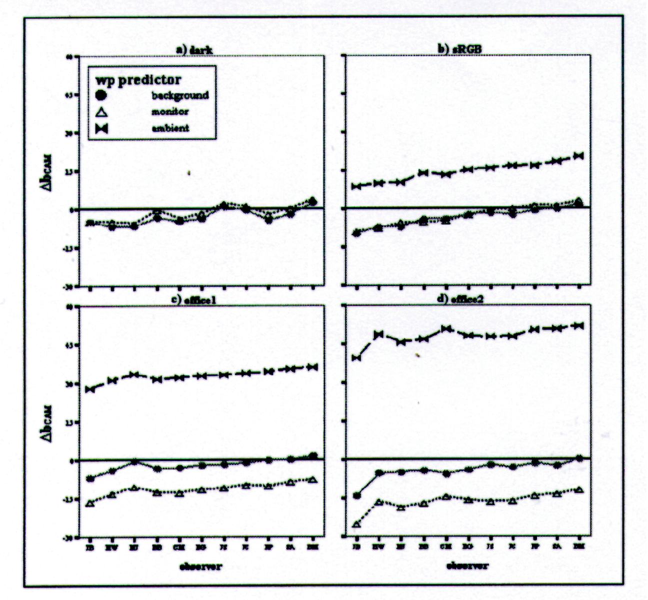

Figure 1. Trends across observers for each viewing condition. Note dots are connected to show trend.

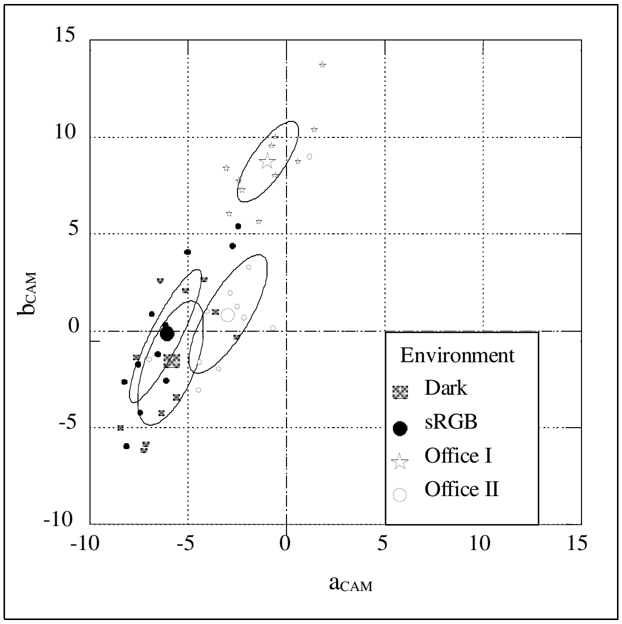

Figure 2. Experimentally determined AWP's plotted in CIECAM ab plane with 95% confidence ellipses around the mean. Data is shown for all 11 observers for each viewing condition.

The next step was to statistically analyze the results across viewing conditions. First the 11 observer's AWP's were averaged together for each viewing condition and 95% confidence limits determined. Figure 2 is a scatter plot in CIECAM of the individual observer results with confidence ellipses of the mean. Just a look at the plot shows that the AWP for the Dark and sRGB conditions are very similar, while both the Offices I and II AWP's are significantly different from the rest. Post-hoc MANOVA testing confirms these results to 99% confidence. In summary, the dark AWP and sRGB AWP are not statistically significantly different from each other. The Office I AWP is different from all other viewing conditions as is the Office II AWP. The mean values for the four AWP's are reported in Table 2 along with the averaged measured values of the background, monitor and ambient white points in Yxy space.

Table 2. AWP results and environmental measurements

Averaged Measurements		Viewing Condition			
		Dark	sRGB	Office I	Office II
AWP	Y	80.1	80.7	84.3	84.8
	x	0.314	0.316	0.325	0.296
	y	0.331	0.332	0.343	0.311
Background	Y	26.1	26.6	29.8	30.1
	x	0.311	0.313	0.321	0.293
	y	0.328	0.329	0.339	0.307
Monitor WP	Y	81.5	80.7	81.1	80.9
	x	0.313	0.314	0.315	0.283
	y	0.330	0.330	0.331	0.297
Ambient WP	Y	0.0	19.4	84.0	84.7
	x	0.0	0.341	0.391	0.392
	y	0.0	0.353	0.403	0.403
Flare	Y	0.0	0.99	4.10	4.29

Key gains from Table 2 are the empirical AWPs. These data can be directly used as the CIECAM input parameter AWPs for any similar environments. For instance, in an environment with a CRT at D65 80 cd/m^2 and overhead CWF (4000) at 84 cd/m^2, the AWP is Y=84.3, x=.325, y=.343. A quick look at the sRGB AWP shows it is very similar to D65 (.313, .330). It is unlikely that a significant difference in image color predictions will result from simply using D65 as the sRGB AWP. However this assumption will be verified in future testing.

At this point, we determine which environmental factors are good predictors of the AWP. There are three environmental influences to be considered: that of the background, the monitor and the ambient illumination. Both the luminance and chromaticity of these factors are considered. It is important to remember that the background is not independent of the other two factors. Instead it is a combination of the monitor and ambient illumination. It is to be expected that the background is the best predictor of AWP since it actually **is** the adapting field.

Figure 3 is a plot of the relative differences between the visually determined adapted white point, and the background, monitor white point and ambient white point. Again, the results are shown in CIECAM with 95% confidence ellipses around the mean. The differences are calculated for each observer and then averaged, since it is the relative position that is important for predicting the AWP. The ideal predictor of AWP would have a difference of 0.

The results of Fig. 3 indicate that the chromaticity of the background most closely matches the AWP for each viewing condition. However it is not exactly 0. Instead there is a shift in the b direction of about –3 units. In fact all of the significant differences are along the b axis. The monitor WP does not predict AWP well as ambient illumination increases. In the worst case, Office II, it is off by –16.3 Δb. Ambient WP is an even worse predictor of WP, as seen in Figure 3c. Again, the worst case is Office II, where the Δb is 48.1.

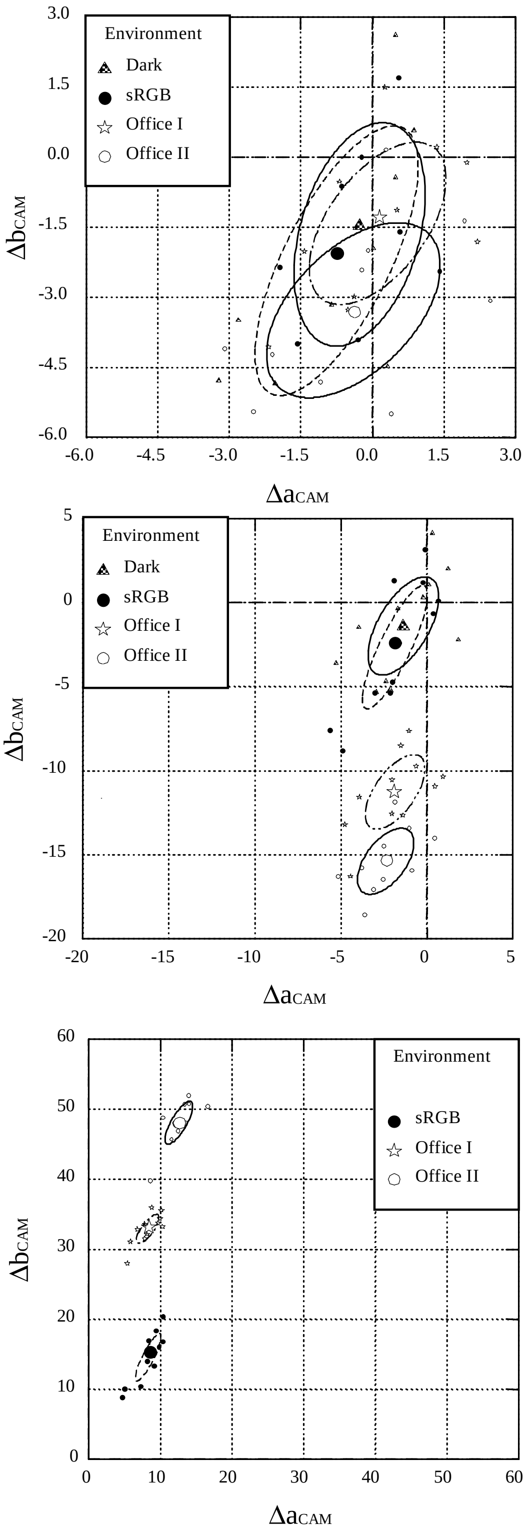

Figure 3. Differences from AWP in CIECAM difference space shown for top) background middle) monitor and bottom) ambient.

Even without knowing the exact size of the JND for CIECAM, it is clear that these differences are large and significant. They indicate that simply substituting monitor or ambient WP for actual AWP will result in large errors. Substituting the background chromaticity for actual AWP, while not exact, will produce significantly better color appearance predictions. Note that with these substitutions, D is set to 1.0. This can effectively be done in situations where users have access to measurement equipment and can simply measure the background chromaticities of their particular environment. However, we are interested in pursuing a model that directly relates the influences of monitor and ambient illumination on AWP.

Model

The above analyses were performed in CIECAM space, where the data were normalized to the particular monitor white point (D65 for Dark, sRGB, and Office I, D93 for Office II). For modeling purposes, however, CIE chromaticity coordinates were used.

Using multi-variate regression, the experimental results were used to create a model of AWP as a function of monitor white point and ambient chromaticity and luminance. It was found that only monitor chromaticity (x_{mon}, y_{mon}) and ambient luminance (Y_{amb}) were significant parameters. Furthermore univariate regression produced the same results as multivariate. The univariate model is expressed as:

$$x_{AWP} = 0.0251 + 0.92(x_{MON}) + 0.000119(Y_{AMB}) \qquad (1)$$

$$y_{AWP} = 0.0202 + 0.94(y_{MON}) + 0.000145(Y_{AMB}) \qquad (2)$$

The coefficients of the equations are so similar it suggests they could be set to the same values. This will be tested in future work.

Figures 4 and 5 show the empirical AWP vs. the predicted AWP for each chromaticity direction. The univariate r^2 is 0.81 for x and .86 for y. Although the fit is quite good, there is still unmodeled error. The fit holds across all 4 viewing conditions tested, albeit gaps in the data indicate more conditions are needed. While refinements can be made in the model, it would be first interesting to see how well this simple model performs with images. It would be useful to know if small improvements in the model would yield visually significant changes in the resultant image predictions.

Applications and Future Work

There are currently three untested ways to use the findings from this paper for determining AWP's of mixed-mode environments where chromatic adaptation is complete. First is to use the empirical values from Table 2 as the CIECAM AWP input parameters for situations that correspond strongly to the viewing conditions tested. At this time we also suggest that D65 is an appropriate approximation for sRGB AWP. A second use is to measure an L* 60 gray background on the monitor with the ambient illumination turned on. The chromaticity of this measurement can be used for the AWP. This value is only approximate; it does not take into account the Δb noted in the results. Thirdly, the model can be used to calculate AWP chromaticities for any other usual mixed-mode environment. Here the term *usual* means not highly chromatic. This is specified since only these environments were employed in creating the model.

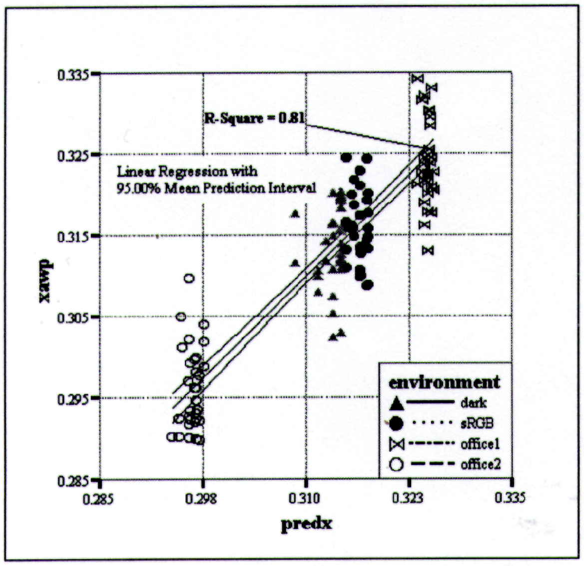

Figure 4. Empirical AWP vs. modeled AWP in x direction.

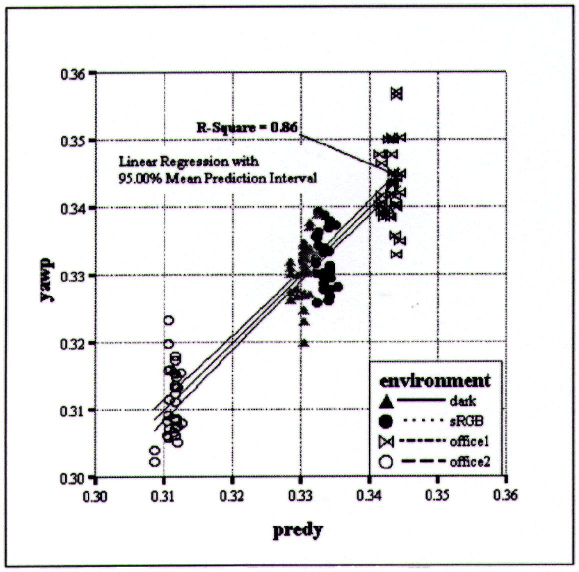

Figure 5. Empirical AWP vs. modeled AWP in y direction

It is difficult to tell at this time the difference in resultant image predictions between these three implementations or whether a more complex solution is needed. For instance, is it necessary to consider the b-direction shift to the background values of the viewing conditions, or, is the simple use of the background measurement as the AWP be good enough? To this end the next step in this research is to test each implementation as applied to images. An essential aspect of this testing will be to closely examine if small refinements in the AWP prediction model will produce visually significant effects.

Using similar environments as the modeling experiments, observers will compare images on a computer monitor to the same image on another monitor under different illumination. The color appearance predictions will be calculated using CIECAM97s2 with D set to 1. Once the implementations are shown effective under these environments, the testing will expand to new environments.

Conclusion

The results provide insight into the AWP for mixed-mode viewing environments. One immediately applicable result is that the AWP for sRGB is very close to D65. Three solutions are proposed for determining AWP in mixed-mode environments. Additional research will be conducted to verify these solutions, specifically the AWP prediction model, using CIECAM97s for images.

References

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