Time Course of Chromatic Adaptation to Outdoor LED Displays

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Abstract

The chromatic adaptation process for the colors displayed on an outdoor LED Display follows two intermediate stages in its path to reach steady-state. In this paper, we investigate the tuning of system parameters in the MACCLED (Mixed Adaptive Color Correction) system in order to insure better color generation while the observer HVS is in transient state. The performance of the system is then analyzed through conducting a series of psychophysical visual experiments in different environmental ambient setup. The resulting z-score of each ambient condition is then compared to select the optimum system parameters adjusting.

Keywords: *LED display, MACCLED, color appearance, ambient lighting, chromatic adaptation, incomplete adaptation, mixed adaptation.*

1. Introduction

The perception of colors in photopic vision mode is a very complex process, requires millions of cells in both the human eye sensor and the nervous system to detect and sometimes predict the perceived color[2]. Such sophisticated process is called the chromatic adaptation. In running this process the Human Vision System (HVS) tracks the ambient white point as a reference used in colors predicting. This complicated process can be explained by the independent sensitivity adjusting or gain control of the three cone responses in order to eliminate the effect of the illumination color and to preserve the appearance of a seen object. The analysis of this process is even more complicated when we consider a softcopy image on a display device. Since the display itself a source of illumination, the HVS becomes affected by both ambient white point and the display white point. The result is then regenerated inside the HVS based on an adapted white point relative to the both luminance sources.

Previous studies on self luminance displays made by N. Katoh, M.D. Fairchild and others show that this point is some where between 40% to 60% relative to the display white point [3][6]. These studies also showed that the adaptation process in this mixed adaptation situation is also incomplete, In which even if we watch a display in complete dark room the HVS will not be a 100% adapted to the display image. The resulting colors in such case suffer from great discrepancies when compared to the original colors intended to be displayed [3][6]. Moreover, the results also become more dramatic when the display is installed in outdoor environment. Figure 1 shows how the lighting conditions white point (measured in correlated color temperature) in outdoors keep changing continuously from one severe state to another.

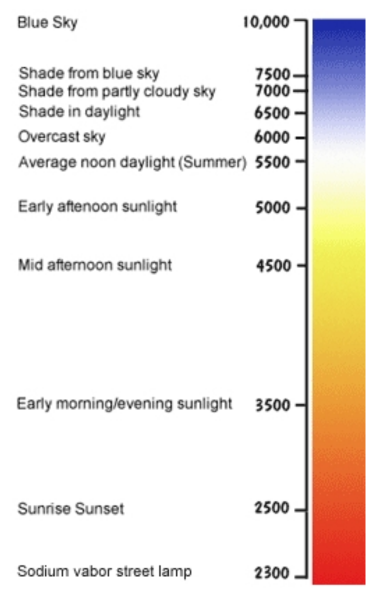

Fig. 1: Ambient white point in CCT through the day [1]

In our previous research, we introduced the MACCLED adaptive color correction system for outdoor LED displays [1]. The system showed significant improvement on the displayed colors in our psychophysical experiments carried in the steady state of chromatic adaptation. In this paper, we continue to examine the system performance in transient chromatic adaptation state. The experiments represented here were conducted in several realistic ambient conditions that simulates outdoor environment in both ambient color and luminance. The time course of chromatic adaptation consists of three phases [2]. The first phase is very rapid and ends in less than 100ms. This phase is considered the starter phase where the photoreceptors initialize. The second phase, which is our concern in this research is the transient phase where the HVS is rapidly trying to adapt to major luminance source in the focus [3][4].

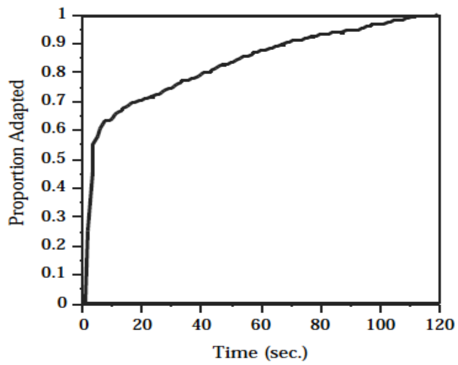

Fig. 2: Time course of chromatic adaptation [4]

This phase approximately ends in the knee of the chromatic adaptation curve shown in figure 2 and takes almost 10 to 20 seconds in average to finish this stage depending on the luminance level. In outdoor LED display the geographical prosperities of the display installation govern the amount of time allowed for the observer and hence to the HVS to adapt to the display area. A typical example to this is an LED display used as a billboard installed in a running street. A case where the amount of time allowed for the HVS to adapt is controlled by the traffic speed. Figure 3 shows an example of such case. The observer has a very limited time to focus on the display area, so we expect the HVS' white point is more shifted toward the ambient white point.

Fig. 3: LED Display in a running street

The MACCLED system is based on correcting adaptively the error in the perceiving of the displayed color using ambient conditions readings taken from a photometer sensor to measure the display adapting field luminance in cd/m^2, and a true color XYZ color sensor to measure ambient light. Figure 4 shows a block diagram of the MACCLED system [1].

The MACCLED system performance was analyzed in steady state in our previous experiment [1]. The Experiment results showed continuous improvements in the displayed colors when applying the MACCLED system, while allowing the observers enough to fully adapt to the environment and the LED display image.

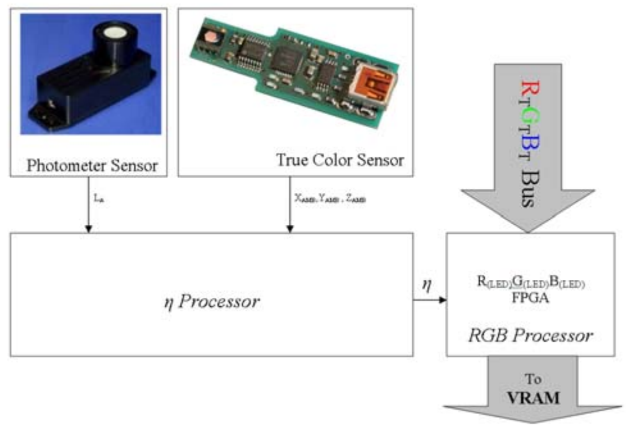

Fig. 4: MACCLED System block diagram [1]

2. Experiment Configuration

The experiments aimed to compare between original non-modified image displayed on a LED display and a corrected image using our MACCLED system while changing the ambient lighting condition to realistic settings and the value of R_{adp} in a time-limited configuration.

2.1 Experiment setup

To insure reliable results, we maintained the same setup we've used in our previous research [1][2] as :

- A Long dark room with eliminated ambient light entrance.
- A 512 x 512 resolutions with 3.2mm pixel size LED display was used. The display was calibrated and characterized at a white point of 6500K CCT. The display was made using high contrast black LED elements. This LED display as most outdoor display has a very wide dynamic luminance range from 0.01 Cd/m2 to a maximum of 4800 Cd/m2 at 6500K. The LED display brightness was automatically adjusted to suit the surrounding luminance level. We adjusted the experiment

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images to be surrounded by 100% white proximal field of two pixels then five pixel wide (20%) uniform gray background. The Display was characterized with a Minolta CS-1000 spectroradiometer normal to the screen at 0° viewing angle. The resulting matrix has average error of characterization for the Macbeth colorchecker of 0.62 ± 0.53 ΔE^*_{ab}. with maximum error of 1.84 ΔE^*_{ab}. The display luminance was set to equal the adapting field luminance L_A using the reading from the photometer sensor.

- Observer seat located 12 meters away form the LED display to suit the display pixel density. In order to avoid viewing angle dependency which is evident on the display at off-axis viewing angles, the experimental arrangement were prepared to forces observers to view a limited region of the front area at angles very near to 10° (θ =10°) by the use of binocular limiter.
- Two digital sensors were used to measure ambient color conditions and photometer to measure the adapting field luminance. The two sensors were carefully positioned by setting the photometer just above the display and the color meter is placed behind the observer to measure ambient light.
- For the matching target, we used a color sheet image as a hardcopy with area 73x73cm (similar to displayed area). The hardcopy was printed using characterized and calibrated HP L65500 printer. The hardcopy were placed attached beside the LED display but can be moved around the display as asked by the observer.
- For the ambient lighting, we used a high power controlled lighting utilizing ten units of 290W LED lamp arrays. Each of these lamps has three controllable CCT modes namely 2300°K, 5000°K and 6500°K used to simulate different ambient lighting conditions. As originally designed to be used in street lighting, the setup configuration of lamp arrays inside the room was powerful enough to achieve a maximum illuminance level of 18600 Lux when measured behind the observer seat at one meter from ground level. In addition, it can be dimmed down to 0.5 Lux. This was crucial to simulate outdoor environment inside the experiment area. The lamps were installed in a manner that inhibits them from being visible by the observer and eliminates casting shadows or glare from the display or hardcopy surface.
- A Remote consol notebook was used to manage the experiment operation with a three keys mouse device used by the observer for scrolling the test images and confirm selections.

We followed the CIE guidelines [5], the ASTM standard guide for designing and conducting visual experiments and the CIE/TC8-04 guidelines to insure experiment comparability [7]. In this experiment twenty normal color vision observers, 16 females and 8 male different from the steady state experiment observers. Their ages ranged from 17 to 22 years. The experiment configuration is showed in Figure 5. We conducted a set of trials initially to judge distance L suitable to match CIE 10° observer specifications. The results obtained from trials have lead us to limit the range of adaptation ratio R_{adp} from 0.3 to 0.5 in order to minimize the experimental trials.

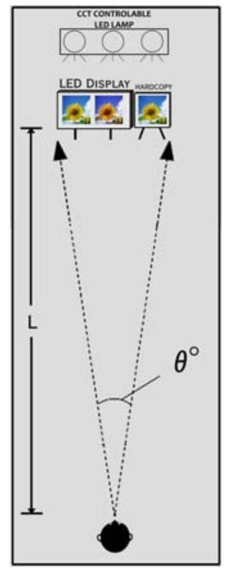

Fig. 5: Experimental Setup

2.2 Experiment Procedure

The aim of this experiment was to investigate the effect of different realistic ambient conditions and observation limitations similar to outdoor installation of LED display to the best value of R_{adp} in transient insufficient timing to adapt to the LED display. We setup this experiment with timing limitation for the observer to make his/her decision.

Table 1 Experiment conditions

Version	White point (K)	Illuminance level (Lux)	R_{adp}
A	2300	200	0.35
B	2300	200	0.4
C	2300	200	0.45
D	5000	1500	0.35
E	5000	1500	0.4
F	5000	1500	0.45
G	6500	16000	0.35
H	6500	16000	0.4
I	6500	16000	0.45

In contrast with the previous experiment we used different setting for the ambient CCT in this experiment, while changing the illuminance level from 200 Lux similar to street condition at night time to 16000 Lux which similar to noon time. Under these variables the system is retested using the same pictures using three values for R_{adp} namely 0.35, 0.4 and 0.45 to minimize the testing trials. Table 1 list all of the experiments conditions.

The observers used the same technique used in the first experiment for image comparisons [2]. The order of the regenerated images pairs was randomly changed with each image. A black screen was shown between the scrolling for ten seconds and the observer was asked to remove their focus from the display to avoid any memory effect. If the observer passed a ten second selection period, the next black screen returns again then another random pair showed for judgment. Figure 6 shows a flowchart for each phase of this experiment.

We used the same four images we used in the steady state experiment setup [1]. The images named Surfing, Swan, Fruits and Sunflower are showed in Figure 7.

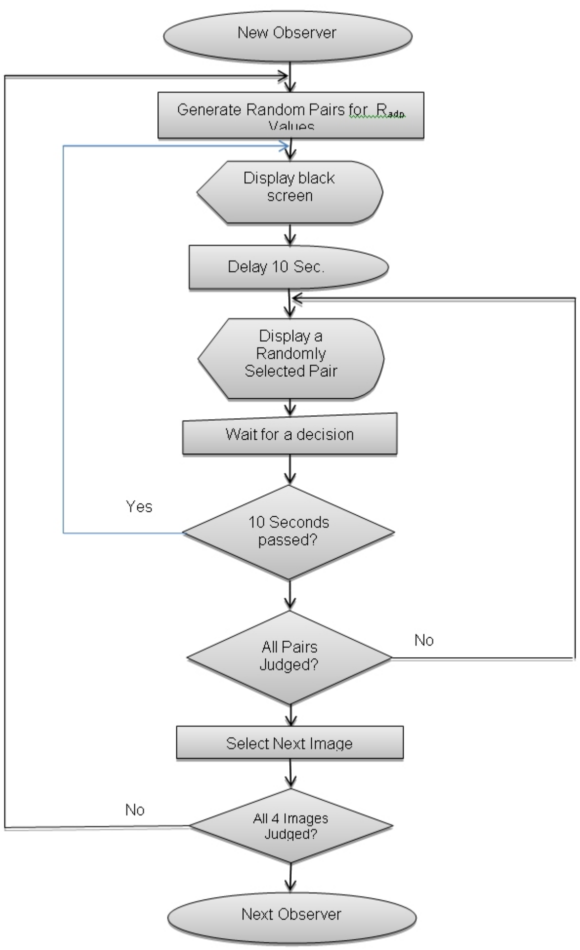

Fig. 6: Flowchart for each illuminance state of the experiment

We used Thurstone's law of comparative judgment in converting ordinal-scale visual decisions to interval psychophysical scale. Using Thurstone's law case V the average results are calculated using 95% confidence interval limited by:

$$\mu \pm \frac{1.96\sigma}{\sqrt{N}} \quad (1)$$

Where μ is the result mean value, N is the number of observations for each pair and σ is the standard deviation.

Fig. 7: Pictures used in the experiments

3.Results and discussion

3.1 Low Illuminance Conditions A,B and C Results:

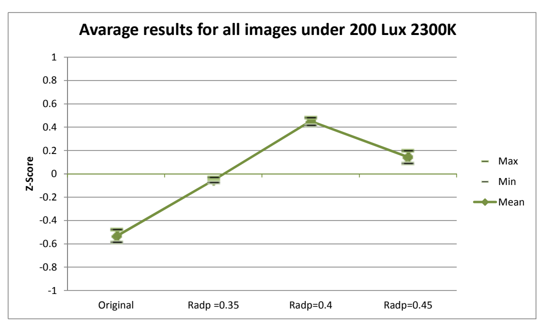

Fig. 8: Average results for all images in 2300°K/200Lux Ambient

The z-score average results of the four images are shown in Figure 8. As expected from adaptation time course the best adaptation ratio was shifted downward when compared to the steady state experiment. The status of 200 Lux illuminance under 2300°K CCT lamp, simulates average street night condition when using sodium vapor lamp.

3.2 Medium Luminance Conditions D, E and F Results:

We next conducted the experiment for viewing conditions D, E and F in table 1 using 5000K CCT lamp in 1500 Lux illuminance environment. This simulates typical overcast day. We maintained this setup by turning on the 5000K LED lamps and carefully adjusting the lamps brightness until we measured average of 1500 Lux around both the observer and LED display. Figure 9 shows the average results for the four images using environment setup of 5000K CCT and illuminance range of 1500 ± 100 Lux.

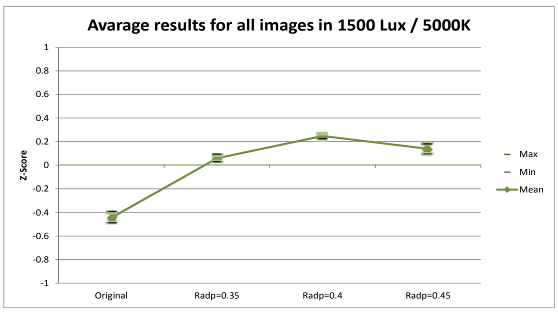

Fig. 9: Average results for all images in 5000°K/1500Lux Ambient

3.3 High Luminance Conditions G, H and I Results:

The later testing conditions simulate normal high luminance sunny day time provided that neither the observer nor the LED display are facing direct sunlight. These conditions were the hardest to achieve inside the testing room, as we had to reach average illuminance of 16000 Lux inside a long shaped area. We had to rearrange the lamps tripods several times to insure no direct contact between the lamp arrays and the observers' eyes.

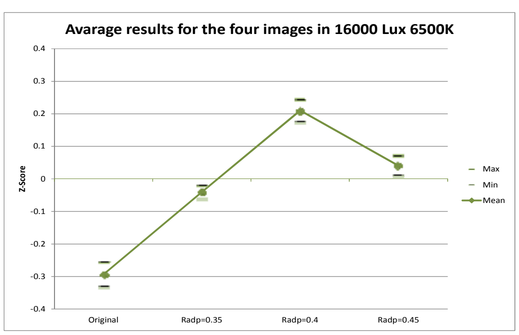

Fig. 10: Average results for all images in 6500°K/16000Lux Ambient

The average results for the four images made in conditions G, H and I are shown in the graph in figure 10 above. The resulting z-score is not far from the results obtained in the steady state experiment for the 6500K condition [1]. Clearly, the adaptation ratio is shifted downward because of limited time for the adaptation process to complete. MACCLED system has succeeded to reduce the effect of flares, which becomes major operative in high illuminance states. Both steady state and the transient psychophysical experiments conducted are aimed to prove our suggested self adaptive model and the MACCLED correction system for outdoor LED display. The results obtained from the paired comparison between original raw images displayed in the ordinary manner without any processing and modified images based on our equations showed significant improvement in the modified images in both experiments.

We conclude also from the experiment curves and the preparatory trials we made that obtaining the best R_{adp} value for optimum model performance depends on the following factors:

- The steady (uninterrupted) period the observer is focusing on the display surface. As following the time course of chromatic adaptation [1].
- The image size (governed by distance L from the display).
- Ambient white point condition. This can be considered as to have the greatest effect.
- The display calibrated white point.
- Illuminance level as the presence of Hunt effect (colorfulness increases with luminance) and Stevens effect (contrast increases with luminance). And the complications caused by the non linearity in these effects.
- The image contents. The degree of colorfulness and the presence of saturated colors inside the image affect greatly its appearance.

The first experiment investigated the performance of the model in near steady state where the observer had enough time to adapt to the LED display. The psychophysical scale results showed that the corrected images were preferred (looks more matching to an original hardcopy) over the original raw image with a z-score varying from 0.3 to 0.7 depending on the ambient condition. While the results from comparing the performance using different values for the adaptation ration R_{adp} show that the best value for R_{adp} is 0.6 (or the observer's eyes are 60% adapted to the LED display) at our setup in steady state adaptation point, however we had better results with approximately R_{adp}=0.7 when the observer seat is moved towards the display. This is understandable as the display image starts to fill the background of the observer vision. The results concerning this phenomenon are extremely important, and suggest future study to estimate the relation between R_{adp} and viewing distance and/or display size. In addition, we found that when using properly calibrated true color sensor to measure ambient white point, the MACCLED system is capable of making great improvement dynamically on the color appearance of displayed images under varying ambient lighting conditions and taking into consideration reflection component from the display surface. The transient state experiment aimed to study the dynamics of the display environment in outdoors. The experiment simulated the early sunny day state, during the day and during sunset or nighttime when the sodium vapor street lights are on. The experiment condition was simulating limited time observer chance to focus into the display. The results obtained from this psychophysical experiment showed that the best R_{adp} value is lower than we got in the first experiment.

Comparing these results with that of the first experiment we can conclude that the adaptation point is shifted on the time course curve shown in figure 1. Moreover, if the observer is not allowed to reach steady state, less values for R_{adp} should be used. Our MACCLED system still can show better Z-scores than the original non-modified images with R_{adp} setting varying from 0.2 to 0.4 under different ambient conditions. The results also showed that our adaptive system performance remained better than the original non-modified images version even with the presence of the following counter effects at the presence of a high illuminance state of 16000 Lux.:

- Higher flare reflection values.
- Hunt effect and
- Stevens effect.

This is justified by the using of the CIECAM02 model, which includes compensations for these effects, and by taking the reflection part into the system modeling.

4. Conclusion

In this paper, we tested the performance of the MACCLED adaptive system to correct the colors generated in outdoor LED displays in transient state of the observers' HVS. We conducted psychophysical experiments to compare corrected images using our system to non-modified images. The results showed that the progress in color correction gained when applying the MACCLED in transient state is not as good as in steady state, however it still represents a significant improvement in the perception of the LED display colors compared to the original non enhanced images. The results also showed that the use of the MACCLED results in a significant reduction in the flare and hue shift effects in the presence of high luminance source.

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