

Illumination-Based Color Balance Adjustments

Janne Laine and Hannu Saarelma
Laboratory of Media Technology, Helsinki University of Technology
Helsinki, Finland

Abstract

In this paper a system for estimating the prevailing illumination conditions on the basis of source information is proposed for digital imaging. Further, a method for utilizing the illumination estimate in color balance adjustment is presented. The goal of the adjustment is to produce images whose color balance is approximately in keeping with the original scene as seen in specified illumination conditions. To estimate the proper amount of color balance shift from what is considered to be a neutral point, a degree of adaptation parameter is used as recommended in CIECAM97s. Although color appearance, in a strict sense, cannot be reproduced by simple white point mappings used here, the system can be used to loosely accommodate the effects of source illumination conditions in the context of color management. It also facilitates intuitive interactive color balance adjustment based on illumination information.

Introduction

A change in illumination color from that for which a photographic system has been calibrated results in color balance shifts in output pictures. Usually, these changes degrade the image quality, and should therefore be compensated. Most digital cameras have white balance controls that automatically adjust the camera's output so that the effects of illumination changes are cancelled. Color balance shifts from what is considered to be a neutral point can also be corrected at later processing stages, for example when making a photographic print from a color negative or slide or when preparing an image in digital form to be printed. However, when this color balance adjustment is done automatically, with no knowledge of the image source, the picture produced often fails to convey the mood of the scene as seen in the illumination conditions prevailing when the photograph was taken. The reason for this is that the illumination-induced shifts in human perception of colors have not been taken into account.

It is well known that despite the process of chromatic adaptation the human visual system does not in all conditions achieve color constancy. In other words, our perception of colors in real scenes is subject to change when there is a change in illumination conditions. It is very difficult for automatic color balancing algorithms to effectively imitate this change when no information, apart from the image to be adjusted, is available. This is a considerable drawback when the feel of the illumination is one of the main elements of a picture. As an extreme example, applied to pictures of candle-lit scenes, automatic white balance adjustment can be disastrous to the romantic atmosphere desired of those scenes. The considerable variation in the quality of daylight also produces some remarkable changes in the appearance of color in our surroundings, the warm colors of objects lit by the sun low in the sky being a good example.[1]

In this paper a system is outlined that makes it possible to estimate the illumination in different weather conditions and to adjust the color balance of digital images accordingly. In the next chapter, methods for estimating the spectral power distribution of illumination based on knowledge of geographical location, date and time, and prevailing weather conditions are presented. When this illumination information is coupled with the image's current white point, the estimation of which is briefly discussed, we can finally adjust the color balance of the picture in a way that is faithful to the appearance of the photographed scene in the specified illumination. The adjustment is calculated as a linear transformation of linearized RGB values, implemented as a 3-by-3 transformation matrix.

A free software application demonstrating the described system is available.[2] The program employs ICC device profiles for input and output device characterization, and the assumed input device characteristics are taken into account in the adjustments. In an ideal situation, an input profile based on careful measurements and employing a suitable color appearance model would take care of transforming the input image color coordinates into a Profile Connection Space representation. When the original is not a picture but a natural scene, photographed with a digital camera, construction of such a profile is very difficult and certainly out of reach for an average camera user. In the system proposed here some input profile is always used, but the image data are further modified based on image analysis and information available on source illumination conditions. This can be understood as modification of the input profile. In fact, instead of modifying the image itself, the modified reproduction instructions could easily be enclosed in a new ICC profile, thereby creating a more suitable profile for reproduction of a particular image[3].

When no profile for the input imaging device is at hand, the sRGB profile is initially used.

Estimation of Lighting Conditions

Metadata concerning the source of an image can be stored in the headers of many image file formats. Usually at least date and time are stored in addition to the actual image data. Lately, applications in which a digital camera also records the geographical coordinates of the location, received from a GPS (Global Positioning System) device, have been introduced. Add to this the possibility of acquiring information on local atmospheric conditions from a weather database, and it becomes feasible to estimate the illumination conditions at the moment the picture was taken. With the integration of digital imaging into wireless communication systems, it can be seen that this kind of source information will be increasingly available to imaging applications. Currently, as in the application described here, this information can be supplied manually by the user. [4]

A simplified parameterized model of atmospheric optics, with scattering restricted to forward and backward directions, was created for the approximation of absolute global spectral irradiance incident on the horizontal plane. The model, loosely based on that of Justus and Paris[5], consists of plane-parallel layers of clear sky and a cloud layer. A 'standard' air constitution has been assumed. The input parameters include cloud type and cloud coverage, and the sun polar angle (the angle of the sun from zenith). The sun angles can also be calculated from date and time, and geographical coordinates. The global spectral irradiance is:

$$E_g(\lambda) = E_0(\lambda) T_d(\lambda, \theta_0, \phi_0) \cos(\theta_0) + \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi/2} E_s(\lambda, \theta, \phi) \cos(\theta) \sin(\theta) \, \mathrm{d}\theta \, \mathrm{d}\phi \quad (1)$$

The first term is for the direct sunlight. The second term is for the diffuse light scattered from the sky and clouds; this is integrated across the hemisphere of the sky. $E_0(\lambda)$ is the solar spectral irradiance incident on the upper boundary of the Earth's atmosphere, called extraterrestrial solar spectral irradiance. $T_d(\lambda, \theta_0, \phi_0)$ is the downward spectral transmittance for the direct path through the atmosphere to the location considered. $E_s(\lambda, \theta, \phi)$ is the scattered irradiance from direction (θ, ϕ). The geometry is illustrated in Figure 1.

Color Balance Adjustment

The starting point for color balance adjustment is the estimation of the image white point. This problem has attracted a lot of attention, but although methods providing good white point estimates in most situations have been proposed, no single universally valid algorithm has been found. In this application the white point is estimated simply by the effective maxima of the RGB channels; the user can also interactively set the white point by specifying a neutral surface in the image.

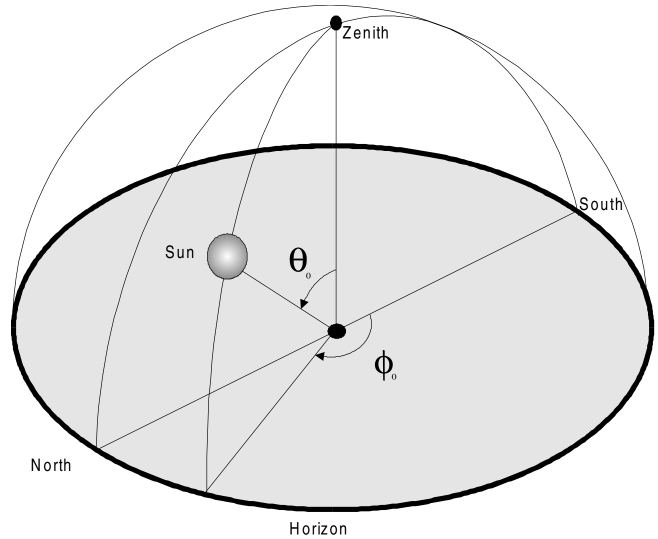

Figure 1. Solar coordinates and scattering geometry

Once the initial white point is known, it is transformed into corresponding XYZ values of the PCS using the specified input profile. These values are now called the corresponding colors of the image white point under illuminant D50, XYZ_{wiD50}.

The Bradford chromatic adaptation transformation is then used to map the adopted white point of the original scene into corresponding colors under D50, XYZ_{wsD50}. Unlike in CIECAM97s,[6] the non-linear portion on the short-wavelength sensitive channel is not included in the transformation. It was excluded for the sake of a 3-by-3 matrix implementation. This is justified considering the approximate nature of the application and the fact that the Bradford transform has been found to provide reliable results even without the non-linearity.[7] The desired amount of color balance shift in the direction of the illumination color is controlled by the parameter D, the degree of adaptation, as in CIECAM97s. The relative XYZ values of the estimated illumination are used as the white point of the original scene, XYZ_{ws}, i.e. the adopted white point. Using the Bradford matrix and giving D an intermediate value between 0.0 and 1.0 to specify the degree of adaptation, the corresponding color XYZ values of the adopted white are calculated under the reference illumination. Again following CIECAM97s, the reference white XYZ values are taken to be those for equal energy illumination, which appears achromatic to a dark-adapted eye. The chromaticity of any estimated illumination is then judged against this reference. The corresponding colors of scene white point are further transformed from reference illumination to corresponding colors under illuminant D50, this time setting D to 1.0 for complete adaptation. The combined transformation from the adopted scene white point to post-adaptation corresponding colors under D50, XYZ_{wsD50}, is then given by:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{wsD50} = M_{BFD}^{-1} \cdot \begin{bmatrix} d_1 & 0 & 0 \\ 0 & d_2 & 0 \\ 0 & 0 & d_3 \end{bmatrix} \cdot M_{BFD} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ws} \quad (2)$$

$$d_1 = \frac{R_{D50}}{R_{wr}} \left(D \frac{R_{wr}}{R_{ws}} + 1 - D \right) \quad (3)$$

$$d_2 = \frac{G_{D50}}{G_{wr}} \left(D \frac{G_{wr}}{G_{ws}} + 1 - D \right) \quad (4)$$

$$d_3 = \frac{B_{D50}}{B_{wr}} \left(D \frac{B_{wr}}{B_{ws}} + 1 - D \right) \quad (5)$$

where $\boldsymbol{M_{BFD}}$ is the 3-by-3 Bradford matrix and R_{D50}, G_{D50}, and B_{D50} are the Bradford cone responses for D50 white, calculated by multiplying the XYZ values, normalized by Y, by $\boldsymbol{M_{BFD}}$. R_{wr}, G_{wr}, and B_{wr}, and R_{ws}, G_{ws}, and B_{ws} are the Bradford cone responses for the reference white and scene adopted white, respectively. The degree of adaptation is set according to the estimated illumination level of the original scene, as suggested in the CIECAM97s specifications.

We now have what are understood to be corresponding colors under D50 for the image white point, XYZ_{wiD50}, and the adapted scene white point, XYZ_{wsD50}. The color balance adjustment is performed by a linear Bradford transformation from XYZ_{wiD50} to XYZ_{wiD50}, with D set to 1.0. The 3-by-3 adjustment matrix Λ is thereby

$$\Lambda = M_{BFD}^{-1} \cdot \begin{bmatrix} d_1' & 0 & 0 \\ 0 & d_2' & 0 \\ 0 & 0 & d_3' \end{bmatrix} \cdot M_{BFD} \quad (6)$$

$$d_1' = \frac{R_{wsD50}}{R_{wiD50}} \quad (7)$$

$$d_2' = \frac{G_{wsD50}}{G_{wiD50}} \quad (8)$$

$$d_3' = \frac{B_{wsD50}}{B_{wiD50}} \quad (9)$$

To perform the transformation on the actual image data, the image RGB values, not to be confused with Bradford cone responses, are linearized using the input profile tone reproduction curves, and then the RGB triplet vectors of each image pixel are multiplied by a combined matrix, calculated as the product of the input device profile matrix, color balance adjustment matrix Λ, and the inverse of the input profile matrix. Finally, inversed tone reproduction curves are applied, and the original image data are replaced by the calculated RGB values. As mentioned in the introduction, the transformation could also easily be implemented as a new modified input profile or as an abstract profile that performs a transform from PCS to PCS. In this case, the image data would not be modified, and the new profile could also be used for other pictures possibly taken in the same conditions as the picture for which the transform was calculated.

Discussion

In addition to the adapting field luminance, L_A, which is taken to be 20% of the luminance of the scene white in the estimated lighting conditions, the factor F is used in calculating the degree of adaptation. For real scenes, average surrounds can usually be assumed. The value of 1.0 for F is suggested in this situation. Although no comprehensive visual testing has been performed yet, the results produced with these settings seem to give the right color balance for pictures of scenes with artificial illumination from a single source. For instance, images of scenes lit quite dimly by typical light bulbs have about the right amount of warmth to them. In the case of late evening outdoor scenes, with the sun low in a clear sky, the adjusted pictures, although warmer in appearance than the images where illumination-induced color changes have been completely cancelled, are usually not quite warm enough compared to the original scene.

The maximum RGB method uses the brightest areas in the image to estimate the white point. Thereby, in a situation in which the scene is not evenly illuminated by a single source but one source is clearly brighter than the others, the white point estimate is for the areas that receive the brightest illumination. This seems a sensible approach, since a person observing the scene is likely to be adapted mostly to the brightest illumination. Still, differently illuminated areas probably decrease the degree of adaptation to the main illumination. Scenes illuminated by a setting sun have been used as an example of this: although the yellowish sunlight is the main light source, the shadows are illuminated only by the diffuse blue light from the sky. In the approach adapted here, this would call for a lower degree of adaptation to the direct daylight. This could be achieved by finding a proper way to set F based on the differences between the total global spectral irradiance and the diffuse skylight, as given by equation (1). Also, the user could manually adjust the degree of adaptation to achieve an illumination-based artistic effect to her liking. Following the creative tool approach further, any desirable illumination conditions could be specified, regardless of the actual conditions, to produce flattering skin colors, for instance.

The accuracy of the white point estimate clearly has a significant effect on the adjustment results, even to the point where a slight intentional deviation in color balance becomes meaningless in the face of greater uncertainty of the original image white point. The widely used maximum RGB algorithm of white point estimation was chosen here for its simplicity of implementation. The algorithm's aforementioned property of giving an estimate based on the brightest surfaces was also seen as desirable in our approach when dealing with multi-illuminant scenes. The maximum RGB algorithm is based on the assumption that the scene contains surfaces that reflect all incident light in the wavelength intervals to which the red, green, and blue camera sensors are sensitive. The algorithm performance is therefore expected to be unsatisfactory for images containing nothing but a single or a few chromatic objects; in the case of a close-up of a green leaf the white point estimate would be biased towards green, for instance. Although images with very limited color content are problematic for the other white point estimation or color constancy algorithms too, other methods, such as those discussed in [8] and [9], or perhaps results of several methods used combined[10], could in some cases provide improved results. A system such as described in this paper could also benefit from the use of spatial analysis and processing; possibilities include identification of shadow areas and other illumination variations within an image.

The fact that the illumination estimate for outdoor conditions is calculated as the spectral power distribution of the visible light that reaches the ground at given location implies an imaging model in which the light reaching the camera is given by the spectral product of the incident light and a surface reflectance function. Effects such as aerial perspective or strong inter-reflections within a scene cannot therefore properly be handled within the system described. Other cases for which the use of the system is limited include pictures that show light sources: a setting sun, very likely to be the brightest point in an image, would differ in color from a white patch at the photographer's feet, which would reflect diffuse skylight also. Apart from these special cases, pictures taken in daylight can be satisfactorily adjusted.

To facilitate fully automatic processing, the sun angles and local weather conditions need to be known. As mentioned earlier, the former can be calculated when the date, time, and geographical location, presumably stored within the image file, are known. As for the weather conditions, a network application could query this information from a suitable weather database system. In the case of "clear sky" or "overcast skies", this seems a feasible option, but if the local weather happened to be very unstable at the time the picture was taken it could be difficult to assign proper values for parameters such as cloud coverage.

It should be noted that although the white point mapping used here is a straightforward application of the chromatic adaptation transform of the CIECAM97s, no exact appearance matches are claimed; those would require the use of a complete color appearance model and better knowledge of the source conditions. Also, in photography, digital or traditional, exact appearance match between the photographed scene and the picture is rarely desired. Still, being able to communicate the atmosphere of the original scene in the picture is often considered important. Color balance adjustment, even approximate, according to the illumination conditions can play a big role in recreating that atmosphere.

Conclusion

Apparent illumination conditions can be controlled in a digital image by means of the algorithm developed. The algorithm can be used for image restoration in cases the original illumination conditions are known but for some reason not reproduced in the image. It can as well be used for enhancement by creating a desired but non-true illumination appearance.

References

1. Paul M. Hubel, The Perception of Color at Dawn and Dusk, *The Proceedings of the IS&T/SID Seventh Color Imaging Conference*, p. 48–51 (1999).
2. See the web page at www.media.hut.fi/henkilokunta/?language=en& staffPage=36
3. Jack Holm, Integrating New Color Image Processing Techniques With Color Management, *The Proceedings of the IS&T/SID Seventh Color Imaging Conference*, p. 80–86 (1999).
4. Helsinki University of Technology, Laboratory of Media Technology. Method and apparatus for adding Illumination information into a digital image. Finnish patent 960044, 1998.
5. CIE Publication Number 85. *Solar spectral irradiance*, Wien 1989. 48 p.
6. M. R. Luo, R. W. G. Hunt, The Structure of the CIE 1997 Colour Appearance Model (CIECAM97s), *Color Research and Application*, **23**, 3, p. 138–146 (1998).
7. Mary Nielsen, Michael Stokes, The Creation of the sRGB ICC Profile, *The Proceedings of the IS&T/SID Sixth Color Imaging Conference*, p. 253–257 (1998).
8. Vlad C. Cardei, Brian Funt, Kobus Barnard, White Point Estimation for Uncalibrated Images, *The Proceedings of the IS&T/SID Seventh Color Imaging Conference*, p. 97–100 (1999).
9. Graham D. Finlayson, Steven Hordley, Paul M. Hubel, Unifying Colour Constancy, *The Proceedings of the IS&T/SID Seventh Color Imaging Conference*, p. 120–126 (1999).
10. Vlad C. Cardei, Brian Funt, Committee-Based Color Constancy, *The Proceedings of the IS&T/SID Seventh Color Imaging Conference*, p. 48–51 (1999).

Biography

Janne Laine received his Master of Science degree in Engineering from the Helsinki University of Technology in 2000. His recently completed Master's thesis examines the use of source information in automated image processing; he currently continues research on automated tools for digital image processing in the Laboratory of Media Technology, at the Helsinki University of Technology.

Hannu Saarelma has been a full Professor of Media Technology at the Helsinki University of Technology since 1982. He received his Master of Science in Engineering in 1973 and Doctorate of Science in 1979 at the same university. Previously, he worked as senior research officer at Academy of Finland and visiting scientist at the Massachusetts Institute of Technology. He is author or co-author of about 200 technical or scientific publications on imaging and media technology.