Camera Color Accuracy Evaluated via Metamer Mismatch Moments

Emitis Roshan, Brian Funt*, Hamidreza Mirzaei

Simon Fraser University, Vancouver, CANADA

**funt@sfu.ca*

ABSTRACT

A novel method for evaluating the colorimetric accuracy of digital color cameras is proposed based on a new measure of the metamer mismatch body (MMB) induced by the change from the camera as an observer to the human standard observer. Previous methods of evaluating the colorimetric accuracy of a camera are the Luther condition [1], the mean CIE ΔE over a set of Munsell papers [2], and the cube root of the normalized volume of the MMB relative to that of the convex hull of the spectral curve [3]. The latter method addresses problems of the previous two methods but, nonetheless, suffers from some instability in cases in which the MMB's shape is very narrow. The method introduced here extends and improves upon the normalized-volume-of-the-MMB method by replacing the normalized volume with a normalized shape measure.

KEYWORDS: color camera accuracy, metamer mismatching, camera sensor design

INTRODUCTION

Digital color cameras record colors that are pleasing but not necessarily accurate in the sense that their sRGB outputs cannot be converted to precise CIE XYZ coordinates. Although the sRGB standard [4] defines a conversion from sRGB to XYZ, most cameras do not actually meet the standard and so applying the conversion transformation will lead to XYZ that are only approximately correct. There are many trade-offs involved in digital color camera design in terms of image noise, cost and physical limitations that mean that perfect color accuracy may need to be sacrificed. This is especially the case since the usual goal in camera design is to get good-looking pictures, not to build an imaging colorimeter. Nonetheless, since digital cameras are often used to 'measure' color, in areas such as dentistry [5] and dermatology [6] there is a definite need to be able to quantify the degree of color accuracy/inaccuracy that a given camera possesses.

BACKGROUND

If the Luther condition [1] (i.e., that the camera sensor sensitivities be within a linear transform of CIE-1931 2-degree-observer color matching functions) is met then colorimetric accuracy is guaranteed. The problem with this condition is that it is all-or-none test in the sense that if it is not met then it does not specify how inaccurate the camera's color may be. One possibility is to measure the RMS error in the best linear fit (possibly a weighted linear fit to account for the low sensitivity of the cones at the ends of the visible spectrum) of the camera sensitivities to the cone sensitivities, but any error other than zero lacks a perceptual interpretation.

As another alternative, Jiang et al. [2] calculate the mean color difference between the actual XYZs of the 1269 reflectances of the Munsell Book [7] illuminated by D65 and those that are predicted based on the camera's spectral sensitivity functions. The camera predictions are based on computing the camera RGB values and then mapping them via a best linear fit to the true XYZ values. The problem with using the mean ΔE is that it is based on a small—necessarily finite, and not necessarily representative—set of sample papers. For 28 different camera models, Jiang et al. [2] also report how closely the cameras approximate the Luther condition by measuring the

RMS error in the best linear fit of the camera sensitivities to the CIE-1931 2-degree-observer color matching functions.

The method proposed here is very different from either of those two methods in that it is based on evaluating the degree of metamer mismatching. In the context of a change of ‘observer’ from a camera to the eye, metamer mismatching refers to the fact that two lights differing in their spectral power distributions (SPD) may match in ‘color’ (i.e., lead to equal RGB for the camera or equal LMS cone response) for one of them and simultaneously not match for the other. If we consider a given RGB and the set of all possible light SPDs for which the camera records the identical RGB then there will be corresponding set of distinct LMS triples generated by those SPDs. This set is convex [8] and referred to as the metamer mismatch volume (MMV) [8] or the metamer mismatch body (MMB) [9]. We will use the MMB terminology to avoid the confusion of referring to a volume’s volume.

The intuition behind using MMBs to evaluate color accuracy is that if a human observer sees a pair of lights as matching then the camera should too, and vice-versa. The volume of the MMB is a measure of the degree to which matches by the observer and camera differ. From the fact that they differ it follows that there does not exist a one-to-one mapping between camera RGB and LMS.

Previous methods for evaluating MMBs in the context of cameras [3] or light sources [10] have been based on normalizing the volume of the MMB’s by the volume of the convex hull of the spectral curve for the second observer (see Eq. 8 of [11] for a formal definition). The normalization makes the measure invariant to any linear transformation of the sensitivity functions. Hull and Funt [3] introduced the Camera Sensor Metamer Mismatch Index (CSMMI) based on the cube root of the normalized volume and used it to evaluate the 28 cameras measured by Jiang et al. [2]. Overall the method was shown to work well, however, the normalized-volume method can become somewhat unstable for cases in which the MMB is very thin or elongated. In a case such as that shown in Figure 1, the MMB is wide in 2 directions but narrow in the third. This narrowness means that the volume is small even though the degree of metamer mismatching can be large. To overcome this problem, we propose, instead, to use a measure of the MMB that considers its shape rather than its volume.

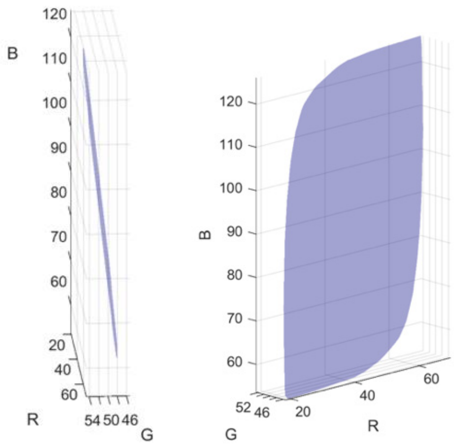

Figure 1: Two views of the very thin metamer mismatch body (MMB) found for the Point Grey Grasshopper2 camera

DETAILS

The normalized-volume method is attractive in that is based on a theoretical measure that considers all possible metameric pairs and not a finite sample. To keep the benefits of the MMB approach while overcoming the problems created by thin MMBs, we propose that the MMB be evaluated in terms of aspects of its shape rather than its volume. In particular, we use the flat grey (uniform 50% spectral reflectance) illuminated by D65 and calculate the MBB that results for a change from camera sensitivities to cone sensitivities, and then characterize this MBB in terms of the radii of its equivalent ellipsoid rather than its volume. Zhang et al. [9] have shown that the MMB of flat grey typifies the MMBs of other colors and so using only this one case is sufficient for our purposes.

To calculate the MMB's equivalent ellipsoid it is treated as a mass of uniform unit density. For any such mass, there exists an equivalent ellipsoid having the same moments of inertia (i.e., characteristics when it is spun) about its principle axes. An ellipsoid is uniquely characterized by its three principal radii and so they concisely characterize the dominant aspects of the shape of the MMB. A linear transformation of the sensor functions, however, will change the principal axes, moments of inertia and radii of the corresponding equivalent ellipsoid. To obtain radii that are independent of linear transformations of the sensor space, the MMB is normalized relative to the 2-transition object color solid (OCS) [12]. Specifically, the principal moments of the OCS are used to determine the unique linear transformation, T, that transforms the OCS so that its equivalent ellipsoid becomes the unit sphere. The same transformation, T, is then applied to the MMB after which the principal radii of the equivalent ellipsoid of the transformed MMB are computed. The Camera Metamer Mismatch Radii Index (CMMRI) of the colorimetric accuracy of a given camera's spectral sensitivity functions is then defined as the mean of these three principal radii.

The CMMRIs for 28 cameras [2] are plotted in Figure 2.

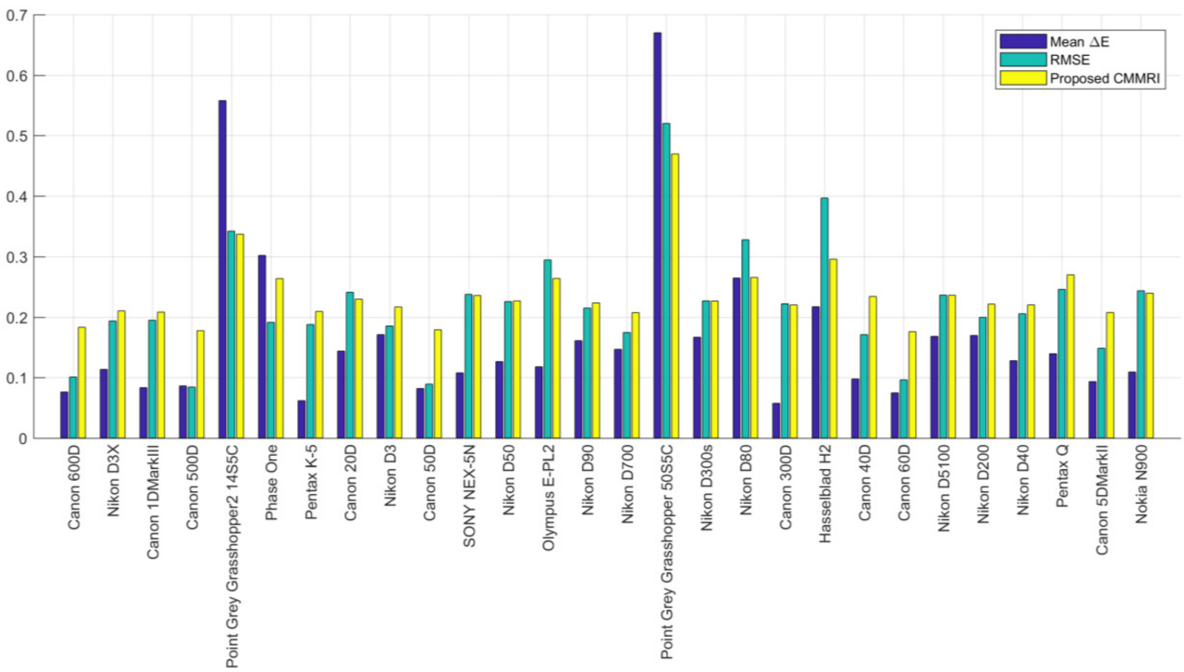

Figure 2: Plot of the three camera color accuracy measures CMMRI, RMSE (data from [2]), and mean ΔE (data from [2]). For clarity of the comparison, the ΔE and RMSE data are each scaled separately to match the CMMRI as closely as possible in terms of RMSE)

CONCLUSION

The degree of metamer mismatching resulting from a change from color camera sensors to the human cones is used here to evaluate camera color fidelity. The amount of metamer mismatching is evaluated in terms of the mean of the principal radii of the metamer mismatch body, normalized relative to the object color solid. The radii describe the overall shape of the MMB and are more representative than the volume in some cases. Crucially, the normalization makes the method independent of any linear transformation of the sensor space. A key advantage of the proposed method over that of Jiang et al. [2] is that it does not require selecting a finite, and necessarily incomplete, set of test reflectances.

ACKNOWLEDGEMENTS

Funding was provided by the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

[1] Luther, R. 1927. *Aus dem Gebiet der Farbreizmetrik (On color stimulus metrics)*, Zeitschrift Tech. Phys 8 540-558.
[2] Jiang, J., Liu, D., Gu, J. and S. Süsstrunk 2013. *What is the space of spectral sensitivity functions for digital color cameras,* In Applications of Computer Vision (WACV), IEEE 168-179.
[3] Hull, B. and B. Funt 2015. *Comparing Color Camera Sensors Using Metamer Mismatch Indices*, AIC
[4] Anderson, M., Motta, R., Chandrasekar, S. and M. Stokes 1996. *Proposal for a standard default color space for the internet—sRGB,* Color Imaging Conference, Society for Imaging Science and Technology, 238-245.
[5] Wee, A.G., Lindsey, D.T., Kuo, S. and W.M. Johnston 2007. *Color accuracy of commercial digital cameras for use in dentistry,* Journal of Prosthetic Dentistry 97(3) 178.
[6] Kunde, L., McMeniman, E. and M. Parker, 2013. *Clinical photography in dermatology: Ethical and medico-legal considerations in the age of digital and smartphone technology,* Australasian Journal of Dermatology 54(3) 192-197.
[7] Parkkinen, J.P., Hallikainen, J. and T. Jaaskelainen, 1989. *Characteristic spectra of Munsell colors*, JOSA A 6(2) 318-322.
[8] Logvinenko, A.D., Funt, B. and C. Godau 2014. *Metamer mismatching*, IEEE Transactions on Image Processing 23(1) 34-43.
[9] Zhang, X., Funt, B. and H. Mirzaei 2016. *Metamer Mismatching in Practice versus Theory*, Journal of the Optical Society of America A 33(3) 238-247.
[10] Funt, B., Hull, B. and X. Zhang 2016. *Evaluation of the IES Method for Evaluating Light Source Color Rendition in terms of Metamer Mismatching,* Color and Imaging Conference, Society for Imaging Science and Technology, Twenty Fourth IS&T Color Imaging 2016(1) 192-197.
[11] Logvinenko, A.D. 2014. *Color variations arising from observer-induced metamer mismatching,* Unpublished manuscript, Available at https://www.researchgate.net/publication/262122838
[12] Logvinenko, A. D. 2009. *An object-color space*, Journal of Vision, 9(11):5, 1–23, http://journalofvision.org/9/11/5/, doi:10.1167/9.11.5
[13] Williamson, B. 1888. *An Elementary Treatise on the Integral Calculus: Containing Applications to Plane Curves and Surfaces, with Numerous Examples,* 266-283.

CONTACT

Brian Funt,
School of Computing Science,
Simon Fraser University,
Vancouver, B.C., Canada, V5A 1S6