The Challenge for Vision of Fluctuating Real-World Illumination

David H. Foster, University of Manchester, UK

In an article published in 2001, Larry Arend drew attention to the environmental challenges for vision, including variations in the appearance of surfaces with time of day and weather [1]. The aim of the present analysis is to show that changes in illumination over short time intervals raise a further problem.

In a cloudless sky, the primary source of variation is solar elevation. But unobservable cirrus clouds and aerosols can be highly inhomogeneous and lead to more variation in the solar beam. Temporal fluctuations in spectrally integrated irradiance over intervals of a minute are of the order of 0.1% around midday and more around sunrise and sunset. The variation over intervals of an hour is an order of magnitude greater and, within any individual spectral band, greater still (data from A. R. D. Smedley and A. R. Webb, University of Manchester).

Fig. 1. Color renditions of radiance images acquired at 14:11 and 15:18 h. Data from [2].

The consequences of this variation are detectable with the scene shown in Fig. 1. The two color images are rendered from spectral radiance images acquired about 1 hour apart with a hyperspectral camera [2]. There are no large-scale changes in direct and indirect illumination. The corresponding correlated color temperatures of the illumination at the sphere were 5868 K and 5745 K. The visual identifiability of the surfaces across the images was quantified [3] with Shannon's mutual information [4] based on triplets of photoreceptor values (l, m, s) drawn pointwise from the scene. The effects of two kinds of illumination changes were considered.

First, under a simulated global spectral change in illuminant [5] from a daylight of 5868 K to 5745 K, the estimated mutual information between the two images was ~36.2 bits, which, if the distribution of the triplets (l, m, s) were Gaussian, would correspond to a signal-to-noise ratio (SNR) of $\sim 4.2 \times 10^3$ per triplet variable. This value is unrealistically high, since the simulated illuminant change is noise free.

Second, under the actual change in illumination, the estimated mutual information between the two images was ~7.3 bits, corresponding to a Gaussian SNR of ~5.3 per triplet variable. This reduced estimate may be inflated since the radiance images were each derived as averages over three acquisitions, and the analysis excludes photon and camera noise and observer uncertainty [5].

The difference in mutual information implies that inferences about the real world are strongly constrained by illumination fluctuations, adding to the environmental challenges described by Arend.

[1] L. Arend, in *Human Vision and Electronic Imaging VI*, Bellingham WA, 2001, 392-399.

[2] D. H. Foster, K. Amano, and S. M. C. Nascimento, *Vision Res.*, 120, 45-60, 2016.

[3] I. Marín-Franch and D. H. Foster, *IEEE Trans. Pattern Anal. Mach. Intell.*, 35, 78-91, Jan 2013.

[4] T. M. Cover and J. A. Thomas, *Elements of Information Theory*, 2nd ed. Hoboken, New Jersey: John Wiley & Sons, Inc., 2006.

[5] D. H. Foster, *J. Opt. Soc. Am. A*, 35, B192-B201, 2018.