Repeatability and reproducibility of a hyperspectral camera as a means of measuring color

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Abstract

Hyperspectral cameras, which allow measuring the complete spectrum for each pixel of an image, have appeared on the market in recent years. Their main components are a digital camera, a spectrograph and an objective lens. An additional moving system allows scanning mechanically the complete scene, although sometimes the scan is performed optically. Using such systems, the scene is sampled spectrally but also spatially, creating a 3D cube of data (x, y, λ). In this work we analyze the repeatability and reproducibility of a hyperspectral system (16-bit camera: AVT Pike F-210B; Spectrograph: ImSpector V10E; Lens: Cinegon 1.8/16) as a means of measuring color. We followed the guidelines specified in the ASTM E2214-08, where the latest multidimensional procedures for characterizing the performance of color-measuring instruments have been established.

To analyze repeatability we performed measurements on a calibrated white plate (BN-R98-SQ10C) and used univariate and multivariate metrics. 50 consecutive readings were taken to account for short-term repeatability, 50 in two consecutive days for medium-term, and 50 along 5 weeks for long-term. To account for reproducibility we used two different sets of samples: 12 glossy ceramic tiles (BCRA CCS-II) and 24 matte patches (CCRC). The multivariate Hotelling and inter-comparison tests were used to compare the readings with those obtained by a conventional tele-spectracolorimeter (PR-655). The reflectance factors from 400 to 700 nm ($\Delta\lambda$=10 nm), a bidirectional geometry of 0/45, illuminant D65 and CIE 10º observer were used to compute the color data.

The results confirmed the good performance of the hyperspectral system in terms of repeatability. For instance, parameter $\Delta R_{560,2\sigma}$, which represents twice the standard deviation of the reflectance at 560 nm was of 0.001 (short), 0.01 (medium) and 0.02 (long). In terms of RMSE, results were 0.14% (short), 0.66% (medium) and 1.87% (long). Using CIEDE2000 color differences the values were 0.03 (short), 0.13 (medium) and 0.40 (long). In the case of reproducibility, the two tests applied reported statistical significant differences between the hyperspectral system and the tele-spectracolorimeter ($p<0.001$). However, it must be mentioned that the statistical tolerance using the methodology proposed by the ASTM E2214-08 is strict as already reported by other authors. The majority of the samples showed RMSE below 10% and CIEDE2000 differences below 2, which is acceptable. The results were better for the CCRC patches than the BCRA tiles. This might be explained by the gloss of the last set of samples and the bidirectional geometry used (0/45), which could contribute to a higher variability among the results. Darker patches as well as those with a high reflectance factor in the green-yellow region, where the observer has its maximum sensitivity, were also associated with worse results.

In conclusion, it could be established that the hyperspectral system provided very good results in terms of repeatability and acceptable data in terms of reproducibility. Therefore, these systems are reliable and could be used in the industry providing advantages in the field of colorimetry, mainly in the characterization of non-uniform materials.