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Case-Study Analysis of Apparent Camouflage-Pattern Color Using Segment-Weighted Spectra

S. Ramsey,[1] T. Mayo,[1] C. Howells,[2] A. Shabaev,[3] S. G. Lambrakos[4]
[1]Signature Technology Office, [2]U.S. Army Reserve (ONR Science and Technology 101Unit),
[3]Leidos, [4]Materials Science and Technology Division, Naval Research Laboratory, Washington, DC

ABSTRACT

Advanced camouflage patterns, consisting of highly detailed camouflage patterning, require additional methodologies for color evaluation, which is with respect to realistic field conditions. A quantitative metric for evaluation of comouflage patterns, as viewed under realistic field conditions, is "apparent color," which is the combination of *all* visible wavelengths (380-700 nm) of light reflected from large camouflage-pattern samples ($\geq 1m^2$) for a given standoff distance (25-100 ft). Camouflage patterns lose resolution with increasing standoff distance, and eventually all colors within the pattern combine and thus appear monotone (the "apparent color" of the camouflage pattern). This paper presents a case-study analysis of apparent camouflage-pattern color using segment-weighted reflectance spectra for the purpose of evaluating apparent color of advanced camouflage patterns with respect to realistic field conditions. Simulation of apparent camouflage-pattern color using this methodology is based on decomposition of camouflage-pattern reflectance with respect to component segments of camouflage patterns.

Keywords: Camouflage patterns, apparent color, reflectance spectra

1. INTRODUCTION

The concept of apparent color within the visible range is examined with respect to its potential for practical utilization in the field and as a criterion for more realistic assessments of camouflaged-fabric viability, which should be with respect to realistic distances from observers, as well as realistic illumination conditions, as would occur during actual operations. The examination considers apparent-color spectra for characterization of camouflaged fabric as would be viewed as a function of distance from an observer, which would be a function of camouflage patterns, dielectric response properties of dye formulation and base fabrics, ambient atmospheres (e.g., fog or desert) and spectral ranges of external sources for camouflaged-fabric illumination (e.g., moonlight or dense overcast). Assessment of apparent color for camouflaged-fabrics based on realistic conditions represents a more quantitative criterion for their operational viability, which is in contrast to essentially qualitative assessments based on visual inspection at unrealistic distances from observers. Quantitative assessment of camouflaged-fabric viability according to apparent color could establish a foundation for more cost saving evaluation procedures, as well as procedures for reevaluating camouflaged-fabric stockpiles resulting from failures to meet previously established criteria. Presented here is a case-study analyses of apparent color for a specific camouflaged fabrics, which is for proof of concept. The quantitative assessment of apparent color represents a metric for predicting target acquisition in the field (see [1]). Camouflaged fabric as viewed under practical field conditions, due to the many different types of external factors, should appear significantly different in contrast to close visual inspection. The inherent complexity of external factors influencing apparent color suggests that assessment of camouflaged fabrics be in terms of their far-field and statistical characteristics, which are consistent with practical field conditions.

A parametric model provides for simulation of apparent camouflage-pattern spectrum characteristics as a function of different types of input information. This model can be constructed according to general characteristics of diffuse reflectance (Refs. 2-9) from a camouflage pattern having a specific set of pattern components, where each pattern

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component is associated with a reflectance spectrum. The condition of diffuse reflectance, which is associated with incoherent scattering of electromagnetic wave from a surface, implies that the total reflectance is the sum of intensities, i.e., component reflectances, rather than the sum of scattered wave amplitudes.

2. CASE STUDY SPECTRAL ANALYSIS

Presented in this section are spectral analyses of camouflage fabrics relevant to both measurement and modeling of apparent color for camouflage pattern and dielectric response characteristics of camouflage fabrics. These analyses entail bench-top spectrometry of the Sample Woodland AOR2 (Sample) combat fabric (made by Milliken) (see Fig. 1). The two spectrometers used were the Perkin Elmer Lambda 1050 (L1050) and the ASD Lab Spec 4 hi-Res (ASD). The L1050 was performed at 5-nm increments from 250-2500 nm, and the ASD was performed at 1-nm increments from 350-2500 nm. The ASD was fitted with a 1-deg foreoptic, which provided a FOV of 17.45 millirad or 8.01 cm^2 circular spot size on a 20 x 20 in^2 fabric.

Shown in Figs. 2 are spectra of the individual AOR2 colors, for fabric type Sample, measured at close distance between target and detector by the L1050 and ASD spectrometers for wavelengths in the range 350-2500 nm. Also shown in this figure is the spectrum correlated with the apparent color of all four AOR2 colors blended at a distance of 6 ft from the ASD detector source. Referring to Fig. 2, one notes good agreement of spectral measurements obtained using the different spectrometers. The spectrum designated "apparent color average," which is shown in Fig. 2, can be correlated with spectra that would be observed at far field, i.e., the apparent color spectrum that is the combination of *all* visible wavelengths (380-700 nm) of light reflected from large ($\geq 1m^2$) fabric-sample sizes for a given standoff distance (25-100 ft). Although the relative intensity of the apparent-color spectrum is expected to decrease with increased target distance, its shape would remain essentially the same, neglecting influences of ambient environments.

The spectra of individual AOR2 colors shown on Fig. 2 can provide, in principle, information for modeling apparent color, which considers the dependence of apparent color on such factors as diffuse reflectance, decreased quality of camouflage pattern, and influence of background environment on observed spectral features. For example, using the pattern segmentation of Fig. 1 and measured spectra of individual AOR2 colors shown in Figs. 2, one may estimate the apparent-color spectrum using

$$R_{app}(\lambda) = P_{ilm}(\lambda) \cdot D_{sen}(\lambda) \cdot \frac{C_a(\lambda)}{z^2} \cdot \left[\sum_{j=1}^{N_j} w_j \cdot R_j(\lambda) \right] \cdot \exp[-\alpha_{ext}(\lambda) z] \qquad (1)$$

where P_{ilm} is the spectral power distribution of the illuminating source, D_{sen} is the spectral sensitivity of the detection system, $\alpha_{ext}(\lambda)$ is the extinction coefficient of the ambient environment between target and observation point, w_j is the relative coverage of camouflage-pattern segements of type *j*, N_j is the number of different types of patterns segments, R_j is the diffuse reflectance spectrum of pattern segements of type *j* that are measured at the fabric surface, and C_a is a scaling factor for calibration of measured apparent spectra. It follows that Eq.(1) can also be applied for modeling the influence of decreases in camouflage-pattern quality. For example, simulated blurred segmentation patterns could be calibrated according to observed camouflage-pattern degradation, and thus used for calculation of relative segmentation covering w_{color} associated with reduced camouflage-pattern quality.

Equation (1) provides a parametric model for decomposition of apparent color with respect to component contributions using three types of information. These are: (1) the diffuse reflectance spectra of materials (e.g., dyed fabrics) associated with the different types of pattern segments; (2) the relative coverage of the different segment types; and (3) scaling of component contributions to the apparent camouflage-pattern color by its measurement at a given distance *z* between pattern sample and spectrometer, i.e., determination of C_a defined by Eq. (4). The weight coefficients defined by Eq.(1) for relative coverage of different camouflage-pattern segments comprising the AOR2 camoflage pattern, which is shown in Fig. 1, are 0.038278 for Tan, 0.47754 for Olive, 0.36651 for Green, and 0.2075 for Black. Pattern-segmentation procedures for determining relative coverage of segments were developed using the image-processing software "imagej" (see Refs. 10-12).

Shown in Fig. 3(A) is the modeled apparent camouflage-pattern color that has been scaled using the measured estimate of apparent color at $z = 6$ ft, which is also shown. Shown in Fig. 3(B) is the modeled apparent camouflage-pattern color as a function of distance from pattern sample. Shown in Fig. 3(C) is the scaling factor C_a for calibration of measured apparent spectrum with respect to distance. This factor is not expected to be constant in general in that the weighting coefficients w_j are determined with respect to relative coverage of pattern segments for a camouflage sample of finite cross section. The factor C_a provides information, in terms of parametric model representation, concerning the dependence of total reflectance on pattern configuration. Shown in Fig. 4 are the modeled component-segment contributions to apparent camouflage-pattern color as a function of distance from sample. The spectra shown in Fig. 4 provide quantitative metrics for pattern characteristics as a function of distance. Referring to Fig. 4, a comparison of component spectra as a function of distance shows that at moderate distances of separation, e.g., above 12 ft, the average reflectance spectrum tends toward wavelengths associated visually with green.

Illumination conditions and detector response characteristics must also be considered for quantitative prediction of apparent color. Detector response characteristics determine the scaling of the power spectrum for target illumination. Referring to Eq.(1), the observed reflectance R_{app} is also a function of the power spectrum of the illuminating source P_{ilm}, and the spectral sensitivity of the detector D_{sen}. Accordingly a quantitiative analysis of apparent color should include scaling of the component spectra (e.g., Fig. 4), as a function of wavelength, by P_{ilm}, and D_{sen}. For example, in the case of color as seen visually, P_{ilm}, and D_{sen} may represent the power spectrum of daylight and the spectral sensitivity of the human eye, respectively (see [5]). Shown in Fig. 5 is the modeled apparent camouflage-pattern color (Fig. 3(A)) weighted by the daylight power spectrum and human-eye spectral sensitivity.

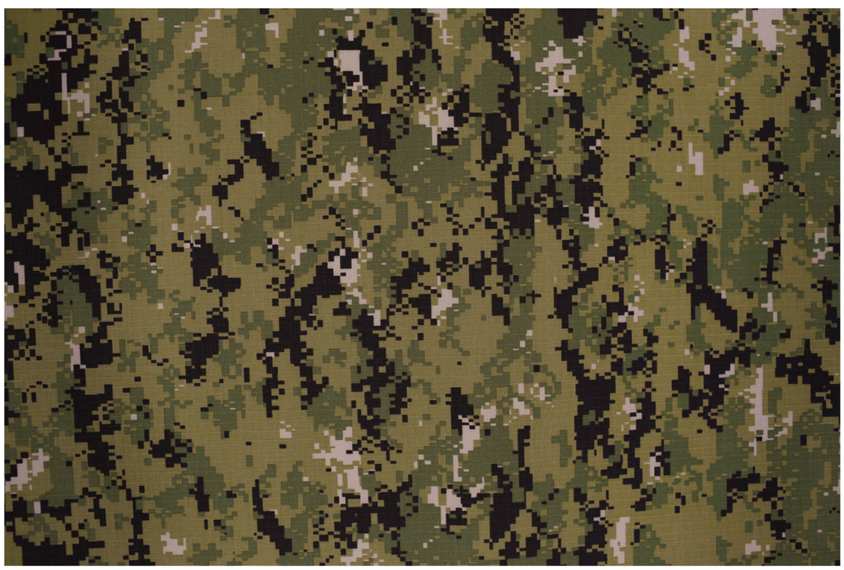


Figure 1. Image (3840 x 2560 pixels) of camouflage pattern AOR2 as viewed at small distances from observer.

4. CONCLUSION

This study describes a parametric model for simulating apparent camouflage-pattern reflectance, which is demonstrated by consideration of the apparent color characteristics of the AOR2 camouflage pattern on fabric. This parametric model combines spectrometer measurements and general image processing algorithms for the purpose of decomposing apparent reflectance spectra with respect to component pattern segment contributions. The concept of apparent color can provide better assessment of camouflaged-fabric characteristics for a given set of field conditions using parametric models and spectral measurements. Further investigation is needed to determine optimal and convenient procedures based on apparent color for the improvement of camouflage fabric inspection, which should result in substantial cost savings.

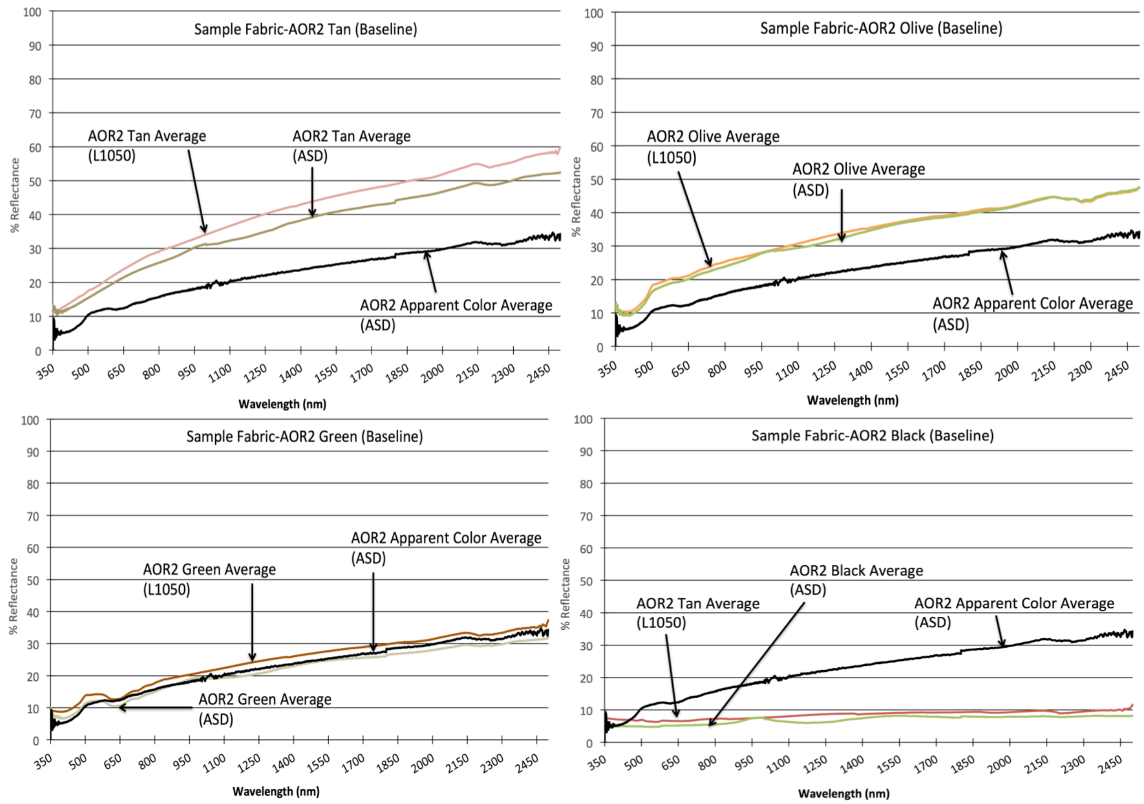
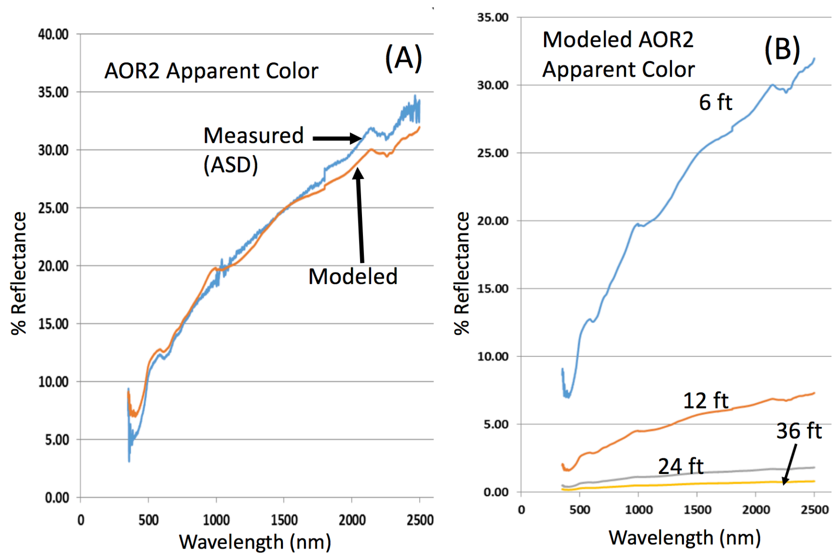


Figure 2. Spectra associated with different colors comprising Sample Woodland AOR2 (Sample) camouflage pattern, which are measured at close distance using laboratory and hand-held spectrometers, L1050 and ASD, respectively, and at 6 ft using ASD.



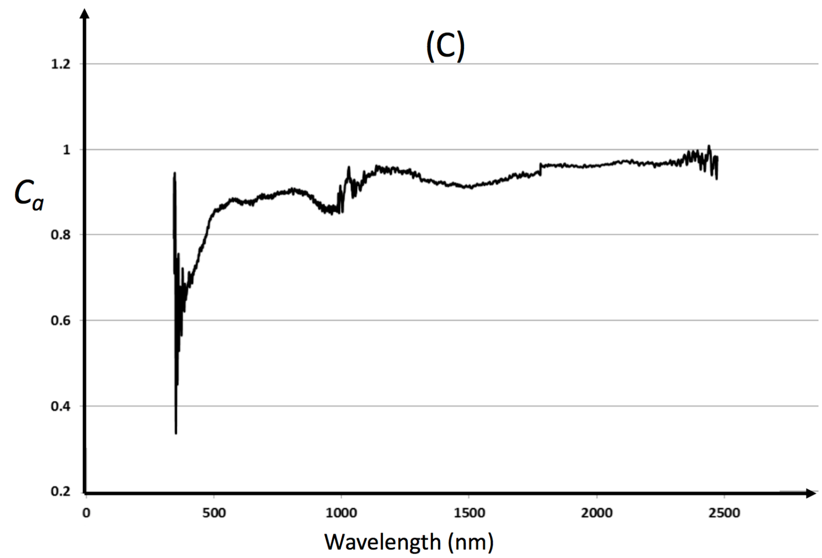
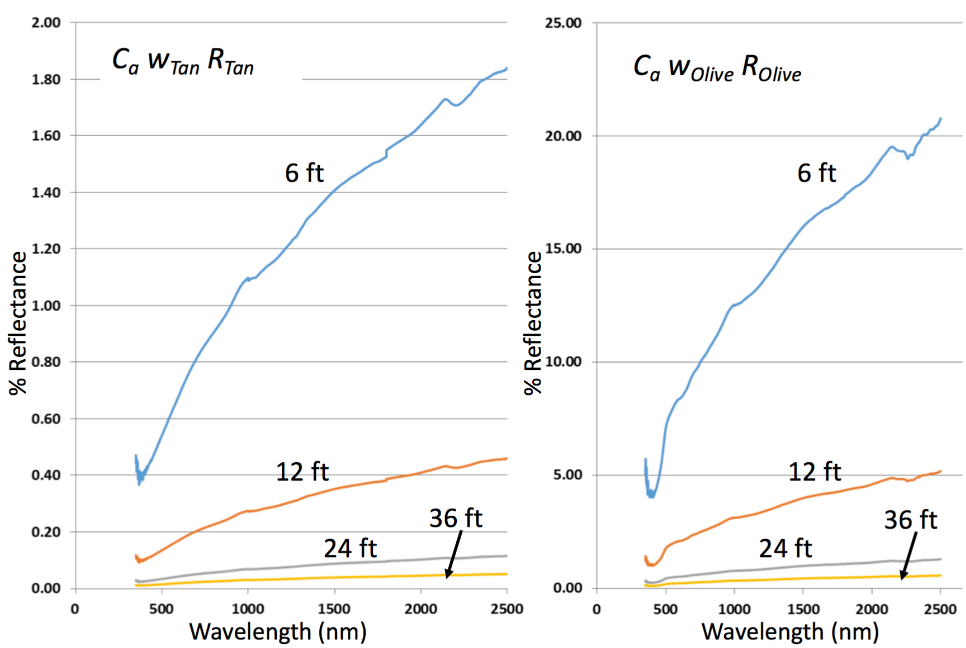


Figure 3. (A) Modeled apparent color that is scaled using measured reflectance; (B) modeled apparent color as function of distance from sample; and (C) scaling factor C_a defined by Eq. (1).



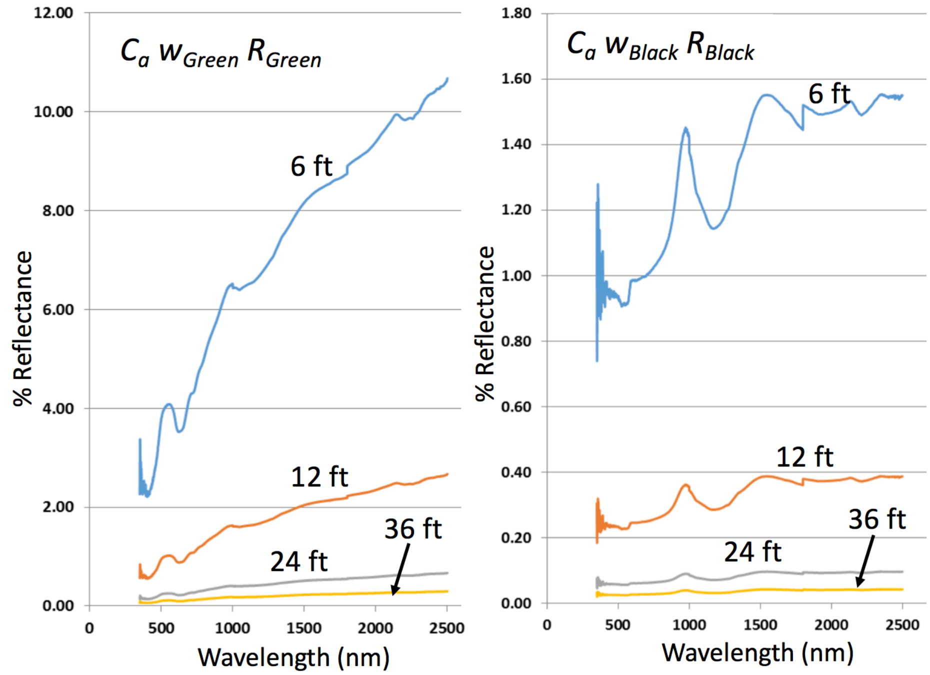
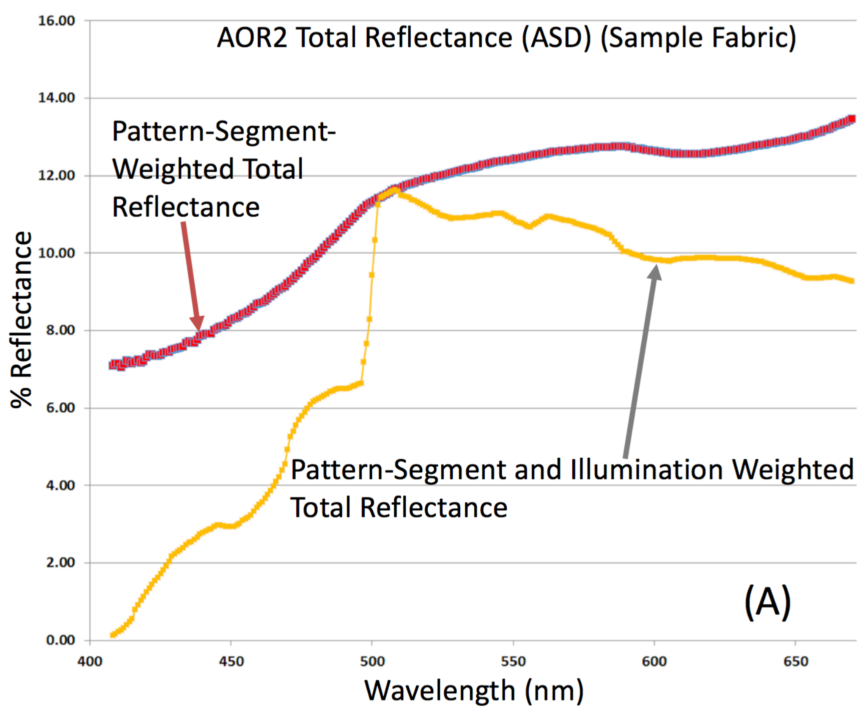


Figure 4. Component-segment contributions to apparent color as function of distance.



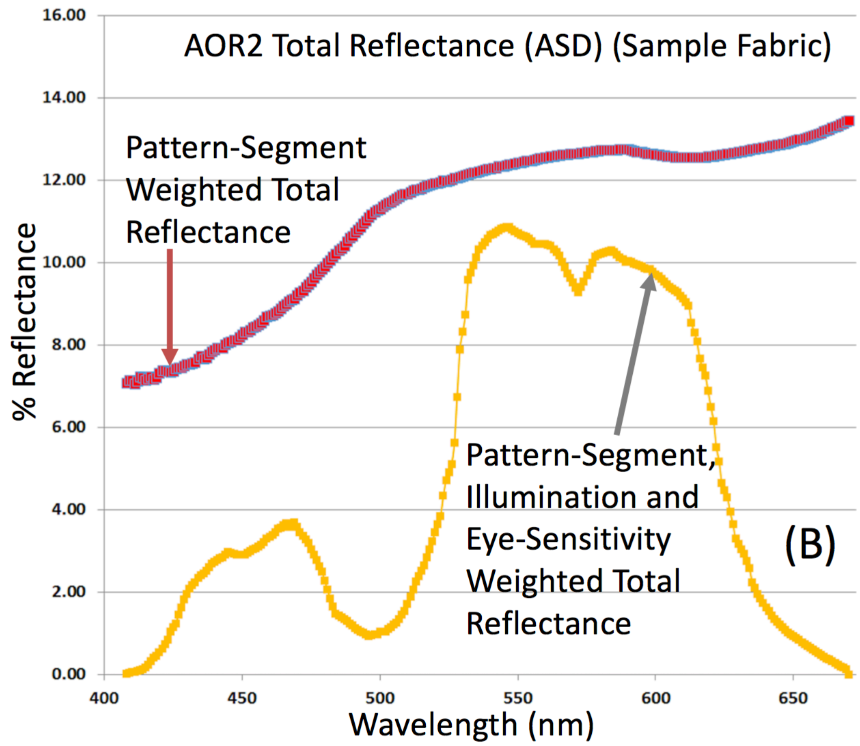


Figure 5. Modeled apparent color weighted by (A) daylight power spectrum and (B) daylight power spectrum and human-eye sensitivity.

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