N94-16677

A FIELD MEASURE OF THE "SHADE" FRACTION

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"Shade" has a technical definition peculiar to linear spectral mixture analysis of imaging spectrometer data: it is the reduction in radiance from a surface due to lighting conditions and geometry, and includes topographic shading described by photometric functions as well as shadowing at all scales. "Shade" is an important constituent of nearly all remotely sensed images, and is one endmember resolved in spectral mixture analysis, where it is represented as a fraction of the measured radiance and a characteristic spectrum. This spectrum is typically the null vector, provided the data have been corrected for atmospheric and instrument effects: i.e., "shade" is the radiance from an ideal black surface.

In topographic shading, irradiance is reduced -- typically in proportion to cos(i), where i (incidence angle) is the angle between the sun and the local surface normal vectors. Therefore, the radiance is lowered by a multiplicative factor. Shadowing occurs when $i>90°$, or when sunlight is blocked by adjacent high terrain; the only irradiance is down-welling skylight and bounce light from adjacent terrain. In spectral mixture analysis, "shade" is regarded as an additive term. In this regard, it is an accurate description of the proportion of a scene that consists of ideal shadows ("checkerboard mixing"); however, "shade" represents the multiplicative cos(i) factor as well, and here it should be interpreted as the proportion of shadow that would darken the scene an equivalent amount. In either case, the "shade" fraction is lessened by adjacency effects, because the scene has a non-zero reflectivity instead of the ideal black surface generally assumed.

In spectral mixture analysis, field and laboratory reflectance spectra are utilized to represent endmembers other than "shade." Laboratory measurements are typically made at $i \approx 0°$, such that darkening due to shade is minimal. However, field measurements are typically made at greater incidence angles, and are affected by both shading and shadows at a "subpixel" scale, due to roughness of the measured surface. This darkening leads to an underestimation of the scene reflectivity, and this underestimation is related to the "shade" fraction, F_s, sought in spectral mixture analysis. Therefore it appears that field radiance data can be interpreted to yield a reflectance spectrum less affected by "shade," in greater agreement with laboratory measurements, and also to yield F_s, which is a measure of scene roughness at the scale of measurement.

Field spectra are commonly acquired by measuring the radiance from a small (10^1 - 10^3 cm^2) area of natural surface, and comparing this to the radiance from a flat smooth standard, such as halon, of known reflectance and at the same viewing geometry. For the target, assumed to be Lambertian,

$$R_t(\lambda) \approx S(\lambda)\cos(i)\, r_t(\lambda) + D(\lambda)\, r_t(\lambda) \tag{1}$$

where $R_t(\lambda)$ is target radiance at wavelength λ, S is the solar irradiance filtered by the atmosphere, r_t is the target reflectance, and D is the downwelling irradiance from the sky, assumed to be isotropic. When the halon or other standard is placed in front of the spectrometer, the measured radiance is

$$R_h(\lambda) \approx S(\lambda)\cos(i)\, r_h(\lambda) + D(\lambda)\, r_h(\lambda) \quad (2)$$

where r_h is the halon reflectance. For $S(\lambda) \gg D(\lambda)$, it is assumed that

$$r_t(\lambda) \approx r_h(\lambda)\, R_t(\lambda)/R_h(\lambda). \quad (3)$$

However, in the visible spectrum $D(\lambda)$ is variable but may be several percent of $S(\lambda)$, so that this value of $r_t(\lambda)$ is in error. Furthermore, for a textured target "shade" must also be considered. Thus,

$$R_t(\lambda) \approx S(\lambda)\cos(i)\, r_t(\lambda)\,(1 - F_s) + D(\lambda)\, r_t(\lambda). \quad (4)$$

It is clear that, even if $S(\lambda) \gg D(\lambda)$, the apparent value of $r_t(\lambda)$ is reduced in proportion to F_s, such that

$$r_h(\lambda)\, R_t(\lambda)/R_h(\lambda) \approx r_t(\lambda)\,(1 - F_s). \quad (5)$$

Equations (3) and (4) are underdetermined, and it is not possible to calculate both r_t and F_s from them. However, it is possible to do this by making two additional radiance measurements, R_t' and R_h', in the field. For these measurements, the target and halon standard are both shadowed (for instance, by holding up a sheet of cardboard), such that $S(\lambda) = 0$:

$$R_h'(\lambda) \approx D(\lambda)\, r_h(\lambda) \quad (6)$$

$$R_t'(\lambda) \approx D(\lambda)\, r_t(\lambda). \quad (7)$$

Substituting R_h' and R_t' for R_h and R_t in equation (3) produces a more correct estimate of r_t. The "shade" fraction may be also calculated:

$$F_s \approx 1 - R_h'\,(R_t - R_t') \,/\, (R_t'\,(R_h - R_h')) \quad (8)$$

where the λ notation has been dropped for simplicity.

It should be noted that the apparent value of F_s will be independent of λ, provided the simplifying assumptions are valid. An important refinement is to consider adjacency factors, which affect primarily the terms containing $D(\lambda)$ but can have an impact of several percent on F_s. We have incorporated a simplistic model of adjacency effects that assumes that: (1) the downwelling skylight is diminished according to i/π (i in radians), and (2) the measured radiance is increased by bounce light from adjacent terrain. It is assumed that the adjacent terrain is flat ($i = 0$) and partially shadowed according to some nominal value F_s^* of F_s (e.g., 10%). The adjusted expression for target radiance is

$$R_t \approx r_t\, S\,(\cos(i)\,(1 - F_s) + r_t\,(1 - F_s^*)\,(i/\pi)) + r_t\, D\,((1 - i/\pi) + r_t\,(1 - F_s^*)). \quad (9)$$

We have calculated the sensitivity of F_s to measurement error by evaluating the above equations. We have also investigated the effect of viewing geometry on F_s and the magnitude of adjacency effects, using simulated surfaces having different roughness scales. This involved integration over a grid of 2500 cells, for which a digital terrain model was specified by a randum number generator. In addition, we have determined F_s for constructed surfaces, using a CCD to measure radiance images. Finally, we have determined F_s in natural field settings.

We discuss the use of F_s in understanding VNIR images. An interesting ramification of this research is that F_s is related to the surface texture at the subpixel level, a difficult characteristic to estimate otherwise. In vegetated terrains such as the Amazon rain forest, F_s determined remotely may be an important parameter for estimating canopy architecture over large areas. It is also possible that the F_s parameter may prove useful in relating VNIR and Radar images.

Measurement of F_s at a range of field scales (i.e., 10^{-3} to 10^{0} m) may provide a way to overlap with textural or roughness measurements made by microtopographic or stereometric surveys (10^{-1} to 10^{2} m). Such data have been used to characterize surface roughness as a fractal dimension for correlation with Radar backscatter coefficients and use in forward scattering models.