**Parsing Shade**

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**ABSTRACT** - Spectral Mixture Analysis (SMA) is a standard way of analyzing spectral images in terms of fundamental components of the scene. It accounts for lighting variations by using a Shade endmember that mixes with the tissue spectral endmembers such as green vegetation to produce observed radiance values. In forests, Shade comprises shadowing and topographic shading (“hillshade”), unresolved shadows cast by the canopy (“treeshade”), and shading plus shadows cast by elements of the canopy (“leafshade”). We use a LiDAR DEM to model treeshade for a low-relief forested area, and SMA to calculate Shade for an ASTER image of the same area taken near the same time of year. The differences between treeshade and Shade give remote-sensing estimates of leafshade in a forest dominated by deciduous trees.

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**Research goal** - analyze image shade in a forest in terms of its unresolved constituent parts: treeshade and leafshade, and make an image of $\Lambda$.

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**Spectral Mixture Analysis and an analytic framework**

**Fundamental equations**

Forward linear mixing model

$$L = \sum_{i=1}^{m+n+1} \xi_i e_i = \mathbf{S} : \mathbf{E} + \mathbf{R}$$

where $\mathbf{S}$ is the vector of scene endmembers $\mathbf{E}$ a mixture of $m+n+1$ scene endmembers and $\mathbf{R}$ is the unmodeled residual for channel $i$.

**Shade endmember**

$$\mathbf{c}_{\text{Sh}} = \mathbf{c}_{\text{SMA}} - \mathbf{c}_{\text{GV}} = (1-\mathbf{c}_{\text{vd}}) \mathbf{S}_{\text{SMA}}$$

where $\mathbf{c}_{\text{SMA}}$ and $\mathbf{S}_{\text{SMA}}$ are the SMA endmember and mixture vectors, respectively.

**Calibration and solution for $\Lambda$** - We measured total shade $f_{\text{SMA}}$ from SMA of 15-m ASTER data and treeshade $f_{\text{Sh}}$ using high-resolution 1-m LiDAR. Assuming $\Lambda$ is a constant for similar forest conditions, we solved the shade endmember equation for $\Lambda$ (calibration) and $f_{\text{Sh}}$, using two or more similar stands with different $f_{\text{Sh}}$ and $S$. $c_{\text{vd}}$ was 0.66; Gain $c_{\text{vd}}$ was 2.58. Knowing $c_{\text{vd}}$, $f_{\text{Sh}}$, and $S$, we can solve for $\Lambda$ for all pixels.

**Results**

**LiDAR images**

First-arrival LiDAR shade image, at full 1-m resolution and complemented as that areas of high shade are dark, and would be seen in an air photo (2.6 km screen). North is up. Image shows 15-m forest LiDAR vs. channel 3 (NIR) vs. channel 2 (R) plane. Arc is locus of a vector rotated about $\Lambda$. The difference between treeshade and Shade give remote-sensing estimates of leafshade in a forest dominated by deciduous trees.

**Discussion**

**Normalization of GV**

**Conclusions**

Remote-sensed spectral images integrate the effects of lighting up to the pixel scale. Blending contributions from topography, canopy and leaves, and shadows, SMA analysis of spectral and LiDAR images can be used to separate contributions from shadows at the tree and stand scales from shading at sub-tree scales, and spectral model mixture models can be constructed so that spectral shade fraction ($f_{\text{Sh}}$) correspond to more direct measurements from LiDAR. For a deciduous forest in coastal Maryland, USA, viewed in late morning during early summer, leafshade was typically $0.7-0.8$ at the tree scale and $0.9-1.0$ at the stand scale.

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