Quantifying Impervious Surface, Vegetation, Soil, and Shade in the Phoenix Metropolitan Area Using Multiple Endmember Spectral Mixture Analysis

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Abstract
Urban land covers (e.g., cement parking lots, asphalt roads, shingle rooftops, grass, trees, exposed soil) can only be recorded as either present or absent in each pixel when using traditional per-pixel classifiers. Sub-pixel analysis approaches that can provide the relative fraction of surface covers within a pixel may be a potential solution to effectively identifying urban impervious areas. Spectral mixture analysis approach is probably the most commonly used approach that models images spectra as spatially distributed by spectral signatures from two or more surface features. However, spectral mixture analysis does not account for the absence of one of the surface features or spectral variation within pure materials since it utilizes an invariable set of surface features. Multiple endmember spectral mixture analysis (MESMA) approach addresses these issues by allowing endmembers to vary on a per-pixel basis. The MESMA technique was employed in this study to model land use/land cover classes in the Phoenix metropolitan area. Field spectra of urban impervious surface, soil, and vegetation were collected with the aid of a fine resolution Quickbird image and pixel purity index tool in ENVI software were modeled as reference endmembers. The MESMA was incorporated in every model. This study employs thirty endmembers and its hundred and sixty spectral models to identify soil, impervious, vegetation, and shade in the Phoenix metropolitan area. The mean RMS error for the selected land use land cover classes range from 0.003 to 0.018. The Pearson correlation between the fraction outputs from MESMA and reference data from Quickbird 60 cm resolution data for soil, impervious, and vegetation were 0.7025, 0.7249, and 0.8144 respectively.

Sub-pixel Analysis
The traditional hard classifiers (e.g., minimum distance, Mahalanobis distance, maximum likelihood) can label each pixel only with one class. Information on the fractional amount of spatially mixed spectral signatures from different ground-cover features is not possible with the per-pixel classifiers (hard classifiers). Hence, the traditional classification of mixed pixels may lead to information loss, degradation of classification accuracy, and degradation of modeling quality in successive applications.

Sub-pixel analysis that can provide the relative abundance of surface materials within a pixel is a potential solution to per-pixel classifiers especially when dealing with medium to coarse spatial resolution satellite sensor images.

Linear Spectral Mixture Analysis (SMA)
Linear spectral mixture analysis (SMA) (Figure 3), which provides sub-pixel endmember abundance information, is probably the most commonly used approach of all subpixel analysis techniques. The approach is based on the assumption that the spectrum of each pixel is a linear combination of the spectra of all ground components within the pixel, and that the linear mixture coefficients are equal to the fractional area of each ground component in a pixel. The mathematical model of linear spectral mixture analysis can be defined as

$$X_k = \sum_{i=1}^{n} \frac{X_k}{X_i} = \sum_{i=1}^{n} s_i X_k$$

where

- $X_k = \text{Total reflectance of band}_i$ of a pixel
- $n = \text{number of endmembers}$
- $s_k = \text{fraction of an endmember}_k$ within a pixel
- $Y_k = \text{known spectral reflectance of endmember}_k$ within the pixel

The root mean square (RMS) error is given by:

$$RMS = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (s_i - \hat{s}_i)^2}$$

where $s_i$ are the error terms for each of the $n$ spectral bands considered. The above constrained least-squares estimate assumes the followings:

- $\sum_{i=1}^{n} s_i = 1$ and $0 < s_i < 1$

Multiple Endmember Spectral Mixture Analysis (MESMA) (Figure 4)
An extension of SMA approach that allows the number and type of endmembers to vary for each pixel within an image. MESMA has been proven to be effective in identifying different types of materials in a variety of environments. The algorithm produces the RMS error and the shade information in each pixel as separate layers.

Data and study area
Primary Data (Figure 1)
Landsat: Thematic Data (L1G product of path 37 and row 37) at 30 m spatial resolution with 6 channels ranging from blue (0.45 $\mu$m) to mid infrared portion of the spectrum (2.35 $\mu$m)

- Location: Phoenix metropolitan area (upper left longitude 112° 47’ 10.96”, latitude 33° 49’ 59.62”, lower right longitude 111° 34’ 15.86”, latitude 33° 12’ 09.81”)
- Date: April 19, 2000

Secondary Data for Accuracy Assessment (Figure 2)
Quickbird 2.4 meter spatial resolution multispectral image with 4 channels - blue (0.45 – 0.52 $\mu$m), green (0.52 – 0.60 $\mu$m), red (0.63 – 0.69 $\mu$m), and near infrared (0.65 – 0.70 $\mu$m) and 60 cm panoramic image (0.45 – 0.90 $\mu$m)

- Location: Downtown Phoenix.
- Date: July 11, 2005

Conclusion
Results from this study demonstrated that the MESMA approach is reliable and the sub-pixel processor picked out the signatures effectively. It should be noted that a careful selection of endmembers that represent all land covers under study play an important role in the MESMA approach. It was noticed that there is some signature confusion between dry soil exposed bare vs. bright impervious surface and water vs. tar roads/parking lots. We recommend that all possible models (combinations of all surface materials) be considered in the analysis. It is also important to note that number of surface features and all possible combinations of endmember models are increased and generate fraction layers repeatedly until a satisfactory result is received. The MESMA approach not only allows unlimited endmembers regardless of the number of spectral bands but also allows the number and type of endmembers to vary for each pixel within an image. One of the key advantages of using the MESMA is that a particular type of endmember (e.g., shingle roof under impervious surface or grass under vegetation endmember) could easily be identified by tracing the number of model identified in each pixel.