ROAD EXTRACTION FROM AVIRIS USING SPECTRAL MIXTURE AND Q-TREE FILTER TECHNIQUES

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1.0 INTRODUCTION

Accurate road location and condition information are of primary importance in road infrastructure management. Additionally, spatially accurate and up-to-date road networks are essential in ambulance and rescue dispatch in emergency situations. However, accurate road infrastructure databases do not exist for vast areas, particularly in areas with rapid expansion. Currently, the U.S. Department of Transportation (USDOT) extends great effort in field GPS mapping and condition assessment to meet these informational needs. This methodology, though effective, is both time-consuming and costly, because every road within a DOT's jurisdiction must be field-visited to obtain accurate information. Therefore, the USDOT is interested in identifying new technologies that could help meet road infrastructure informational needs more effectively.

Remote sensing provides one means by which large areas may be mapped with a high standard of accuracy and is a technology with great potential in infrastructure mapping. The goal of our research is to develop accurate road extraction techniques using high spatial resolution, fine spectral resolution imagery. Additionally, our research will explore the use of hyperspectral data in assessing road quality. Finally, this research aims to define the spatial and spectral requirements for remote sensing data to be used successfully for road feature extraction and road quality mapping. Our findings will facilitate the USDOT in assessing remote sensing as a new resource in infrastructure studies.

2.0 DATA AND METHODS

Our research to date has focused on two primary objectives: development of a regionally specific spectral library for urban areas, and using advanced techniques to map urban materials from hyperspectral AVIRIS data.

2.1 AVIRIS Data

High resolution Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data acquired over Santa Barbara, California, in October 1999 were initially used in this research. AVIRIS samples between 0.37 and 2.5 µm in 224 spectral bands, providing detailed and continuous radiance information in this region. To retrieve surface reflectance from AVIRIS, we used an algorithm developed by Green et al. (1993; 1996) that fits radiance modeled using MODTRAN radiative transfer code to radiance measured from AVIRIS. A field target was used to remove artifacts from AVIRIS reflectance due to a variety of sources, including AVIRIS wavelength calibration and errors in MODTRAN.

The spatial resolution for these data is approximately 3.9 meters. This data set was selected because it covers a wide range of surface materials (industrial, residential, agricultural, barren, and natural areas and a wide assortment of road types) at a fine enough spatial resolution to be used in urban areas. The large number of bands and fine spatial resolution also make it possible to synthesize most major broad-band systems, including sensors such as SPOT, Landsat TM, and IKONOS.

2.2 Development of the Urban Spectral Library

A regionally specific urban spectral library was developed by extracting and averaging 3.9 meter resolution spectra from the 1999 AVIRIS flight over Santa Barbara (Roberts et al., 1999). Our initial objective was to develop a spectral library that included high quality spectra of many urban materials. To accomplish this, distinct cover types were first identified in the field then spectra were extracted from the image (Figure 1). Spectra were averaged over a

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range of pixels depending on the size of the target. Once extracted from the image each spectrum was given a unique identifier in the spectral library.

2.3 Mapping Urban Materials

Urban areas are spectrally complex and vary greatly across fine spatial scales. Therefore, it was imperative that a technique be used that accounts for the complexity and mixtures present in urban areas. Urban materials were mapped using Multiple Endmember Spectral Mixture Analysis (MESMA, Roberts et al., 1998). Traditional Spectral Mixture Analysis (SMA) is a technique designed to decompose spectra, acquired from "mixed" targets (more than one material within the Instantaneous Field of View of the instrument) into "fractions" of pure spectra, called endmembers. This technique, while well suited for natural areas, is inappropriate for urban areas where the number of unique spectra greatly exceeds the 3 to 4 endmembers typically used in SMA.

MESMA departs from the simple model in that it allows the number and type of endmembers to vary on a per pixel basis, and thus has the potential of mapping hundreds of unique materials. For this analysis, endmembers derived from the urban spectral library were coupled with shade and used to unmix the 1999 Santa Barbara AVIRIS data. The final product is a set of maps, one showing the model selected per pixel (essentially a land-cover map), two or more fraction images showing abundance of each endmember and a final image showing model error.

Utilizing MESMA is an iterative process—once the procedure is run for a scene the user is able to identify which models are working best and to adjust the library for a subsequent run. The goal is to determine the optimal set of models that extract the road features with least error. However, not all materials are spectrally distinct, and the potential exists for map errors due to spectral confusion between materials. Urban examples of spectral confusion include some types of road surfaces, which can appear spectrally similar to dark composite shingles. To alleviate this confusion, a spatial pattern recognition technique--termed a Q-tree filter--was applied that identifies linear, continuous pixels within the classified map as roads (Figure 2). Therefore, the technique developed in this research exploits both spectral *and* spatial information, creating a cleaner road map than traditional methods that incorporate only one of these components.

MESMA will also be the technique used in road condition assessment, although our initial emphasis in this project is on road extraction. Once the road extraction technique is completed, a spectral library including roads of various conditions will be utilized within MESMA to map road quality.

3.0 RESULTS AND DISCUSSION

A ten-scene AVIRIS flight line over Santa Barbara, California was processed to reflectance for this research. From this, a total of over 140 image spectra were extracted for the urban spectral library. For each spectrum, metadata describing the location and type of material were recorded in an Excel spreadsheet. Sample spectra from this library are plotted in Figure 3. As indicated, many urban features are spectrally distinct from one another, and similar surface materials such as roof and road cover types have unique, though subtle, differences in their spectral signatures.

Initial results from MESMA were promising, showing that the technique is capable of mapping a large number of urban surfaces, including roads, given a high quality spectral library of endmembers (Figure 4, center frame). However, the results also showed areas where MESMA was incapable of separating road surfaces from composite shingle roofs. In these cases, either the spectral contrast between these materials was low or the spectral library lacked sufficient spectra for separation. This confusion occurs because many roofs and roads are composed of the same basic materials. Although most road surfaces can be extracted utilizing MESMA alone, many roof materials become misclassified as road due to their spectral similarity to the road signatures. When combined with the Q-tree filter technique, confusion between roads and roofs was reduced (Figure 4, right frame). For example, while road surfaces and composite roofs may appear spectrally similar, their spatial patterns should be unique--roads are likely to form linear features, while roofs are likely to be more rectangular. Therefore, in a classified map of “road materials” in which many roofs are misclassified as roads due to spectral confusion, the Q-tree filter can be used to extract the true roads from the map.

An alternate approach towards improved map accuracy is to further refine the spectral library. The current spectral library is limited in that endmembers were image derived--homogeneous pixels within the image were averaged to build the endmember library. Due to the 3.9-meter spatial resolution of the imagery, these endmembers inherently contain mixtures of different surface materials. Purer endmembers may be obtained by using a field spectrometer to collect known surface types. Therefore, the next major step in this project will be to develop a reference spectral library from field-collected spectra. A reference endmember library will provide a better “start point” for MESMA because the user has more control over the specific material included in the endmembers.

A second significant challenge in road feature mapping is tree covered and shadowed roads. This leads to discontinuous road maps. For instance, a tree canopy over a road is spectrally represented as vegetation. To overcome this, one approach would be to apply a secondary level of Q-tree spatial filter. After the initial application of the Q-tree filter--which basically “cleans” the roads--a second type of Q-tree filter will be used to reclassify some vegetation pixels that occur along classified road pixels as road (Figure 5). A threshold will specify the maximum number of pixels that can be reclassified in this manner to achieve optimum results.

4.0 CONCLUSIONS AND FUTURE WORK

As indicated, road feature extraction from remote sensing is a complex problem. However, the solutions that are being explored in this research have potential to bring hyperspectral remote sensing into a new and large application area. Once the road extraction technique is further developed with high resolution AVIRIS, we will explore the use of hyperspectral imagery in condition assessment. Next, we will begin determining the minimum spectral and spatial requirements for mapping urban materials. AVIRIS will be spatially degraded to test the resolution required to be successful in urban areas. To evaluate broad-band systems such as Landsat TM or SPOT, we will convolve AVIRIS wavelengths to the equivalent broad-band spectra. This will allow us to better define the imagery requirements—and therefore cost—for the technique to be used on the large scale.

5.0 REFERENCES

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6.0 ACKNOWLEDGEMENTS

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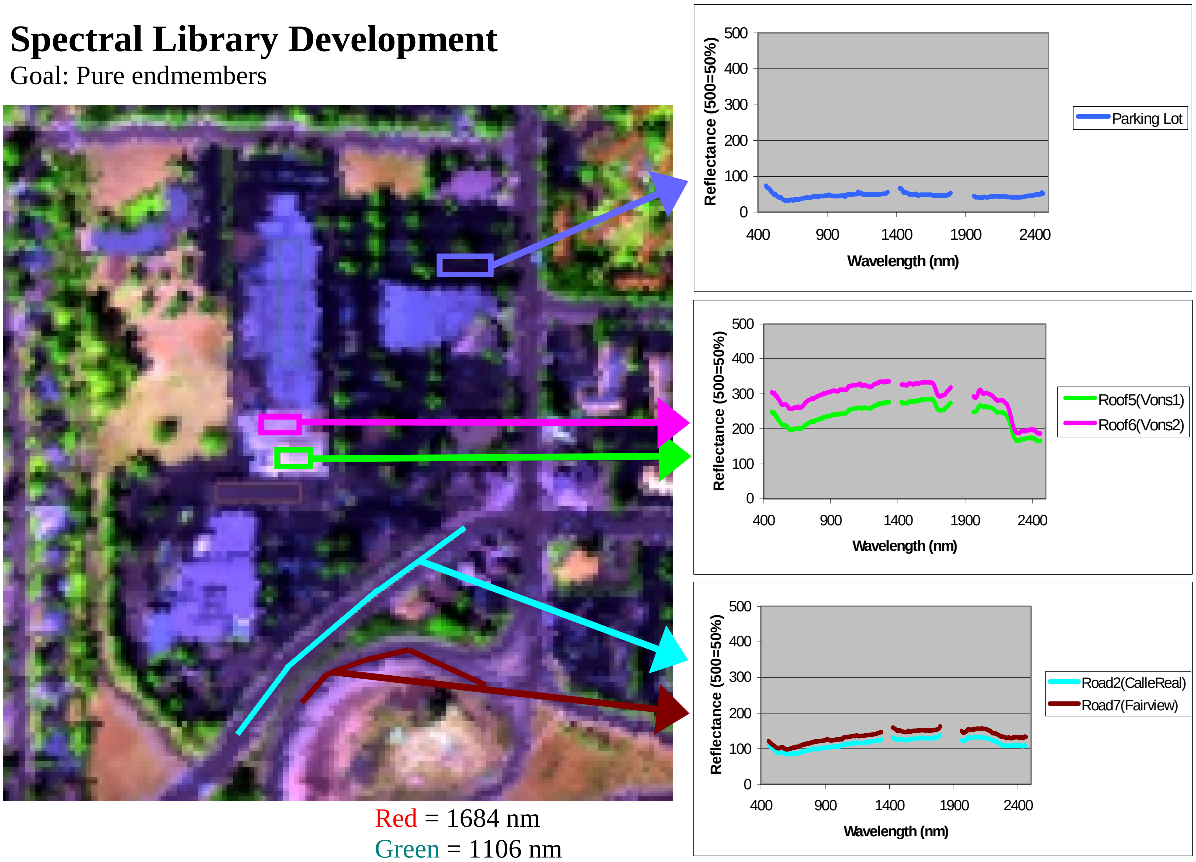
Spectral Library Development

Goal: Pure endmembers



Red = 1684 nm
Green = 1106 nm
Blue = 675 nm

Figure 1. Methodology for creating the urban spectral library. Homogeneous areas were first identified in the field and then identified in the AVIRIS image to be included in the library.

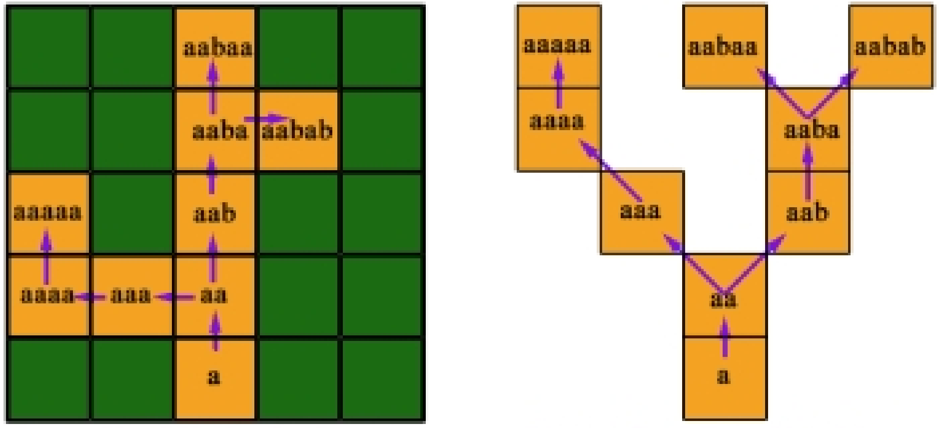


Image with neighborhood assignments beginning with pixel 'a'.

Corresponding Q-Tree with nodes linked to 'a'. Total length = 9.

Pan-chromatic image of urban intersection.

Q-Tree filtered white lines.

Figure 2. Q-tree filter concept. This approach incorporates spatial information into the procedure to alleviate spectral confusion, particularly between composite shingles and roads.

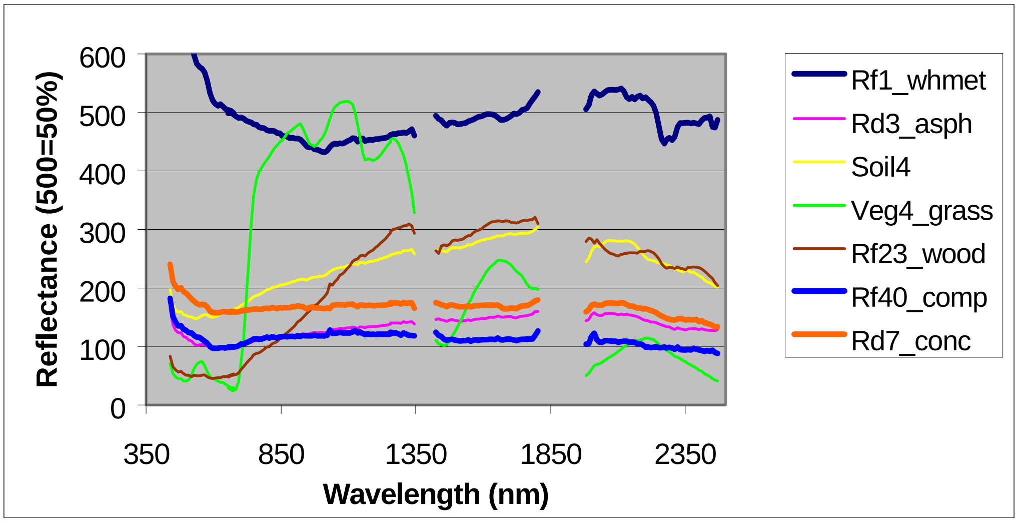


Figure 3. Example Library Spectra. Rf1_whmet=white metal roof; Rd3_asph=asphalt-concrete road; Soil4=bare soil; Veg4_grass=irrigated grass; Rf23_wood=wood roof; Rf40_comp=composite shingle roof; Rd7_conc=concrete road

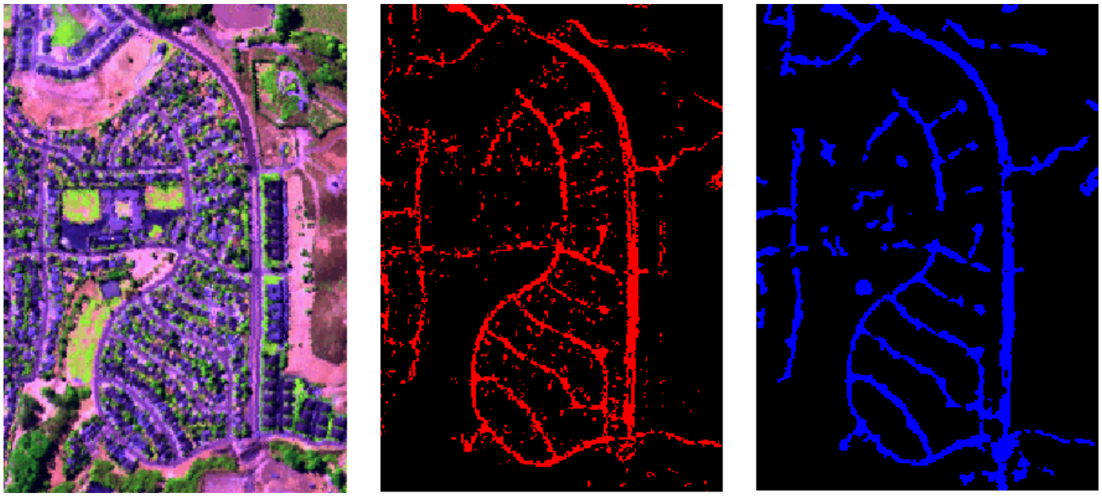
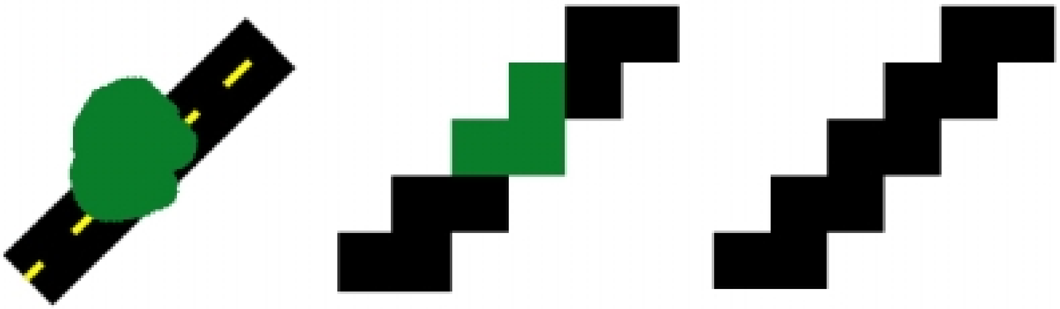


Figure 4. Road extraction procedure. Left image is a color composite of the original image; middle image contains the MESMA results for classified road pixels; right image is the final road map from the Q-tree spatial filter.



Tree canopy over road → classified pixels → Q-tree filter “removes” the tree

Figure 5. Q-tree road “gap” filling. Gap filling is a second application of the Q-tree filter that enables a cleaner and more accurate final road map.