SPECTRAL/SPATIAL EXPLOITATION OF DIGITAL RASTER GRAPHIC MAP PRODUCTS FOR IMPROVED DATA EXTRACTION

Timothy J. Eveleigh, Kevin D. Potter,
Autometric Inc., 5301 Shawnee Rd.,
Alexandria, VA 22312

ABSTRACT

In recent years, much research and development has been successfully applied to using image processing technology to exploit multispectral scanner remote sensing products for geographic information. Recent developments in technology have made affordable scanners that can allow systems as small as home computers the ability to scan-digitize map products through broad spectral filters. The resulting digital raster graphics (DRG) are also becoming increasingly available commercially. The spectral and spatial nature of these products shows great potential as a source of exploitable geographic data. The same image processing techniques now applied to remotely sensed imagery can in many cases be applied to DRG. The advantage of such an approach is that it can speed data extraction while performing data reduction. By performing spectral classification of the DRG and intelligently assembling thematic components of the resulting classified image, items such as vegetation and water can be extracted. Further processing could extract linear features like boundaries, roads, and even contour lines. These linear features have the potential to generate geographic information like road networks and DTMs. This paper presents the preliminary results of an investigation into the spectral and spatial exploitation of DRG using image processing technology.

INTRODUCTION

Since the early 1970's, the extraction of geographic data from multispectral imagery products has evolved from a laboratory curiosity to an essential tool. Classifying multispectral imagery into discrete spectral classes that can be correlated with geographic knowledge and subsequently managed by a geographic information system is an effective tool used widely by resource managers.

Recently, advances in computer technology have made affordable powerful small computers capable of supporting image processing software and geographic information systems. Optical scanners which can convert hardcopy products like maps to digital images have also become more available to the low end user. Traditionally at the disadvantage of being memory intensive, the digital map products have seen limited use as analysis backdrops and to support manual softcopy digitizing of geographic features. Developers of memory technology, however, are continually introducing more capable, higher volume, cost effective data storage solutions for small computers.

In addition to the increased accessibility of hardware, an increase in the availability of digital map data is imminent. This is due in part to the increased availability of low cost scanners. It is also due to the map data production community's intention to introduce the widescale production and dissemination of cartographic products in digital raster graphic (DRG) form.

In light of the potential increased availability of DRG, and that DRG is already resident in a form that a computer can manage, it is useful to consider how scanned maps can most effectively be exploited. For resource managers and users of geographic information systems (GIS), one of the most desirable uses of scanned maps would be to employ them as a source of data to rapidly populate a geographic database. It would be very desirable to feed a scanned map to a process that would interpret the map and create a topologically valid geographic information model that described the mapped terrain. Such a tool could perhaps even obviate the labor intensive manual digitizing and attribution process commonly applied to hardcopy and softcopy products. Although such a technique would not correct map errors and would retain any biases or defects in the map product, it could provide a rapid 'first cut' that would be suitable for many applications.

Such a tool would have to be able to discriminate individual colors, patterns, and shapes on the map product. The tool would have to be told the ranges and manifestations of map data and what the geographic features represent on the earth's surface. This is a considerably involved task and in many respects is similar to automated image understanding. This paper presents some preliminary findings of applying to raster scanned map products existing and emerging technology developed to support image understanding.

SPECTRAL EXPLOITATION OF DRG

Scanners used to convert hardcopy products to a digital form are similar to the multispectral scanners employed by earth imaging aircraft and space platforms. Both instruments collect a grid of samples of an objective through optics, pass the incoming radiation through bandpass filters, convert the filtered radiation levels to electrical charges, digitize the electrical charges, and store the digital data in a form that can be reconstructed to produce brightness images for each of the filtered bands. Table 1 shows some of the similarities and differences between the scanners and data from the two systems.

If the two systems generate images that share many characteristics, it would follow that traditional multispectral analysis could be applied to the DRG. On first inspection, it would appear that the application of traditional multispectral analysis to DRG is a much simplified case of classifying remotely sensed imagery of the earth's surface. Due to the generalized and symbolic

Category	Traditional Remotely Sensed Imagery	Digital Raster Graphics of Maps
SPATIAL SAMPLE RESOLUTION	Usually fixed and determined by platform.	Most scanners capable of several.
SPECTRAL BANDS	Can be many, determined by choice of platform.	Rarely more than three, determined by hardware.
REGISTRATION TO GEOGRAPHICS	Requires registration via rigorous sensor model and/or extractable control points.	Usually retains the projection and tick marks of original map therefore can be modeled using map registration software.
SPECTRAL QUALITY	High spectral quality due to calibration and design of sensor payload and knowledge of illumination conditions.	Depends on machine used and how operated.
SPATIAL QUALITY	High spatial quality due to precise knowledge of data collection activity.	Depends on machine used and how operated. Contiguous patches may not join up.
APPEARANCE OF FEATURES	Imaged features are as they actually appear in location, size, and shape.	Imaged features are often symbols that differ in size, shape, and sometimes location of actual items portrayed.

Table 1

nature of maps, there should be far fewer spectral clusters for the computer to resolve.

Computer extraction of geographically significant spectral classes or colors from the printed map surface can be complicated by several factors, however. The first such factor is the aliasing inherent in the sampling approach used by scanners.

When the human eye reads a map, the mind automatically performs several functions that a computer might not ordinarily perform. For example, most printed maps contain colors and shades of colors that have been printed with dot screens. A small light blue lake, for example, is actually printed as several thousand blue dots. The size and distribution of the printed dots will determine how the brain processes and classifies the overall color of the stippled area. A computer, however, if fed a buffer of pixels that contains the blue dot field will not reclassify all the pixels near the blue dots and the dots themselves as another shade of blue, it will continue to handle each pixel as a discrete element - unless it is instructed to do otherwise. The computer will simply classify the blue pixels as lake, and the white background as not lake.

The literal translation of dot patterns begins to approach the desired result of seeing the lake 'color' if optical mixing occurs during the scanning step. If the resolution element size of the scanner is increased out of the size range of elements of the printed dot screen pattern, the white and blue contributions to each pixel begin to mix producing a set of light blue colored 'mixels'. These mixed contribution pixels can be spectrally identified and used in the classification stage. The sample interval will determine how many mixture classes there will be for a given screened pattern. Choice of the scanner's sample resolution is important, as it not only affects data storage requirements, but it will determine the number and nature of the spectral classes that indicate map colors (and therefore, the complexity of the data classification and extraction process). Pixel mixing will also occur along edges of features resulting in the generation of several new mixed boundary classes.

Due to all the sample mixing, successfully defining the spectral representation of a screened pattern like a lake begins to approach the complexity of classifying an actual lake on remotely sensed imagery. Instead of a sharp, low spectral diversity cluster, the map lake color definition becomes the product of the many pixel mixes that will occur when the water pattern is sampled. Extraction, however, is still possible as long as the contributing clusters are mathematically resolvable within the set of all scanned map reflectances. We find that in many instances, this is the case for DRG map data, as it is for multispectral remote sensing imagery.

Another factor that can interfere with the raster map to thematic map conversion is that many of the geographic features depicted on a map are represented by cartographic symbols that mean nothing to the computer. Features like structures, roads, political boundaries, text, tick marks, and contours are all represented by a mix of linear and point symbols. Often these symbols accurately depict the location of geographic features, but distort the dimensionality of the features. Spectral classification of the map product could potentially locate these symbols, but could not convert them to appropriate geographic analogues. These items will require an additional spatial analysis or even pattern recognition step before being thematically attributed.

RESULTS

By applying existing multispectral image classification software to DRG maps, we were able to explore the process of spectrally classifying the map images into geographically significant cell maps. We found that by using a supervised spectral training approach, the majority of shaded and solid map color spectral clusters could be determined, and that these clusters when fed to a maximum likelihood classifier resulted in useable thematic geographic information. We also found that the process requires a large amount of guidance from the operator (or as we propose, a knowledge-base system). Guidance was required both in the spectral training phase and in the conversion of the classified cell map from a 'color' map to a geographically significant thematic map. The conversion of the 'color' map to the geographically significant thematic map is where we found the most significant departure from the remotely sensed imagery to geographic data conversion.

Let's take the example of the task of extracting forested areas from imagery and from DRG maps.

A forest as seen on an image will manifest itself as a complex cluster or set of clusters in spectral space. Many factors will contribute to the total range of spectral space caused by the interception and filtering of energy reflected by the forest's canopy into the sensor's optics. To classify accurately the entire image into classes of forest and not forest, one would hope to describe this complex spectral distribution as completely as possible before or during classification. Groundtruth permitting, one would have the option of attempting to establish additional subclasses of forest based on measurable or known differences in canopy refection between tree types. Following the definition of the forest's spectral space definition(s), the entire image would be subjected to classification and a raster map of forest distribution would result.

On a simple map, however, the forest could appear to the eye only as a solid shade of green. Were this the case, classification and extraction would be simplified. The green reflectance of the map should hold nearly uniform assuming that the illumination of the map during scanning is uniform. The dot spacing of the screen used for the green printing should also hold constant across the map. In this simplified case, the delineation of the spectral space definition of the forest should itself be simple. Once the discrete signatures of the important colors (green and not green) are delineated, the classification step should provide a raster map of green color distribution which we will call forest. Unless individual forest types were symbolized by the map maker, however, the ability to distinguish forest types as classes is lost.

The simple map case is rapidly complicated when actual maps are used. First, we have the aliasing effects introduced by the dot pattern and forest edges that we mentioned earlier. We also encounter another pixel mixing effect - this time caused by overlapping map colors. The overprinting of cartographic elements such as text, symbols, and contours alters what must be identified as the forest's spectral space. For example, the overprinting of a brown contour on a green forest color can result in several new discrete spectral clusters. In this case, the spectral definition of a forest on a map must be amended to include contours within the forest, otherwise the classified raster forest map might not include pixels containing contours (see Figure 1).

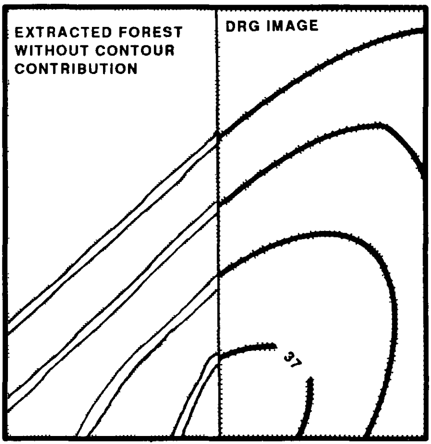

Figure 1

This is also true for other mixtures like political boundary demarcations, colored text, and relief shading. What began as a simple hunt for light green pixels can end as a hunt for pixels in a variety of colors, and a need to combine intelligently many of the classes from the output map to assemble the entire 'forest' distribution. For example, the 'forest' class might end up being the combination of the following resolved classes: Mid green shade + edge green shade 1 + edge green shade 2 + brown and green + edge brown and green + brown and blue.

Let's examine the case of the extraction of forests from DRG maps further. For example, it is entirely possible that forests might not be the only features represented with green ink. If the above technique encounters an orchard for example, the resulting classified raster map will contain blobs of forest where the green orchard symbols were encountered. Although this is not always undesirable, the exact boundaries of the orchard are lost, and potentially incorrect positions for trees are retained (see Figure 2). Orchards, scrub, and vineyards could all fall prey to this problem if one were extracting from a chart that represented these features with a pattern versus an individual color.

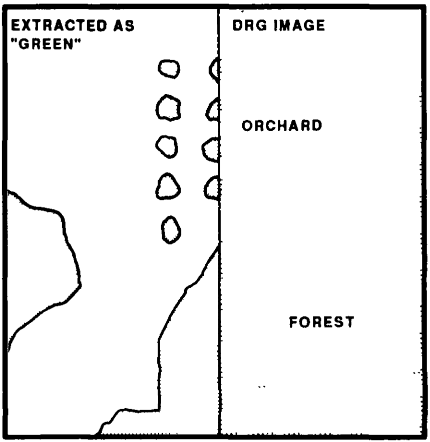

Figure 2

Certain patterns can also introduce additional aliasing issues. Consider if you will a symbol or shading pattern that contains closely spaced stripes, dots, or cross hatching. If the sampling interval of the scanner was smaller than the width of the individual dots, stripes, or cross hatches, they would be converted to the target class. If, however, the sample size increases, the potential for interference colors increases. Interference colors are not a problem if they are expected, and if they are accounted for.

SPATIAL PROCESSING

Spectral processing of DRG can be used to provide a classified cell map representing the discrete colors of a digital raster graphic as seen by a scanner. Many shaded polygonal map features like forests and water bodies can be assembled out of the classified colors that result. Some polygon features, and most linear features, however, will need additional spatial processing to more correctly represent the geographic items depicted. Tools like line following algorithms can be brought into play to help achieve this end.

A good example of the need for such processing is provided by an attempt to create an arc-node contour map from a raster scanned portion of an USGS quadrangle.

The first stage in this study was to identify the discrete spectral signatures that represented the various colors that the brown contour lines make as seen by the scanner. We found that two discrete signatures defined ninety percent of the brown color used to denote the contours. These two colors were mainly the result of additive mixing of the contour color with the color that it overlapped. Contour (brown) on background (white) and contour (brown) on vegetation (green) were the two dominant signatures. The remaining ten percent of the contour pixels fell into a series of signatures that represented various combinations of green and brown, white and brown, brown and blue (at stream crossings), and brown and black (at road crossings). In an attempt to define areas that were not contour, pure black, solid green, solid red, solid blue, and solid white signatures were measured. When maximum likelihood classification was applied to the entire map using all of the above signatures, a raw raster contour map was produced.

Observing the spectrally classified map, it was obvious that many segments of contour pixels could be used by line following software to create clean linear features. Furthermore, when these linear features are correctly linked and attributed, the resulting vector map could be used to generate a rough terrain model.

Other segments of contours fell victim to the choice of scanner sample size. Problems arose when two or more contour lines were in close enough proximity to occupy the same or adjacent sample pixels. This problem manifested itself as contours that appeared to melt into each other. In areas of high slope this could present a significant challenge to contour extraction and editing software. One solution to this problem would be to increase the density of the scanner's sampling. This approach would allow the technique to reduce or discard many of the mixed signatures that fringe the contour lines, and to resolve smaller gaps between printed contours. The disadvantage of this approach would be an increased cost due to increased data storage requirements and the time spent processing the map.

A few contours also contained breaks with numbers indicating the elevation of the contour. The classification technique classified these numbers as contours as they were printed in brown. In our approach, we will attempt to filter out these discontinuities during processing of the contour data, though potentially they could be automatically exploited by pattern recognition software and used to assign a quantitative attribute to the linear vectors being assembled.

The processing of streams and linear cultural features like roads, rails, political boundaries, and map tick marks could follow a process like the contour extraction example. A big difference here is that the symbology used to depict these features is far more varied in color, thickness, and shape compared to the relatively easy to extract contours. Dedicated software could be written to extract each of these entities.

Point features also have a potential for extraction. Like the above mentioned polygonal and linear extraction examples, it is possible to extract classes of color used to depict point features. The extracted features would not appear as points however, they would appear as the shape of the symbol used to represent the point features. Here too, it is conceivable that pattern recognition technology could be brought into play to convert the cluster of pixels into an attributed point feature.

FUTURE CONSIDERATIONS

During our study of applying a remote sensing image data extraction approach to DRG maps, we found that several of the existing tools (multispectral signature measurement and management, maximum likelihood spectral classification) could be effectively applied to DRG to create a cell maps that represented unique combinations of map colors. We also noticed that this approach generated several mixed colors resulting from optical mixing during the scanning process, and the overprinting of map colors. Following color classification, available software allowed us to combine classes to form cell maps that were geographically relevant or that could be made geographically relevant by additional spatial processing. What was missing, however, was any guidance that could be used to direct the task of extracting a given feature category from a given DRG. Such guidance would have to available if the technique were to be automated. This is where we believe a knowledge base system (KBS) could be applied.

A knowledge base system establishes and administers a set of rules and procedures for accomplishing tasks. For example, a knowledge base system could provide a mechanism for directing the extraction of a particular geographic feature type from a given DRG source. The knowledge base would direct the operator or spectral clustering algorithm to collect the spectral signatures necessary to define all of the color manifestations of the feature(s) being extracted. The knowledge base system would then be called on to assemble intelligently the thematic cell map from the jumble of available cell classes following the classification step. Finally, the knowledge base system would direct the assembled map to any appropriate spatial processing algorithms for further extraction.

A knowledge base system can be used to make the classification algorithms more efficient by limiting the total number of mixed color signatures to the minimum required. The knowledge based system performs this task by pruning irrelevant signatures.

An important feature of a knowledge base system is that it is heuristic and can be trained to respond to a variety of applications and source data types. We believe that a properly trained knowledge base system can be effectively employed to automate most or all the phases of geographic feature extractions from DRG. This capability would greatly enhance the utility of DRG products by making them sources of geographic information.

DATA AND EQUIPMENT USED

Our study examined sections of a rural USGS 7.5 minute quadrangle map that were scan digitized into three 8 bit images (red, green, and blue). A HOWTEK Scanmaster tabletop scanner was used to raster digitize the map product. A 200 sample per map inch resolution was used. We employed a Compaq 386-based version of the ERDAS image processing package to perform our experimentation with the DRG's spectral nature and spectral reclassification. We employed the capabilities of ERDAS' cell file management software (GIS) to perform class reassembly.

CONCLUSION

Recent developments in technology will soon unleash a flood of affordable rasterized map products. These digital raster graphic map products have a great potential as a source of geographic information. Moreover, this information could be extracted in a semi-automatic manner. The ability to perform automated geographic data extraction from DRG products will increase their value to managers and collectors of geographic information, and could eventually reduce the labor intensive step of manual data extraction.

We have examined how off-the-shelf remote sensing image processing software can be employed to extract the basic colors and patterns from a map surface necessary to build geographically relevant information. We have also experimented with the guided recombination of the spectrally classified cell data and examined some of the factors that contribute to the generation of the cell classes. It remains to be seen how successfully we can apply spatial analysis tools to further develop the geographic information that results from class assemblage. Similarly, it remains to be seen how automated entire feature extraction scenarios can be made when a rule base system is employed to control the process. We believe that both approaches have the potential for extracting a variety of feature types from digital raster graphics. It is important to note, however, that the best-case extraction possible from a DRG product will only be as accurate as the map product used as a source.