Development and Automation of High Resolution Image Extraction Methodologies for Transportation Features

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Development and Automation of High Resolution Image Extraction Methodologies for Transportation Features

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Executive Summary

This proof-of-concept project was a joint effort between Geographic Paradigm Computing, Inc. (GPC), Iguana Software Research Center (ISRC), and NASA’s Affiliated Research Center (ARC) at the University of New Mexico's Earth Data Analysis Center (EDAC). The objective of the project was to demonstrate the commercial feasibility and utility of automated transportation feature identification and extraction from high spatial resolution imagery. However, because of the range of surface transportation features present in the images (e.g., roads, bridges, parking lots, railroads) and the imposed time constraints, the research project was limited to identifying and extracting roadway features only.

This ARC project explored a variety of image data sets and a commonly used commercial image-processing program during the course of its investigations. While it was demonstrated that 1- to 2-meter resolution data were sufficient to identify and extract roadways, it was also found that "off-the-shelf" software and conventional image processing techniques were of limited use in the process. Consequently, GPC and ISR developed a proprietary extraction methodology and a set of specialized algorithms that extract roadways of various surface types in both urban and rural settings. The approach has been implemented in a prototypical commercial software package – iPAVER.

Preliminary technical findings demonstrate that, for the study areas, 75% of true roadway pixels can be correctly identified and over 95% of true non-roadway pixels can be correctly eliminated using this automated process. Roadway occlusions caused by shadows, tree canopies, and vehicles preclude a 100% true roadway pixel automated solution, while similar material types and feature geometries make it difficult to eliminate 100% of non-roadway elements.

GPC and ISR are now in the process of refining and extending iPAVER and are developing a joint venture business model based on this successful proof-of-concept demonstration.
1.0 Introduction

The U.S. ground transportation system has over 4,000,000 miles of surface facilities, primarily roadways and railways. The system is quite dynamic as new roads and other facilities are being added to the system annually, while existing roads and facilities are continuously being improved or reconstructed. This system is the responsibility of thousands of public- and private-sector agencies that create and maintain individual, interdependent spatial and non-spatial databases of transportation information. Many more thousands of civil and military fleet operators, emergency services providers, and others depend on having up-to-date information concerning the location and status of system facilities. Consequently, one of the most challenging issues in building and maintaining a Geographic Information System for Transportation (GIS-T) is obtaining highly accurate spatial data in a timely and cost-effective manner. Once established, the GIS-T would combine the spatial and non-spatial data bases into an efficient program.

Recent advances in remote sensing and data capture technologies appear to offer many advantages over more traditional spatial data acquisition methods. With the recent announcements of commercially available or soon-to-be-available digital imagery at spatial resolutions of 1 to 5 meters, the opportunity now exists for utilizing satellite imagery for mapping and for updating and registering existing road maps. These resolutions permit not only the extraction of road centerlines but also edge-to-edge roadway geometry, including intersection areas. The convergence of the next generation of high spatial resolution imagery from satellite and airborne platforms, the Global Positioning System (GPS) for location and registration, digital cameras, and new advances in digital image processing and distribution all point to a new paradigm for GIS-T. However, the resource demands that result from these very large image data sets and the lack of automated means for extracting transportation features present a formidable barrier to more effective use of this new data source.

This industry-wide need for low-cost, automated methods for creating and maintaining highly accurate transportation data bases forms the basis for this Affiliated Research Center (ARC) project. Geographic Paradigm Computing, Inc. (GPC), Iguana Software Research Center (ISRC), and NASA’s ARC at the University of New Mexico’s Earth Data Analysis Center (EDAC) are partners in this study of transportation feature geometry extraction from high spatial resolution imagery.

2.0 Implementation

The project objective was to develop a test methodology for identifying, classifying, and extracting surface transportation features over large geographic regions using commercially available image data sets. Moreover, the project was intended to demonstrate the utility (i.e., cost-effectiveness) of such a method. If the method were both generally applicable and inexpensive compared to current extraction methods, GPC and its partner could introduce highly accurate, low-cost, small-volume data sets and specialized image processing tools into the market.
This ARC project used simulated high spatial resolution satellite imagery to develop and test automated mapping tools for the transportation industry. Technical issues of interest to GPC included the effects of different spatial and spectral resolutions on roadway identification, the effects of seasonal and diurnal variations, and the value of commercially available image processing software. Table 1 lists the task schedule for addressing these issues.

Table 1. Meeting dates and tasks.

<table>
<thead>
<tr>
<th>Mtg. #</th>
<th>Date of the Meeting</th>
<th>Work Assigned for the Following Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>May 1999</td>
<td>Literature search, creation of feature matrix</td>
</tr>
<tr>
<td>2</td>
<td>June 1999</td>
<td>ERDAS software introduction</td>
</tr>
<tr>
<td>3</td>
<td>June 1999</td>
<td>Filter matrix, ATLAS image geocorrection</td>
</tr>
<tr>
<td>4</td>
<td>July 1999</td>
<td>Application of filters to ATLAS</td>
</tr>
<tr>
<td>5</td>
<td>July 1999</td>
<td>C code, GPS overlay</td>
</tr>
<tr>
<td>6</td>
<td>August 1999</td>
<td>C code</td>
</tr>
<tr>
<td>7</td>
<td>August 1999</td>
<td>C code, Supervised classification, GPS overlay</td>
</tr>
<tr>
<td>8</td>
<td>August 1999</td>
<td>C code</td>
</tr>
<tr>
<td>9</td>
<td>September 1999</td>
<td>Supervised classification and histogram matching</td>
</tr>
<tr>
<td>10</td>
<td>September 1999</td>
<td>Supervised classification</td>
</tr>
<tr>
<td>11</td>
<td>September 1999</td>
<td>Supervised classification</td>
</tr>
<tr>
<td>12</td>
<td>September 1999</td>
<td>Supervised classification</td>
</tr>
<tr>
<td>13</td>
<td>October 1999</td>
<td>Supervised classification, IKONOS “first image” acquisition</td>
</tr>
<tr>
<td>14</td>
<td>October 1999</td>
<td>IKONOS “first image” analysis</td>
</tr>
</tbody>
</table>

Activities:
- Literature search
- Ongoing review and evaluation
- Problem area identification
- Digital Orthophoto Quarter Quad (DOQQ) acquisition
- Image processing on DOQQ’s
- Airborne Terrestrial Applications Sensor (ATLAS) data set acquisition
- Image processing on ATLAS data
- Normalized Difference Vegetation Index test vegetation masking
- C code development for feature extraction
- Supervised classification on the data sets
- Histogram matching on the data sets
- IKONOS “first image” preliminary analysis
2.1 Data Acquisition and Image Processing

Multiple test sites within the Albuquerque, New Mexico, region were selected for several reasons – the team’s proximity to the road network, availability of multiple sources of imagery, and variety of land use/transportation network combinations. Each site was several square miles in area and covered by high spatial resolution satellite or airborne scanner data as well as digital orthophoto quadrangles. Because of the high degree of correlation between land use, functional classification, and roadway surface material, the test sites were selected to reflect a variety of land uses ranging from urban residential to rural. This selection resulted in a variety of road surface materials and roadway geometries.

Data acquisition was the first step in this project. Since the commercial viability of the project will depend on low-cost, readily available data sources, data sets such as the U.S. Geological Survey (USGS) DOQQ’s, NASA ATLAS, and the Indian Remote Sensing Satellite (IRS-1C) were used to develop the methodology. Image processing techniques were used to perform a variety of operations on the acquired images, including spatial enhancement, georeferencing, supervised classification, histogram matching, and model making.

2.1.1 Data Sets

DOQQ: Digital Orthophoto Quarter Quads are digital images produced by the USGS. They contain orthorectified aerial photographs with a spatial resolution of 1 meter. DOQQ’s are panchromatic with pixel gray-scale values ranging from 0 to 255. The images are “leaf-on” photography.

ATLAS: NASA’s Stennis Space Center acquires ATLAS images from an aerial platform. The ATLAS data set is multispectral and has a spectral range of 0.45 - 12.2 µm, which is divided into 14 different bands of visible through thermal infrared wavelengths. The spatial resolution of the image is 5 meters and the data are 8-bit.

IRS-1C: The IRS-1C data set is panchromatic and also has a spatial resolution of 5 meters. The data are 7-bit.

2.1.2 Image Processing Software

ERDAS IMAGINE Version 8.3 was the image processing software used for this project. This system incorporates the functions of both image processing and geographic information systems (GIS’s). The functions include importing, viewing, processing, and analyzing raster and vector data sets. A variety of activities were performed using this software package, including image enhancement, supervised classification, geocorrection, and thresholding.
2.2 Image Processing

2.2.1 Image Processing on the DOQQ Images

The DOQQ image files were processed with various filters, including edge enhancement, edge detection, texture, directional, and statistical filters. Filtering refers to the processing of spatial or spectral features within the constraints of a moving window called a “kernel.” The filter combinations listed above were tried at different kernel sizes (unit = pixel): 3x3, 5x5, and 7x7. The filters that were the most useful were the edge enhancement filter, which emphasizes the edges between homogeneous groups of pixels, and the variance filter, which determines the degree of digital number (DN) variance within a kernel.

While each filter was able to highlight certain roadway characteristics, the amount of non-roadway pixel noise was judged unacceptable, particularly in urban settings. In other words, no single filter or filter combination was able to unambiguously identify roads (true positives) and to simultaneously ignore non-road features (true negatives). Also, the human interaction required to group 256 gray levels into a dozen or so distinct colors in the resulting filtered images was time intensive, making the filter processing a costly consideration.

Since most two-lane roads are approximately 7 meters wide, the 5-meter IRS-1C data were judged to be not of sufficient spatial resolution to meet the study's objectives of extracting horizontal road geometry.

2.2.2 Image Processing on the ATLAS Image

The next step was to explore the ATLAS image. The ATLAS data were geocorrected using the ERDAS software. Of the 14 spectral bands (Table 2), the 9th band had been removed from the sensor and the 11th band was very noisy and was eliminated from the data set. The image was edge-enhanced, and different band combinations were viewed in an attempt to identify those that would allow extraction of transportation features. Different paving materials could be identified using the band combination 3, 13, 14. Bands 1, 3, 5 were also a good combination to extract some ground features.

<table>
<thead>
<tr>
<th>Visible/Near-Infrared</th>
<th>Short Wave Infrared</th>
<th>Thermal Infrared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1: 0.45-0.52 μm</td>
<td>Band 7: 1.55-1.75 μm</td>
<td>Band 10: 8.20-8.60 μm</td>
</tr>
<tr>
<td>Band 2: 0.52-0.60 μm</td>
<td>Band 8: 2.08-2.35 μm</td>
<td>Band 11: 8.60-9.0 μm</td>
</tr>
<tr>
<td>Band 3: 0.60-0.63 μm</td>
<td>Band 9: removed</td>
<td>Band 12: 9.0-9.40 μm</td>
</tr>
<tr>
<td>Band 4: 0.63-0.69 μm</td>
<td></td>
<td>Band 13: 9.60-10.2 μm</td>
</tr>
<tr>
<td>Band 5: 0.69-0.76 μm</td>
<td></td>
<td>Band 14: 10.2-11.2 μm</td>
</tr>
<tr>
<td>Band 6: 0.76-0.90 μm</td>
<td></td>
<td>Band 15: 11.2-12.2 μm</td>
</tr>
</tbody>
</table>
Since these data were multispectral, a vegetation index was derived and a vegetation mask was applied to the corresponding DOQQ. Although the mask was intended to reduce the amount of false positive pixels in the filtered DOQQ image, the method produced unacceptable results because of problems with geometry from poor image registration.

Processing the ATLAS data was very time-consuming and therefore costly. Since the geocorrection was not satisfactory and the thermal bands were not available in the commercially available high-resolution data sets, the ATLAS data were not considered appropriate for this ARC project.

2.2.3 DOQQ and GPS Centerline Data Overlay

The City of Albuquerque collected GPS road centerline data for the Albuquerque area. These data were imported into ERDAS IMAGINE and overlaid on the DOQQ for the study area. Sample images of the DOQQ and DOQQ with centerline overlay are shown in Figure 1. Note that the GPS road vectors do not lie on the road centerlines. The collection of centerline GPS data was not of high enough resolution to be used with the image data and proved to be inappropriate for use in this project.

![Figure 1](image.png)

Figure 1. The left image is a subset of the DOQQ for an urban residential area. The right image shows the same subset with the GPS road centerline overlay.

2.2.4 Supervised Classification Using Image Processing

A supervised classification was performed on an image that was obtained from stacking the DOQQ and variance filter images. Seeds were grown in different areas of interest. The image was classified into several categories, including road, tree shadow, roof top, residential lawn, sidewalk, and driveway, with a probability of 1.00 and a maximum likelihood decision rule.

The output table from the classification contained class values, class names, color table, class statistics, and histograms. Using the resulting statistics, DN threshold values were computed
within two standard deviations of the class means. A new image was created from these class thresholds. Sample output images are shown in Figure 2.

![Sample output images](image)

**Figure 2.** The left image is a subset of a DOQQ for a rural area. The right image shows the DN thresholding algorithm applied to the subset.

Histogram equalization was performed on the same image and the results were similar to those from the supervised classification. But this procedure was a more time-consuming process; therefore, supervised classification was preferred over histogram equalization.

DOQQ's of different, nearby areas were considered at this point to identify other potential problems, including unpaved roads in urban areas. Supervised classification was performed as explained above, and the results were compared with the original classifications. However, different acquisition dates and environmental conditions (such as sun angle and tree canopy) made the image mosaic unsatisfactory for information extraction purposes.

### 2.2.5 Feature Extraction Using C Programming Algorithms

Under the guidance of GPC, an algorithm was written in the C programming language to extract roadways from the DOQQ images. The results were somewhat better than those received from the classification and DN thresholding methods. This limited success gave new direction for GPC and ISRC to pursue independent algorithm development.

### 3.0 Results

The different data sets used in this experimental process were the USGS DOQQ's, the IRS-1C, and the NASA ATLAS. Among these data sets, the DOQQ's had the best-suited spatial resolution (1-meter panchromatic) for the feature extraction. The geocorrection for the ATLAS data set was not satisfactory; therefore, any kind of analysis on that image was not
useful to the project. Thermal bands are not available in any of the commercial high-
resolution imagery and so were not considered here. No spectral advantage was found in any
of the data sets.

The Washington, D.C., “first image” from IKONOS was downloaded and a preliminary
analysis was conducted. However, because the image received over the web was 8-bit rather
than 11-bit and the sun angle was low, producing shadowing, good results were not obtained.
Several desirable image attributes were identified that would improve the accuracy of road
identification. These attributes included using leaf-off images with a moderate sun angle,
implying that the optimal acquisition season for the Northern Hemisphere would be mid-
summer. GPC is pursuing obtaining IKONOS 1-meter, 11-bit panchromatic data for additional
study.

While the most promising approach to road identification and extraction is the supervised
classification with DN thresholding, the standard image-processing techniques used by
EDAC do not produce acceptable results. That is, the amount of human effort necessary to
produce an acceptable product would be cost-prohibitive on a commercial basis. Among the
reasons identified for the relatively poor results are the following:

1. the difficulty in distinguishing roads from other human features (e.g., buildings,
   drainage structures),
2. the range of surface materials used on the same roadway, and
3. the geometric complexity of the road network (e.g., interchanges, overpasses).

Occluded portions of the roadways add additional challenges.

Because of the above-mentioned difficulties, GPC and ISRC concurrently and independently
have developed a specialized method and a suite of algorithms (iPAVER) designed to
overcome the limitations identified in this ARC Project.

Preliminary technical findings demonstrate that 75% of true roadway pixels can be correctly
identified and over 95% of true non-roadway pixels can be correctly eliminated using this
automated process (Figure 3, Figure 4, and Figure 5). Roadway occlusions caused by
shadows, tree canopies, and vehicles preclude a 100% true roadway automated solution,
while similar material types and geometry make it difficult to eliminate 100% of non-
roadway elements.
Figure 3. Original image of a DOQQ subset with embedded road network.
(Same image subset as Figure 1.)

Figure 4. Manually extracted road network solution representing 100% true roadway.

Figure 5. Extracted roads using iPAVER algorithm.
GPC and ISRC are now in the process of refining and extending the methods and algorithms. The prototype version of iPAVER can process small images (<1 Mb file size) in seconds, achieving similar extraction accuracy. Future development efforts will focus on larger areas (100 Mb file size) and a wider range of road surface types.

### 4.0 Conclusions

Geographic Paradigm Computing, Inc., the ARC project partner, and Iguana Software Research Center, Inc., have studied the potential for extracting accurate transportation feature geometry from high spatial resolution imagery. The project identified and tested several methodologies for identifying, classifying, and extracting surface transportation features over large regions. A methodology was developed by GPC and is now under review and refinement. If cost effective, this methodology will allow GPC and its partner to jointly develop accurate, small-volume data sets and a suite of image processing tools to assist transportation base mapping and derivative products.

Based on the success of this proof-of-concept, GPC and ISRC have approached several agencies and private companies seeking additional funding to develop a commercial product. GPC and ISRC are also refining and extending iPAVER and are developing a joint-venture business model focused on producing image-based road network geometry.

GPC and ISRC are conducting a market analysis to assess the profitability of supplying pre-processed road data for the global transportation community. These data can be used to rapidly develop or update highly accurate, current road networks for GIS-T applications. Current production costs for existing road extraction processes can exceed $100 per mile. Although no final production costs using iPAVER have been established, preliminary estimates suggest significantly lower costs using the approaches identified in this project.

### 5.0 Bibliography


