Evaluation of SPOT Panchromatic Digital Imagery for Updating Road Locations in a Harvested Forest Area

Rachida Jazouli, David L. Verbyla, and Dennis L. Murphy

Abstract

Maintaining and updating road inventory information for Geographic Information System (GIS) applications can be costly in large areas that are managed for timber production. We evaluated the positional accuracy of SPOT (Systeme Probatoire D'Observation de la Terre) 10-metre panchromatic imagery to update road locations in a forested area in northern Idaho. One 7.5-minute quadrangle of SPOT level 1B panchromatic data was precision rectified using a digital elevation model. A 3 by 3 high pass filter was used to enhance linear features such as roads. The data were then resampled from the original 10-metre pixels to 3.3-metre pixels to increase the precision of on-screen digitizing of roads. The digitized roads arcs were compared with reference road arcs that had been compiled using an analytical stereoplotter. An 18-metre buffer of allowable error was established around the reference roads. Ninety-six percent of the road arcs digitized from SPOT imagery were within this error buffer. The distribution of road arcs outside the error buffer did not differ significantly among slope classes. This may be due to the fact that (1) there is little relief displacement when imagery is acquired from great distances above the terrain or (2) the SPOT data were rectified using a digital elevation model. We concluded that roads digitized from SPOT panchromatic imagery had positional accuracies that were within our GIS horizontal error standard and that on-screen digitizing from SPOT panchromatic imagery would be an efficient method of updating roads for GIS applications in our harvested forest study area.

Introduction

Acquisition of accurate and current data is a major investment cost associated with geographic information systems (GIS). Forest management agencies need quality road data for applications such as forest harvest scheduling, watershed monitoring, road maintenance, big game habitat evaluation, and for access information. Some forest managers need annual GIS updates of road information.

Traditionally, road information has been acquired for GIS applications using two photogrammetric methods. The first method uses analytical stereo-plotting instruments with stereo aerial photography. This method is very accurate and can be used for other applications such as generating digital elevation models and orthophotos. However, it is expensive and requires extensive photogrammetric skills and ground control. The second approach, more commonly used by some forest management agencies, is to use single-print transfer instruments such as zoom transfer scopes. Using single-print devices, roads can be compiled at lower cost and with little photogrammetric knowledge (compared to high-order classification using analytical stereoplotters). However, these instruments do not remove tilt or all topographic displacement and are not capable of generating digital elevation models. Positional errors caused by displacements and distortions are not removed, but are averaged out between control points by stretching and enlarging or reducing the photographic image (Paine, 1981). This method is slow and tedious because it involves four steps: (1) delineation of the effective area on each photograph, (2) interpretation of each effective area, (3) transfer of detail from each photograph (using a zoom transfer scope) to a base map, and (4) manual digitizing (or scanning) of road locations from the base maps into a GIS. In general, road information acquisition for GIS applications is tedious and slow, especially in cases where hundreds or thousands of photographs cover the forest management area.

SPOT panchromatic data offer several advantages over traditional photogrammetric methods. One SPOT scene covers 3,600 km², offering a seamless coverage over an area typically covered by hundreds of medium-scale aerial photographs. SPOT data are available world wide on a constant cyclic basis for regular updating of road inventories. Also, efficient automated operations such as geometric rectification and edge enhancements are possible because the data are in digital format. However, there are disadvantages in using SPOT imagery when compared with aerial photography. Because SPOT coverage cannot be acquired daily, availability of cloud-free imagery may be a problem in some areas (Leckie, 1990). Second, the positional accuracy of SPOT imagery may be too poor for some GIS applications.

R. Jazouli and D.L. Verbyla were with the Department of Forest Resources, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, ID 83843.

R. Jazouli is now at Rue Baakili, Residence Zohor #13, Rabat, Morocco.

D.L. Verbyla is now with the Department of Forest Sciences, University of Alaska, Fairbanks, AK 99775-0100.

D.L. Murphy is with Potlatch Corporation, P.O. Box 1016, Lewiston, ID 83501-1016.

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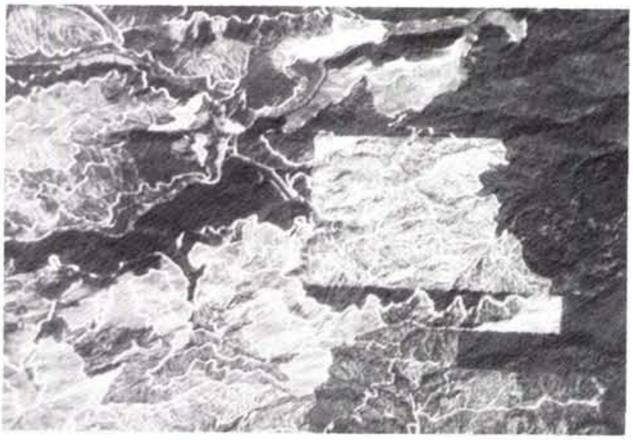

Figure 1. SPOT panchromatic image of study area (12 September 1990).

Background

SPOT panchromatic imagery can be used for efficient input of forest information (such as forest clearcut locations, shoreline locations, and road locations) into a GIS. Because the *potential* planimetric accuracy of SPOT panchromatic imagery corresponds to a map scale of 1:17,000 (Doyle, 1984), for the first time the positional accuracy of satellite imagery may be acceptable for many GIS applications in natural resources. SPOT multispectral 20-metre pixel images have been used with multispectral classification to extract planimetric information for map production at a scale of 1:50,000 (Maillard and Cavayas, 1988); however, linear features such as roads were not extracted. SPOT panchromatic 10-metre pixel images are superior for mapping of narrow linear features. For example, Dowman and Peacegood (1989) found that highways, most major roads, and double-track railways are generally 100 percent visible on SPOT panchromatic imagery.

Automatic extraction of roads from satellite imagery is possible using seed pixel/line following algorithms (Destival and LeMen, 1986; Berthod and Serendero, 1988; Ton *et al.*, 1989; Maillard and Cavayas, 1989), knowledge-based systems (Yee, 1987; Wang and Newkirk, 1988; Van Cleynenbreugel *et al.*, 1990), and analysis of multi-temporal images (Guindon, 1988). These techniques may allow for more efficient updating of forest road locations when compared with on screen-digitizing. However, on-screen digitizing permits interpretation by managers familiar with on-the-ground road information, such as surface type (e.g., gravel or soil), road type (haul road, jeep trail, or skid trail), and access (location of locked gates, culverts, etc.).

Methods

Test Site

The study area encompassed one USGS 7.5-minute quadrangle, Alderman Ridge, Idaho, centered at 116° 18' 45" W. longitude, 46° 41' 15" N latitude. This area was selected because it had diverse topography ranging from flat terrain to slopes exceeding 100 percent. Also, new roads have been constructed in this area during the past three years. The area is predominantly forested and is managed for timber production. Extensive timber harvesting and road building has occurred in the area during the past three years (Figure 1).

Data

SPOT panchromatic data were acquired for two different dates: 12 September 1990 and 20 December 1990. An existing GIS road inventory (compiled using an analytical stereoplotter) was acquired as reference data to test the positional accuracy of the roads compiled from the SPOT imagery.

The SPOT data were pre-processed to level 1B by SPOT Image Corporation. The processing included equalization of detector responses (radiometric calibration) and corrections for systematic geometric distortions, including Earth rotation, Earth curvature, sensor viewing angle, and satellite attitude variations. A digital elevation model (DEM) was used by STX Corporation for precision rectification of the image. The digital elevation model was produced using an analytical stereoplotter; elevations were estimated every 38 metres along a profile, with profiles spaced every 76 metres. The accuracy of the DEM is probably better than the standard USGS 7.5-minute DEM (Fahsi *et al.*, 1990) and meets national map accuracy standards for 10-metre contour intervals.

The winter and summer images were visually compared to select the best season for road delineation. The roads on the winter image were obscured by drifting snow and long winter shadows. Therefore, the summer image was judged superior for road delineation and was used in the analysis.

Data Analysis

The data processing and analyses comprised four steps:

- Image enhancement to improve visual contrast of roads,
- Resampling of 10-m pixels to 3.3-m pixels for more precise digitizing from the monitor screen,
- Digitizing of roads from the monitor screen and conversion raster arcs to vector arcs, and
- Assessment of accuracy by comparing the digitized road locations with the existing stereo-compiled road locations. The stereo-compiled roads met national map horizontal accuracy standards at 1:15,840 scale.

Image Enhancement

During the filtering process, a kernel or window is used to represent a pixel's neighborhood (Chavez *et al.*, 1976). The optimum kernel size is dependent on the variation of the individual image. We used the horizontal first difference technique (Chavez and Bauer, 1982) to select the optimum kernel size for image enhancement. Based on this method, we determined the best kernel size to be 3 by 3. However, we also examined 5 by 5 and 7 by 7 kernels to visually confirm that the 3 by 3 kernel size enhanced the roads the best.

Next, we compared filtering algorithms to enhance the road network and thus allow for easier delineation of road arcs. Three different spatial filters were considered in this study (Jensen, 1986): (1) edge enhancement or high-pass filter, (2) edge detector zero sum filter, and (3) a combination of a high-pass filter and a low-pass filter. The visual comparison of the three different filters with the different kernels (3 by 3, 5 by 5, 7 by 7) showed the high-pass filter with a 3 by 3 kernel size to be best for the road delineation.

Data Resampling

In the digitizing step, road arcs were traced from the monitor screen using a mouse to estimate the State Plane Coordinates of vertices along the road arcs. To increase the precision of

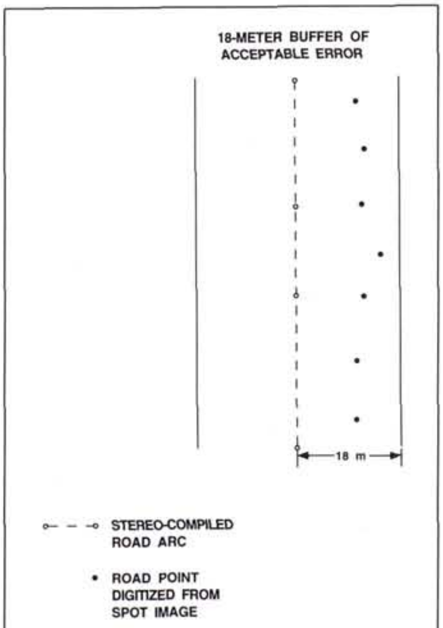

Figure 2. Allowable error buffer from reference road arc.

the on-screen manual digitizing, the 10-m SPOT panchromatic data were resampled to a 3.3-m by 3.3-m grid cell. After resampling, each pixel becomes nine smaller pixels, making it possible to perform subsequent operations (digitizing) at a "sub-pixel" level (3.3m by 3.3m). To estimate the sample values on the new grid, it was necessary to interpolate the original pixel values. We used cubic convolution resampling in this study to avoid block image structures (disjointed appearance) of the nearest neighbor method and to provide a slightly sharper image than the bilinear interpolation method (Keys, 1981). However, all three methods (nearest neighbor, bilinear interpolation, and cubic convolution resampling) were tested to confirm that cubic convolution resampling produced the best appearing image.

The resampling of the 10-m pixels to 3.3-m pixels was accomplished without a significant loss of positional accuracy because the linear transformation model had a root-mean-squared (RMS) error of 0.0 pixels. (This resampling process is analogous to dividing 10-meter pixels into smaller 3.3-metre pixels.)

On-Screen Digitizing

Road arcs were digitized by tracing a cursor along the center pixels of each road. The image was displayed using a 512-column by 512-row by 32-bit image processing system and a 20-inch RGB monitor. After the digitizing process was completed, the digitized pixel locations were converted from a raster format (used by the image processing software) to a vector format (used by the GIS software). The vector data were then compared with the stereo-compiled reference roads.

Positional Accuracy Assessment

A positional error of up to 18 metres was considered acceptable by Potlatch Corporation. The interval of 18 metres was the sum of two accuracies tolerances: (1) stereo-compiled reference roads tolerance of 8 metres (horizontal national map accuracy standard at 1:15,840 scale) and (2) SPOT image tolerance of ± half a pixel (10 metres).

TABLE 1. COMPARISON OF DIGITIZED ROAD ARC POSITIONAL ERRORS BY SLOPE CLASS.

Slope Class	Slope Gradient (percent)	Percent of total road arcs	Percent of road arcs outside 18-metre buffer
1	0.0–4.6	27.73	29.73
2	4.6–10.0	31.97	34.14
3	10.0–21.5	23.75	21.28
4	21.5–46.4	12.85	11.14
5	46.4–100.0	3.56	3.55
6	>100.0	0.14	0.16

A buffer zone of acceptable horizontal error (18 metres) was established using the reference roads. This buffer coverage and the roads digitized from the SPOT image were compared to assess the positional accuracy of the digitized roads (Figure 2).

Comparison of Positional Errors with Slope Class

To determine the effect of terrain on the positional accuracy of road arcs, five slope-gradient classes were generated from a digital elevation model. The percentage of road arcs existing outside the allowable error buffer (18 metres) was tabulated by slope class.

Results and Discussion

The results were encouraging; 96 percent of the 17,132 tested road arc points were within the 18-metre tolerance set by Potlatch Corporation. For this study area and application, on-screen digitizing of enhanced SPOT panchromatic imagery is an attractive method for efficient updating of forest road locations.

There was no significant relationship between slope-gradient class and the frequency of road arcs outside the 18-metre buffer of error tolerance (Table 1). This may be due to two reasons:

- The SPOT data were georectified using a digital elevation model to correct for distortions associated with terrain, and
- Terrain displacement varies inversely with the distance between a sensor and the surface being imaged (Paine, 1981). Because the SPOT satellite orbits the Earth at an altitude of 830 km, relief displacement is negligible and is a minor problem when compared with conventional low-altitude aerial photography.

Because one SPOT scene covers 360,000 ha, on-screen digitizing from SPOT panchromatic images may be a more cost-effective method than traditional aerial photography/map transfer/manual digitizing methods for frequently updating timber harvest areas, roads, and other high contrast features.

The results are encouraging and the method used might be considered for updating of forest road information in areas where there is a high contrast between roads and surrounding features. In this study, most of the roads were dry and therefore were light in tone. SPOT panchromatic imagery may not be as useful in other areas where (1) roads are narrow and often shaded by surrounding forest, (2) roads are shaded due to topography in steep canyons, or (3) roads are surfaced with low contrast materials such as wet soil, a cover crop, or asphalt that would result in a dark tone on panchromatic imagery.

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