Application of Remote Sensing Data for Monitoring of Gas Pipeline Right-of-Way

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Abstract:

Networks of oil and gas pipelines carrying petroleum products are significant to our economy. Even though most of the pipeline is buried underground, it can still pose a threat to our fragile environment. Over the last 10 years, monitoring of the network has been done mainly through the use of black and white aerial photographs, ground surveys and airborne inspection. Of concern to the oil and gas industry are disturbances to the network by accidental spills, encroachment from human activities, and land form changes due to fires, floods and other natural events.

Under the Local Environmental Applications Program, NOVA Gas Transmission Ltd. is collaborating with the Canada Centre for Remote Sensing (CCRS) in a demonstration project to use remote sensing techniques for monitoring the pipeline right-of-way (ROW). In July 1997 CCRS acquired remote sensing data from satellite and airborne platforms along the Western Main pipeline that runs through Cochrane, Alberta. Ground measurements were also made within a few weeks of the airborne data acquisition. This paper will present some of the GIS concerns in this project and describe the structure of a compact disk for the demonstration project results.

Introduction:

The main challenges involve the understanding of the technological requirements of the geomatics industry, an awareness of changing environmental priorities and advances in research and development. The geomatics community members are charged to develop new and cost effective methods to apply geomatics to local environmental issues [2].

Gas and oil pipelines are routinely inspected and monitored by the operational organizations during the planning, construction, operation, and decommissioning phases [1]. Environmental monitoring of the pipelines involves the following activities:

- assessment of conditions of vegetation along and across the pipeline;
- assessment of environmental disturbance during construction and operational phases;
- detection and monitoring of spills and impacts from pipelines and facilities;
- determination of slope stability;
- identification and location of landuse change (including agricultural, forest, industrial and residential);

- evaluation of recovery and rehabilitation from accidental spills and decommissions;
- detection of human encroachments.

Remote sensing technology has been widely used for monitoring natural resources. In the early 1980s, spaceborne sensors were inadequate to provide the spatial resolution required for monitoring the right-of-ways which are about 30 m in width. Black and white aerial photography has been the main remote sensing tool used in pipeline monitoring. The recent rapid technological improvements in sensor and computer technologies has expanded the utility of remote sensing in these applications. With higher spatial resolution data (~1 m) and hyperspectral data (>100 narrow spectral bands), remote sensing may augment or replace some of the established procedures for pipeline monitoring.

The National Energy Board and the gas pipeline industry concluded after several studies that:

- current remote sensing technology has the potential to be applied to pipeline right-of-way monitoring;
- a demonstration project is required to identify where the use of remote sensing may provide cost-effective solutions and reduce the current amount of ground surveys.

In 1997, the Canada Centre for Remote Sensing and NOVA Gas Transmission Ltd. jointly planned a remote sensing demonstration project with the following objectives:

- demonstration of the use of off-the-shelf remote sensing technology;
- enhancement of the current pipeline monitoring procedures;
- evaluation of the effectiveness of the application of remote sensing technology to reduce operating costs;
- evaluation of the capabilities of different spatial resolution remote sensing images for pipeline monitoring.

The selection of the test sites was based on the following criteria discussed at the December 1996 workshop at Emerald Lake, British Columbia [3]:

- overall logistics and subsequent processing costs to the demonstration project;
- effective coverage of different pipeline monitoring issues;
- test sites must be close together and include landforms of interest to the gas company so that different technologies could be applied without overwhelming logistic problems;
- accessibility to sites to reduce cost of ground measurements.

Limited by budget, and constrained by time and distance, the Western Main pipeline near Cochrane which was chosen, runs from Sundre to Crowsnest (about 200 km, see figure 1). Along segment of the pipeline, there were a number of interesting sites for this project: sites remedied from mercury spill, weed problems, encroachment, agricultural fields. Ground measurements, and airborne data acquisition was organized and carried out in the last week of July 1997. Other satellite and airborne data were acquired in subsequent weeks. Spaceborne images including SPOT and RADARSAT images at spatial resolutions of 10 m, 8.5 m and 25 m respectively, were acquired (Table 2 and Figure 2). During the field campaign, airborne multispectral images were acquired over the test sites by *casi* (Compact Airborne Spectrometry Imager), multispectral video and infrared frame camera. Moreover black and white survey photography was acquired a few weeks later for visual reference. Ground measurements included spectral measurements of vegetation, control point position readings using GPS (Global Positioning Satellite) instrument, and 35 mm survey photographs.

Information products concerning the spatial distribution of the land cover along the ROW and the continuity of the land cover across the ROW with respect to the adjacent land use will be derived from several different image sources. The procedures to generate environmental image products, the image products themselves and their associated costs will be used to evaluate their effectiveness for operational pipeline monitoring applications. A cost/benefit analysis will also be made between the digital technology and the standard black and white aerial photography for the purpose of illustrating the net worth of value-added information.

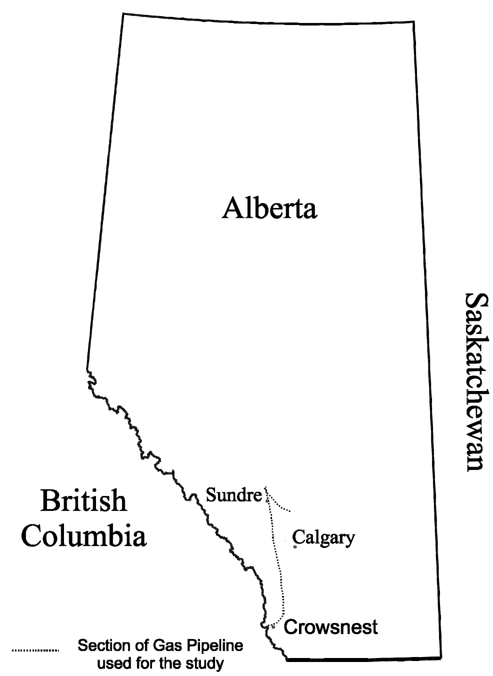

Figure 1. A sketch map of the province of Alberta, Canada. Depicted in this sketch is the section of pipeline that was imaged during the 1997 field campaign.

Integration of Remote Sensing data into a Geographic Information Systems (GIS)

In this project the raster remote sensing data is to be integrated with a vector-based geographic information system. The integration issues facing this project are discussed below.

1. **Image storage scheme for satellite and airborne image data**

The satellite and airborne images have different image size and orientation. Because civilian remote sensing imaging satellites have prescribed orbits, the acquired images are relatively regular in terms of the number of lines and pixels. The viewing and illumination geometry causes some distortion, but they can be calibrated using standard image calibration tools. These images can be stored in "matrix-like" files. Airborne images are mostly long strips of images which are narrow in width but may contain thousands of scan lines in length. Besides, airborne image strips "meander" like rivers when they are overlaid on top of a topographic map. Therefore, instead of storing whole airborne image strips, they are divided into segments and indexed for easy access and storage. Satellite images are stored as regular matrix files.

2. **Different Spatial Resolutions**

As shown in Table 1, the spatial resolution of the image data acquired for this project ranges from 0.75 m to 30 m. This makes image overlay and combining of image channels of different spatial resolutions difficult. Images from different sensors must be resampled to a common pixel size before they can be overlaid. This is a time consuming operation. Instead, side-by-side visual comparison of image data is encouraged. It can also provide the "zoom in" effect when multiple windows of different resolution images are placed side-by-side for viewing.

3. **Data Formats**

Internal to an operational GIS system which includes image analysis functions, raster image data is stored in a common image file format. Yet the pixel data type can cause problems. Remote sensing images are stored in 8-bit, 16-bit and floating point formats. Not all image analysis packages work with all these formats for all the routines. For example, there is a case where the image classification software operates solely with 8-bit image data for high dimension images (greater than 8 channels). Thus it cannot operate on the multi-channel casi data (14 image channels in spatial mode, 72 or 96 channels in hyperspectral mode) which is included in this project. Moreover image data are stored internally either in TIFF or PCI DISK formats.

4. **Management of Raster Products derived from images**

Thematic products derived from images are usually in raster format. However, for integration with GIS, they may have to be converted to a vector representation for database update or presentation. These data products include:

- digital terrain models
- thematic class files
- environmental change files

5. **Visualization and Presentation**

The enhancement of the information of interest to an analyst from a remotely sensed image is always an issue. An image channel of the raw data (i.e. image acquired from a remote sensing instrument without any radiometric or geometric enhancement) represents the measurement of the energy within a range of electromagnetic frequencies reflected from the surface of the earth. When the range of frequencies is narrow enough, the surface cover type (e.g. soil, plant species, etc.) can be determined in specific channels. However, only three image channels can be combined as a false colour image for viewing. The challenge is to identify the features that are of interest to pipeline monitoring and through some mathematical operations, transform the multiple image channels into a three specific ones for display. Research is currently underway on this problem.

Products for the monitoring of pipeline right of way

The products to be developed in the initial phase of the current project include the acquired images from different sensors and also value-added-products. The cartographic products and acquired images are listed in Table 1 and Table 2 respectively**.** The information products to be developed include: vegetation condition and continuity maps across and along the pipeline right-of-way in five areas dealing with an old condensate spill, a decommissioned compressor station, two important river crossings, and an area where weed control programs are in effect. Also three-dimensional representations of the right-of-way river crossings will be produced.

Data Set	Scale	Source
National Digital Topographic Data	1: 50000	Center for Topographic Information, Geomatics Canada, Natural Resources Canada, Canada
DTED	1:20000	Department of Environmental Protection, Province of Alberta, Canada

Table 1: Cartographic data acquired for the pipeline monitoring project.

Sensor	Description	Resolution		
		Sample interval (m)	Spectral Range	No. of bits
CASI	airborne multi-spectral images (14 channels)	2	blue, green, red, near infrared	16
Airborne Video	multispectral images acquired using a digital video camera (5 channels)	1	blue, green, red, near-infrared	8
Digital Frame Camera	RGB imagery acquired using a digital camera (3 channels)	0.75	blue, green, red	8
Scanned Aerial Photographs	Panchromatic analogue photographs acquired using a conventional mapping camera.	2	visible - panchromatic	8
Radarsat	SAR satellite image (1 channel)	8	radar C-band (HH)	16
Spot HRV	multispectral satellite imagery (3 channels)	20	blue, green, red	8

Table 2: Remote Sensing Images acquired during the 1997 field campaign along the Western Main pipeline near Calgary.

Demonstration Compact Disk for Pipeline Monitoring

One of the project deliverables is a demonstration compact disk to exemplify the present capabilities in applying remote sensing technology to environmental monitoring of gas pipelines. The secondary objective is to show those utility companies that are not yet familiar with remote sensing technology, what remote sensing techniques can offer for their daily operations. Consequently, the audience of this compact disk ranges from those who do not know much about computers and remote sensing to experts in the field. This poses the following constraints to the design of the structure and operation of the compact disk:

- computer device independent (must be operational under different operating systems such as UNIX, Windows95, NT, Macintosh, etc.);
- observe System Integrity (there will be no CGI programs nor any requirements to create temporary files on the host machine);
- limited to the maximum size of storage capacity of a single compact disk;

- user friendly (no special learning , viewing sequences is interactively defined by intuitive point-and-click of a mouse).

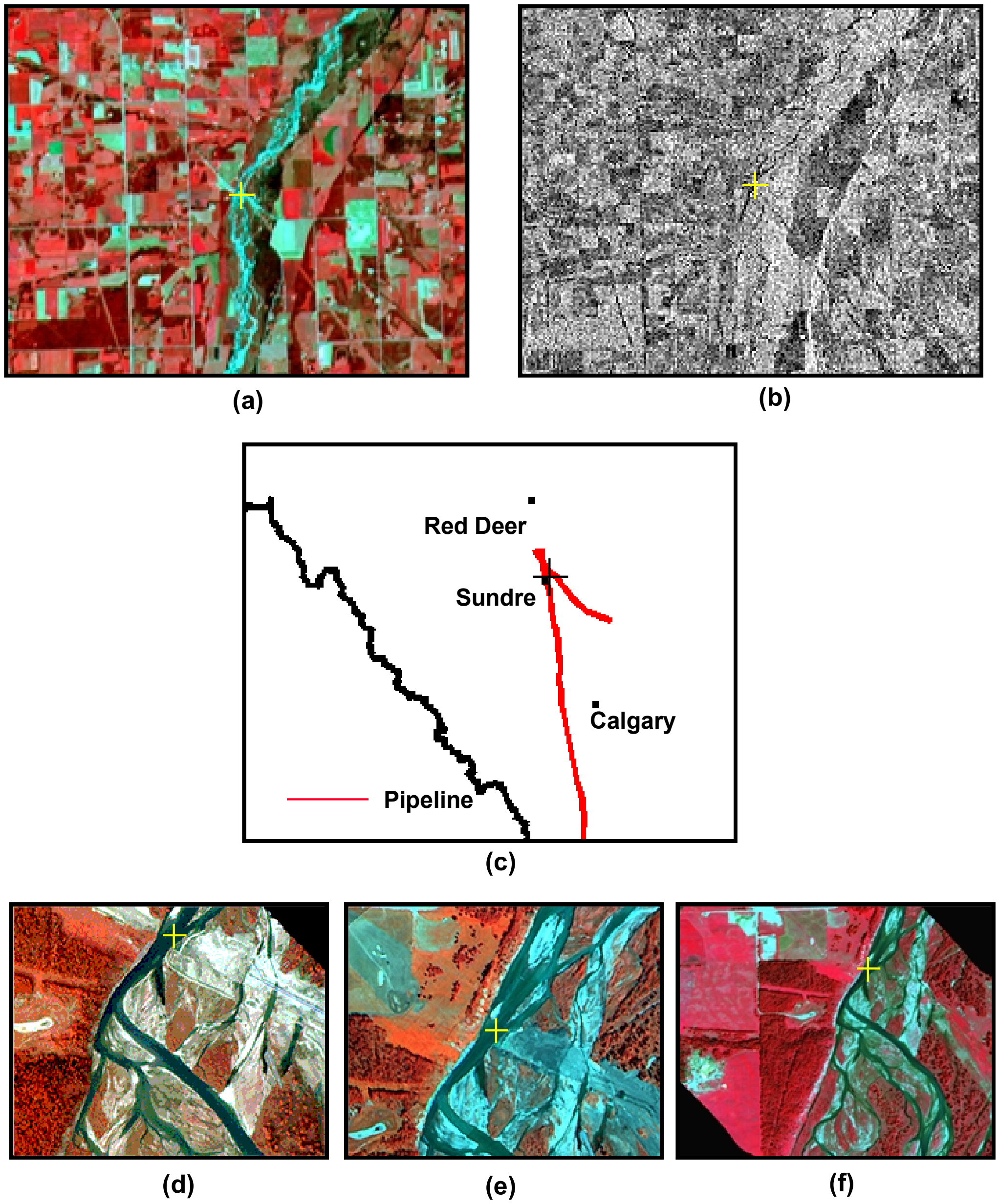

Figure 2. Diagram showing an example of the images acquired from different sensors and a sketch of the location where these images were taken. The hair-line cursor depicts the intersection between the Right-of-Way and the Red Deer river on each of the image and also on the sketch map. (a) SPOT MLA on July 28, 1997, (b) RADARSAT image acquired on August 20, 1997, (c) sketch map of the image location, (d) Frame camera image in August 1997, (e) video image mosaic in July 1997, (f) casi data on July 25, 1997.

Because of the constraints and the popularity of several off-the-shelf browsers, the HTML (Hyper-Text Marked-up Language) was chosen for the development. The HTML pages are designed according to the published version 3.0 standard. Plug-in and special programs that depend on specific features of the underlying operating systems, are avoided. Furthermore, the display of images that have more than three channels becomes a conflict with the constraints. HTML web pages display the prescribed image format of three channels. In order to allow users to dynamically select any three channels for display, there must be a program on the compact disk that can select and generate new compatible display files. This operation would require the generation of temporary file and CGI programming which are both restricted. To circumvent the situation, dynamic channel selection is replaced by prescribed sample display images stored on the compact disk. A similar strategy is used for vector overlay. Instead of real time manipulation, pre-processed vector overlaid files are stored. The disadvantages of this approach include: (1) only the prescribed samples are available, it might not cover certain channel and vector combinations that could be found useful later; and (2) it increases the storage requirement.

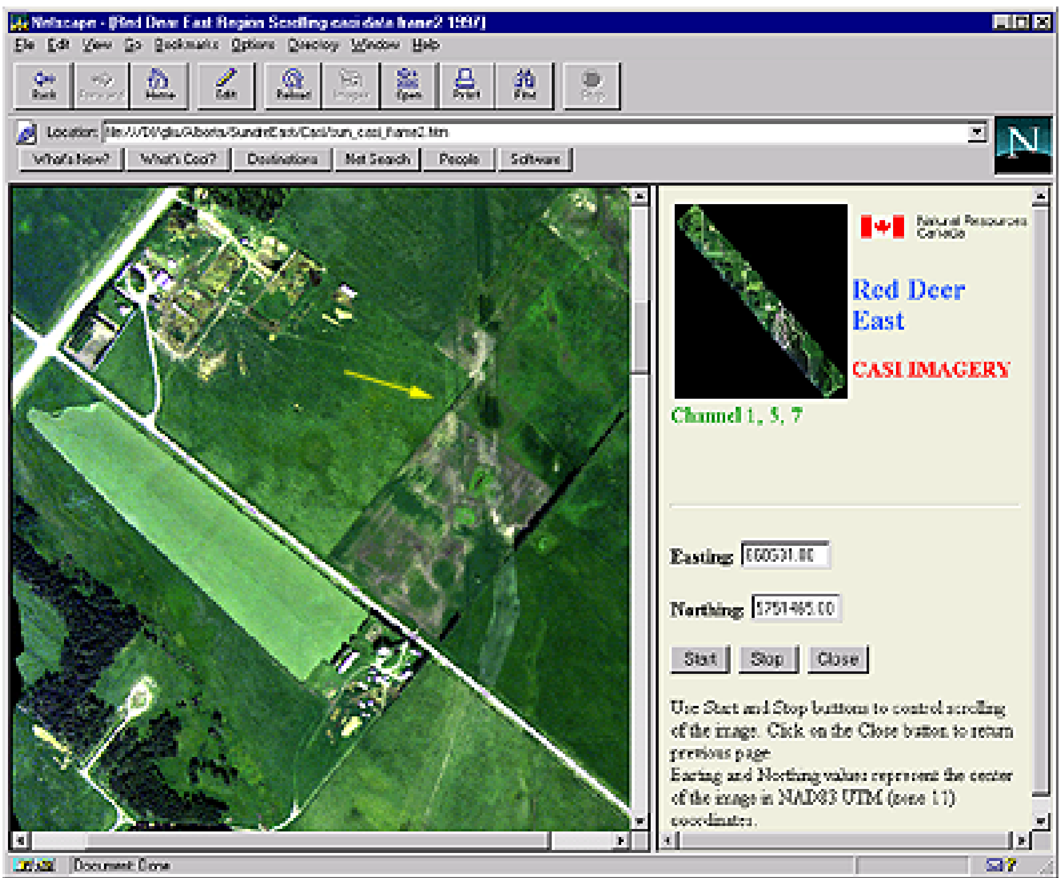

Figure 3. A screen capture of one of the web pages displaying a portion of the flight line in a scrolling window. The image was acquired using the casi instrument by ITRES in July 1997. Pointing by the yellow arrow is the Right-of-Way corridor.

The demonstration compact disk has several salient features. For viewing large files, a scrolling function is implemented such that a large image can be viewed dynamically at full spatial resolution (Figure 3). A large display image can be scrolled from top to bottom. The coordinates of the centre of display window are readout in real time in

UTM (Universal Transverse Mercator) northings and eastings. Scrolling images can be stopped and panned within a window.

Ground photographs (35 mm) acquired at specific locations can be viewed by clicking on the marked yellow dots where they were taken. Ground photographs have been found to be essential for understanding and analyzing different environmental situations. They provide in-situ information on the ground slope and vegetation conditions.

The HTML pages are organized in a hierarchical fashion according to image types and themes. It is easy to navigate among the images. All the images are geographically corrected to UTM geographical projection.

Conclusion:

High spatial resolution black and white photographs have been used for pipeline monitoring for several decades. This project intends to show that given the advancement in remote sensing technology, new digital remotely sensed image data can be applied to enhance some of the routine environmental operations and provide cost benefits to these operations for pipeline right-of-way monitoring.

We have reported on the issues and challenges of this project. At this time, the project has achieved two significant milestones:

1. project planning and development of data acquisition plan in consultation with our main industrial partner NOVA Gas Transmissions Ltd.;
2. execution of data acquisition through contracts to geomatics industry.

The demonstration is now proceeding into the value-added phase again through contracts to the geomatics industry as well as some in-house algorithm development by LEAP program staff.

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References:

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