THE EVOLUTION OF OPERATIONAL SATELLITE IMAGE GEOCODING IN CANADA

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ABSTRACT

For the past 15 years the Canada Centre for Remote Sensing (CCRS) and Canadian industry have been involved in joint efforts to design, develop and operate a series of leading edge preprocessing systems for the generation of geocoded image products of the Canadian land mass. This paper briefly summarizes these systems with particular emphasis on the evolution of processing and product requirements.

During the mid-1970s scientists at CCRS conceived and developed, in-house, the Digital Image Correction System (DICS), a geocoding facility which provided Landsat MSS geocoded imagery. DICS relied on manual control point (CP) marking and polynomial approximation to map imagery onto a UTM projection to sub-IFOV accuracy (typically 40-50 meter position accuracy). The key elements of the DICS development and operation included the specification of an image product compatible with existing topographic map standards, extensive 'hands-on' experience in an operational environment, and ultimately, the creation of an extensive control point data base encompassing most of Canada. Although the DICS architecture was effective for Landsat MSS correction, it did not lend itself well to meet the higher throughput and precision needs of the sensors of 1980s, namely, the Thematic Mapper and the SPOT MLA and PLA. CCRS therefore funded and jointly participated with MacDonald Dettwiler Associates (MDA) in the development of a new system, the Multi-Observational Satellite Image Correction System (MOSAICS). Extensive requirements studies ultimately led to the following MOSAICS system characteristics; sophisticated spacecraft modelling, aputomatic CP marking, automated work order processing, a compatible pixel size hierarchy and first order elevation correction.

MOSAICS spawned the development of a generic correction product line, GICS, which has been successfully marketed abroad by MDA and is also employed in two further correction systems procured by CCRS for ERS-1 and AVHRR processing. The ERS-1 GICS, developed in the period 1987-1990, forms an integral component of the Canadian ERS-1 Ground Segment. Because of its steep-viewing configuration, the ERS-1 SAR generates imagery exhibiting extreme terrain-induced parallax. This GICS therefore incorporates full parallax correction given the availability of dense digital elevation models (DEMs). The product line has also been extended to include two additional cartographic projections, polar stereographic and Lambert Conformal, in anticipation of the needs of Arctic and oceanographic applications. Recent interest in global change issues has led to the identification of a system, GEOCOMP, to both geocode and composite Canadian AVHRR coverage. GEOCOMP, a further GICS development, will allow for the processing of all Canadian AVHRR coverage, maintenance of 10-bit radiometric fidelity and merging of comparatively localized individual geocoded products into final composite products on a country-wide scale. The system is presently under development and will be operational in 1992.

Key Words: Geocoding, Operational, Production

DICS (DIGITAL IMAGE CORRECTION SYSTEM)

To foster the utilization of Landsat MSS imagery and its integration with geographical databases, CCRS initiated in 1976 the development of DICS, the first operational system to offer geocoded digital products to remote sensing users. The system was in operation from 1980 to 1985. During its five years of operation it produced, on demand, map-compatible Landsat MSS products for more than 75 percent of the Canadian landmass below 60 degrees, including many areas with extensive multi-temporal coverage. DICS products were also used for the determination of the position of isolated islands in the northern regions of Canada. The achieved accuracy was comparable to the compilation standards used then for Arctic mapping (Fleming and Guertin, 1980).

DICS geocoded products consisted of Landsat MSS subscenes (0.5 degree latitude by 1.0 degree longitude) covering four National Topographic System (NTS) map sheets at 1:50,000 scale or one quarter of a map sheet at 1:250,000 scale. The pixel size was 50 by 50 meters and was registered to the Universal Transverse Mercator (UTM) grid with the top-left corner of the first pixel being registered on a one-kilometer grid boundary. Irrespective of the sensor scan line orientation, the geocoded image lines were aligned with the UTM grid. The 50-meter pixel size was chosen to be smaller than the MSS 79-meter IFOV in order to avoid possible aliasing (Friedmann, 1981), and to form a convenient hierarchy with products from other remote sensing missions. Some of the geocoded product pixel sizes now in use include 25 meters for Thematic Mapper, 12.5 and 6.25 meters for SPOT, 500 or 1,000 meters for NOAA AVHRR data.

The DICS system configuration consisted of a Digital PDP-11/70 minicomputer, a colour display subsystem and a parameter driven 32-bit microprocessor based corrector. The minicomputer was responsible for input-output, data handling functions, and geometric as well as radiometric corrections modelling.

Geometric correction consisted of a manual Ground Control Points (GCP) extraction and a two-dimensional least squares transformation model. Using GCP locations digitized from 1:50,000 NTS maps, the operator could measure on the display subsystem their position in the uncorrected Landsat image to a sub-pixel accuracy by local zooming and contrast stretching.

Based on a bi-variate polynomial fit the geometric correction model was sensitive to the number and the distribution of the GCPs, as well as GCP marking blunders. This limitation resulted in the gradual creation of a large database of quality GCPs from 1:50,000 maps, covering most of the non Arctic regions of Canada. Automatic registration of GCP by digital correlation of image chips achieved only limited success and was not practical on an operational basis due to the nature of the geometric model and the lack of processing power in the host computer.

Using 1970s computer technology, DICS did not have the system and data management capability, the data input-output bandwidth and the processing power needed to achieve the throughput required to correct the higher resolution imagery from future remote sensing missions such as Landsat-4's Thematic Mapper and SPOT. The radiometric and geometric correction models were built in the corrector firmware and had been designed for MSS-like mechanical scanners. The system had the ability to apply pixel and line dependent additive and multiplicative radiometric correction, however it did not include a suitable scene dependent atmospheric model. Image resampling was performed in two one-dimensional passes, along the input scan lines and along the output image columns. The resampling was therefore significantly non-orthogonal for northern images, where the satellite local heading is important. DICS could not apply a digital terrain model for local relief correction.

The DICS experience at CCRS contributed significantly in the charting of future developments for remote sensing satellite data correction. It demonstrated that precision geocoded satellite products could be generated routinely on a production basis. The demand for geocoded products proved that such datasets could facilitate the analysis of remote sensing imagery and its integration with other geographical databases. However, to be well adapted to future missions, satellite image correction systems had to take advantage of the latest advances in computer hardware and software, as well as in attitude and orbit modelling.

The definition of geocoded products developed for and implemented in DICS have become widely accepted standards in Canada. The data processing and integration requirements posed by large environmental monitoring projects have illustrated the importance of geocoded product standards. DICS was clearly a forerunner in this area.

MOSAICS

The strong user acceptance of the DICS geocoded products, showed that there was a large demand for these products. Though the DICS architecture was effective for Landsat MSS correction, it did not lend itself well to meet the higher throughput (e.g. Landsat Thematic Mapper) and precision needs of the 1980s and 1990s. To meet these new requirements CCRS initiated a contract with MDA to develop the Multi-Observational Satellite Image Correction System (MOSAICS), a production facility to produce high quality geocoded products from multiple satellite sensors.

Extensive requirements studies led to the following MOSAICS design requirements.

(i) Multiple satellite/sensor processing
Processes data from Landsat 1 to 5 MSS, Landsat 4 and 5 TM, SPOT 1 and 2 Multi-spectral Linear Array (MLA) and Panchromatic Linear Array (PLA). The MOSAICS architecture which was built around a sensor dependent front-end and a sensor independent processing channel has been extended in the MDA GICS to process data from several new sensors.

(ii) Workorder Processing
The operator enters the information required for processing, such as product type, desired location, desired output format, on a MOSAICS workorder. Then, in the majority of cases, production proceeds automatically with intervention required only for routine operations, such as mounting of tapes or loading of films.

(iii) Automated Control Point Marking
Precision products are registered to ground control by correlating the imagery with image chips stored in a control point library (which was developed during the DICS operation).

(iv) Spacecraft Modelling
Implementation of sophisticated spacecraft modelling capable of high positional mapping accuracy over large portions of a satellite orbit with very few control points. This model has been used for a wide range of satellite/sensor systems.

(v) Wide Range of Output Products
Geocoded products are produced in a pixel size hierarchy which greatly facilitates subsequent data integration. Digital and film products in the satellite projection are also produced. A wide range of film product enhancements, which cater to specific uses, such as forestry and agriculture are supported.

(vi) Terrain Correction
A first order terrain correction can optionally be applied to compensate for terrain-induced geometric parallax.

Two limitations of MOSAICS that have been addressed in later CCRS developments are:

(i) It does not have the capability to apply a full elevation correction to remove terrain-induced geometric parallax.

(ii) It cannot mosaic geocoded images due to the absence of a suitable atmospheric correction model.

MOSAICS was designed first and foremost as a production system, that is to say, high throughput and minimized operator interaction were important design and implementation considerations. Since it was commissioned in January 1987 it has consistently produced a large number of high quality products. This is confirmed by extremely positive user feedback and increased data sales.

On the industrial side the GICS technology is used in a majority of satellite stations around the world for LANDSAT, SPOT, ERS-1, MOS, NOAA, and JERS-1 (1992) data. It has become a de facto world standard. The technology has found applications in other fields (e.g. underwater sonar mapping).

ERS-1 SAR GEOCODING

As part of Canadian participation in the ERS-1 program, CCRS has funded the development of a ground processing facility which includes reception, SAR processing, archiving, transcription and geocoding (Sack et al., 1989). The geocoding subsystem was built by MDA based on the GICS architecture. Although the GICS processing flow can be directly applied to SAR image correction, a number of enhancements were included to meet specific needs (Kavanaugh et al., 1989).

(i) To meet the requirements of oceanographic and Arctic applications geocoding to two additional cartographic projections, Polar stereographic and Lambert conformal has been included. At the same time, compatibility with LANDSAT and SPOT geocoded products has been maintained by offering UTM-corrected SAR products with a pixel size of 12.5 meters.

(ii) Because of the steep-viewing geometry of the SAR, ERS-1 image products exhibit terrain-related parallax 4-5 times greater in magnitude than the maximum parallax observed in SPOT (Guindon and Adair, 1992). Accurate elevation correction is therefore essential if the geocoded ERS-1 products are to be accurately merged with GIS and other cartographic-based data sets. The CCRS system therefore has the capability to ingest dense DEMs (i.e. DEMs whose horizontal sampling interval is comparable to the pixel size of the output image product), compute and apply terrain-related geometric corrections during the first pass (range-directed) of image resampling.

Initial testing both with SEASAT and early ERS-1 imagery has demonstrated that the robustness of the GICs architecture/correction methodologies in producing high quality radar image products. It is important however to note that operational SAR image geocoding is still in its infancy and that a number of issues such as optimum kernels for resampling in the presence of layover and shadow and the development of auxiliary or "value-added" product lines to complement geocoded SAR images require further study. The results of such studies should lead to a further improvement in SAR processing technology in time for RADARSAT.

GEOCOMP

With concern over environmental issues increasing, there is a demand for continued continental and global scale monitoring of vegetation from satellites. The NOAA Advanced Very High Resolution Radiometer (AVHRR) presently is the most suitable sensor for this initiatives. To meet Canadian requirements, CCRS is funding the development of a high throughput AVHRR geocoding and image compositing facility, GEOCOMP. Geocompositing differs from classical image mosaicking. A mosaic can be viewed as a "patch-work" quilt of contiguous blocks of imagery from individual input scenes. Mosaicking is not however an effective method for continental-scale vegetation monitoring since an individual AVHRR pass is likely to exhibit significant cloud contamination some of which, such as cumulo-nimbus buildup, is characterized by individual clouds which are smaller in scale than the AVHRR instantaneous field of view thereby rendering visual detection difficult. To generate a "cloud-free" product a composite process is employed. In this case all images are first geocoded. All available spectral measurements at each output location are then compared and are selected based on a vegetation index criterion.

GEOCOMP is being built by MDA as a variant of their GICS product line but with the following additional features

(i) In conventional geocoding systems, an output product constitutes a portion of the image data of a single input scene. For GEOCOMP, on the other hand, the final output product covers all of Canada and hence is a geo-composite of numerous input scenes acquired over a limited time window. High geometric correction precision is normally required to produce a "seamless" image mosaic product but is even more critical for compositing since precise co-registration is needed across the full scene swath. Our goal is routine geocoding to an accuracy of 800 meters (2-dimensional). To achieve this goal:

(a) a pass processing technique is used to allow for the derivation of a single spacecraft model for the correction of all imagery acquired during a single orbital pass over the Canadian land mass,

(b) ground control point marking on low resolution imagery such as AVHRR data is difficult and a major contributor to overall geocoding error. Following the proposal of Cracknell and Paithoonwattanakij (1989), a high precision control point data base has been created by marking cartographic features first on full resolution LANDSAT MSS and MESSR scenes. These scenes are then been spatially degraded to create image "chips" which can be digitally correlated with AVHRR imagery to provide desired geodetic control.

(ii) Since a prime application of the composites will be long-term monitoring, accurate radiometric corrections (i.e. both sensor calibration and atmospheric correction) are required to allow for the detection and quantification of temporal variation in surface cover properties. State-of-the-art radiometric correction techniques have therefore been included (Teillet, 1992).

(iii) In addition to geocoded imagery, GEOCOMP will provide a series of auxiliary and "value-added" products including vegetation indices, local solar illumination and sensor viewing angles.

FUTURE REQUIREMENTS

Although the need for and desirability of geocoded products have been successfully established there remain outstanding issues.

Improved Product Precision

In order to be fully integrateable with other cartographic data sets, geocoded images must be "true orthoviews". This implies that correction for terrain-related parallax must become routine, i.e. the norm rather than the exception. Extensive digital elevation data bases must become an integral part of future systems, a direction which has already been taken in the development of the German ERS-1 Processing and Archiving Facility (Schreier, et al., 1990).

Current systems rely on digitization of paper map features as a source of geodetic control. For SPOT image geocoding, map quality and the manual digitization process are major sources of error which effectively preclude the achievement of positioning accuracies at the level of the sensor IFOV (Sharpe and Wiebe, 1989). Future systems must be more flexible and capable of ingesting geodetic control from sources such as GPS networks.

Expanded Product Lines

With the exception of GEOCOMP, Canadian systems are limited to the generation of geocoded imagery of small geographical extent (i.e. either 1 or a block of 4 1:50,000 map sheets). Product lines must be expanded to include the generation of:

i) "value-added" products. These are raster overlays, co-registered with the geocoded imagery, which can be used to aid in scene interpretation.

ii) large area "seamless" image mosaics for both visible and SAR data. SAR mosaics have been shown to be particularly effective in capturing geo-morphological structures (Kwok, et al., 1990). There is a requirement for RADARSAT image mosaicking particularly for the provision of synoptic views from SCANSAR mode coverage. Mosaicking can be efficiently executed through pass rather than scene-based processing. High precision orbit/altitude modelling techniques have already been developed to meet this end (Sharpe and Wiebe, 1989).

Expanded Operating Strategy

To date only a minute fraction of all SPOT, Thematic Mapper and Landsat MSS coverage acquired over Canada has been geocoded. There are two reasons for this: (i) the modest throughput capability of current systems and (ii) the current operating strategy in which geocoded products are only generated upon customer request.

Although this strategy will be different for GEOCOMP in that all Canadian coverage will be processed, it is unlikely that full processing of high resolution coverage will be feasible in the foreseeable future. We would propose however that future systems alter their operating mode to allow for a two stream processing program, the traditional stream to meet specific customer needs and a second on-going, long-term program to systematically "map" either the whole country or to provide temporal coverage of limited areas of particular interest (e.g. urban areas undergoing rapid change, environmentally sensitive areas, etc.). The latter program would serve many goals such as to (i) provide an on-hand inventory of products of general interest which could be widely distributed to potential customers and educational institutions, (ii) provide additional high resolution information in support of national and global environmental programs and (iii) serve as an archival data source of historical/cultural significance.

CONCLUSION

For nearly 20 years Canadian government and industry have jointly worked to develop and operate facilities to geocode imagery from a wide range of spaceborne remote sensing satellites. The evolution of this initiative has been governed by two, at times, conflicting considerations; (i) to provide sensor-to-sensor product continuity and (ii) to address sensor-specific issues such as the accurate modelling of each sensor's unique geometric and radiometric characteristics and the provision of products which best exploit these characteristics. The pioneering efforts of DICS, particularly in the areas of product definition and system operation, and the industrial development of the GICS correction system line have highlighted this effort.

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