Large Scale Mapping: The Multispectral Airborne Solution

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From the first time that a land survey permitted mortgages on property in great number—the funds from which were promptly squandered on eighteenth century speculative stocks—there has been insistent commercial demand for definitive large scale land-related data. Today the rapidly expanding mandate for storage and management of this data, and its exponentially multiplying uses, is accelerating development in the fields of photogrammetry, remote sensing, image analysis, geographic information systems, and cartography.

Advances in these fields allow new approaches to the more traditional aspects of mapping. Remote sensing in large scale mapping has, in the past, been a poor cousin in terms of the needed photogrammetric properties; the solution lies in integrating airborne sensor technology and its supporting systems.

The traditional mapping process relies on aerial photography and photogrammetry to establish a ground relationship through aerial triangulation, and also on the extraction of land base features through manual interpretation from the analog imagery. Producing maps from photography is a time-consuming process with many phases, including aerial triangulation and stereo compilation.

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The most recent advances combine digital imagery with a number of supporting technologies, such as GPS (Global Positioning System). Also the development of analytical models helps in exploiting land-related information for automated mapping. These technologies promise to deliver a better product at lower cost and in a much shorter time. The collection, processing, storage, and management aspects of all these data have gone well beyond traditional mapping methods in improved performance and ease of operation.

Until recently, remote sensing sensors were used primarily for terrain feature identification as opposed to strict mapping function. The latter was typically limited to small scale thematic mapping from satellites; the geometric properties needed for an accurate imagery/ground relationship being limited by the unmodelled parameters of platform motion, image distortion in the focal plane, and spatial resolution. On the ground, development of digital image analysis demonstrated the capacity for computer-assisted thematic classification; techniques readily applicable to large scale mapping projects. The current revolution in the design of airborne digital sensors combines the best aspects for multispectral thematic classification and the optical properties for rigorous photogrammetric processing.

The Multispectral Electro-optical Imaging System (MEIS) sensor meets both thematic and photogrammetric requirements. MacDonald Dettwiler Associates of Vancouver and the Canada Centre for Remote Sensing in Ottawa developed the system. Based on linear array focal plane detectors—one for each of six recorded spectral bands with two separate optical channels for stereo capture—the design includes precise focal plane calibration for spatial properties and integration of precise navigation data, both essential elements to establish ground relationship. Improved spectral radiometry results from the push-broom imaging, giving a longer integration time per pixel than conventional scanning optics.

In operation, the MEIS sensor is linked to an inertial navigation system and differential GPS giving the imagery the necessary time element to provide the precise flight profile of the sensor in position and attitude. The spectral imagery is captured by detectors and recorded digitally in parallel onto high density tape. The digital imagery is then married up with the navigation data enabling direct geometric processing and imagery analysis. The stereo aspect immediately enables two specific functions: photogrammetric manipulation and generation of digital terrain models.

The thematic and photogrammetric output from MEIS come together at this stage in associated GIS databases. With the recent evolution of sophisticated raster format GIS, complete with faster, more powerful individual workstations, the transcription of huge quantities of imagery data is possible. The most notable

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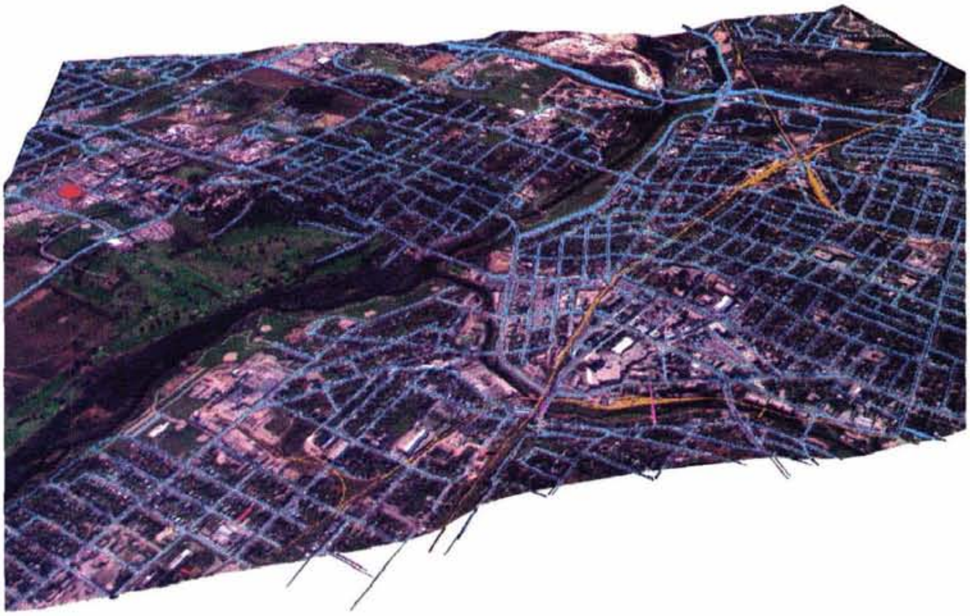

MEIS digital ortho-imagery and the GIS data for the streets and railways are combined with the digital terrain models to produce this high resolution perspective of the Guelph area.

advances in applying large scale mapping to GIS have been related to high quality images from airborne sensors, such as MEIS. This unique *all digital* method has the distinct advantage of providing the best information without the drawbacks associated with scanned imagery, which can include errors in transcription and the limitation to essentially three spectral bands.

The development of digital mapping closely parallels the advances in computer technology. The first developments were specifically in the area of automated cartography in an attempt to expedite the production of paired drawings used in mapping. The next stage saw digital stereo compilation developed as a means of removing one part of the process by attaching shaft encoders to the output of the stereoplotter. It was not necessary to digitize the compilation manuscript that traditionally resulted from the stereo compilation process. Instead, a digital file was produced directly from the stereo compilation activity. On the output side, digital cartography has advanced substantially with the introduction of desktop mapping systems based on processing and display capabilities. Of course, there is still the element of art associated with cartography which is achieved through the graphic editing tools which are now part of most GISs.

Because MEIS captures imagery data in digital form, the fundamental elements used to derive information are pixels. Each pixel encodes a spectral reflectance value for each of the individual bands; the pixels provide spectral radiometric characteristics of the terrain. The imagery analysis techniques have emerged as a complex series of actions that range from initial ground correction to feature classification to deliniation and abstraction. When carried out well, this analysis allows the direct relation of the data to any specific GIS.

The first task is to build a good ground relationship so that each pixel is associated with a specific ground position, defined in terms of geodetic coordinates, such as Universal Transverse Mercator (UTM). In order to associate each pixel with a given ground position, it is necessary to know the exact attitude of the aircraft at the time the pixel value is recorded by MEIS. The inertial navigation system and GPS give a faithful and continuous record of the exact sensor position and attitude at any point in time, which then may be interpolated to any level of resolution required. In the geometric processing, GCPs (Ground Control Points) are referenced to the imagery, and, with the addition of the digital terrain model, are input to enable a resampled digital ortho-image. This establishes the rigorous ground relationship. The ortho-image retains the spectral radiometric information needed for the later feature exploitation. It is the combination of these features which makes the MEIS technology so attractive for automating many of the GIS functions.

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The cover of this month's issue shows MEIS imagery of the City of Guelph, Ontario which contracted GEOREF Systems and Innotech Aviation to build a municipal GIS database to meet all of the land-related data requirements for the municipality. Pam Ross, the GIS Manager for Guelph summarized the background thus:

> "[the city]...needed to update and expand its 1:2,000 large scale mapping to reflect changes to the land base within the city. Guelph's topographic mapping, though used extensively, had become increasingly outdated since the project's onset in 1982 and no coverage existed for the periphery of the city or proposed annexation areas. To meet this need, the city was flown in October of 1991 using MEIS technology. The result was a full color, digital image that was used to update the topographic database in Guelph's GIS.
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> "The [Ontario] Ministry of Natural Resources (MNR) is responsible for the administration and delivery of the Ontario Basic Mapping Programme (OBM). The usefulness of the OBM is a direct reflection of its currency, content, and accuracy. As a result, a key responsibility of the MNR is to perform regular map/database updates and revisions to its existing base. From time to time, MNR reviews and investigates new update and maintenance procedures, technologies, and techniques toward ensuring cost effective map revision and update.
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> "In an effort to combine both interests of the city and MNR, and to eliminate duplication of effort and cost, both parties entered into a joint agreement, realizing the mutual benefits of the work to be completed."

To fully exploit the MEIS data, a digital topographic database for the OBM 1:2,000 mapping first had to be created. Over the course of several years, 60 percent of the city had been mapped in this manner, using money from the Engineering Department's budget. For those parts of the city not mapped at 1:2,000, the OBM 1:10,000 map base was used. The difficulty in using the 1:10,000 alternative was that even while being built, it was rapidly becoming dated and unreliable for the planning and engineering functions, requiring frequent field checks. The primary reason for starting with a topographic base was to build a simple ground relationship for the municipality which could then be used to register other land-related data.

The second major component was the parcel fabric used in building the cadastre. We used existing assessment maps from the Ontario Ministry of Revenue. These maps were drafted from existing subdivision plans, survey plans, and any other relevant information that was available within the municipality. The assessment maps were digitized on a block-by-block basis. Each block was digitized as a polygon system with topological and geometrical consistency as part of its underlying fabric. The block was then fitted to the OBM map base by referencing block corner locations on the OBM fabric and using a least squares adjustment. In all cases except one, the fit was better than one metre. A subsequent phase allowed us to check for geometric consistency; for example, the block faces on opposite sides of the street should be parallel, etc. Individual dimensions, such as lot frontage and various metes and bounds descriptions, were also maintained

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The MEIS digital mosaic is overlaid with the OBM 1:2,000 digital GIS map.

Three of the six MEIS calibrated spectral bands are employed to produce this false color digital image. The reflected infrared band enhances the red-encoded vegetation for computer-assisted feature extraction.

to check the accuracy of the result and base. It was felt that this was more than sufficient for the needs of the municipality in carrying out its day-to-day functions.

The resulting database accurately describes the subdivision of the land for ownership. However, many of the attributes associated with the various properties are found in other databases, such as the assessment database provided by the Ministry of Revenue. Thus, this information was loaded into a property database and linked to the associated cadastral fabric. The relational database structure was used to maintain this information, since much of it is tabular in nature.

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The next major database to be developed is the engineering database. It must be accurate to a few centimetres in order that capital work projects and operations related to the infrastructure can be carried out directly from the database without requiring major field surveys. This database is currently being built using a somewhat different method-

The process for automated extraction of spatial and spectral features is illustrated for the water area in this image. Boundaries of homogeneous features form the GIS polygons.

requiring major field surveys. This database is currently being built using a somewhat different method-ology. Because of the accuracy requirements, total station technology is being exploited.

The above set of information provides an extensive GIS for the municipality. It should be recognized that maintenance of the space and validation of its quality is an ongoing process that requires further effort. This is one of the key reasons that it was decided to fly comprehensive MEIS imagery for the city and to use this information for change detection and updating the topographic map base.

The image resolution was set at one metre to be consistent with the OBM map base. Acquisition operations were scheduled for late fall of 1991, when foliage would be off the trees and land-referenced features would be readily distinguishable. Eighteen flight lines were laid out to cover the city and surrounding area. The total area covered was approximately 200 square kilometres. Actual acquisition time to complete the area was less than three hours. Subsequently, the imagery was geometrically corrected to establish the relationship to the existing digital topographic map base. The image database was tiled using 100 metre square tiles, the RMS error was found to be less than

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GIS features, such as streets, building, and parks are extracted from the MEIS data using computer-applied expert reasoning techniques. The process enhances efficiency in updating or constructing the urban digital map.

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one pixel, or one metre, for over 90% of the data. The result is a seamless digital imagery database with no visible evidence of the merging of the adjacent map sheets.

So MEIS provides extremely versatile data rendered directly into GIS format, readily available to those who plan for the municipality, region, or government. "This is the most efficient way to acquire the data we need for the city, and the methods used are already pushing the limits of traditional municipal mapping," is how Pam Ross characterizes the digital imagery potential.

> **Providing large scale mapping data . . . is the primary challenge to the acquisition and processing elements of this field.**

The next chapter of this story lies in the broader mapping applications considered by Guelph and other urban organizations. Feature extraction of the spectral and spatial properties for thematic classification cover a multitude of topics, a short list of examples includes: transportation networks, communication networks, power grids, waterways and drainage, land use, and green space definition, all of which are probable thematic applications. The change detection feature covers all aspects of municipal land registry issues with the added efficiency of a rapid update capability. Urban development aspects such as residential, commercial, industrial, and agricultural planning and controlling issues are also made readily available to users.

Meeting the demands of providing large scale mapping data in a timely and accurate manner, and benefitting from the inevitable improvement to digital sensors in the years to come, is the primary challenge to the acquisition and processing elements of this field. In a world that is being forced to better assess its natural and constructed resources for an improved utility and responsible public planning, the employment of adaptable and efficient means to define these assets is becoming mandatory. The results are self evident; as Pam Ross concludes, "MEIS incorporates a new all digital technology in a broad range of GIS applications, and is likely to replace traditional analog photogrammetric methods."

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The Remote Sensing Division of Innotech Aviation provides unique all digital airborne remote sensing products for environment, urban development, and natural resource issues from its base in Ottawa. GEOREF Systems Ltd. of Waterloo provides both comprehensive services and software solutions for GIS and LRIS (Land Related Information Systems) applications.