HIGH-RESOLUTION IMAGERY IN GENERATING SPACIAL INFORMATION

Satellite Mapping in Bhutan

High-resolution satellite imagery (HRSI) has significant potential for producing 3D spatial information products. Nowhere is this more apparent than in remote areas of the world such as the small Himalayan Kingdom of Bhutan. A project was designed to both demonstrate the utility of HRSI for medium-scale map production, and to pass these technological skills and tools to the Bhutanese. The authors show the potential shown by HRSI in meeting the spatial information needs of a developing country.<P>

To support national development initiatives, Bhutan needs more comprehensive topographic and cadastral mapping. In many fields, ranging from environmental management to land and infrastructure development, and from town planning to forestry and agriculture, progress has been impeded by a lack of medium-scale maps; most maps are at least thirty years out of date and thus of questionable quality.

Mapping Needs

The challenges in providing map data are daunting; Bhutan has, for example, only one airport and two aeroplanes, both commercial jets. The mountains offer challenges for aerial photography, complicated by airspace restrictions in neighbouring countries that preclude commercial aerial photographic missions. As a result, there has been no aerial photography mission of any significance since 1991. The ongoing collaboration with the Survey of India to acquire new aerial photography has not, over the past several years, resulted in useful imagery. A potential solution at hand is high-resolution satellite imagery (HRSI), which offers an attractive alternative to aerial photography for spatial-data generation in remote areas. Ideally, 50cm to 1m-resolution satellite images could be used for topographic map compilation, but with an area of approximately 40,000km² to cover, cost constraints must be considered. A second, more cost-effective option involves the use of 2.5m-resolution imagery, but while the metric performance of SPOT5, CartoSat1 and ALOS PRISM approaches that required for 1:25,000 mapping, it is widely acknowledged that the feature information required at this scale cannot generally be extracted from such imagery. Further options involve use of both 1m and 2.5m imagery, including ALOS PRISM or SPOT5, to provide DEM data, along with topographic feature information for less populated rural areas. Imagery from Ikonos, WorldView or Quickbird, to name three prospective sources, could provide from single images (monoplotting mode) 1m-accurate 3D mapping of the principal towns and high-priority areas.

The Project

Over the past five years, a research project to assess the potential of HRSI for 3D spatial data generation in Bhutan has been underway. The main participants are The National Land Commission of Bhutan, the Department of Geomatics at the University of Melbourne and the Institute of Geodesy and Photogrammetry at ETH Zurich. The aim has been twofold. Firstly, to evaluate HRSI as a data source for meeting Bhutan’s mapping needs. And secondly to assist the National Land Commission by way of technology transfer in the form of training and the provision of software tools and sample HRSI data that will enable Commission personnel to improve their skills. Through the generosity of HRSI providers, stereo Ikonos, Quickbird, SPOT5 and ALOS PRISM imagery has been made available to the project, as have the software systems of Barista and SAT-PP, from the Cooperative Research Centre for Spatial Information at the University of Melbourne and ETH Zurich, respectively. (See for a description of ALOS, GIM International, May 2006, Vol. 20, No. 5). The capacity building that this has enabled has included the generation of DEMs, orthoimagery and landscape visualisations, and 3D-feature extraction via monoplotting. The latter has been applied to tasks as varied as road centreline mapping and the coarse verification of cadastral data. Moreover, the imagery has facilitated the creation of high-precision testfields for verification of new sensor orientation models for HRSI, and DEM generation strategies for mountainous terrain. The outcomes that have had, or currently have, the potential for immediate impact upon the enhanced provision of spatial information by the National Land Commission are summarised below.

Geopositioning Accuracy

The first question posed by the Bhutanese was, with what accuracy can feature points be positioned from HRSI, especially when the opportunity for establishing ground control is limited. The answer was found through experiments involving Ikonos, Quickbird, SPOT5 and ALOS PRISM stereo imagery (three-line images in the case of PRISM). An array of sixty GPS-surveyed points was established in an area of 50 x 60km with elevation range of 1,900m to 3,300m and with most points along the relatively few roads. For 1m-imagery, the use of rational polynomial coefficient (RPC) bias correction, which requires a single ground-control point (GCP), yielded ground point positioning to 1-pixel accuracy. The 1m accuracy easily surpasses requirements for Bhutan’s 1:25,000 mapping and is also sufficient for coarse verification of digital cadastral maps compiled over the past twenty years, often from plane-table surveying. The orientation of the SPOT5 and ALOS images was performed using a rigorous sensor model, due to the absence of RPCs. Here too, 1-pixel geopositioning accuracy was obtained from as few as four GCPs.

Computations were carried out independently with SAT-PP and Barista, and equivalent results obtained.

DEM Generation
The next step was to assess the quality of DEMs of the mountainous terrain produced from stereo-image pairs. Because of the absence of 'true' terrain surface data, a hierarchical approach was adopted. First, DEMs were generated using area-based matching with geometric constraints, as implemented within SAT-PP. Computed elevations were then compared with available checkpoints, the RMS error being generally in the range of two to 2.5 pixels. The DEM data from Ikonos and QuickBird was then used as a basis to assess the precision achieved with the SPOT5 and PRISM imagery. The results indicated an agreement between the DEMs from the 1m- and 2.5m-imagery of 5-7m RMS, except in areas where the terrain was excessively steep, where many blunders were detected in the samples of more than a million points. Nevertheless, all HRSI stereo pairs produced DEMs consistent in quality with expectations. While it is always tempting to adopt the freely available 3-second SRTM DEM for Bhutan, such radar-derived terrain data has quite severe accuracy limitations in Bhutan's mountains, where the average slope may well be higher than 30%. Comparisons between 250,000 points from a QuickBird-derived DEM and the corresponding SRTM DEM revealed a high RMS discrepancy value of 13m, with 32% of the SRTM elevation values being classed as blunders.

Orthoimagery
Assessments were carried out on the orthoimagery produced by all four satellite sensors, employing DEMs derived from these same sensors, comparing planimetric position against GPS-surveyed checkpoints. The accuracies were basically equivalent to the above figures, though a little poorer. A thorough analysis of orthoimage generation from Ikonos and QuickBird imagery using a SPOT5- or ALOS-derived DEM has still to be undertaken, since a near-nadir image would usually be preferred over one of the more oblique images from each stereo pair. Nevertheless, considering the very narrow field of view of 1m HRSI sensors, only small planimetric error effects would be anticipated for modest errors in the DEM.

Monoplotting
Once a DEM of sufficient quality is in place, monoplotting from single, oriented images becomes a viable approach for extraction of 3D points, lines and polygons. The Barista system also supports 3D building modelling via monoplotting. Tests of monoplotting performance using Ikonos and Quickbird images with DEMs from SPOT5 and ALOS PRISM showed that geopositioning accuracy to one to three pixels may be readily achieved, even in steep terrain. The left-hand image in Figure 4 shows a monoplotted line of a steep road. After back projection into the right image, the degree of correspondence between left and right is a verification of positional integrity. One interesting potential application of monoplotting from HRSI lies in the identification and rectification of discrepancies in digital cadastral data. Figure 5 shows a section of the cadastre in the Paro area of western Bhutan, registered with the Ikonos orthoimage. Differences between boundary data and the current situation on the ground are readily apparent. Moreover, the provision of HRSI and the ability to reliably position boundary points is beneficial in the resolution of land disputes.

Concluding Remarks
The project will be continued, but with the focus more upon practical implementation and technology transfer. For example, the photogrammetric section of the National Land Commission is now using Barista for monoplotting. An extension of the project will involve the use of HRSI for 3D-modelling of an archaeological site in the Bumthang Valley.

Box:

Bhutan

Wedged between the emerging economic powerhouses of India and China, Bhutan is known for its adoption of "Gross National Happiness" (GNH) as a measure of national wellbeing. This exotic land has an excess of riches in cultural tradition, but a paucity of financial resources, and it has long faced development constraints due to its mountainous terrain and geographical isolation (Figure 1). Bhutan aspires to develop in a way that balances the four pillars of GNH: socio-economic development, environmental preservation, cultural promotion and good governance. The economy is primarily agrarian. Other industries include forestry, hydroelectric power and, increasingly, eco-tourism. Bhutan's record on environmental preservation is impressive, as has been its ability to keep development goals in harmony with Buddhist social traditions. Bhutan is to become a constitutional democracy in mid-2008.

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Further Reading
- Kocaman, S., Wolff, K. and Gruen, A., 2007. Geometric Validation of ALOS/PRISM Images. Proceedings, 1st Joint Principal Investigator Symposium of ALOS Data Nodes, JAXA, Kyoto, 19-23 November, five pages (on CD-ROM).

-Willneff, J., Poon, J. and Fraser, C., 2005. Single-Image High-Resolution Satellite Data for 3D Information Extraction. Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, (eds. Heipke, C., Jacobsen, K., and Gerke, M.), Hanover, Vol. 36, Part I/W3, six pages (on CD-ROM).

-Poon, J. and Fraser, C.S., 2006. High-Resolution Satellite Imagery in Remote Regions, a Case Study in Bhutan. Australian Remote Sensing and Photgrammetry Conference, ARSPC2006, Canberra, 20-24 November. p5.

-Weser, T., Rottensteiner, F., Willneff, J. and Fraser, C.S., 2007. A Generic Pushbroom Sensor Model for High-Resolution Satellite Imagery Applied to Spot 5, QuickBird and ALOS Datasets. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, (eds. Heipke C., Jacobsen K., and Gerke M.), Hanover, Vol. 36, Part I/W51, six pages (on CD-ROM).

-Zhang, L. and Gruen, A., 2006. Multi-Image Matching for DSM Generation from IKONOS Imagery.ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 60, pp 195-211.