HIGH-RESOLUTION SATELLITE IMAGERY FOR SPATIAL INFORMATION GENERATION IN BHUTAN

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ABSTRACT:

High-resolution satellite imagery is a viable source of imagery for spatial data generation in a developing country such as Bhutan. Half-metre to 1m resolution HRSI has the potential to be used for topographic map compilation and 2.5m stereo imagery could be employed for DEM generation and for mapping in more remote, non-urban and non-agricultural areas. This paper overviews an ongoing project, the main aim of which is to verify the potential of HRSI for 3D spatial information generation in Bhutan. A further aim is to assist the National Land Commission of Bhutan by way of technology transfer in the form of training and the provision of software tools and sample HRSI data to enable an up-skilling of Commission personnel. This capacity building component of the project has so far included evaluation of geopositioning accuracy, the generation of DEMs and orthoimagery, 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. In summarising the project the authors will touch upon aspects related to the terms of reference of the Special Studies Group "Technology Transfer Caravan", namely the transfer of knowledge and technology with special consideration being directed to the needs of developing countries.

1. INTRODUCTION

As a landlocked developing country, wedged in the Himalayan foothills between India and China, Bhutan faces many changes in its quest to provide up to date map coverage of its small but mountainous territory. Indeed, the challenges are daunting and not confined to the familiar lack of resources. The country has, for example, only one airport and a few aeroplanes, all commercial jets. The high elevation mountainous terrain offers challenges for aerial photography, a fact complicated by airspace restrictions in neighbouring countries which effectively preclude commercial aerial photographic missions. As a consequence there has been no aerial photography mission of any significance in the country since 1991. Though there is an ongoing collaboration with the Survey of India to acquire new aerial photography for the entire country, there has been no useful imagery delivered within the past several years.

The lack of basic image data for map compilation is causing a number of problems for Bhutan, which is developing at an accelerated rate. In a host of areas, ranging from land development, town planning, forestry, agriculture, road engineering and even cadastral surveying, development is constrained and made more difficult as a consequence of there being very limited current medium scale topographic map coverage; the majority of the coverage being at least 30 years out of date and thus of questionable quality in many areas.

The Topographic Mapping Division of the National Land Commission (NLC) of Bhutan has responsibility for the production and maintenance of the topographic maps and especially the national 1:25,000 series. As can be appreciated, the lack of access to suitable imagery for photogrammetric processing has an impact that goes beyond the imposition of constraints upon the ability to produce new and updated mapping. An unintended consequence is the growing difficulty in maintaining the skill levels and experience of technical and professional staff. One of the aims of the project to be described is to provide an effective program of technology transfer and local capacity building, in the form of training, joint project work, seminars and workshops, and through the provision of imagery data and photogrammetric software systems that will allow the NLC staff to stay abreast of relevant new developments. They can then apply these within Bhutan's mapping overall program.

The aim stated above is fully consistent with the Terms of Reference of the Special Interest Group "Technology Transfer Caravan" of Commission VI of the ISPRS. In the remainder of this short paper, the authors briefly overview the project, which is investigating the applicability of utilising high-resolution satellite imagery (HRSI) for providing geospatial data for Bhutan, principally to support topographic mapping, cadastral mapping and various local and regional planning functions.

2. HRSI AS AN INFORMATION SOURCE

Bhutan needs to look towards information sources that can provide low cost and quick-delivery land information products, without compromising metric accuracy. HRSI is thus a potentially ideal data source, since it supports geopositioning and production of numerous spatial information products, such as digital surface models (DSMs), orthoimages and visualisations. While HRSI can be costly, particularly when acquiring stereopairs, it does not require any supporting infrastructure, such as equipment, mobilisation, or complex processing abilities.

Ideally, 1m HRSI will be used for topographic map compilation, though there are cost constraints involved when it is considered that the country has an area of approximately 40,000 km^2. A second, more cost effective option involves the use of 2.5m resolution imagery, but while the metric performance of SPOT5, Cartosat-1 and ALOS PRISM can satisfy metric accuracy requirements for 1:25,000 mapping, it is by no means clear that the feature information generally required at such a scale could be comprehensively extracted from such imagery. A further option involves utilisation of both 1m and 2.5m imagery, and here there are a number of permutations that might be considered. These include, for example, use of ALOS PRISM, Cartosat-1 or SPOT5 to provide DEM data, along with topographic feature information for less populated rural areas.

Half-metre resolution imagery from WorldView or 1m imagery from IKONOS or QuickBird, to name three prospective data sources, could then be employed in a monoplotting mode to map the principal towns and other priority areas. While it is tempting to adopt the freely available 3-second SRTM DEM, such radar derived terrain data has some quite severe accuracy limitations in Bhutan, where the average terrain slope could well be more than 30 degrees.

Over the past half decade there have been a number of evaluations of the potential of HRSI for topographic mapping. For example, Great Britain's National Mapping Agency (NMA) has investigated the use of QuickBird imagery for updating mid-scale (1:25,000 and 1:50,000) and large scale (1:10,000 through 1:2500 to 1:1250) mapping (Holland et al., 2006). Also, the use of IKONOS imagery for mapping has been evaluated by several European mapping agencies and institutions in the EuroSDR Organisation (formerly OEEPE). Findings were that rural regions can benefit from such imagery when mapping at 1:10,000 and 1:50,000 scales (Holland et al., 2003). Developing countries similarly consider IKONOS imagery for large scale map revision and there have been studies that conclude that mapping to scales of 1:10,000 and larger is feasible. The potential of IKONOS stereo images for 1:25,000 topographic map production is currently being investigated at the Institute of Geodesy and Photogrammetry, ETH Zurich. First results are actually quite discouraging when the very high mapping standards set by Switzerland are taken into account (Gruen and Wolff, 2008).

Despite positive reinforcements about the geometric potential of HRSI, the technology is not as widely used within national topographic mapping programs as its potential might suggest. This is partly because there is a viable, currently preferred and generally less expensive alternative, namely aerial photography. However, Bhutan does not have this alternative; its practical options are effectively limited to HRSI.

3. THE HRSI PROJECT

Over the past five years, a project which assesses the potential of HRSI for 3D spatial data generation in Bhutan has been underway. The aim of this initiative has been twofold: 1) to evaluate in a practical way the use of HRSI as a data source for mapping, and 2) to assist the NLC by way of technology transfer in the form of training and the provision of software tools and sample HRSI data. The tools and training will enable an up-skilling of NLC personnel, who would otherwise not have access to HRSI technology. Through the generosity of HRSI providers, stereo and mono 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 University of Melbourne and ETH Zurich, respectively. The capacity building that this has enabled has included the generation of DEMs and orthoimagery, 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 a high-precision testfield for verification of new sensor orientation models for HRSI, and DEM generation strategies for mountainous terrain.

In the following sections, we will briefly overview some of the outcomes of the Bhutan HRSI project and discuss progress with the technical evaluation components of the work. The conduct of the project has included technology transfer and capacity building aspects at various stages.

4. BHUTAN HRSI TESTFIELD

The Bhutan testfield spans approximately 3000 km^2 and it covers alpine peaks up to 4200 m elevation, as well as forested mountains, cultivated valleys and the two main urban centres in the country, Thimphu and Paro. The average terrain slope in the testfield is a very high 27^o, which is representative for most of Bhutan. Figure 1 shows the testfield, which is covered by a single SPOT5 scene. Also shown in the figure are the positions of 65 ground control points (GCPs). Most of these served as checkpoints for the experimental accuracy assessment of geopositioning, DSM and orthoimage generation, and monoplotting. Given the relatively limited access to much of the area in the testfield, GCPs were confined to roads. They generally comprised road intersections or roadside features identifiable within the SPOT5 imagery. Unfortunately not all theses features were visible in the imagery from other HRSI sensors and they were not optimal for accuracy assessment of the imagery from IKONOS and QuickBird. Nevertheless, they sufficed for the purpose of evaluation HRSI for 1:25,000 mapping and for other purposes such as cadastral map data verification.

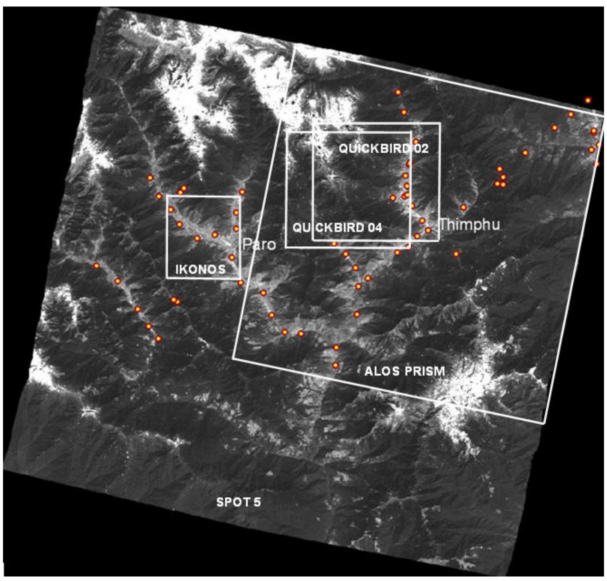

Figure 1. 60 x 60 km Bhutan testfield with 65 GPS-surveying GCPs.

HRSI data for the test field was made available by Spot Image, JAXA, GeoEye and DigitalGlobe, with the areas covered by the respective scenes being shown in Figure 1. The SPOT5 HRG, ALOS PRISM and IKONOS coverages were stereo, whereas for QuickBird, there was stereo and a mono coverage on two different dates.

In considering the testfield data available, it is useful to keep in mind that one of the practical scenarios for 1:25,000 mapping from HRSI data in Bhutan calls for use of stereo 2.5m imagery for DEM and orthoimage generation over the whole country, and then employment of 1m imagery for orthoimage mapping and feature extraction in the urban and selected rural areas. Monoplotting from the 1m imagery could then be employed in conjunction with the DSM data generated from SPOT5, ALOS PRISM or Cartosat-1, for example.

5. PROJECT RESULTS

5.1 Georeferencing

Fundamental to all derived mapping products is the integrity of the sensor orientation model and the georeferencing accuracy of HRSI. Important in the case of Bhutan is the accuracy achievable with a minimal provision of ground control since access to much of the country is quite difficult. For 1m imagery, it was shown that utilising the technique of rational polynomial coefficient (RPC) bias correction, which requires a single GCP, ground point positioning to 1-pixel accuracy was readily achievable. In this case the 1m accuracy attained easily surpassed requirements for Bhutan's 1:25,000 mapping series and it is also sufficient for the purposes of coarse verification of digital cadastral map data which was compiled over the past 20 years, often from plane table surveying.

The orientation of the SPOT5 and ALOS PRISM images was performed using a rigorous sensor model approach 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 (Kocaman et al., 2007) and Barista (Weser et al., 2007; Fraser et al., 2007) and equivalent results were obtained.

5.2 The Generation of DEMs

The quality of DEMs produced from HRSI has a strong bearing on the accuracy of subsequent orthoimage generation and feature extraction via monoplotting, especially in Bhutan's mountainous terrain. In order to assess DEM (actually DSM) accuracy, the terrain models generated from the stereo pairs of IKONOS, QuickBird and SPOT 5 imagery, along with that from the 3-fold ALOS PRISM coverage, were compared via both ground checkpoints, and relative to one another and to a 3-second SRTM DEM. Because of the absence of 'true' terrain surface data, a hierarchical approach was adopted in the assessment. In the first instance, DEMs were generated using area-based matching with geometric constraints, as implemented within SAT-PP (Zhang and Gruen, 2006). Computed elevations were then compared with available checkpoints, the RMS error being generally in the range of 2-2.5 pixels. The DEM data from IKONOS (Figure 2) 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 RMSE, except in areas of excessive terrain steepness where many blunders were detected within the samples of more than a million points (Poon and Fraser, 2006). Nevertheless, it was demonstrated that all HRSI stereo pairs produced DEMs consistent in quality with expectations. While it is always tempting to adopt the freely available 3-second C-band SRTM DEM for Bhutan, such radar derived terrain data has quite severe accuracy limitations in Bhutan's mountains. Comparisons between 250,000 points from a QuickBird derived DEM and the corresponding 1-second X-band SRTM DEM (processed by DLR, Germany) revealed a high RMS discrepancy value of 13m, with 32% of the SRTM elevation values being classed as blunders.

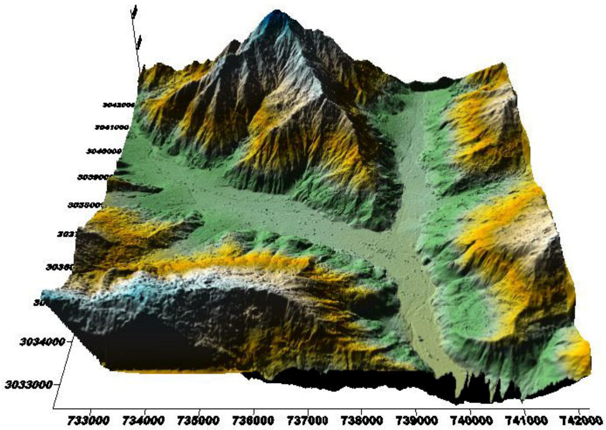

Figure 2. DEM of PARO area produced from IKONOS.

5.3 The Generation of Orthoimages

Orthoimagery was produced from images from all four satellite sensors employing DEMs derived from those same sensors. Accuracy checks involving comparisons of planimetric position against GPS-surveyed checkpoints indicated that accuracies basically equivalent to the geopositioning results reported earlier were obtained, though they were a little poorer. A thorough analysis of orthoimage generation from IKONOS and QuickBird imagery utilizing a SPOT5 or ALOS PRISM derived DSM 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, when 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.

5.4 Monoplotting for Mapping

Monoplotting from single, oriented HRSI images becomes a very viable approach for extraction of 3D point, line and polygon data in situations where there is accurate sensor orientation and an underlying DEM. The monoplotting function is a particular feature of the Barista system, which also supports 3D building modelling via this technique (Willneff et al., 2005). Tests of monoplotting performance utilising IKONOS and QuickBird images with DEMs from SPOT5 and ALOS PRISM showed that geopositioning accuracy to 1-3 pixels can be readily achieved, even in relatively steep terrain.

A practical application of monoplotting from HRSI is in identifying and rectifying discrepancies in cadastral data. Figure 3 shows a section of the cadastre in the Paro area of western Bhutan, registered with the underlying IKONOS orthoimage. Differences between the 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 very beneficial in the resolution of land disputes.

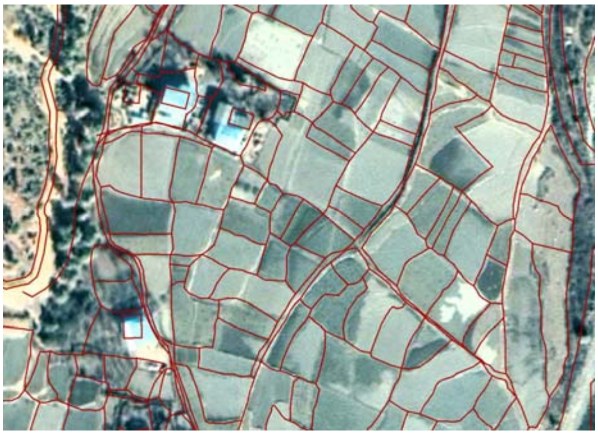

Figure 3. Cadastral boundaries overlayed on an IKONOS orthoimage in order to highlight coarse discrepancies.

6. CONCLUSIONS

The Bhutan project has shown that there is considerable potential for HRSI to be an effective, practical and economically viable method of extracting 3D information to be used for medium-scale mapping in developing countries that lack ready access to aerial photography. The next phases of the continuing Bhutan Project will focus more upon practical implementation aspects, and upon technology transfer and capacity building. For example the photogrammetric section of the National Land Commission is now utilising Barista for selected monoplotting operations.

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REFERENCES

Fraser, C.S., Rottensteiner, F., Weser, T. and Willneff, J., 2007. Application of a Generic Sensor Orientation Model to SPOT 5, QuickBird and ALOS Imagery. *Proceedings, 28th Asian Conference on Remote Sensing, ACRS 2007*, Kuala Lumpur, 12-16 Nov., 7 pages (on CD-ROM).

Gruen, A. and Wolff, K, 2008. 3D Mapping from High-Resolution Satellite Images. Paper submitted to the XXIth ISPRS Congress, Beijing, 3-11 July; accepted for oral presentation

Holland, D., Guilford, R. and Murray, K. (Editors), 2003. Topographic Mapping from High Resolution Space Sensors, *OEEPE Official Publication No. 44.*

Holland, D., Boyd, D.S. and Marshall, P., 2006. Updating topographic mapping in Great Britain using imagery from high-resolution satellite sensors. *ISPRS Journal of Photogrammetry and Remote Sensing*, 60(3), pp. 212-223.

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 Nov., 5 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 Nov., 5pages

Weser, T., Rottensteiner, F., Willneff, J. and Fraser, C., 2007. A Generic Pushbroom Sensor Model for High-Resolution Satellite Imagery applied to Spot 5, QuickBird and ALOS data sets. *Intern. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, (Eds. C. Heipke, K. Jacobsen & M. Gerke), Hannover, Vol. 36, Part I/W51, 6 p. (on CD-ROM).

Willneff, J., Poon, J. and Fraser, C., 2005. Single-Image High-Resolution Satellite Data for 3D information extraction. *Intern. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, (Eds. C. Heipke, K. Jacobsen & M. Gerke), Hannover, Vol. 36, Part I/W3, 6 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.