DEM Generation Using QuickBird St

Using Tie Points Only

This article examines the extraction of Digital Elevation Models (DEMs) from QuickBird stereo image pairs without the use of ground control points (GCPs). Due to the frequent unavailability of ground control points, a DEM generation method requiring no GCPs would be of significant interest to users of stereo data. The article also explores the refinement of extracted DEMs by applying horizontal shifts based on reference DEMs from the Shuttle Radar Topography Mission (SRTM).

By Philip Cheng and Chuck Chaapel

Extracted DEM Results for the Libya Dataset

Figures 1a, 1b and 1c show an overview of the orthorectified QuickBird multispectral image, the extracted DEM, and the SRTM 3 arc-sec DEM, respectively. The extracted DEM required almost no DEM editing. Offset values of 44m in X and 60m in Y were applied to the extracted DEM in order to match the SRTM DEM horizontal positions. After applying the offset, the average vertical difference between the extracted DEM and the SRTM DEM is about 3m.

Stereo Image Viewing

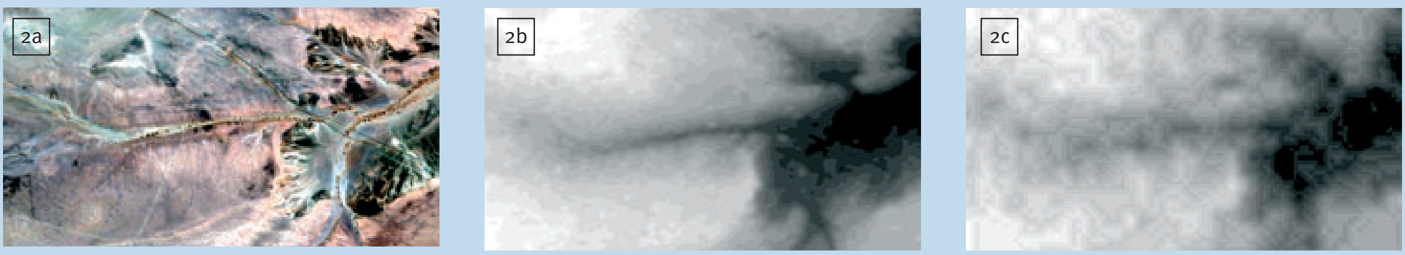
The production of Digital Elevation Models (DEMs) from satellite image data has been a vibrant research and development topic for the last thirty years, beginning with the launch of the first civilian remote sensing satellite.
Stereo image viewing has been the most common method of elevation modeling used by the mapping, photogrammetry, and remote sensing communities.
To obtain stereoscopy with images from satellite scanners, two methods are possible: along-track stereoscopy from the same orbit, using fore and aft images, and across-track stereoscopy from two adjacent orbits.
The across-track approach has been applied frequently since 1980, first with Landsat from two adjacent orbits, then with SPOT using across-track steering capabilities, and finally with IRS-1C/D by "rolling" the satellite.
Nevertheless along-track stereoscopy has recently gained renewed popularity. Along-track stereoscopy is applicable to a large number of satellites, including JERS-1's Optical Sensor (OPS), German Modular Opto-Electronic Multi-Spectral Stereo Scanner (MOMS), ASTER, IKONOS, QuickBird, OrbView, SPOT-5, Formosat II, and CartoSat. In addition, the simultaneous acquisition of along-track stereo data has a strong advantage in terms of radiometric variations versus the multi-date acquisition of across-track stereo data.

Collection of GCPs

Generating DEMs from stereo data normally requires the use of a geometric model and ground control points (GCPs). The collection of GCPs presents a significant problem in many practical applications, as an existing source of GCPs may not be available. It is often prohibitively expensive to collect new points, especially for areas inaccessible by road, or too impractical to acquire manually.
A DEM generation method which requires no GCPs would therefore be of significant interest to users of stereo data.
In this article, we will examine the automatic DEM extraction of QuickBird stereo data without the use of GCPs, as well as the improvement of extracted DEMs using the Shuttle Radar Topography Mission (SRTM) DEMs.

QuickBird Satellite

Since the launch of DigitalGlobe's QuickBird satellite, QuickBird imagery has quickly become a popular choice for large-scale



Figures 2a, 2b and 2c show full resolution subsets of the orthorectified multispectral QuickBird image, extracted DEM, and SRTM DEM of the same area resampled at 5m resolution. These figures show clearly that the extracted DEM contains more detail than the SRTM DEM.

ereo Data Without Ground Controls

Extracted DEM results for the Mongolia dataset

Figures 3a, 3b and 3c show an overview of orthorectified multispectral QuickBird image, the extracted DEM, and the SRTM 3 arc-sec DEM, respectively. The extracted DEM required almost no DEM editing. Offset values of 15m in X and 20m in Y were applied to the extracted DEM in order to match the SRTM DEM horizontal positions. After applying the offset, the average vertical difference between the extracted DEM and the SRTM DEM is about 3m.

mapping projects using high-resolution satellite imagery. First, the satellite has panchromatic and multispectral sensors with resolutions of 61-72cm and 2.44-2.88m, respectively, depending upon the off-nadir viewing angle (0-25 degrees). The sensor therefore has a coverage of 16.5-19km in the across-track direction. In addition, the along-track and across-track capabilities provide a good stereo geometry and a high revisit frequency of 1-3.5 days.

There are two geometric models which can be used for correcting QuickBird data: the rigorous method and the rational polynomial coefficient (RPC) method. Since GCPs were not available for the datasets used in this research, the RPC method was chosen. It is capable of operating without GCPs, though the accuracy will be lower due to uncorrected biases or errors in the RPCs.

Renewed Attention

The RPC method uses an empirical/statistical model developed by DigitalGlobe, which approximates the 3D physical sensor model of QuickBird. Occasionally used during the 1980s, this method received a great deal of renewed attention with the launch of Space Imaging's IKONOS satellite, because its sensor and orbit parameters are not included with the image metadata. The RPC method could be a useful method to avoid the development of 3D physical models because it enables users, having little familiarity with the QuickBird sensor, to perform a geometric correction without GCPs; only a DEM is required.

Since biases or errors still exist after applying the RPCs, the results can be post-processed with a translation and several precise GCPs; alternatively, the original RPC parameters can be refined with linear equations and precise GCPs. Several recent articles and papers addressing IKONOS data showed good results by using RPCs together with a few GCPs to apply a complementary zero order polynomial adjustment to the data. More information about the RPC method can be found in the paper written by Grodecki and Dial (PE &RS January, 2003).

Automatic DEM Generation

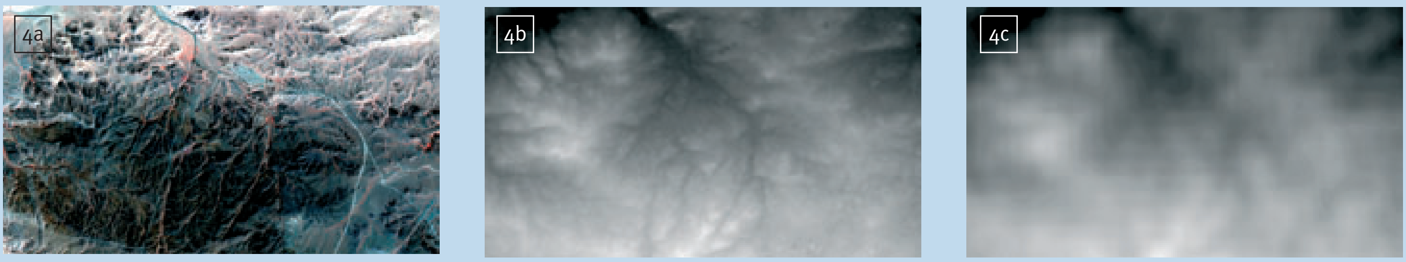
PCI Geomatics' OrthoEngine v10.0 software was used for the testing in this article. The software supports reading of the data, manual or automatic GCP/tie point (TP) collection, and geometric modeling of different satellites (using Toutin's rigorous model or the RPC method). It is also capable of automatic DEM generation and editing, orthorectification, and provides options for both manual and automatic mosaicking.

OrthoEngine's RPC method is based on the block adjustment method developed by Grodecki and Dial and was certified by Space Imaging (www.pcigeomatics.com/support_center/tech_papers/rpc_pci_cert.pdf). The method computes the polynomial adjustment math model for each image.

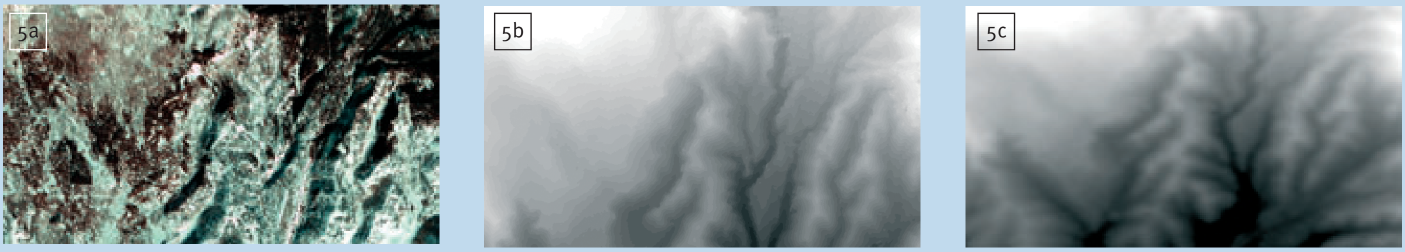
$$\Delta P = Ao + AS \cdot Sample + AL \cdot Line + ASL \cdot Sample \cdot Line + \ldots$$

$$\Delta R = Bo + BS \cdot Sample + BL \cdot Line + BSL \cdot Sample \cdot Line + \ldots$$

Ao, AS, AL, ASL ... and Bo, BS, BL,BSL ... are the image adjustment parameters, Line and Sample are the line and sample coordinates of an image, and ΔP and ΔR are the adjustable functions expressing the differences between the measured and the nominal line and sample coordinates. For IKONOS images, a zero order polynomial adjustment (Ao and Bo) is adequate in most cases. For QuickBird images, a first order polynomial adjustment is required to achieve the best results. The OrthoEngine software supports both zero and first order RPC polynomial adjustments.



Figures 4a, 4b and 4c show full resolution subsets of the orthorectified multispectral QuickBird image, extracted DEM, and SRTM DEM of the same area resampled at 5m resolution. Again, it can be seen from these figures that the extracted DEM contains more detail than the SRTM DEM.



Extracted DEM results for the Utah dataset

This dataset presents the most challenging case because the Utah image consists of snow, trees and rugged mountains. The extracted DEM required significant editing. Figures 5a, 5b and 5c show an overview of orthorectified multispectral image, the extracted DEM, and the SRTM DEM, respectively. Offset values of 10m in X and 60m in Y were applied to the extracted DEM in order to match the SRTM DEM horizontal positions. After applying the offset, the average vertical difference between the extracted DEM and the SRTM DEM is about 30m.

RPC Block Bundle Model

To generate a DEM using a stereo pair, tie points were first collected automatically inside the OrthoEngine software. The RPC block bundle model was computed for each image. A pair of quasi-epipolar images is generated from the stereo images to retain elevation parallax in the X direction. An automated image-matching procedure is then used to produce the DEM through a comparison of the respective gray values of these images. To find the corresponding pixels in the left and right quasi-epipolar images, this procedure utilizes a hierarchical sub-pixel mean normalized cross correlation matching method.

The actual matching method employed generates correlation coefficients between 0 and 1 for each matched pixel, where 0 represents a total mismatch and 1 represents a perfect match. A second-order surface is then fitted around the maximum correlation coefficients to find the match position to sub-pixel accuracy. The difference in location between the images gives the disparity, or parallax, arising from the terrain relief. This is then converted to absolute elevation values above the WGS84 ellipsoid using a 3-D space-intersection solution.

QuickBird Stereo Data

Three QuickBird along-track stereo datasets were chosen for this research. The first dataset covers an area of Libya, Africa, acquired on May 27, 2005, see Figures 1 and 2. The area has an elevation range of 260m to 360m, and consists of moderate terrain with bare soil, rocks and almost no vegetation. The second dataset covers an area of Mongolia, Asia, acquired on Oct 7, 2005, see Figures 3 and 4. This area includes both flat terrain and mountainous areas with an elevation range of 1200m to 1400m. The third data set covers an area of Utah, USA, acquired on Jan 22, 2005, see Figures 5 and 6. The area has an elevation range of 2000m to 3300m, and consists of snow, trees and rugged mountains.

These data provide us with two choices for DEM generation: using either the panchromatic stereo pair or the multispectral stereo pair. The multispectral stereo pair was chosen because it contains fewer high-detail features (such as trees), thereby reducing noise in the extracted DEM. All DEMs were generated at 5m resolution and converted to mean sea level heights.

International Project

To compare the accuracy of the extracted DEMs, the SRTM 3 arc-sec DEMs were used as a benchmark. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The program's key technology is a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. It obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. The NASA-NGA agreement on data distribution calls for 3 arc-sec (~90 m) resolution data to be released to the public for areas outside the United States. Within the USA, full resolution 1 arc-sec (~30 m) data have been released.

Since only tie points could be collected between each stereo pair, the horizontal positions of the extracted DEM will include errors caused by uncorrected biases and errors in the RPCs. These errors can be reduced by comparing similar features between the extracted DEM and the SRTM DEM, and applying offset values in X and Y to the extracted DEM to match the SRTM DEM horizontal positions.

Conclusions

It was proven with this research that it is possible to extract DEMs using QuickBird stereo data without GCPs, using tie points only. The horizontal accuracy of the extracted DEM can be improved by comparing similar features between the extracted DEM and the SRTM DEM, then applying offsets in X and Y to the extracted DEM to match the horizontal positions of the SRTM DEM. For areas with gentle to moderate terrain, the extracted DEM showed an average difference of 3m in vertical values compared to the SRTM DEM, and up to 30m for rugged terrain.

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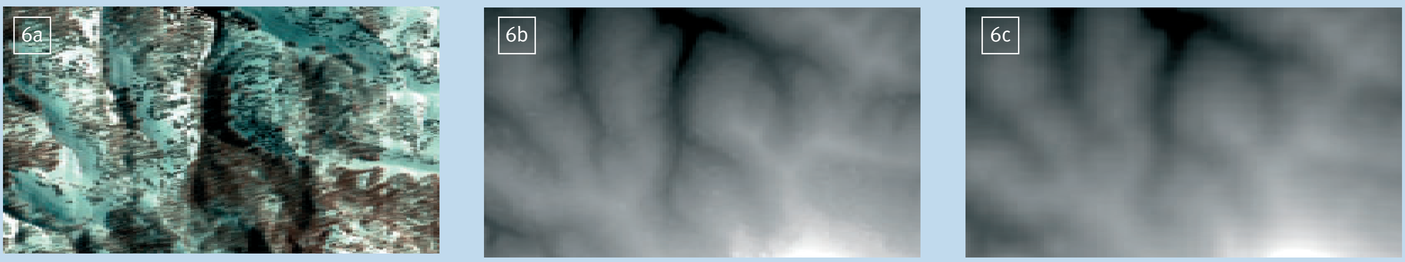

Figures 6a, 6b and 6c show full resolution subsets of the orthorectified image, extracted DEM and the SRTM DEM of the same area resampled at 5m resolution.