White Paper

Accurate, Detailed Elevation

LEVERAGE HIGH RESOLUTION SATELLITE STEREO IMAGERY TO DERIVE DETAILED, ACCURATE ELEVATION MODELS IN INNACCESSIBLE AREAS

Dr. Waldir Paradella and Dr. Philip CHeng

Accurate, Detailed Elevation

This article describes how high resolution satellite data can be used to extract accurate digital elevation model (DEM) for a mining application in the Amazon region. The resulting vertical accuracy can be within RMS error of 1.5m when using a minimum number of ground control points.

Derive detailed, accurate elevation models in inaccessible areas

Digital Elevation Model (DEM) represents the elevation of the top surface of vegetation cover and other features (building, manmade structures, etc.) above the bare earth. It is a very important layer for many types of applications such as topographic mapping, three dimensional GIS, environmental monitoring, geo-spatial analysis, among others. In addition, continuous growth in the telecommunication and engineering industries has created even greater demand for DEM data. This data allows engineers to plan and manage infrastructure growth with the high accuracy required by new spatial applications. However, for most areas, DEMs suffer from a few common problems; they are unavailable, outdated, or available only in low resolution (such as the SRTM DEMs, with 1 to 3 arc second spacing – or 30/90m postings). DEMs generated from satellite stereo-pair images can be used for the applications mentioned above, and also can address the common problems customers face when working with existing (or missing) elevation data. Obtaining DEMs from satellite images is possible through two main methods: along-track stereoscopy from the same orbit, using fore and aft images, and across-track stereoscopy from two adjacent orbits. The simultaneous acquisition of along-track stereo data has a strong advantage in terms of radiometric variation versus the multi-date acquisition of across-track stereo data. The across-track approach has been applied frequently since 1980, first with Landsat TM from two adjacent orbits, then with SPOT using across-track steering capabilities, and finally with IRS-1 C/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, OrbitView, SPOT-5, Formosat II, CartoSat, and the latest addition of WorldView, GeoEye-1 and Pleiades satellites. In this article, we will show an example of using GeoEye-1 stereo data to extract DEM for a mining application in Brazil.

Amazon Forest

The Amazon forest is a moist broadleaf forest that covers most of the Amazon Basin of South America. This basin encompasses seven million square kilometers (1.7 billion acres), of which five and a half million square kilometers (1.4 billion acres) are covered by the rainforest. This region includes territory belonging to nine nations. Approximately, 60% of the Amazon forest lies in Brazil. In this region, with a continental dimension (almost 5,500,000 km2 of the national territory), due to adverse environmental conditions (rain, cloud and dense vegetation), difficult access and large size, the topographic knowledge is still poor, with only 15% of the region covered by maps at detailed scale (1:50,000). In addition, the available information for the remainder of the region was mainly produced in the 1960's and 1980's, and is in desperate need of updating or needs to be remapped. This area also includes, under an apparently homogeneous physiognomy, an enormous variability in forests, rivers and lakes, soils, geology, climate, plants and animal. The lack of reliable terrain information impairs the ability of the government to formulate policies, establish priorities and perform essential activities like regulate colonization and exploitation of natural resources in ecologically sensitive areas.

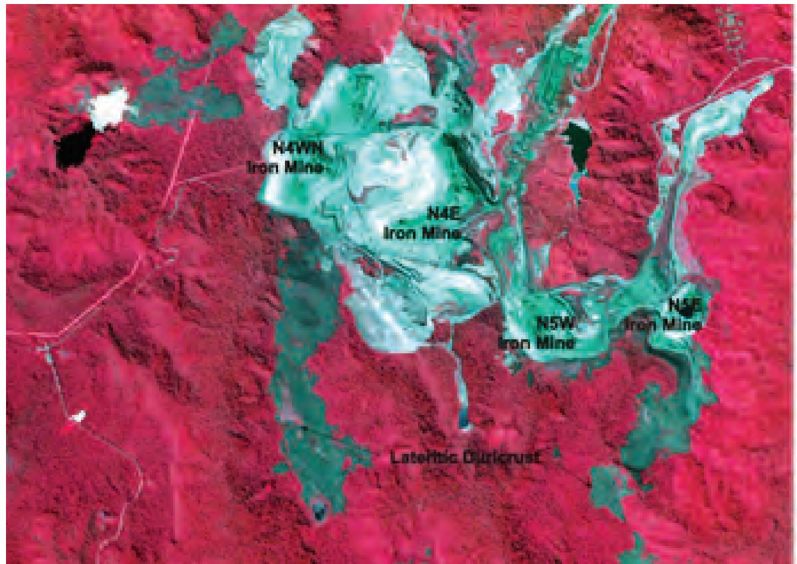
DEMs are a primary source of input for topographic mapping. The classification of topographic maps in Brazil should be performed in accordance with the National Cartographic Accuracy Standard (PEC in Portuguese), established by the Brazilian Cartographic Commission. PEC is a statistical indicator (90% of probability) for planialtimetric accuracy, corresponding to 1, 6449 times the Root Mean Square Error (RMSE) (PEC = 1.6449 x RMSE). For a 1:25,000 and 1:10,000 scales A Class map, the altimetric RMSE corresponds to 3.33m and 1.66 m, respectively (1/3 of the equidistance of contour lines on the map scale). A preliminary evaluation of the altimetric quality of a DEM extracted from a GeoEye panchromatic stereo pair was conducted for a mountainous region of the Carajás Mineral Province. The results show a promising alternative for a production and updated detailed topographic mapping in the Amazon region, where this kind of terrain information is lacking or is currently only available in poor quality.

The Carajás Mineral Province is located on the easternmost border of the Amazon region. The Province, with an area of 120,000 square kilometers, is marked by mountainous terrains, characterized by a set of hills and plateaus (altitudes from 500 to 900m) surrounded by southern and northern lowlands (altitudes around 200m), deep chemical weathering which produces thick oxisols (latosols) and few outcrops. Vegetation cover is typical of the Up-Land Ombrophilous Equatorial forest communities with complex and multilevel canopies and numerous species. Since 1967, when the iron deposits were discovered, a remarkable geobotanical control given by the iron-mineralized laterites and specific vegetation types has been recognized. The deposits are covered by thick, hard iron-crusts (lateritic duricrusts) developed over volcanic rocks and ironstones. Specific low-density savanna-type vegetation (campus rupestres) is associated with the deposits, and shows a strong contrast (clearing) with the dense equatorial forest.

Fully owned by Vale mining company, the world's second largest mining company, leader in iron-ore production and second biggest nickel producer, Carajás Province contains known reserves of the order of 18 billion tons with an average grade of 65.4% Fe content. Following these discoveries, numerous other metalliferous deposits have been identified including manganese, alumina, nickel, tin, gold, platinum group elements and copper. More recently, the area has been recognized as a major copper-gold province, after the discovery of a number of world-class iron oxide, copper-gold deposits, and an emerging nickel laterite district, making Carajás an important and under-explored metallogenic province. The iron mining

Carajás Mine, Brazil

activities in the Province are concentrated on two main ore bodies: the N4 (mines N4E and N4WN) and N5 (mines N5W and N5E). The reserves of both bodies totaled 1.4 billion tons of ore with 65% of Fe content. Mining is carried out by conventional open-pit methods. In addition, an important manganese deposit (Azul) was also discovered in 1971, with reserves of 65 million tons of manganese with manganese dioxide content of over 75%.



GeoEye-1 multispectral color composite with main active open pit mines.

INPE and Vale initiated a research project in Carajás that investigates the applicability of orbital Synthetic Aperture Radar Interferometry (InSAR) to determine surface deformations induced by open pit and mining operations. Implementing differential interferometry approaches (DInSAR) for monitoring of mining deformations could provide better, continuous coverage. As a consequence, this should lead to determination of more precise deformation models of rock strata and increase the safety margins of mining operations. Monitoring of pit depths and deformations, highlight areas that require real-time monitoring (e.g. with ground based radar), identify faults/fractures controlling deformation in and around pits, heights of stockpiles and waste dumps, and levels of tailing dumps, may provide additional important production data.

The key-element in any interferometric analysis is the phase value of each radar image pixel. Phase values of a single SAR image depend on distinct factors, particularly the contribution of topography. If a detailed DEM is available, the topographic component can be known and used in the interferometric process. Thus, the production of a high-resolution DEM was fundamental in the DInSAR project in Carajás, not only as input for the Advanced DInSAR approaches

(PSInSAR, SqueeSAR), but also for the production of orthoimages (panchromatic and multispectral GeoEye, StripMap TerraSAR-X, etc.), which are used as geospatial reference basis for the validation of surface displacements.

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The GeoEye-1 Satellite

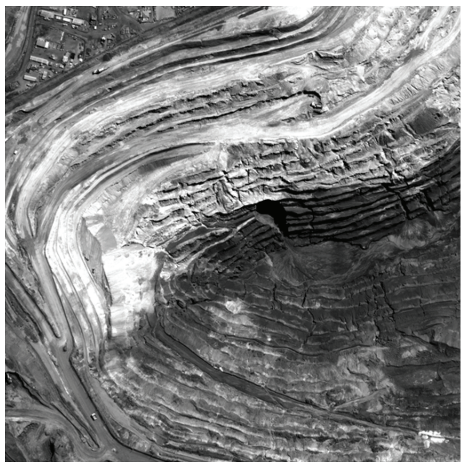
The GeoEye-1 Satellite sensor was developed by GeoEye Inc and features the most sophisticated technology ever used for a commercial remote sensing system. GeoEye-1 is capable of acquiring image data at 0.41 meter panchromatic and 1.65 meter multispectral resolution in 15.2 km swaths. It also features a revisit time of less than three days, as well as the ability to locate an object within just three meters of its physical location. The newly developed sensor is optimized for large projects, as it can collect over 350,000 square kilometers every day. The spacecraft is intended for a sun-synchronous orbit at an altitude of 681 km and an inclination of 98 degrees, with a 10:30 a.m. equator crossing time. GeoEye-1 can image up to 60 degrees off nadir. It is operated out of Herndon, Virginia and was built in Arizona by General Dynamics Advanced Information Systems.

GeoEye-1 Stereo Data

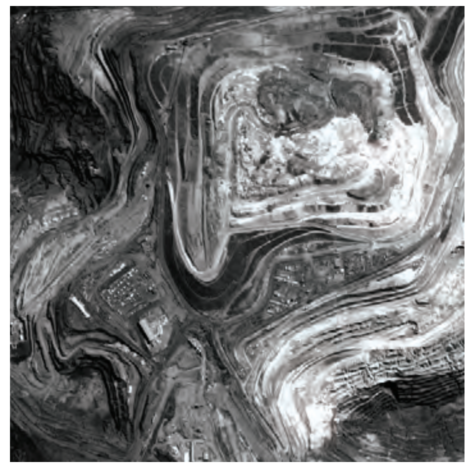
In this article we will test the vertical accuracy of automatic DEM extraction using a stereo pair of GeoEye-1 panchromatic data. The data was standard geometrically corrected at 0.5m resolution with rational polynomial coefficients (RPCs) provided. Panchromatic and multispectral in-track stereo pairs were acquired over Carajás on July 1st, 2012 at 13:42 GMT with 39.81 and 51.59 degrees of Sun azimuth and elevation. The first scene was collected with nominal collection azimuth and elevation of 29.4 degrees and 82.4 degrees, respectively. The second scene was collected with nominal collection azimuth and elevation of 187.42 and 62.20 degrees, respectively.

Geometric software and model

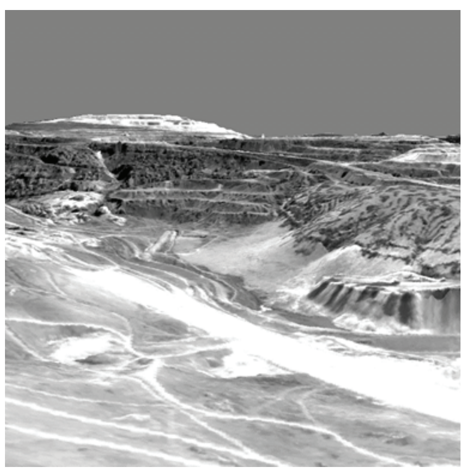
A geometric modeling method is required in order to extract the DEM from the stereo data. The Rational Function Method (RFM) has been the most popular geometric modeling method in the past decade. This method uses the Raster Polynomial Coefficients (RPCs) provided with the satellite data to compute the model. Since biases or errors still exist in the RPCs, the results can be post-processed with a polynomial adjustment and several accurate ground control points (GCPs). More details about the RFM can be found in the paper written by Grodecki and Dial (2003). Since the GeoEye-1 data is provided with RPCs, the RFM can be used to as the geometric model.



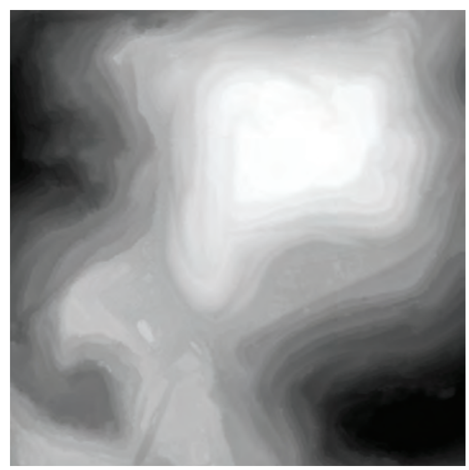
GeoEye-1 full resolution panchromatic image of the western sector of N4E mine



Resampled image at 2m spacing



Perspective view of image generated with the extracted DEM



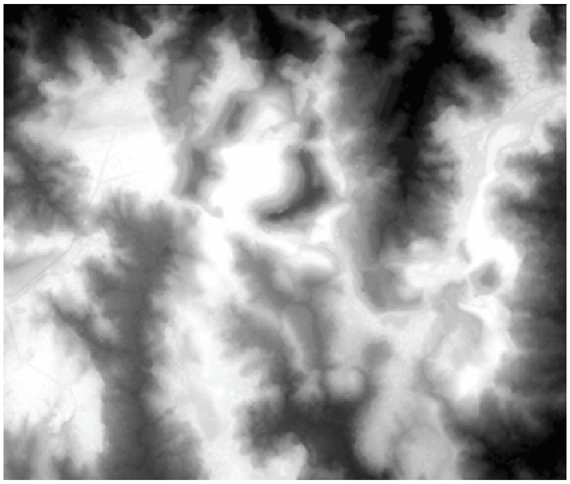
Extracted DEM at 2m spacing

The 2013 version of PCI Geomatics' OrthoEngine software was used for this testing. This software supports reading of the data, manual or automatic GCP/tie point collection, geometric modeling of different satellites using RFM or Toutin's rigorous model, automatic DEM generation and editing, orthorectification, and either manual or automatic mosaicking.

Two stereo Differential GPS (DGPS) GCPs were collected on the stereo panchromatic images. The RMS residuals when using two GCPs were 0.4m and 0.1m in X and Y, respectively. When using only one GCP, the RMS errors of the check points were 0.4m and 0.3m in X and Y, respectively. When both GCPs were changed into check points, the RMS errors of the check points were 3.1m in X and 0.8m in Y, respectively. This means it is possible to achieve an accurate geometric model within 0.5m horizontal accuracy with only a minimum of one accurate GCP. Even without GCPs a horizontal accuracy within 3m is still useful for areas where accurate GCPs cannot be obtained.

DEM Extraction Results

DEMs were extracted at 2m spacing using zero, one and two GCPs, respectively. The results were compared with seven well-defined accurate vertical check points. The RMS and maximum errors when using two GCPs, one GCP, and no GCP are 1.4m and 2.2m, 1.2m and 1.6m, and 1.1m and 2.4m, respectively.



DEM Extracted from the Imagery

Summary

High accuracy DEMs can be extracted using the GeoEye-1 stereo data. Only a minimum of one accurate GCP is required to achieve a horizontal accuracy within RMS error of 0.5m. The extracted DEM has a vertical accuracy within RMS error of 1.5m when comparing to well-defined vertical check points. These results showed that the planialtimetric quality of the GeoEye DEM fulfilled the Brazilian Map Accuracy Standards requirements for 1:10,000 A class map.

About the Authors

Dr. Waldir Renato Paradella is a senior researcher at INPE (Brazilian National Institute for Space Research). He can be reached at waldir@dsr.inpe.br.

Dr. Philip Cheng is a senior scientist at PCI Geomatics. He can be reached at cheng@pcigeomatics.com.

Dr. Waldir Paradella
INPE

Dr. Philip Cheng
PCI Geomatics