GEOMETRIC CORRECTION AND AUTOMATIC DEM EXTRACTION OF WORLDVIEW STEREO DATA

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ABSTRACT: The successful operation of the WorldView-1and 2 satellites have enabled advanced high-accuracy mapping using high-resolution satellite images, with and without the use of ground control points (GCPs). The stereo capability of the WorldView sensor also provides the opportunity to extract high-resolution digital elevation models (DEMs). In this paper we will examine the following areas: (1) Each WorldView data is distributed with Rational Polynomial Coefficients (RPCs). The coefficients can be used to correct the WorldView data using Rational Function Method (RFM). What is the minimum number of GCPs required to achieve the best geometric accuracy? (2) WorldView data is distributed in Basic 1B and Ortho-Ready Standard (OR2A) formats. Which format should be used to produce the best accuracy in geometric correction? (3) In addition to the high-resolution panchromatic sensor, WorldView-2 has eight multispectral bands which can be used for many applications such as classification and pansharpening. We will examine the pansharpening of WorldView-2 data using an algorithm developed at the University of New Brunswick, Canada. (4) Different stereo pairs can be acquired by the WorldView satellite. What is the best stereo viewing geometry for automatic DEM extraction? This paper tested different WorldView satellite data to provide the answers to the above questions.

1.0 INTRODUCTION

On October 8, 2009, WorldView-2 joined its sister satellites, WorldView-1and QuickBird in orbit. WorldView-2 panchromatic resolution is 0.46m GSD and multispectral resolution is 1.8m GSD. Distribution and use of imagery better than 0.50m GSD pan and 2.0m GSD multispectral is subject to prior approval by the U.S. Government. As the first high-resolution commercial satellite to provide eight spectral bands, WorldView-2 offers imagery with a high degree of detail, unlocking a finer level of analytical discernment that enables improved decision-making. In addition to industry-standard blue, green, red and near-infrared, WorldView-2 includes four previously unavailable bands, collected at 1.8m resolution: coastal blue, yellow, red edge and near-infrared 2. These bands offer a range of benefits to analysts, who will be able to identify a broader range of classification, (e.g. more varieties of vegetation or water penetrated objects), to extract more features (e.g. cotton-based camouflage from natural ground cover), to view a truer representation of colors that match to natural human vision, and to track coastal changes and infractions.

WorldView-2's large-area collection capabilities and rapid retargeting are two important features of the satellite. Enabled by the combination of the satellite's 770km orbiting attitude, its state-of-art Control Moment Gyroscopes (CMGs) and bi-directional push-broom sensors, WorldView-2's enhanced agility and bi-directional scanning allows for the collection of over 10,000 km^2 in a single overhead pass, plus efficient in-track stereo collections of over 5,000 km^2. WorldView-2's advanced geopositional technology provides significant improvements in accuracy. The accuracy specification has been tightened to 6.5m CE90 directly right off the satellite, meaning no processing, no elevation model and no ground control, with measured accuracy expected to be approximately 4m CE90.

In this paper we will examine the following areas: (1) Each WorldView data is distributed with Rational Polynomial Coefficients (RPCs). The coefficients can be used to correct the WorldView data using Rational Function Method (RFM). What is the minimum number of GCPs required to achieve the best geometric accuracy? (2) WorldView data is distributed in Basic 1B and Ortho-Ready Standard (OR2A) formats. Which format should be used to produce the best accuracy in geometric correction? (3) In addition to the high-resolution panchromatic sensor, WorldView-2 has eight multispectral bands which can be used for many applications such as classification and pansharpening. We will examine the pansharpening of WorldView-2 data using an algorithm developed at the

University of New Brunswick, Canada (Zhang, 2005). (4) Different stereo pairs can be acquired by the WorldView satellite. What is the best stereo viewing geometry for automatic DEM extraction?

2.0 GEOMETRIC CORRECTION USING RFM

In order to leverage the WorldView images for applications such as GIS, it is necessary to orthorectify the images. A geometric model, ground control points (GCPs) and digital elevation model (DEM) are required. The RFM has been the most popular method in orthorectifying high resolution images. More details about the RFM can be found in the paper written by Grodecki and Dial (2003).

The latest version of PCI Geomatics' OrthoEngine software was used for this testing. This software supports reading of the data, manual or automatic GCP/tie point (TP) collection, geometric modeling of different satellites using Toutin's rigorous model or the RPC model, automatic DEM generation and editing, orthorectification, and either manual or automatic mosaicking. OrthoEngine's RFM is based on the block adjustment method developed by Grodecki and Dial (2003) and was certified by Space Imaging [4]. Since biases or errors still exist in the RPCs, the results can be post-processed with a polynomial adjustment and several accurate GCPs. PCI Geomatics' OrthoEngine RFM computes the polynomial adjustment math model for each image.

$$\Delta P = A_0 + A_S \cdot \textit{Sample} + A_L \cdot \textit{Line} + A_{SL} \cdot \textit{Sample} \cdot \textit{Line} + \ldots$$

$$\Delta R = B_0 + B_S \cdot \textit{Sample} + B_L \cdot \textit{Line} + B_{SL} \cdot \textit{Sample} \cdot \textit{Line} + \ldots$$

Where $A_0, A_S, A_L, A_{SL} \ldots$ and $B_0, B_S, B_L, B_{SL} \ldots$ 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. The OrthoEngine software supports zero, first and second order RPC polynomial adjustments. It is recommended to use zero order for IKONOS satellite data, first order for QUICKBIRD satellite data, and second order for IRS AWiFS satellite data. One of the purposes of this paper is to determine which order of RPC polynomial adjustment would be suitable for WorldView satellite RPC data.

Although the RFM only requires a small number of GCPs and TPs, high accuracy may not be achieved if the GCPs are not well distributed within the block. To improve the relative accuracy, a DEM can be used if it is available. During each bundle adjustment iteration, the computed elevation of each tie point can be replaced by the elevation at the computed TP *X* and *Y* coordinates from the DEM, similar to the results of changing the planimetric TPs into altimetric points. This method helps to improve the relative accuracies between the ortho images, which helps to minimize differences during the mosaicking process. This option is available within the OrthoEngine software.

3.0 WORLDVIEW DATA PRODUCTS

WorldView data is distributed in five different products, i.e., Basic 1B, Basic Stereo Pairs, Standard 2A, Ortho-Ready Standard (OR2A) and Orthorectified. For custom orthorectification the Standard 2A and Orthorectified products are not recommended. Standard 2A is not recommended because of the coarse DEM correction already applied to the image data.

Basic 1B products are the least processed of the WorldView imagery products. Each strip in a Basic Imagery order is processed individually and therefore, multi-strip Basic Imagery products are not mosaicked. Basic Imagery products are radiometrically corrected and sensor corrected, but not projected to a plane using a map projection or datum. The sensor correction blends all pixels from all detectors into the synthetic array to form a single image. The resulting GSD varies over the entire product because the attitude and ephemeris slowly change during the imaging process. Basic Stereo Pairs are supplied as two full scenes with overlap, designed for the creation of DEMs and derived GCPs.

OR2A has no topographic relief applied, making it suitable for custom orthorectification. OR2A is projected to an average elevation, either calculated from a terrain elevation model or supplied by the customer. It can be ordered from a minimum of 25 km^2 from the library, or from 64 km^2 for new tasking.

In general Basic 1B data should be used with a rigorous sensor model and OR2A product should be used with RFM. This is because there are parts of a Basic1B image where the RPC's do not have enough degrees of freedom to properly model the sensor. This can occur near the beginning or end of an acquisition when the satellite is still moving slightly before settling down. These relatively rapid movements in roll, pitch, or yaw can create portions of an image that cannot be modeled correctly by the RPCs. Although Basic 1B product does have RPCs supplied with it, the RPCs for the corresponding OR2A product would probably be better because the rapid movements are already corrected in OR2A product.

To demonstrate the differences between Basic 1B and OR2A product, WorldView-2 Basic 1B and OR2A products of same data of Phoenix, Arizona, USA were obtained from DigitalGlobe. Ten DGPS sub-meter accuracy control points were collected from the data. Table 1 shows the check point errors when using 1 and 4 control points as GCPs and the remaining as check points with 0 and 1^{st} order RPC adjustment order. Several conclusions can be drawn from the table: (1) OR2A has better accuracy than the 1B product for the same number of GCPs when using RFM, (2) Only a minimum of one accurate GCP is required to correct OR2A product using 0 order RPC adjustment order. The GCP can be collected anywhere on the image. Several GCPs are recommended if the GCPs are less accurate.

Table 1: Comparisons of Basic 1B and OR2A RPC results of Phoenix in meter

Product	No. of GCPs	No. of Check Points	RPC Adjustment Order	RMS(m)		Maximum Error(m)	
				X	Y	X	Y
Basic 1B	0	10	0	0.94	1.41	1.71	1.82
	1	9	0	1.00	1.10	1.90	2.44
	4	6	0	1.22	1.22	1.84	2.46
	4	6	1	1.56	1.51	2.54	2.75
OR2A	0	10	0	0.56	1.15	0.98	1.53
	1	9	0	0.55	0.44	0.97	0.69
	4	6	0	0.54	0.24	0.91	0.67
	4	6	1	0.69	0.38	1.23	0.67

4.0 PANSHARPENING

The availability of a WorldView-2 0.5m panchromatic band, in conjunction with the 2m multispectral bands, provides the opportunity to create a 0.5m multispectral pan-sharpened image by fusing these images. Based on the thorough study and analysis of existing pan-sharpening algorithms and their fusion effects, an automatic pan-sharpening algorithm has been developed by Dr. Yun Zhang at the University of New Brunswick, in New Brunswick, Canada. This technique solved the two major problems in pan-sharpening – color distortion and operator dependency. A method based on least squares was employed for a best approximation of the grey level value relationship between the original multispectral, panchromatic, and the pan-sharpened image bands for a best color representation. A statistical approach was applied to the pan-sharpening process for standardizing and automating the pan-sharpening process. This new algorithm is commercially available within the PCI Geomatics software.

OR2A products are recommended for pansharpening because the panchromatic and multispectral data are resampled to exactly the same geographic extents; hence, it is possible to perform pansharpening of the data before geometric correction if a pansharpened orthorectified image is desired. This method works for most areas with gentle terrain. Performing pansharpening after geometric correction of the panchromatic and multispectral data separately often requires the need to deal with small misalignments between the orthorectified panchromatic and multispectral data due to the inaccuracy of GCPs and DEM used in the orthorectification process.

In figure 1a, 1b and 1c, examples of the WorldView-2 panchromatic, multispectral and pansharpened images of Phoenix, USA, are provided.


Figure 1a: Panchromatic image of Phoenix, USA


Figure 1b: Multispectral image of Phoenix, USA


Figure 1.3: Pansharpened image of Phoenix, USA

5.0 DEM EXTRACTION

WorldView is equipped with state-of-the-art geo-location accuracy capability and exhibits unprecedented agility, with rapid targeting, efficient in-track stereo collection, and maximum viewing angles of ± 45 degrees. The stereo collection provides the opportunity to extract the highest resolution DEM from satellite stereo images. In general, fore and aft looking stereo pair produces the highest accuracy but only limited to areas with gentle terrain. Nadir and fore/aft looking stereo pair can be used in most kinds of terrain.

A stereo data of Phoenix acquired 7.5 degrees fore and -26.7 degrees aft were used to test DEM extraction. Figure 2a and 2b show the image and the extracted DEM. When comparing to the ten control points, the average vertical error is about 0.1m with a maximum error of 1.4m.

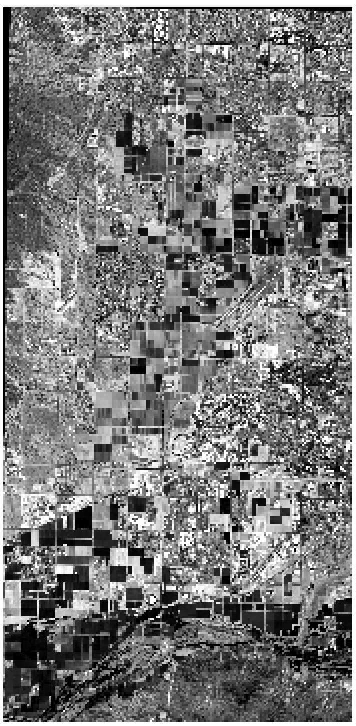

Figure 2a: Phoenix Image

Figure 2b: Phoenix extracted DEM

Figure 3a and 3b show a stereo dataset of a mining site in Australia and the extracted DEM. The stereo pair has a fore looking angle of 20.0 degrees and an aft looking angle of -8.2 degrees. The extracted DEM has a vertical RMS error of 3.9m with a maximum error of 5.7m when compared to the control points. Eleven GCPs were collected from each image. The GCPs were not as accurate as in the previous two cases because they were extracted from an ortho airphoto mosaic. When no GCPs were collected, the check point RMS vertical error was 2.2m, with a maximum error of 4.7m. When only one GCP was collected from each image, the check point RMS vertical error was 3.9m with a maximum error of 5.7m. These results show that if accurate GCPs are not available, it may be preferable not to collect any GCPs at all. The absolute RPC model accuracy of WorldView data without GCPs is sufficiently accurate to generate a DEM. More examples of WorldView DEM extraction can be found in Cheng (2008).

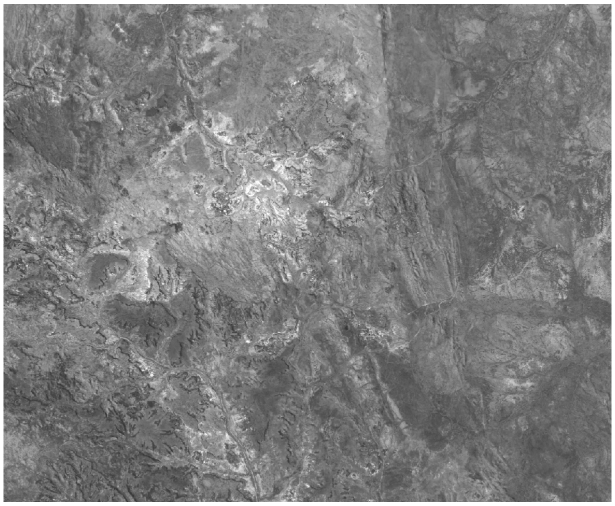

Figure 3a: Australia mining site

Figure 3b: Extracted DEM

6.0 Conclusions

This paper examined difference aspects of the WorldView data. Pansharpening of WorldView-2 data can be performed by using OR2A panchromatic and multispectral products before geometric correction. The RFM with zero order polynomial adjustment can be used as the geometric model to orthorectify WorldView data. It is possible to achieve RFM accuracy within 1m RMS with a minimum of one accurate GCP. Stereo WorldView data can be used to extract DEM. It is recommended to use nadir and fore/aft looking images to extract DEM. The vertical accuracy of the extracted DEM can be within a few meters depending on the types of terrain.

7.0 Acknowledgement

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8.0 References

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