Horizontal Accuracy Assessment of High Resolution Satellite Imagery for Mapping Purposes

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Abstract

The New generation remote sensing satellites that are being designed to image objects on the Earth's surface with a resolution of one meter and less. It is believed that such high resolution satellite imaging systems will lead to a paradigm change in mapping science, considering the high resolution, wide spectral range, and stereo mapping capabilities. This will be the first time that users around the world will be able to use satellite imagery to map products on the plane ground at a sub-meter level. This paper presents the results of an assessment of the horizontal accuracy of the new generation of high-resolution satellite imagery WV02 one of the Digital Globe productions for mapping purposes. Based on Evaluation of the planimetric accuracies of Worldview02 Ortho Ready Standard image acquired under a Space Imaging/NASA Data was found the value range to be (1.1 m and 1.55 m) CE90 at test site. The experimental results are very encouraging. It is demonstrated that with two or more GCPs, the sub-meter satellite imagery will have a potential to generate mapping products with a map scale of 1:4,000, which is sufficient for many GIS applications.

تقيم الدقة الأفقية لصور الأقمار عالية التميز لأغراض إنتاج الخرائط

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الخلاصة

الجيل الجديد من أقمار الاستشعار عن بعد المصممة لتميز صور العوارض على الأرض مع قدرة تميز واحد متر واقل. يودى ذلك إلى الاعتقاد أن أنظمة التصوير للأقمار الصناعية عالية الدقة سوف تؤدي إلى تغيير نموذج في علم رسم الخرائط، ونظرا لارتفاع قدرة التميز، والمجال الواسع الطيفي، وقدرات الخرائط المسجلة. وستكون هذه هي المرة الأولى للمستخدمين في جميع أنحاء العالم الال تمكن من استخدام صور الأقمار الصناعية في إنتاج الخارطة للأرض المستوية و لمستوى اقل من واحد متر. هذا البحث يعرض نتائج تقييم لدقة أفقية من الجيل الجديد من صور الأقمار الصناعية عالية الدقة WV02 التي هي واحدة من إنتاج شركة ديجيتال لأغراض رسم الخرائط. بناء على تقييم دقة planimetric منصورة Worldview02 اورثو القياسية جاهز المكتسبة من خلال بيانات الفضاء التصوير/ وكالة ناسا، وجد تقيمة الدقة البلانمترية تتراوح ما بين (1.1 مو 1.55م) CE90 في موقع الاختبار. هذه النتائج للتجارب وجدت مشجعة للغاية. حيث ثبت عمليا أن مع اثنين أو أكثر من نقاط مراقبة أرضية، وصور الأقمار الصناعية اقل من متر سوف يكون لها القدرة على إنتاج خرائط مع مقياس رسم الخرائط 1:4،000، وهو ما يكفي لتطبيقات نظم المعلومات الجغرافية كثيرة.

1. Introduction

Sensor Information

Basically the WorldView02 Images are of line scanner type. As such the image geometry is central perspective in the line direction. In this sense the exterior orientation parameters of each line are different, but the relationship of the exterior orientation to the satellite orbit is only changing slightly. Hence for the classical CCD-line cameras, the attitudes are not changing in relation to the satellite orbit. The Earth is spinning in this system. The projection centers are located in the satellite orbit – this can be expressed as a function of the image components in the orbit direction. [4]

The new generation of sensors has the flexibility of changing view direction while acquiring the image. In this sense the sensors can change continuously the view direction in such a way that their image lines are located parallel to local or national East – West map projection grid direction. This is a continuous on the orbit change of the yaw and roll movements to reach the scene border line with a fixed east value. This is shown in Figure 1. [4]

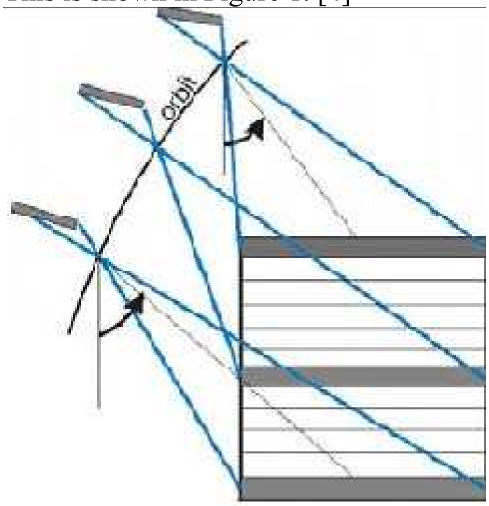


Figure 1- Imaging Geometry Of The Very High Resolution Satellite System With Flexible View Direction

One product of the Worldview-02 Imagery is the so called “Basic Imagery” that is close to the original sensor image. The basic imagery is a sensor corrected merged image taken by a combination of shorter CCD-lines. DigitalGlobe is commercializing it as level 1B .It is very close to the geometry taken by a unique CCD-line of 27552 panchromatic and 6888 multispectral pixels without geometric distortion. The information regarding the focal length differs for the scenes; it is in the range of 8835 mm leading the 12 μm pixel size to 61cm ground pixel size in the nadir. Within the orbit direction 6900 lines/second are being exposed supported by a Transfer Delay and Integration (TDI).[1]

The reflected energy is summed up not only in one CCD-line but by shifting the generated charge in correspondence to the image motion over a group of CCD-elements. High frequency attitude motions of the platform during image acquisition are removed from the basic imagery and only low frequency disturbances remains. Along with the images, the ephemeris and the attitude data are delivered. The ephemeris data can be used for the orientation of the image by making use of the ephemeris data included in the *.eph file with respect to a geocentric system and the attitude data included in the *.att file represented by four-element quaternion. These four parameters describe the attitude of the camera with respect to the Earth Centre Fixed (ECF) geocentric system, rotating with the Earth.[1]

Digital Globe distributes also two other image products. The so called “Standard Imagery” is a projection of the image to the rough Digital Elevation Model GTOPO 30 having a point spacing of 30” or nearly 900 meters. The panchromatic image has a ground pixel size of 61cm. The main disadvantage of the GTOPO 30 is its low vertical accuracy. This can range between 10 to 450 m. Hence it is necessary to carry out a geometrical improvement by using an acceptable DEM in addition to the use of GCPs for a precise geo-location.[1]

The other commercialized imagery product is the “Ortho Ready". It is a projection of the image to a plane with constant height, available in a cartographic projection been selected by the customer. It has the same ground pixel size like the Standard Imagery.[1]

2. Accuracy and Ground Control Requirements

The accuracy standards for National Map Accuracy Standards class (A) maps require that 90% of all well-defined points tested be accurate to within 0.5 mm.The accuracy standard as stated is a circular map accuracy standard (CMAS). [2]

It is somewhat more common to measure a mean squared error (MSE). If the assume that the errors have a Gaussian distribution with mean zero then the CMAS and MSE accuracies are related by: CMAS = 1.5174 MSE

The ASPRS standard also introduces three classes of maps based on the limiting RMS error. Class 1 maps are the highest and are shown, for planimetry, using Imperial units,in Table 1. The metric values are shown in Table 1. Class 2 maps are those were theacceptable limiting RMS error is twice that of Class 1 while Class 3 allow an RMS error ofthree times that in Class 1. [2]

	Limiting RMS error in X or Y		
Typical Map Scale	Class 1	Class 2	Class 3
1:50	0.0125	0.025	0.0375
1:100	0.025	0.050	0.075
1:200	0.050	0.1	0.15
1:500	0.125	0.25	0.375
1:1000	0.25	0.5	0.75
1:2000	0.50	1.0	1.5
1:4000	1.0	2.0	3.0
1:5000	1.25	2.5	3.75
1:10000	2.50	5.0	7.5
1:20000	5.00	10.0	15.0

Table 1- Planimetric Coordinate Accuracy Requirements (Ground X And Y) In Meters For Well-Defined Points. [2]

Note that these accuracies are two-dimensional. It is common in the literature to report accuracies separately for x and y map directions. These accuracies are typically the same and so are related to a MSE by a factor of $\sqrt{2}$:X_{error} or y_{error} = MSE/ $\sqrt{2}$

3. Methodology

The approach used to measure accuracy starts with the marking of well-defined features (check points) in the imagery to determine their input coordinates (Orthoready Standard type production). The input coordinates has been transformed to ground location using the models by the DigitalGlobe distributor. The ground locations thus determined are then compared with ground truth, that is, the locations as determined independently, from field surveys.

All the marked pointsare used as independent points at which to measure accuracy.

4. Types of Accuracy

Several different kinds of accuracy were measured for WV02 imageryfor study area. Errors are often resolved into one-dimensional components (X and Y), where the dimensions are, for example, map (x, y) or along-track and across-track directions. Let X_i and Y_i denote the measured error at the ith check point and N the number of check points.

The absolute accuracy (AA) is the mean square error

$$AA = MSE = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} (X_i^2 + Y_i^2)}$$

Relative accuracy (RA) is a measure of internal accuracy. It is based on the difference between true and measured distances between all pairs of check points:

$$RA = \sqrt{\frac{1}{N(N-1)} \sum_{i \neq j} ((X_i - X_j)^2 + (Y_i - Y_j)^2)}$$

Note that the sum of squared errors is divided by one-half the number of pairs to arrive at a value reflecting the error at one point rather than at both in the pair. It can be shown that relative accuracy is equal to the standard deviation of the errors, and so is a measure of what the absolute accuracy would be if any average errors were removed.

Scale accuracy (SA) is another measure of internal accuracy. It is similar to relative accuracy except that the error in the distance between points is normalized by the true distance (in a given map projection):

$$SA = \sqrt{\frac{2}{N(N-1)} \sum_{i \neq j} \frac{(X_i - X_j)^2 + (Y_i - Y_j)^2}{D_{ij}^{\,2}}}$$

Where:

D_{ij} is the true distance between points i and j.

Theplanimetric accuracy was assessed using ICP datasets, the ICP coordinates were obtained from rapid-static GPSsurvey data and had RMS x and y accuracies between 3-5 cm.The ICPs wereselected a prior at locations in the imagery that were sharp and distinct point features. Thisfacilitated the identification of these points in the orthoimagebasemaps and subsequentcomparison with the known GPS-based ICP locations.

The RMS Radial Error (RMSRE) and the Circular Error @ 90% probability (CE90) werecalculated for each Orthoreadyimage base-map using the ICP datasets. The RMSRE is given by

$$RMSRE = \sqrt[2]{RMS_x^2 + RMS_y^2}$$

Where

RMS_x and RMS_y are the RMS errors in the x and y directions, respectively. The RMSerror in each coordinate is computed using

$$RMS = \sqrt{\frac{\sum_{i=1}^{N}(P_{ICP_i} - P_{image_i})}{N-1}}$$

Where

P_{ICP} and $P_{IMAGE}$are the x or y positions obtained from the ICPs and the image locations,respectively. The CE90 is estimated by rank ordering the radial errors from smallest to largestand selecting the radial error corresponding to the 90th percentile, i.e. the abscissa value of the90% point of the Cumulative Distribution Function (CDF) of the radial (circular) error is used.

In an ICP dataset of N = 17 points, the 18^{th} (0.9 × 17) radial error value in the rankordered dataset is used to estimate CE90. For a purely random error distribution in both x and ycoordinates, the relationship between the circular error @ 90% and the RMSRE is CE90 = 1.54 ×RMSRE. The actual relationship will vary slightly from this due to small bias errors in the x andy directions.

5. EXPERIENCES

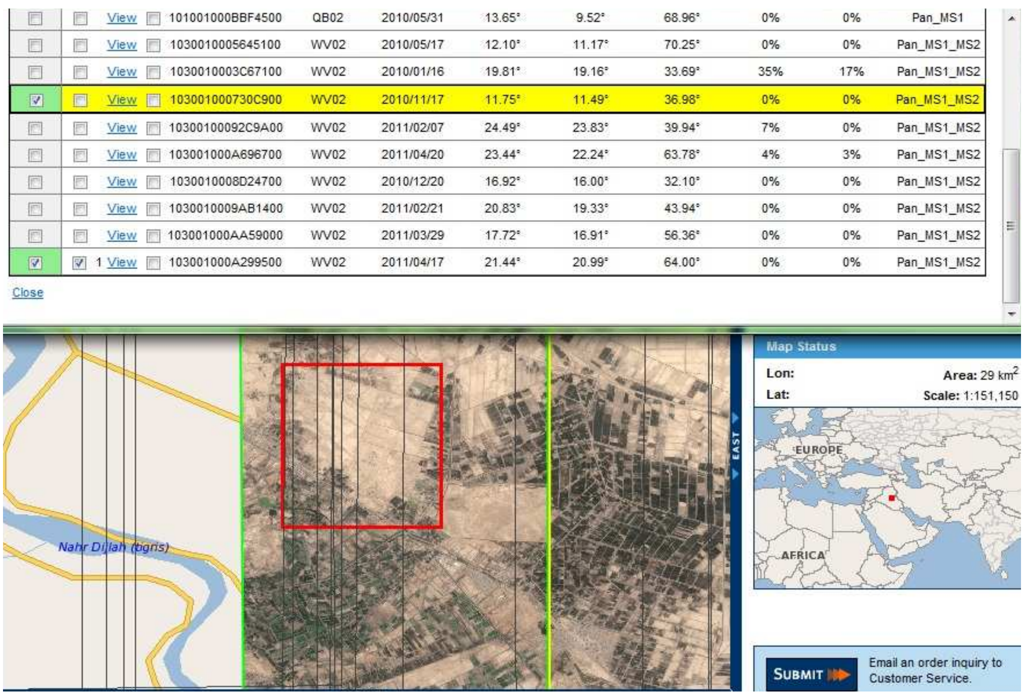
With geometric reconstruction or sensor depending RPCsolution, in general sub-pixel accuracy of the object points can be reached with well determined control and check points (table 1). If no accuracy of 1 GSD has been reached for the projects listed in table 1, there was a special problem, in most cases with limited accuracy of the control and check points.

5.1 WorldView-2 (0.5m GSD)

A WorldView-2 tile of Al-Wahdadistrict has been investigated without any influencing the geometry.The scene has a nadir angle of 11.49°, so the object point height is strongly uninfluenced the location with WV02 imagery product tile specification shown in table 2.

Table 2- WV02 Imagery For The Area Of Study (Al-Wahda District / South Of The Baghdad City)

Product Type:	Ortho Ready Standard	Product Option:	0.50 m
Bit Depth:	8	File Format:	Geo TIFF
Tiling:	No Tiling	Nadir Angle	11.49°
Delivery Method:	DVD	Map Projection:	UTM_38N
License Type:	Single End-User License	Datum:	WGS84
Acquisition Date	17/11/2010	Area	29 Km^2
Spectral Mode	Natural Color	Cloud Cover	0%



Instruments used for the field test are GPS TopCon GR3, equipped with Software, used for the field survey.
Instruments have been positioned on sites accurately described in the documentation provided with the GCPs locations.
The CORS station that provided RINEX observations used for post processing is ISKU (the nearest one, located in Baghdad: 33°20'29.09558"N, 44°26'18.25081"E).
Post processed locations have been compared with given GCPs, and Euclidean distances within corresponding points have been calculated with GIS software. RMSe (Root Mean Square error) has been calculated for the post processed dataset as:

$$RMSe = \sqrt[2]{\frac{(\sum_{d=1}^{n} d^2)}{n}}$$

Where:
n=number of GCPs.
d=Euclidean distance between the on screen digitized point and the corresponding GPS point.

5.2 Satellite Image Processing

Before satellite imagery can be used as a data source for research of the earth surface and / or atmosphere, the raw sensor data must be
rocessed to derive useful information from the digital numbers produced by the sensors.
The basic imagery product is in the satellite frame of reference. It is not tied to ground location, and is therefore a geometrically raw product with no implied accuracy. However, when the data are processed with the supplied refined Image Support Data (ISD), a horizontal geolocationalaccuracy of 5 m CE90, excluding terrain and off-nadir effects, can be achieved, with actual accuracy in the range of 4.0 - 5.5 m CE90 at less than 30° off-nadir. Vertical accuracy is 5.0 m LE90 at less than 30° off-nadir.
The most basic, but necessary processing involves geometric and radiometric correction. When these corrections are applied, the image is registered to a coordinate system, so the location of every pixel at the earth surface is known and the digital numbers are converted to radiance. This radiance values can then be converted into surface reflectance or brightness temperature.

Table 3- GCP's Image Coordinates

Name	Y_{Image}	X_{Image}
1	3671902.826	464819.248
2	3674584.211	466670.224
3	3674935.248	462482.740
4	3675423.694	462933.771
5	3674471.845	463411.771
6	3673882.279	462164.723
7	3672089.277	462407.792
8	3671556.766	463180.213
9	3671199.252	463353.753
10	3670715.764	463823.237
11	3670771.680	464664.759
12	3670063.241	466632.189
13	3669551.711	465715.232
14	3670965.504	466834.984
15	3672213.747	464782.699
16	3674944.263	464788.370
17	3674738.177	466329.283

5.3 Processing Software

All processing was carried out in image processing program: Erdas Imagine 9.4 (http://www.gis.leica-geosystems.com), Erdas Imagine has all the functionality that is needed.

5.4 Georeferenced And Resample

This step is dealing with the processing of satellite image using the GCPs. Satellite images 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.
Furthermore for Geo-referencing G.C.P's were established using DGPS [TopCon GR3], their WGS84, UTM are given in table (4) and their distributions are shown in figure (3).
The GCP's processed in WGS84 coordinate system and global datum of elevation system (vertical datum). Adjustment processing has been considering (CORS) Continuous Operating Reference Station Iraq Sury Baghdad (ISBA).

Table 4- GCP's Coordinates WGS84

Name	Easting (m)	Northing (m)
1	464819.4657	3671902.547
2	466670.7607	3674583.843
3	462483.6157	3674934.428
4	462934.123	3675422.198
5	463411.9	3674471.5
6	462164.697	3673881.092
7	462406.2	3672089.164
8	463180.86	3671555.698
9	463354.583	3671198.463
10	463822.698	3670716.343
11	464663.9	3670770.73
12	466632.977	3670063.197
13	465714.772	3669551.181
14	466834.239	3670964.878
15	464783.065	3672214.195
16	464789.628	3674943.996
17	466328.935	3674738.482
ISBA	447740.601	3689278.101

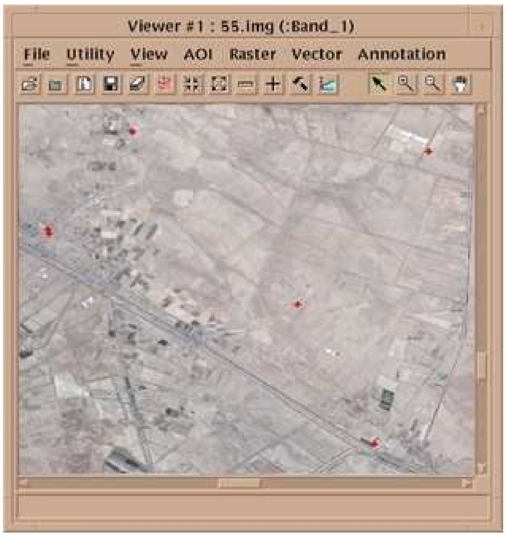


Figure 3- GCP's Distributions.

6. Measurements:

The data set was used to study WV02 precision modelling accuracy. They are described in Table 3 & 4.

All the 17 points have been successfully post processed. The accuracy rangeis 15cm-30 cm.

The calculated distances between on-screen digitized and GPS field collected (post processed) coordinates, are in the range 0.354m-1.596m.The RMSE calculated at 90% (N=15) gives a result of RMSE = 1.1 m, even if calculated at 100% (N=17; no GCPs discarded) gives a result of RMSE = 1.55 m.

7. Conclusion

RMSE90% obtained for the test is <2.0m, even the RMSE is calculated 100% for all ground points,and the result is again <2.0 m. Therefore the planimetric map produced is sufficient to scale 1:4000 with map classification is class two.

8. References

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