GEOMETRIC EVALUATION AND VALIDATION OF AERIAL AND SATELLITE DATA USING SIOUX FALLS GEOMETRIC TEST RANGE

Aparajithan Sampath [a], Don Moe[a], Jon Christopherson [a], Gregory Stensaas[b]
[a]SGT, Inc[1], U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD 57198 USA
[b]U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD 57198 USA

ABSTRACT

The U.S. Geological Survey (USGS) has developed the first of a series of geometric test ranges over Sioux Falls, South Dakota. The purposes of these test ranges are for evaluating, validating and characterizing high resolution satellite and aerial images. The Sioux Falls test range uses accurate and standardized high resolution aerial orthophotos as a reference dataset to compare and characterize the geometric accuracy of satellite and aerial images. This paper first provides a report on the characteristics of the test range and the accuracy of the reference data. The paper goes on to show the use of automated image assessment methodology and results for the geometric assessment of GeoEye image using the reference imagery over the test range.

INTRODUCTION

Geometric assessment of a remote sensing product involves independently assessing the geometric characteristics of the imagery, without the information required to perform a systematic absolute calibration, including the sensor's exterior orientation elements [1]. For high resolution remote sensing imagery, this is traditionally accomplished by comparing the ground coordinates of well surveyed photo-identifiable ground targets with those obtained from the assessment image (study image). Another method uses a well characterized reference image (usually an orthorectified product), of a resolution equal to or higher than the study image, as the source of ground targets. The reference image can be used to assess the study image by manually comparing tie points or by automatic means, using cross-correlation techniques. In this paper, such techniques are termed Image-to-Image (I2I) matching techniques [2].

As a part of its mandate and in accordance with the recommendations made by the American Society of Photogrammetry and Remote Sensing (ASPRS), the Remote Sensing Technologies (RST) group at the US Geological Survey (USGS) Earth Resources Observation and Science (EROS) center in Sioux Falls, SD is involved in establishing Geometric test ranges across the country. The ranges will form the foundation of the Data Provider Certification component of the USGS Plan for Quality Assurance of Digital Aerial Imagery ([3], [4]). A detailed description of the certification process is provided in [4]. The Data Provider Certification plan aims to assess a sample orthoimage produced by data providers from mosaicked images collected over the ranges. The ranges also provide the means for the system characterization of high resolution satellite images, which supports the USGS mandate to support the efforts of the Joint Agency Commercial Imagery Evaluation (JACIE) team. In the near future, the test ranges are also planned to be used for *in situ* camera calibration, as has been done with similar test ranges ([5], [6]).

In this paper, we will first present a new Geometric test range that can be used for validation of other high resolution data products. An assessment technique that leverages the available open source tools for manipulating geographic data is also presented. This paper is divided into five sections: Section 1 introduces the necessity for ranges, and the motivation for this research, Section 2 details the Sioux Falls Geometric test range and the reference data used for geometric evaluation, Sections 3 and 4 detail the methods employed for validating the test range, Section 5 presents the methods used for evaluation of the products, and Section 6 presents concluding remarks and future projects.

[1]Work performed under U.S. Geological Survey contract 08HQCN0005

Sioux Falls Geometric Test Range

The Sioux Falls test range (centered at 43°33'5.70"N, 96°43'22.54"W) includes the entire areas of both Minnehaha and Lincoln counties in South Dakota, USA. It is approximately 34 miles (54.7 km) E-W and 53 miles (85.3 km) N-S. The range is covered by orthoimagery (reference data) collected by Sanborn LLC. As shown in Fig. 1, the reference data consists of 30cm (1ft) imagery over the Minnehaha and Lincoln counties, and 7.5cm and 15cm (0.25 and 0.5ft) imagery over the city of Sioux Falls. The data were collected in 2008 as a joint effort between the USGS EROS and a consortium including the City of Sioux Falls, and Minnehaha and Lincoln Counties. The data are in UTM Zone 14N and its native units are in feet. A complete LiDAR coverage at 1.4m point density is also available for the whole region. The LiDAR DEM was used to generate the orthoimages.

The orthophotos were generated at a stated accuracy of 3.3ft at CE95, which met the National Map Accuracy Standards (NMAS). However, it was felt that a more complete characterization of the orthoimages would yield a better estimate of its accuracy. It was also decided to conduct a GPS-RTK (Real Time Kinematic) survey of photo-identifiable points visible in the orthoimages, for this purpose. A total of 112 photo-identifiable points were selected from the orthophotos and were surveyed using GPS-RTK surveying techniques. Root mean square error (RMSE) values were generated for these points using Accuracy Analyst™ software.

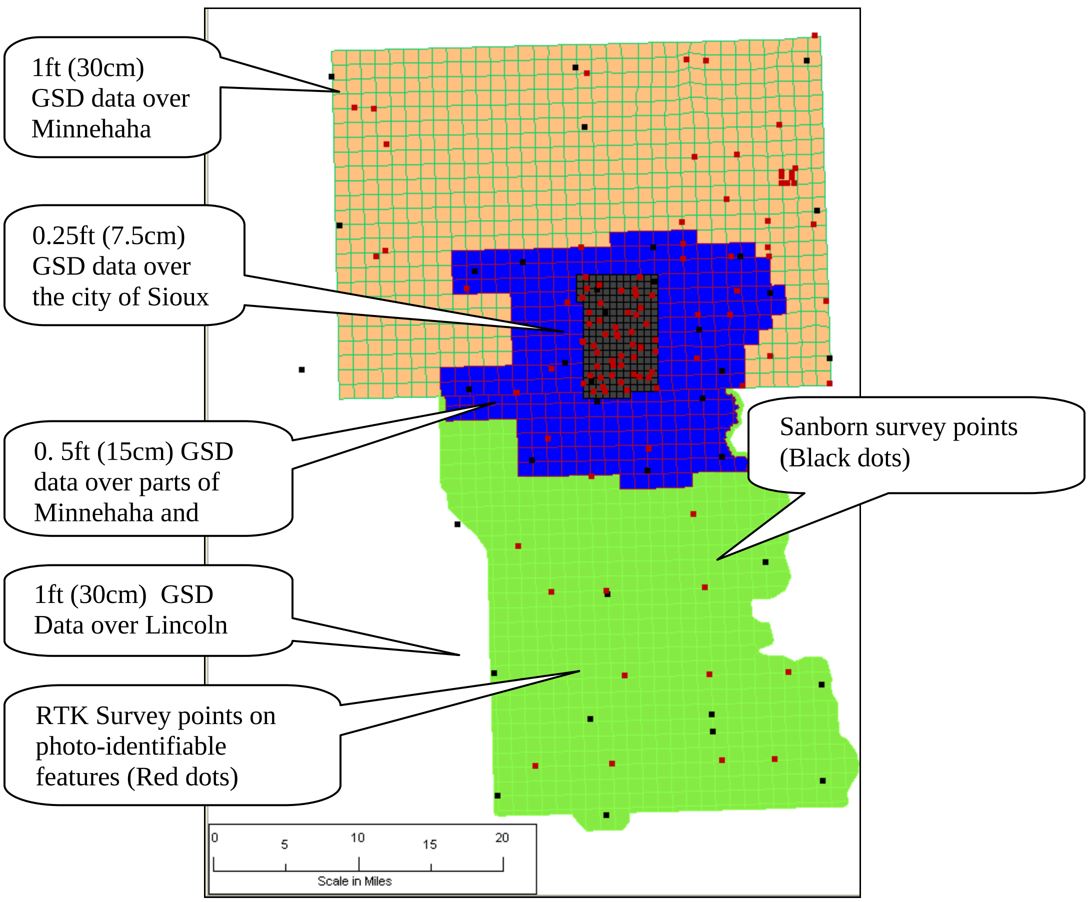

Figure 1. The three different resolutions of orthophotos over Minnehaha 1ft (30cm) (Orange), Lincoln 1ft (30cm) (Green), Sioux Falls 0.5ft (15cm) (Blue) and Sioux Falls 0.25ft (7.5cm) (Black) and the survey point distribution.

GPS-RTK Survey

The GPS survey consisted of two steps. In the first step, photo-identifiable points were selected from the images, using ArcMap and ENVI software. The points were picked such that they are well distributed over the entire area (Figure 1). An attempt was made to pick points from different types of terrain. However, a lack of sharp photo-identifiable features, particularly in rural areas prevented this. The points were picked on uniform slopes, or flat regions. In the next step, GPS survey was used to determine the coordinates of these photo-identifiable points. Close-up and contextual ground photographs were taken at each survey location (Figure 2). These are not only a record of the survey conditions, but also aid in the final accuracy assessment, as they help avoid gross errors. A total of 112 photo-identifiable points were surveyed, with 56 points in the 0.25ft GSD area, 13 points exclusive to the 0.5ft GSD area and the rest exclusive to 1ft GSD area.

Figure 2. Photo-identifiable points were selected from the orthophotos (top) and surveyed. Close up and contextual photos of all locations were collected.

Accuracy Assessment

The accuracy of the orthophotos was measured using the Accuracy Analyst™ software. The software provides a quick and easy way to assess the accuracy of orthophotos. The assessment was made for the three different GSD separately. The summary of the report is presented in Table 1. Table 1 shows the results of the comparison of the coordinates of photo-identifiable points between the 0.25ft, 0.5ft and 1ft GSD orthophotos and the GPS-RTK survey. The mean errors in both the Easting and the Northing directions are very small, indicating there are no significant systematic biases in the data. The CE90 and CE95 for the 0.25ft GSD data are 0.59 ft (0.17m) and 0.67ft (0.20m). For the 0.5ft GSD data, the CE90 and CE95 values are respectively 0.83 ft (0.25m) and 0.95 ft (0.29m). For the 1ft GSD data, the CE90 and CE95 values are respectively 1.48 ft (0.45m) and 1.68 ft (0.51m). The results of the accuracy assessment indicate that the Aerial orthoimages can be used as reference imagery for a range of products (both high resolution satellite, as well as aerial imagery).

Table 1. Comparison of survey points and photo coordinates. All measurements are in feet.

0.25 ft GSD data	**Min (ft)**	**Max (ft)**	**Mean (ft)**	**RMSE (ft)**
ΔX	-1.19	0.52	-0.02	0.36
ΔY	-0.5	0.28	-0.09	0.2
RMSE Ratio=0.56 CE90: 0.59 ft (2.36 pixels, 0.18m) CE95: 0.67 ft (2.68 pixels, 0.20m)				
0.5 ft GSD data	**Min (ft)**	**Max (ft)**	**Mean (ft)**	**RMSE (ft)**
ΔX	-0.94	0.92	-0.04	0.43
ΔY	-1.17	0.42	-0.15	0.34
RMSE Ratio=0.79 CE90: 0.83 ft (1.66 pixels, 0.25m) CE95: 0.95 ft(1.9 pixels, 0.29m)				
1 ft GSD data	**Min (ft)**	**Max (ft)**	**Mean (ft)**	**RMSE (ft)**
ΔX	-1.49	1.3	-0.07	0.66
ΔY	-1.24	2.16	0.06	0.71
RMSE Ratio=0.93 CE90: 1.48 ft(1.48 pixels, 0.45m) CE95: 1.68 ft(1.68 pixels, 0.51m)				

Image Assessment Methods

The Sioux Falls reference data was used to determine the Geometric accuracy of GeoEye-1 Standard Geometrically Corrected 0.5m panchromatic imagery. The comparison was carried out by combining open source Geospatial Data Abstraction Library (GDAL) tools and the Image Assessment System (IAS), designed primarily for assessing the geometric registration of Landsat.

The IAS uses the normalized correlation measure for determining the similarity between two image pairs. The IAS I2I program uniformly samples pixels in the reference image and measures the corresponding pixels in the study image. A correlation surface is generated for all the pixels within a user specified distance from the selected pixels (usually a 64 x 64 or 32 x 32) window in the study image.

$$CC(i,j) = \frac{\sum (\mathrm{I_R} - \bar{\mathrm{I}}_\mathrm{R})(\mathrm{I_S} - \bar{\mathrm{I}}_\mathrm{s})}{\sqrt{\sum (\mathrm{I_R} - \bar{\mathrm{I}}_\mathrm{R})^2}\sqrt{\sum (\mathrm{I_S} - \bar{\mathrm{I}}_\mathrm{s})^2}}$$

The use of a normalized correlation measure helps remove the effects of difference in the scale of images due to intensity [7]. The correlation measure is determined for every pixel using a 3 x 3 or 5 x 5 window. The peak of the correlation surface represents the exact location of the reference image pixel, in the study image. The results for the geometric analysis are presented in Table 2.

However, it has been found that while correlation based image registration measures work very well in lower resolution data, this may not be the case with higher resolution data. This case is exacerbated when the matching is done for areas that have very high self-similarity (Auto-correlation) [7]. This is particularly true in rural areas, where the uniformly selected point may be in the middle of a field. Also, the effects of shadows in urban areas and building lean can cause correlation mismatch, or the presence of multiple peaks. Many of these disadvantages can be eliminated by carefully picking reference image pixels to match, instead of doing so in a uniformly random manner. Since the Sioux Falls test range data was evaluated using carefully selected photo-identifiable ground points, spread across the range, these points can also be used for the purpose of geometric evaluation. .

GDAL is a very useful tool to manipulate geospatial data and was used extensively for this purpose. In this case, GDAL was used to search the headers of the GeoTiff files (of the reference images), to identify the image in which the control points were located. Small 32 x 32 chips were generated around all the control points. The image chips are stored as separate images, with their own header files. These header files of the chips are changed to reflect the errors associated with the orthoimages (from Section 5). A similar set of chips are also generated from the study image.

The control point chips generated by the above process can be considered more accurate than actual reference image, as the image errors are eliminated. This process also eliminates the need to rectify and resample the original reference orthoimage (to match the results of the GPS-RTK survey). It also reduces the need to create large mosaics of reference images, which are difficult to manipulate. Also, because GDAL can handle different coordinate systems and map projections, the process can potentially validate images in different projections, without having to reproject the whole image into UTM (the map projection of the reference image). The IAS I2I program determines the peak correlation within these chips. The above tries to minimize some of the disadvantages of correlation based image matching, by using distinctly visible known control points.

The process was tested on GeoEye-1 imagery over the city of Sioux Falls, covering the region shown in black in Fig. 1 (0.25ft or 7.5cm data). GeoEye-1 was launched in September 2008, and collects panchromatic imagery at a nominal resolution of 0.41m and multispectral imagery at 1.65m[8]. For this study, GeoEye had provided their standard geometrically corrected imagery, at 0.5m resolution for panchromatic images, which was tested against the Sioux Falls reference orthoimages. The Sioux Falls 0.25ft (7.5cm) region had 56 control points, of which only 32 were usable. This was because some of the points fell outside the extent of the GeoEye-1 image, and some of the points were unusable due to obstruction, resolution, shadows etc. The result of the test is presented in Table 2. The results indicate that there is a bias involved in the Northing (Y direction). The results match well with a manual registration process that was also carried out using the Accuracy analyst™ software for the same image.

Table 2 Results from GeoEye-1 I2I analysis

GeoEye-1	Min (m)	Max (m)	Mean (m)	RMSE (m)
ΔX	-3.7	3.8	0.05	2.1
ΔY	-3.5	4.2	1.38	3.13
RMSE Ratio=0.67 CE90=5.6m CE95=6.4m				

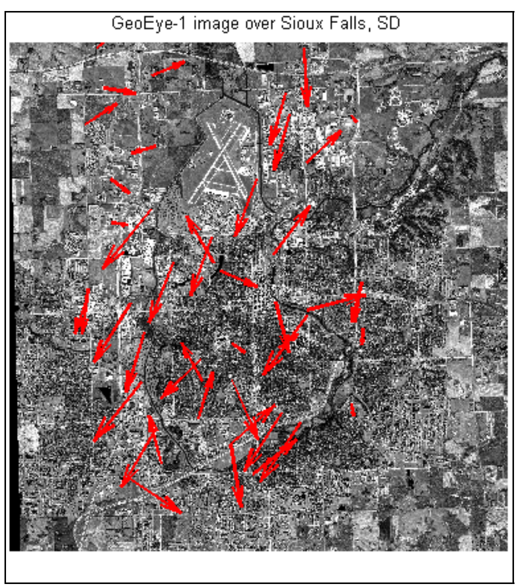

Figure 3. Error plots from the I2I analysis of GeoEye-1 imagery over Sioux Falls.

CONCLUSIONS AND FURTHER WORK

The Sioux Falls Geometric test range has been shown to be highly accurate, and capable of validating high resolution imagery. As a part of the Data Providers certification process, a total of six ranges are being planned across the United States. In addition to Sioux Falls, two more of these ranges will be located in Pueblo, CO and Rolla, MO. The remaining three are TBD. To assess the images, an automated process of evaluation was presented, by combining available tools. However, the current I2I may not be sufficient to characterize a study image, particularly if it is rotated, in addition to being translated. This is because the tool currently uses only cross correlation as a means of similarity measurement. Further research is planned on exploring image registration techniques suitable for the process. Further work on *in situ* calibration techniques are also planned for the ranges, particularly since the ranges provide enhanced elevation in the urban areas. Well surveyed points on the roof of some of the taller buildings in these urban areas may help in a more reliable determination of interior orientation parameters.

REFERENCES

USGS EROS Data Center, 2007:Guidelines for the Characterization Of Satellite Data, 2007, Remote Sensing Technologies (RST) Project, Version 1.0 December 2007.

USGS EROS Data Center, 1998: Landsat 7 Image Assessment System (IAS) Geometric Algorithm Theoretical Basis Document, Version 3.2, Sioux Falls, South Dakota, July 1998.

G. Stensaas, G.Y.G. Lee, J. Christopherson, 2007: The USGS Plan for Quality Assurance of Digital Aerial Imagery. Available at: http://calval.cr.usgs.gov/documents/The_USGS_and_IADIWG_Plan9.pdf (Accessed on 19th Feb, 2009).

G. Stensaas and G. Lee, 2008: Driving toward a worldwide acceptance procedure for digital airborne sensors, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B1. Beijing 2008.

M. Cramer, 2007: The EuroSDR performance test for digital aerial camera systems, in Fritsch (ed.): Photogrammetric Week 07, Wichmann, Heidelberg, p. 89-106.

D.C.A Merchant, A. Schenk, A. Habib, T. Yoon, 2004: USGS/OSU progress with digital camera in situ calibration methods, International Archives of Photogrammetry and Remote Sensing, 35(2): 19-24.

B. Zitova and J. Flusser, 2003: Image registration methods: A survey. Image and Vision Computing, vol. 21, no. 11, pp. 977–1000, 2003.

GeoEye-1 Fact sheet. Available at http://launch.geoeye.com/LaunchSite/assets/documents/geoeye1_factsheet.pdf (Accessed on 19th Feb, 2009).