

Accuracy Analyst: A Horizontal Accuracy Assessment Tool

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Abstract—Spatial error analysis and estimation is an important task pertaining to geospatial imaging and mapping that can enable the user to establish the accuracy of information obtained from georeferenced images. Spatial error analysis techniques allow the user to quantify and understand spatial uncertainty and discrepancies in data. The objective of this work is to develop a set of software tools that may be used to analyze and estimate the spatial inaccuracies and quantify findings using industry standard terms for georeferenced image data accuracy specifications. Accuracy Analyst is a software tool that can be used to analyze the horizontal accuracies pertaining to the spatial coordinates surveyed for certain well-defined survey checkpoint locations and the locations of those photo-identifiable points extracted from georeferenced orthorectified image data

Keywords – Image Horizontal Accuracy, CE₉₀, CE₉₅

I. INTRODUCTION

Mechanical limitations of instrument, sensor position and orientation, curvature of the earth and unforeseen human errors are some of the sources for mapping inaccuracies that are usually encountered in geospatial mapping or imaging processes. One such spatial discrepancy is the horizontal positional inaccuracy of the remotely acquired image. Due to the aforementioned sources of errors, the horizontal positional information of an object obtained from a remotely acquired image may deviate from its true real world surveyed or measured location. Although some of the potential causes for spatial errors can be eliminated or reduced, estimation of horizontal inaccuracies is still an important task that needs to be undertaken to assess the reliability of the information retrieved from the image. In this paper, authors explain the Accuracy Analyst toolkit, which has been developed to provide a user friendly graphical user interface, implementing the circular error distribution analysis procedures described by Greenwalt and Shultz [1] for analyzing and estimating the horizontal accuracy.

II. FUNDAMENTALS OF CE90/CE95

The horizontal positional error of an object can be represented by a random variable pair, (x, y) . The random variables x and y correspond to the error encountered in the X (longitude) and Y (latitude) directions respectively. The error can be considered as the deviation of the measured values from the true values. The two random variables can be assumed to be independent, with a Gaussian distribution and zero mean. The joint probability density distribution for these random

variables (x, y) is given by equation (1). Rearranging equation (1) results in (2).

$$p(x, y) = \frac{1}{2\pi\sigma_x\sigma_y} e^{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right)} \quad (1)$$

$$-2 \ln[p(x, y)2\pi\sigma_x\sigma_y] = \left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right) \quad (2)$$

As it can be observed from equation (2) for a given value (x, y) the probability density function represents the square of the radius of circle assuming that variances $(\sigma_x$ and $\sigma_y)$ in both the dimensions are equal. The probability for an error random variable pair (x, y) to be contained within a circle of radius R can be defined by the circular error probability function $P(R)$. The circular error probability function can be derived from equation (2) and is detailed in [1]. A condensed form for $P(R)$ for the case when σ_x and σ_y are equal is given by equation (3)

$$P(R) = 1 - e^{-\frac{R^2}{2\sigma_c^2}} \quad (3)$$

where R is the radial distance.

For CE90, the National Map Accuracy Standard (NMAS) specifies that 90% of well-defined points in an image or map should fall within a certain radial distance R . For CE95, the National Map Accuracy Standard (NMAS) specifies that 95% of well-defined points in an image or map should fall within a certain radial distance R . Therefore substituting the left hand side of (3) with 0.90 will yield the horizontal accuracy standard as specified by NMAS which is given by equation (4).

$$CE_{90} = 2.1460\sigma_c \quad (4)$$

where $\sigma_x = \sigma_y = \sigma_c$.

Similarly, for CE95 substituting 0.95 instead of 0.9 and simplifying yields

$$CE_{95} = 2.4477\sigma_c$$

The calculation for σ_x is shown below.

$$\sigma_x = \sqrt{\frac{\sum(x_{image} - x_{realworld})^2}{n}} \quad (5)$$

where x_{image} and $x_{realworld}$ are the coordinates of the checkpoint location measured from the image and real world respectively, and n is the number of such checkpoints. σ_y is calculated similar to (5).

For cases where σ_x and σ_y are not equal, the error distribution takes on a more elliptical shape rather than being truly circular. Although this is the case, it is shown in [1] that a Gaussian circular distribution can be still substituted for the elliptical distribution for certain $\frac{\sigma_{min}}{\sigma_{max}}$ ratios, where σ_{min} is the minimum value between σ_x and σ_y , and σ_{max} is the maximum value between σ_x and σ_y .

For cases where σ_x and σ_y are not equal and $\frac{\sigma_{min}}{\sigma_{max}}$ ratio is between 0.6 and 1.0, [1] shows that σ_c is estimated by a linear combination of σ_x and σ_y as given by equation (6).

$$\sigma_c = 0.5222\sigma_{min} + 0.4778\sigma_{max} \quad (6)$$

where σ_{min} is the minimum value between σ_x and σ_y , and σ_{max} is the maximum value between σ_x and σ_y . A further approximation of (6) is given in equation (7), which was adopted by NSSDA (Federal Geographic Data Committee 1988) for United States standard for spatial data.

$$\sigma_c = 0.5(\sigma_{min} + \sigma_{max}) \quad (7)$$

For cases where σ_x and σ_y are not equal and $\frac{\sigma_{min}}{\sigma_{max}}$ ratio is between 0.2 and 0.6, σ_c is estimated using an interpolated value from statistical data that relates $\frac{\sigma_{min}}{\sigma_{max}}$ to $\frac{\sigma_c}{\sigma_{max}}$ found in Table 1 of [1].

III. ACCURACY ANALYST

Accuracy Analyst version 1.0 automates accuracy evaluation and circular error distribution analysis procedures. The application has been developed using Microsoft Visual Studio primarily using the C# programming language. The application is optimized for the evaluation of large ortho-photography image collections and also may be used to evaluate the horizontal accuracy of single images in a variety of well-known and industry standard georeferenced image formats. The application is primarily an accuracy analysis tool wherein the coordinate pairs (x and y locations) of surveyed checkpoint locations are compared to photo identifiable locations obtained from the remotely acquired image(s). Surveyed checkpoints are loaded into the application as are image data and an index tile layer (for evaluating large ortho-production acquisitions).

The Accuracy Analyst graphical user interface is shown in Figure 1. The coordinates and offsets data frame with loaded surveyed checkpoints is shown in figure 2. Upon loading the data using either of the data input methods, the data is displayed on the data list window as shown in Figure 3. Along with the data listing the root mean square error in both the directions, σ_x and σ_y are calculated and displayed (RMSE_x and RMSE_y in Figure 5). The $\frac{\sigma_{min}}{\sigma_{max}}$ ratio is also calculated and displayed on the user interface (RMSE_{min}/RMSE_{max} in Figure 5).

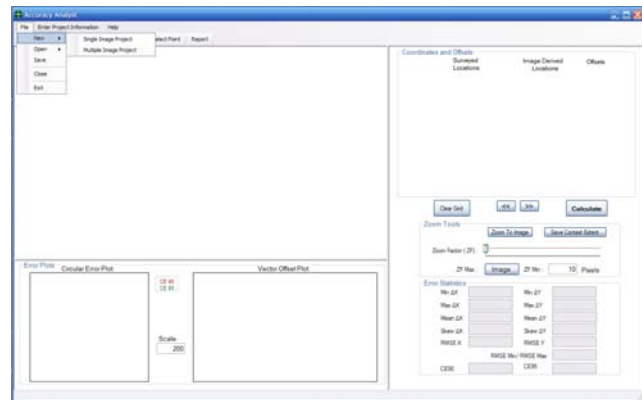


Figure 1 Accuracy Analyst graphical user interface.

Coordinates and Offsets								
		Surveyed Locations		Image Derived Locations		Offsets		
USE	ID	X1	Y1	X2	Y2	ΔX	ΔY	Status
<input checked="" type="checkbox"/>	1	973739.90	1410246.30					
<input checked="" type="checkbox"/>	2	978152.30	1437474.20					
<input checked="" type="checkbox"/>	3	979038.20	1450404.60					
<input checked="" type="checkbox"/>	4	996748.30	1435566.40					
<input checked="" type="checkbox"/>	5	993498.30	1456892.60					
<input checked="" type="checkbox"/>	6	1009897.00	1457394.00					
<input checked="" type="checkbox"/>	7	1005519.30	1427923.00					
<input checked="" type="checkbox"/>	8	1017434.70	1420224.90					
<input checked="" type="checkbox"/>	9	1017301.60	1446861.50					

Figure 2 Accuracy Analyst GUI showing surveyed locations in the Coordinates and Offsets data frame.

Error distribution analysis is performed automatically after the user identifies all photo-identifiable locations that correspond to the surveyed checkpoint locations. Along with reporting of accuracy characteristics, the application generates error plots in the form of a Circular Error Plot and a Vector Offset Plot as shown in Figure 4. The Circular Error Plot provides an error distribution graphic, where the user can visually observe where these positional errors fall with respect to the CE_{90} and CE_{95} values estimated using (4). An example case is shown in Figures 3 and 4. The user can select the data points by highlighting them on the data list window as shown in Figure 3 (location 9 selected). The positional error of this point is highlighted in both the Circular Error Plot as well as the Vector Offset Plot. For the Circular Error Plot, the red circle on Figure 4 represents the CE_{90} radius whereas the green circle represents the CE_{95} calculated according to equation (4).

The Accuracy Analyst Vector Offset Plot represents the magnitude and direction of the error random variables (x, y). The user can also input an appropriate scale factor to increase the relative distance of vectors thereby making error magnitude and directions more readily visible and allowing spatially varying patterns in error distribution to be easily understood.

Accuracy statistics generated are readily displayed on the application as shown in figure 5. As shown in figure 6, the user may determine and establish ideal zoom settings for locating and reviewing photo identifiable points. After all points are located, they may be easily reviewed and adjusted as desired. Specific points may be unselected if the user can not identify the location or if a surveying error is suspected. Adjustments to selected photo-ID point locations result in automatic changes to the error calculations as well as to error plots.

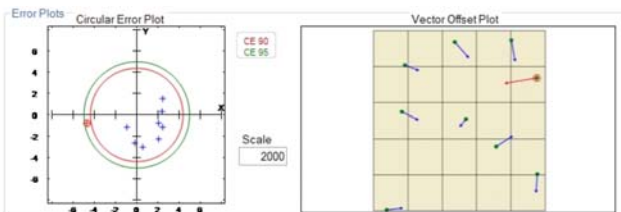


Figure 4 Accuracy Analyst GUI displaying the circular error and vector offset plots.

Coordinates and Offsets								
		Surveyed Locations		Image Derived Locations		Offsets		
USE	ID	X1	Y1	X2	Y2	ΔX	ΔY	Status
<input checked="" type="checkbox"/>	2	978152.30	1437474.20	978154.74	1437473.07	2.44	-1.13	
<input checked="" type="checkbox"/>	3	979038.20	1450404.60	979040.27	1450403.85	2.07	-0.75	
<input checked="" type="checkbox"/>	4	996748.30	1435566.40	996747.36	1435565.27	-0.94	-1.13	
<input checked="" type="checkbox"/>	5	993498.30	1456892.60	993500.37	1456890.35	2.07	-2.25	
<input checked="" type="checkbox"/>	6	1009897.00	1457394.00	1009897.56	1457391.00	0.56	-3.00	
<input checked="" type="checkbox"/>	7	1005519.30	1427923.00	1005521.74	1427924.50	2.44	1.50	
<input checked="" type="checkbox"/>	8	1017434.70	1420224.90	1017434.51	1420222.27	-0.19	-2.63	
<input checked="" type="checkbox"/>	9	1017301.60	1446861.50	1017300.91	1446860.75	-0.69	-0.75	

Figure 3 Accuracy Analyst GUI showing surveyed locations, image derived locations, and X and Y offsets in the Coordinates and Offsets data frame.

Zoom Tools

Zoom To Image Save Context Extent

Zoom Factor (ZF):

ZF Max: ZF Min: Pixels

Error Statistics

Min ΔX	-4.69	Min ΔY	-3.00
Max ΔX	2.44	Max ΔY	1.50
Mean ΔX	0.68	Mean ΔY	-1.10
Skew ΔX	-1.66	Skew ΔY	0.45
RMSE X	2.34	RMSE Y	1.73
RMSE Min/ RMSE Max		0.74	
CE90	4.37	CE95	4.99

Figure 5 Accuracy Analyst GUI showing accuracy statistics.

Figure 6 Accuracy Analyst GUI displaying the ability to set a context view zoom setting for rapidly identifying location and for review of locations.

IV. CONCLUSION

The objective of this work is to create an application and user interface to enable efficient spatial error analysis and estimation and provide the user with statistical and graphical results delivering understanding as to the accuracy and uncertainty characteristics of the georeferenced image data evaluated. In this work, a highly integrated toolkit, Accuracy Analyst, is shown to perform horizontal error analysis based on the principles of error theory described by Greenwald and Shultz [1]. The application enables optimized evaluation of large ortho-photo data collections and rapid evaluation by considering image elements that are of interest to identifying a specific photo-identifiable location from a selected image that corresponds to a surveyed location. The application readily manages the input of data, the measurement of image locations, the compilation of location offsets, the calculation of error statistics, and generation of error plots. In addition, the application generates a full report that comprehensively documents the entire project, provides all statistical error characteristics calculated, and includes images of all photo locations with surveyed and photo derived locations shown as points on the image as well as in coordinate locations with offsets. The subject application provides a fully functional software environment for image horizontal accuracy analysis.

REFERENCES

- [1] C. R. Greenwalt and M. E. Shultz., "Principles of error theory and cartographic applications;," *ACIC Technical report*, No. 96, pp-89 Aeronautical Chart and Information Center, US Airforce, St Louis MO June. 1968.
- [2] Federal Geographic Data Committee 1988. "Geospatial Positioning Accuracy Standards", Part 3: *National Standard for Spatial Data Accuracy*, FGDC-STD-007.3-1998 pp-25
- [3] U.S.Bureau of the Budget, 1947. United States National Map Accuracy Standards, U.S.Bureau of the Budget, Washington D.C.