A
Pictometry International, Corp
White Paper

Absolute Horizontal Accuracies of Pictometry's Individual Orthogonal Frame Imagery©

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PICTOMETRY
INTELLIGENT IMAGES

Contents

Glossary

DEM	*Digital Elevation Model*
FOV	*Field Of View*
GPS	*Global Positioning System*
GSD	*Ground Sample Distance (a.k.a. Pixel size)*
GSE	*Ground Surface Error*
IMU	*Inertial Measurement Unit*
SBET	*Smoothed Best Estimate Trajectory*
PDOP	*Positional Dilution of Precision*
USGS	*United States Geological Survey*

Introduction

This paper will outline the procedures used, and the results of, absolute horizontal accuracy testing of individual orthogonal frame imagery captured and processed utilizing Pictometry's patented system.

Problem Statement

The goal of this testing is to generate values suitable to use in the "compiled to meet" accuracy statement as defined in the *Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy (FGDC-STD-007.3-1998)*

Conclusion

Based on testing in accordance with the procedures outlined in *(FGDC-STD-007.3-1998)* the absolute horizontal accuracy of Pictometry's individual orthogonal frame imagery has the following "compiled to meet" horizontal accuracies at the 95% confidence interval utilizing a DEM accurate to 1 meter:

3 inch [7.5 cm] GSD = 2.9 feet [88 cm]
4 inch [10 cm] GSD = 3.5 feet [106 cm]
6 inch [15 cm] GSD = 4.4 feet [134 cm]
9 inch [22.5 cm] GSD = 5.8 feet [176 cm]

Equipment and Software

Camera System

Pictometry's Pentaview and C6 camera systems are based on architecture designed and patented by Pictometry. The Pentaview camera system is a multi-camera system comprised of five digital camera modules and an acquisition computer (with sensor control hardware and software). The C6 system is comprised of six digital camera modules that includes two overlapping nadir (a.k.a. "ortho") cameras allowing for an increased capture width and an acquisition computer (with sensor control hardware and software). Key components of the both systems are manufactured and assembled by qualified suppliers under contract to Pictometry. Individual subsystems of the Pentaview system are integrated and tested at Pictometry's facilities in Rochester, NY. The finished camera systems are calibrated and tested in the laboratory at Pictometry's facilities in Rochester, NY.

Pictometry's 16-megapixel Pentaview imaging system carries the United States Geological Survey (USGS) Camera Type Certification and comprises five custom designed cameras and an Applanix Position and Orientation System (POS) which includes both a Global Positioning System (GPS) antenna and an Inertial Measurement Unit (IMU). The five cameras are aimed with one looking nadir and four looking in each of the four cardinal oblique directions.

Pictometry's 29-megapixel Pentaview imaging system is constructed on the USGS approved platform and incorporates upgraded 29-megapixel sensors. Pictometry's C6 imaging system is comprised of six custom designed cameras and an Applanix Position and Orientation System (POS) which includes both a Global Positioning System (GPS) antenna and an Inertial Measurement Unit (IMU). The six cameras are aimed with two cameras each looking 10 degrees from nadir (resulting in a ~33% overlap) and four looking in each of the four cardinal oblique directions.

As part of the manufacture, Pictometry's individual cameras are put through a rigorous calibration process developed by Pictometry and licensed to the USGS. This process is used to solve for the camera's precise focal length, principal point location, and radial distortion coefficients. These parameters are then incorporated into the camera model. Each camera is also put through a color calibration process designed by Pictometry in order to ensure consistent response.

Collection procedures

In advance of capturing the data, an additional aerial boresight calibration is performed on each of the systems involved in the project. An adjustment then is computed to solve for the alignment between the optical axis of the camera and the internal coordinate axes of the Inertial Measurement Unit (IMU). This adjustment is then applied to the imagery captured throughout the project. Each system completes a boresight flight at regular intervals to ensure that the sensors have stayed in alignment.

Once the cameras are calibrated and the system is aligned, data capture can begin. Throughout each of the capture missions, GPS/IMU data is logged on the aircraft, the GPS data is recorded at a minimum rate of 2Hz and the IMU data is logged at a minimum rate of 200Hz. Concurrently, one or more GPS reference stations are logging data on the ground. These reference stations may be either part of the NGS CORS network, or a base station set up and run by Pictometry or a licensed Surveyor sub-consultant.

The imagery is nominally captured while PDOP values are monitored and the aircraft is within 45 kilometers of an operating GPS reference station. Due to the small format of Pictometry's camera, and automatic aerial triangulation techniques available, Pictometry limits its sensor to 6 degrees of pitch and yaw; this limit can be utilized due to the narrow field of view of Pictometry's cameras which, by design, limits the off-nadir distance of features at the edge of the frame.

Applanix POSPac software is utilized to post process the GPS/IMU data utilizing the SmartBase (IN-fusion) or single base station technology. The SmartBase technology uses a centralized filter approach to combine the GPS receiver's raw observables (psuedorange and phase observables) with the IMU data (tightly coupled solution). The Applanix SmartBase engine processes the raw observables (phase and psuedorange to each tracked satellite) from a minimum of four to a maximum of 50 continuously-working GPS reference stations surrounding the trajectory. The computed ionospheric, tropospheric, satellite clock, and orbital errors at all the reference stations are used to correct for the errors at the location of the remote receiver. The SmartBase Quality Check tool is utilized to perform a network adjustment on all the base-lines and reference stations in the network. Quality checks are also performed on the individual reference station observation files before the Applanix SmartBase is computed. The result of this process is that the integrity of the reference station's data and coordinates are known before the data is processed.

The single base technology is different as only one dedicated base station is used as a reference station and atmospheric delay and other correction data are only retrieved at the dedicated master station.

The final smoothed best estimated trajectory (SBET) is computed from the GPS track (including Kalman Filtering) utilizing either the SmartBase or single base station mode. Once the trajectory has been generated, it is applied to the imagery on the basis of the individual time stamps associated with each frame. The location (X, Y, Z) and orientation (Roll, Pitch, Yaw) values derived from the SBET and assigned to each frame serve as the initial exterior orientation (EO) values for the aerial triangulation phase of the processing.

Concurrent with the GPS/INS processing, the imagery in RAW format is "developed" to uncompressed TIFF format. After the development process, the imagery is put through a rigorous QA/QC process whereby images of low quality, due to either improper exposure or sensor artifact, are identified and marked for recapture. Pictometry uses both automated software it has created (proprietary) and human examination when considering whether to reject an image or pass it for production.

The final approved imagery is put through a verification process wherein common points are compared in the images (tie-points). The calculated coordinates for each tie-point are then checked against those from the other tie-points of the same point in different images. Any anomalous points are investigated to ensure the tie-point is valid and the image data is reprocessed if necessary.

Standard Product Horizontal Accuracies

Background

The absolute horizontal accuracy (of features) within a particular frame of Pictometry orthogonal imagery depends on a number of factors. Among these are the accuracy of point location within the image, the accuracy of the ground surface (DEM) used for rectification, and the accuracy of the exposure station coordinates and orientation of the sensor at the time of the exposure (Exterior orientation Parameters). The Position and Orientation System (POS) data provides the Exterior Orientation Parameters of the sensor at the time of exposure in a ground coordinate system. These parameters (commonly referred to as EOs) are primarily derived from the post-processed POS solution, the accuracy of which in turn depends upon the accuracy of the GPS reference station coordinates and the solved vector to the capture system.

The absolute horizontal accuracy of individual pixels as measured within individual orthogonal frames is dependent primarily upon the accuracy of the POS solution. In orthogonal imagery, the DEM used for rectification is generally of less significance than the POS solution and the error introduced by the DEM increases as we move away from the nadir point. At the nadir point, the contribution to the horizontal error from the DEM is zero and at the edge of the field of view (FOV) the contribution is at its maximum. For standard Pictometry orthogonal imagery, the maximum horizontal error introduced at the edge of the FOV, due to feature distances from the nadir point, is calculated to be approximately 0.32 times the error in the ground surface.

Testing

Coordinate points were collected across the project area, in accordance with specifications set forth in FGDC-STD-007.3-1998. These surveyed points were then compared against the coordinates measured in the imagery captured and produced by Pictometry.

The data tested consisted of well-identified points within Pictometry imagery, measured against surveyed ground control points, at different project locations. Testing was performed in accordance with the "*Case 2*" procedures outlined in *(FGDC-STD-007.3-1998)*.

Case 2: Approximating circular standard error when RMSEx is not equal to RMSEy

If RMSEmin/RMSEmax is between 0.6 and 1.0 (where RMSEmin is the smaller value between RMSEx and RMSEy and RMSEmax is the larger value), circular standard error (at 39.35% confidence) may be approximated as 0.5*(RMSEx + RMSEy) (Greenwalt and Schultz, 1968). If error is normally distributed and independent in each the x- and y-component and error, the accuracy value according to NSSDA may be approximated according to the following formula:

ACCURACYr ~ 2.4477 * 0.5 * (RMSEx + RMSEy)

Summary Absolute Horizontal Accuracies

Pictometry has tested 58 total projects containing 1,407 total points across varying GSD's over the 2013 and 2014 flight seasons:
3-inch areas – 18 projects, 415 points
4-inch areas – 27 projects, 682 points
6-inch areas – 6 projects, 166 points
9-inch areas – 7 projects, 144 points

The computed "compiled to" 95% absolute horizontal accuracy results of the tested areas are as follows:

3 inch [7.5 cm] GSD [1, 3] = 2.9 feet [88 cm] @ 95%
4 inch [10 cm] GSD [1, 3] = 3.5 feet [106 cm] @ 95%
6 inch [15 cm] GSD [2, 4] = 4.4 feet [134 cm] @ 95%
9 inch [22.5 cm] GSD [2, 4] = 5.8 feet [176 cm] @ 95%

[1] Meets or exceeds *ASPRS Class V, Accuracy Standards for Digital Geospatial Data (2014)*
[2] Meets or exceeds *ASPRS Class IV, Accuracy Standards for Digital Geospatial Data (2014)*
[3] Meets or exceeds *ASPRS Class I @ 1"= 150' Accuracy Standards for Large Scale Maps (1990)*
[4] Meets or exceeds *ASPRS Class I @ 1"= 200' Accuracy Standards for Large Scale Maps (1990)*

Additional conditions that may affect actual accuracies achieved include specific project site conditions, accuracy of the DEM utilized in imagery rectification, GPS and IMU errors, and variability in control station (e.g. CORS network) availability, accuracies and geometry. The areas tested in support of this document are areas with DEMs having nominal vertical accuracy of 1 meter* for orthorectification of the nadir frames and the imagery was captured with Pictometry's Pentaview and/or C6 Camera system.

Due to the impact of DEM error stated previously ("approximately 0.32 times the error in the ground surface") the following additional absolute horizontal errors may exist in the imagery created utilizing DEMs of the accuracy listed below:

Assumed Source DEM Error	Equivalent Contour Interval of Source DEM	Additional Possible Horizontal Error from Source DEM
2.98 feet [91 cm] *	5-foot [1.5 m] contour	0
5.96 feet [1.82 m]	10-foot [3 m] contour interval	1.9 feet [58 cm]
11.92 feet [3.63 m]	20-foot [6 m] contour interval	3.8 feet [116 cm]
17.89 feet [5.45 m]	30-foot [10 m] contour interval	5.7 feet [174 cm]