Lewis and Clark, MT
2012 Imagery Project

Aerial Triangulation Report

July 23, 2012

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EXECUTIVE SUMMARY

Sanborn has successfully completed the aerial triangulation (AT) task for the aerial photography acquired May 7th through 11th, 2012 for the Lewis and Clark project.

Using fully analytical aerial triangulation (FAAT) methods incorporating automatic analytical aerial triangulation (AAAT) procedures, Sanborn determined ground coordinates for each exposure by flying at an average altitude of 3100m AMSL covering the project area.

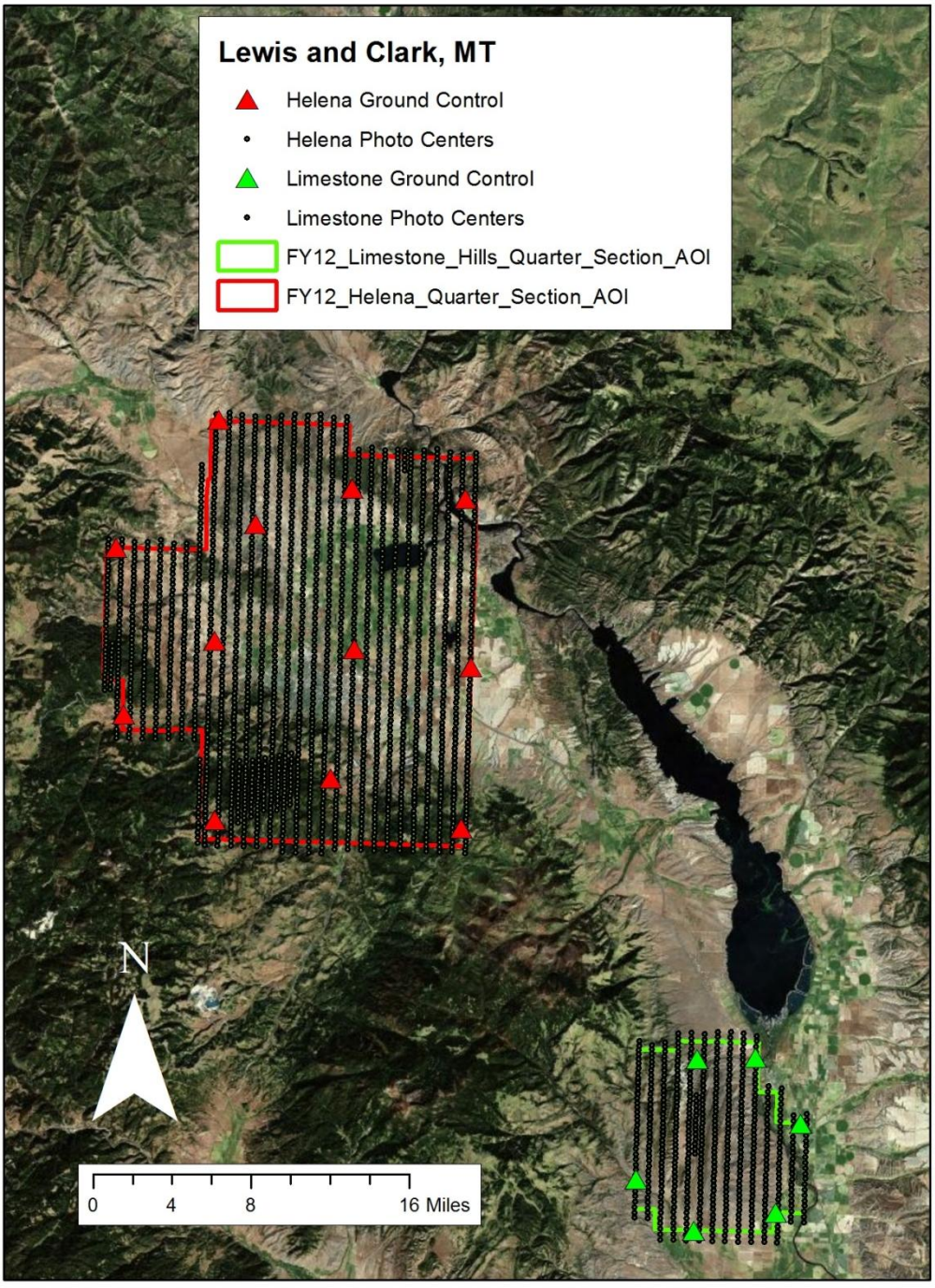
The results of the final adjustment are sufficient to enable Sanborn to produce digital photogrammetric mapping with an appropriate ground pixel resolution that meets project accuracy requirements (ASPRS Class 1 for 1:1200 mapping).

AT Accuracy Statement

The mean standard deviation of all adjusted terrain points indicate the AT solution exceeds the accuracy requirements for ASPRS Class 1 1:1200 scale mapping.

1. FLIGHT/CONTROL MAP

Dates of photography: May 7th through 11th, 2012
Number of flight lines: Helena: 53, Limestone: 20
Number of exposures: Helena: 2250, Limestone: 552
Flight Height: 3100m AMSL
Image Overlap: 60% FOL / 30% SOL



2. AIRBORNE – GPS/INS PROCESSING

The airborne-GPS data were processed using POSPac™ (version 5.4) Mobile Mapping Suite; GPS-IMU tightly coupled processing software which uses Kalman Filtering techniques, and On-The-Fly (OTF) ambiguity resolution techniques. Multiple CORS stations are being used in SmartBase trajectory processing.

2.1 SmartBase Processing Technique

Applanix SmartBase processing mode creates a virtual base station, which follows plane trajectory allowing faster and more accurate on the flight kinematic ambiguity resolution. In order to process trajectory in SmartBase processing mode multiple CORS stations (usually from 6 to 11 CORS stations per mission) are imported into the project. The network of the CORS stations creates a closed polygon around the plane trajectory. Within the polygon atmospheric corrections are well modeled and applied to each photo center. One of the most reliable CORS stations is chosen as primary station. The SmartBase quality check wrt primary is performed on all CORS stations involved in the network. Any CORS stations failing QAQC check are eliminated from processing. In the following step Applanix SmartBase CORS network adjustment is run to adjust all CORS stations to a common datum. The final step in Applanix SmartBase processing is 'GNSS-Inertial Processor' which combines GPS CORS data with inertial data in tightly coupled process. SmartBase processing creates a virtual base station, which follows plane trajectory within SmartBase region polygon. All CORS stations contribute to virtual base station accuracy.

The precise position of the camera lens node was interpolated from the trajectory of GPS positions utilizing polynomial fitting techniques. The time-tag for each event served as a basis for the interpolation.

The lever arm offset values are applied to this data resulting in a final AGPS file containing the coordinates of the camera lens node at each instant of exposure. Final Exterior Orientation parameters and positions are outputted using project assigned datum, projections and units.

2.2 ABGPS Ground Reference Stations

POSPac 5.4 SmartBase processing technique requires multiple GPS ground reference stations of at least 18 hours of data to process plane trajectory. The networks of CORS stations imported into the project, created 'SmartBase Region' polygon for each mission. The 'SmartBase Region' assists in virtual base station creation and atmospheric corrections model.

3. AERIAL TRIANGULATION

3.1 Overview

Aerial triangulation is the simultaneous space resection of image rays projected and recorded at one source, the perspective center of the aerial camera. These image rays projected from two or more overlapping images, stereo-models, intersect at the corresponding ground location to determine the three-dimensional coordinates of each point measured. This collection of image rays is fit to known ground survey control in a simultaneous 3-dimensional least squares adjustment. After the completion of this adjustment, coordinates of the 'unknown' ground points are derived by the intersection of the adjusted image points.

The purpose of aerial triangulation is to densify horizontal and vertical control from relatively few ground control points (GCPs). Since obtaining GCPs is a relatively significant expense in any mapping project, AT procedures are used to reduce the amount of field survey required by extending control to all stereo-models.

This method is essentially a mathematical tool, capable of extending control to areas between ground survey points using several contiguous uncontrolled stereo-models.

3.2 Simultaneous Adjustment by Bundles

The surveyed control, along with the reduced image coordinates, served as input into the 'combined' block adjustment. Three–dimensional, simultaneous least squares adjustments by bundles, commonly referred to as "bundle" adjustments, were undertaken using Match-AT adjustment software. This particular bundle method is very sensitive to systematic errors of the photo measurements and provides the correction of constant and regular errors through self-calibration. This concept regards these types of errors to be common to all photographs or to be present in sub-sets of the photographs. This bundle block adjustment software has proven to be a very rigorous and stable platform.

A series of aerial triangulation solutions were completed. The adjustment strategy was devised to provide the optimal solution for the subsequent mapping, while providing comprehensive quality control to detect errors, omissions and spurious data.

3.2.1 Fully Constrained Adjustment

The final adjustment, and the optimal solution to be used for mapping, included all control points as constraints.

All Ground Control Points were assigned a Weighting Factor of 0.10m in X, Y, and Z.

All image points were assigned standard deviations of 4μm.

Helena Block

residuals horizontal control points in [meter]

control point ID	rx	ry
H01	-0.050	-0.187
H02	0.069	0.068
H03	-0.007	-0.229
H04	-0.082	-0.039
H05	-0.067	-0.005
H06	-0.070	-0.068
E100	-0.238	0.046
E113	-0.090	0.016
E120	0.023	-0.004
E114R	0.127	0.111
E116R	0.121	0.101
E123R	0.264	0.191

residuals vertical control points in [meter]

control point ID	rz
H01	0.031
H02	-0.063
H03	-0.110
H04	0.028
H05	-0.039
H06	-0.035
E100	0.016
E113	0.144
E120	0.085
E114R	0.023
E116R	0.012
E123R	-0.094

Limestone Block

residuals horizontal control points in [meter]

control point ID	rx	ry
LT01	-0.016	0.189
LT02	0.063	-0.182
LT03	-0.165	-0.151
LT04	-0.132	-0.003
LT05	0.074	0.136
LT06	0.175	0.011

residuals vertical control points in [meter]

control point ID	rz
LT01	0.036
LT02	-0.005
LT03	0.044
LT04	0.019
LT05	0.002
LT06	-0.095

3.2.2 Project Ground Control

Helena Block

Point	Easting	Northing	Elevation
E100	408629.414	256699.438	1410.968
E113	399201.797	267877.958	1255.814
E114R	420019.182	265754.345	1201.870
E116R	410540.966	267167.375	1139.469
E120	402544.727	277388.370	1221.635
E123R	410387.306	280263.226	1241.793
H01	399512.416	285834.965	1415.547
H02	419601.478	279374.378	1152.787
H03	391161.680	275454.501	1619.363
H04	391812.319	261862.002	1357.931
H05	399179.508	253317.512	1564.673
H06	419251.956	252627.866	1583.512

Limestone Block

Point	Easting	Northing	Elevation
LT01	443186.057	233976.038	1183.936
LT02	433455.713	224088.551	1424.844
LT03	438195.977	219926.338	1308.445
LT04	444849.509	221402.841	1191.875
LT05	446877.573	228615.398	1179.600
LT06	438451.785	233858.119	1355.783

3.3 Final Coordinates and Elevations

Montana State Plane Coordinates, NAD 83 HARN, meters

3.4 Summary of AT Results

```
================================================
```

Helena Block

```
  Active Block                                          : Block_All

  Number of photos                                      : 2271
  Number of strips                                      : 54

  Photo scale                                           : 1:15716
  Mean terrain height [m]                               : 1300

  Automatic blunder detection                           : OFF


  Use all adjusted points in project file
  as control (absolute mode)                            : OFF


  Control parameter for block adjustment :
  ----------------------------------------

  Selfcalibration                                       : OFF
  GNSS-Mode                                             : ON
  Drift-Mode                                            : ON
  drift per block                                       : ON only shifts
are enabled
  drift for X,Y,Z                                       : ON,ON,ON
  IMU-Mode                                              : ON
  IMU-Boresight                                         : ON
  Earth's curvature correction                          : ON
  Atmospheric correction                                : ON
  Do not eliminate manual points                        : OFF


  Standard deviations (a-priori) :

  --------------------------------


  Ground control (planimetry) [m]

      Set
       0 (=default)                                     :  0.100


  Ground control (height) [m]

      Set
       0 (=default)                                     :  0.100
```

```
  Automatic image points [mm]

      Set
       0 (=default)                                          :  0.004


  Image points of ground control and manual measurements [mm]        :  0.004



  GNSS                X Y Z [m]                               : 0.300 0.300
0.300


  INS                 omega phi kappa [deg]                   : 0.008 0.008
0.008

  Used Cameras in block:
  ----------------------

    1 UCD-SU-1-0022
       Distortion                                            : No correction
```

total of 236496 measurements in 2271 photos are used for adjustment (total 2271 photos)

```
  sigma naught        1.8 micron (10:58:51)
  sigma naught        1.7 micron (10:58:57)


  found      12559 points connecting   2 photos
  found      17185 points connecting   3 photos
  found      11089 points connecting   4 photos
  found      15193 points connecting   5 photos
  found       5805 points connecting   6 photos
  found        238 points connecting   7 photos
  found        184 points connecting   8 photos
  found         86 points connecting   9 photos
  found         26 points connecting  10 photos
  found          7 points connecting  11 photos
  found          1 points connecting  12 photos


  number of observations      485832
  number of unknowns          200754
  redundancy                  285078



  RMS automatic points in photo (number: 229760)
```

```
        x           1.2 micron
        y           1.2 micron

  RMS   control and manual points in photo (number: 6325)
        x           2.9 micron
        y           2.6 micron


  RMS control points with default standard deviation set (number: 12)
        x         0.126 [meter]
        y         0.115 [meter]

  RMS control points  with default standard deviation set (number: 12)
        z         0.070 [meter]

  RMS IMU observations (number: 2271)
        omega     0.005 [deg]
        phi       0.004 [deg]
        kappa     0.007 [deg]

  RMS GNSS observations (number: 2271)
        x         0.144 [meter]
        y         0.151 [meter]
        z         0.100 [meter]
```

Limestone Block

Active Block : complete
Block

```
  Number of photos                                    : 552
  Number of strips                                    : 20

  Photo scale                                         : 1:17085
  Mean terrain height [m]                             : 1200

  Automatic blunder detection                         : OFF


  Use all adjusted points in project file
  as control (absolute mode)                          : OFF


  Control parameter for block adjustment :
  ----------------------------------------

  Selfcalibration                                     : OFF
  GNSS-Mode                                           : ON
  Drift-Mode                                          : ON
  drift per block                                     : ON only shifts
are enabled
  drift for X,Y,Z                                     : ON,ON,ON
```

IMU-Mode : ON
IMU-Boresight : ON
Earth's curvature correction : ON
Atmospheric correction : ON
Do not eliminate manual points : OFF

Standard deviations (a-priori) :

Ground control (planimetry) [m]

Set
0 (=default) : 0.100

Ground control (height) [m]

Set
0 (=default) : 0.100

Automatic image points [mm]

Set
0 (=default) : 0.004

Image points of ground control and manual measurements [mm] : 0.004

GNSS X Y Z [m] : 0.300 0.300 0.300

INS omega phi kappa [deg] : 0.008 0.008 0.008

Used Cameras in block:
---

1 UCD-SU-1-0022
Distortion : No correction

total of 61446 measurements in 552 photos are used for adjustment (total 552 photos)

```
sigma naught        1.6 micron (09:53:08)
sigma naught        1.4 micron (09:53:09)


found       2514 points connecting   2 photos
found       3937 points connecting   3 photos
found       3395 points connecting   4 photos
found       3913 points connecting   5 photos
found       1543 points connecting   6 photos
found        202 points connecting   7 photos
found         74 points connecting   8 photos
found         22 points connecting   9 photos


number of observations      126222
number of unknowns           50121
redundancy                   76101



RMS automatic points in photo (number: 60361)
        x           1.1 micron
        y           1.1 micron

RMS   control and manual points in photo (number: 1085)
        x           1.0 micron
        y           1.3 micron


RMS control points with default standard deviation set (number: 6)
        x         0.119 [meter]
        y         0.136 [meter]

RMS control points  with default standard deviation set (number: 6)
        z         0.046 [meter]

RMS IMU observations (number: 552)
        omega     0.004 [deg]
        phi       0.005 [deg]
        kappa     0.006 [deg]

RMS GNSS observations (number: 552)
        x         0.144 [meter]
        y         0.170 [meter]
        z         0.121 [meter]
```

APPENDIX A – CAMERA CALIBRATION REPORT

UltraCam D, Serial Number UCD-SU-1-0022

VEXCEL IMAGING a Microsoft company

Calibration Report

Short version

Camera:	**UltraCam D, S/N UCD-SU-1-0022**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Date of Calibration:	**Sep-30-2008**
Date of Report:	**Nov-25-2008**
Camera Revision:	**5.0**
Revision of Report:	**5.0**

UltraCam D, Serial Number UCD-SU-1-0022

Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track	67.5mm	7500 pixel
	cross track	103.5mm	11500 pixel
Image Extent		(-33.75, -51.75)mm	(33.75, 51.75)mm
Pixel Size		9.000µm*9.000µm	
Focal Length	ck	101.400mm	± 0.002mm
Principal Point	X_ppa	0.000 mm	± 0.002mm
(Level 2)	Y_ppa	0.180 mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Multispectral Camera

Medium Format Multispectral Output Image
(Upscaled to panchromatic image format)

Image Format	long track	67.5mm	2400 pixel
	cross track	103.5mm	3680 pixel
Image Extent		(-33.75, -51.75)mm	(33.75, 51.75)mm
Pixel Size		28.125µm*28.125µm	
Focal Length	ck	101.400mm	
Principal Point	X_ppa	0.000 mm	± 0.002mm
(Level 2)	Y_ppa	0.180 mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Explanations:

1) Calibration Method:

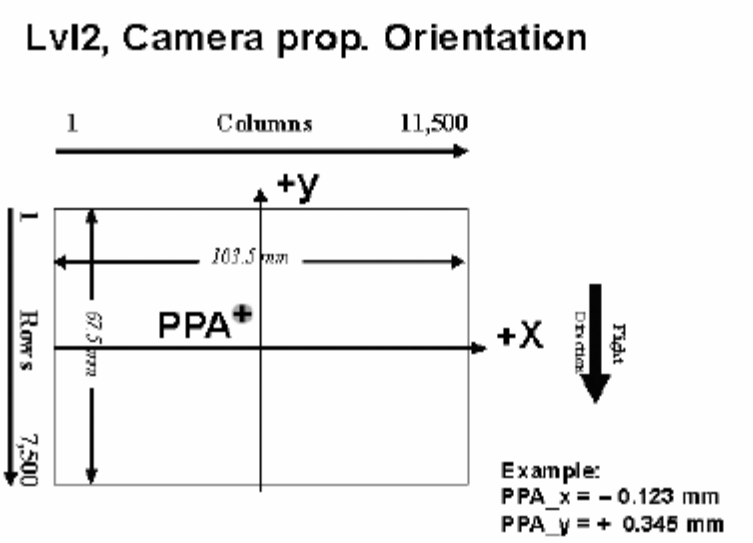
The geometric calibration is based on a set of 84 images of a defined geometry target with 240 GCPs.

Number of point measurements for the panchromatic camera :	19415
Number of point measurements for the multispectral camera :	64864

Determination of the image parameters by Least Squares Adjustment.
Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

2) Level 2 Image Coordinate System:

pan	11500 pixel by 7500 pixel
MS	3680 pixel by 2400 pixel



The image coordinate system of the Level 2 images is shown in the above figure. The level 2 image consists of 11500 columns and 7500 rows, which leads to a total image format of 103.5 * 67.5 mm. The coordinate of the principal point in the level 2 image is given on page 3 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).

UltraCam D, Serial Number UCD-SU-1-0022

Calibration Report

Summary

Camera:	**UltraCam D, S/N UCD-SU-1-0022**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Date of Calibration:	**Sep-30-2008**
Date of Report:	**Nov-25-2008**
Camera Revision:	**5.0**
Revision of Report:	**5.0**

The following calibrations have been performed for the above mentioned digital aerial mapping camera:

- Geometric Calibration
- Verification of Lens Quality and Sensor Adjustment
- Radiometric Calibration
- Calibration of Defective Pixel Elements
- Shutter Calibration
- Sensor and Electronics Calibration

This equipment is operating fully within specification as defined by Vexcel Imaging GmbH.

Dr. Michael Gruber
Chief Scientist, Photogrammetry
Vexcel Imaging GmbH.

DI (FH) Michael Kröpfl
Senior Calibration Engineer
Vexcel Imaging GmbH