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Montana Department of Transportation

PO Box 201001
Helena, MT 59620-1001

Memorandum

To:	Paul Jagoda, PE CES Bureau Chief
From:	Fred Beal CESB Construction Reviewer
Date:	February 15, 2019
Subject:	Small Unmanned Aerial System (sUAS or UAS) Mapping Accuracy Test

Background

In early 2018 MDT CES Bureau acquired two new UAS equipped with survey grade GPS. In June 2018, an area of the Lincoln Rd.-West of Green Meadow project was mapped using the new equipment. This memo summarizes accuracy results, comparing the resulting models with conventionally surveyed check points. It also describes the equipment and general workflows used to collect the imagery and process it to create a surface model and an orthomosaic image.

Executive Summary

Mapped Area: 125.7 acres
Ground Sample Distance: .96 inch per pixel
flights: 3 (about 25 minutes per flight)
images: 955
Ground Control Points: 7
Independent, Ground Surveyed Check Shots: 262

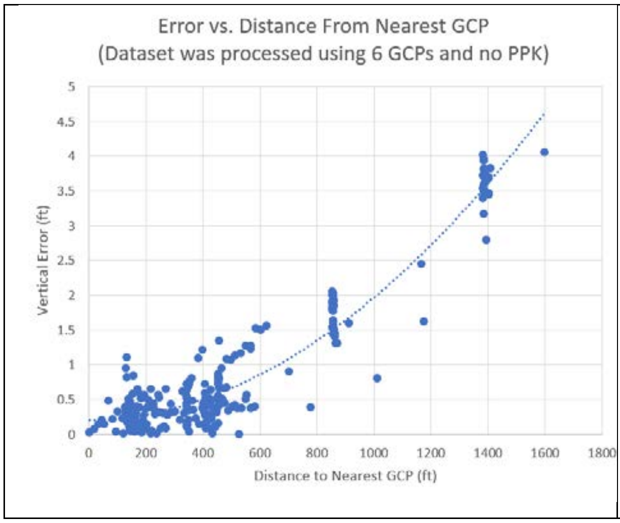
The UAV was equipped with a survey grade GPS. A Trimble base station was set up on a known control point to record location data during the flights. The location and correction data were processed afterward to generate accurate coordinates for the camera positions for each image. This method is called Post Processed Kinematics (PPK).

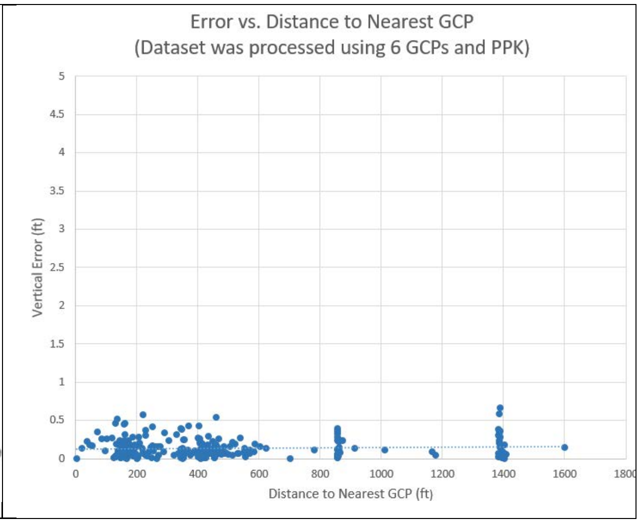
Imagery was processed using Pix4d software several ways to compare results:

- with/without survey grade GPS image coordinates (PPK)
- with/without Ground Control Points (GCPs)

The graphs below illustrate several important points:

- When mapping using GCPs and without PPK, vertical error in the model increases exponentially as distance from a GCP increases.
- When mapping without PPK, GCPs should be placed no more than about 500’ apart.
- With PPK, distance from a GCP had little effect on vertical accuracy.





Definition: “95% accuracy” means 95% of the check shots had an error less than the stated value.

The MDT Photogrammetry Unit mapped this project with their equipment as well. They set the vertical 95% accuracy goal at .30’ and achieved .22’.

UAS Survey 95% Accuracies for the Lincoln Road Mapping Test Area		
Processed with 6 GCPs and without PPK	Vertical: 0.70 ft	
Processed using PPK and no GCPs	Vertical: 0.34 ft	Horizontal: 0.12
Processed with 6 GCPS and PPK	Vertical: 0.36 ft	

Using GCPs in conjunction with PPK did not produce better results than when the model was developed using PPK alone, however use of GCPs is recommended.

The quality of the resulting model is highly dependent on the amount of vegetation at the site and the how much of it was successfully removed from the model during processing to produce a true bare-earth model. Most of the site had sparse vegetation although a few areas had more dense brush that obscured the ground.

The Project

The Lincoln Rd. - West of Green Meadow project will reconstruct Secondary 279 (Lincoln Rd.), between its intersections with Green Meadow Drive and Birdseye Road. An area within the project where a major realignment of the roadway is planned was selected for mapping with the UAS.

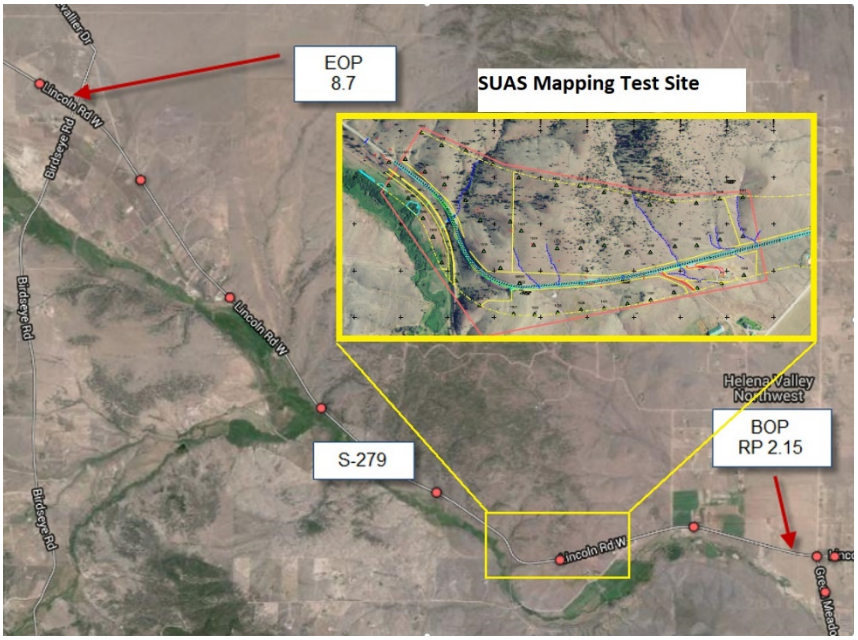


Figure 1 Project Location

Equipment

The UAS is made up of a DJI Inspire 2 UAV equipped with a Zenmuse X4S camera and an aftermarket GPS receiver (LOKI), a remote controller, a mobile device and two software applications (apps) installed on the mobile device: DJI Go and Map Pilot. Descriptions are provided below.

UAV: Inspire 2.

- The UAV is equipped with multiple sensors used for navigation control and obstacle avoidance. Sensors include barometer, compass, internal consumer grade GPS receiver (used for navigation), and optical sensors used for obstacle avoidance and aircraft hover positioning.

Figure 2 Inspire 2 UAV

Zenmuse X4S Camera

- 20.8 MP
- Mechanical Shutter. (Rolling shutter lenses are not desirable because they increase image distortion)
- The camera was lab calibrated by the vendor at the time of purchase. However, there apparently was a problem with the calibration values because poor results were obtained when processing using that calibration. Much better results were obtained using “in-situ” calibration which means the calibration parameters are calculated as part of the photogrammetry solution.

LOKI Survey Grade GPS/GNSS

LOKI is the brand name for a Global Navigation Satellite System (GNSS), Post-Process Kinematic (PPK) direct geopositioning system for UAVs. It is easily attached to the Inspire 2. It uses the AsteRx-m2 multi-frequency, multi-constellation GNSS engine from Septentrio and is said to be capable of centimeter accuracy.

Remote Controller:
Maximum Transmission and Video Downlink Range: 4.3 miles

Mobile Device: IPad mini 4

Apps:
Map Pilot. This app allows the user to easily create and autonomously fly a flight path to map an area. It also triggers the camera automatically.

DJI Go App 4.0. This app was created by the UAV manufacturer and allows for adjustment of all aircraft and camera settings and can be used to fly the aircraft.

Flight Planning

Much of the selected mapping area is private property. Linda Cline (MDT Great Falls Right of Way) assisted with getting signed permission letters from the landowners for MDT to operate the UAS there. MDT Survey staked additional control and check points throughout the mapping area prior to the flight.

The Map Pilot app was used to adjust settings and create the flight plans. Three flights were necessary to cover the 125.7-acre mapping area. Flights were planned to overlap one another.

The app simplifies flight planning and execution. The user identifies the survey area on a map and specifies the Ground Sampling Distance (GSD) and photo overlap %. GSD is the distance on the ground represented by a single pixel in the image. The app computes and sets all parameters such as altitude, flight speed, photo interval, and flight path. The same app will also autonomously take off the UAV, fly the route, take all the photos, return, and land the UAV with no intervention by the user. (The user can take over the controls at any time). Image overlap was set to 80% for both sidelap and endlap. GSD was set to 1 inch per pixel for this project. For the X4S camera at 20 MP resolution, this results in an altitude setting of 300 feet. In order to maintain a consistent GSD, the UAV must maintain a constant distance from the ground (AGL). The app was set to enable the “Terrain Following” feature to accomplish this.

Imagery Collection

955 photos of the mapping area were collected in 3 flights of approximate duration of 25 minutes each. During the flights, a Trimble R8s GNSS Receiver base station was set up over a control point by MDT Survey to record location data.

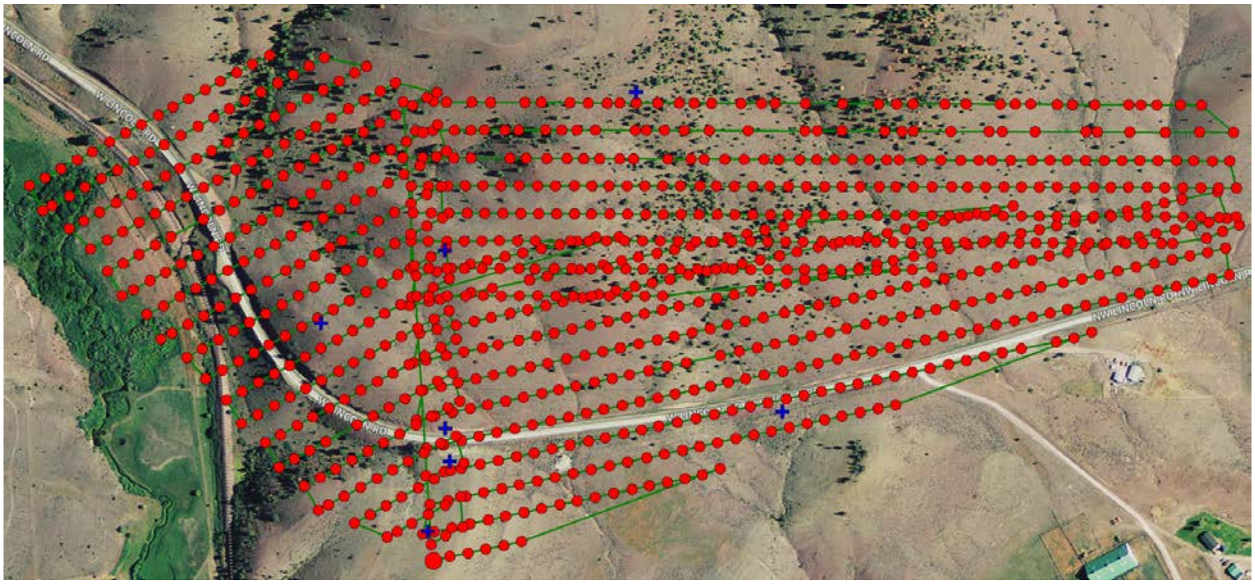


Figure 3 UAV/Camera Positions

Processing

<u>Camera Position GPS Coordinate Correction</u>
When captured, the images are geotagged with low accuracy GPS coordinates from the UAV's consumer grade internal GPS. The first step of processing the imagery is to update the image geotags with high accuracy coordinates.

The LOKI survey grade GPS unit was externally attached to the UAV. The LOKI system is designed to record precise coordinates of the camera at the time of mid exposure for each photograph. Those coordinates contain some error that must be corrected during post processing in order to make them accurate. (This method is known as PPK, or Post Processed Kinematic correction). The ASP Suite of software was included in the purchase of the LOKI GPS system and was used to update the image geotags with the precise, corrected coordinates. That software takes the images, rover data, base station receiver data and published ephemeris data and outputs a new set of images tagged with the new coordinates. For comparison, the imagery was also processed using the uncorrected image coordinates.

<u>Photogrammetry Software Processing</u>
The next step is to process the imagery in photogrammetry software to produce a point cloud, an orthomosaic, and digital surface model (DSM). Pix4d was used for this.

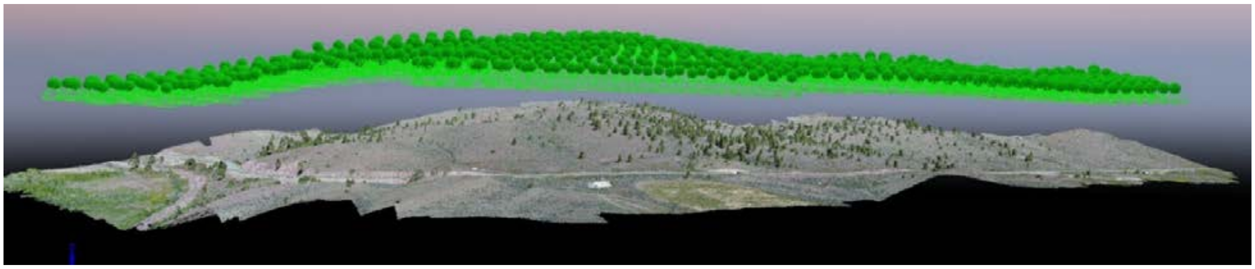


Figure 4 Oblique View of Model and Camera Positions.

DSM “Cleaning”

DSMs contain vegetation, buildings, people, vehicles, etc. These must be removed to produce a bare-earth model. Pix4d has limited capability for cleaning DSMs and analyzing the results so another software called Virtual Surveyor was used. Limited cleaning of the model was performed.

Analysis

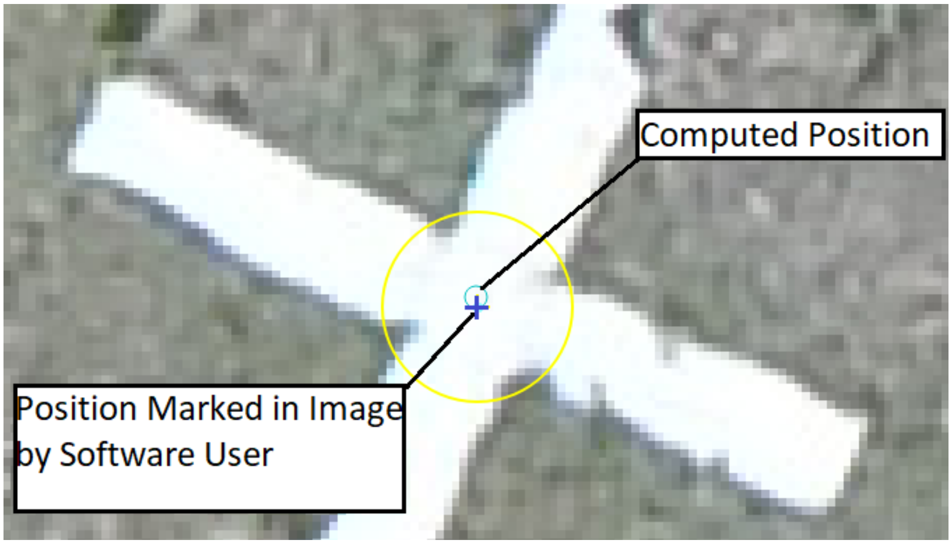
262 independent check points were used to determine the vertical accuracy of the various models. 7 independent check points were used to assess horizontal accuracy of the model generated using PPK and no GCPs.

Most of the check points were simply surveyed shots having no aerial targets, so they are not identifiable in the images. 27 of them were staked, using painted 2” x 2” wooden hubs as the targets. That size target had been easily visible in the imagery at previous flights flown at 200’ AGL but unfortunately were too small to be visible in the imagery for this project because the flights were at an AGL of 300’.

Horizontal Accuracy:

In order to quantify horizontal accuracy, the check points must be visible in the images so that the software user can identify the pixel in the imagery that correlates to the center of the target. The software then can compare the model coordinates of that pixel to the known coordinates of the check point to determine the horizontal error.

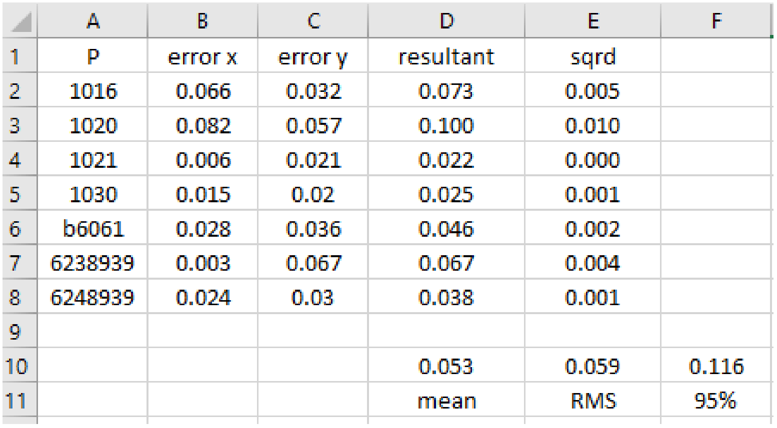
For the reasons stated above, none of the 262 checkpoints were visible in the imagery so they could not be used for this purpose. However, there were 7 GCPs that were visible which provided an opportunity to assess horizontal accuracy of the model that was processed using PPK only. GCPs were not used to generate that model, so they can be used as check points. (Ideally at least 20 checks should be used).



Cleaning of the model is not necessary for assessing the horizontal accuracy since the check points identified in the images are not obscured by vegetation.

The general workflow used for calculating the horizontal accuracy was as follows. If more than a few points were being evaluated, a more efficient process would be needed.

1. Import the GCP file into Pix4d.
2. Change the point type from GCP to checkpoint for all GCPS.
3. Mark the center of the targets in the imagery for each.
4. Select each check point and read the displayed horizontal error values. Enter them into an excel spreadsheet.
5. Calculate the mean error, the root mean square (RMS) error, and the 95% accuracy. (The 95% accuracy equals 1.96* the RMS error).



	A	B	C	D	E	F
1	P	error x	error y	resultant	sqrd	
2	1016	0.066	0.032	0.073	0.005	
3	1020	0.082	0.057	0.100	0.010	
4	1021	0.006	0.021	0.022	0.000	
5	1030	0.015	0.02	0.025	0.001	
6	b6061	0.028	0.036	0.046	0.002	
7	6238939	0.003	0.067	0.067	0.004	
8	6248939	0.024	0.03	0.038	0.001	
9						
10				0.053	0.059	0.116
11				mean	RMS	95%

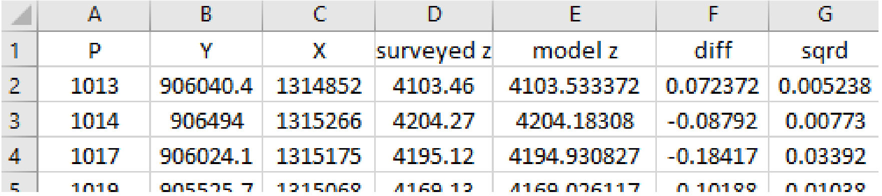
Figure 5 Horizontal Accuracy Analysis for Model Created with PPK Only

Vertical Accuracy:

The general workflow used for calculating vertical accuracy was as:

1. Create the model in Virtual Surveyor software by importing the orthomosaic and digital surface model files that were generated by Pix4d.
2. Clean the model as much as possible to remove vegetation, manmade objects, etc.
3. Import the check point coordinate file (comma delimited .CSV file)
4. In the software, select the checkpoint group and drop it to the model surface. This adjusts all the z values of to the model surface.

5. Export the group of points as a new coordinate file.
6. Using an Excel spreadsheet calculate the vertical error for each check point. Calculate the mean error, the root mean square (RMS) error, and the 95% accuracy. (The 95% accuracy equals 1.96* the RMS error).



	A	B	C	D	E	F	G
1	P	Y	X	surveyed z	model z	diff	sqrd
2	1013	906040.4	1314852	4103.46	4103.533372	0.072372	0.005238
3	1014	906494	1315266	4204.27	4204.18308	-0.08792	0.00773
4	1017	906024.1	1315175	4195.12	4194.930827	-0.18417	0.03392
5	1019	905525.7	1315068	4169.13	4169.026117	[illegible]	[illegible]

Figure 6 Vertical Accuracy Analysis Spreadsheet

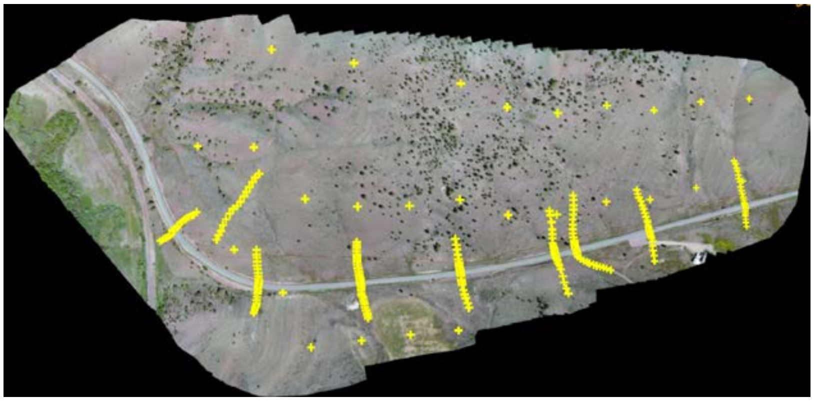


Figure 7 Independent Check Point Locations

Discussion

This mapping test demonstrated that good results can be achieved with relatively low-cost equipment. The cost of the UAS (UAV, GPS, misc.) was just over $10,000. The 95% accuracy was .34 feet which is only slightly worse than the goal (.30 feet). There are some ways accuracy could have been improved:

- Collect imagery from a lower altitude (decrease GSD).
- Increase image overlap %.
- More careful cleaning of the model.

125 acres was mapped in approximately 2 hours. Mapping very large areas would require multiple setups but would be feasible. Fixed wing UAVs have longer flight times and are more efficient for mapping larger areas.

This site had relatively sparse vegetation. Sites having dense vegetation are problematic for photogrammetry using unmanned and manned aircraft alike. LIDAR systems are more effective at penetrating vegetation and are available for small UAS.

The workflows used to process the imagery can produce the following deliverables:
PIX4D:

- Orthomosaics
- Point Clouds (.LAS, .LAZ, .PLY, .XYZ)
- Digital Surface Models

Virtual Surveyor:

- Digital Terrain Model (i.e a cleaned Digital Surface Model)
- Triangulated Network files (.TIN)
- 3d Textured Mesh files (.PLY, .FBX, .DXF, .OBJ, 3D PDF)

Again, neither software product has effective tools for cleaning point clouds.

Lessons Learned

- For the future, ground control target size should be at least 5 times the ground sample distance to ensure they are easily visible in the images.
- If lab derived camera calibration values are available, process a portion of the imagery using those values then process it again using in-situ calibration and compare resulting accuracies. Process the entire image set using whichever method produced the better result.
- If mapping using only ground control, set ground control no more than 500’ apart. The optimal distance probably varies depending on flight altitude but 500’ is likely conservative for all altitudes up to 400’ AGL, the maximum allowed by the FAA part 107 rules.

copies:

Kevin Christensen, PE
Lisa Durbin, PE
Bill Weber, PLS
District Preconstruction
Grant Frazier
CES Bureau
John Schwartz, PE
EPMs
Dave Hedstrom, PE
Chris Blumberg
Dwane Kailey, PE
Stephanie Brandenberger, PE
DOEs
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Dave Thompson
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