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UAS MAPPING ACCURACY WHITEPAPER

Strix Imaging is a UAS service company providing mapping services across the United States. We've provided mapping, GIS and remote sensing analytics services across a range of industries, including mining, land surveying, construction, civil engineering, transportation, environmental, agriculture, forestry, infrastructure assessment, and DoD.

The number one question we receive is "What is the accuracy of your products?". UAS mapping has only been around for a few years and this is a logical question. Manned fixed-wing & rotary wing photogrammetry and LIDAR have been around significantly longer. Customers across all industries understand the type of products and the accuracy they can expect from these mature platforms.

Even within the UAS industry there is a lack of understanding of what accuracy is, how to measure it and how mapping projects should be designed to meet a customer's requirements. As new UAS providers come into the marketplace, customers need to know what to expect from a UAS with respect to accuracy and that the products they receive meet the standards they need. There is a lot of literature and statements within and from the UAS industry claiming fantastic accuracy numbers that is not supported by data.

This whitepaper details what type of mapping accuracy Strix Imaging can provide using structure from motion (SFM) photogrammetry. Bottom line, Strix Imaging has the capability to provide the following repeatable accuracies:

- NMAS: 1:200 (1"=16.67') map scale and 6" contour intervals
- ASPRS: 5 cm horizontal class and 5 cm vertical class
- RMSEs less than 2.5 cm horizontally and 4cm vertically are repeatable in areas conducive to higher accuracies

ACCURACY

Before we can describe the accuracy of a UAS derived mapping product, it is important to understand how accuracy is defined and how these definitions apply to the various mapping standards used within the United States. As a note, the discussion below is not intended to cover all the factors inherent in map accuracy, nor all the details within the various standards. It is intended as an intro to mapping standards for those unfamiliar with their use

In its simplest form the error from a single point is defined as the distance from measured point (such as a surveyed ground control point) to its predicted point (where the location is defined on the map). This is measured in the x, y & z axis. This only defines the error at that one point. To understand the error across the entire map, statistical methods are applied.

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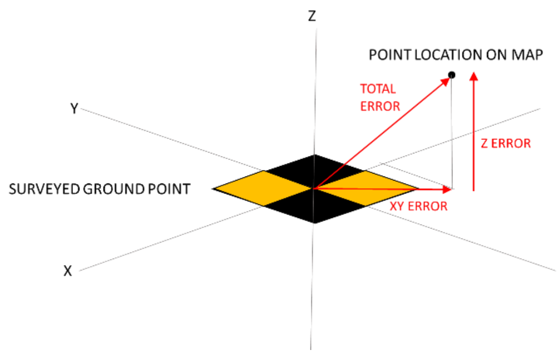

The most common term used in photogrammetry software and mapping standards to define accuracy across the entire map is root mean square error (RMSE). RMSE is the sample standard deviation of a predicted point from a measured point. In other words, 66.7% of all measured error falls within this number.

In the United States, there are three map accuracy standards:

- The National Map Accuracy Standard (NMAS)
- The American Society for Photogrammetry and Remote Sensing (ASPRS) Standard
- The National Standard for Spatial Data Accuracy (NSSDA)

NMAS

Developed in the 1940s, NMAS defines map accuracy using map scale horizontally and contour interval vertically. Map scale is a term not often seen in UAS discussion and can be easily substituted with ground sample distance (GSD), or the resolution of the images taken. Horizontally, for the map scales that most UAS produce images at, not more than 10% of the measured points shall not have errors greater than 1/30 in. The table below relates this to GSD and RMSE.

Map Scale	GSD	90% accuracy	XY RMSE
1:200 (1”=16.67’)	1 inch	6.67 inches	4 inches
1:600 (1”=50’)	3 inches	1.67 feet	1.02 feet
1:1,200 (1”=100’)	6 inches	3.33 feet	2.02 feet
1:2,400 (1”=200’)	1 foot	6.67 feet	4.05 feet
1:4,800 (1”=400’)	2 feet	13.33 feet	8.1 feet

Vertically, accuracy is measured by contour interval, with not more than 10% of measured points having errors greater than one-half the contour interval.

Contour Interval	90% half-contour	Z RMSE
3 inch	1.5 inches	.91 inches
6 inches	3 inches	1.82 inches
1 foot	6 inches	3.65 inches
2 feet	1 foot	7.30 inches

5 feet	2.5 feet	1.52 feet

ASPRS

These accuracy standards, last updated in 2014, are broad in scope and cover several technology upgrades that have occurred in the mapping industry over the last 20 years. Horizontally and vertically, they are divided into accuracy classes.

Horizontal Accuracy Class $RMSE_x$ and $RMSE_y$ (cm)	$RMSE_r$ (cm)	95% Horizontal Accuracy (cm)	Approximate GSD of Source Imagery (cm)
1.25	1.8	3.1	.63 to 1.25
2.5	3.5	6.1	1.25 to 2.5
5.0	7.1	12.2	2.5 to 5.0
10.0	14.1	24.5	5.0 to 10.0
15.0	21.2	36.7	7.5 to 15.0
20.0	28.3	49.0	10.0 to 20.0
30.0	42.4	73.4	15.0 to 30.0

Vertical Accuracy Class	$RMSE_z$ Non-Vegetated (cm)	95% Non-Vegetated Vertical Accuracy (cm)	95% Vegetated Vertical Accuracy (cm)
1-cm	1.0	2.0	3
2.5-cm	2.5	4.9	7.5
5-cm	5.0	9.8	15
10-cm	10.0	19.6	30
15-cm	15.0	29.4	45
20-cm	20.0	39.2	60
33.3-cm	33.3	65.3	100

NSSDA

This standard provides statistical guidelines for determining the horizontal and vertical accuracy of a map, but does not set an accuracy standard that a map must meet. The document provides the methodology for calculating a 95% accuracy number (confidence interval in statistical speak). The 95% confidence interval can be calculated by multiplying the RMSE value by 1.96.

FACTORS AFFECTING ACCURACY

For a UAS provider, several factors outside aircraft equipment, can affect the final accuracy of a map, some of which can be controlled, and others which cannot.

- Resolution – typically, the better the resolution of the individual images, the better the accuracy

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of the final product. There is a limit where an increase in resolution will not produce better accuracy. Also, an increase in resolution increases the flight time required to image an area.

- Image Overlap – unlike traditional aerial photogrammetry, which may only take two images of a site, UAS photogrammetry may take thousands of images. The higher the number of images that overlap, the better the possible accuracy. Again, an increase in overlap increases the flight time required, and there is a limit to how much overlap will increase accuracy
- Time of day of the flight – shadowing or changes in shadowing throughout a flight can reduce the accuracy of the final product
- Change in cloud cover throughout the flight – changes in cloud shadows throughout a flight can reduce final accuracy
- Terrain contrast – areas of high contrast, such as urban areas, tend to produce better accuracies. While areas of low contrast, such as sand dunes, snow or dry lake beds, produce lower accuracies.

These factors can produce day-to-day variations in a product if the same area is flown multiple times on different days. These variations can be quite significant depending on the method used to georeference the imagery.

ACCURACY TEST SETUP

To measure the accuracy of Strix Imaging's UAS, workflow and photogrammetry software, a test site was set up. A 1 sq km (250 acre) area was selected, located in Prescott Valley, AZ, which included sageland, roads, terrain changes of up to 400', three story buildings, residential areas, and water features. A licensed surveying firm shot 19 ground point panels and other hard features that could be used to either georeference the imagery or provide QA values for accuracy.

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Seven days of flights were conducted and processed over 225 times using four different georeferencing techniques. Each flight produced approximately 1500 images with an average resolution of 1.65 cm. An onboard internal navigation system (INS) and GPS provided image location and aircraft pitch, roll and heading for when the image was taken.

The georeferencing techniques used were:

- Aircraft only using a single-band GPS (L1 only)
- Aircraft only using a dual-band GPS / GLONASS system (L1 / L2)
- Aircraft only using a dual-band GPS / GLONASS system adjusted with PPK from on-site base station
- Ground control – six different ground control geometries tested.

In all cases, ground points not used to georeference were used to determine the accuracy of the final product. All techniques using aircraft only georeferencing were using the GPS and INS derived positions of the images to build the vertical model. Ground points in this case are used for QA / QC only. This is also known as airborne GPS.

For each technique, an overview of the results, a table with accuracy numbers, and an image showing errors from airborne PPK are provided.

The table provides the RMSE for all QA/QC points (in feet), the average RMSE across all of the days, and the standard deviation of the error across all of the days (how well did flight compare day to day). For all of these numbers, smaller is better.

The image provides a visual depiction of the vertical errors overlaid on the imagery. Green shows areas with 0 – 3 inches of error, blue areas of 3 – 6 inches or error, etc. Errors were calculated using vegetated elevation models, and compared against the most accurate PPK solution.

AIRCRAFT ONLY SINGLE BAND GPS

This method used a single airborne GPS frequency to develop the terrain model. Using a L1 only GPS for georeferencing produced the worst accuracies of any method. L1 only GPS is the most common system used in UAS. These errors may be acceptable in some GIS or agriculture applications, but L1 only with no correction should not be used in volumetric or high-accuracy mapping work.

	XY – RMSE (ft)	Z – RMSE (ft)	Total RMSE (ft)
Day 1	31.29	3.45	31.48
Day 2	16.54	13.93	21.62
Day 3	25.34	14.09	28.99
Day 4	20.31	28.54	35.03
Average Error	23.37	15.00	29.28
Day-to-day variation	6.39	10.31	5.68

AIRCRAFT ONLY DUAL BAND GPS

A dual band GPS, without RTK or PPK updates, provides significantly better accuracies than a single band GPS, but still does not meet the accuracy needs of most industries. Dual band GPS is rare in most UAS, but is typically available in specialized mapping UAS.

	XY – RMSE (ft)	Z – RMSE (ft)	Total RMSE (ft)
Day 1	8.66	1.71	8.83
Day 2	9.88	5.94	11.53
Average Error	9.27	3.83	10.18
Day-to-day variation	0.86	3.00	1.91

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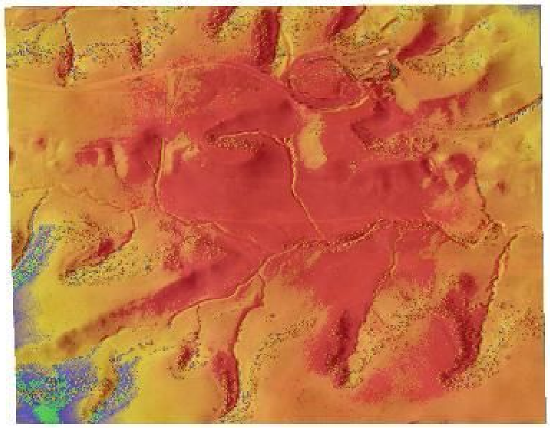


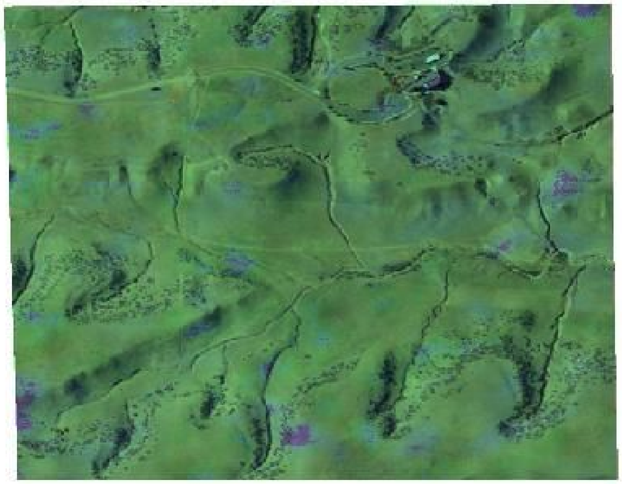
AIRCRAFT ONLY DUAL BAND GPS WITH LOCAL BASE PPK CORRECTION

The most accurate method tested is using a dual-band GPS in conjunction with PPK processing. In this method, the position of the aircraft is updated using GPS data from a static GPS base station. This is similar to base & rover operations in surveying, where the aircraft is a rover. Although not testing as part of this study, we have seen in other work that the distance between the base GPS and the aircraft impacts accuracy.

This georeferencing technique provides repeatable, accurate vertical models that meet the standards of most industries. For large areas requiring higher accuracy, or for highly vegetated areas, LIDAR is recommend.

	XY – RMSE (ft)	Z – RMSE (ft)	Total RMSE (ft)
Day 1	0.18	0.17	0.25
Day 2	0.12	0.12	0.17
Average Error	0.15	0.14	0.21
Day-to-day variation	0.04	0.04	0.05

DAY to DAY VARIATION IMAGE



GROUND CONTROL

This method is the most common method used in both traditional and UAS photogrammetry. Six different ground control configurations, using 19 different panels, were tested with a wide range of accuracies depending on which configuration was used. If a ground point was used for georeferencing, its errors values were not used in the final RMSE calculations.

Discussion will center around three of these configurations.

One Control Point @ the Center of the Area of Interest – This produced the worst accuracy of any of the ground control configurations. In all cases Z-error was better than the XY-error. In general, the imagery had a rotational shift centered around ground control point. The large day-to-day variation should also be noted.

	XY – RMSE (ft)	Z – RMSE (ft)	Total RMSE (ft)
Day 1	29.55	6.47	30.25
Day 2	15.41	6.93	16.90
Day 3	24.92	5.05	25.42
Day 4	19.48	4.71	20.04
Average Error	22.34	5.79	23.15
Day-to-day variation	6.19	1.08	5.90

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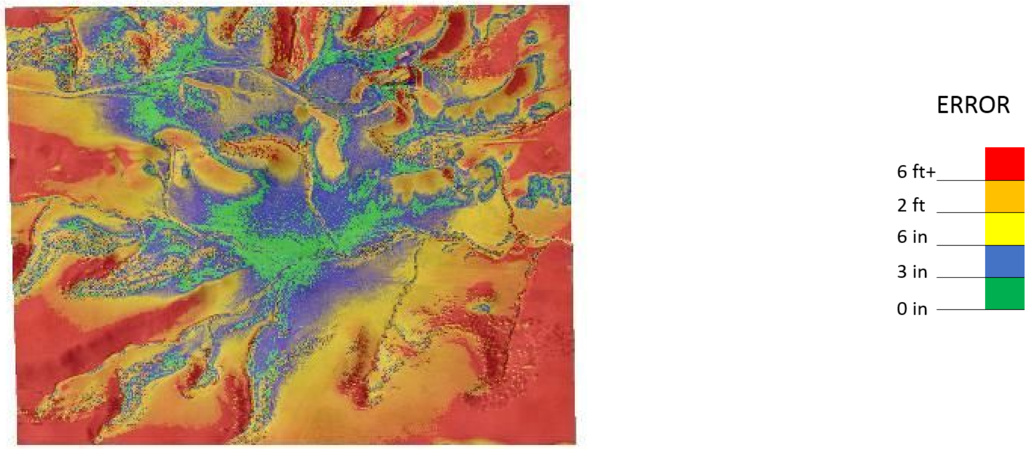

Four Control Points @ the Corners of the Area of Interest – This is a common configuration of ground control for traditional photogrammetry. With UAS platforms, this can provide reasonable XY error values depending on the map requirements, but produces poor Z values. Most photogrammetry software will produce a bowl-shaped Z-error in the imagery as shown below.

	XY – RMSE (ft)	Z – RMSE (ft)	Total RMSE (ft)
Day 1	0.46	5.96	5.98
Day 2	0.36	8.37	8.38
Day 3	0.43	3.91	3.94
Day 4	0.28	6.10	6.11
Average Error	0.38	6.09	6.10
Day-to-day variation	0.08	1.82	1.81

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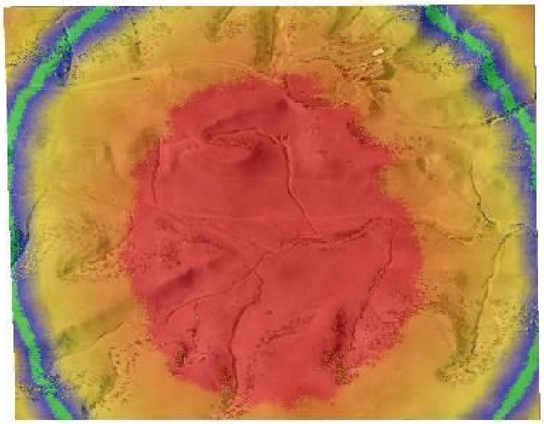

Most Accurate Control Point Configuration – In SfM photogrammetry, with ground points used for georeferencing, the accuracy of a control point configuration can be tied to the distance between points and the angle between nearby control points. In one of the more accurate configurations for large areas, ground control can achieve a similar level of accuracy as a PPK georeferenced product, however day-to-day variation can be larger. Also, locations where control or check does not exist, can exhibit significantly higher errors, as shown in the blue areas in the imagery below, where some locations showed errors up to 6 inches.

	XY – RMSE (ft)	Z – RMSE (ft)	Total RMSE (ft)
Day 1	0.14	0.11	0.18
Day 2	0.09	0.31	0.32
Day 3	0.22	0.13	0.25
Day 4	0.10	0.16	0.19
Average Error	0.13	0.18	0.24
Day-to-day variation	0.06	0.09	0.07

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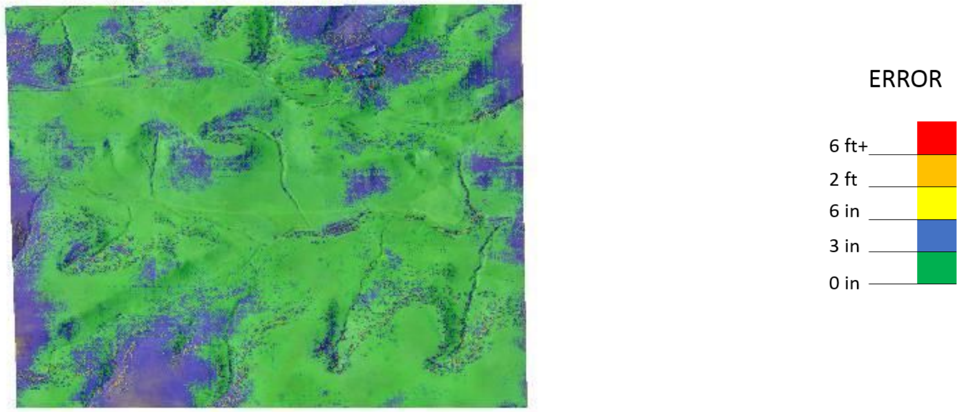

In general, ground control georeferencing is useful for small areas, but for larger areas (such as 250 acres), the number of ground points required and the exact location they need to be placed at, limits the ground control technique usefulness. With the sheer number of images in UAS photogrammetry and the not having a ground control point in each image, large shifts in accuracies can occur.

CONCLUSION

Strix Imaging, using GPS base and rover technology, in conjunction with PPK processing, can produce mapping accuracy results that meet the products needs for most industries. We feel strongly about providing products that have gone through a robust QA processes for accuracy and routinely conduct blind shots for vertical QA.

Customers should be aware that with the growth of UAS providers, not all firms understand the factors that go into producing an accurate mapping product. Please see our paper on “questions to ask before selecting a UAS service provider” to get an idea of what should be considered prior to accepting a bid.

NOTE

Within the United States, each state has different laws governing the creation of maps. In some cases, any map with an elevation or contour must be overseen by a licensed surveyor. In other states this can be a licensed civil engineer. Other states do not require a license if the map is non-authoritative in nature. In other cases, any image that is georeferenced, even for GIS purposes, requires a licensed professional. If you have questions on your State’s law, you should always contact your State Board of Engineering for clarification.