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Unmanned Aerial System Survey Point Collection Accuracy Assessment

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Summary

Keystone Aerial Surveys, Inc. performed two Unmanned Aerial System (UAS) survey flights of a private building located in eastern PA in December of 2015 (see image below). Keystone, in conjunction with Dennis W. Sklar, Inc., placed multiple survey points both on the ground and on the building to use as control and check points (38 points in total). Keystone then used the Datugram3D software package from Datumate, Ltd. to georeference the imagery and then perform measurements and data collection. The findings are presented below highlighting the high level of accuracy that can be obtained using relatively inexpensive cameras and UAVs combined with specialized processing software. With residuals under ½ inch possible, the use of UAS in conjunction with traditional ground survey techniques appears to be a viable solution for many applications.

Equipment

Keystone used two UAS to acquire the data for testing. The first was the DJI Inspire 1 with a DJI Zenmuse X5 camera that is 16 MP and uses a 15 mm lens. The second system was a SteadiDrone Mavrik with a Sony A7R camera. The A7R is a 36 MP camera with a 35mm lens. The X5 and A7R cameras are available for under $2,500 and $3200 respectively. The Inspire 1 UAS is approximately $5,000 complete with control stations and spare batteries while the Mavrik is approximately $7000 with the same accessories. Despite the low cost of entry ("prosumer" cameras and drones), these systems showed remarkable results in both image quality and accuracy.

Acquisition


Figure 1: Building to be Surveyed, East side looking West

Acquisition was performed at nearest to 30 degrees of sun angle as is possible during winter months. Cloud conditions were scattered, causing lighting to be variable at times, which is not ideal for image matching algorithms. The X5 imagery was acquired at an altitude of 35 feet AGL at a distance of 58 feet from the target on average. While the Sony camera was at 68 feet AGL and a distance of 137 feet on average for its flight. The estimated pixel size on the ground for Nadir imagery for both was 0.10 inch while the X5 averaged 0.17 inch on the building and the A7R camera averaged 0.22 inch on the building. The survey points were collected using RTK with a reference point on site. The resulting measurements are estimated to have an accuracy of 1-2cm (0.4 -0.8 inches).

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Workflow

The Datugram3D software has a streamlined workflow of loading images, georeferencing images, measuring/data collection, approving the collected features and exporting the measurements. Before ingesting the images into the software, redundant images, those with blur and inconsistent lighting were removed from each set. After this process 31 images were ingested from the X5 set and 30 from the A7R set. During the georeferencing step control points are measured in several images until a solution for the entire dataset is calculated. This is done in an iterative process until a georeferencing solution is generated for the entire project. Image reference quality is indicated by a green, yellow and red system to show levels of accuracy. These levels can be set by the user to allow for quick visual reference of the quality of the solution for each image and to be variable with the pixel size of the imagery. The default value of 3 pixels for green was used in this case, with most points generating less than 2 pixels of latency.

In the measurement section, points, lines or polygons are drawn using a single image and then automatically detected on at least two other images and projected on all images in the set. If the automated feature detection fails, the user manually places the feature at the appropriate location (point, line, polygon) in other images. In the approval stage, each feature can be confirmed in multiple images and more measurements can be made from suggested locations. Error estimation of point accuracies are available to view and saved to a file before continuing to the data export stage.

Methodology: Test 1

The first test performed with each dataset was to use a large portion of the 4 ground points and 34 building survey points as control in the georeferencing stage. 15 points were selected on the building for both the X5 and A7R while 2 ground points were used on the X5 and A7R. Each point was measured in at least 2 images with the same points used for each camera type. A solution was automatically generated by Datugram3D from the points as described above. The results of the georeferencing are listed for all tests in Table 1.

In the next phase, an additional 19 check points were measured in the data collection module and then refined in the approval stage. The ability to select the point in any image, view the projection in every image and immediately see the effect on the measurement quality allows the user to achieve the best possible fit. The calculated locations of these points were exported for review and comparison to the surveyed points. The results of the measurements and refinements are in Table 2 below.

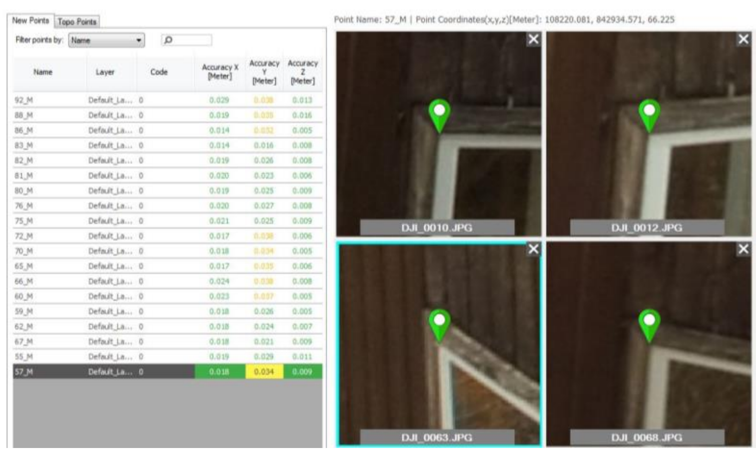

Figure 2: Feature Measurement in Approval Phase

Test 1 Observations: DJI X5

Even before viewing the final results, it was determined that the number of control points was likely too large. The georeferencing results are measured in pixels and represent the relative accuracy of the solution (Table 1). The first test of both the DJI and Sony have a slightly larger RMS due to the force of the control points on the solution causing the marking (or relative) accuracy to suffer, but resulting in absolute accuracy increasing (Table 4). This is a common phenomenon among AT and georeferencing solutions.

Additionally, the X5 imagery was captured under changing light conditions, which is not recommended by Datumate and likely led to matching and overall solution quality reduction. Despite the drawbacks of the dataset, the results in Tables 3 and 4 show that the final product is still excellent.

Test 1 Observations: Sony A7R

The Sony images had an overall solution that was better than the X5. The Sony imagery was captured further from the building, allowing for better visualization of some of the ground points, but did not sacrifice image quality due to the superior camera resolution.

Additionally, the south side of the building was captured at a greater distance than other sides of the building with both sensors. This resulted is slightly poorer resolution and more difficulty with measurement of the control points. Bolt heads were used as measurement points on the south side of the building and may have been a poor choice for visualization reasons. Below is a Table with the RMS values of the marking accuracy across all the images for each test type (in pixels). Note that the ½ and ¼ pixel matching between images on the A7R with a pixel size of 0.22 inch.

Camera	Test Type	RMS i	RMS j	Measure-ments	Images Used
DJI X5	High Control	1.003	0.942	63	16
DJI X5	Low Control	0.998	0.876	37	9
Sony A7R	High Control	0.528	0.669	75	17
Sony A7R	Low Control	0.247	0.266	16	4

Table 1: RMS of Marking Accuracy in Image Space for Each Test Type in Pixels

Methodology: Test 2

For the second test, a minimum amount of control was used in the georeferencing stage in order to determine the effects of less control on the final accuracy. Only 7 points on the building and 2 on the ground were used for both the X5 dataset and the A7R imagery. The remaining visible points were then measured, approved and exported.

Test 2 Observations: DJI X5

This methodology was slower than the previous tests, however, the resulting georeferencing was more effective (see Table 1). The overall marking accuracy of the solution was stronger than the previous X5 test. This is probably due to the reduction in rigidity in the solution as the absolute accuracy of check points was not as high as the first test. There was also less automatic feature matching in the measurement phase, resulting in more time spent adjusting point locations in both the measurement

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and approval stages. The end result were measurements just as precise as previously (or more so) (see Table 2), but extrapolated out over more features, the time spent may limit the saving of using less control.

Test 2 Observations: Sony A7R

While slower than test 1 in the measurement and approval stages, the ability to choose the best images for measurement generated excellent results (Table 2). When using limited control, planning of the locations of the control to guarantee visibility on images at 90 degree angles from each other would be ideal, however this did not significantly affect the accuracy. The limited control test resulted in excellent georeferencing values in a short amount of time (see Table 1).

As with the DJI image set, there were a few blunders in the automatic feature matching, but not significant. The increase in time spent in the measurement and approval was not a detriment, especially considering that the results of the point matching were superior to the high control test. Below are the error estimations by data set on the measured points (in US feet) displayed in the approval stage of the software workflow.

Camera	Test Type	X	Y	Z
DJI X5	High Control	0.056	0.065	0.022
DJI X5	Low Control	0.098	0.076	0.029
Sony A7R	High Control	0.020	0.026	0.013
Sony A7R	Low Control	0.008	0.011	0.006

Table 2: Measured Point Error Estimation (Mean of Absolute Error in US Feet) as Estimated by Datugram3D

Results

The control point estimations and measured points were exported and then compared to the surveyed locations. The points used as control had the accuracy expected (1 pixel or better) but the measured points (check points) had better than expected results when compared to the surveyed locations. All of the tests resulted in Absolute error values of 0.60 inch or less in X, Y and Z, with the Sony A7R tests generating sub to one-pixel accuracy for both types of tests. With residuals evenly distributed among X, Y and Z, it is a stable and impressive solution. See the charts below for the full results, noting that the X5 had a pixel size of approximately 0.17 inches and the Sony had an average size of 0.22 inches:

Control Point Residuals (Inches)		Absolute Mean			Min			Max		
Camera	Test Type	X	Y	Z	X	Y	Z	X	Y	Z
DJI X5	High Control	0.13	0.16	0.15	0.02	0.01	0.01	0.33	0.54	0.56
DJI X5	Low Control	0.13	0.17	0.10	0.02	0.01	0.00	0.28	0.49	0.36
Sony A7R	High Control	0.12	0.08	0.11	0.01	0.00	0.01	0.43	0.26	0.27
Sony A7R	Low Control	0.03	0.06	0.05	0.01	0.03	0.00	0.06	0.12	0.16

Table 3: Mean, Min, Max of Absolute Residuals in Inches (Comparison of Surveyed Location and Measured) for Control Points

Check Point Residuals (Inches)		Absolute Mean			Min			Max		
Camera	**Test**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
DJI X5	High Control	0.34	0.33	0.28	0.01	0.01	0.02	1.25	1.16	0.76
DJI X5	Low Control	0.60	0.47	0.31	0.02	0.04	0.02	1.96	2.03	1.12
Sony A7R	High Control	0.20	0.31	0.28	0.01	0.04	0.05	0.72	0.77	1.10
Sony A7R	Low Control	0.14	0.37	0.24	0.00	0.02	0.03	0.47	1.44	0.75

Table 4: Mean, Min, Max of Absolute Residuals in Inches (Comparison of Surveyed Location and Measured) for Check Points

Additionally, based on the field times and office work time, the Survey\UAS hybrid mission is a cost effective solution. In approximately 2 hours, two crew members measured 38 points for an average of 19 points per hour. The UAS completed the building flight in 15 minutes, with a two-man crew on site for approximately 1 hour. Office times varied depending on the test performed and the camera, but using the A7R with minimum control took approximately 1 hour for production and generated 34 features for an average of 34 points per hour. Assuming that the time spent creating additional line features will be the same for both a UAS solution and a surveyed solution, the greatest difference will be seen in the initial collection. In the case described here, a survey crew could spend one hour in the field for control point placement with one hour spent by the flight crew. The savings would cut the field expenses by half. The hours spent in the office (by one individual) would reduce the total hours spent on the project. Due to limitations imposed by FAA rules, operators such as Keystone must use a pilot and an observer in order to conduct a UAS flight. However, with the release of Part 107 rules, only a pilot will be needed to conduct a flight, which will further reduce man hours. Extrapolated out over a large area or number of features, the estimated savings are substantial as shown below:

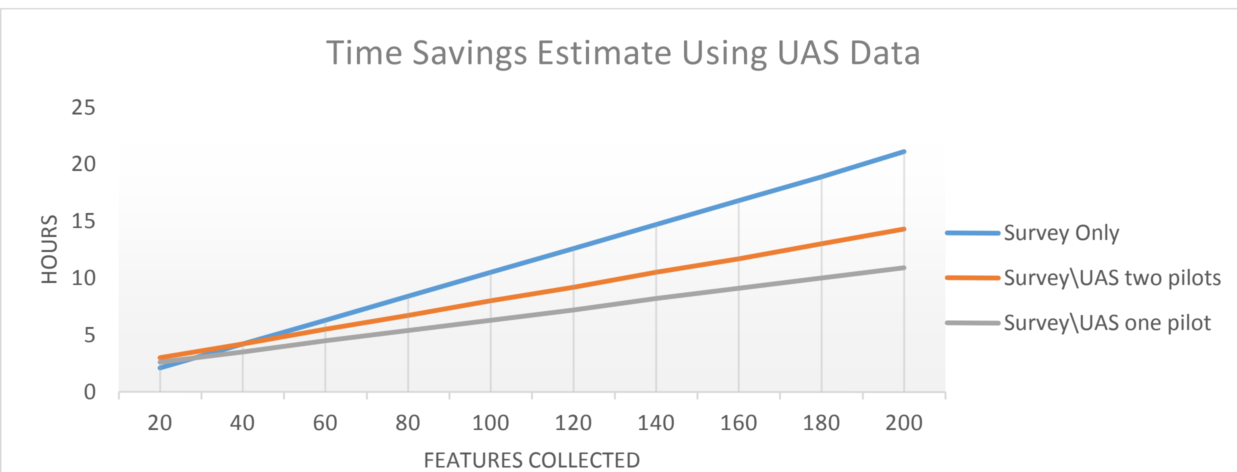

Figure 3: Chart Depicting Growth in Time Savings using UAS

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Conclusions

Despite some portions of the project being less than ideal: ambient lighting changes, control placement, flight distance from object, etc., the Datagram3D software was able to generate highly accurate data. Both the DJI Zenmuse X5 and the Sony A7R generated survey grade results, but the A7R was superior. The use of control points on the ground around the structure (not just on the structure) proved to be important for obtaining the best results. A large number of control points also does not seem necessary, with the quality of the camera playing the largest role in the final results.

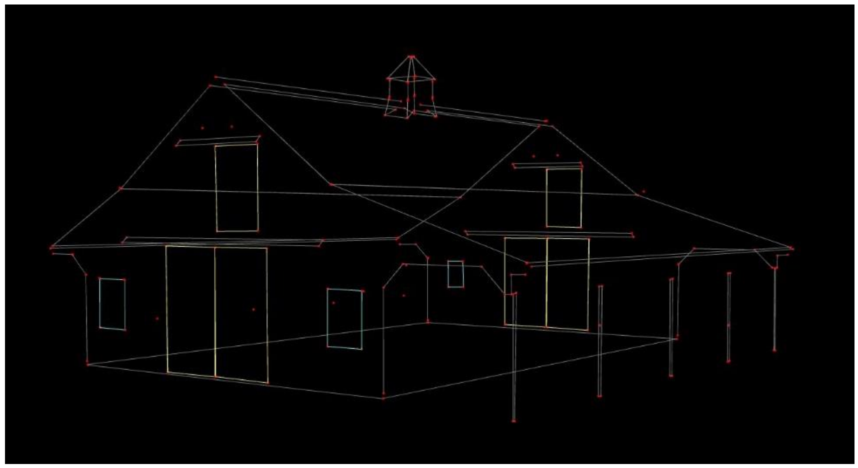

Figure 4: 3D View of Features Extracted Via Datugram3D

It is likely that surveyors and photogrammetrists can use the data from these relatively inexpensive systems to supplement their work – reducing expensive field time and replacing it with office or machine time.

While this test describes a very specific business use case and application, the findings of the high levels of accuracy derived from uncalibrated cameras with relatively low costs suggest many other uses. Products such as point clouds, surface models, contours and ortho photos can be generated from these sensors with similar quality in order to solve an innumerable amount of business needs. As regulations become clearer and more UAS friendly, the applications and usage of this new and exciting tool will increase greatly.