Optimal UAS Parameters for Aerial Mapping and Modeling

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DroneDeploy is a widely-used photogrammetry software package that is used by contractors to create surveys, orthorectified maps and 3D models. This paper analyzes the accuracy of DroneDeploy using a Phantom 4 Pro UAS. An experiment was created using a 4'x4'x8' orange cuboid and four high visibility ground targets in an unobstructed field. Elevations of the cuboid and targets were surveyed and used to compare against the DroneDeploy models. The accuracy of the models were evaluate with respect to horizontal distance, vertical distance, volume and percent deformation of the 3D modelled cuboid. A total of 28 flights were preprogramed to collect images at seven different elevations that ranged from 75 – 375' and four different image overlap settings that ranged from 55% - 85%. This study found that image overlap did not influence the accuracy of the models. The study also found that at optimal elevation, the vertical and horizontal distances shown in the models were within 6 inches of actual. Similarly, the volume (stockpile) calculations were within 1cubic yard of actuals. On average, 15% of the cuboid's 3D shape was deformed when modeled using 2D images.

Key Words: DroneDeploy, drone, UAS, survey.

Introduction

In the construction industry, photogrammetry from drone captured images is a rapidly growing tool for contractors because of its usefulness in documenting field conditions and improving site logistics. Photogrammetry involves the extraction of 2D and 3D information from multiple, sometimes thousands, of photographs stitched together. Some of the most commonly used photogrammetry software packages are Pix4D, Agisoft and DroneDeploy among others. The images used with the various photogrammetry systems are often supplied by unmanned aerial systems (UAS) commonly referred to as drones. When collecting images with the UAS, the same photogrammetric software is typically used to preprogram an automated flight. The automated flight will capture images along a preselected flight path at a given elevation. Images will be captured at regular intervals based on the percent overlap selected by the user. This paper will detail an experiment to test the accuracy of DroneDeploy and a common UAS. A total of 28 preprogrammed flights were created with seven distinct elevations and four image overlap settings. The elevations ranged from 75' – 375' in 50' intervals. The four overlap settings were 55%, 65%, 75% and 85%. Accuracy was tested using four metrics. The first two were horizontal and vertical distances, where horizontal distances and vertical elevation changes were measured with traditional surveying practices and compared with the DroneDeploy models. Volume was also tested by comparing the models to a 4'x4'x8' cuboid. The fourth metric was to measure what percentage of the cuboids surface was deformed by the waxing effect common with 3D aerial modeling.

Available Data

The use of Unmanned Aerial Vehicles/Systems has increased in construction and engineering projects in the United States (Santos de Melo et. al, 2017). The potential use of UAS in the engineering environments has gained a great deal of attention in recent years. In Civil construction and engineering, UAS has been used for the monitoring and maintenance of pavements and highways, inspection and monitoring of bridges and buildings (specifically monitoring damages, cracking, etc.), the maintenance of facades, and mapping of historic monuments (Santos de Melo et. al, 2017).

According to Dorafshan et. al (2017), the Michigan DOT conducted an analysis experimenting with UAS and reported UAS to be low cost, flexible, and time-efficient tools that could be used for multiple purposes; including but not limited to: traffic control, infrastructure inspections and 3D modeling of bridges and terrain. Dorafshan et. al (2017) claimed state DOTs' research historically assessed UAS use for surveillance and traffic control. However, recently, UAS-based bridge inspection has become a popular area of research. UAS are currently used in an assistive capacity by an inspector for performing bridge inspections faster, more cost effectively, and without traffic closures in some cases.

Due to the improvements made to graphic processing units most UAS assessing teams are not focusing their research on vision-based testing. This is mostly motivated by the need to create dense 3D models of the sensed environment, and the capacity to analyze and capture details at a smaller scale (DuPont et. al, 2017). According to DuPont et. al (2017) other effective uses of UAS during construction include the 3D bird's eye view of the site, allowing for the efficient surface and/or volume measurements. DuPont notes that the work that UAS provide is similar to the function that is conducted by resident engineers utilizing photography, schedules, spreadsheets, and/or diverse types of other forms; however there is yet to be a process in place for the accurate and efficient merge of project information collected by these various means similar to UAS into a global management system successfully.

The lack of emphasis on vision-based mapping beggars the need for a standardized mode of testing for photogrammetry software. This paper therefore seeks to assess DroneDeploy's accuracy based on horizontal distance, vertical distance, volume (stockpile) and surface deformation with 3D modeling. This study is being conducted to generate the optimal altitude and overlap to obtain the drone images.

DroneDeploy

DroneDeploy is photogrammetry software that is used to preprogram UAS flights and process the images collected into 2D maps, orthorectified surveys, 3D models and point clouds. It has built-in modes and settings that allow the user to adjust the camera and flight path to capture the most relevant data. It does not have all the features as some of the other competing photogrammetry programs, but it is very easy to use and provides most of the functions used by novice photogrammetric modelers. Because of its ease of use and relatively high functionality, it has become a leading software application for many contractors such as Brasfield and Gorrie, Reconn Tech and McCarthy Building Companies. Additionally, Procore is a gold level partner with DroneDeploy giving many contractors a seamless workflow from field to office.

In 2014, Brasfield and Gorrie collaborated with Auburn University and Leica Geosystems to launch their first UAS flight (Cole et. al, 2016). The flight was conducted to inspect the 1 million square foot Grandview Medical Center in Birmingham, Alabama. Although Brasfield and Gorrie's path to compliant operations took longer due to the Section 333 exemption than it would have under the current Part 107, they were able to capture detailed images and compare them to their Building Information Modelling software plans. They were able to detect the problems at their jobsite and make a cost-effective savings of over 75% in productivity (Cole et. al, 2016).

In 2017, Reconn Tech applied drone mapping in field inspection to reduce their time spent on the field and technician costs for utility locations by up to 50% (Bartlett, 2017). With over 25,000 utility locations across the nation, each site inspection took over two hours to map. With the use of a common drone (DJI Phantom 4 Pro), Reconn Tech eliminated the need for technicians on site and improved the inspection of each site to less than forty-five minutes each. After the images were uploaded to DroneDeploy, their orthomosaic maps were easily generated without the use of GIS mapping, which further streamlined the process and improved productivity drastically.

McCarthy Building Companies launched and expanded their UAS program after the FAA introduced the Part 107 regulations to allow for commercial use. In 2016, McCarthy implemented an enterprise drone program with DroneDeploy that helped staff mobilize UAS on jobsites to streamline workflow into a standardized procedure (Moret, 2017). In this process, standard and manual flights were conducted to capture orbitals images for 3D modeling on large, complex projects. The entire process took less than twenty minutes per jobsite. The data was then analyzed by measuring stockpiles and square footage on the various sites. Within a year of the enterprise launch, over twenty UAS were being used to access and share site data sets for incorporation into DroneDeploy's App Market. In this way, drone maps were connected to top industry solutions from stakeholders, which improved communication and coordination. According to Moret (2017), McCarthy hopes to leverage drone data on solar sites by using infrared imaging for testing building enclosures.

How DroneDeploy works

DroneDeploy has a web-based interface where users log into their account and start by creating a flight mission. Google Earth images are used as the base layer and the user will "draw" an area they wish to map. DroneDeploy will then create a lawnmower path for the drone to fly and capture the images. Most of the images will be vertical (straight down) but if "structures mode" is selected, oblique images from the perimeter of the map angled toward the center will be taken. These images eliminate the horizon and provide an additional perspective which greatly improves the quality of the 3D models. The user must also set the altitude of the aircraft and the amount of overlap between the images. The higher the altitude the more the ground will be captured with each image reducing flight time. However, the higher the altitude the further away the camera is from the objects reducing image resolution. Increasing the overlap increases the number of images taken with the flight which also increases the flight time.

There is little literature available on optimal altitude and overlap settings that should be used; however, DroneDeploy indicates that low elevation flights with overlap between 65% and 75% produce the highest quality models and maps (Colby & Love, 2016). After the images are downloaded from the aircraft and processed with DroneDeploy, 2D maps, 3D models and point clouds are made available through a web-based interface. Digital outputs for download such as GeoTIFF, OBJ, PDF and JPG can be exported to the App Market or other programs.

DroneDeploy recommendations for capturing images include 99%+ coverage of the area of interest, high data quality, flight with increased overlap and flight on an overcast day (DroneDeploy, 2017). Flying at a higher altitude gives the camera more land area to cover in a single image. In this way, common unique features would be covered in areas with homogenous imagery. Modifying the flight path can assist with capturing a narrow shape or flying in and out of the wind. This also conserves battery life. Flight on an overcast day allows the pilot to use the cloud as a light diffuser which then gives an even lighting for the object. Overlap refers to the side lap and front lap in DroneDeploy. Side lap refers to the percentage of overlap between each leg of a flight, while front lap refers to the percentage of overlap between one image and the next.

Methodology

For this experiment, a 100' x100' (1,000sq. ft) area of land with a slight slope was selected. The area was in a public park, free from overhead obstructions and not near an airport or helipad. To aid in the capturing of images, a highly visible target was constructed out of plywood and 2x4 framing lumber to create a 4' x 4' x 8' cuboid. Four highly visible targets were set at the 90-degree compass direction (North, South, East, and West) relative to the cuboid. The elevations of the targets were measured with a surveyor's transit relative to the top of the cuboid. The weather was clear with little wind and no precipitation. All FAA regulations were adhered to.

The DJI Phantom 4 Pro drone was used to capture the photogrammetry data. The Phantom 4 Pro drone is one of the most commonly-used unmanned aircraft on the market for personal and commercial purposes (Craigi, 2016). It is a reliable drone that, like all DJI UAS, is compatible with DroneDeploy. The Phantom 4 Pro's gimbal camera is capable of capturing images at various angles and altitudes while remaining stable enough against the elements. The stock camera takes 20 megapixels/inch images with a 1" inch CMOS sensor. It is easily programmable to capture the required data for our experiment, especially at higher altitudes. The Phantom 4 Pro, like all multirotor UAS has a limited battery life. Each battery afforded between 15 to 20 minutes of total flight time.

A total of 28 separate flights were performed to collect all the necessary data. The two variables of interest were altitude and image overlap as indicated in Table 1. The altitude ranged from 75ft – 375ft at 50ft intervals. Image overlap were set at 55%, 65%, 75% and 85%. The image data was corrupted with flight 17 so a total of 27 flights were analyzed.

Table 1
Test flights at different altitudes and image overlaps

Altitude (feet)	**Image Overlap (percent)**			
	55%	**65%**	**75%**	**85%**
75’	Test Flight 1	Test Flight 4	Test Flight 7	Test Flight 10
125’	Test Flight13	Test Flight 16	Test Flight 19	Test Flight 22
175’	Test Flight 2	Test Flight 5	Test Flight 8	Test Flight 11
225’	Test Flight 14	Test Flight 17*	Test Flight 20	Test Flight 23
275’	Test Flight 3	Test Flight 6	Test Flight 9	Test Flight 12
325’	Test Flight 15	Test Flight 18	Test Flight 21	Test Flight 24
375’	Test Flight 25	Test Flight 26	Test Flight 27	Test Flight 28

*Note. Test Flight 17 was corrupted and was eliminated from the data set

Recording of Information

After the flights, the images from all 27 flights were processed using DroneDeploy. The distance tool in DroneDeploy was used to measure the distance between two targets and then compared to what was surveyed in the field. Similarly, the elevation tool in DroneDeploy was used to measure the elevation difference between two targets and the center cuboid. Those measurements were also compared to what was surveyed in the field. DroneDeploy has a “stockpile” tool which estimates the volume of an object. Often this is a stockpile of soil or stones which is how this feature derived its name. The user will draw a line around the object in the software and DroneDeploy will calculate the volume based on the elevation of the drawn line and the elevations (point cloud) of the object in the center. The center target was a 4’ x 4’ x 8’ cuboid so the precise volume was known for the comparison. Finally, the 3D model was also measured for accuracy. Screen shots of the cuboid in the 3D model were taken on all five sides (four sides and the top). The screen shots were input into an estimating software program (OnScreen Takeoff) where the percent of the side that was distorted was taken off. The percent distortion was then compared to the known surface area of the cuboid.

Results

The accuracy of the DroneDeploy models was evaluated by comparing known field conditions to what was calculated in the models with relation to horizontal distance, vertical distance, volume (stockpile) and surface deformation of a 3D cuboid. Figure 1 shows the difference between actual and modeled for the 27 test flights. The x-axis is oriented left to right by increasing altitude first then by increasing overlap (altitude’ / overlap %). The left y-axis shows the difference in horizontal and vertical distance in linear feet and difference in volume by cubic yards. The surface deformation is provided as a percentage of the surface area of the cuboid on the right y-axis. In general, the accuracy of models begins to degrade significantly at 225’ above the target. However, to fully understand the data, a review of the statistically significant differences between the flights was conducted.

Overview of the Model Accuracy

A student’s t-test analysis of all the combinations of flights was conducted to determine if the differences found between actual and measured results were statistically different between any of the flights. The first t-test analysis conducted was to determine if there was a significant difference between flights with different image overlap. To the researchers’ surprise, there was no significant difference between actual and modeled information for any of the 4 overlap groups (55%, 65%, 75% and 85%). It was assumed that with higher overlap, more images would be captured increasing all measured data points but especially the 3D models. That was not what the data showed. The results of the experiment were that overlap variations between 55% and 85% were meaningless with respect to the accuracy of the maps and models.

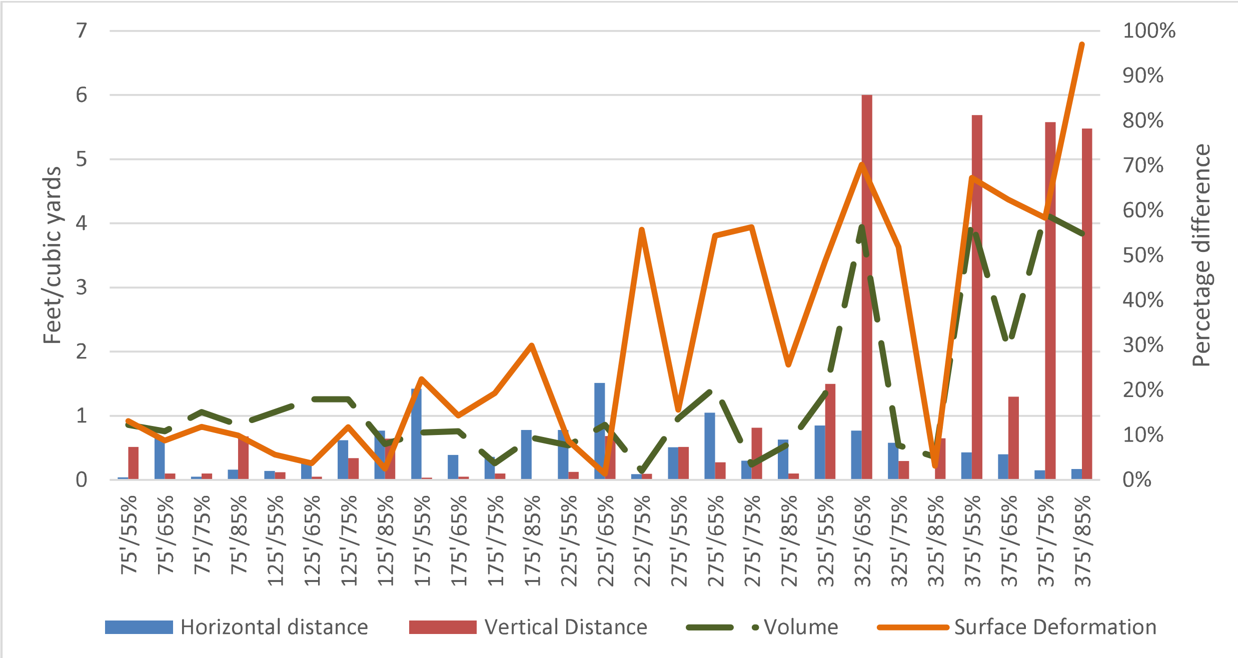

Figure 1: Variances in modelled horizontal distance, vertical distance, volume, and surface deformation from actual

The second t-test analysis was between the results of the models with data collected at different altitudes. The results of that analysis are provided in Table 2 where the difference between actual and measured, the p-value, and if the difference was significant at 95% confidence is shown. If there was a significant difference, it was noted with a "Yes" and if not, a "No." The horizontal distance recorded no significant difference in accuracy between any of the models. However, there were significant differences in accuracy of the models with relation to vertical distance with the flights above and below 325' above the surface. A similar trend was observed with the volume calculation at 375'. The surface deformation percentage was significantly different for images captured above and below 275'.

Horizontal Distance

The actual distance between the North and East targets was 70.71ft. Figure 1 graphically shows the average difference between the actual length between the targets and what DroneDeploy modeled in all 27 models was .52' and ranged from .01' to 1.51'. Flight 24 had the highest degree of accuracy and captured the data at 375'. However, at this elevation, the targets in the model were blurry and made locating the exact center difficult. It wasn't reflected with the measurement, but some inaccuracy from high altitude images creating low resolution in the model is worth noting. As shown in Table 2, there was no statistical difference between any of the DroneDeploy horizontal distance estimates. The test flights were limited to 375' so it is likely that if the images were taken from higher elevations that eventually there would be significant loss of accuracy. However, as Part 107 of the FAA regulations limits flights to 400', this gap in data is largely irrelevant to contractors.

Vertical Distance

The elevation of the targets was compiled from the average of the actual elevations of the north target, the east target, and the cuboid. These averages were then compared to the estimates provided in DroneDeploy as shown in Figure 1 and Table 2. Figure 1 indicates that the average difference from actual in all 27 flights was 1.4'. The known elevation is 7.1' so a variance of 1.4' is an error of nearly 20%. Table 2 indicates that there were significant differences between the models starting at elevation 325'. Averaging only the flights below 325, the difference of model to actual was only .28' with a range of .01 - .82. Traditionally, obtaining accurate vertical elevations is more difficult than horizontal elevation which we are seeing with this experiment as well. However, models created from images captured at lower altitudes had the same level of accuracy as horizontal distances.

Table 2

Significant Differences in Actual to Modelled Values

Compared Flight Elevation	Horizontal Distance (ft)			Vertical Distance (ft)			Volume (Cyd)			Surface Deformation (%)		
	Diff	P-val	Sig	Diff	P-val	Sig	Diff	P-val	Sig	Diff	P-val	Sig
75-125	0.00	0.42	No	0.02	0.89	No	0.03	0.79	No	0.05	0.71	No
75-175	0.01	0.08	No	0.05	0.74	No	0.06	0.63	No	0.10	0.43	No
75-225	0.01	0.07	No	0.01	0.92	No	0.08	0.55	No	0.11	0.44	No
75-275	0.01	0.17	No	0.01	0.96	No	0.02	0.89	No	0.27	0.05	Yes
75-325	0.00	0.26	No	0.26	0.07	No	0.14	0.26	No	0.33	0.02	Yes
75-375	0.00	0.83	No	0.59	0.00	Yes	0.57	0.00	Yes	0.60	0.00	Yes
125-175	0.00	0.32	No	0.03	0.84	No	0.09	0.45	No	0.15	0.26	No
125-225	0.00	0.27	No	0.00	0.98	No	0.11	0.40	No	0.16	0.27	No
125-275	0.00	0.56	No	0.02	0.86	No	0.05	0.68	No	0.32	0.02	Yes
125-325	0.00	0.73	No	0.28	0.06	No	0.11	0.38	No	0.37	0.01	Yes
125-375	0.00	0.55	No	0.61	0.00	Yes	0.53	0.00	Yes	0.65	0.00	Yes
175-225	0.00	0.85	No	0.03	0.83	No	0.02	0.89	No	0.01	0.96	No
175-275	0.00	0.68	No	0.05	0.71	No	0.04	0.73	No	0.17	0.21	No
175-325	0.00	0.51	No	0.31	0.04	Yes	0.20	0.11	No	0.22	0.10	No
175-375	0.01	0.12	No	0.63	0.00	Yes	0.63	0.00	Yes	0.50	0.00	Yes
225-275	0.00	0.57	No	0.02	0.89	No	0.06	0.64	No	0.16	0.26	No
225-325	0.00	0.43	No	0.27	0.08	No	0.22	0.11	No	0.22	0.14	No
225-375	0.01	0.11	No	0.60	0.00	Yes	0.65	0.00	Yes	0.49	0.00	Yes
275-325	0.00	0.81	No	0.25	0.08	No	0.16	0.20	No	0.06	0.67	No
275-375	0.00	0.24	No	0.58	0.00	Yes	0.59	0.00	Yes	0.33	0.02	Yes
325-375	0.00	0.35	No	0.33	0.03	Yes	0.42	0.00	Yes	0.28	0.04	Yes

Volume (Stockpile)

The actual measured volume of the cuboid was 128 cubic feet, or 4.74 cubic yards. DroneDeploy was used to estimate the volume of the cuboid at the various altitudes and overlaps and compared with the actual value. The average difference between the known volume and what was modeled for all 27 flights was 1.30 cubic yards. However, as shown in Table 2, there were statistically significant differences between the flights at and below 375'. If we remove the flights at 375', the average difference between modeled and actual is .91 cubic yards and ranged between .14 and 3.94 cubic yards. These findings are showing a level of inaccuracy higher than what was observed with the horizontal and vertical distances.

Surface Deformation

DroneDeploy has a feature that takes georeferenced images and stiches them together in a 3D model. Most models have a "waxing" effect where the models show deformation from a true representation of the 3D space. For this experiment, the deformation was measured by taking off the surface area of the cuboid that showed waxing. Only shape was considered with this experiment and excluded other characteristics such as color and texture. The distortion of each 3D model increased with the altitude of each test flight. Figure 2 gives three examples of the distortion observed with the models. From left to right, the level of distortion measured <30% for "little distortion," 30-60% for "moderate distortion," and >60% for "extensive distortion." Flight images that demonstrated little distortion were an almost accurate depiction of the cuboid's shape and showed minor waxing. Moderate distortion was characterized by the image being sufficiently deformed, with noticeable waxing. For extensive distortion, the form of the target was severely compromised and presented as lumps in profile. This was most apparent with flights performed at higher altitudes of 225ft and above.

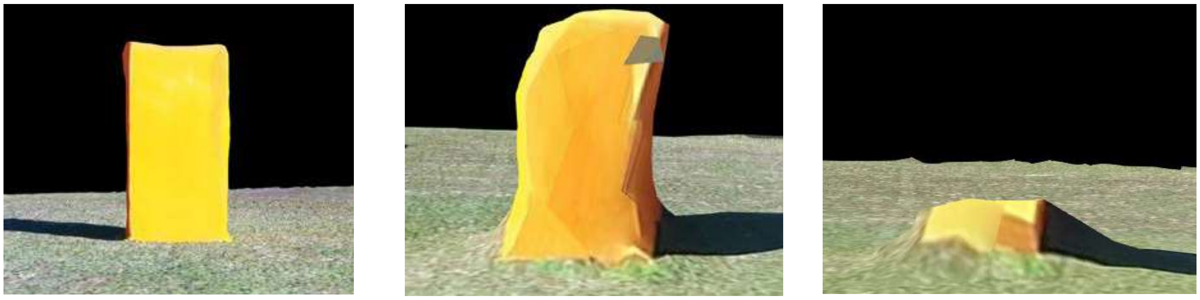

Figure 2: These images show the levels of distortion per flight based on altitude. From left to right: little deformation, moderate deformation, extensive deformation.

As before, the average percentage of distortion was calculated. From all 27 flights, the average distortion was approximately 31% of the shape of the cuboid. As was shown in Table 2, there were significant differences between flights above and below 275' elevation. If you exclude the flights at 275 and above, the average deformation of the shape was 15% and ranged from 1% - 56% of the cuboid.

Conclusion

This study confirms that the use of commercially available UAS and DroneDeploy are valuable tools to the contractor. There are several specific conclusions that this study adds to the literature. One of those findings is related to overlap. DroneDeploy indicates that the optimal overlap setting is between 65% and 75% (Colby & Love, 2016). This study confirms those recommendations as we found no significant difference between any of the models with overlap that ranged from 55% to 85%. As greater overlap requires longer flights and more data storage, evaluating overlap less than 55% is recommended for a future study.

We also found the software and UAS are a quick and convenient way of field testing as-built conditions. A survey for a 100+ acre site could be created from a 10-minute flight to obtain both horizontal and vertical elevations with an average accuracy of 6 inches. This is insufficient for laying out buildings or true surveys but is certainly sufficient for spot checking structure locations, parking lots and document subsurface utility locations. In line with this is the stockpile calculation. The DroneDeploy models were within .91 cubic yards of actual and a very useful tool in tracking progress with civil project and verifying quantity-based pay applications.

The 3D models also have significant value to the contractor. When data was gathered at 275' and below, the models were on average 15% distorted. This is much too high for as-builts or to replace other BIM type models but has the benefit of capturing the current conditions much more rapidly. This feature is particularly useful with planning logistics on a daily basis, recording progress and, as demonstrated with recent hurricanes, documenting site progress before and after storms for insurance claim purposes.

Limitations of the study

Some limitations that may have corrupted the data included the change in lighting that occurred over the course of the 27 flights. This led to shadows occurring in some images which may have influenced the accuracy of the 3D models. Also, some test flights had to be reprogrammed and rerun since the waypoints of some test flights appeared to be too close together in the flight paths. The use of one drone (Phantom 4 Pro) was a limitation to the study. UAS with different camera specifications will have different results.

Future Study

The study did not compare and contrast the types of material that would be best suited to improve the texture of a 3D image. Since this study was conducted on a relatively small target on a level ground, it would be prudent to apply these parameters on a larger target such as a bridge or a building. In this study, it was assumed that all flights would be conducted relative to level ground. However, it is hoped that in future studies, the test flights would be conducted at heights relative to the target objects, and how that would affect the elevation and volume differences. The authors of this paper hope to use other drones with different camera quality to capture improved images within DroneDeploy or any other photogrammetry software. They also hope to be able to compare DroneDeploy's functions with other photogrammetry software for surveys and inspections.

References

Bartlett, C. (March 2017). "Drone Mapping Reduces Utility Location Times by up to 50%" *DroneDeploy blog.* Retrieved from url: https://blog.dronedeploy.com/drone-mapping-reduces-utility-location-times-by-up-to-50-b7b265081d93

Colby, C. Love, J. (2016). "Choosing Your Flight Settings." *Drone Deploy 2016 Agriculture Webinar* [video webinar]. Retrieved from url: https://www.youtube.com/watch?v=iisQNxc2l6Q

Cole, H. Gibbs, R. Millin, J. (2016). "Drones in Construction: A Drone on Every Job Site." *DroneDeploy Webinar* [video webinar]. Retrieved from url: https://www.dronedeploy.com/resources/webinars/start-scale-drone-operations/

Craigi. (2016). "DJI Phantom – the Drone that Started it All." *DroneFlyers.* [website] Retrieved from url: https://www.droneflyers.com/dji-phantom-drone-started/

Dorafshan, A. Maguire, M. Hoffer, N. V. & Coopmans, C. (2017). "Fatigue crack detection using unmanned aerial systems Under-Bridge Inspection." *Idaho Transportation Department Research Program*. Contracting Services Division of Engineering Services.

DuPont, Q. F. M. Chua, D. K. H. Tashrif, A. & Abbott, E. L. S. (2017). "Potential Applications of AUV along the construction's value chain." *Procedie Engineering.*

Moret, R. (August 2017). "Proving the Value of Enterprise Drone Programs in Construction." Retrieved from url: https://blog.dronedeploy.com/proving-the-value-of-enterprise-drone-programs-in-construction-afd60ee8c94

Santos de Melo, R. R. Costa, D. B. Alvares, J. S. & Irizarry, J. (2017). "Applicability of unmanned aerial system (UAS) for safety inspection on construction sites." *Safety Science*. Iss. 98, pp. 174-185.

Seven Ways to Improve the Accuracy of Your Drone Maps (April 2017). *DroneDeploy.* Website. Retrieved from url: https://blog.dronedeploy.com/seven-ways-to-improve-the-accuracy-of-your-drone-maps-9d3161f05956