DECEMBER 2019 | FHWA-HIF-20-034

Tech Brief

USE OF SMALL UNMANNED AERIAL SYSTEMS FOR LAND SURVEYING

INTRODUCTION

Unmanned aerial systems (UAS) are being used to change the way data are collected for land surveying. By utilizing sensors that provide high-resolution images or light detection and ranging (LiDAR), or both, on small UAS, the systems enable the collection of highly accurate data with a high density of data points collected.

By utilizing photogrammetric and LiDAR point clouds, which are very dense sets of data that represent three-dimensional (3D) objects in space when collected via UAS in land surveying, more data can be collected in less time. The improved data collection capability can save costs while increasing productivity, not only by providing a better product, but also by preventing return visits to a site to collect additional data.

There are also several challenges to face in using small UAS for reliable surveys. System accuracy, weather, system limitations, regulatory restrictions, training, and liability are some that must be considered prior to using UAS.

Unmanned aircraft can fly lower than traditional aircraft and achieve the same if not better quality data at a lower cost for small to medium sized surveys. Much of the mapping can be completed using automated software to help ensure quality control with minimal training. UAS produce high-resolution imagery along with high-quality point cloud data that can be used in design to supplement conventional survey tools.

With the advent of UAS, many questions have been raised about what airframe, hardware, and software may be required to collect data that provide sufficient quality to be called “survey grade.” By utilizing ground control points (GCPs), real-time kinematic (RTK) positioning satellite navigation, or post-processed kinematic (PPK) global positioning, trained professionals can achieve survey-grade accuracy for deliverables using UAS.

While there are many facets to the questions, this tech brief provides basic knowledge on the best uses to achieve the desired results.

SURVEYING TOOLS

Surveying tools are evolving and allow for faster and denser data collection than ever before. Land surveying has undergone a lot of changes over the centuries, but perhaps not as rapidly as within the last 20 years (Reed 2015). Enhancements to the state of the art, such as global positioning systems (GPS), LiDAR, robotic total stations, and now UAS, allow for surveying at scales that weren’t possible with traditional technologies of the past.

What once took a large, full-staffed survey crew months, even years, to survey can be completed within days using the advanced technologies of today, and with a 1–2 person crew. Surveyors can also achieve higher accuracy and precision without needing to remove vegetation due to line-of-sight restrictions.

During the past 50 years, surveying and engineering measurement technology has made five quantum leaps: electronic distance meter, total station, GPS, robotic total station, and laser scanner. UAS or drones (also known as unmanned aerial vehicles or UAVs) are becoming the sixth quantum leap in technology (Willis 2013). What Willis envisioned in 2013 has now become a reality and is changing the way many survey firms collect data.

U.S. Department of Transportation
Federal Highway Administration

Safety is another important aspect when discussing UAS. Traditional surveying methods were often very dangerous, being exposed to traffic, dangerous terrain, obstacles, and unexpected situations. UAS can be used to collect data where it is dangerous or extremely difficult for a person to access, such as active roadways, riverbeds, unstable landslide areas, steep terrain, toxic areas, and cliffs.

By utilizing UAS, we are able to collect high-quality survey data and minimize the time surveyors spend in dangerous situations. The Moki Dugway, Utah landslide was an instance where photogrammetry was used, and it would have been impossible to safely survey the area with traditional methods (see Figure 1).

UDOT

Figure 1. Moki Dugway, Utah landslide 3D point cloud collected using UAS photogrammetry

ROTORCRAFT VERSUS FIXED-WING UAS

Many choices exist when it comes to the procurement of a UAS fleet. Most fall within two main classes: rotorcraft and fixed-wing (see Figure 2).

It is beneficial to understand the benefits and weaknesses of each class of aircraft. Each platform has its strengths and weaknesses, and it is important to understand the characteristics of each to ensure they will meet the needs of your agency.

Both rotorcraft and fixed-wing UAS may be needed to complete an operation at times. The primary goal should be to base the decision on the sensor and the compatibility of the aircraft to the software being used for flight and processing. Tables 1 and 2 list the strengths and weaknesses of rotorcraft versus fixed-wing UAS.

Rotorcraft are useful in many situations and are typically less expensive than fixed-wing aircraft; however, fixed-wing aircraft are more efficient for flight. Fixed-wing UAS depend on their wings for lift and the motor to move the aircraft, while rotary-wing aircraft must depend on their energy to keep them airborne at all times.

Rotorcraft are excellent for capturing data in difficult areas such as those during bridge inspections and in urban areas where space is limited. They are also much more versatile than fixed-wing aircraft.

Due to the efficiency of fixed-wing UAS, they have longer flight times, which are typically double that of a rotorcraft UAS. This makes them an efficient tool for mapping large areas. The weakness of fixed-wing UAS comes from their lack of being able to stop in mid-air and the need for a larger area in which to take-off and land. Rotorcraft are easier to use when in areas where there are many obstacles present or if limited space is available for take-off and landing operations, such as an urban environment.

Pixabay (left), Wingra (right), used with permission

Figure 2. Rotorcraft (left) and fixed-wing (right) drones

Table 1. Rotorcraft UAS strengths and weaknesses

Strengths	Weaknesses
Vertical take-off and landing and flexibility on take-off and landing sites	Battery life
Stability	Aerodynamics/less efficient
Easy to fly	More maintenance
Variety of aircraft/sensors easily available	Expensive repairs
Ability to hover	Slower airspeed
Ability to change camera angles	Smaller payload capacity
Precision maneuvering	

Table 2. Fixed-wing UAS strengths and weaknesses

Strengths	Weaknesses
More aerodynamic/efficient	Larger area ftake off and landings
Fewer parts to maintain	Difficult to fly manually
Glide ratio	Higher speeds
Longer flight times/endurance	Inability to fly slow or hover while taking images
Large area coverage	Fixed camera angle on most aircraft
Higher speeds	Target for birds of prey

GPS EQUIPMENT

The accuracy of the data can be attributed to not only the sensor being used but also the quality of the GPS on board the aircraft. The GPS solutions available on UAS fall into three categories: consumer, RTK, and PPK. Most lower-cost aircraft have consumer-grade GPS integrated with the aircraft. This can be problematic if additional steps aren't taken to increase the accuracy of the data captured. Typically, if higher accuracy is needed, GCPs, which are addressed more below, are necessary. As more UAS have been utilized, higher quality GPS solutions have been made available.

As mentioned previously, two other solutions that can reduce the number of GCPs, while still maintaining quality, are RTK and PPK solutions. These help enhance the precision of the satellite positional data, which leads to greater accuracy and precision of the data collected. If utilizing aircraft with RTK or PPK solutions, it can reduce the number of required GCPs, but not eliminate them completely.

The Utah Department of Transportation (UDOT) has found that including GCPs is necessary for accurate data regardless of the technology used. In addition to the RTK and PPK solutions on the aircraft, a base station is also required, which adds additional cost. Most survey companies already have base stations as part of their equipment or utilize a statewide continuously operating reference station (CORS) or virtual reference station (VRS) network. It is beneficial to confirm that the system on the aircraft is compatible with the base station that is being used. Even with these solutions, considerations must be taken to understand the limitations.

RTK positioning satellite navigation can record accurate corrections, yet it can have issues if the signal is lost during flight. If the signal is lost, the positional data is unknown and will not capture or record the corrected positions to the metadata while the image is being captured. This can cause an image to be rendered useless.

PPK global positioning can provide more flexibility, as it doesn't require constant communication with the base station during flight. This prevents signal loss from interference or obstruction during flight, which can occur when using RTK solutions. The data can then be processed and input into the system after the flight to geotag the images with the proper correction data. PPK solutions also allow data to be collected from more than one source for redundancy during flight.

While these are viable solutions for most projects, there are GPS limitations. Positioning accuracies for GPS measurement and mapping using PPP or RTK can be very challenging even under the best conditions. Global Navigation Satellite System (GNSS) signals can be affected by space weather in the ionosphere causing signals to be slowed. Additionally, accuracy may be compromised by other factors such as satellite shadowing, non-line-of sight receptions, signal diffraction, or multipath effects.

These are real world challenges regarding the use of GPS that have also faced the safety-critical aviation industry. Checking the quality of the data is important and should be incorporated into the workflow to fully verify the accuracy of what is being collected.

GROUND CONTROL POINTS

GCPs can be any seen feature on the ground that can be identified in the aerial imagery. Typically, aerial targets are used, whether by painting, tape, or temporary targets (see Figure 3).

UDOT/Meridian Engineering, Inc.

Figure 3. Aerial target for GCP

The points are precisely measured for x, y, and z values and assist with improving the quality of the aerial data.

One of the most critical factors in ensuring a profitable and accurate drone survey is ground control (Campbell and Katz 2018). Without the use of GCPs, issues can arise that aren't always apparent, such as warping or scaling of the imagery and the point cloud. It is important that the points are visible and placed properly to prevent errors in the data. Having the points not disbursed properly can cause issues worse than not using them at all.

GCP Placement

It is important to place the GCP locations disbursed around the site in a manner that resembles that of the five side of a die, as shown on a sample site in Figure 4.

UDOT

Figure 4. Placement of GCPs on the five side of a die (one die next to the other in the aerial image on the right)

The points should be uniformly placed around the site as shown. If the points are too close to the edges of the site, warping can occur. For longer corridors, the control points should be staggered along the roadway. Other technical considerations are as follows:

- Keep GCPs no more than 500–1,000 ft apart from each other
- Distribute points throughout the flight area
- Prevent the location of the points being located on the far edges of the flight area where overlap is not sufficient
- Have targets large enough to see for the specified ground sampling distance (GSD)
- Avoid obstructions and shadow areas

GCP Visibility

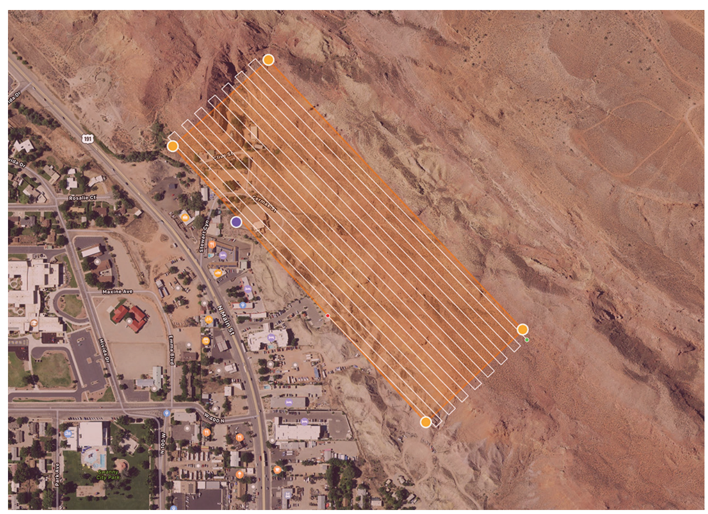
When placing GCPs, the visibility of the target from the air is just as important as the disbursement around the site, and it isn't always apparent from the ground if the target can be seen from the sky. It is important to assess the area for any obstructions that could obscure the point during different times of the day and make it difficult to see and select the target when processing the data (see Figure 5).

Figure 5 (top) illustrates the shadow from a guardrail that obscures the GCP, making it difficult to see and select the target when processing the data. The type of material (e.g., sand, loose soil, silt) on which the GCP is placed or painted can also have an impact on the longevity of the target, and Figure 5 (center) shows a target that is painted on the dirt. The target may only be visible for a short time until the wind or rain blows or washes the paint away. Using aerial tape or temporary targets is often preferred when placing targets on natural ground. It is also important to have good contrast on the targets for the best visibility.

GCPs also should be placed in areas where they have low probability of a vehicle parking on top of them and obscuring the view from the air. It is also important to consider the size of the numbers and ensure they are large enough to be identified from the air. If the numbers aren't large enough, they will become blurry and it may be difficult to determine one point from another, as shown in Figure 5 (bottom).

UDOT

Figure 5. Examples of problematic GCP locations: guardrail shadow (top), paint on dirt that can wash or blow away (center), and blurry numbers (bottom)



Paul Wheeler

Figure 6. Example of land survey flight plan

FLIGHT PLANNING

Flight planning is crucial to a successful mission (see Figure 6). Many considerations must be planned to ensure quality data and a safe flight. It is advisable to plan a site visit prior to flying to scan for any potential obstacles or conflicts prior to flight. Brief descriptions of various planning considerations follow.

Time of day (e.g., lighting conditions): Lighting and shadows can play a large part in achieving optimal results, especially when mapping large sites. Areas that are either overexposed or in shadow make it very difficult for the processing software to match similar features, which will leave areas of the data blank.

Another consideration when surveying areas during multi-day missions, if one flight is completed in the morning and another in the evening, for example, software can have issues matching key points in those areas and see them as two different surfaces, causing errors in the data. A way to negate this effect is to fly when the lighting is similar for the flight lines, or process the areas separately.

Airspace and air traffic (e.g., low flying planes or helicopters, nearby airport): When surveying in controlled airspace, it may take extra time to receive authorization to fly. An alternative plan is also useful in case the authorization request is rejected.

When flying near a heliport or airport, it may prove difficult or impossible to safely fly without impacting the other air traffic. An aviation band radio or automatic dependent surveillance-broadcast (ADS-B) in device to monitor traffic in these areas may mitigate any safety issues.

Obstructions (e.g., powerlines, trees, structures): Distances can be deceiving from the ground. Before completing an autonomous mapping mission, it is important to determine the actual height of obstacles above the ground to prevent incidents.

Weather and temperature: Due to limitations in sensors, hardware, and the regulatory environment, weather may impact the ability to fly. Temperature has a drastic effect on the performance of the aircraft and its batteries. Performance may differ due to heat, cooling, and density altitude.

Suitable take-off and landing sites: For a suitable take-off and landing site, a portable, durable landing pad that can be placed on the ground is useful. Areas with fine dust or dirt can cause the camera lens to become dirty on take-off and landing, in addition to getting particulates into the engine, which can cause damage and reduce the life of the motor.

When planning a flight, one or more backup or alternative landing sites are important in case the primary site becomes unusable.

Terrain: Terrain can have a drastic effect on the overlap settings for the images. If the software doesn't follow the terrain and provide a relative constant altitude, it can change the GSD and reduce the accuracy. Depending on how drastic the changes are in altitude, it may make it impossible to use certain images. By using software that will follow the terrain, it will keep the GSD constant and make for improved data sets.

Overlap settings: Overlap is an important part of the settings in the software that can have a drastic effect on the quality of the data gathered. An understanding of the proper overlap to achieve the desired results for both front and side lap is needed. If the mapping area includes simple objects, enough images to obtain four angle measurements are necessary, while complex objects require nine angle measurements (see Table 3).

Table 3. Image overlap setting recommendations

Overlap Characteristic	Front Angle	Side Angle
Minimum	75%	60%
Dense vegetation	85%	70%
3D models (i.e., towers, buildings)	90%	60% at different height levels

Landscape characteristics to consider in the flight plan include trees, fields, corridors, and mountains. Areas with dense vegetation may need 90% overlap to achieve the desired accuracy; however, it is not advisable to use a higher overlap than needed, as it can have an exponential effect on flight and processing time.

Camera settings: To obtain the highest quality images, it may be necessary to adjust the settings manually for the camera to properly set the white balance, aperture, and shutter speed.

Battery charging capabilities: Unless mapping smaller sites (when minimal battery life is needed), it is beneficial to have the capability to charge batteries on site. Two options include power inverters that run off 12 volts on a vehicle or a portable energy source that has enough capacity to charge the batteries as needed for the project.

Mapping software: To work effectively, the mapping software should have, at a minimum, the ability to adjust camera settings, resume at the last point when changing batteries, and include terrain following, GSD indication, and overlap setting features.

Permits or authorizations: Authorizations including permits are required to fly in a controlled airspace and may be required in locations such as national parks. Prior notifications to entities like national parks can also help foster good ongoing relationships.

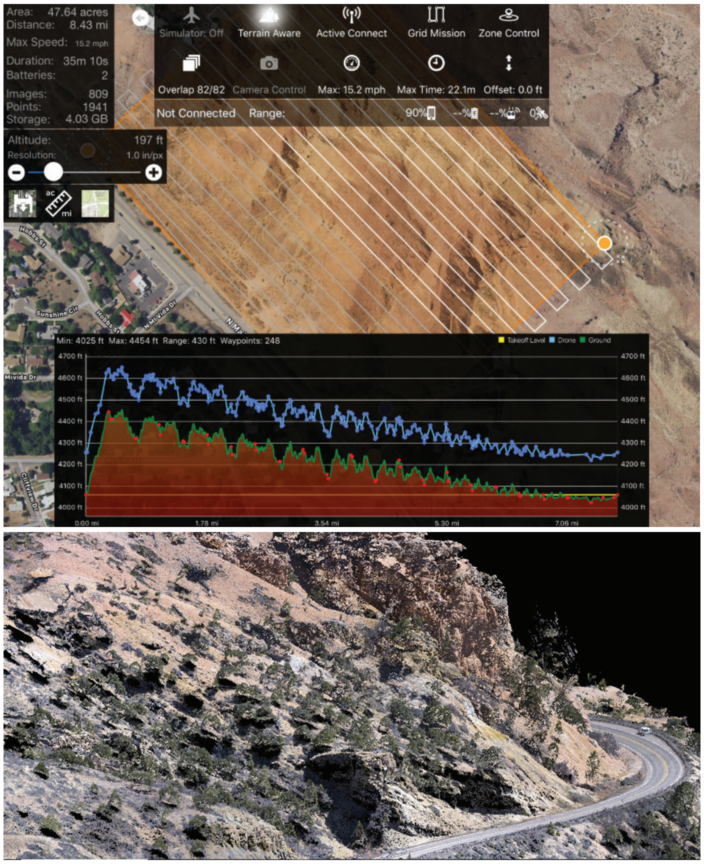
Use of Mapping Software

The majority of the mapping software available is programmed for autonomous missions in order to ensure the proper overlap and flight lines and limit pilot error. While this can allow for ease-of-use in the field, it is necessary to understand what the software is doing and why. It is important to understand all the nuances of the software to reduce the possibility of a crash or unsatisfactory mapping results.

For example, if the return-to-home altitude is set below the height of the tallest obstacle, the UAS may fly directly into the obstacle. It is important to check all of the settings for the aircraft and software prior to each flight to help prevent otherwise easily avoidable problems during flight and data collection.

Many different varieties of mapping software are available that can achieve different goals. The following questions/features merit evaluation prior to purchasing the software: Does the software offer terrain following? Does it have the ability to resume a mission after changing a battery? Can the camera angle be adjusted?

Figure 7 depicts the capability of mapping software to follow the terrain to fly a constant altitude above the ground with changing terrain elevation.

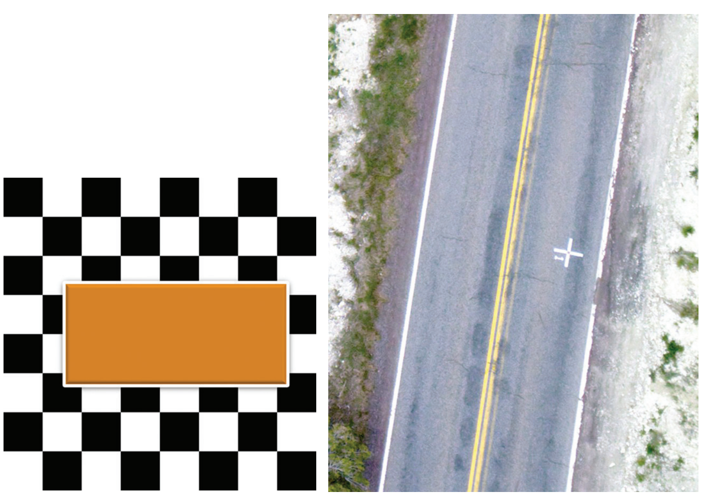


UDOT

Figure 7. Terrain awareness feature in mapping software

Ground Sampling Distance

Understanding GSD is important to achieve the desired results and can be overlooked. By understanding the concept, it can save time by gathering the data for the context in which it is needed. Figure 8 demonstrates an example of GSD in the context of capturing the proper ground sampling distance.



Paul Wheeler (left), UDOT (right)

Figure 8. GSD example

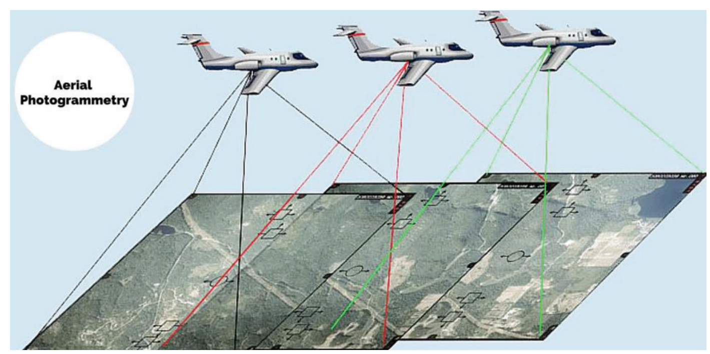
Each square in the checkered image represents a pixel on the image. To measure a paint line that is 4 in. wide, for example, a GSD that is less than that (or of what is being measured) is necessary. For a 4 in. painted line, a GSD less than 4 in. per pixel is necessary for the accuracy to define the line. However, too low of a GSD increases both the flight and processing time exponentially.

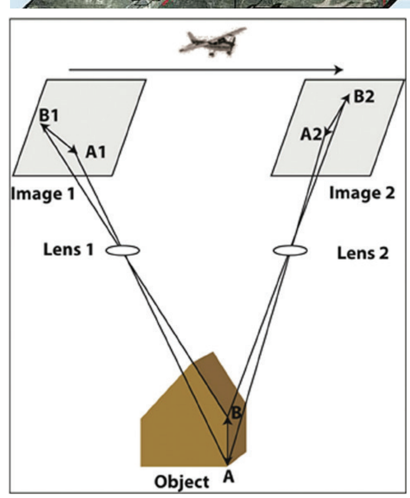
PHOTOGRAMMETRY POINT CLOUD VERSUS LIDAR POINT CLOUD

Each point in a point cloud is defined with an x, y, and z coordinate. Additional information, such as intensity values, red-green-blue (RGB) color information, or classification, can also be stored within the data set. Point clouds can be created from images or LiDAR. Both collection methods have their advantages, yet also some disadvantages. Photogrammetry point clouds can be produced for less cost than a traditional LiDAR point cloud.

Advances in technology have created the ability to take overlapping images and develop them into a dense point cloud whether the source is from a cell phone or from a UAS. This allows for a lower-cost solution to create rich data that are also infused with RGB color, so that it looks similar to an image that has coordinate values attached to each pixel for x, y, and z.

Photogrammetric point clouds use many images with a large overlap between them to calculate points on the ground, as illustrated in Figure 9.





Jamal 2017 (top), Laribi et al. 2015 (bottom) copyright © 2015 Elsevier B.V., reprinted with permission

Figure 9. Use of digital photogrammetry requiring many images with a large overlap between them to calculate points on the ground

For a majority of situations, photogrammetry point clouds are less expensive and oftentimes produce a more dense point cloud. However, the weakness of photogrammetry lies in the penetrating properties of LiDAR, which can penetrate through vegetation, with multiple returns. LiDAR also achieves better accuracy on flat surfaces, such as pavement, where photogrammetry point clouds tend to have a lot of noise that is inherent for these surfaces.

Another item to consider is the quality of the LiDAR unit. Less-expensive units without calibrated lasers can be less accurate than photogrammetry point clouds with GCPs.

For softscape (vegetated) surfaces with low vegetation, UAS aerial photogrammetry can achieve 0.1 ft accuracy or better with confidence if using GCPs, RTK positioning satellite navigation, PPK global positioning, or a combination of the technologies. LiDAR creates a similar point cloud but is collected differently.

While photogrammetry requires the image to be clear and have the same points visible in multiple images, LiDAR can be used in environments that are shadowed, or even at night. LiDAR sends out light beams that can penetrate through vegetation by using multiple returns while photogrammetric point clouds cannot.

The biggest disparity between the two is the cost. LiDAR is much more expensive to procure and maintain and isn't always needed. LiDAR may be the best solution for 3D quantities on pavement sections, when areas have a lot of shadows, for fine edge detection, and for vegetated areas. LiDAR also requires less processing, which can increase productivity over processing large photogrammetric data sets. Using specialized software to process LiDAR images can also help utilize its strengths given the large data size. It is also beneficial to have a computer that is capable of loading and processing the point cloud data efficiently.

The benefit of using UAS for either sensor is the ability to capture the data from an aerial perspective, which creates highly detailed imagery and data that are able to give a new perspective that wasn't always readily available otherwise. The cost saved from one project may justify the cost of procuring a UAS.

Point clouds have a distinct technical advantage over traditional breakline surveying methods. Breakline surveys only capture the data where it's collected at each point and often fail to define the specific nuances of a surface. Point clouds are the most comprehensive method of modeling the terrain, and, as such, contours should have no place in today's digital mapping environment and are unnecessary and should not be used to define a topographic surface in digital form (Abdullah 2017).

Figure 10 illustrates the difference between a traditional breakline survey and a point cloud.

UDOT

Figure 10. Breakline survey (top) versus point cloud (bottom)

A breakline survey only captures the top and bottom of the slope as shown with the red lines. By only capturing these two areas, the middle section and all the deviations and fine details are not included in the data. A point cloud captures all this detail and more to create a more accurate representation of the surface.

Figures 11 and 12 illustrate the difference between point clouds generated using photogrammetry versus LiDAR.

UDOT/W. W. Clyde & Co.

Figure 11. Photogrammetric point cloud

UDOT

Figure 12. LiDAR point cloud

The photogrammetric point cloud gives the appearance that the pavement is rutted and wavy due to the noise inherent in the data. Using photogrammetry on asphalt, the software has difficulty deciphering the pavement nuances due to the similarity between the images. The LiDAR, on the other hand, shows the true nature of the surface and shows the vegetation that is growing out of the pavement.

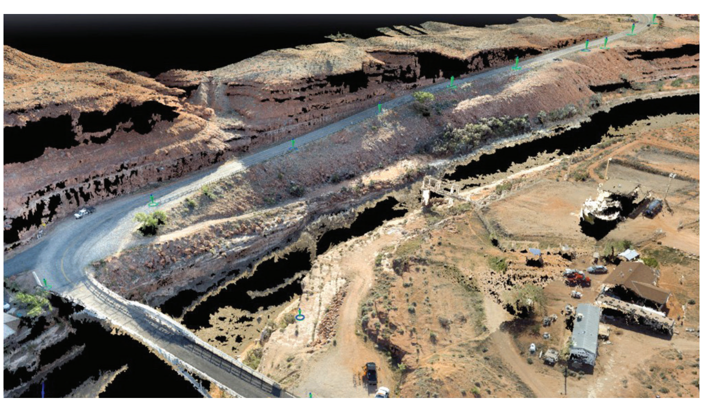
For pavement surfaces, LiDAR produces a technically superior result due to the differences in the way the point cloud is produced and processed. LiDAR reflects directly off the surface, giving a true representation of the surface.

This example clearly shows the benefits that LiDAR has over photogrammetric point clouds on surfaces that are similar in nature, such as asphalt or concrete.

Photogrammetric Camera Angle

The camera angle can have a significant impact on the quality of the data. If the terrain is flat, nadir (directly downward from the observer) works the best; but, if there are deviations, outcroppings, or cliffs, this camera angle can leave holes or shadows in the surface data. For most mapping, nadir works best; however, a different camera angle may be the optimal solution to sufficiently capture vertical faces when mapping steep terrain with cliffs or outcroppings.

Figure 13 illustrates data collected with a nadir camera angle in Mexican Hat, Utah, which has high cliffs and steep terrain.



UDOT

Figure 13. Nadir camera angle in Mexican Hat, Utah

UDOT

Figure 14. 70-degree camera angle in Mexican Hat, Utah

The black areas show gaps or holes in the data on the cliff faces where the camera wasn't able to capture data on the cliffs. Contrast that with Figure 14, which was collected using a camera angle of 70 degrees.

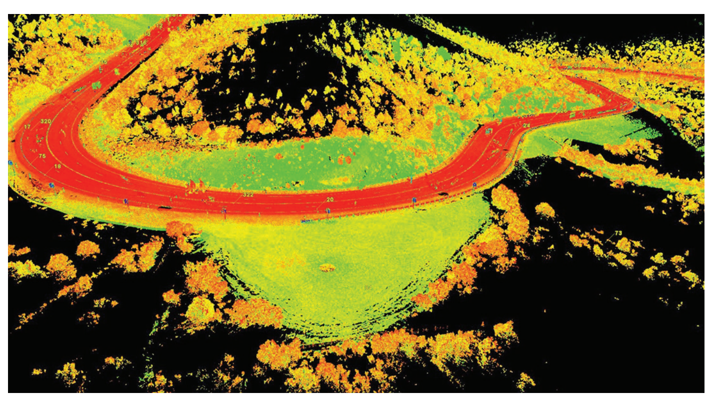
By using a 70-degree angle, the data on the majority of the terrain was able to be sufficiently collected using UAS.

Proper planning and using the proper camera angle and sensor for the terrain can prevent return trips to capture missed areas in the data. The key is to properly plan for the terrain being flown and use the proper camera angle for each situation.

HYBRID METHODS

Different tools and sensors have inherent strengths and weaknesses. By using the strengths of each tool and combining the data to create a hybrid model, surveyors can assimilate the best possible data set. Where photogrammetry is weak on pavement, for example, LiDAR is well suited to collecting data on pavement.

As an example, the Utah Department of Transportation (UDOT) utilized this hybrid method on the State Road 20 (SR-20) project. The roadway data and images were collected using terrestrial LiDAR, while the softscapes were collected using photogrammetric point clouds. The two were combined into a hybrid model. By combining the use of these technologies, it allows for a dense, highly accurate, 3D model that has all the strengths with minimal weaknesses (see Figure 15).



UDOT/ W. W. Clyde & Co.

Figure 15. Hybrid model SR-20 project

The aerial imagery from the UAS was also used to colorize the LiDAR to save time and eliminated the need for the terrestrial scanner to take images, which can be time consuming. The data were used to verify construction progress and quantities with the 3D model from design. By utilizing this and other technologies, a significant savings of $82,672 (2.58%) was realized on this project.

QUALITY CONTROL/QUALITY ASSURANCE

To verify the accuracy and precision of the data, it is worthwhile to check the data on the ground and not always depend on the verification reports provided by the software. By taking random survey points throughout the area and using it to compare with the point cloud, it allows for quality control and quality assurance to determine the actual accuracy of the data.

Some software packages allow for using checkpoints, but not all. The verification reports are required on all hardscape and softscape surfaces for UDOT projects. This helps to provide confidence and knowledge of the accuracy and precision of the data collected.

FAA REQUIREMENTS

UAS operators in both the public and private sectors must adhere to statutory and regulatory requirements. Public aircraft operations (including UAS operations) are governed under the statutory requirements for public aircraft established in 49 USC § 40102 and § 40125. Additionally, both public and civil UAS operators may operate under the regulations promulgated by the Federal Aviation Administration (FAA).

The provisions of 14 CFR Part 107 apply to most operations of UAS weighing less than 55 lbs. Operators of UAS weighing greater than 55 lbs may request exemptions to the airworthiness requirements of 14 CFR Part 91 pursuant to 49 USC § 44807.

UAS operators should also be aware of the requirements of the airspace in which they wish to fly. The FAA provides extensive resources and information to help guide UAS operators in determining which laws, rules, and regulations apply to a particular UAS operation. For more information, please see https://www.faa.gov/uas/.

CONCLUSIONS

UDOT has found UAS to be a great asset. What started as a test in 2011 has grown to a fleet of more than 40 UAS in 2019. UDOT's uses for UAS grows each day due to the ease in which they allow for safe and accurate collection of data. UDOT has found the key to quality survey data using UAS is to use the proper tools for the job.

UAS provide advantages but don't necessarily fully replace the other survey tools being used. The hybrid model or method achieves the greatest results by using all tools that are available and combining them together. Determinations on the proper aircraft, sensor, and pre-flight planning are vital to achieving satisfactory results.

UAS have increased in popularity among the land surveying community due to the repeatable accuracy that can be attained from using these new tools. The sole use of UAS may not always give the desired results, so it is important to understand the weaknesses and supplement the data with use of other technologies when needed. This is why UDOT has adopted the hybrid method to ensure the accuracy and precision needed.

By sharing lessons learned through utilization of these tools, it can increase agency productivity, help agencies collect more accurate data, and foster the next generation of land surveyors into the field.

REFERENCES

Abdullah, Q. A. 2017. Mapping Matters: Breaklines for Lidar Data, Do We Really Need Them? *Photogrammetric Engineering and Remote Sensing*, Vol. 83, No. 9, pp. 599–602. https://www.asprs.org/wp-content/uploads/2018/03/09-17-MM.pdf.

Campbell, L. and D. Katz. 2018. How to Use Ground Control in Drone Surveying. *Point of Beginning (POB) Magazine*. https://www.pobonline.com/articles/101529-how-to-use-ground-control-in-drone-surveying.

Jamal, H. 2017. Surveying and Leveling: Principal Method of Terrestrial Photogrammetry. About Civil Engineering. https://www.aboutcivil.org/Principal-method-of-Terrestrial-Photogrammetry.html.

Laribi, A., J. Walstra, Jan, M. Ougrine, A. Seridi, and N. Dechemi. 2015. Use of Digital Photogrammetry for the Study of Unstable Slopes in Urban Areas: Case Study of the El Biar Landslide, Algiers. *Engineering Geology*. Vol. 187, No. 17, pp. 73–83. https://www.sciencedirect.com/science/article/abs/pii/S0013795214003524?via%3Dihub.

Reed, J. 2015. Land Surveying Transforms Along with Technology. *The Gazette*. https://www.thegazette.com/subject/news/business/land-surveying-transforms-along-with-technology-20150307.

Willis, F. 2013. How Can Drones Transform Surveying? *Point of Beginning (POB) Magazine*. https://www.pobonline.com/articles/96996-how-can-drones-transform-surveying.

This Tech Brief was developed under Federal Highway Administration (FHWA) contract DTFH61-13-D-00009/10. For more information contact:

Task Manager
James Gray
UAS and Construction Technology Engineer
Federal Highway Administration
1200 New Jersey Avenue, SE
Washington, DC 20590
703-509-3464 / James.Gray@dot.gov

Author
Paul Wheeler, UAS Program Manager
Utah Department of Transportation Division of Aeronautics
135 North 2400 West
Salt Lake City, UT 84116
801-965-4700 / pwheeler@utah.gov

Distribution and Availability
This Tech Brief can be found at http://www.fhwa.dot.gov/uas.

Key Words
drones, land surveys, unmanned aerial systems