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Tech Brief

USE OF SMALL UNMANNED AIRCRAFT SYSTEMS FOR CONSTRUCTION QUANTITY ESTIMATION

INTRODUCTION

Multiple Departments of Transportation (DOTs) have reported using unmanned aircraft system (UAS) as a tool for multiple tasks over different construction phases such as pre-construction mapping and surveying, construction progress tracking, quality control, quantity estimation, traffic control inspection/monitoring, and safety inspection. Nearly all State DOTs are using small unmanned aircraft systems (small UAS) to improve safety and collect data faster and better (AASHTO 2019). The fast-growing market of UAS has stimulated the expansion of its application in various sectors of the economy (Zhou 2018). Small UAS are being used for various quantity estimation/verification tasks, including earthwork, stockpiles, and paving estimates. Construction quantity estimation is a significant cost item on infrastructure construction projects. Because earthwork and stockpiling are largely influenced by unstable construction conditions, they may have an effect on cost control during construction. Precise estimates of actual earthwork, stockpiles, and paving volumes are important to both owners and contractors.

In infrastructure construction projects, surveying as-built conditions traditionally has relied on robotic total stations and tachymetry. These technologies can be labor-intensive, expensive, and prone to human error. Technologies such as global positioning systems (GPS), terrestrial laser scanning, and air or space-borne sensors have been used as alternatives, but they have limitations regarding cost, measurement range, and accuracy. Using small UAS as a data acquisition platform and a measurement instrument is attractive for many users surveying applications in civil engineering because small UAS can offer a cost-effective and rapid three-dimensional (3D) mapping approach.

This document provides information about successful UAS integration–specifically into construction quantity estimation practices. Surveying tools are evolving and can produce 3D accuracy that is equal to or better than conventional aerial photography (Willis 2013). Changes in land surveying within the last 20 years have been significant (Reed 2015). Enhancements to the state of the art, such as GPS, Light Detection and Ranging (LiDAR), robotic total stations, and now small UAS, allow for surveying at scales that were not possible with the traditional technologies.

U.S. Department
of Transportation
Federal Highway
Administration

FAA REGULATIONS

UAS operators in both the public and private sectors must also 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. 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 as well as the requirements for the remote identification of unmanned aircraft. 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/

Public aircraft operation is significantly limited in purpose under the statute and activities such as mapping, surveying, planning or monitoring infrastructure construction and other generalized public works activities do not qualify for public aircraft authority. These UAS activities must be carried out under the authority of part 107. All government entities qualify for operation as a civil entity and may operate under the rules of part 107. Unlike public aircraft operation, part 107 has few restrictions on operational purpose. Public aircraft operations face additional requirements. Operating in accordance with part 107 requires the remote pilots in command to have a remote pilot certificate which is done on an individual pilot basis, while public aircraft operations require additional coordination with the FAA for approval for the organization as a whole, as well as determination that the function for which the operation would occur falls within the parameters of § 40125(a)(2). Public aircraft operations also require the organization to take on additional risk and liability. Table 1 provides a comparison of the requirements for part 107 and public aircraft operations. As part 107 has evolved, there are many advantages to flying under part 107. It provides few restrictions on operational purpose, use of the Low Altitude Authorization and Notification Capability system (LAANC), less reporting requirements, and ongoing beneficial updates, which has made part 107 a choice for many State DOTs.

Safety is a crucial element of each flight and is the responsibility of the Remote Pilot in Command (RPIC). The FAA regulations for the commercial use of small UAS help mitigate risk for operations. It is the duty of the RPIC to ensure that the small UAS is in a condition for safe operation. (14 CFR § 107.15) Positive relationships with other agencies and the public to coordinate and notify those whom the operations may affect (e.g., medical helicopter flights, nearby airports, property owners) can help facilitate local awareness of recurring operations.

Table 1. Comparison of FAA Part 107 and Public Aircraft Operator

	Commercial Operations 14 CFR § 107	Public Aircraft Operator 49 U.S.C. § 40102 and § 40125
Aircraft Requirements	UAS <55 pounds	Self-certification by the public agency
Pilot Requirements	Part 107 remote pilot certificate with small UAS rating	Self-certification by the public agency
Airspace Requirements	Airspace waiver or authorization for Class B, C, D, E airspace.	Blanket Certificate of Authorization (COA) or Standard COA for Specific Airspace
Types of Operations	Visual Line of Sight, Class G Airspace, Below 400 ft above ground level (AGL)	Public Aircraft Operations (AC 00-1.1A)

Safety programs vary between agencies and involve an understanding of the nature of the work and the obstacles that are on-site. It can be beneficial to develop risk management procedures that include the following topics:

- Part 107 rules
- Airspace
- Weather
- Proximity to traffic and people
- Radio interference
- Emergency procedures
- Identification and understanding of potential site hazards before flying
- Pilot experience and proficiency

Furthermore, detailed logs, including the time of the day, weather, aircraft/sensor, and the number of construction personnel on-site, are other considerations when planning and documenting a flight.

RPIC of small UAS must be cognizant of the requirements of the airspace in which they wish to fly. When flying in controlled airspace, FAA uses the LAANC system to provide near-real time approval from Air Traffic Control (ATC) at many airports where appropriate. The FAA offers extensive resources and information to help RPICs determine which laws, rules, and regulations apply to a particular small UAS operation. For more information, see https://www.faa.gov/uas/.

UAS AIRCRAFT PLATFORMS

A variety of factors should be considered when investing in small UAS for construction quantity estimation. Three major types of small UAS are available based on the type of aircraft: namely multi-rotor, fixed-wing, and helicopters (see Table 2). Each type of aircraft has its strengths and weaknesses depending on the applications. Fixed-wing can be the most advantageous to cover large areas efficiently, provided the operator obtains a waiver from the FAA for beyond visual line of sight operations.

Helicopters tend to be larger aircraft (some even outside the small UAS definition in 14 CFR § 107.3), often gas-powered with heavier lift. For construction quantity estimation applications, multi-rotor aircraft are typically preferred because they can take off and land vertically, easily maneuver under challenging environments, and hover in place. Multi-rotor aircraft are generally limited to 25-30 minutes of flight time. Depending on the size of the area that is being measured, multiple batteries may be involved.

Table 2. Aircraft Platforms Strengths and Weaknesses

Multi-Rotor UAS	
Strengths	**Weaknesses**
Vertical take-off and landing and flexibility on take-off and landing sites	Battery life
Hover in place	Generally lower payload capacity
Easy to fly	Lower endurance than fixed-wing
Maneuverable	Expensive repairs
Lower cost	Smaller payload capacity
Ability to change camera angles	
Precision maneuvering	
Fixed-Wing	
Long endurance	Cannot hover unless VTOL
Aerodynamically efficient	Can be target for birds-of-prey
Cover large areas more efficiently	Need large take-off and landing zones
Helicopters	
Carry larger payloads (gas-powered aircraft)	Difficult to fly manually
	Higher cost

REMOTE SENSING TECHNOLOGIES

Remote sensing technologies for small UAS include high-resolution red, green, blue (RGB) cameras, thermal cameras, ultrasonic sensors, and LiDAR. The decision to use images or LiDAR data to calculate construction quantities depends on the type of construction work being measured, project sites, the ability to set up control points, and the project budget.

RGB cameras are equipped with charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS) sensors, typically with a Bayer array to produce red, green, blue (natural color), and these are generally higher-end cameras (DSLR or mirrorless). High-resolution RGB visual camera sensors come in various configurations and specifications, which should be evaluated when choosing a small UAS for construction quantity estimation. Data collection using RGB cameras can be enhanced by having a fundamental knowledge of:

- ISO (standard industry scale for measuring the sensitivity of image sensor to light)
- Aperture (size of the opening; given by f-stop, as aperture increases, f-numbers decrease)
- Shutter speed (controls how long image sensor is exposed to light)

While automated settings can be helpful, they can also be detrimental in areas with complex or changing lighting conditions. Proper exposure affects image quality, amount of noise, and motion blur. The quality of these images affects the accuracy of construction quantity estimates because they are processed using structure from motion (SfM) photogrammetry software to extract 3D geometric information from two-dimensional (2D) images.

SfM is a photogrammetric range imaging technique for estimating 3D structures from 2D image sequences to create multiple data outputs such as ortho-imagery, 3D mesh, Digital Elevation Models (DEM), or point clouds. SfM is an increasingly popular approach due to its advantages in cost, computation, and ease of use. (Carrivick et al. 2016) It has been used in several engineering and construction applications, including earthwork volume calculations and progress monitoring. Several SfM software packages are available in the market.

The main SfM steps include:

- Automated identification of matching features (key points) in multiple images

- Feature tracking from image to image allowing to estimate initial camera positions and object coordinates
- Iterative least-squares fit process to minimize errors
- Development of dense point clouds using multi-view stereo algorithm (see Figure 1)
- Identification of ground control points (GCPs)

SfM is gaining momentum and acceptance as a tool for the volumetric calculations that are necessary for construction quantity estimation (Mora et al., 2019). The number and location of GCPs used for SfM can affect the accuracy of the quantity estimates. As a result, it can be beneficial to establish five or more GCPs strategically across the site to avoid undesirable results. In addition to GCPs, random checkpoints are suggested to establish the accuracy of the project.

Figure 1. Dense point cloud developed using SfM (Image courtesy of Xi Wang, UKY)

LiDAR is an active remote sensing technique that uses electromagnetic energy (laser). Laser pulses transmitted by the LiDAR system travel down toward the Earth's surface, reflect off a surface patch, and return to the airborne sensor where the roundtrip travel time is measured. LiDAR scanners emit pulses of light (at speeds ranging from thousands to millions of points per second) to acquire X, Y, Z (3D) positions of points within an area of interest, producing a point cloud. Because LiDAR is an active sensor, solar illumination (e.g., clouds, low sun angle) does not affect the measurements/data collection. LiDAR sensors can be classified as survey (5 to 10-millimeter accuracy) or mapping grade (1 to 3-centimeter accuracy). For quantity calculation, a survey-grade LiDAR is necessary to obtain accurate results.

When metric information is needed (i.e., measuring in the photograph), GCPs are helpful to provide accurate, repeatable results. GCPs are image-identifiable points whose coordinates have been obtained by a field survey—typically using real-time kinematic (RTK) global navigation satellite systems (GNSS). GCP acquisition can be a big part of the time and cost of the project when required (10 to 50 percent of total project costs). Survey-grade (i.e., carrier-phase, multi-frequency, multi-constellation) GNSS on the small UAS that can support RTK or post-processing kinematics (PPK) can reduce some of the GCP demands.

Although UAS-SfM and UAS-LiDAR techniques typically provide comparable data accuracies (with some differences, as a function of terrain and ground cover type), the application of UAS-SfM is generally less expensive, imposes less stringent standards for the remote aircraft, needs less expert knowledge and training to operate, and yields higher data densities. Therefore, a general recommendation in the industry is that SfM processing should be the default platform used for typical small scale, less than 2 square kilometers, high-density topographic mapping applications based on its low cost, attainable accuracy, and usability (Simpson 2018). Simpson found that disadvantages associated with SfM include moving objects, dense foliage, and blurry imagery. However, UAS-LiDAR are suggested when any of the following conditions apply:

- The Area of Interest (AOI) has homogenous surface texture over a large area
- Data acquisition through a thick canopy is involved
- Poor light conditions (e.g., extreme amounts of shadowing throughout the AOI, data collection at night) are anticipated
- Surface characteristics derived from intensity returns are needed
- The AOI contains substantial vertical gradients
- A large amount of tall (relative to flying height) vertical obstructions are located throughout the AOI

Regardless of the mapping system being used, a thorough understanding of the acquisition platform and processing procedures may contribute to accurate final products for quantity estimation.

FLIGHT OPERATIONS

Pre-Flight Planning

Flight planning should include a thorough assessment of the site of interest to:

1) Identify any obstacles (e.g., powerlines, tall buildings, cell towers)
2) Choose take-off and landing zones
3) Determine if there is radio interference

4) Address privacy issues and coordinate with affected parties (e.g., airports, site personnel, medical/military helicopters in the vicinity, property owners, permits)

5) Obtain a COA/waiver if needed for operation

Additionally, the RPIC must complete a preflight familiarization, inspection, and other actions prior to beginning flight operations (14 CFR § 107.49) for part 107 small UAS operations.

Next, data collection goals should be established, which involves selecting the appropriate airframe and sensor combination and determining the number and distribution of GCPs based on the project specifications. SfM software enables processing of the data with or without geo-locations; however, accurate and well-distributed GCPs can improve the global accuracy of the project.

Once project specifications are established, the flight plan to meet these specifications can be designed. For example, increasing the flying height will commonly decrease the resolution of the imagery. Flight parameters, such as image overlay settings, camera angle for data collection, and flight line patterns, can be determined using the flight software. Commercial small UAS typically come with their own flight planning software packages that can be operated either using a remote controller or with brand-specific applications available for smartphones. Third-party applications are also available that may provide additional functionality, including terrain-following or the ability for modular flights or advanced operations.

After the flight is planned or concurrently with flight planning, if needed, GCPs should be established with an RTK GNSS unit or total station. GCP targets should be the right size and shape and made of materials (not too shiny) so that they are visible and easily identifiable in the collected images. Additionally, they should be evenly distributed over the AOI, as illustrated in Figure 2. If GCPs are not evenly distributed (i.e., if GCPs are all at the same location, all on one side, or the very edge of the area), georeferencing could be unbalanced, making GCPs unreliable. (Wang 2018) This may also lead to a warped 3D surface, as illustrated in Figure 3.

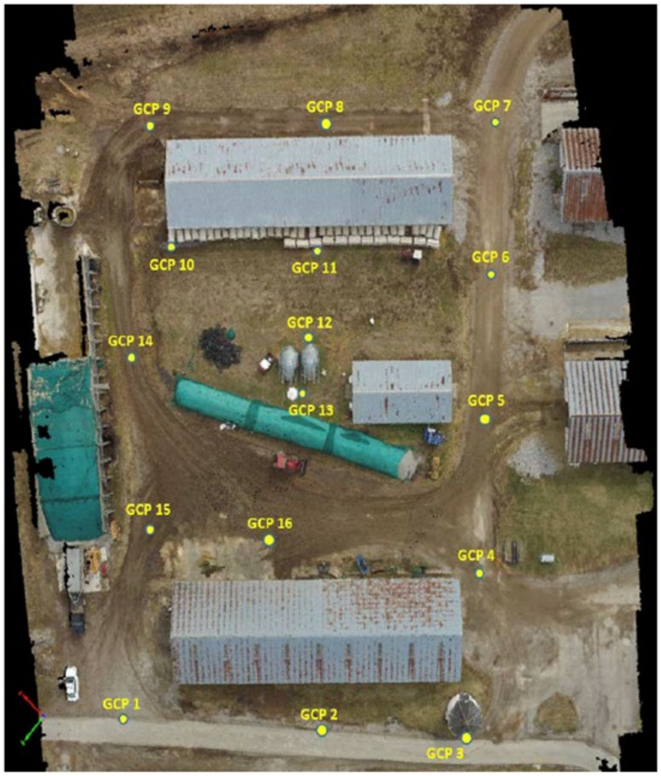

Figure 2. Distribution of GCPs (Image courtesy of Xi Wang, UKY)

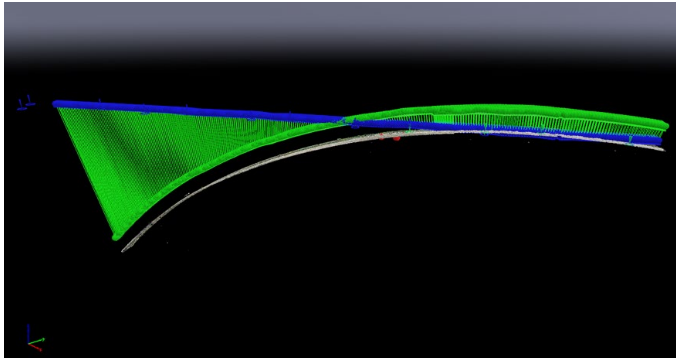

Figure 3. Warping of model from improper layout of GCPs (Image courtesy of Utah DOT)

Mission Operation

Final coordination prior to the flight includes a final site review, examination of primary/alternate take-off and landing locations, and coordination with pertinent parties (e.g., medical/military helicopters, ATC, and property owners). In addition, the airframe should be inspected thoroughly, and the flight software should be set up before the flight.

Flight software setup involves determining flight lines and sensor (RGB camera or LiDAR) settings. GCPs should not be established on the edges of the flight area, and overlap settings (front and side overlap), and the orientation for best data capture should be determined. The flight altitude for best Ground Sample Distance (GSD) should also be determined because this affects the resolution of the images captured, ultimately affecting the accuracy of quantity estimates. GSD is the distance between two consecutive pixel centers measured on the ground. The larger the value of GSD, the lower the image's spatial resolution and the less visible details. It is helpful to consider the balance between spatial resolution and area covered in selecting flight altitude. Higher spatial resolution may result in higher image quality, but the flight duration can be longer. Because of the battery life limitations of the small UAS, the flight may need to be fragmented into multiple flights. Under different flight conditions, the image quality cannot be guaranteed because of variations in illumination, saturated images, or the appearance of shadows. Therefore, flight altitude is one of the most influential factors affecting the quality of the end product. Planning flight lines for the object is important to achieve accurate results. For complex objects, a crosshatch flight line (Figure 4) may be needed to adequately capture all angles of the site; a simple linear style pattern (Figure 5) may be sufficient for simple geometry.

Figure 4. Crosshatch flight line pattern (Image courtesy of WSP USA)

Figure 5. Linear flight line pattern (Image courtesy of WSP USA)

For RGB cameras, as described under Remote Sensing Technologies (above), the way ISO, aperture, and shutter speed work together affect image quality; thus, these variables should be set up carefully. For example, motion blur may occur if the small UAS are flying too fast with respect to the shutter speed. Motion blur is the distance traveled by the small UAS camera over a single exposure. Typically, motion blur should not be greater than 1 x GSD, where GSD is the distance on the ground for every two adjacent pixels in the image. It is difficult to completely eliminate motion blur; however, it is possible to reduce it considerably by:

- Reducing flight speed
- Increasing shutter speed
- Increasing GSD by increasing the mission altitude

Poor lighting conditions also may be experienced during the flight, which can be overcome with:

- Proper exposure
- Illuminance (brightness)
- Exposure time

To maintain proper exposure, shutter speed (exposure time) can be changed by adjusting the f-stop setting (aperture area). Aperture refers to the opening of a lens diaphragm through which light passes; a higher aperture (e.g., f/16) means less light enters the camera. Similarly, a lower aperture (e.g., 1.8) means more light enters the camera, which is better for low-light scenarios. Flight crews should have a basic knowledge of photography to be prepared for multiple lighting conditions. If the small UAS are equipped with a LiDAR sensor, the density and the optimal overlap between flight lines should be set up to ensure that the project goals are met.

Post-Flight Inspection

At the end of data collection, before leaving the site, the airframe should be inspected to ensure there is no damage and that all the sensors are working. If sensors are not working, they should be repaired or replaced.

The collected data should be reviewed to make sure that it meets the project requirements and is of sufficient quality for the data goals. If the images are blurry or have abnormalities, the flight may need to be repeated. Problems are easier to remediate while still on-site. It is also important to back up the data, either to a computer or a cloud-based platform.

Before leaving the site, the flight crew should perform coordination calls with the pertinent parties (e.g., medical/military helicopters, ATC, property owners). These coordination calls should also occur prior to commencing flight operations and after the flight operations have commenced.

Data Post-Processing

The first step in data post-processing involves cleaning the data of blurry images and removing noise if LiDAR was used as the sensor of choice. Depending on the sensor (RGB camera or LiDAR) used, an appropriate software package should be selected and used for data processing.

If RGB cameras are used, the SfM procedure described under Remote Sensing Technologies (above) should be applied to obtain the 3D information used to estimate construction quantities. The final deliverables can be digital terrain models (DTMs), ortho-images, 3D mesh, or point clouds. If LiDAR is used, the data processing workflow involves processing the flight trajectory to determine the geo-location of LiDAR data, followed by flight line alignment to increase relative accuracy. Next, the point cloud can be colorized if using co-acquired imagery (this is an optional step). The final product is generated in the form of DEM, DSM, or classified point cloud, which can directly be used for quantity estimation.

Finally, a comprehensive data management plan, including data backup, retention, quality control, and delivery can help ensure that the collected data and post-processing products such as point clouds and ortho-imagery are checked for accuracy, backed up, and retained for the agency's records.

Data Management

UAS data collection produces a considerable amount of information that needs an efficient management plan to allow for the dissemination between organizations. A data management plan should be developed and followed early in the process to achieve the best results and include all phases of construction. Having a process and framework for data management can create a repeatable and reliable system that are key elements for success, as illustrated in Figure 6.

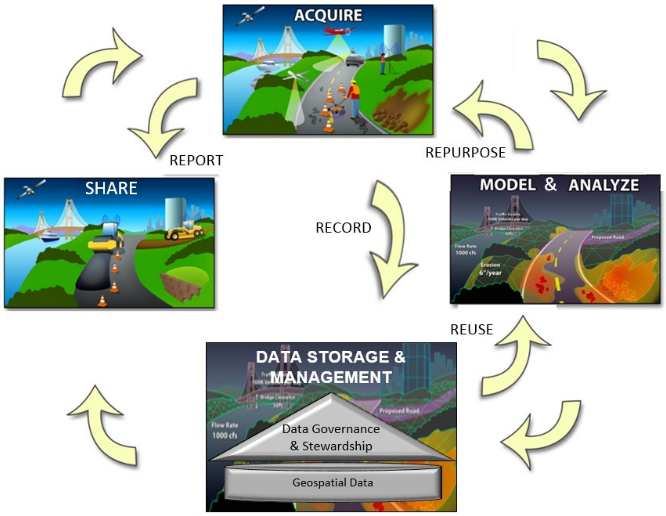

Figure 6. Data Management Life Cycle (Mallela, et al. 2018)

The data management plan should include:

- Goals and purpose for the data
- Considerations on the proper tool to acquire the data and achieve the required goals
- Hardware and plans for processing the data
- Means for quality control and assurance
- Plan for dissemination, storage, and management
- Data sharing

As digital delivery becomes more prevalent, small UAS can help play a key role in data collection. Dynamically incorporating data into a management plan can assist with:

- Partnering and collaboration between parties on construction projects.
- Helping to reduce the likelihood of errors through higher density data collection.
- Increasing return on investment from faster collection times.
- Helping to facilitate progress reporting through 3D models throughout the life of the project.
- Enabling additional tools to supplement conventional technologies.

CONSTRUCTION USE CASES

Pre-Construction

Pre-construction practice sets the foundation for any successful construction project. Early in the pre-construction phase, it can be time-consuming to gather critical details about topography. Traditional ground surveying can take days to collect data about a new site. The data processing and delivery of a report can take weeks, depending on the size of the project site. Small UAS can capture existing conditions or verify survey measurements or both prior to initiating a construction project. Existing conditions can be evaluated directly from images, and for survey verification, images can be processed into a 3D point cloud using SfM technique. Multiple DEMs or point clouds can be compared to determine the accuracy of the existing topography prior to construction as illustrated in Figure 7. Verifying the surfaces before construction is an added benefit that can improve design quality and prevent change orders because the design is based on accurate 3D measurements. As the industry moves more toward digital delivery over traditional plan sets, higher quality data are important. Information collected via small UAS can allow for more precise bidding and feasible and realistic expectations for design elements and timelines. A bid that overestimates the amount of earth to be moved would inflate the bid cost, and the contractor would likely lose the project. Alternatively, a bid that underestimates the amount of earth to be moved could be attractive but would cause the contractor to lose money later. Having access to dense, accurate information about existing conditions can facilitate transparency and build better relationships.

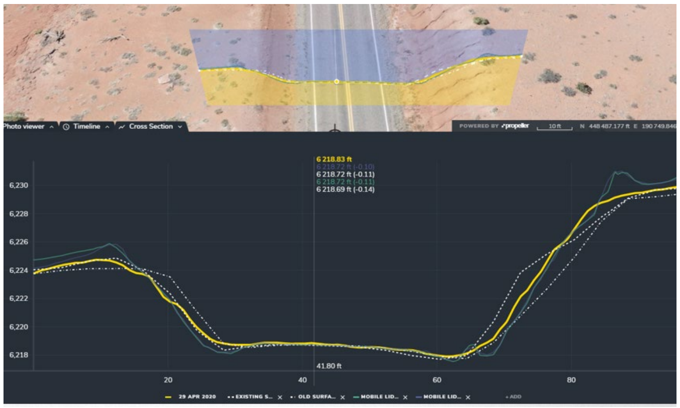

Figure 7. Existing topography comparison of multiple surfaces for verification (Image courtesy of Utah DOT)

Construction

Small UAS can be suitable for documenting different phases of a construction project, as illustrated in Figure 7. As noted above, accurate and reliable estimates of earthwork quantities is important to both State agencies and contractors because they are used for project payments and digital inspection methods. Developing an accurate bid or project schedule also depends on accurate estimates.

Earthwork involves moving massive quantities of soil or rock. The goal is to reconfigure the topography of a construction site to meet the project owner's design requirements. Most earthwork operations are executed in the early stage of the construction process, meaning that the earthwork progress controls the overall project schedule.

During construction, small UAS can be used to monitor earthwork quantities, including subgrade and final surface quantities (Figure 8), linear elements such as fence, curb and gutter, drainage elements, and structures. At the end of the construction phase, small UAS can be used to document as-built conditions.

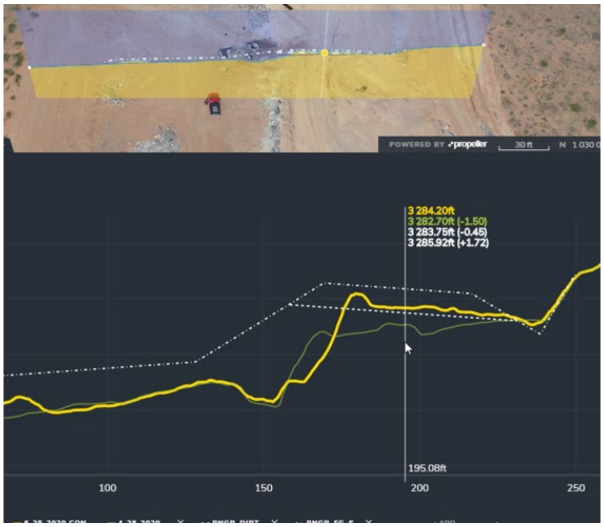

Figure 8. Construction phase cross-section views (Image courtesy of Utah DOT)

SfM is one processing tool that can be a beneficial for 3D quantity measurements. (Simpson 2018) When using SfM, the quality of the 3D models depends on the number of images, the percentage of overlap between images, and tie points. The use of GCPs is an effective method to further improve the accuracy of 3D models when using SfM. (Wang 2018) GCPs are typically measured using highly accurate GNSS units in the AOI. Furthermore, because these points are measured using GNSS units, they can be used to determine the scale, orientation, and positions of the results.

Several studies evaluated the impact of DEM resolution on earthwork calculations (Siebert and Teizer 2014, Tobias 2020). DEMs are commonly used during the project planning phase and directly affect earthwork estimation and construction costs. DEMs generated using small UAS and GNSS were compared to determine the impact of the resolution on earthwork calculations using the data obtained from different road construction projects. The variance was found to be 1-2 percent in volume, which is within acceptable tolerances. Wang (2018) assessed the application of small UAS in measuring earthwork quantities, including stockpiles (Figure 9) and trench volumes (Figure 10), and the accuracy of the results they obtained was comparable to those obtained using traditional surveying methods. Utah DOT reports that small UAS and SfM photogrammetry technologies have been suitable and helpful in some construction quantity estimations.

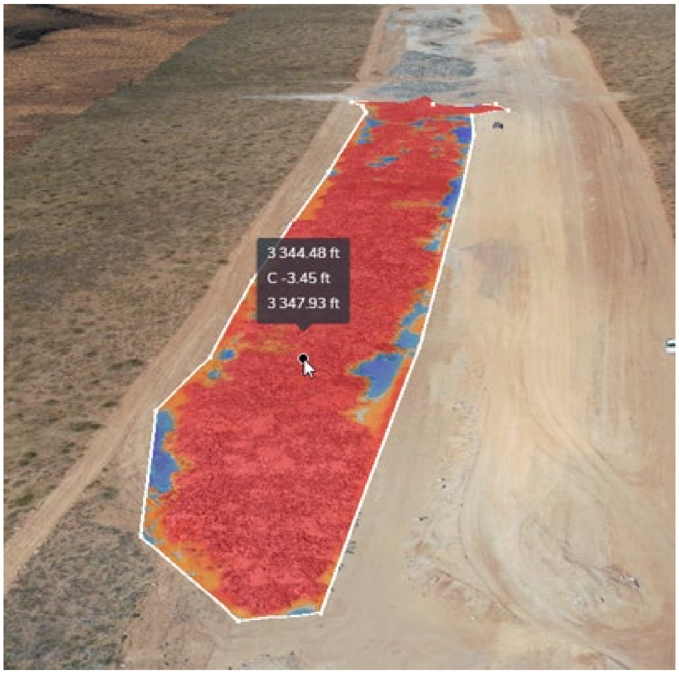

Figure 9. Construction quantity calculation (Image courtesy of Utah DOT)

UAS may offer a quicker and more cost-efficient way of measuring stockpile volumes. A study by Mora et al. found that compared to terrestrial LiDAR, the average difference observed in the vertical component was 2 millimeters with a standard deviation of 31 millimeters (Mora et al., 2019).

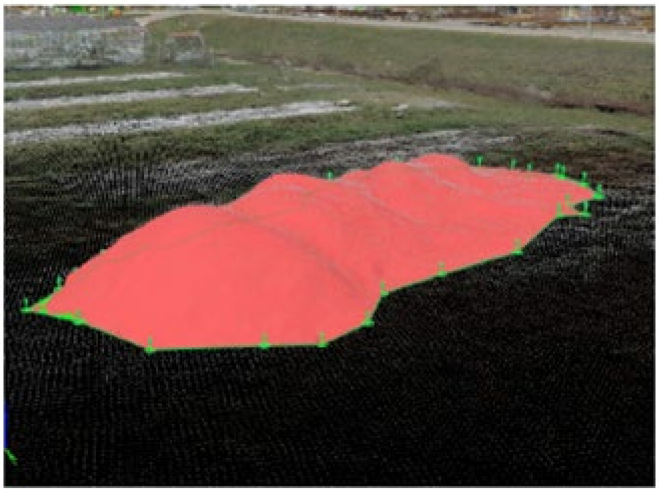

Figure 10a. Stockpile volume drawn in point cloud (Image courtesy of Xi Wang, UKY)

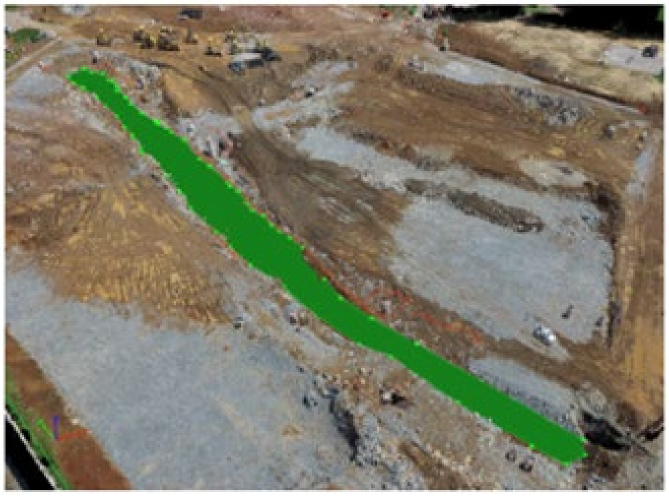

Figure 10b. Trench volume drawn in point cloud (Image courtesy of Xi Wang, UKY)

Post-Construction

At the end of the construction phase, the responsibility of the property often passes from the contractor to the owner or manager through contract documents. This process involves preparing handover documents, taking measurements to prepare as-built plans, and verifying quantities for final payment. Compared to traditional survey measurements, small UAS can help rapidly measure and verify quantities and develop final as-built documents. Traditional survey methods involve manual measurements of ground data points, which increases the amount of time needed for data collection while also increasing the project costs. Furthermore, using small UAS for data collection from larger, more complex sites does not necessarily require additional time.

CONCLUSION

The affordability and capabilities of small UAS and SfM software have improved over the last few years. Small

UAS technology can be an effective way to provide accurate and usable data (Zhou 2018). Mapping with small UAS can provide vital information regarding the quantity of soil removed from borrow pits by measuring clay and topsoil volumes separately, determining the distance soil is hauled, and verifying the compaction rate on the finished project. Small UAS and SfM software for construction quantity estimation can be purchased from multiple suppliers for between $2,000 and $35,000, depending on the sensors and technology. Small UAS can be an effective tool for estimating quantities for transportation construction. They can reduce the time needed for such calculations, improve efficiency, decrease costs, and improve overall project safety (Li & Liu, 2019). According to American Society for Photogrammetry and Remote Sensing (ASPRS) published standards[1], accepted practice, and literature, the measurement errors are in an acceptable range when parameters are under control. In addition, the UAS technique demonstrates its advantages in balancing between accuracy and efficiency compared with conventional earthwork volume measurement methods (Mora et al., 2019).

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[1] The use of ASPRS standards is not a Federal requirement.

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