OCTOBER 2019 | FHWA-HIF-19-096

Tech Brief

USE OF SMALL UNMANNED AERIAL SYSTEMS FOR CONSTRUCTION INSPECTION

INTRODUCTION

Unmanned aerial systems (UAS) have become increasingly popular on construction sites. In fact, UAS utilization has flourished in nearly all areas of engineering and construction. At the same time, both the affordability and capabilities of small UAS have dramatically increased.

Many transportation agencies and contractors have begun to implement UAS efforts into their daily work flow. This has been especially effective in transportation infrastructure construction inspection. These users have been able to reduce inspection times, improve inspection effectiveness, increase safety, and lower the cost of inspection with a modest investment in training and equipment.

Currently, UAS are being used by agencies for a variety of inspection tasks including erosion control, quality assurance and quality control (QA/QC), structure inspection, and construction progress monitoring. In these cases, the UAS has become an integrated part of the inspectors' tool kit.

The purpose of this document is to provide information about successful UAS integration into infrastructure construction inspection practices.

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/.

INSPECTOR PILOTS VERSUS PILOT INSPECTORS

As with many new and emerging technologies, our workforce needs to be brought up to speed with training and hands-on demonstration. The implementation of a UAS, wrapped in a whirlwind of tech and aviation acronyms, can seem like a daunting task. Often the temptation arises to out-source UAS inspections to UAS or drone companies that offer turnkey services. However, it is important to understand that being licensed to operate a UAS does not qualify the operator as an inspector.

If the decision is made to outsource work to UAS or drone companies, agency staff should consider insurance requirements. The owner's insurance requirements will require the UAS operator to provide insurance, as well as name all parties as insured.

U.S. Department of Transportation
Federal Highway Administration

Experienced inspectors are essential in the decision-making process of selecting areas of interest for inspection and understanding the level of detail required at each location. The visual feedback of the UAS allows each inspector to decide and act accordingly, adjusting the inspection in real time (Zainudin 2015). Accordingly, the presence of a knowledgeable inspector during flights is critical for optimum efficiency and quality.

UAS FOR CONSTRUCTION INSPECTION

When considering the acquisition of a UAS for construction inspection, a variety of factors should be weighed.

In UAS construction inspection, rotary wing aircraft generally play the primary role. These aircraft typically consist of quad- and hex-copter configurations.

At this time, there are more than 100 available UAS sensors on the market. However, many of these sensors are emerging technologies and have not found their way into everyday use. This document focuses primarily on sensors in the visual and infrared spectrums.

Visual camera sensors are available in a wide variety of configurations and specifications. Primary cameras are generally mounted on the front of the aircraft often on a two- or three-axis stabilized gimbal.

When considering UAS for inspection use, there are a number of platform features to consider:

- Sensor size
- Focal length
- Camera combinations
- Obstacle avoidance sensors
- Battery life
- Payload

Given that each inspection is different, no exact configuration is recommended for each payload type. However, some trends are noted across inspection UAS users. Table 1 shows the primary factors for each inspection type.

Table 1. UAS key considerations

Factor	Sensor Size	Obstacle Avoidance	Wide Angle Lens	Adjustable Focal Length	Battery Life	Top Mounted Camera	Thermal Camera
Erosion Control		●	●		●		
Construction Progress	●		●	●			
Construction QA/QC			●	●			●
Structures	●	●	●	●	●	●	

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While each agency's needs will vary, there are some general guidelines for each factor. When considering sensor size, most entry level UAS pilots will gravitate toward comparing sensor resolution by pixel count, even though the size and inherent complexity of the sensor are often more important than the pixel count in most cases. Larger sensors generally have a better dynamic range (DR) and much lower signal to noise ratio (SNR). Increased DR allows better clarity in unevenly lit subjects and a lower SNR results in less image "static."

Quick Tip: If the work involves detailed and complex subjects, consider a UAS with a 1-inch image sensor.

Obstacle avoidance sensors are becoming standard equipment on many commercially available UAS. For operations near objects, or where the PIC may have difficulty gauging range, it is recommended to have, at a minimum, forward-facing obstacle avoidance sensors. Depending on the application, additional sensors may be useful.

When considering the lens for visual or infrared cameras, first consider the task at hand. Wide-angle lenses provide context, allow for easier first-person control, and allow quick inspection of large areas. Wide-angle lenses are the most common and generally have a field of view of 70° or greater. Some UAS cameras have the ability to provide optical zoom for detailed examination of objects without the need to have the UAS close to the subject. For these types of inspection, a minimum of 2X optical zoom should be considered.

Work that involves overhead inspection requires the ability to mount the camera on top of the UAS. An alternative may be a camera that allows upward vertical tilt.

A variety of infrared (IR) cameras are currently available for UAS platforms. Due to their cost, however, they have been slow to be implemented into general construction inspection. Lower-end IR cameras often do not provide enough detail for construction inspection while a mid-range IR camera can easily double the cost of a UAS. In some applications, the IR camera replaces the visual spectrum camera making first-person control more difficult. Many inspectors become familiar with UAS inspections before acquiring an IR camera.

Quick Tip: Consider an IR sensor with a sensor size of more than 240x320 pixels or dual cameras with the ability to blend images for greater clarity during inspections.

Construction inspection UAS primarily consist of rotary wing aircraft. These UAS are generally limited to 20–25 minutes of flight time, although some can approach closer to 30 minutes. For inspection tasks that require long hover times or the inspection of large areas, extra battery life may significantly reduce downtime.

Quick Tip: Spare batteries and the ability to charge batteries from a vehicle can make or break an inspection trip.

UAS vary in price nearly as much as they do by configuration. Typical entry-level commerical platforms start around $1,000 while professional models can easily climb above $50,000. For a state agency perspective, inspectors operating on North Carolina DOT (NCDOT) projects, for example, generally have platforms in the $2,000–$5,000 category.

SAFETY

The safety program requires an understanding of the nature of the work and the limitations and/or obstacles that are onsite. For example, if one or more cranes or concrete boom pumps are present, the UAS pilot needs to understand where to avoid flying. Also, the work crews on the ground need to understand the fight plan and be in contact with the pilot to prevent the crew from being surprised by UAS presence.

It is important for the UAS pilot and the project supervisor to develop a job hazard analysis (JHA) that lists all of the potential site hazards prior to flying. Other concerns may include the specified flying time period and zone constraints based on type of construction and density of construction personnel.

A best practice is to have a visual observer who has active radio contact with local air traffic and the PIC at all times and can alert the PIC of any conflicts with manned aircraft or fixed objects.

OUTPUTS AND DATA PROCESSING

Most commercially available UAS are capable of recording and displaying images and videos using both visible and infrared sensors (if equipped). The preference of using video or images to complete an inspection varies between inspection type, operators, and even sites.

Images provide an instantaneous snapshot at a particular time, offering concise documentation that can be scaled and measured. Videos provide an immersive record that depicts an evolution of perspective. Image inspections can create hundreds of files for a single inspection that need to be sorted and organized. Video inspections generate large data files that can quickly fill up storage space on computers and servers.

Proficiency using image editing software can be an essential part of UAS post-processing because the ability to digitally filter and enhance different aspects of inspection images can be invaluable in discerning details and communicating inspection issues (see Figure 1).

The market has evolved to provide a wide range of post processing software and services and various price points and payment options, from onetime fees to recurring licensing, and capabilities ranging from simple volumetric calculations to complex three-dimensional (3D) point clouds.

Images from Paul Rogers

Figure 1. Simulated image editing software screenshot

Photogrammetry software that helps extract geometric information from two-dimensional (2D) images or video is another valuable tool for the construction inspector. Primarily targeted toward survey applications, these software packages allow for the generation of geo-referenced orthomosaics (see Figure 2).

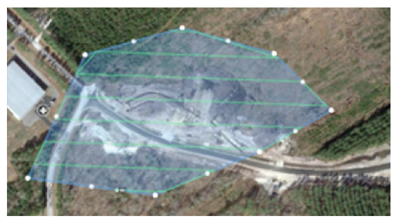


Image from Paul Rogers

Figure 2. Image editing and orthographic software screenshot

Unlike uncorrected aerial images, orthomosaic images can be used to measure true distances with accurate representations of the earth's surface adjusted for topographic relief, lens distortion, and camera tilt. A variety of companies offer standalone platforms and subscription-based services. The ability to share files and data between offices or between contractors and consultants can be an important consideration.

UAS INSPECTIONS

UAS are being used for a variety of construction inspection roles, the majority of which are carried out using rotary aircraft with a cost of less than $5,000. Largely, UAS construction inspections fit into one or more of these categories: erosion control, construction progress, construction QA/QC, and structures.

EROSION CONTROL

Key UAS Characteristics: Obstacle avoidance for flying low and adjacent to trees or structures and longer battery life for large sites

A 2015 study conducted by Auburn University concluded that aerial images gathered by UAS provide an advantageous and unique perspective that allow quick and easy identification of problems areas such as rill erosion (removal of soil by surface water running through little streamlets or abrupt vertical drops, also known as headcuts or knickpoints, in the stream bed into deeper, faster-flowing channels). The researchers found aerial images to be useful in determining the source of eroded material (Perez et al. 2015).

In North Carolina, both contractor and DOT crews have successfully completed UAS inspections of erosion control measures on highway projects. Typically, these inspections are being performed using relatively low-cost, entry-level, commercial UAS with a retail price under $2,000.

The use of small UAS can increase productivity and improve inspection quality. Some of the benefits include the following:

- Access to difficult locations by air, instead of traversing soft, slippery ground, to reduce inspector fatigue and hazard exposure
- The ability to quickly scan long distances of silt fence without having to walk each segment
- Access to the center of large retention facilities to inspect risers, baffles, and other critical components (see Figure 3)
- The generation of highly effective record keeping in video and digital image format that allows the quick and efficient conveyance of discrepancies
- Inspection of construction and repairs that limits exposure to trench and excavation hazards for the inspector
- Final inspection of difficult to observe features after establishment of vegetation and wildlife hazards

In some cases, large complex sites that took an entire day to inspect are now being completed in a matter of hours. In addition, personnel are able to access areas that might otherwise be inaccessible.

Assuming an average inspector loaded rate of $75 per hour with 50 rain events per year, a two-year project could expect an approximate labor-hour savings of $10,000. Figure 4 represents a typical two-year project.

The payback period on the initial investment is approximately 35 inspections. This does not include the savings from decreased exposure to site hazards.

NCDOT

Figure 3. UAS images of retention ponds

CONSTRUCTION PROGRESS

Key UAS Characteristics: Large sensor-based camera and adjustable focal length for high definition orthomosaics and detailed still images

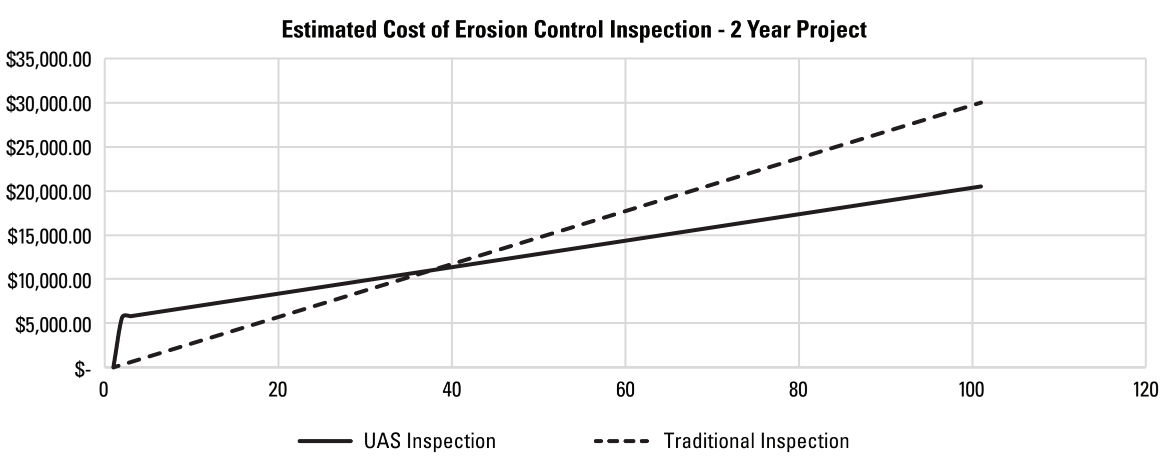
Monitoring construction progress, verifying pay applications, and maintaining schedules can be difficult and time-consuming. Using a UAS, a single operator can streamline this process while providing a more complete record (see Figure 5).

UAS images and videos can be used to verify progress for pay applications and project milestones and create accurate representations for tracking and calculating liquidated damages and responding to claims.

Site photos can be combined to create site-wide, high-resolution imagery in what is called an orthomosaic. In an orthomosaic, high-resolution images are taken in an overlapping and usually automated fashion using a built-in or third-party application. Images are stitched together using the automated collection application or can be stitched together using cloud and desktop software.

NCDOT

Figure 5. Construction progress on a flyover bridge



Assumes a loaded rate of $75 per hour with 40 hours of UAS training, a $2,500 investment in equipment, and time savings of 2 hours on a typical 4-hour inspection.

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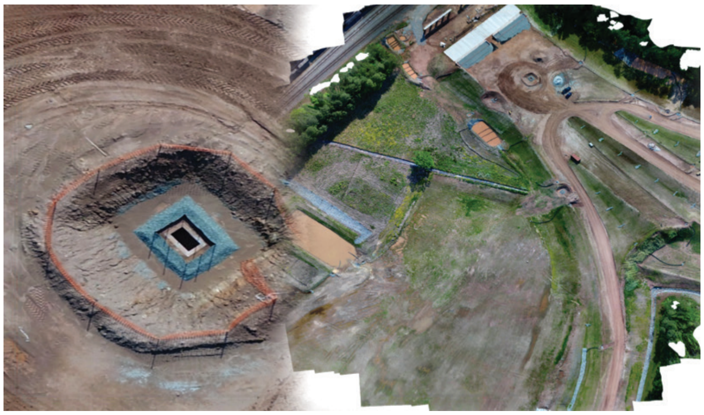
Figure 4. Estimated cost of erosion control inspection with UAS vs. traditional

Completed files are available in native image formats or georeferenced formats for geographic information system (GIS) applications. Figure 6 shows a sample orthomosaic stitched using commonly used software and captured using a prosumer UAS.

Collection of the images in Figure 6 was completed in approximately 15 minutes onsite. The image on the left is a full resolution crop of the image on the right.



Images from Paul Rogers

Figure 6. UAS orthograph images

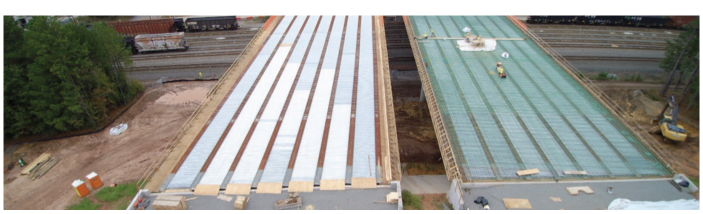
Orthographs are georeferenced and can be used to update satellite imagery in Google Earth or other GIS platforms and are easily shared with project teams. Operators can create a site-wide image map on a weekly or monthly basis to create a permanent record on a construction timeline. These records allow the verification of as-builts during expansion and repair projects in the future.

Pay Verification

UAS images provide a quick and precise way to account for material line item costs. Some of these items include the following:

- Prefabricated members – steel beams, precast sections
- Traffic control – cones and delineators, barricades, signage
- Stockpile materials – base course, fill, ballast stone, recycled materials
- Embedded materials – reinforcing steel, dowel bars, conduit (see Figure 7)
- Embankment/borrow quantities
- Clearing and grubbing

Aerial images do not replace field verification procedures but can help provide context and perspective.



NCDOT

Figure 7. Bridge reinforcing steel as viewed from a UAS

CONSTRUCTION QA/QC

Key UAS Characteristics: A zoom camera (adjustable focal length) for detail clarity and infrared cameras for hot-mixed asphalt and surface treatments

UAS will likely never replace boots on the ground inspections. The skilled inspector deduces, reasons, and uses a variety of senses to get the total picture in each situation; however, conveying these details can often be difficult. Aerial perspectives provide unique context to offsite engineers and projects managers.

UAS can help save time inspecting large areas while helping to verify that discrete testing is representative of the project. In highway construction, UAS can be used to quickly look for segregation in new hot-mixed asphalt (HMA) and for dowel bar placement in Portland concrete. Tasks that generally require head down concentration near equipment or adjacent to traffic can be completed from a safe location in line of the site.

UAS also allow the inspector to augment routine inspection tasks and collect a real-time aerial perspective that provides context to a current situation. Issues discovered during routine inspections can be viewed from an aerial perspective, allowing recognition of patterns.

Some sites can be difficult to observe from the ground. In pavement surface treatments, UAS are being used to check application consistency, coverage and overlap, and aggregate placement. The construction process of many surface treatments can be difficult to inspect on foot or by vehicle.

UAS allow inspectors to monitor and log activities over a long stretched out site without constantly having to reposition, allowing more time to be focused on inspection. In North Carolina, for example, chip seals and asphalt rejuvenation projects have been successfully inspected on highways and at airports.

Surface Treatments

Equipped with a thermal camera, UAS have been successfully used to locate thermal segregation in HMA pavement projects while staying clear of the placement and compaction operations. Infrared cameras are also successfully being used to observe application temperature and consistency in surface treatments and application consistency in pavement markings (see Figure 8).

When the applied materials are a different temperature than the base pavements, the pavement and material temperature move toward the same temperature.

Figure 8. UAS surface treatment inspection (visible and IR)

Thinner applications will have less stored thermal energy than thick applications and will change temperature at a different rate. These areas are easily identifiable using a UAS-mounted thermal camera. In these fast-paced construction activities, UAS provide a unique perspective on materials, processes, progress, and the end product.

Low-end infrared thermal cameras run approximately $2,000; whereas, mid-range cameras quickly approach $10,000.

Safety Inspections

In many jurisdictions, Occupational Safety and Health Administration (OSHA) and jobsite safety inspection are expected to be conducted as part of the onsite QA/QC teams' daily duties. With the use of a UAS, inspectors and engineers can view a variety of construction scenarios without being directly exposed to the hazards or getting in the way of production.

For example, UAS have been used to document jobsite safety violations and to provide inspections of unsafe excavations. On resurfacing jobs, UAS have also been successfully utilized to verify lane-closure configurations and attenuator spacing for the safety of both workers and motorists in work zones.

Quality of Pavement Markings

Pavement markings are a significant part of construction and maintenance projects, but they are often overlooked as projects are coming to end. Color and retroreflectivity can be measured using a variety of portable and vehicle-mounted instruments. Size and geometry verification of individual markings is often done by hand and occasionally by survey. However, many projects are impractical to see from a single vantage point, making it difficult to check alignment for conformity to the plans.

Oblique and top-down images allow for the best perspective when verifying marking layout, alignment, and consistency. The images are easily captured using an inexpensive UAS (see Figure 9).

Inspection Training

The unique perspectives that UAS provide are also becoming instrumental in developing media for demonstrating construction processes. Aerial images and video footage can be used to highlight common issues and show how to identify these issues; perhaps just as important, the images and video can help keep the attention of inspectors and contractors during training.

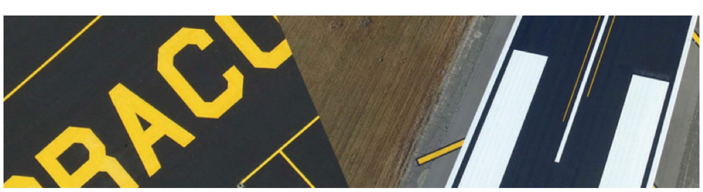


Figure 9. Airfield marking inspection

For many agencies, work has begun to create updated training materials for inspection tasks as the popularity of UAS increases. For example, UAS stills and video documentation from surface treatment inspections are being transformed to train new hires and contractors in hopes of combating a rapidly retiring workforce. In the private sector, UAS video is being utilized to train airfield inspectors about runway markings from a new perspective.

STRUCTURE EVALUATION

Structural evaluation by UAS is one of the fastest developing regions of infrastructure inspection. In bridge construction, UAS are capable of providing inspection in difficult to access locations using significantly less equipment and in significantly less time. The location of segregation in concrete structures or verification of puddle welds, shear studs, and bolted connections in steel structures can be completed quickly and safely using a UAS with a high-resolution camera.

CONCERNS AND LIMITATIONS

Weather can be a constraint with timely UAS construction inspections. A site may need to be inspected, but high winds and rain limit the abilities to do UAS inspections. Although aerial images will always be weather dependent, the UAS can be quickly deployed as soon as weather permits.

Flying in wind can deplete the UAS battery faster than normal. Wind makes it more difficult to keep control and can impact image quality. Cold temperatures, rain, and extreme heat can also be detrimental to UAS components.

Another consideration is the time of day the flights are being performed. The angle of the sun can prevent inspecting specific site objects or areas due to glare or shadows.

CONCLUSIONS

Both the affordability and capabilities of small UAS have dramatically improved. Construction inspection UAS primarily consist of “off-the-shelf” units in the $2,000–$5,000 price range. Despite unique project inspection needs, many platforms work well in multi-role missions.

UAS have proven to be an effective tool in transportation infrastructure construction inspection. UAS have reduced inspection time, improved inspection effectiveness, decreased the cost, and improved inspection safety.

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ONLINE RESOURCES

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FHWA Center for Accelerating Innovation Every Day Counts-5 (EDC-5): Unmanned Aerial Systems (UAS). https://www.fhwa.dot.gov/innovation/everydaycounts/edc_5/uas.cfm.

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

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

Key Words
construction inspection drones; infrastructure construction practices; transportation infrastructure construction; unmanned aerial systems