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# Unmanned Aerial Vehicle Applications and Issues for Construction

**Prof. Neil D. Opfer, University of Nevada, Las Vegas**

UNLV Associate Professor Department of Civil & Environmental Engineering & Construction

**Dr. David R. Shields P.E., University of Nevada, Las Vegas**

David R. Shields, Ph.D., P.E. Dr. Shields is an Associate Professor in Department of Civil and Environmental Engineering and Construction in the Howard R. Hughes College of Engineering at the University of Nevada, Las Vegas. He has received two outstanding faculty awards and two service awards at UNLV. He has over 25 years of industry and government experience in construction, engineering, and research and eight years of academic experience. He was Co-Chair of the ASCE Civil Engineering in the Oceans V conference. He was the only manager in the 55-year history of the Naval Civil Engineering Laboratory ever to win the Employee-of-the-Year Award. He has won numerous awards for project management. He has conducted research for the Construction Industry Institute, Center for Construction Industry Studies, U.S. Navy, U.S. Army, OSHA and other organizations. He has published 45 journal and conference papers. He holds a Ph.D. in Civil Engineering from the University of Texas at Austin and the M.S. and B.S. in Ocean Engineering from Texas A&M University.

# Unmanned Aerial Vehicle Applications And Issues For Construction

## Introduction

Unmanned aerial vehicles (UAVs) besides military uses have seen increasing prevalence in the U.S. for law enforcement and border enforcement applications. While currently facing certain regulatory restrictions by the Federal Aviation Administration in the United States for general utilization, UAVs have a number of potential applications in the construction industry. Thirty-one contractors who were using UAVs were informally surveyed by the authors in the course of their other work as to their application and utilization of UAVs. These contractors either had their own UAVs or were subcontracting out UAV work such as with photography to commercial photography firms. It is not the intent of this paper to cover all possible technical details regarding the variety of UAVs on the market but instead to inform those in construction education and the industry on overall concepts and potential benefits. UAVs can replace other conventional techniques in certain construction applications. In other instances, it was found that more conventional techniques such as web cams are a better application as compared to UAVs. The most obvious application for UAVs is as a camera platform. Aerial photography of a project accomplished by conventional plane or helicopter means carries a significant expense. UAVs, as an example in this area, can provide high-quality photographs and video for significantly less cost.

Construction education has traditionally focused on state-of-the-art applications to be applied to the construction industry. Computerization of management processes such as CPM scheduling and estimating found early residence in academic construction programs. Computerized techniques in estimating and scheduling have now been in the construction education arena for so long that most faculty take them for granted. Technologies such as CAD and laser surveying later became incorporated into other academic classes. Newer items such as BIM are now being rapidly assimilated into construction coursework across the country. The same would apply to concepts such as integrated project delivery, green/sustainable construction, and lean construction that were not on the radar screens for most faculty just two decades ago. The authors feel that such is the case with UAVs for construction. UAVs are a technology that can help those in construction do their jobs better and faster over a number of applications.

Places to incorporate the use of UAV topics in the construction curricula would be classes that currently deal with some of the most common areas where UAVs have been found useful. A camera-equipped UAV can be ideal for certain job progress photography that formerly was the province of planes and helicopters. Project management courses can note and use this technology for instruction with these job-progress documentation tasks. Coursework focusing on construction productivity improvement can utilize UAVs on field trips to take aerial photos for later use by students in analyzing site utilization and work operations. Construction marketing coursework can utilize results from UAVs to develop unique construction project views for student-produced marketing brochures and videos. Students in mechanical/electrical/energy systems classes on some campuses already utilize thermal imaging to view energy losses in building components. UAVs can be used with thermal imaging units to view roofs and other items that may have been previously inaccessible for a variety of reasons to those students.

Classes in surveying could incorporate UAVs to illustrate techniques with topographic mapping, photogrammetry, and volumetric surveys. Coursework in construction inspection could illustrate to students how a UAV can help in QA/QC non-contact inspection tasks on a job site. Construction safety coursework could note that UAVs find applications in dull, dirty, or dangerous jobs. Spraying of herbicides for noxious-weed control, grass seed/fertilizer, and dust control chemicals on steep hillsides have been successfully handled by larger UAVs with attendant safety benefits.[8]

## The UAV And Its Role In Construction Education

Those that have been involved in construction education and the construction industry for some time understand that fads come and go. These fads come onto the scene and in many cases are found to be impractical or unworkable in actual practice. Sonic digitizers for construction estimating and various computer programs either never caught on or were supplanted by better ideas. Tools such as the personal computer while morphing in its various forms to include the tablet and smartphone have stood the test of time. At one time computers were looked at askance but academic computer science departments are not going away anytime soon. While no one can predict the future, UAVs offer an opportunity for those in construction education to help pioneer this technology. The Introduction Section noted a number of potential academic applications in courses to utilize UAVs. Aerial photography with full-scale planes or helicopters is frequently utilized on construction sites to document job progress as an example. Full-scale helicopters are utilized to install certain items such as HVAC units on rooftops or set communications towers. Academic budgets for the standard class could not support the aforementioned costly applications with full-scale planes or helicopters but UAVs can be very economical. UAVs in the basic sense are simply low-cost scaled-down remote-control versions of their human-pilot-control full-scale counterparts. In a lab setting dealing with construction methods, a faculty member could demonstrate the work involved to set a roof-top HVAC unit by UAV helicopter including the rigging and signaling issues in scale-model size. This type of demonstration in a practical sense would not be possible otherwise. A construction safety class instructor could utilize the same example scenario to develop the safety issues involved with helicopter rigging and placement.

As noted in the previous section of this paper, coursework involving topics of construction inspection, surveying, construction productivity, mechanical/electrical/piping/energy systems and project management can utilize UAVs for photography and thermal imaging tasks related to these areas. The authors of this paper liken the above UAV applications to digital photography. When print film was the rule, fewer photos were taken on jobsites due to the cost of film and development times, etc. Now, high-capacity/low-cost digital memory cards along with inexpensive storage media with CDs and hard drives have meant that taking numerous photos has a very low marginal cost on a project. The high-cost of full-scale aerial photography places this out of reach relative to academic program budgets. As an example, the widely-used R.S. Means Building Construction Cost Data Book notes that a one-time site visit with aerial photography for six shots will cost $950.[9] Professors can talk about these techniques and what can be done but are prevented from actual demonstrations due to these cost considerations. With the low-cost UAV alternative now a course involving construction productivity or construction methods can readily photograph a campus construction project. For a campus parking garage under construction, this aerial photography could be done over a few weeks and used for contemporaneous class projects and case studies. Aerial photographs from construction sites could be utilized in a course lab dealing with construction methods or productivity to teach a method or look for inefficiencies. These aerial views can sometimes help to better educate students than a ground-only perspective. Ask almost anyone who has driven over a construction site and then flown by small plane or helicopter over the same site about the aerial view of a vastly different perspective. With this technology, professors can provide the same benefit to their students.

The overarching goal of construction education is to improve industry practice through providing better-educated personnel for construction. Therefore educators should look for multiple opportunities to incorporate the information contained in this paper into their classes.

The UAV And Its Role In Construction Academic Research

Some universities are already working with UAVs on research projects under contract with various governmental agencies.[8,10] The authors envision that the ideas in this paper can be utilized by construction-area faculty to work with the construction industry to apply UAVs to a variety of applications. This application-research work could also be done in concert with students working with those in the construction industry providing a valuable educational experience for them. At our campus, students in other areas such as mechanical engineering have even built UAVs from scratch to demonstrate certain concepts for senior design projects. Partnering of faculty/students from diverse disciplines in engineering and related areas as is often done for other research work should be examined for this area as well where not already taking place.

UAV Definition

The Federal Aviation Administration (FAA) refers to UAVs as "unmanned aircraft" and they have defined them as:
"a device that is used, or is intended to be used, for flight in the air with no onboard pilot. These devices may be as simple as a remotely controlled model aircraft used for recreational purposes or as complex as surveillance aircraft flying over hostile areas in warfare. They may be controlled either manually or through an autopilot using a data link to connect the pilot to their aircraft. They may perform a variety of public services: surveillance, collection of air samples to determine levels of pollution, or rescue and recovery missions in crisis situations. They range in size from wingspans of six inches to 246 feet; and can weigh from approximately four ounces to over 25,600 pounds.[5]" While there are other definitions, the FAA definition seems to cover this area well. In addition, the FAA, as explained later in the paper is the federal agency tasked with regulatory jurisdiction in this area.

UAV Fundamentals

Remote-controlled (RC) planes and helicopters in the past were typically gas-engine powered or some variant. The advent of lithium-polymer batteries has meant substitution of electric motors with weight savings and or-equal flight times compared to engine units. Battery power makes these units quieter along with ease of operation and maintenance. With this, increasingly-light-weight cameras are now offering high-quality photo and video capabilities that makes these units when paired with a UAV very useful in construction. Most construction photographic applications require a steady platform that has hover-ability to achieve quality results. These applications mean that an RC helicopter will be the preferred choice versus a plane. In the past, RC helicopters presented users with a significant learning curve. The advent of multi-rotor helicopter units with three to eight separate propellers as compared to the single standard-helicopter rotor has yielded units that are significantly easier to fly and to easily achieve solid results.

UAVs for construction applications can range from hobby-grade remote-control planes and helicopters to units that can best be categorized as industrial-grade units. These should be differentiated from toy models that while flight-capable suffer from a number of problems including the ability to work in outdoor conditions, flight times, and capabilities to do actual work. With UAVs, in general, one gets what they pay for. A battery-operated hobby-grade RC helicopter including high-quality camera with camera remote-control can be purchased together for less than $1,000. More capable units are priced in the $1,000-$5,000 range. Given the high value of tools and equipment investment undertaken by contractors, these costs are relatively minor. Typical RC helicopter flight times range from less than ten minutes to twenty minutes. These flight times seem short but with RC helicopters operating at air speeds in excess of 45 mph, a great deal can be accomplished in a short period.

Applications besides standard aerial photography can include inspection tasks, productivity surveys and interference documentation related to construction claims. A few contractors have used stable multi-rotor units to deliver additional fasteners to crews up on tower work saving labor time. Outfitted with thermographic cameras these RC units can "see" roof leaks or electrical hot spots on transformer installations not ground-visible.

As seen from the above, UAVs in terms of both size and capability run the gamut from simple toy-like items costing less than $100 and that can maintain flight for a few minutes devices to ultra-high-end units costing millions of dollars which can stay aloft for days. Acquisition of these ultra-high-end units are limited to US military or NATO military purchases.[1] This paper's scope concerns itself with UAVs costing from a few hundred dollars to several thousands of dollars as a limit. Instead of UAVs being controlled remotely on location from a remote site halfway around the world, construction UAVs are focused over a project with typical line-of-sight control.

## Self-Perform UAV Work Versus Subcontracting

One key decision for those looking to implement UAVs on a project is whether to subcontract this task or self-perform this work. The general parameters of this decision are commonplace for general contractors/construction managers with subcontractors or trade contractors. Currently the most common subcontracting application is when a contractor hires a firm to perform site video/still photography. The firm will then travel to the subject project at the desired time interval and perform the requisite photography. From here the firm produces the video/still photographic results and submits a monthly bill. Other firms that act as subcontractors are those utilizing the UAV platform as an adjunct to their third-party inspection services. Again, periodically these firms will travel to the site and utilize the UAVs as a supplement to their inspection work. Subcontracting these tasks means that the construction manager or contractor does not have to have the on-board expertise for UAV operation and general maintenance. However, not having a UAV on site when needed reduces flexibility.

UAV Cost-Effective Considerations

Aerial photography via conventional plane or helicopter is an expensive consideration for a project. Operational costs of hundreds of dollars per hour place these periodic costs beyond the budgetary abilities of many projects save for brief periods of time over the course of a project. In contrast, the operational costs of a UAV are significantly less since both equipment costs and operational costs as for example between a conventional helicopter and the UAV version are far lower. It takes less time and skill to learn to capably operate a UAV as opposed to piloting its conventional equivalent. Time savings also accrue to the project since the UAV is stored, when not in use, at the project site in the job trailer or vehicle's trunk. Conventional planes and helicopters require basing remotely at an appropriate facility that is often at a significant distance from the project site. This remote-basing also creates its own separate cost structure for storage.

Educational Safety Concerns

In educational settings, safety of students is of paramount importance. Lab safety has been a long-standing faculty concern for students utilizing power tools and other equipment where participants have to follow safety procedures. Those faculty conducting outside labs such as for surveying where lasers are involved have to be not only concerned with students enrolled in the lab but also with that portion of the campus population interacting in the same environment. These same concerns hold for UAVs. Inside a high-bay lab building, a professor or graduate student demonstrating UAV applications is in a controlled environment. All should have prior instruction in the lab that contact with UAV propellers can be dangerous and that these units can move quickly potentially hitting a student. Notably the UAV demonstrations inside a high-bay lab building would not come under FAA jurisdiction. On a campus during normal campus class times in an outside context, UAV-safety concerns for student safety increase significantly. A UAV falling due to mechanical failure or a spent battery from an altitude of a hundred feet or higher hitting a student is an important concern. An out-of-control UAV on the same horizontal plane can also hit a student with the UAV body or with a propeller. Here it is suggested that these outside campus demonstrations be held in a controlled area that may have fencing or with barricades to control access. Another solution is to schedule a demonstrations such as this on a Saturday again in a controlled campus area but where based on the day, the potential issues with the general campus population is less of a problem. Those campuses with large land-holdings including unused land such as rural land-grant university campuses have a distinct advantage in this area over urban universities and their inherent land-use constraints.

UAV Jobsite Safety Concerns

UAV where utilized must have safety as a key concern on any jobsite. UAV helicopter blades turn at thousands of rpm. Deaths and disabling injuries from UAV contact to either the operator or others present while not common have taken place. UAV operators need to carefully read and follow manufacturer's safety/operational instructions related to their particular unit. UAV operators must ensure that they don't create their own safety hazards on a project. Construction workers have enough safety concerns in the field without also having to worry about UAVs. Prior to flight within the constraints and complexity of a jobsite, the operator should first practice and hone their skills in open areas. A UAV due to mechanical failure or loss of power can quickly fall onto the ground with little or no warning. The operator due to these considerations when possible should avoid hovering or flying the unit over areas of the project where people are on the ground. Instead the operator should consider safety standoffs when operating the unit. An example of a standoff in taking project photos would be to utilize the zoom features of the camera that allow the UAV to be some distance from the work. With a failure, the UAV would fall to the ground in an unoccupied area. For inspection or photographic tasks in occupied areas consideration should be given to off-shift utilization of the UAV such as after work or on weekends.

For some tasks, a UAV will have to hover relatively close to workers but the overall safety improvement yields a net benefit. As an example, workers atop a communications tower require a small hand tool or some fasteners. In this case they may not have a hand line. A UAV could bring them the necessary item on a lanyard or it could take the top of a hand line to them thereby allowing them to proceed with their work. While the UAV may be over the workers if its power fails, it is falling from a short distance with minimal impact. Moreover the unit supplies a net safety benefit compared to additional trips on the communication tower's ladder.

Another safety consideration with UAVs concern the storage of either batteries or liquid fuel. Liquid fuel for UAVs is needed in fairly small quantities but still must be stored safely in adequate containers. Lithium polymer batteries in other applications in devices ranging from laptops to electric vehicles have caught on fire. These batteries can overheat and if left near flammable items start fires. Low-cost fireproof-storage pouches for these batteries are available as a key safety precaution. It is recommended that when not in use batteries be removed from the UAV and stored in these protective pouches.

In order to minimize the possibility of failures while in flight, the UAV operator should perform a pre-flight check wherein parts are checked for correct tightness and other considerations. Fuel levels if liquid-fueled should be full or with batteries fully charged. Battery life should be monitored and a safety margin left to minimize the possibility of a failure. Therefore if a flight time maximum of twelve minutes with fully-charged batteries is allowable, at ten minutes the operator should be landing the unit. If additional flight time is then required, a fresh battery pack can be installed to continue the work. If a UAV crash takes place, the unit should be carefully checked prior to again placing the unit in operation.

## Operation And Maintenance Learning Curve

It takes time to learn how to fly a UAV along with learning the targeted application with the UAV such as a remote camera. In addition there are periodic maintenance tasks and inspection of the UAV prior to and after flights. If the UAV was purchased at a hobby store, knowledgeable store staff can often offer useful tips for novice users. Better hobby stores, if carrying planes and helicopters are a good source of spare parts and ideas for UAV modifications. Those contractors operating in larger cities will find that there are radio-control flying clubs which are another source of guidance and useful information. The writers would also suggest available books in this area along with subscribing to radio-control flying publications for product reviews, tips, and maintenance ideas.[6]

Prior to actual work with a UAV including carrying a camera, the UAV operator will want to get familiar with operation of the unit including the ability to hover in a location. Different operators will learn faster than others but the UAV operator has to be comfortable with the UAV. The UAV operator may want to consider practice flight work with a smaller unit so that costly crash damage is eliminated while learning to fly. Once flight skills have been practiced, then the operator can utilize the actual unit. In order to limit potential UAV damage, the helicopter platforms can be equipped with training pods. These pods hold the unit higher up off the ground and provide a broader landing base to prevent high-revving helicopter blades from contacting the ground. In a sense these pods are similar to training wheels for a child's bicycle. Once the operator has obtained sufficient ability, then the camera or other device can be installed to allow the UAV to perform usable work.

## Platform Choices

Most available platforms come direct from the manufacturer fully assembled with minor tasks such as battery installation the only remaining tasks. Kits are available in some cases but most opt for assembly by the manufacturer. The only work necessary on an assembled unit is typically modifications to carry a payload such as a camera.

Those considering the use of UAVs are confronted with the choice between fixed-wing units (planes) and rotary-wing units (helicopters). A contractor on horizontal construction such as a pipeline project may find that a fixed-wing unit provides the required capabilities needed in their work. The problem that a plane has is the inability to hover over a given location to take a picture or perform other work requiring this ability. On vertical construction, the capability to stay or move up and down in a limited area dictates the necessity for rotary-wing units. The helicopter can be readily controlled in a hover mode that is useful in a number of construction project applications. A UAV helicopter placed in a hover mode with GPS-stabilization can take high quality photographs. Based on the aforementioned discussions with contractors, all were utilizing helicopter platforms due to the above-noted considerations. Therefore, for the purposes of this paper the discussion, unless otherwise noted, will concern itself with helicopter platforms.

The next decision once a helicopter platform has been selected is to choose between a single-rotor design and multi-rotor designs. Multi-rotor designs are commonly available with three, four, six, or eight separate rotors. Multi-rotor designs with contractors were found to be more popular since they are significantly easier to fly. Flying a conventional single-rotor design requires substantially more experience and technique on the part of the person operating the unit.

## Power Source Considerations

A common choice in UAV acquisition is choice of power source between gas engines, gas turbines or battery power. Ni-cad batteries had problems with short operational times and weight. The advent of lithium-polymer (li-po) batteries with higher amperage charge densities has revolutionized UAV operation much as battery power has replaced corded power tools in many aspects of the construction industry. Advances in battery technology with lithium polymer have yielded flight times that are comparable to or exceed those offered by conventionally-fueled units. Gas engines or turbines tend to require more adjustment, more maintenance and are noisy in operation. This operational noise unless counterbalanced out by construction equipment operations can be distracting to those on the jobsite. Requirements for care and maintenance with engine or turbine units increase costs. Because of these considerations with fueled units, the industry with smaller units is moving to battery power.

## Costs And Choices

Generally contractors will want to spend from a few hundred dollars to several thousands of dollars on UAVs. In terms of cost, differentiation must be done between toys and UAVs that will in practice be usable for construction applications.

UAV toys would be those items typically costing in the range of $100 or less. While these toy units have a very favorable purchase price, they have significant limitations. UAVs require maintenance with parts replacement due to items simply wearing out or from crashes due to operator error, mechanical failure, fuel/battery issues, and other reasons. The problem with purchasing one of these toys is the unavailability of replacement parts. When an item on the toy breaks the only solution for parts replacement is often to re-purchase the same toy and place the new unit in operation or cannibalize it for spare parts. Another problem with these toys is that their capabilities have significant limitations. These capability limitations include environmental issues, flight-time issues, and payload issues. In terms of an outdoor environment, the toys are not wind-capable meaning that in anything over a slight breeze, they will not be able to operate which is problematic. The toys have very limited flight times in some cases as short as a few minutes. These limited flight times then require landing in order to change battery packs. UAVs to be useful need to be able to carry a payload consisting of a camera, thermography detection unit, or other tools. Toy UAVs do not have this ability or that ability is severely constrained such that a camera payload is sharply limited to low-capability cameras. The rule is to avoid purchasing toys that will create problems in the future.

Instead, contractors need to move up-market when acquiring UAVs. Generally one gets what one pays for in this area. An expenditure of a few hundred dollars for the UAV itself currently represents a reasonable floor for purchase costs. Some UAVs come without dedicated ground-control units but have downloadable apps that enable the user to operate the unit with a smartphone. These UAVs therefore offer a slightly-lower price since the control unit is not part of the system package. Higher expenditures yield UAVs with greater payload capacities, longer flight times, and better abilities to achieve flight objectives in windy environments. In this class are units that have GPS capability and return-to-home features. GPS capability can allow a UAV, once on location, to hover at a set point and take video/still photography or perform other work requiring this ability. A return-to-home feature means that the UAV will automatically return to the launch site if radio contact is lost. Otherwise a lost-contact UAV would keep flying until out of power and crash with resultant damage or be permanently lost if not found.

In conjunction with these increased abilities, capable low-weight high-resolution cameras with remote control features are available for less than five hundred dollars. Other items such as additional battery packs, safety battery storage units will add some cost to the above numbers. Therefore with high-quality photo camera included, the overall cost with standard accessories of additional battery packs foe extended flight times would have an approximate thousand-dollar target. Other units such as infrared cameras, paint mil-thickness sensors can also be purchased to enhance the UAV capabilities but will add approximately one thousand dollars per unit to the above price. Even more up-market UAVs currently utilized by law enforcement agencies and equipped with infrared cameras have price points between fifteen and thirty thousand dollars. These more up-market UAVs can operate in minimum/maximum temperatures of -25$^{o}$C to 38$^{o}$C (-13$^{o}$F to 100$^{o}$F) and in maximum winds of up to 30 km/h (18 mph). While spending fifteen-thirty thousand dollars on a UAV may seem impractical, this is in the range of common new purchase prices for construction skid-steer loaders. With conventional helicopter flight costs at four-to-five-hundred dollars per hour versus less than one-hundred dollars per hour for a UAV, this price delta can be made up fairly quickly on a series of projects. The bulk of the one-hundred dollars or less in this case would be salary/benefit costs for whoever operates the unit.

## UAV Environmental Limitations

Commercially-available UAVs tend to have some significant limitations in the climatic environmental conditions found at certain times of the year on projects. They typically do not operate well at either end of temperature extremes found on some construction sites. As an example, one of the best UAVs on the commercial market can operate in minimum/maximum temperatures of -25$^{o}$C to 38$^{o}$C (-13$^{o}$F to 100$^{o}$F). [2] It has a limitation to operate in maximum winds of up to 30 km/h (18 mph) with GPS-controlled hovering mode limited to 10 km/h (6 mph).[2]

There are a variety of reasons for these limitations. With very cold temperatures the mechanical controls for flight functions can be problematic. Batteries are not nearly as effective in cold weather. The compact characteristics of these units means that they are more affected by wind speed as compared to a conventional helicopter. A conventional helicopter depending on type can operate in wind speeds of approximately twice the above numbers at 58 km/h (36 mph). However, temperature extremes while not as narrow on some conventional helicopters at -45$^{o}$C to 50$^{o}$C (-49$^{o}$F to 122$^{o}$F as the above UAV limits are still limiting factors in its operation. However, at these upper/lower temperature limits most jobs would be shut down for weather considerations anyway.

## UAV Environmental Advantages

Utilization of a conventional helicopter for site photography is typical in the construction industry. However, helicopters create noisy conditions that can upset neighbors and run afoul of certain regulations in this area. Helicopters flying too close to the ground create "prop wash" issues from the rotor blades which can create damage depending on the state of material storage at the site. This "prop wash" due to its strength can scatter objects on a construction site including full-size sheets of plywood. UAVs do not have these same problems due to their significantly smaller size and therefore a smaller environmental footprint. UAVs with battery power are quieter in operation with the only noise in this case being from their rotors. Compared to the noise level of a full-size conventional helicopter, a UAVs' noise level for battery-powered units is barely noticeable. Even liquid-fueled units produce significantly less noise as contrasted with their conventional counterparts. The small size of the UAV means that it can fly much closer over a construction site without creating "prop wash" issues.

From a size perspective, the UAV can obviously go within the interior of a construction project where a conventional helicopter would have size-restriction issues limiting it to only to venues such as open-air stadiums. The UAV is also significantly safer than a conventional helicopter in the case of mechanical failure again obviously due to the difference between their two footprints.

Some Common UAV Construction Applications

Contractors utilizing UAVs are involving them in a wide variety of project applications. The UAV is only application-restricted due to its practical ability to be able to "see" an item from its perspective. While it can't practically replace a physical person for every relevant task with a camera or other device, it can provide a supplement on a wide range of construction project tasks. In essence, the UAV is a force multiplier in saving personnel time on a project over a variety of tasks or allowing work to be performed from a safer vantage point through remote-control cameras.

Job Progress Aerial Photography

Currently the most common utilization for UAVs is with aerial photography inside and outside at project sites. This is typically done to catalog job progress. While the authors are currently unaware of any specific project specifications that require photography with UAVs, there are certain contract requirements that mandate periodic job photographs. These photographs are often required on a weekly or monthly basis. The UAV can provide unique overall perspectives of the job's progress with a fraction of the cost of conventional alternatives involving planes or helicopters. The UAV also offers the advantage of being able to visually capture a certain construction operation on short notice whereas conventional plane/helicopter work requires advanced scheduling.

Construction Marketing

Those in marketing are often looking for a unique way to showcase a project to potential buyers or lessees. UAVs can over fly a project to provide this unique perspective. Moreover, from inside a facility they can provide aerial views in an atrium space or other areas not achievable with standard photography-on-the-ground video and photographic techniques. The UAV can therefore differentiate a project to potential clients with its fly-over or fly-through perspective.

Construction Estimating

Site visits to a proposed project sites are a key element prior to estimating the cost of a project. Site visits are also time consuming for estimating staffs that typically already face significant time constraints. Environmental barriers such as fences and ditches may prevent vehicular travel to portions of a greenfield site thus requiring foot travel. The UAV can obviously travel at much faster speeds than a person on foot while acquiring aerial photo and video site documentation at the same time. Utilization of a UAV launched at the site can photograph wide areas at high resolution. The UAV can fly close to the ground to also inspect the area for any potential issues impacting the construction estimate such as ground-cover density. There are some roofing contractors that utilize UAVs for roofing estimates. Certain roofs such as those with slate or clay tile are problematic to walk on since foot traffic may damage the roof. With steep slope roofs there are safety considerations. On other roofs, access to a certain roof area may be problematic and time consuming requiring difficult ladder work. Roofing contractors therefore can utilize UAVs to yield both safety benefits and time savings in their estimating work.

Construction Inspection

UAVs can assist in certain construction inspection tasks. The UAV is limited to non-contact inspection work on a site. Therefore, a task such as inspecting the torque readings of structural steel bolts with a torque wrench is clearly outside the capabilities of a UAV. The applications for a UAV with a conventional camera can assist construction inspectors in their work in a number of areas. Inspectors are often constrained in their visual surveillance on a site because a view is unavailable in hard-to-see locations such as outside the building envelope or there are significant personal safety issues in attempting the surveillance. The UAV allows the inspector to see in first-person point-of-view through a remote-controlled camera these areas from a safe vantage point. On a structural fire such as a roof fire, the UAV would be able to accurately assess the fire damage to the roof close-up while the inspector views camera images capturing video and still photography in a safe place. UAVs can be equipped with thermographic cameras to record heat flow thereby mapping issues with roof insulation or piping insulation. The thermographic camera senses differences in heat in objects thus a breach in insulation within a building would show up as a "hot spot" due to the increased heat flow. Items such as walls are typically easy for a ground-based inspector to "see" with the thermographic camera. The ability to ascertain roof insulation problems for the inspector's thermographic camera is often more difficult due to access and other issues. A thermographic camera-equipped UAV can readily provide aerial views of the roof. The thermographic camera in rooftop views can help to pinpoint water leaks a water under roof plies will show as a colder image. The quality of insulated piping in a congested pipe rack may be difficult to view from the ground but again a UAVs' thermographic camera can provide an important aerial perspective.

Other areas for supplementing construction work with UAVs include non-contact sensors for measuring paint mil thickness or that of other coatings. Coating-thickness inspection has typically involved contact inspection but many areas are inaccessible to the inspector once scaffolding or aerial lifts have been removed from the site. These previous coating inspection techniques have required contact sensors. With newer technology non-contact sensing is available but must be relatively close to the surface to be measured for thickness. A UAV so equipped can be utilized for this task. It is also faster and therefore is a force multiplier for an inspection staff on projects.

Construction Site Security

Security guards are commonplace on many construction sites. Due to the large size of certain construction sites it is particularly difficult for these guards to adequately "see" the project during nighttime periods. People and vehicles give off "heat signatures" as compared to their background environment. A UAV equipped with a thermographic camera operating at night can help to spot a potential thief hiding in the darkness on a project. During the night the security guard can periodically over fly the site to visually detect these "heat signatures." Pinpointing the heat signature from a recently-parked vehicle outside a security fence or that of an intruder inside the site then helps direct the security force to potential trouble.

Construction Productivity Improvement

Overview of a site from the air can readily pinpoint productivity constraints that otherwise would not be readily noticeable from a ground view. Aerial views of equipment, material, and craft flow can therefore assist project management in improving productivity. Project management observing an operation close-up may unnerve craft personnel and their supervisors. The UAV perspective with camera abilities to zoom in from distant perspectives can help to eliminate these issues. Still craft personnel may have an issue with this UAV surveillance. However, it should be explained to project personnel that the goal is improvement of management. It is not a worker's fault if, as an example, the project site is poorly laid out which hinders productivity.

Construction Claims

Certain construction claims arise on jobsites including those from issues of weather delays, work interference, site restrictions, and site constraints. Aerial photography taken on a contemporaneous basis can document these issues to buttress or refute construction claims. Aerial views can often illustrate these issues with enhanced clarity as compared to ground-based photographs. The aerial photography from a UAV is immediately available rather than relying on a request for a conventional plane or helicopter that may be days away or into the next week. Given the costs of project delays and liquidated-damages issues, the cost of the UAV work provides a significant benefit in either proving or disproving a potential claim.

Web Cam vs. UAV Photography

Web cams have been commonplace on numerous construction sites for a number of years. A web cam is mounted on a pole or nearby building and provides users with a view of the construction site and its progress. Web cams have been utilized to provide a timelapse history of a construction project as well by snapping pictures on a predetermined interval to record over a period of weeks, months or years. Depending on the timelapse interval and review rate, a project of a year's duration, for example, can be reviewed in as short of timeframe as several minutes. If more detail will possibly be required, the review period can be extended out. The continually decreasing cost of video image storage on servers means that numerous images snapped during the construction day accumulated over a year can be stored at low cost.

The web cam has certain advantages compared to a UAV application for project photos. Once the web cam has been installed in an optimal location it can stay at that installation location with little attention. Only periodic maintenance may be required for lens cleaning and other minor tasks. Therefore the cost structure of web cam installation is that of first cost, any monthly charges, and periodic maintenance. The web cam view stays fixed at the same elevation so users are always receiving the same view of the project. This same point of view is helpful in assessing the overall progress and providing a timelapse history. The web cam photographic history can be helpful in documenting or refuting construction claims on a project. Web cams can also offer pan-tilt-zoom features to focus in on a certain aspect of the project so the project viewer has certain options. The web cam is always on so a viewer given the project access code can log in at any time without consuming the time of on-site project personnel to perform photographic tasks or work verification issues in certain cases. A home-office based scheduler, for example, can log in to the web cam to view project progress to update certain aspects of a CPM schedule without having to conduct a site visit.

There are disadvantages with web cams versus UAV photography. The web cam requires connectivity to the Internet which may not be available at remote project sites. The web cam needs to be mounted such that it will be useful during continuing project construction. With a horizontal project, web cams need to be continually moved with the progress of the project such as a highway or pipeline. With a vertical project such as a multi-story building, the web cam needs to be mounted high enough to be able to capture useful aspects of the project. If other buildings are nearby, permission may be then secured from these building owners to install a web cam on their building at a sufficient elevation to be usable during the project's duration. If permission is not forthcoming, the use of a web cam is problematic. Or buildings of sufficient height to permit a usable web cam platform may not be within practical camera range. Web cams are limited in camera viewing to their location unless multiple web cams are installed at the site. As construction progresses, web cam views can be impeded by project construction such as curtain wall construction blocking certain views.

The UAV has the ability to take photographs from a variety of elevations and is therefore not limited to a fixed location. Aerial views from various angles are available as well as views from inside a structure. The UAV platform therefore has substantial flexibility as compared to the web cam platform. The UAV obviously does not require a mounting platform since it can fly to almost any location thereby offering the user a multitude of choices. With high wind conditions UAVs are not flight capable whereas the web cam will not be affected in this environment. The key limitation of the UAV versus the web cam is that someone has to fly the UAV in order to capture photographic information. If project personnel are time-limited, UAV work may not get done whereas the web cam is working all the time. Therefore, the operator labor costs associated with a UAV must be factored into the equation. In addition, the UAV requires someone experienced in its operation to be effective.

The consideration of a UAV versus a web cam often should not be an either/or decision. The writers talked to several contractors who utilized both at their projects and felt both the UAV and the web cam offered them important benefits. The web cam took pictures/video every day on their projects whereas the UAV was utilized on a weekly or monthly basis as needed for other project aspects.

Federal Aviation Administration Restrictions and Legal Issues

In the United States, starting in 2007, the Federal Aviation Administration (FAA) imposed certain legal restrictions on the use of UAVs. For contractors operating outside the U.S. they may be in countries that have no such restrictions or in countries with similar restrictions. UAV users should check the regulations in their relevant jurisdiction. Within the United States, the FAA governs the use of civilian airspace. As an example, someone constructing a tall building near a commercial airport especially on flight paths in the U.S. will need to get FAA approval that the structure does not create a flight hazard. Historically, this FAA jurisdiction has either prevented the construction of certain structures, limited their height, or changed their location to gain compliance. The FAA is concerned about UAVs because of their potential to create problems for civilian aviation. As an example, a UAV intruding into a flight path and taken into a plane's jet engine could disable the engine creating the same problem as bird strikes that have brought down aircraft.

The FAA has a blanket restriction in that entities may not utilize UAVs for commercial applications. The FAA permits the utilization of UAVs for recreational use only at elevations limited to 400 feet. A question not yet answered by the FAA is that when a UAV is used for solely educational purposes such as at a non-profit public university whether this would be a commercial application or not? The FAA has also banned the use of UAVs near airports when the 400-foot elevation would intrude on a flight path. Notably the FAA has permitted law enforcement agencies to utilize UAVs on a county-wide or larger area basis in certain areas of the country.[3] Other public entities granted FAA approval for the use of UAVs has included federal agencies, universities, and state departments of transportation.[3] A review of the list of private entities granted FAA approval appear to be currently limited to defense contractors and others that actually manufacture UAVs.[4]

A contractor or educator utilizing a UAV inside a structure would not be subject to the FAA restrictions since the airspace within the confines of the structure obviously do not constitute commercial airspace. Thus a contractor performing inspection work with a UAV inside a domed stadium, an arena, a building's atrium, or other similar area would not be limited by FAA strictures. Thus a contractor could inspect the inside of a 60-story building's elevator shaft (≈ 600 feet) and not pay attention to the FAA 400-foot height restriction with no consequences.

Subcontractors such as commercial photography firms are getting around the restrictions on UAV-commercial-use limitations by not charging for UAV time. Instead their photographic services billing ignores UAV time and instead places this time in the editing category. Other subcontractors in this area such as inspection firms also do not separately bill out UAV time but place these expenses in other categories. Contractors self-performing work with UAVs currently fall into one of two categories. Either contractors are completely unaware that there are FAA restrictions on their UAV use or they ignore these restrictions. The FAA has attempted to fine one operator $10,000 for use of a UAV to perform commercial photography work.[7] This operator is currently litigating this fine and the ability of the FAA to impose restrictions on UAV use. Part of the lawsuit's contentions are that the 2007 FAA UAV Policy never went through the customary governmental requirements for public notice/comment provisions. In addition, the suit contends that the FAA incorrectly drew a distinction between permissible recreational-UAV use and non-permissible commercial-UAV use.

Conclusion

UAVs present many opportunities for those in the construction industry and for construction education. In a number of instances they can produce significant cost savings as compared to conventional techniques. For university budgets that are already constrained, a UAV provides a low-cost solution to explore aerial photographic, construction inspection techniques, and for other applications that otherwise would be impractical. Safety both in the academic environment and on the jobsite is a key consideration. Contractors and educators considering these will want to analyze potential costs, operator training, usable applications, and legal issues. Contractors and academics in the U.S. are under the jurisdiction of the FAA with regard to UAV usage when such usage is outside. A professor utilizing a UAV in a high-bay lab building or a contractor inspecting an indoor atrium space doesn't face any FAA restrictions. Contractors or educators operating in other countries may face the same types of FAA strictures or no regulation depending on the jurisdiction.

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