Usability and Limitations of Unmanned Aerial Vehicles in the US Construction Industry

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Abstract

The construction industry is facing major challenges in owner requirements and contractors' roles in terms of project delivery systems, LEED requirements, globalization, skilled work force shortages, increased role of suppliers, reduced cycle time requirements, and increased capital effectiveness requirements. In addition, construction industry is moving to fully integrated/automated project processes that resulting outsourcing, alliances, contractor consolidation, and experimentation. This article will highlight the existing and future issues and opportunities for using Unmanned Aerial Vehicles (UAVs) in construction. In the recent days, advances in unmanned aerial vehicle (UAV) technology has enabled these tools to become easier to use and afford in construction. In a budget-limited environment, these flexible technologies can help address owner needs in operations, maintenance, asset management and marketing while increasing safety and decreasing cost. This paper is written based on the literature survey and informal interviews with UAVs users in construction.

Keywords: Unmanned aerial vehicles, Drones, Construction industry, Construction management

1 Introduction

The increasing scope and complexity of construction projects, along with a greater number of externally imposed requirements, has expanded the challenge to project managers for successful completion. Increased competition and changing client demands are requiring the construction industry to address a wider range of issues than ever before in areas such as strategic analysis, worker problems, knowledge management, and emerging technologies (Banik and Barnes, 2002). The world economic big picture today is characterized by world population growth, a large number of developing countries, aging infrastructures, international competition, sophisticated approaches, and accelerating technological change. However, these can be used either as threats and/or opportunities in U.S. construction research and development to assimilate new technologies. (Banik and Barnes, 2002).

The construction project itself, has its own set of complexities. It involves the entire life cycle of a physical facility beginning with a 'gleam in the eye' of an owner who is exploring the need for the facility to its completion. The normal steps in the project life cycle are: conception, planning, authorization and financing, design, procurement, construction, start-up, operation/maintenance and dismantling. Each has a peculiar set of problems, and each needs an appropriate technology/strategy/management to move from one step to the next step.

Unmanned aerial vehicles (UAVs) are an emerging technology known for their role in military applications (Nisser and Westin 2006). More recently, the potential use of UAVs as tools in civilian environments has gained significant attention in domains such as agriculture, forestry, archaeology, architecture, and construction (Irizarry and Bastos, 2016). In addition, federal and state agencies in the United States have been operating UAVs for law enforcement or surveillance purposes. Current studies found in academic literature suggest uses of UAVs in the civil engineering, construction, and transportation fields for collecting terrestrial images, creating 3D models, bridge inspection, crack detection in buildings, highway traffic monitoring and simulation, construction education and construction safety (Puri et al. 2007; Rathinam et al. 2008; Hudzietz and Saripalli 2011; Barazzetti et al. 2010; Huang et al. 2010; Eschmann et al. 2012; Zhang and Elaksher 2012; Irizarry et al. 2012; Opfer

2014; Irizarry and Johnson 2014; Karan et al. 2014). It has been found that UAVs are extremely valuable in road construction and road damage, inventorying roadway structures and others (Barfuss et al. 2012).

2 Background

The most profound recent developments in construction are seen as the increasing complexity of many of its projects and organizations, the increasing technological complexity of projects, more complex interdependencies and variations in the relationships between its organizations and institutions, and proliferating regulations from government. At the project level, management has just begun to integrate design, procurement, and construction into one total process through innovative project delivery systems, total quality management (TQM), value engineering and constructability analysis. Based on previous and existing industry conditions, the author foresees the continuance of shortages of skilled workers, and technical and supervisory staff in terms of technological advancement.

Although there are significant changes happening in the construction industry, but most of the changes are in the use of advanced technology in respect to UAVs, 3D printing, Building Information Modeling (BIM) and Robots. Although it is easy to brush these technologies off as fads or luxuries until the industry as a whole understands some of the use cases that are being applied by integrating these emerging technologies. As each of the technologies mature, industry will be getting closer to building the structures completely automated and unmanned. This paper is focused on providing an overview on using UAVs in construction and their limitations for the US construction industry.

3 Unmanned aerial vehicle (UAV)

The definition of UAV according to FAA and its fundamentals are provided.

3.1 UAV Definition

The Federal Aviation Administration is the entity charged by the United States Congress to define the rules for the use of Unmanned aerial systems (UAS) in the U.S. National Airspace System (FAA 2012). The use of UASs is allowed only by special authorization from the FAA through a certificate of authorization (COA) (FAA 2015a).

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. (FAA, 2007) "

3.2 UAV Fundamentals

Remote-controlled (RC) planes and helicopters in the past were typically gas-engine powered vehicles. The advent of lithium-polymer batteries has replaced electric motors with weight savings and quieter along with ease of operation and maintenance. With this, increasingly-lightweight 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. 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 expected 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. 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.

4 UAV Cost-Effective Considerations

Aerial photography via conventional plane or helicopter can be an expensive items for a construction 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 are far lower compared to helicopters. It takes less time and skill to learn to capably operate a UAV as opposed to piloting planes and helicopters. 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 in a 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.

5 UAV Jobsite Safety and Insurance Concerns

Operators utilize UAV must have safety as a key concern on any jobsite. UAV helicopter blades turn at thousands of revolutions per minutes (RPM) and have the potential to cause more injuries compared to UAVs (Nisser 2006). UAV operators usually read and follow manufacturer's safety/operational instructions related to their particular unit before the operations to 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 can quickly fall to the ground with little or no warning due to mechanical failure or loss of power. Due to these considerations, the operators when possible should avoid hovering or flying the unit over areas of the project where people are on the ground. For inspection or photographic tasks in occupied areas, UAVs can be used in after work or on even weekends.

Another safety consideration with UAVs concerns 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 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. With all the advantages of using UAVs, uses also brings several liability and insurance issues which are

- Operator errors causing personal injury and property damage to others including operators
- Damage itself and associated equipments
- Product liability of manufacturers, suppliers, assemblers, installers and apparent manufacturers
- Invasion of privacy, trespass and property rights

Although currently USA does not need to have insurance for commercial and recreational uses, but multiple companies are offering UAV insurance to minimize liabilities.

6 Platform Choices

Most available platforms come direct from the manufacturer fully assembled with minor tasks such as battery installation the only remaining task. 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) (Dragonfly 2013, Tradelius 2006). 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.

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.

A common choice in UAV acquisition is choice of power source between gas engines, gas turbines or battery power. 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.

7 Costs and Selections

Usually contractors don't like to spend a significant amount of money on UVAs - a few hundred dollars to several thousand dollars. UAV toys would be those items typically costing in the range of $100 or less, can complete some works. 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. 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 including environmental issues, flight-time issues, short flying time and payload issues. To be useful, UAVs 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.

Instead, contractors need to spend more when acquiring UAVs to satisfy their requirements. 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 -13°F to 100°F and in maximum winds of up to 18 mph. 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.

8 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.

Applications besides standard aerial photography can include inspection tasks, productivity surveys, marketing and interference documentation related to construction claims.

8.1 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 monito job progress. 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.

8.2 Construction Estimating

Site visits to a proposed project site are a key element prior to estimating the cost of a project. Site visits can also be time consuming for estimating staffs that typically 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. There are some roofing contractors that utilize UAVs for roofing estimates (Opfer and Shields, 2014). 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 climbing works. Roofing contractors therefore can utilize UAVs to yield both safety benefits and time savings in their estimating work.

8.3 Construction Inspection

UAVs can assist in certain construction inspection tasks but have limitation 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 (Eschmann et el., 2012). 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. 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. In a recent study Irizarry and Johnson found that satisfaction for construction inspection through UVAs is very high.

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. A UAV so equipped with sensors can be utilized for this task. It is also faster and therefore is a force multiplier for an inspection staff on projects.

8.4 Construction Site Security

Security guards are commonly used on many construction sites for site safety. Due to the large size of certain construction sites it is particularly difficult for these guards to adequately see the project during the night. 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 by visually detecting 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 (Opfer and Shields, 2014). Whether company likes to take preventative measures to make sure the job is being done right and safely, or needs to verify the actions of someone in particular, today's camera-equipped drones can be very helpful.

8.5 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.

If company likes to keep its workers safe and productive, Drones can patrol the area to keep an eye on everyone in general or to conduct surveillance on a specific person or group who might not be following protocol. Today's drones are non-invasive and in many instances the workers may not even be aware that they are under surveillance.

8.6 Marketing and Promotions

Savvy construction companies may use drones to film aerial shots of the area prior to development. Along with scale models and 3D renderings of the finished product, sky-high shots of the area from multiple angles help potential clients visualize the transformation of the barren land. If company likes to stand out to potential clients and help them see how their ideas can become reality, some construction companies consider adding drone photography and videos as a sales tools. This strategy can also be used to convince communities, task forces and policy makers of the viability of the project. Drones are also a helpful way to provide updates to clients who are unable to visit the area.

8.7 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 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.

9 Conclusion

From the existing literature and discussion with many contractors, it has been found that UAVs present many opportunities for those in the construction industry if properly used. In a number of instances, they can produce significant cost savings and improve safety as compared to conventional techniques. UAV provides a low-cost solution to explore aerial photographic, construction inspection techniques, and for other applications that otherwise would be impractical. Contractors should analyze potential costs, operator training, usable applications, and legal issues before starting their uses on construction sites.

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