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Opportunities for UAV's in Construction Planning, Performance and Contract Close-Out

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Abstract

Quadcopter drones and other unmanned autonomous vehicles (UAV's) have become common-place and their use is widespread among consumers and professionals in numerous industries. Aerial imagery and video can provide useful perspectives and have great value in communicating progress, for use in documentation of site activity and for use in marketing services. Drones, either through imagery or LIDAR, can further provide quick and accurate surveying information, which is valuable for positioning of facilities and activities. LIDAR data can also be used effectively for quality control and for quantity measurement. Imagery also has further applications in safety evaluation, productivity improvement, security and real-time job-site monitoring. Such additional uses have the potential for making a real impact on successful project delivery while increasing and competitiveness. Progressive construction companies and service providers throughout the globe recognize this potential and see significant promise for tangible return on investment. This paper will evaluate these opportunities for quadcopters and other UAV's based on experiences of the authors in using drones in Dubai and in the United States. The examination concludes with evaluation of the opportunities and avenues for research using UAV's.

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1. Introduction

Unmanned aerial vehicles (UAV's), commonly known as drones, have become ubiquitous throughout the globe for hobbyists and within professional communities. Surveying and construction are one of notable profession where the integration of unmanned quadcopters have become commonplace over the last decade. Today, drones are frequently routinely employed somewhere in the delivery of a construction project along the life-cycle from concept through completion. This increase in the use of drones makes sense as resulting aerial imagery has great value in documenting, communicating and recording current conditions with visual perspectives previously unavailable without large expense. Considering just aerial imagery, the prevalence of drones makes sense at nearly all levels and for all participants in the project delivery process. Planners and designers can use aerial imagery in conceptual and preliminary design. Construction professionals can use imagery to layout construction sites and monitor job-site activity, owners can use likewise use the imagery for marketing and business development.

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To use drones for these purposes requires very little investment since low-priced commercial off-the-shelf quadcopter drones have sufficient photographic and video resolution and capture capabilities at high-definition or 4K resolutions. All that is required to implement such low-cost solutions is proficiency with drone operation and proper licensure, where and if such licensure is required. Many of these drones have become very easy to fly with drone software assisting with smooth flight operations. With these products, there is drastically increased availability of image and video-based information for construction project delivery. While video capability may be a primary attraction of drones, there are many other applications with remote sensing and delivery which could be explored. This examination will begin by looking at drones available for application in construction with a focus on low-cost quad and hexacopters, which have four and six propellers respectively. Known commercial or public-domain applications of drones will be summarized followed by examination of research activity for construction and across the project life-cycle. The examination will conclude with a discussion of opportunities for research and application of drones to improve construction project delivery.

2. Consumer and Commercial Drones

Unmanned aerial vehicles (UAV's) are widely used and commonplace in many different commercial industries, such as agriculture, surveying, forestry and ecology, and even in video game development. There are numerous manufacturers of UAV quad-copter drones that serve the needs of the commercial marketplace. Drones have different selling points, including range and flight time, carrying capacity and videographic/photographic capabilities. Examples of low-cost commercial drones for video capture by DJI, a leading consumer drone manufacturer, are shown in Figure 1. There are many other manufacturers selling consumer drones and other noteworthy providers of professional-level commercial drones and similar products may be found within the marketplace.

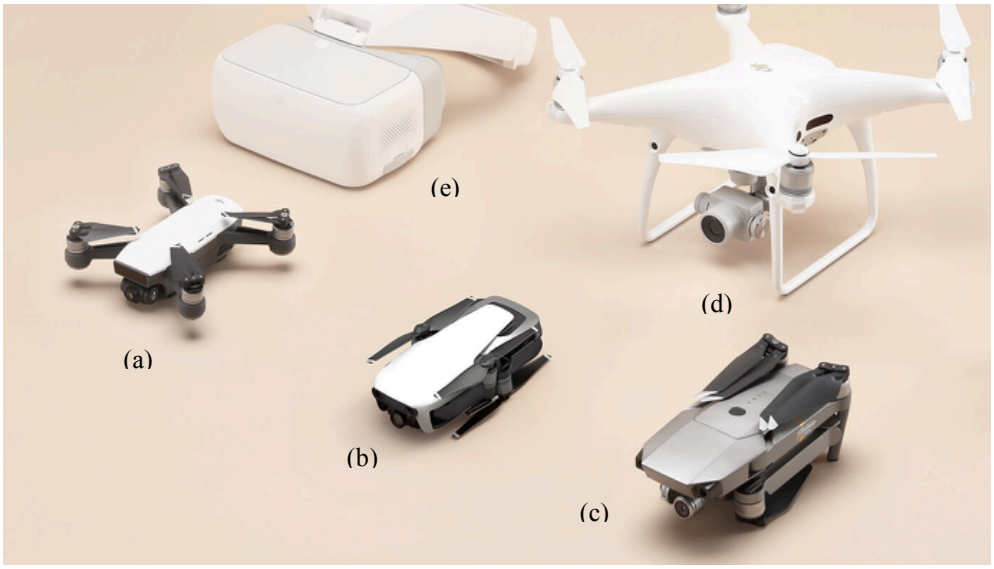

Figure 1: DJI Consumer Drones [source: DJI.com, accessed 04/29/2018]

Low cost drones come in many form-factors and with a wide variety of capabilities. Shown in Figure 1 are the Spark (a), Mavic Air (b), Mavic/Mavic Pro (c), and the Phantom 4 Series (d). These drones have differing camera resolutions, flight-times, sizes, and gimbal capabilities. The gimbal allows the camera to remain stable and somewhat isolated from the rotation of the drone. DJI Goggles shown in Figure 1(e) allow the user to incorporate the use of head-tracking technology and immerses the operator in the video being captured through dual screen projection.

Commercial Drones with increased power and size, increased flight times and ranges, and respectable flight load carrying capacity are available within the marketplace and being used within the industry. These drones are more powerful and faster thereby increasing the range and the amount of imagery that can be collected during a flight. Better batteries promise to increase the flying time further which would advance the capabilities of the drones for construction applications. Lifting capacities of larger quadcopter drones permit payloads that can further extend the application of the drone beyond photographic and video applications. For instance, aerial mounted LIDAR enables quadcopter

drones to capture 3D laser scanning data and develop digital terrain models and digital elevation models. An example of an aerial mounted LIDAR unit is shown in Figure 2. Significant accuracy results when the approach is referenced to georeferenced control points. LIDAR and videography can also be implemented through fixed-wing drones, which would dramatically increase coverage area. Fixed wing drones have been found to be particularly useful for highway planning and programming given increased range and flight times. They will not be considered as part of this examination. Many of the techniques discussed for copter-drones could be equally applied to fixed wing drones.

Figure 2: Commercial Drone with Aerial Mounted LIDAR [source: Cargyrak, Wikimedia Commons, accessed 4/29/2018]

3. Uses and Applications of Drones in Construction

Cursory internet searches reveal a large number of commercial providers for drone base imagery and videography. There are numerous examples of aerial imagery provided on the web, which is typically presented to show and market drone services or to communicate information about a particular project in question. A typical image shows site progress and current status, such as that shown in Figure 3 depicting the current status of the construction of a school gymnasium at the end of March 2018.

Figure 3: Drone captured imagery of construction status [Source: Wikimedia Commons, March 2018]

Sites marketing the benefits of drone-based aerial imagery frequently provide rationale and discussion of opportunities for benefit of the approach throughout the project life-cycle. Opportunities discussed on various sites include:

- Construction progress photography and development of promotional and marketing materials – This could be for documenting progress or static imagery could be "turned into a time-lapse video or GIF' [1]
- Preconstruction planning and evaluation visual surveying of site terrain – "Before ground is broken and after it is cleared, you can get a detailed aerial view of the proposed construction site to use for logistics and production planning." [1]
- Visual inspection and auditing – With line-of-sight consumer drones, video can be live-streamed allowing real-time inspection of conditions on the job-site. This could be used as an effective tool to evaluate construction conditions in hard to reach areas to ensure quality and successful completion/progress of activities.
- Safety improvement – Drones can also be used to evaluate workers in hazardous areas removing the inspector from the hazardous area and providing frequent real-time feedback. This can mitigate risks and cut costs [2]
- Volumetric measurement – "using accurate aerial photogrammetry techniques, large areas (2D and 3D) can be measured to within CM accuracy. This can be accomplished quickly, cost effectively and with minimal disruption to the day to day workings of the site." [3]
- 3D Modeling – Drone based LIDAR can be used for developing digital terrain models and digital elevation models. Photogrammetry can also be utilized and a study on commercial drone industry trends revealed significant increases in the use of drones to develop 3D models. [4]

In 2015, a survey was performed by Navigant to evaluate applications of drones in the construction industry. The survey engaged the following with the percentage of respondents indicated in parenthesis: contractors (38%), construction managers (13%), owners/owner's reps (13%), architects/engineers (14%), and others (9%) or unspecified (13%). The survey asked participants to indicate which applications they would like to use a drone and the results are summarized in Table 1. Potential indicates the respondent's opinion on whether drones are useful the specified purpose in construction. Percent actual use indicates the percentage that the same respondents had actually employed drones. Of interest, for the applications specified, the majority of respondents (69%) also indicated that they would prefer to employ drones in-house rather than hire a commercial service. Also, when asked, the primary concern expressed by the respondents regarding implementation of the technologies was legal issues with 76.2% indicating that this was the primary or secondary concern holding back implementation. Privacy, learning curves and costs were not significant concerns of the respondents when considering issues that might preclude the implementation of drones. The Navigant report also indicated that, "[i]n the US, at the time of [the] report, the FAA rules on commercial use [of drones] are clearly holding back more widespread use." [5]

Table 1: Use of Drones by Construction Participants (Navigant Survey) [5]

Applications	% Potential	% Actual Use
Aerial photography to track job progress	92%	76%
Inspection of areas difficult or impossible to access	80%	59%
Aerial photography for marketing	74%	66%
Aerial photography for logistics and production planning	64%	45%
Safety monitoring and support	57%	28%
Land surveying, thermal imaging, laser scanning or other data collection	52%	26%
Transporting materials	15%	0%
Other	8%	10%

Tatum and Liu [6] discussed the implementation of drones recognizing the primary application, based on FAA authorized commercial exemptions, to be aerial photography and videography (65% of applications). Approximately 7% of the 1400 applications were for construction use, though it would be expected that a sizeable portion of use of drones in construction would be for aerial photography and videography. This is recognized by the authors whom summarize available literature and state that "[c]onstruction companies have primarily been using [drones] to

provide real time reconnaissance of this jobsites and to provide high-definition (HD) video and still images for publicity and documentation of progress." [6, 7] Tatum and Liu discuss the use of the technology with respect to aerial photography, surveying, inspections and safety/security monitoring. To learn more about the commercial use of drones in the construction industry, a survey was conducted among construction professionals. For companies whom had used drones, 57% indicated that the drones provided cost advantage and 42% indicated that the drones provided positive schedule impacts [6]. The survey inquired as to the perceived risks of implementing drones. There was a small response rate to this question but the results were contrarian when compared to the Navigant survey. The "top four risks were identified [as] 1) the risk of crashing the [drone], 2) the risk of causing personal injury to the employee or civilians, 3) the risk of privacy concerns, and 4) the risk of causing property damage (either on the jobsite or on surrounding properties)." [6]

4. Current Research in the Use of Drones for Construction

Research activities on drones for construction were explored through a search of peer-reviewed journals and conferences. Ham, Han, Lin and Golparvar-Fard explored and summarized the use of drones for visual assessment and monitoring of civil infrastructure systems [8]. This study focused on reviewing methods that streamline "collection, analysis, visualization, and communication of the visual data captured," with a vision towards "automatic construction monitoring and civil infrastructure condition assessment." [8] The authors recognized image based approaches for progress monitoring, site monitoring, building inspection, building measurement, surveying and safety inspection. Published papers in each of these areas were identified and evaluated, data analytics available were summarized and the integration of the approaches with BIM were identified. The authors recognize that drones, "provide an unprecedented mechanism for inexpensive, easy, and quick documentation [but] … that there are still numerous open problems for further research." [8] This is especially true when trying to automate the use of the imagery and video collected.

Liu, et. al., [9] focused on the electromechanical systems and algorithms for mapping and image processing with a summary of civil engineering applications. Specific applications discussed including the use of UAV's for seismic risk assessment, transportation, construction management, and disaster response. For seismic risk assessment, through the new solutions the collection of building inventory data, enhanced efficiency of post-earthquake reconnaissance, and establishment of reliable seismic fragility databases for buildings and infrastructure. With disaster response, the authors discussed assessments, lifeline prioritization and information dissemination. For transportation, applications focused on real time traffic congestion mitigation. For construction, the authors focused on better decision making with enhance visual information, especially with respect to improved risk management. The authors also discussed the development and use of enhanced 3D models of the construction site.

Research papers have also explored the potential of drones of for construction safety [10], for mapping and earthquake response [11], for visual inspection in a wide-variety of applications, for security and materials management [12]. Researchers have also been exploring whether drones could be used to perform the construction activity itself. Of note is research performed in collaboration between Université catholique de Louvain (UCL) and the Massachusetts Institute of Technology (MIT) on masonry construction [13], which was shown to be viable and efficient given re-design of the masonry units.

5. Future Application and Research in the Use of Drones for Construction

In Tatum and Liu's survey, participants were asked to speculate as to future uses of drones. Responses included: "automated employee check-in/check-out, automated safety checks, scanning RFID tags on materials in laydown areas for inventory, material delivery, parts delivery, remote job walks, preview views from a building prior to construction, thermal scanning of utility scale PV plants, [and] interior missions." [6]. Dupont, et. al., explored the integration of UAV's with BIM as a method for improving construction productivity and identified coupled applications to integrate site imagery into the BIM model, to perform autonomous and regular monitoring of the construction site, and to automate construction tasks, especially through integration with autonomous construction vehicles. [14].

Certain applications for drones have already proven their effectiveness and have shown tangible return on investment. This include surveying applications, progress reports, imagery for communication among parties, and development of promotional and marketing materials. It would be expected that more drone activity would be seen for these purposes in the future. Site inspections are an obvious area where the use of drones will expand. Permitting a real time visual 'look' at conditions that might be difficult to get to or hazardous provides numerous benefits.

Research on image processing and automation will enable the development of automated inspections, which could have significant impact on quality and safety. Right now, the use of drones for inspection purposes is dependent upon personnel to examine the video; however, as research advances and automation increases, drone-based inspection will become more prevalent.

Survey respondents indicated that there is a use for remote job-site walks. Streaming a live-feed through virtual reality glasses provides a valuable tool for off-site professionals to 'experience' and 'see' the site conditions in a new way. This could be facilitated with the DJI goggles or with Oculus integrated through BIM with a connection to the drone video. It is expected that as the technology becomes more sophisticated and seamless, owners and architects/engineers may drive the use of such virtual walk through contract.

Scanning opportunities have been discussed in terms of LIDAR and research was identified that integrated drones with RFID's for inventory management and/or security application. Thermal imaging could also be employed on drones, which could be used effectively as a quality control tool. Drones and RFID tags could be used for tracking of any time of asset on the job-site, be it material, tools or even safety equipment worn by personnel. RFID clothing has already found a niche market outside of construction and could be employed to track personnel and correlate locations with work performance. This would ideally simplify productivity evaluation, which would provide useful real-time information for project control.

Material and parts delivery were indicated through the survey performed by Tatum and Liu as a future use for drones in construction. [6]. Retailers in the United States, such as Amazon, have been exploring the use of drones for package delivery. Government agencies in the United Arab Emirates have explored the use of drones for delivery of official documents. Drones have also been explored to rapidly deploy life-saving equipment, such as defibrillators, or medicine, such as Epinephrine/Epi-pens. The feasibility of using drones for delivery has been proven and extension to the construction site could provide benefit. For instance, drones could be implemented to delivery small tools and light-weight construction materials throughout a job-site.

Many of these uses for drones which have been discussed have already seen application in construction or a parallel industry, such as retail. Additional research is required to add capabilities, such as better automation or image processing. As the technology advances, it is expected that applications will become commonplace and the use of drones even more pervasive in the construction industry. The area with little real-time application at this point is the use of drones to perform the construction activity. It could be argued that such application is a complex form of material delivery; however, the challenge and the value is to re-think how the system can be developed to permit delivery and assembly in a fast and reliable matter. This has been shown to be effective through the research on masonry construction. Other applications could be explored and such approaches may have significant long-term impact on construction practice.

6. Conclusions

The examination began by recognizing the transformation that has occurred over the last decade of construction practice with respect the use of unmanned autonomous vehicles (UAV's) in construction, otherwise known as drones. Drones are ubiquitous and widely employed, most frequently, for capturing of imagery and videos regarding construction site conditions. The information is then used for wide variety of purposes, including but not limited to: planning, for site monitoring, for safety evaluation, for promotion and marketing, and for surveying. Drones can also be coupled with LIDAR for surveying purposes and the development of digital terrain models and digital elevation models. Thermal imaging cameras can also be employed for a variety of purposes, such as quality control. Photographic, video and live-stream data can further be used for monitoring, control, inspection and so on, when accessed and acted upon by experienced professional personnel. As research advances, more automation will be integrated and the technology will become more pervasive. For instance, image processing techniques can be used to automatically highly safety hazards and bring them to the attention of safety management personnel. Additional research will also continue to expand the reach and develop new ways to use drones, such as for time goes on, more natural hazard mitigation and for reconnaissance activities of existing buildings and sites. Applications developed for other industry, such as package delivery, will further have benefit for the construction industry which could make use of drones for small tool and light material delivery. But perhaps the most exciting application of the use of drones involves research being performed to integrate the drone into the actual physical activity construction, such as has been seen with the research on masonry construction. As creativity continues to expand, more construction processes can be redefined to employ drones for positive benefit in order to advance the industry.

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