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APPLICATIONS OF UNMANNED AERIAL VEHICLES IN CONSTRUCTION WITH A CASE STUDY ON LEVEE INSPECTION

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Abstract
The history of Unmanned Aircraft Vehicles (UAVs), or drones, can be traced back as far as the late 19th century. Since early 2000's, technological advancement of UAV began to accelerate rapidly. As a result, new affordable and simplistic UAVs have quickly emerged in the field of building construction, especially in the areas of filed inspection, construction progress monitoring, site logistic management, safety control and earth work estimation. This paper reviews the current status of UAV implementation in construction, including its hardware and software development and applications on construction jobsites. A case study is also presented on the procedure and cost anaylsis of using a UAV for a levee system inspection. In the conclusion, this paper includes discussion of potential benefits of UAVs for specific construction processes in the future.

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Keywords: construction, drone, inspection, levee, uav.

1. Introduction

The genesis of Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, dates back to 1849 Italy during the first Italian war of Independence when the Austrian Empire devised a system of unmanned hot air balloons that dropped bombs on Venice. Later, during the American Civil war and the Spanish American war, hot air balloons and kites were used to gather and telegraph reconnaissance. Military needs were the predominant driving force behind developing Unmanned Aircraft Systems (UASs) technology until the 21st century. The only commercial developments were iterations in radio-controlled toy technology until early 2000's. Military practices, on the other hand, were quickly developing largely due to innovations in manned aviation technology and practices [1].

In the last decade, UAV's have being used in various fields and in different purposes by equipping them with cameras, sensors, or other intelligent devices providing useful information for different applications. Their commercial use has exploded into numerous industries including recreational, education, photography/videography, disaster response efforts, deliveries of packages, insurance, marketing, engineering, construction, aviation, mapping, tourism, utilities, maritime, and mining [2]. Significant attention has been placed on the use of drones in architecture, engineering and construction (AEC) [3]. With development of real-time monitoring technologies, UAVs provide many positive applications to control the construction process of buildings, bridges, and infrastructure systems through capturing videos and images from the projects and processing the data gathered using various photogrammetry software packages. Some studies have considered UAVs for checking structures to assist in maintenance. Moreover, they have been used in various transportation areas such as monitoring of roads during and after emergency incidents, severe weather conditions, road surface distress, repair and maintenance activities including management of the work site to enhance the safety of workers.rCompared to traditional systems, UAVs can fly over the work environment covering a large area in a short amount of time [4].

2. Construction UAVs

The construction industry has already seen a huge increase in the use of UAVs during the construction process. This section introduces various hardware, software and applications of UAVs that are currently being used in construction.

2.1. Hardware

UAVs can range in design and size depending on its uses. As shown in Figure 1, there are four main types of commercially used UAVs: multi-rotor, fixed-wing, single-rotor helicopters and fixed-wing hybrid vertical take-off and landing (VTOL) vehicles.

Multi-rotor drones have multiple propellers and were developed for vertical take-off and landing. Having multiple propellers allows the drone to have more maneuverability and stability. Fixed-wing drone have one single wing on both side of the body and requires catapult or a runway to get off the ground. This type of drone is typically used to cover large distances or areas. The single-rotor helicopter is just a smaller version of its manned counterpart. These are rarely seen in construction applications. Lastly, then newest type of drone is the fixed-wing hybrid VTOL. It is capable of longer flight duration like the fixed-wing drone with the vertical takeoff and landing capability of a multi-rotor drone. A good example is one developed by Amazon for package deliveries. See Fig. 1 below [5,13].

a. Multi Rotor Drone

b. Fixed-Wing Drone

c. Helicopter Drone

d. Fixed-Wing Hybrid VTOL

Fig 1. Four Basic Types of Drones

Because of their capabilities and affordability, several particular UAV manufacturers and models are commonly used in construction. They include the DJI Inspire series, DJI Phantom series, DJI Mavic series, Yuneec Typhoon, Skydio S2/X2, and Parrot Ebee. These UAVs range in price and flight time. The flight time range is from 25 to 45 minutes. The price ranges between $800 and $30,000 [6]. Refer to Fig, 2 below.

Fig 2. UAVs Commonly Used in Construction

2.2. Software

There are multiple software platforms available in the market used for processing data captured from construction jobsites by UAVs. Aside from the standard software that comes with a commercial grade UAV there are multiple software companies that offer greater capabilities. The company, Pix4D has developed a software that can generate topographic surveys, a visual record of excavations, stockpile measurements, cut and fill calculations and haul cost estimates based on distance [7]. DroneDeploy, a cloud-based UAV data processing platform, gives contractors access to visual documentation as well as many of the features Pix4D provides. Both of these software packages use photogrammetry to produce a point cloud similar to a laser scan which is useful for measuring accurate distances from the photographic data. Chet World-Class Software Solutions offer a more customized software development catered to individual large scale projects [8]. Skydio produces a drone capable of flying indoors and can autonomously map its own flight path to gather data for a photogramic point cloud. The availability of these types of software provides many uses for the UAVs in addition to simply providing aerial photographs.

3. Applications of UAVs in Construction

Some common usages of UAVs on construction sites include: 1) project progress controls, 2) inspection, 3) testing, 4) surveying, and 5) safety monitoring. The following sections further describe some of these more common applications.

3.1. Software

Project progress monitoring of construction site is one of the important tasks in the construction projects. The progress assessment provides the chance of recognizing the current as-built conditions of a project efficiently, to identify disparities between the as-built and as-planned drawings, and to aid in deciding on corrective actions. Progress monitoring is considered a critical factor to deliver projects on time, within budget, and with expected quality. Progress monitoring has become one of the most difficult tasks due to the complexity and interdependency of activities.

With the development of various technologies for project progress monitoring, UAVs can be more useful than other methods. It has been suggested by the Associated General Contractors of America (AGC) that UAVs can document a projects progress, providing a visual record being capable of reducing later disputes between contractors and landowners. Drones can gather data from many vantage points throughout the project. By using real-time images and videos, construction managers can create a relationship between preconstruction and construction phases [4].

3.2. Inspection

During construction, inspection of work is critical to a project's success or failure. Poor quality control can lead to tear-out, rework, increased costs and schedule impacts. Traditionally inspections are done by individuals walking through the jobsite, visually checking components of work throughout construction. Sometimes these inspections can be difficult and require specialized training, such as inspections in confined spaces, inspections taking place at elevated heights with special equipment, or hazardous areas such as power plants or waterways. With the introduction of UAVs, many of these inspections can be accomplished using UAVs with high resolution cameras. It has been shown that inspections performed with UAVs are just as effective as being at the location in person. UAVs equipped with the right surveillance instruments can even take measurements on the fly if there are dimensions that may be in question during an inspection flight.

Inspections of dangerous or hazardous locations is an area where UAVs have been put to use and have had tremendous success in terms, of quality, production, costs, schedule, and safety. Construction activities such as inspecting exteriors of high-rise buildings or the interiors of power plant reactors have always been difficult and expensive due to high safety concerns and inaccessibility. With UAVs, safety issues are minimal the ability to access certain areas is enhanced. Figure 3 shows the quality of images captured using a UAV to inspect a high-rise building's façade for cracks and separation in caulking between stones [9,10]. UAVs can also be used to inspect curtain wall systems for building renovations as shown in Fig. 3.

Fig. 3. Drone Inspection of a High-Rise Building

As construction is progressing on a project site, contractors must also manage expectations of the customers they are working for and provide them updated information on a regular basis. In most cases this is either project reports that are developed and sent to customers or periodic onsite inspections by the customers or a representative of the customer. Real-time imagery, available via the internet, that UAVs can provide, gives both the contractor and the customer a valuable tool. A fly-by video or several aerial high-resolution images can be sent to customers in seconds for their review of how the work is progressing, and this is increasingly valuable for remote customers who may not be close to the site. It's an incredible selling point for UAV usage on construction projects as it makes reporting to customers simple and effective.

3.3. Testing

Testing on construction projects can vary greatly depending on type of the project and stage of the construction process. For example, in building construction the early stages may have various testing requirements for soils and earthwork activities such as compaction and soil composition. Later, there may be testing on the structural framing and then toward project end there may be testing of the building systems such as the HVAC, fire alarm, electrical components, lighting, etc. UAVs equipped with the necessary equipment can assist in these efforts. Another application is building envelope testing or air barrier testing. Using UAVs for this testing can have benefit in gathering data especially in hard to reach areas or on large roof structures. Figure 4 shows thermal imagery captured using an UAV equipped with a FLIR thermal camera, which gives preliminary data to testers and reveals areas that may have higher levels of air leakage as depicted in Fig. 4 below [11].

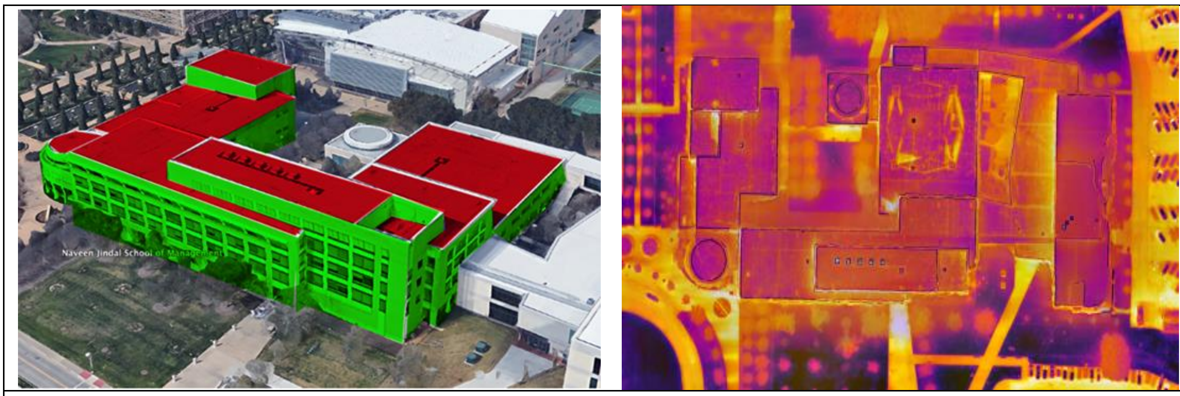

Fig. 4. Thermal Imagery of Roof Captured by a UAV

While this is valuable to the process of building envelope testing and roof inspections, it doesn't completely change how the testing procedures are done. There are still many other aspects of this testing where inspections must be done in person and other various testing apparatus used to complete the full testing.

3.4. Surveying

3D mapping is a very important aspect of geological surveying. In recent years, the use of UAV for visual surveying as well as generation of 3D images of sites has steadily become relevant. UAV technologies can collect high-resolution images that are then transformed into 3D surface models and can be used for topographic mapping, volumetric calculations, or for showing the construction site in 3D form. Many UAV systems finding application in the civil domain have already offered cost and time competitive alternatives to the conventional surveying applications. At the construction phase, the same UAVs can be employed to provide a 3D birds eye view of the site, making efficient surface or volume measurements possible as shown in Fig 5 [11]. The UAV is also able to derive both geometry and texture data from aerial images.

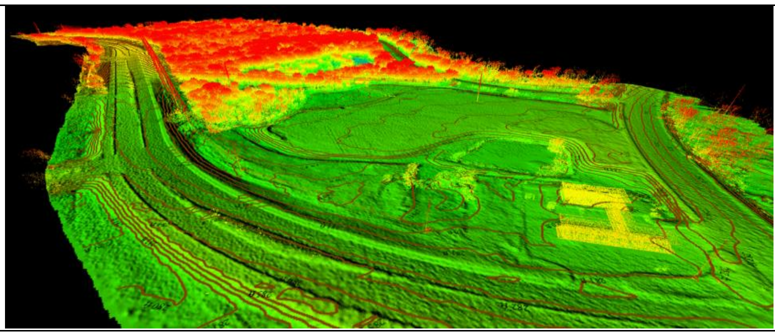

Fig 5. 3D Survey of Site Using UAV Data

3.5. Safety Enhancement and Monitoring

Research studies and statistics indicate that construction sites are known as one of the most dangerous workplaces all over the world. Since there are high risks in construction and worker-hazard interactions are unavoidable, safety systems have been developed to prevent fatalities and accidents. Nearly all accidents in the work environment can be prevented through applying efficient safety inspection during the project. Worker safety would be enhanced through elimination of some of the high-elevation inspections by workers, such as inspecting caulking joints in a tall building environment, using drones instead [12].

UAVs are also very helpful to warn about unsafe situations in large construction projects from site preparation to project completion. The new technology can fly over the construction environment collecting the real-time information of personnel and equipment, hazardous materials, moving equipment as well as the blind spots on the construction site in order to prevent unsafe conditions before accidents happen. UAVs help safety managers become aware of unsafe conditions or locations that may exist on the construction site. They are capable of presenting real-time feedback against hazardous situations at any time [12].

4. A Case Study of Using UAVs for Levee System Inspection

Levee inspections are typically conducted by deploying field inspection crews to walk the entire length of the levee systems to identify and record the conditions of the levee system, which ultimately produce an inspection report used to document the specific condition, recommended repairs, recommended maintenance items, and provides an overall rating of Acceptable, Minimally Acceptable, or Unacceptable. The results of the inspection help the individual owners and sponsors identify areas of immediate or routine maintenance attention in order to ensure the levee system continues to function as designed. These inspections typically focus on the condition of unwanted vegetation growth within the identified clear space (15 feet), turf cover, encroachments, stop log condition, sand bag inventory/supply, animal control, erosion, scours, slides, and drainage structure obstruction.

4.1. Conventional Levee Inspection Procedure and Cost Assessment

An interview was conducted with a Levee Safety Program Management (LSPM) crew in the US's state of Oklahoma to gather information about the procedures, duties, and process involved in conducting a field-led levee inspection. A typical routine inspection begins with the crew chief gathering all previous inspection data and equipment and scheduling a specific inspection date and time with the levee maintenance crew. Once on site, following interviews with the levee maintenance personnel and reviews of their maintenance records, the LSPM crew walks the length of the levee system and visually inspects, photographs, and documents any noted deficiencies or areas of dilapidated maintenance. This information is captured in hand held notes and electronic tablets which are later referenced and used for development of the written levee inspection reports. Budgetary cost information was also gathered during this interview and was utilized for development of an average cost for field inspections. This cost estimate was created specifically for use of this research paper and provides an average, assumed cost, based on typical inspection procedures. For the basis of this research the following assumptions were made: crew size would include three inspectors and one driver, the crew would average 5 miles per day, an extra day was given for communications with the levee maintenance personnel and reviewing of maintenance records, each crew member reserved their own hotel room, and one vehicle was reserved. Additional assumptions are provided in the list in Table 1. Based on this analysis, the total cost of a boots-on-the-ground levee inspection (without the use of a drone) would cost an average of $23,029.50.

Table 1. Levee Inspection Cost Estimate

CREW LIST:	RATE	HOURS	TOTAL
Levee Safety Program Mgr	$ 130.00	40	$ 5,200.00
Inspector 1	$ 120.00	40	$ 4,800.00
Inspector 2	$ 120.00	40	$ 4,800.00
Driver	$ 120.00	40	$ 4,800.00
Administrator/Clerk	$ 100.00	4	$ 400.00
TOTAL LABOR>>			$ 20,000.00

OTHER DIRECT COSTS	RATE	QUANTITY	TOTAL COST
Partial Per Diem (First/Last Day)	$ 41.25	8	$ 330.00
Full Per Diem	$ 55.00	12	$ 660.00
MILEAGE	$ 0.58	500	$ 287.50
Lodging	$ 96.00	12	$ 1,152.00
Tolls	$ 10.00	10	$ 100.00
Supplies	$ 500.00	1	$ 500.00
SUBTOTAL ODCs>>>			$ 3,029.50
GRAND TOTAL			$ 23,029.50

Assumptions:

1. GSA Pay Scale for Labor (overhead included).
2. Standard GSA per diem, lodging, and mileage rates apply.
3. Crew of 3 inspectors and 1 driver.
4. One day provided for each mobilization and demobilization.
5. Three day inspection (5 mile average per day with one day added for interviews and record reviews.
6. Work day equals 8 hours.
7. Estimate is for the inspection component only. Time is not included for development of the levee inspection report.

4.2. UAV-Involved Levee Inspection Procedure and Cost Assessment

It was learned from interviews with LPSM personnel that the levee inspection process would be no different for UAV-involved inspections than the conventional methods. Based on the available technology, UAV systems are currently utilized to enhance the quality of the inspection, rather than enhancing the timing for completion of the inspection. Traditional aerial imagery is valuable data for inclusion in the inspection reports; however, the imagery is typically limited to the top of vegetation and is also subject to weather, tree/vegetation cover, and shadows. Additionally, the UAV is operated with a separate, licensed crew involving one pilot and one spotter. The type of data collected and produced is directly dependent upon the software used for data analysis as well as the capabilities of the technicians running the analyses.

Table 2. Drone-Involved Levee Inspection Cost Estimate

CREW LIST:	RATE	HOURS	COST
Levee Safety Program Mgr	$ 130.00	40	$ 5,200.00
Inspector 1	$ 120.00	40	$ 4,800.00
Inspector 2	$ 120.00	40	$ 4,800.00
Driver	$ 120.00	40	$ 4,800.00
UAS Pilot	$ 120.00	24	$ 2,880.00
UAS Driver/Spotter	$ 120.00	24	$ 2,880.00
Administrator/Clerk	$ 100.00	8	$ 800.00
TOTAL LABOR>>			$ 26,160.00

OTHER DIRECT COSTS	RATE	QUANTITY	TOTAL COST
Partial Per Diem (First/Last Day)	$ 41.25	12	$ 495.00
Full Per Diem	$ 55.00	14	$ 770.00
MILEAGE	$ 0.58	1000	$ 575.00
Lodging	$ 96.00	16	$ 1,536.00
Tolls	$ 10.00	20	$ 200.00
Supplies	$ 5,000.00	1	$ 5,000.00
SUBTOTAL ODCs>>>			$ 8,576.00
GRAND TOTAL			$ 34,736.00

Assumptions:

1. GSA Pay Scale for Labor (overhead included).
2. Standard GSA per diem, lodging, and mileage rates apply.
3. Crew of 3 inspectors and 1 driver.
4. One day provided for each mobilization and demobilization.
5. Three day inspection (5 mile average per day with one day added for Sponsor interviews).
6. Work day equals 8 hours.
7. Estimate is for the inspection component only. Time is not included for development of the levee inspection report or processing of the UAV data (see description below).

As a result, the UAV-supported levee inspection cost as shown in Table 2 is actually higher than traditional methods shown in Table 1 due to the increased personnel involvement. Based on this analysis, the total cost of a UAV-involved levee inspection would cost an average of $34,736.00. If the data processing portion of the drone support was included in this estimate, the cost would increase by approximately $9,000, depending upon the complexity of the site and the efficiency of the technician. Including this cost into the assessment would bring the grand total cost up to about $43,736.00.

4.3. Analysis & Discussion

The assumption made at the start of this research was that implementing UAVs into the levee inspection program could offer a more cost, quality, and time effective solution over traditional methods. For the particular case study used, it was quickly evident that UAVs would not reduce cost or time as a replacement for boots-on-the-ground levee inspections based on the way the LPSM group was implementing and utilizing the UAV resource. It was determined that simple, aerial imagery and photogrammetry are useful tools for visual purposes and high level overviews of the levee systems; however, this alone offers little in the way of inspection enhancement. In the case studied, boots-on-the-ground inspections are still the most cost effective means for the conventional inspection.

4.4. Another Look at the Case Study

The added cost of the UAV, software, and additional personnel to operate the drone and software represented a substantial investment. There were no modifications to the existing workflow in Table 2 and the UAV costs were a direct add to the already existing project expenses from Table 1. A closer look at the Table 2 cost estimate reveals substantial savings could be realised if one inspector was a licensed drone operator and the second served as the visual observer eliminating the 2 additional personnel being used in this scenario. Integration with existing inspection personnel would allow the UAV to replace the manual inspection as a duplicate effort.

Additional cost reduction would be realized if the supplies for the drone project (representing the cost of the drone and required programs for data processing) were spread over multiple inspections reducing the cost more in line with the Table 1 non-drone scenario. Recent advances in data processing software (DroneDeploy as an example) provide a significant amount of AI in analysing the content of the photogrammetric data making data processing a largely automatic process which could be customized for particular applications – this is a new and quickly advancing field.

In the cost comparison, no consideration was given for the value that may have been added with the photos and processed data. This was partly due to the reluctance to rely on the UAV capabilities to replace existing activities. Recent advances in UAV equipment offers both LiDAR and thermographic capabilities that can be well suited for identifying animal burrow holes, large depressions, or changes in topography that may be difficult to identify from the ground level. This data is also useful in being able to archive the topographic, point cloud data for comparison and anomaly detection between inspections. As a result, UAV technology can offer a great benefit to the inspections, but is highly dependent on the experience of the team and the way the users implement the system.

5. Conclusion

With its rapid advancement in the last two decades, UAV technology has been quickly adopted by the construction industry. Contractors fly UAVs equipped with cameras and sensors on construction sites to conduct project progress controls, inspection, testing, surveying, and safety monitoring. This research highlighted the current status of the implementation of UAVs in construction, including its hardware and software development, and applications on construction jobsite.

Consideration should be given to the roles a UAV might play and how to offset the additional costs to increase overall value. Value may be realized by reducing the cost of current methods being used to obtain a goal and/or leveraging new capabilities the UAV might bring to the project to provide additional benefits from its use. As shown in the case study, UAVs may not be cost effective if only used to capture visual data to supplement existing workflows. Based on the assessment provided in the case study of this research, it was determined that UAVs can offer valuable data for levee inspection reports; however, if the additional capabilities aren't used to represent added value, they may not be a viable replacement for traditional, field led operations. From the LPSM cost analysis, the cost of UAV levee inspections is higher than that of the traditional methods. This was due mainly to the adding of the UAV as an additional expense to existing workflows without any cost reduction in the existing methods (which might be replaced by the UAV) or allowance to value added by enhanced data acquisition.

As UAV technology advances, companies will look for new ways to utilize these versatile machines. Image if UAVs could incorporate an apparatus that could do actual work in the field such as laying brick at high elevations, eliminating the need for a scaffold and decreasing the safety risk involved in that work activity. Or utilizing drones to do above ceiling work where spaces are tight, making it difficult for workers to access. These are areas UAVs really haven't branched. As advancements are made, the UAV will become a more viable option to consider in the construction field.

The decisions to utilize a UAV, including the type of equipment, associated software and cost is a complex matter. As shown by the levee case study, the viability of implementation has a considerable number of variables, including some that are not easy to quantify. Many times the justification for the cost of the equipment is realized in bringing new capabilities to the job that don't currently exist.

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