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Applications of Drones in Infrastructures: Challenges and Opportunities

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Abstract**—**Unmanned aerial vehicles (UAVs), also referred to as drones, equipped with various kinds of advanced detecting or surveying systems, are effective and low-cost in data acquisition, data delivery and sharing, which can benefit the building of infrastructures. This paper will give an overview of applications of drones in planning, designing, construction and maintenance of infrastructures. The drone platform, detecting and surveying systems, and post-data processing systems will be introduced, followed by cases with details of the applications. Challenges from different aspects will be addressed. Opportunities of drones in infrastructure include but not limited to the following. Firstly, UAVs equipped with high definition cameras or other detecting equipment are capable of inspecting the hard to reach infrastructure assets. Secondly, UAVs can be used as effective tools to survey and map the landscape to collect necessary information before infrastructure construction. Furthermore, an UAV or multi-UVAs are useful in construction management. UVAs can also be used in collecting roads and building information by taking high-resolution photos for future infrastructure planning. UAVs can be used to provide reliable and dynamic traffic information, which is potentially helpful in building smart cities. The main challenges are: limited flight time, the robustness of signal, post data analyze, multi-drone collaboration, weather condition, distractions to the traffic caused by drones. This paper aims to help owners, designers, engineers and architects to improve the building process of infrastructures for higher efficiency and better performance.

Keywords**—**Bridge, construction, drones, infrastructure, information.

I. INTRODUCTION

THIS paper presents the applications of drones in infrastructures with respect to planning, designing, building and maintenance. Drone technologies and analytical methods focused on infrastructure are examined. Some case studies are presented. The key challenges are also discussed.

Infrastructures, such as roads, bridges, tunnels, water supply towers, oil pipelines, hydro-power dams and buildings, have close relationships with our lives including public and private physical improvements. It is extremely important to improve construction productivity in every possible phase of the projects, including planning, design, construction and maintenance. With the explosion of innovative technologies in this era, UAVs - expected to have a worth of $91 billion over the next decade [1] and $45 billion market value usage in civil infrastructure [2] - are one of the most promising devices that can help to achieve the goal.

Infrastructures contributed to long-term economic growth [3] and have positive impact on alleviating income inequality [4]. It is a trend for greater members of the society to get involved in planning decisions [5]. Therefore, it is critical to gather solid information to develop proper plans and make good decisions. However, for large-scale infrastructures that traverse complex terrain, it is not always easy to gather solid and adequate information. Furthermore, precise and accurate traffic study is needed in order to make a good urban traffic plan. But due to high surveying cost of real time traffic monitoring in conventional ways [6]-[8], simplified urban travel demand models are used [9]. UAVs can be used as efficient tools to accurately survey and map the landscape to collect necessary information before infrastructure construction to make good plans [10]-[12].

Designing new infrastructures could be complex and time consuming, particularly for critical ones. UAVs are potentially useful in improving design efficiency and quality. For example, UAVs can be used in post-disaster assessment of critical infrastructures that are not easy to reach or detect after an extreme event such as earthquakes [13]-[17]; and then provide valued information for future design. For instance, three different types of drones were deployed to examine damage of the nuclear plant failure which was fatal to human even for short exposure [18], [19]. Improved design can be conducted by taking into account the knowledge gained from post-disaster assessment. Furthermore, data from real time traffic monitoring are useful for new road and bridge designs. For instance, drones are cost effective in collecting length-based vehicle classification data, which are important information for pavement design due to differences in size and weight between long vehicles and short vehicles [20]. Compared to conventional traffic monitoring, drones can be used to collect real time traffic information [21] and further guide the building of smart cities with respect to reversible lane systems [22] and movable bridges [23]. Lastly, accurate landscape characteristics data acquired through UAVs can be taken into account to integrate better design quality and reduce cost. UAVs are capable of gathering key information to guide new infrastructure design.

Constructions of large-scale infrastructures are intricate processes that need careful site survey, construction process monitoring, post-build checks and safety supervision. After project planning and design, detailed surveys are usually necessary to make a workable field construction plan. As mentioned previously, UAVs are efficient tools to survey construction sites. UAVs allow enhanced visibility which is more helpful in construction monitoring [10]. Furthermore, many cases of construction monitoring using UAVs have

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proven to be practicable. The construction process of Rocky Ridge Facility in Calgary, Alberta, Canada [24], a single-story residential apartment [25] and the Sacramento Stadium in Illinois [26], [27] were monitored by using UAVs. UAVs linked with Building Information Modeling (BIM) [28] can potentially improve construction productivity [29] by monitoring not only construction process but also material delivery [30] and equipment usage. UAVs coupled with visual equipment provide real-time view on sites that help to enhance safety [31]. Although the load capacity of a single drone is very limited, multi drones can collaborate to lift relative heavy loads [32]. Combined with prefabrication technology, a 6-meter tall tower was assembled successfully by four drones [33], which indicates the direct use of UAVs in constructing infrastructures. Some counties also use drones as delivery tools to place cables in suspension bridges, which greatly improved the construction productivity.

Well maintenance infrastructures have reduced maintenance and repair cost and elongated service life. In order to inspect infrastructures, conventional means require trained workers and engineers to climb the structure to get desired information. This process could be time-consuming and unsafe, sometimes even dangerous. With the flying ability of drone platform, various detecting and surveying equipment can be used to monitor health conditions of infrastructures. For instance, Mattar and Kalai developed a wall-sticking drone to inspect the crude oil storage tank [34]; drone-based images were used to detect concrete crack damage in infrastructure [35]; fatigue crack detection of steel bridges were carried out by using UAVs [36]; the use of drone to detect deflection of bridges was investigated [37]; a corrosion analysis of a 225 meters high rise chimney was conducted by using a drone [38]; UAVs were used as support tool to visually inspect concrete dams [39]. Some other devices such as thermal cameras, X-ray camera and radio detectors incorporated with drones could also be useful in inspecting hard to reach parts of infrastructures.

II. METHODOLOGY

Construction productivity can be potentially improved by appropriately using of the information. With the flying platform combined with various kinds of advanced detecting or surveying systems, drones are capable of aiding different infrastructure building phases, including planning, designing, construction and maintenance.

A. Drone Platform

Drones can be defined as aerial vehicles that are independent from on-board human operator for flight, either autonomously or remotely operated [40]. Drones' size ranges from inches to nearly 200 feet and flight distance ranges from a few feet to miles [41]. The drones applied in civil infrastructures are usually small ones, which are easier to operate and flexible to execute infrastructure-related missions. The flight altitude varies from a few feet to more than 10,000 feet [42]. While the flight altitudes of drones for civil use are limited to 400 feet according to current FAA regulations [43], it is enough for most surveying, inspection and construction events. Commercial drones are able to fly up to 55 minutes without charging [44]. If a single fly is not enough in civil infrastructure application cases, multiple times of flying can be conducted.

UAVs are currently classified as fixed-wing UAVs and rotary-wing UAVs. Fixed-wing UAVs advance in longer flight endurance and range coverage, which are useful in large scale infrastructure's case, such as rail way and high way. On the other hand, rotary-wing UAVs allow for easier take-off and landing as well as heavier payload [45]. Furthermore, rotary-wing UAVs are capable of hovering, which are important in civil infrastructure applications, particularly in taking high resolution photos or videos. There is also an arising third type of UAVs, the hybrid UAVs, which can overcome the shortages of the two conventional UAVs [46].

Compared to conventional aerial platforms, drone platform has many advantages. Very high-resolution photos or videos can be obtained since drone platforms allow for low altitude operations and they are agile and flexible to get the objects. It is less time consuming to inspect infrastructures or survey a job site compared to manually working on the same mission, especially for hard to reach parts of some infrastructure assets. The technical advantages discussed can result in a relatively lower cost. Another advantage is that drone operation does not need licensed pilots, thus, further reduced operating costs.

B. Detecting and Surveying Systems

Most of the applications of drones in civil infrastructures require the incorporation of detecting or surveying systems. High resolution visual cameras are the most popular one for they can be used to, not limit to, monitor construction site and inspect infrastructures. Thermal cameras are another choice to survey or detect while vision field is constrained, such as places with illumination issues or inaccessible buildings [45]. Impulse thermography is a non-destructive investigation method that suits well for detecting voids in concrete structures [47]. Instead of collecting the passive thermal heat flux, impulse infrared thermography from UAVs could provide information about structural degradation with enhanced accuracy [48]. Radio detection and ranging (RADAR) and light detection and ranging (LiDAR) incorporated in drones provided alternative ways of mapping. Metal detector and X-ray cameras have been proposed for military purposes in drones [49], which could also be potentially equipped in commercial drones.

C. Post-Data Processing Systems

Besides conventional post-data processing system, innovative ways are used in extracting information. Machine learning is an arising approach in dealing with large amount of data [2]. For infrastructure planning and design, typical data acquired through drones are images. 3D geometrical models can be generated from these images through manually method or semi-automated algorithms. For construction monitoring, either real time videos or 3D models are needed. As for infrastructure inspection, machine learning and deep learning algorithms are employed. Gopalakrishnan et al. proposed pre-trained deep learning models for crack damage detection in UAV images [35]. Kang and Cha successfully detected

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concrete cracks with 97.7% specificity and 91.9% sensitivity from UAV video [50]. Additionally, color and texture algorithms were developed to detect missing or deformed structural members and corrosion [51]. Many available commercial software and algorithms could be adopted from other fields to deal with large amount of data gained from drones.

III. APPLICATION OF DRONES IN INFRASTRUCTURE CONSTRUCTION

Drones can be used from planning to maintenance phase of a project. A few application cases with details focused on construction phase will be introduced. Construction monitoring can be achieved by using drones to create 3D models and compare this model to BIM models. The overall concept is illustrated in Fig. 1 [25]. Firstly, a case study of using drones to monitor the construction process of a residential apartment will be introduced. Furthermore, using drones to deliver construction prefabricated unit will be introduced. At last, a few examples of using drones to place the pilot lines of suspension bridges in China will be introduced.

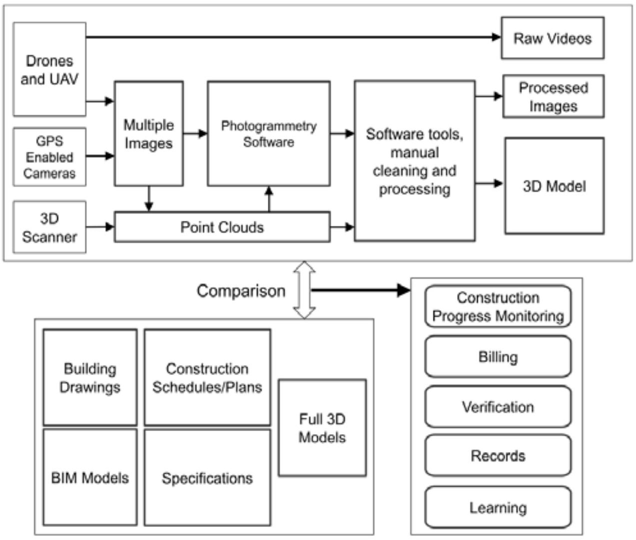

Fig. 1 The overall concept of using drones to monitor construction [25]

A. Construction Monitoring and Reporting of a Residential Apartment

Naveed et al. used a drone to monitor the construction process of a residential apartment [25]. During the construction process of the single-story apartment, the drone was flown at least four times to capture data at various heights and camera angles. The first data set was captured with 0-degree camera angle with a height of 30 m. The second one was at 80-degrees angle and a height of 20 m. The third one was at 45 degrees and a height of 30 m. The last one was at 30 degrees and a height of 50 m [25].

After gathering all the photos, the data were used to build the 3D models by the aid of “3DF Zephyr” software. Once upon the creation of the 3D model, it is exported and rebuild in REVIT (a commercial software that supports BIM models). The rebuild REVIT model was overlaid with the actual REVIT models to compare differences of dimensions. For instance, comparison shows that toilets were installed on schedule and the placement of windows was delayed [25]. This showed that a lag was building up between windows and toilets installation. The lag detected with window installation could be recovered by the time toilets were being installed.

B. Drones Deliver Construction Prefabricated Unit

Research result has shown that special designed UAVs have the possibility of capturing objects while hovering. In contrast to more constrained approaches, such as attach load by a human operator or using hanged magnet to collect ferrous objects, Pounds et al. had grasped and delivered unstructured objects by UAV platforms [52].

The architectural installation to be assembled by UAVs was done in FRAC Centre Orléans. Prefabricated module size was 30 cm × 15 cm × 10 cm. The four drones were guided by a network of intercommunicating programs based on a real-time camera system to pick up location and the desired placing location. Note that glued modules were manually placed to the pickup location. The drones pick up one lightweight module at each flight and place it to the desired location. After placing 1500 lightweight modules, the tower has a height of 6 meters [33]. Although it is a scaled tower, this process demonstrates the possibility of using drones as a delivering tool to build prefabricate structures such as the conceptual "Vertical Village" in Fig. 5 [33].

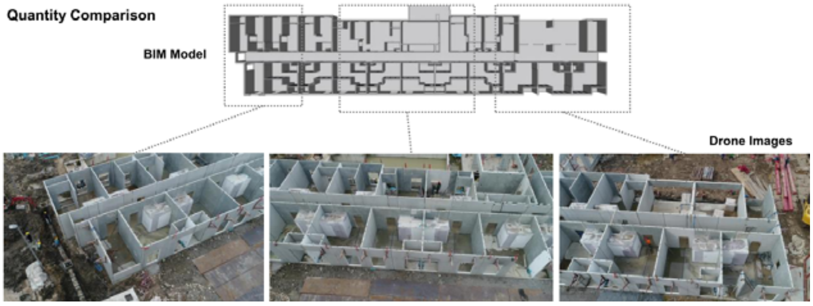

Fig. 2 Quantity comparison for the placement of toilets [25]

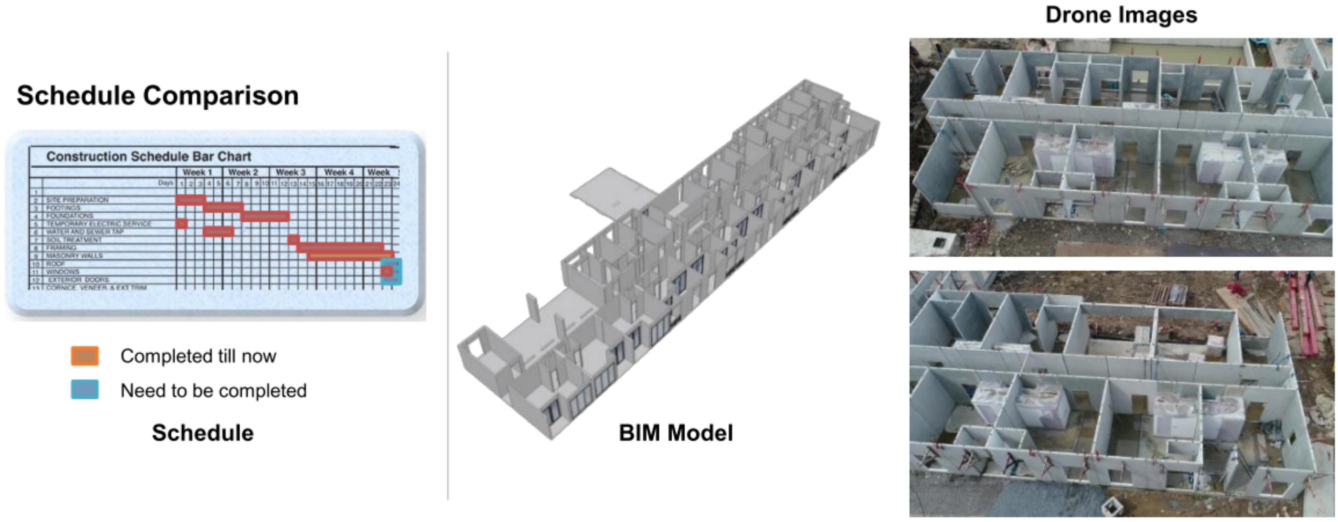

Fig. 3 Quantity comparison for the placement of windows [25]

Fig. 4 Concept of vertical village (image courtesy: Yao Zhang) [33]

C. Drones Used in Placing Pilot Lines of Suspension Bridges

In the construction process of the cables of suspension bridges, a pilot line must be placed first from one anchorage across the tower to another anchorage before the catwalk is constructed. Then the cables could be formed. Several ways have been used to position the pilot line. There is a story of a young man flying a kite to carry the pilot line to build the Niagara River Railroad Suspension Bridge [53]. Nowadays people use helicopters or boats. However, in mountain areas, boats are not likely to be used and helicopter could also be risky due to the local whether or landscape restrictions. Furthermore, both boats and helicopter need licensed professional operators and could be time-consuming and costly. Drones are capable of placing pilot lines in suspension bridges. This process has been proved to be practical by some newly built suspension bridges. The 2470-meter-long bridge, Longjiang Suspension Bridge (Fig. 5), is located in a mountainous area in China. Chishuihe bridge (Fig. 6), with a main span of 1,200 meters, connects two provinces in China. Xingkang Bridge (Fig. 7) has a main span of 1,100 meters. Yansigang Bridge (Fig. 8) is under construction and is expected to be completed in 2019. All these bridges used drones to aid construction [54]. A drone carrying a pilot line is shown in Fig. 9.

Fig. 5 Longjiang Bridge (open source image)

Fig. 6 Chishuihe Bridge (open source image)

Fig. 7 Xingkang Bridge (open source image)

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Fig. 8 Yangsigang Bridge (open source image)

Fig. 9 Drone carrying the first pilot line between the towers [55]

IV. CHALLENGES

Drones have limited flying time; some missions may not be done with one time flying. The payload of drones is still very limited, and multi-drone cooperation may be needed to address the material delivery function in some construction projects. Manipulating drones need professional trainings, which decrease productivity to some degree. FAA has regulations that drones cannot fly out of sight, which is a limitation for some cases [43]. Drones are easily affected by tough weather conditions, such as heavy rain, snow or strong wind [56]. While drones are useful for monitoring real-time traffic conditions, it may also distract driver to some degree and undermine traffic safety. Large amount of data is a great challenge even though many advanced algorithms are available. The image sharpness or clarity is another critical challenge that hinders drones from further application in infrastructures [44]. Well understanding of input and output relationship is of great importance before widespread applications of drones in infrastructures. However, this relationship is not easy to understand or evaluate. Furthermore, searching the balance between public concerns of safety and privacy and drone benefit is a challenging issue [57].

V. CONCLUSION

Drones incorporated with various detecting equipment can be used as efficient tools to aid planning, design, construction and maintenance of infrastructures. Each phase has effect on productivity for either the output increase or cost reduce indirectly brought by drones. This paper firstly introduced the overall concept of using drones in different phases of civil infrastructure construction events. Then, the platforms of drones, detecting equipment and data-processing systems were introduced. At last, several case studies were shown to demonstrate the practices of using drones in infrastructure. The key challenges and limitations were also addressed.

1) During planning phase, UAVs can be used as efficient tools to accurately survey and map the landscape to collect necessary information to make good plans. Good plans improve productivity by reducing cost without sacrificing serving quality.
2) During designing phase, UAVs can gather key information to guide new infrastructure design. With better designs, the overall productivity of infrastructure construction can be potentially improved.
3) During construction phase, UAVs are able to both monitor the construction process and deliver materials. It is less time-consuming and cost-effective to use drones during infrastructure construction.
4) Drones could also be useful in inspecting hard to reach parts of infrastructures, such as underneath bridge parts, high towers, remote railways, hydropower dams, and tall building roofs. Well maintenance promotes social value of infrastructures.

Further studies are needed to address the challenges and more practices are required to validate drone applications in infrastructures.

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