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UNMANNED AERIAL VEHICLES (UAVS) FOR INSPECTION IN CONSTRUCTION AND BUILDING INDUSTRY

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Abstract: Digital data capture is a key component of Industry 4.0 practices. In the past few decades Unmanned Aerial Vehicles (UAVs) have entered the construction industry to capture site data and to cover topographic as well as different types of inspection matters. Photographs, live video, photogrammetric digital elevation models and 3D point clouds can be generated using different photogrammetry facilities, cameras and lasers attached to either a fixed wing or rotorcraft UAVs. UAVs have the ability to deliver information by monitoring, 3Dmaping, measuring, analysing, as well as recording on-site activities. This paper presents the state of art of UAVs usage in construction and building industry and evaluates their applications by experimental case studies. The challenges of using UAVs and their links to BIM will be also discussed. This study found that visual imaging is currently the most popular use of UAVs on construction sites to ensure integrity of structural inspection, however, 3D models derived from LiDAR and photogrammetry techniques are surpassing more traditional methods as they are still significantly cheaper and faster to use. UAVs is also used to monitor workers on site to identify what resources they need in order to carry out their tasks more efficiently and also for the purposes of their health and safety. Despite the approved efficiency of using UAVs on sites to provide better visualization of the working environment, there are still key issues to be tackled such as: the limited flight time of UAVs and its weight. Structural/site investigations have shown that there are some defects on the use of aerial vehicles, with the most important to be the cost along with the precision of the results which may vary depending on the technologies used. There is further study required into the combination of UAVs derived data and its inclusion into BIM, as barriers remain regarding translatable data platforms. There are also some ethical concerns of surveying workers on site and how to protect their privacy.

Keywords: *UAV, Construction Site, Data Capture*

1. Introduction

Over the last decades, new technologies have appeared to enhance productivity, reduce time and cost of construction tasks. The introduction of Unmanned Aerial Vehicles (UAV also known as Drones) to the construction industry is recent, although their use in other fields has been frequent, like in military activities, firefighters, search and rescue, forestry, mining, oil platforms and a wide range of other sectors (Irizarry et al, 2012). In civil and infrastructure industry, aerial vehicles have been used for numerous purposes; such as: the inspection of highways (Themistocleous et al, 2014), bridges (Morgenthal and Hallermann, 2014), as well as mapping of elements of ancient value (Torok, 2014). With the availability of increasingly sophisticated hardware and software, companies are able to contribute to their BIM models by producing 3D models, site photographs, and video from a short UAV survey.

The collection of data for civil and building projects used to be a very time consuming exercise. However, the advances in sensor and drone technology allow a single operator to collect thousands of data points in very short time compared with the traditional exercise. Mounting cameras and radar sensors to drones has unlocked several new methods of collecting data and allows new data types to be explored. The equipment is not cheap but, compared to hiring a team of dedicated data gatherers for extended periods of time, it does make financial sense, particularly as the cost of the sensors and drones decreases. This is in addition to avoiding any risk accounted for human interactions on dangerous sites. These drones equipped with sensors can gather data for a wide range of functions from mapping terrain and topographic analysis, to observing the structural integrity and inspection of buildings, bridges or tunnels over its life, and to ensure health and safety compliance.

The purpose of this paper is to provide the state of art of the UAVs technologies and methods of use. The analysis of their different practices, the way they are being used and the additional software, technologies and methods will provide the knowledge needed to further understand UAVs, as well as trigger further studies on the subject and enhance its future. Case studies will be discussed along with the different technologies and Building Information Modelling (BIM) combined with UAVs.

2. UAV technology

UAV is a booming industry at the moment and the potential utilisation in the construction industry is very promising for a wide range of uses to improve the efficiency of processes. These vehicles use payloads and software to gather and interpret/analyse data on site, rather than carry out specific constriction activities (Dupont et al., 2017).

The most obvious use for drones is taking aerial photographs which used to require an aircraft, pilot, on-board photographer and, in the care of helicopters, special permission due to the downdraft and noise of the aircraft. The only alternative to take such images used to be the expensive high resolution satellite images, but now a single skilled operator can pilot a drone which can take the same aerial images at a much lower cost, with far less risk to human life. In addition, drones can get to places no manned aircraft ever could, e.g. the risk presented by flying a helicopter between buildings in an urban environment would be correctly deemed to be unacceptable, and therefore unmanned drones allow new perspectives to be explored, filling the gap between purely aerial and ground photography. Figure 1 shows a drone with a digital camera mounted to its underside.

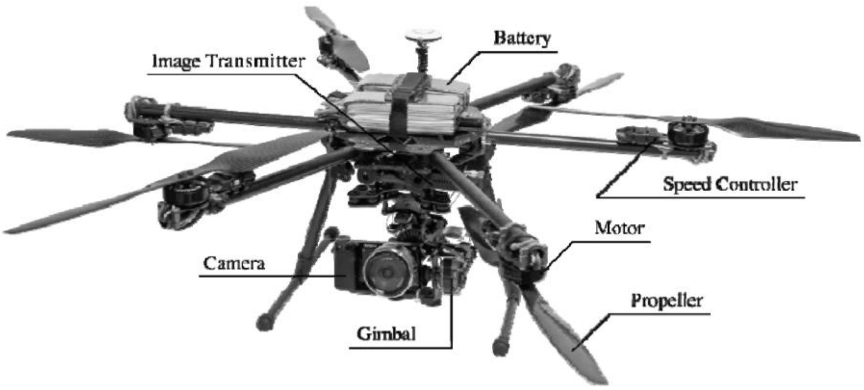

Figure 1: Example of a "hexacopter" drone, fitted with a digital camera (Liu et al., 2014)

UAVs are aircraft which can fly either automatously or controlled by an operator on the ground. These vehicles exist in a variety of shapes and versions, however they all follow the same system design of a frame/structure, electromechanics, flight controller and telemetry control system (Liu et al., 2014).

Two structures exist for UAVs, multi-rotor and fixed wing, both of which have advantages and drawbacks pertaining to their design. Rotorcraft UAVs, as shown in Figure 2, contain between two and eight rotors and are mechanically more complex than fixed wing. However, with this complexity come advantages such as vertical take-off and landing, hovering capabilities, manoeuvrability and larger capacity for different payloads (UAV Insider, 2018). There are drawbacks to this type of UAV as there is a trade-off with mechanical complexity and manoeuvrability with battery capacity and speed.

Fixed wing UAVs, as shown in Figure 3, fly like a traditional aeroplane as they use wings rather than rotors in order to generate their lift. This method is far more efficient and as a result they can travel faster for longer; this makes them the ideal choice for survey sites of a large area. Difficulties associated with fixed wing are the launching procedures as this requires some form of runway and its inability to maintain one position to gather detailed data of a specific area. With the popularity surrounding UAVs in industry and their increasing use in construction, the focus begins to fall on what method can be utilised to capture data using these vehicles (Buczkowski, 2018).

Figure 2 – Rotorcraft UAV (Source: DJI)

Figure 3 – Fixed Wing UAV (Source: GEM Systems)

3. Technology used with UAV

UAVs use many additional technologies to complete a task. It was shown eventually that the chosen UAV for an operation is not the only important parameter for a successful result, but also the additional technologies and software are crucial as they are part of the process of data manipulation and extraction. Photogrammetry and LiDAR are commonly used along UAVs to provide the 3D mapping service. In addition, generating algorithms to automatically determine suitable and anticipated routes for the drone is important to its operation. A GPS system is essential for visual navigation and exact positioning. Drones use GPS coordinates (latitude, longitude) for the position and the height of the barometric altimeter with respect to the take-off point. In this respect, Jun and D'Andrea (2003) proposed algorithms to define the trajectories of autonomous aerial vehicles in known environments. Russell et al (2005) have used genetic algorithms for routing drones to allow eventualities to be combined with regular routes, so it can be utilised in a general heuristic of inspection routes for complex sites such as for construction sites.

3.1 Photogrammetry

Photogrammetry is a technique used by scientists and engineers to measure distances and produce 3D models from photographic data using cameras in general that can be also fixed on UAVs (Kwon et al., 2017). This is achieved by taking sequential images which overlap, typically 80-90%, and mathematically analysing the parallax produced by the overlay of the images (the process is also known as image-processing algorithms), Hudzietz and Saripalli (2012). This work used to be undertaken by measuring chains, theodolites and total stations (Wilkinson, 2017).

In order to gain photographs which overlap, the UAV must follow a set of marker which can be pre-programmed. At each marker, the camera will be programmed to take a photograph of the area and the elevation is worked out by triangulation of the x, y and z coordinated from two different images (Corrigan, 2017). Once the digital images are gathered they can be "stitched together", or composited, by computing facility to form large, highly detailed images and, more impressively, maps with three spatial dimensions (Turner et al., 2013). Due to minimal set up time and low cost, drones can be redeployed to update maps over a short space of time. These new maps can be added to existing ones producing a three dimensional maps capable of showing changes to a site, landscape, etc. over a given time (i.e. 4D models), Ham et al. (2013).

Processing of images using multiple cameras and in multiple frequencies is one of the fast growing research to improve the quality of produced images. One of the objectives of processing with multiple cameras is the reconstruction of images and/or 3D models from images taken at different points in space. This allows the reconstruction of the geometry of the scenes by optimising the position, location, and orientation of certain points (Sappa et al (2016), Aguilera et al (2012), Zhao et al (2017), Kim et al (2017))

At present drones can provide impressive photos from the air, however creating models from these images depends on the available computing power. Care should be taken as providing the computer with more and more images will increase the time needed to produce a model. These models are also highly dependent on the drone being able to accurately identify where the images were taken in three dimensions, if this data is not included then that image cannot be used for 3D modelling, and conversely increasing the accuracy of the drone location information will further improve the model. This issue could be addressed by mounting additional sensors to the drone, however their payload is limited. As sensors continue to decrease in size and weight, current problems relating to the drone's uncertainty regarding where it is in three dimensional space and warping of images taken from the drone can be combatted, Wallace et al. (2012).

This technique is found to be reasonably accurate in producing 3D models when used on simple sites (e.g. flat without many objects). However, more complex sites will need more sophisticated process for accurately producing 3D models. Data captured by photogrammetry depends also on the conditions of light, shadow and wind. Any deficiencies in these conditions can lead to inaccurate data, Karpowicz and Higgins (2018).

3.2 Light Detection and Ranging (LiDAR)

LiDAR is a method of mapping which uses laser beams to produce highly accurate 3D models. The technology is commonly used to examine surfaces. LiDAR works by fixing a laser with a wavelength of 1000-1600 nm to a UAV and sending out pulse signal and measuring the time the pulse takes to be deflected by an object on a surface of the ground and return to the transmitter. This technique is particularly effective as, unlike photogrammetry, Digital Terrain Models (DTM) can be produced even when there is coverage on the ground such as trees and bushes (Dong and Chen, 2017).

With each returned pulse, a data point is created and given an x, y and z coordinate. These coordinated points are used to construct a 3D point cloud, and this is essentially what becomes the model. Depending on how many points are taken per metre squares (frequency rate), the more or less detailed the model will be. The product of these data points will be a monochrome representation of what is on the surveyed area, and will need to be edited during post-processing by the operator to add colour and details to be usable for engineering applications (Buczkowski, 2018).

There are drawbacks of using LiDAR as although savings can be made through the fast survey and processing times, the equipment is still expensive. This can lead to associated costs concerning maintenance and damages which occur from UAV crashes or transportation. The equipment is also heavy and will have a significant impact on the UAV battery capacity, which could limit the size and the time of surveying (Puliti et al., 2017).

4. UAV and BIM

In the construction industry, adopting Building Information Modelling (BIM) concepts and technologies become essential in delivering projects. With more streamlined methods of capturing real data in projects to accurately develop 3D models and facilitate post-handover, UAVs are likely to be integral to the contribution of data involved in 3D modelling. BIM is pushing forward the way in which industry approaches surveys by saving time, costs, and improving the quality of survey models. In conjunction with LiDAR, which is able to capture data even through tree canopies and low lighting conditions, point clouds can be imported into BIM models. BIM models can also provide geometric data to determine UAV routes as experienced by Lin and Su (2013). Applications to control the routes of mobile robots using BIM models also showed possibilities, Siemiątkowska et al (2013).

5. UAV for Structural and Sites Inspections

It has become common practice within the field of civil engineering to monitor structures after they are completed to observe their performance over time as the materials degrade. However, UAVs do not cover all the needs of a detailed structural inspection, as sometimes the engineer needs to see the structure physically to identify any faults. Thus, UAVs are partially covering the needs of a structural inspection when visual surveillance is required. Using UAV for inspection can give a much clearer indication of when the structure requires maintenance, for example after a storm or excessive concrete shrinkage. This is typically performed using strain gauges attached to several elements of the structure, over the years these strain gauges have become digital sensors. Eschmann et al (2012) have demonstrated the implementation of an autonomous aerial vehicle (rotary octocopter) for visual inspection of constructed buildings with a microcontroller and image processing for the detection of possible structural faults.

The sensors used for monitoring structures are highly useful, provided they have sufficient power, however in critical situations it is unreasonable to assume that power can be provided to the sensors either by a cable or by sending a person onto the structure with a power pack, hence the sensors may become useless in a crisis. Drones can also provide power wirelessly to sensors and then collect data captured by them (if the sensors are designed with this capability of data collection). The drone can be sent to fetch the data from the sensor provided the weather is calm enough to allow the operator to remain in control of the drone. This can become useful in the case of natural disasters to provide rapid assessment of a structure, despite all aerial vehicles struggle in high wind conditions (Jordan, 2015).

In cases of natural disaster, images can be taken by drones. The density of the damage can be determined by comparison with old images. Then the size of the affected area can be measured and the value of lost assets can be estimated (Vincenzi et al., 2014). The results obtained from a damage survey can even be reverse engineered to provide forecasts, e.g. what level of damage can be expected in future to assess the utility of a prevention scheme for example (Li et al., 2010).

6. UAV and Traffic Surveillance

Managing traffic is an on-going and complex challenge, currently fixed CCTV cameras are used to observe traffic flow. The CCTV network is only capable of providing a snapshot of the traffic, i.e. is there a traffic jam right here, right now? This system is incapable of identifying when a jam will form, or clear. It can offer how long the queue is, but that is of little to a driver stuck in the queue. Drones are able to observe the traffic and provide insight which is sufficient to pre-emptively predict where a jam will form. This information would be incredibly useful to motorists as they could reroute before the jam even forms, minimising time loss.

Drones are being used to study traffic patterns and driver behaviour over major roads. This includes studying vehicle speeds, weaving & trajectories, as well as overall traffic flows & densities. They are also being used to assess the utilisation of parking spaces and the movements, flows & queue lengths at busy junctions (Puri, 2005). The traffic flow data could be used to assess the viability of a road, providing insight of why a particular road is always busy, and whether or not a new route be constructed to ease the congestion. The driver behaviour data gathered by these drones could be particularly useful for teaching self-driving cars how to negotiate a complex junction or how to react if the car ahead begins to drive erratically. A vast amount of computing power will be required to make sense of driver behaviour data and converting that into useful information which can be used to inform, for example, how long a red light will last (Coifman et al., 2004).

As traffic management is often utilised in urban areas where data must be captured, this raises the issue of signal interference from phone signals, radio waves etc. Care must be taken during the drones flights to use an available wavelength. Otherwise, disruption may cause anything from minor image damage to complete loss of drone control.

7. UAV for Health and Safety

Rodriguez Santos de Melo et al. (2017) investigated the applicability of UAVs for assisting with the safety examinations in large construction sites. Safety during the construction stage is of paramount importance, and the responsibility for providing a safe environment is given to all involved parties. To ensure the enforcement of the safety procedures on site, regular inspections are key for identifying non-compliances early and ensuring appropriate actions are taken to rectify them. However, managing such inspections can prove challenging due to staff limitations, communication issues, and an absence of standardized processes (Park et al., 2013).

Rodriguez Santos de Melo et al. (2017) used a UAV system to inspect the safety procedures in two large construction sites in Brazil. Larger visualization of the site provided valuable information about the general organization and logistics, whereas zoomed-in inspections produced specific data with regards to safety procedures. The site knowledge of the pilot/examiner is very important, in order to identify key times and locations for conducting the inspections. The non-compliances on sites have many forms, such as: workers not using fall arrest protection equipment, safety platforms are not available, destroyed handrails and safety nets, and inappropriate storage for materials.

Eventually, the correct use of UAVs for construction site inspections was proven to be cost and time effective, the main limitation is that examinations are limited to areas visually reachable by the aircraft. Therefore, the effectiveness of this method would greatly depend on the circumstances of each individual site. However, for a suitable project and by following the correct standardized inspection procedures, UAVs can prove remarkable tools for assisting with safety compliance procedures.

UAVs can also be used to monitor site labour activities to capture data on the efficiency and habits of workers in order to increase efficiency of the site. This may be faced with some resistance from workers due to the possibility of preaching their privacy and the pressure to work excessive hours to perform better. Knight (2018) argued that the rationale behind such use is to identify the resources which are required for the labours to work more efficiently, not their own performance; and also there is already significant worker monitoring on site any way even without UAV usage.

8. UAV operational problems

There are always issues related to data capture which may include costs, impacts on the UAV, and errors. Photogrammetry needs ideal conditions regarding light and weather in order to gather quality usable data. There are also significant post-processing times required for photogrammetry, which is pushing the industry into using LiDAR as a solution. However, the issues regarding LiDAR as the large costs and weight of the equipment. The heavy laser limits the UAV to a shorter battery life which may not be suitable for large sites. This may require companies purchase a larger and more powerful UAV to cope with the extra weight. The LiDAR equipment itself is also very expensive and can limit smaller companies from investing at the moment, especially with the risk of a crashed UAV causing damage to the system (Dukowitz, 2018).

Erdelj et al (2017) refers to UAVs' limited flight time, which is definitely not long enough for a complete structural inspection. Also, a structural inspection requires a stable vehicle which is able to provide accurate results, so sensors like LiDAR need to be used, which cause the life of the vehicle to get drained even quicker.

Alternative methods have been tested, like internal combustion engines, but they appear to create further issues like making the vehicle heavier and bigger in volume, thus less flexible, as well as costlier and prone to risk during flight time. However, this update does indeed increase the flight time, even though it does not offer the best solution. Aerial vehicles with fixed wings would also offer a longer flight time, but still, it is not possible to offer the right results required for structural inspections, so they are usually not preferred for the operation. Another solution is the use of more than one aerial vehicles for the procedure. Yet, this makes the operation costlier and more complicated, if there is the need to control multiple vehicles. Burkle et al (2011) uses many autonomous and automatic quadcopters (swarms), which were controlled by a ground controlling system successfully.

Furthermore, another attempt took place to solve the issue of the short flight time of UAVs with the creation of an advanced system to prolong flight time of an aerial vehicle. This system works on battery charged vehicles as it automatically swaps a used and drained battery with a fully functioning one, while it recharges multiple others. The experiment was successful after a three-hour flight and the need to change the battery approx. every 10 minutes, Ure et al (2015). Similarly, Matthew et al (2015) proposes a group of robots to dock with the aerial vehicles with the aim to recharge their batteries.

Erdelj et al (2017) also developed an algorithm that can communicate with UAVs to control the vehicles in fleet to give destination, time of arrival, and replacement of data transmission when batteries need recharge. The algorithm uses the values of Operation time, Time of flight, Time of battery replacement, and Time of battery to recharge. The recharge operation seems to be finally continuous, but it should be noted that it is a costlier method as there is the need of automatic recharging pads of each one of the vehicles.

For other use of drones, there is always the problem of BIM compliance environments. If the data captured required its own viewing platform, then it will not be possible to integrate into the BIM environment.

9. Conclusions

The rise of UAVs will have a significant impact on the construction industry, which traditionally, struggles with efficiency and productivity. The vast resources of data which can be acquired using drones is revolutionary, and as the technology becomes more and more accessible, more novel use cases will continue to be found. At present, aerial imaging is the most common application of drones being used to gather data, this is because the data collected being easily handled by today's computers. As cameras and sensors reducing in size and weight the accuracy and precision of the data will continue to increase, resulting in more accurate models. As computing speeds continue to accelerate, the interpretation which can be performed by machines will increase in complexity, allowing for more detailed analysis.

LiDAR and photogrammetry have revolutionized data capture for 3D models of large areas. Photogrammetry is a passive technique only requiring image input to derive 3D models and can be carried out from a UAV, eliminating the need for satellite footage or helicopter hire. Post processing relies on the triangulation of points taken from overlapping images by which accurate 3D models can be produced. LiDAR technology is being widely implemented across various industries. It's ability to penetrate foliage, trees and other barriers make it an ideal technology for construction, mining, forestry and other industries. Studies have proven the reliability of the data captured and its post-processing speed.

Many companies within the industry are using rotorcraft vehicles in order to capture photographic and video data. With the use of geographically referenced way-markers, a UAV can be deployed and capture images from the same positions at regular intervals, thus showing an effective overview of the progress. These types of images are commonly of high interest to the clients and other stakeholders as well as the construction teams for analysis.

Structural inspections can happen with the use of aerial vehicles as they offer the benefit of the absence from site to a safer environment. Similarly, close up inspection of high, dangerous or difficult to reach areas are much more accessible when using a UAV as a live stream of the conditions can be fed to a mobile device on the ground. This removes the need for any worker to go into dangerous conditions to carry out a survey.

Construction managers and other stakeholders can access data on and off site to review the current conditions of a project against the planned schedule and drawings. This process will effectively help streamline a construction process as the construction manager will be able to assign more attention or resources to a certain area which has been flagged. While it raises some concern in terms of workers' privacy, worker monitoring is also proposed by UAV usage in construction sites. Compliance with health and safety procedures on site becomes essential in most projects. UAVs have approved its usefulness in identifying non-compliances early and ensuring appropriate actions are taken to rectify them.

With more and more projects using BIM, it is becoming more essential to provide data which is compatible to the BIM software. It is possible to take a survey and integrate it into a BIM model and then overlay as-built and architectural plans; revealing areas of the project which may require attention or resources. With 4D simulation development, BIM models can be used too to generate route algorithms for UAVs in integration with temporal calendar and spatial definition. In general, there are advances in the development of UAVs routes, but they have not been associated with 4D programming to allow the route of an UAV to be established to perform a real inspection of buildings with auto-recognition of construction objects.

The major challenge facing UAVs is the short flight time and battery life. Many propositions are developed with the use of multiple vehicles as the most efficient so far. There is still need for improvement on this area. Drones also struggle in high winds and require a skilled operator to really get the best data possible. Light weight vehicles are also required which should be also able to handle weather conditions.

In addition, legal restrictions vary from country to country. Considering that the rise of UAVs is so quick, most governments still do not have comprehensive legal infrastructure to regulate their operations completely. In the UK, the operator must hold a license if operating a UAV above 7kg. Within populated areas there are also restrictions regarding height and size of the UAV which can affect the survey type permitted in the area.

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