Practical issues on the use of drones for construction inspections

Elena Ciampa, Luca De Vito and Maria Rosaria Pecce
University of Sannio, Department of Engineering, Piazza Roma 21, 82100 Benevento (Italy)
eciampa@unisannio.it

Abstract. The aging and deterioration of structures such as bridges or buildings is becoming an urgent social issue; regular inspections for the preservation of the structures are needed, but it means high cost especially in terms of safety for workers due to the difficulty to access. Visual inspection of workers can be replaced by using basic drones, which share many advantages such as speed, safety for the workers, cost-effectiveness, share-ability with more stakeholders instantly and manoeuvrability by making use of automated flights. A visual inspection made by drone is the first part of a complex survey campaign, and its use allows planning experimental investigation for diagnostic. This study analyses both the positive and negative aspects of the use of drones for structural inspection, underlying the low cost, immediacy, instant measurement and the possibility of developing a 3D model, with an acceptable level of definition and reliable for a diagnostic process. Two application examples are proposed.

1. Introduction
An Unmanned Aerial Vehicle (UAV) is an aircraft flown with no pilot on board. UAVs are sometimes referred to as drones and the name can be used interchangeably. Drones are an emerging technology with many potential applications in the civil engineering field. The aging and deterioration of structures such as bridges is becoming an urgent social issue. In fact, structures are subject to ageing processes due to external effects like weather conditions, intensive use or increasing loads and also internal effects like fatigue of materials or natural deterioration. The maintenance and preservation of any kind of structures is a very complex and responsible task for civil engineers that have to carry out regular inspections by visual investigations in order to preserve structure from fall. Often this involves considerable risks for safety of workers, due to the fact that many structures are difficult to access. A visual inspection allows to plan diagnostic measures, cleaning and maintenance operations, to verify the accuracy of drawings, to detect the degradations of the materials and each structural part. The process of data acquisition for a reliable condition determination and the complete documentation of these results is a time consuming, labour intensive and technically complex task [1].

The use of drones should be considered as an assistive tool for routine inspections to improve the quality of the inspection by obtaining information and detail that may not be readily obtained without expensive access methods and sometime the interruption of the service is required. This technology can aid structural engineers in performing different nondestructive tests and plan future destructive ones. The goal of this research is to evaluate the capabilities of the drone technology as an assistive tool for inspectors. To that end, two cases study have been performed using a drone, DJI Phantom 4. The
obtained data in terms of drone images can be used to construct a 3D model, using modern photogrammetric computer vision methods like Structure-from Motion (SfM) implemented in software such Pix4D. The workflow provides for site acquisition, flight path planning, images acquisition and post analysis.

2. Application field in civil engineering
The UAVs are known for their role in military applications but more recently, the potential use of drones as tools in civilian environments has gained significant attention. Drones are being used in various fields and in different purposes all over the world since being able to be equipped with cameras, sensors, or other intelligent devices providing useful information for different applications. In fact applications at the present are manifold, for example daily pictures, deliveries of packages, mapping, safety surveillance, search and rescue operations, visual inspection of hard-to-reach locations and in domains such as agriculture, forestry, archaeology, architecture, and construction. With development of real-time monitoring technologies, a significant attention has been paid to the potential use of drones in engineering environments, including many potential applications in the civil engineering field: environmental monitoring for leak detection, rivers surveying to predict inundations, traffic jams and accidents individuation, structural pathways of mineralized fluids’ identifications, and so on. In addition, they are used to monitor and maintain pavements and highways, to control construction processes of infrastructure systems such as buildings and bridges through capturing videos and images from parts of views of the project site [2,3,4,5].

In figure 1 a pie chart representing the top industries in US using drones is shown. Paying attention to the yellow wedge, it is possible to state that the use of drones in constructions is only about 9%.

![Pie chart showing top industries using drones in US](image)

**Figure 1.** Percentage of Section 333 Exemptions Issued in US (Source: FAA, The Verge Drone Project, 2015).

Recently, the use of drones for checking structures during maintenance is getting powerful: checking damages and cracks and making instantly measurements of structures are catching on. A variety of structures needs to be inspected such as dams, high mast luminaires, photovoltaics, facades and building roofs, industrial and historical buildings, bridges [6]. Given to the large scale of civil infrastructures, inspections become more and more complex, hampered by access issues and involving large costs and relatively long intervals between inspections [7, 8].
In current practice, the condition assessment of structures by conventional inspection practices mainly relies on human-based visual inspection and the main approaches for conducting the inspection are via scaffolding, rope, elevating platforms or a special vehicle, and often require specially trained climbers for data acquisition (figure 2) [6, 8]. The scaffolding is a traditional method for inspection, however it is labour-intensive and time-consuming. The use of an inspection vehicle equipped with massive robot arm, such as a “cherry-picker”, performs the inspection in a safer and more efficient manner than scaffolding. However, the inspection on small-scale bridge becomes difficult due to the working space requirements of such a vehicle that is in large size so as to balance the weight of the robot arm [9]. Since a bridge is always constructed on cliffs or riversides and because of the high elevation, a close visual inspection becomes a difficult task, thus evaluating the condition below the bridge becomes the most difficult action [6].

According to statistics, the construction site is one of the most dangerous workplace all over the world [2]. Drones are a great potential tool for reduction of injuries on construction work sites through reducing the unsafe situations, for instance eliminating some of the high-elevation inspections [2, 10, 3]. Drones are turning out to be a speedy and cost-saving solution and without traffic closure in some situations.

![Figure 2](image)

**Figure 2.** Current practices for inspections: via scaffolding (a), via by-bridge (b), via ropes (c).

3. Structure inspections

Damage assessment in constructions is a significant factor and drones can help engineers at the very beginning of the occurrence of damage and allow planning experimental investigations for diagnostic. The use of infrared thermography supported by a drone is such a great non-destructive method which evaluates buildings without any contact and carry out rapid investigations [3, 11]. Its use is useful for discovering types of materials with which structures are made (masonry, concrete), discovering the presence of steel rebars, water leakages or humidity, or the thermal patterns within the building envelope as well as the movement through and across various building materials (table 1). The non-contact nature of infrared thermography is well-suited to projects that deal with historical buildings or to areas that have experienced catastrophic disasters.

In addition, there is growing attention on the extraction of quantitative information from images (table 2) in consequence of the identification of deterioration regions and crack detection [7, 12]. The ability to detect and measure concrete crack thickness and length using drones has already been
researched. Ellenberg studied the effectiveness of drones to detect cracks in terms of the distance to the structure [12]. The study demonstrated that with a high-resolution camera it is possible to detect a crack thickness of 0.75 mm at a distance of 3 m [6]. In another study, reported in [1], the analysis of aerial images of a façade has shown that it is possible a visual identification of cracks of 0.3 mm at distance of 10 m from the surface, but only if images have sufficient sharpness and good exposure as well as the lowest possible image noise (minimum ISO value). Using a specific software, it is possible to measure distances, specifically dimensions of structural elements, comparing them with project drawings. Moreover, it is possible to measure span deflections over the time on bridge or beams, caused by increasing loads or by long term effects [12].

Table 1. Thermal measurements executed by means of thermal camera.

| Thermal measurements                                                                 |
|--------------------------------------------------------------------------------------|
| Discover type of material of structures (masonry, concrete)                          |
| Discover the presence of steel rebars                                                |
| Discover water leakages or humidity                                                 |
| Thermal bridges                                                                      |
| Performance of conducts and pipelines                                               |
| Concrete delamination                                                                |
| Determination of fresh and hardenest stages of concrete                              |
| Determination and location of voids in concrete                                      |

Table 2. Geometrical measurements executed by means of post-processing images.

| Geometrical measurements            |
|-------------------------------------|
| Crack thickness and length          |
| Sizes of elements                   |
| Long term deflections               |

The inspection process includes four steps (figure 3): structure identification, flight path planning, image acquisition and post processing (or post-analysis) [9, 11, 13]. The last step allows analysing the status of the structure.

Figure 3. Inspection workflow divided in four steps.

The kind of mission depends on what you are flying over and the images are taken at different locations of the structure and for this purpose a flight path is needed. The images with satisfactory quality will be used to recreate the structural components in 3D virtual space [14, 15, 16, 3, 4].

4. Accuracy of measurements by drones

The accuracy of the provided measurement result depends on either the sensor type and characteristics, but also on the drone platform itself [17].

Regarding thermal measurements, it is necessary to distinguish between position accuracy and temperature accuracy. Position accuracy is mainly affected by the thermal sensor characteristics, such as the sensor resolution and the color depth. Instead, temperature accuracy is again determined by the color depth as well as by the accuracy of the calibration. A proper calibration of the thermal imager is
Indeed necessary to extract scientifically relevant data in all the applications where the surface temperature needs to be measured [18].

Regarding geometrical measurements, it is possible to distinguish two categories of applications. In the former case, it is needed to survey a wide area, in order to get all the geometric dimensions of the objects in the area. For example the inspection of large structures such as buildings, bridges and dams, requires to obtain 3D measurements of the structural elements that are mainly developed by aerial photogrammetry or aerial laser scanning.

Aerial photogrammetry is typically carried out by the Structure from Motion method, where, different pictures are taken in different positions during the drone flight. Then, the 3D reconstruction of the scene is carried out by finding common features in the images. As shown in [19], the accuracy of these 3D dimensions is affected by two main contributions. The former one is related to the resolution of the camera and to the sensor size. Keeping fixed the sensor size, a higher resolution of the camera results in a smaller pixel size and therefore allows appreciating smaller details. The latter one is instead due to the uncertainty in the knowledge of the positions where the pictures were taken and the focal length of the camera. In aerial photogrammetry, often, the positions of the images are estimated by finding common features in the images. When this procedure is used, it is necessary to calibrate an object in the scene by a different measurement method and the whole 3D scene is scaled according with such knowledge. In this case, several uncertainty sources arise, such as the ambient lighting, the texture of the objects in the scene, the color difference between the objects and the background. Moreover, an additional uncertainty of the calibration phase should be considered.

Alternatively, a precise positioning method could be used to obtain the position of the images. An option is the use of the Real Time Kinematic (RTK) that allows to enhance the accuracy of the Global Navigation Satellite System (GNSS) positioning by means of phase corrections generated by a base station [20].

In [19], the authors proposed a model for the evaluation of the uncertainty of the height of an object surveyed by aerial photogrammetry. According to this model, the squared height uncertainty \( u_h^2 \) is given by:

\[
    u_h^2 = \left( \frac{dh}{dcrm} \right)^2 u_{crm}^2 + \left( \frac{dh}{dcim} \right)^2 u_{cim}^2 + \left( \frac{dh}{dcrg} \right)^2 u_{crg}^2 + \left( \frac{dh}{dclg} \right)^2 u_{clg}^2 + \left( \frac{dh}{db} \right)^2 u_b^2 + \left( \frac{dh}{df} \right)^2 u_f^2,
\]

where:
- \( c_{lm} \) and \( c_{rm} \) are the pixel projections of a pixel on the camera sensor array, corresponding to a point (M) on the top of the object, in two images, respectively;
- \( c_{lg} \) and \( c_{rg} \) are the pixel projections of a pixel on the camera sensor array, corresponding to a point (G) on the ground, in two images, respectively;
- \( \theta \) is the drone elevation angle of drone in a second waypoint referred to the first;
- \( b \) is the distance between the positions related to image acquisitions;
- \( f \) is the camera focal length.

The first four terms in (1) depend only on the camera resolution and sensor size. Instead, the remaining three terms depend on the position accuracy, as well as on the accuracy of the calibration.

In aerial laser scanning, the drone is equipped with a Light Detection and Ranging (LIDAR) system, directly providing a 2D point cloud, referring to a plane of the observed scene, in each waypoint. The LIDAR measures the time-of-flight of the light from the LIDAR sensor to the object. The accuracy of this measurement depends on the distance between the sensor and the object, as the uncertainty increases with the distance. Moreover, the point clouds of the different observed planes must be merged to obtain a full map of the scene. Since it is necessary for this step to know the position and orientation of the drone, the final point cloud is also affected by the uncertainty related to the position and orientation measurements.
In some application of structure inspections, it is not needed to obtain a 3D map of a wide area or widespread objects, however it is necessary to measure the size of details of a single structure. This is the case of the measurement of crack sizes in walls or pillars.

In this case, the size of the observed detail $s$ is obtained from the corresponding pixel interval $\Delta p$ in the image by the following formulation:

$$ s = D \frac{\Delta p L_s}{N f} $$

(2)

where $L_s$ is the size of the sensor (in SI units) in the direction of the measurement (horizontal or vertical), $N$ is the number of pixel of the camera in such direction, $f$ is the focal length of the camera and $D$ is the distance between the camera and the observed object. Usually, $f$ is known or it can be determined by a proper calibration procedure, while the distance $D$ must be obtained by a separate measure.

Therefore, the uncertainty of this measurement is affected by: (i) the resolution of the camera, (ii) the uncertainty of the knowledge of the camera focal length, and (iii) the uncertainty of the knowledge of the distance.

5. Case study 1

5.1. Description of the bridge

A bridge constructed in 2017 near Benevento (Italy) was studied. It is a single-span bridge of about 36 m supported by elastomeric disc bearings, leaning on concrete abutments, 12.45 m wide and 5.40 m high (figure 4). The width of the bridge deck is 12.00 m consisting of two lanes limited with road safety barriers. The bridge deck is realized by four girders made of steel COR-TEN S355JOW with the height variable between 1900 mm at the supports and 1500 mm in the middle of the span. The RC slab has variable thickness with a mean value of 44 cm at the sidewalks.

![Figure 4. Schematic lateral view of the composite bridge in the province of Benevento (Italy).](image)

5.2 Inspection and model

The aim of this drone mission was to check the real dimensions of structural elements. Furthermore, the inspection enables to control any missing bolts, or the state of the bridge bearings which are essential for the global behaviour of the structure.

After the review of the design, the inspection images were taken at different locations of the bridge. The bridge was accessed from one of the river banks and from the top of the deck. It was established that a general bridge view should be inspected first, and then more detailed structural components, such as abutments, girders and deck.

The inspection was piloted manually (controlled by pilot) and not autonomously (predefined path with no pilot), taking 148 pictures at variable heights and distances. Before performing the task, it was important for the aircraft to take off and hover at a given height to check the signal of the remote radio, since losing the signal during flight may cause the aircraft to crash. The flight time was of about two
hours using more than one battery. It was possible to monitor the flight staying on the riverbank, not losing the visual check of the aircraft even underneath the bridge. The position of the bridge caused some problems due to the wind speeds and it was not permitted to come within 2 meters. It was necessary to process the images for parts: abutment 1, abutment 2 and lateral view (figure 5). It was only possible to develop the front view of one side because in front of the other side arises an ancient bridge and the drone could not get closer. It was not possible to generate a unique 3D model for the difficult access to one side and for the lack of view of the whole bottom of the girders. For each part, it was necessary to scale the images to real dimensions.

Doing the math, it was possible to measure and compare the geometric dimensions, to get closed to the supports and also to the bolts of the steel girders, allowing to detect the degradation of materials. As expected for a new construction, it was not observed evident damage, such as concrete spalling, corrosion or exposed rebar. Nevertheless, on the abutments 1 it was noted a water leakage coming from the upper slab or caused by a groundwater; this phenomenon would cause a rapid deterioration of the structure. In table 3 the elements inspected are listed.

Table 3. Bridge elements inspected by drone.

| Structural component | Drone inspection report |
|----------------------|-------------------------|
| Abutment 1           | yes                     |
| Abutment 2           | yes                     |
| Girders              | Yes (but outer side only)|
| Front side           | yes                     |
| Back side            | not                     |
| Deck                 | yes                     |
| Bottom girders       | not                     |

In order to test the reliability of geometrical measurements the structure was scaled with only one scale constrain, using the measure in site of the width of the abutment. The values obtained are reported in table 4.
### Table 4. Design values and geometrical measurements of the elements.

|                  | Design value | Measured value | Error |   |
|------------------|--------------|----------------|-------|---|
|                  | Width [m]    | Height [m]     | Width [m] | Height [m] | Width | % | Height |
| Abutment         | 12.5         | 2.75           | 12.0  | 2.62       | 3.9   | 4.7 |
| Longitudinal steel girder | 0.850        | 1.90           | 0.850 | 1.81       | 0.0   | 4.7 |
| Transversal steel girder  | 2.90         | 1.02           | 2.75  | 0.960      | 5.2   | 5.5 |

In order to scale the model referring to the longitudinally view of the structure, the height of the guardrail was used and easily measured in-situ. In table 5 the measurements obtained by the elaboration of the images are reported and compared with the design values.

### Table 5. Design values and geometrical measurements of the elements.

|                  | Design value | Measured value | Error |   |
|------------------|--------------|----------------|-------|---|
|                  | Length [m]   | Middle height [m] | Length | Middle height | Length | % | Middle height |
| Longitudinal steel girder | 36.0        | 1.50           | 35.7  | 1.49       | 0.8   | 0.7 |

The errors are in within an acceptable range, furthermore the elaboration of many more photographs could provide a more accurate model. However, from the results, it is clearly a higher error for transversal measurements. This is due to the framing of the pictures, since it was not possible to take pictures from a viewpoint below the bridge and the transversal elements were not framed parallel to the camera plane in any picture. This was instead possible for longitudinal elements. Moreover, the pictures of the transversal elements had a lower exposure due a scarce lighting below the bridge.

### 6. Case study 2

#### 6.1. Description of the bridge

The second case study is a prestressed concrete bridge built by the cantilever method in the ’50 years. It overtakes a torrent in the centre of Benevento, becoming a very important connection. The width of the deck is 9.00 m and consists of two traffic lanes, 7.00 m width, and two sidewalks 2.00 m width. The bridge structure has a total length of 120 m and consists of one main span (80.0 m) and two cantilevers of 20.0 m (figure 6). The bridge is a frame with two piers 9.40 m high; each pier consists of eight columns 40.0 cm thick with a variable height from 1.50 m to 4.00 m. The piers are linked to the foundations underneath by hinges made of steel rebars. The deck is made of four prestressed box-girders varying in height from 2.70 m to 3.60 m.

![Figure 6. Lateral view of the prestressed concrete bridge in the centre of Benevento (Italy).](image-url)
6.2. Inspection and model
In this second case, the focus was on the use of drone as a tool for safely, speedy and inexpensive inspection. For this bridge an urgent and rapid inspection was needed because of the degradation of the materials. Thanks to the use of the drone, the investigation with by-bridge along the entire structure was avoided, reducing the traffic interference and reducing the safety risk for workers. The bridge was accessed from one of the river banks and from the top of the deck.

In this case study, a video was recorded instead of taking pictures. It allowed a quick survey of the structure to identify and localize damaged areas to better finalize further and invasive inspections.

Few minutes were extracted from the total recorded video. The software took out pictures to implement the 3D model. The bridge is surrounded by wooded area and the elaboration to create the point clouds took a long time, in addition the picture extracted from the video were approximately in number of a thousand. In figure 7 a particular of the model developed by the software is reported. The elements surveyed are summarized in table 6.

The area of major interest is more or less at one third of the span where there are evident degradation phenomena. Thanks to the detection of this area by drone, a local test was finalized removing the concrete cover; the local essay allowed to check a high corrosion level of the tendons (figure 8).

![Figure 7. A detail extracted from the software model obtained by the post-processing of images.](image1)

![Figure 8. Local test at one third of the span; a high corrosion level of tendons is shown.](image2)

| Structural component | Drone inspection report |
|----------------------|-------------------------|
| Pier 1               | yes                     |
| Pier 2               | yes                     |
| Girders              | Yes (but outer side only)|
| Front side           | yes                     |
| Back side            | yes                     |
| Deck                 | yes                     |
| Bottom girders       | not                     |

In this second case study, it was not possible to maneuver the drone underneath the bridge staying on the deck; furthermore, the drone flew under the bridge, only a partial view of the bridge bottom was available due to the presence of threes. Moreover, shadows, as well as the greenery, affected the elaboration of the model.

7. Conclusion and future developments
An ever-growing number of infrastructure across the world need to be inspected to ensure appropriate serviceability and sufficient structural integrity. It takes an immediate analysis and there is a need for a more efficient and affordable technique to visually inspect structures. Drones are an emerging
technology with great potential to assist future structures inspections practices, with some advantages over conventional inspections practices including cost, time, reduced risk for inspectors and inspection quality. The results are encouraging, therefore it is necessary to study in the future all the negative aspects that are underlined in the following.

It is necessary a qualified person to pilot a drone, liability, insurance, flight permission by Enac (Italian Civil Aviation Authority) and property permission to fly on private soil.

A mechanical malfunction or loss of power due to batteries that lose their effectiveness, can cause the drone to rapidly fall to the ground and crush. Because of that the operator should avoid flying the drone over areas where people are working whenever possible. It is not excluded operator errors causing personal injury and property damage [5]. Another issue is the limited flight time and the need to change batteries. Probably for inspections of small structures is not necessary but for bigger ones it represents a problem: it means to stop the fly and more time to finish the inspection is required. Drone flight time of a battery is approximately 25 minutes but it could be lower in case of windy day. Weather conditions can affect the quality of the visual data collected: shadows and glare from reflective surface can affect the results of the 3D process [13]. Of course the drone could not fly at the presence of high wind speed, or in rainy days a fortiori [5]. Generally temperature can affect the drone operation: the aircraft does not function well at extremely hot or cold temperatures [5].

Another issue is the large amount of visual data collected in a single visit [5]. The main challenge with visual inspection is that obtained results can vary significantly depending on the experience of the inspector.

The drone can be controlled by a pilot, manually, or referring to a predefined path established thought a mobile application. Generally the mobile application is useful to survey large areas. Using drone with autopilot controls such as sonar, Lidar, visual sensors or obstacle avoidance is a necessary when GPS is denied. Loss of signal underneath a bridge makes the aircraft difficult to be controlled. The ability to fly without a GPS signal is an important feature when using this technology as an inspection tool [8].

Since a drone is equipped with electrical sensors like gyroscope and magnetometer, it can be affected by communication interference if there are magnetic sources around the drone. Thus, the drone takeoff location and flight path should be away from large metal objects or reinforced concrete structures [5,13]. Measurements can be estimated from images, but tactile functions (e.g. cleaning, sounding, measuring, and testing) equivalent to a hands-on inspection cannot be replicated using drones.

This paper presented, by means of two cases study, the capability of drones as professional assistive tool for engineers. Images obtained from such studies have been used for element measurements, to detect cracks, corrosion and other damages. Both positive and negative aspects of the use of drones were highlighted.

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