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CIVIL ENGINEERING INSPECTIONS ON NUCLEAR SITES BY DRONE

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ABSTRACT

EDF is a French electric utility company that operates 58 nuclear power plants in France. In 2016, EDF generated more than 72% of the electricity in France. To improve the maintenance of different structures within a nuclear site, EDF has been working on developing the use of innovative technologies to undertake civil engineering inspections, with a particular focus on drones. Since 2016, different drone inspections have been conducted on nuclear plants to inspect part of a cooling tower, the exterior of reactor-containment buildings and the interior of the main turbine hall. This new tool, which offers a rapid operational inspection capability, is equipped with a high-resolution camera to take multiple pictures of the target structure. The pictures enable high-quality orthophoto maps of the inspected structure to be generated. The results from the drone inspections enable a global view of the structure to be obtained and make it easier to follow the evolution of defects. While currently defects are only detected with the manual assistance of experts, EDF R&D is focusing on optimising the data processing of images and building new tools to make it easier for the experts to detect and quantify defects.

INTRODUCTION

EDF is a French electric utility company that operates 58 nuclear power plants in France, which generated more than 72% of the electricity in France in 2016. EDF is one of the first French companies to use drones for the inspection of industrial structures and the environment.

Concrete structures of nuclear power stations are regularly inspected in order to verify their condition and to meet the statutory requirements for regular monitoring. These inspections determine the state of the concrete surface to detect and follow the evolution of cracks and other defects. Historically, in order to undertake this monitoring, EDF required rope access with risk of falls, or the use of a telephoto lens which lacked the ability to give detailed views of the concrete structure inspected (especially when the viewing angle from the ground is unfavourable).

A drone or UAV (Unmanned Aircraft Vehicles) is a remotely piloted aircraft. It can carry different sensors and provide measurements or highly detailed information by taking high definition photographs, 3D point clouds, thermography images, etc. Being really easy to deploy on an industrial site, drones are innovative tools for inspection of structures.

The use of professional drones has been regulated in France since 2012. This regulation, while quite restrictive, enabled the development of a new industrial sector.

The first civil engineering inspections using drones were applied to hydro power buildings (such as dams for example) and began in 2012. As sensors and flight reliability have improved, drone inspections have since been deployed on thermal power plants. In 2016, the Security Department of EDF gave its approval to use drone for inspection of nuclear installations with a new procedure and opened up opportunities for innovative drone solutions.

This paper describes results from two drones trials on nuclear power plants in 2016. The first was a visual inspection inside a turbine hall and the second was a civil engineering inspection of a cooling tower. Also described are some other research projects in development which build on the results of the trials.

VISUAL INSPECTION INSIDE A TURBINE HALL

The objective of this inspection was to visually assess the condition of equipment and areas where access is restricted due to the rails of the overhead crane and the structural framework of the turbine hall. In order to perform these visual inspections in a controlled and secure manner, a specific drone was used which is surrounded by a carbon protective frame. This drone is light (only 0.6 kg, including payload) and is able to move almost everywhere in secure non-intrusive manner as contact with obstacles is prevented because its frame protects its propellers. Figure 1 shows the characteristics of this innovative drone.

Figure 1: Flyability drone characteristics @ http://www.flyability.com/elios

The preparation of this mission was quite easy, as the trial was organised inside the turbine hall and the drone flight was not subject to civil aviation legislation. A study was also made, prior to the trial, on the frequencies used by the drone in order to avoid interference with important sensors and instrumentation located inside the turbine hall.

The drone was really easy to deploy. Within 10 minutes, the video obtained by the drone was sufficient to have an idea of the state of the overhead crane and areas which traditionally required visual inspection by rope access. The following photographs in Figure 2 and Figure 3 illustrate the views taken by the drone in action.

Figure 2: Photograph taken by the drone of the turbine hall interior

Figure 3: Views of the drone in flight @SITES

There are numerous benefits to adopting this type of inspection approach. First of all, safety on the site is improved by reducing risks of falls, the inspection cost is cheaper than traditional methods as there is no need to build scaffolding or utilise rope access. The drone is also really easy to use and can significantly reduce inspection times as setup only takes 10 minutes. Safety is also improved by using the drone regularly, which permits early detection by monitoring areas that are too difficult for manned access.

Finally, the results of this trial have conformed to the requirements for a regulatory inspection of this type applicable to turbine halls. It permits validation of the use of this innovative drone in order to inspect the interior of buildings such as the turbine hall within nuclear power plants. This new tool has now been included in the range of possible methods that the maintenance teams could use to rapidly inspect the good state of the turbines and the inside the turbine hall buildings.

CIVIL ENGINERING INSPECTION OF A COOLING TOWER

Cooling Tower and nuclear containment structures are regularly inspected visually in order to follow the evolution of concrete defects. The objective of an inspection by drone was to evaluate the state of the concrete degradation and compare this state with previously inspections. This evaluation consists of identifying every crack, closely examining them and locates them in the topographic reference of the inspected structure. External surfaces of a cooling tower are traditionally inspected by telephoto lens from the ground. Depending on the number of defects, this inspection can take up to 4 weeks. Only photographs of defects are taken, which allows their characterization by type, dimension, location and characteristics.

Figure 4: A drone for cooling tower inspection

The objective of this trial with a drone on the cooling tower was to challenge traditional inspection approaches in terms of price, duration of inspection, image quality as well as the innovative deliverable by producing a 3D model of the cooling tower.

Figure 5: Views of the drone in action @GEOSCAN

The trial lasted 4 days; the pilot worked 6 hours per day. The wind was sometimes strong and stopped some flights. The weather was good, with clear sky and high temperatures (30-35°C in the middle of the afternoon). Photographs were taken on a single axis, only when the drone was going up in order to conserve the battery. In total, more than 12,000 photographs were taken for a quarter of the cooling tower. The resolution of the photographs is 0.5 mm and the photographs recovery is high at around 80%.

EDF R&D performed the data processing (image geometry reconstruction and 3D model creation). This high resolution 3D model of the cooling tower permits the user to identify and locate all defects on the structure, improving the understanding of defects with a global point of view. As concrete defects are geo-located, it will be possible to superimpose the next 3D model of the structure and compare the evolution of the defects. The resolution of the 3D model is around 0.5 millimetres and the reconstruction is really easy to navigate around and to zoom until the required view is obtained.

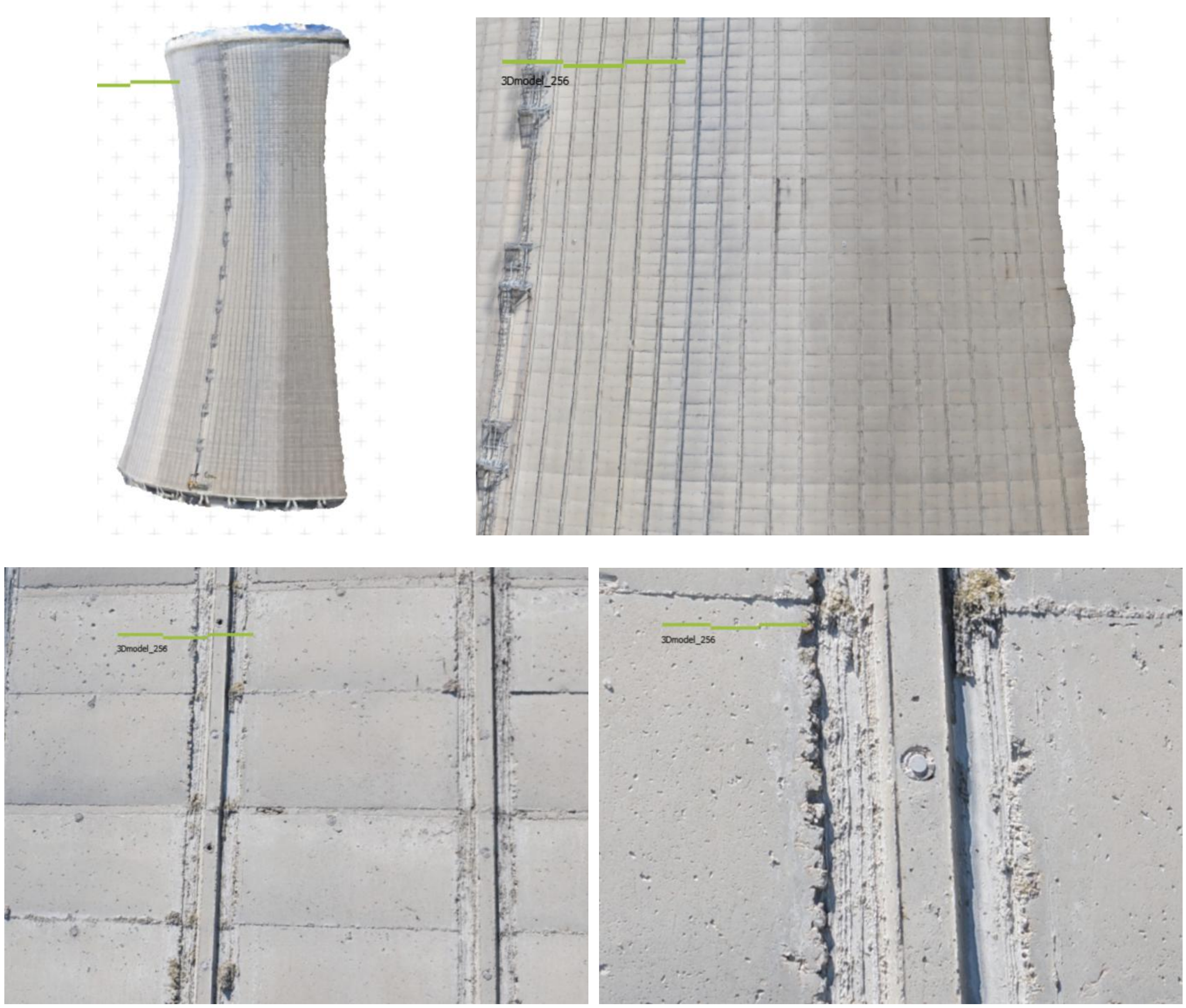

Figure 6: Example of different zoomed views of the cooling tower 3D model surface @ EDF R&D

For undertaking future inspections, the most important benefit today is the entire and exhaustive cartography of the structure which opens up the possibility of re-examining defects. It’s a real gain compared to traditional methods, such as telephoto lens inspection which only gives photographs of identified defects. For instance, the two illustrations in Figure 7 illustrate this benefit: on the left side, a crack has been detected on the drone's cartography but it's not possible to compare this crack with other previous inspections because there are no photographs of this area available as showed on the right side.

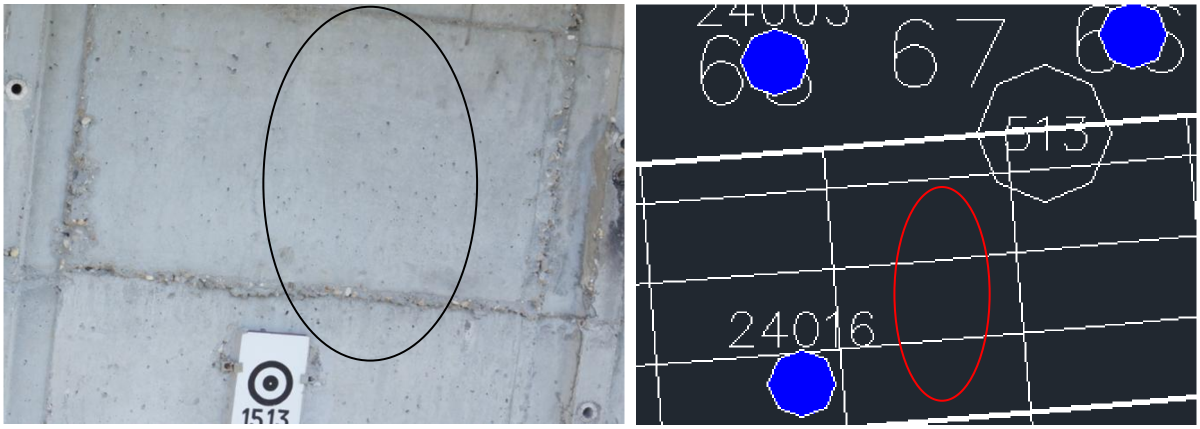

Figure 7: Comparison between 3D model obtained by drone and the traditional deliverable for telephoto lens

However, there are some drawbacks specific to this particular drone application, especially concerning flight limitation due to weather conditions: the drones cannot fly when it's raining or windy. In addition, while the drone takes a lot of pictures, the data processing can be quite long and currently take 2-3 weeks to build the entire cartography of a quarter section of the cooling tower. Once this is done, the civil engineering expert needs to detect and draw the different defects on the cartography. This part isn't automatic and requires manual analysis by an expert. In terms of inspection duration, 2 weeks need to be added to the work schedule to obtain all authorizations from the authorities to use a drone on a nuclear site, the drone acquisition takes 1 week, the data processing lasts around two weeks and two weeks more are required to analyse the data which totals 7 weeks before the results to be obtained. Therefore, a drone inspection can only be useful if the inspection isn't urgent.

Today, the use of drones for civil engineering inspection is increasing, especially on nuclear sites. Piloting a drone, doing the data processing and assessing the civil engineering implications are 3 competences that are totally different which require very specific expertise. Vigilance must be maintained to ensure the quality of each of these steps by the required experts.

CONCLUSION AND PERSPECTIVES OF USES

EDF Organization around Drone Uses

Drones are a fantastic tool for monitoring structures and the environment. It improves security and safety by taking exhaustive photographs of a structure especially where manned access is difficult, and therefore reduces cost of inspection support logistics (scaffolds or rope access). However, the drone market isn't mature yet, so there is a need to develop and qualify drone systems and coordinate their development in order to deploy it for all directorates of EDF Group. Moreover, French regulations for professional drone use are not well known and differ from hobby use rules.

In order to develop, coordinate and harmonise the different drone solutions, EDF decided to create a Drone Expertise Centre. The tasks of this centre are:

1. Preparing the future: regulatory watch (technical and regulatory), development of drone solutions (platform, sensor, data processing) and experimentation and trials on site in order to compare results with traditional methods

2. Industrializing the drone solutions by developing industrial standards (technical guide, standard service catalogue, framework contract, …) and capitalizing lessons learnt and good practices

Progressive deployment

Visual and civil engineering inspections by drone are two applications which utilise drone solutions for deployment at EDF. On nuclear power plants, EDF conducts multiple drone experiments in order to finalize the industrial standards for these applications. But other drone solutions need improvement or new development before industrialization. Drone technology performance is also improving rapidly, therefore EDF focus today on two research projects is to aim for improving tomorrow's drone solutions.

The first one concerns optimising the data processing of drone images to facilitate the human analyse on the cartographies obtained by drones. EDF R&D launched a project to develop tools for data processing automation acquired by drones (orthophoto, automatic defect detection to facilitate diagnosis). The first results concerning the evaluation of tools for automatic detection of civil engineering defects will be delivered at the end of the year 2017.

The second project is looking for solutions to achieve autonomous drone flight inside a building where there isn't any GNSS signal in order to inspect buildings under radioactivity control. The first trial will be done during summer 2017. The aim of this trial is to evaluate some technical solutions already used on autonomous cars. Those solutions use real time data processing during the flight, which permit detection and avoidance of different obstacles, and the ability to understand its localization in real time by recognising specific aspects of its environment.

Drone flights on industrial sites are just beginning, and possible uses are increasing every day. EDF is also involved in different European projects in order to improve both regulation and the drone technology. The company works with the French aviation authorities in order to open the regulation to facilitate some specific use cases such as long distance surveys and contributes to accelerating the miniaturization of specifics sensors on drones such as LIDAR or hyperspectral sensors for accurate measurements.

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