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RPAS TO MONITOR DIKES: AN OPTIMISED INTERVENTION

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ABSTRACT

The monitoring system has been identified as one of the leading potential obstacles to controlling the risks of structural failure.
Experience and feedback from the Compagnie Nationale du Rhône (CNR), France's second largest producer of hydraulic energy, has shown the importance of visual supervision. Human eyes are the primary first-line detectors of structural flaws. However, under certain circumstances, it is no longer possible to access the structure, or the site has become too dangerous to send a team in.
New airborne devices, such as Remotely Piloted Aircraft Systems (RPAS), provide an effective way to fly over inaccessible sites. CNR's innovation is to combine the images from RPAS with some high-resolution geographical information to create geo-referenced 3D models.
For this operation, CNR has combined its efforts with the expertise of the IGN (the French National Mapping Agency). For some years now, this geographical institute has been developing MicMac, an open-source software used throughout the photogrammetric process to automatically convert images into a 3D model. The technology is expected to deliver heights to an accuracy of one centimetre, which is not possible with other techniques.
There are many fields to which we could apply our approach, such as backfilled dams, concrete structures and pressure pipes, or in the aftermath of a major event such as an earthquake or flooding preventing access to the section.
After describing our innovative calculation method in the article, we discuss some of the applications we have already tested on CNR's sites.
Using RPAS to monitor our structures enables warning signs to be detected as soon as possible with a high degree of flexibility. Defects detected early are identified in a national geographical system, and allows action to be taken and the alarm to be sounded early on.

Keywords: *UAV, drone, RPAS, Monitoring, Dam, Photogrammetry,*

1. INTRODUCTION

Unmanned Aerial Vehicles (UAV), Remotely Piloted Aircraft Systems (RPAS), drones... these terms all refer to the same thing. People used to regard them as a tool for dropping bombs, but now the civilian world is using them too. From precision crop management to beer delivery during music festivals, many applications have been explored.

As a hydraulic energy producer, the Compagnie Nationale du Rhône (CNR) is particularly interested in a system that could help them monitor their dikes. Considering the major issues in the event of a breach and given the French regulations, they have to be regularly inspected and monitored. CNR has set up a network of topographical references by means of a precision levelling process all along the river, from the Swiss border to the Mediterranean sea (over 400 km). Four offices specialising in land surveys have been contracted to monitor structures all year round.

This organisation has been sufficient to avoid any major problems, but we think that it is possible to use UAVs combined with the latest photogrammetric tools to build a complementary system. The idea is to establish a system which is cheaper, faster and more accurate, and with a better resolution than traditional surveying methods.
UAVs are interesting as they offer a cheap alternative to aircrafts or helicopters. They also fly closer to the ground, and so have the capability to acquire pictures with a ground sampling distance measured in centimetres or even less.

This article presents the project on which CNR and IGN have been working since December 2012. The first part introduces the legislative duty to monitor structures, as well as the way it has been implemented so far. Then, in a second section, we set out our expectations and requirements of a new system. The third part details the organisation and the main problems of the project, and also provides some initial results. To conclude, we explain how the project is to be continued, with the objective of concluding it by the end of 2015.

2. DIKE MONITORING IN CNR

In France, the monitoring of structures and thus of dikes is governed by regulatory texts; dikes in canals under permanent load are considered to be backfill dams, and subject to application of the "Dams" regulations of the safety decree of 2007. As the concessionaire for the Rhône, CNR must be organised and have suitable systems for monitoring these structures.
The monitoring is based on three components: visual monitoring, examination measurements, and tests and inspections.

2.1. CNR’s dikes

CNR's dikes represent some 400 linear km between Switzerland and the city of Arles just before the Mediterranean Sea. They were built between 1950 and the end of the 1980's. From 10 to 20 metres high, they were built using the materials found on site. They are permeable and under a permanent hydraulic load.

The main pathologies observed are: internal erosion, surface erosion and differential settling. Due to the aging of these structures, their examination needs to be more detailed and more precise.

Figure 1 : Arial view of a dike

2.2. Visual monitoring

The first link in the monitoring of structures and thus of the dikes consists of the field agents and the regular patrols carried out on site on a weekly basis. These inspections allow visual findings to be tracked back to flaws which can be seen on the surface of the structure.

2.3. Measurements from examinations

Measurements from examinations, allowing the changes of the measured magnitude to be quantified, allow a historic view of the structure's behaviour to be obtained. Linear structures such as dikes are examined by means of one-off measurements of interstitial pressures regularly distributed and established from the start.

All the CNR’s dikes are fitted with piezometers allowing the changes in the water level in the body of the dike to be tracked. This level is measured at two points on the profile in order to be able to verify the correct hydraulic drawdown between the Rhône and the counter-channel (cf. Figure 2).

In addition to this network, topographical levelling points allow individual zones to be tracked, which requires closer monitoring.

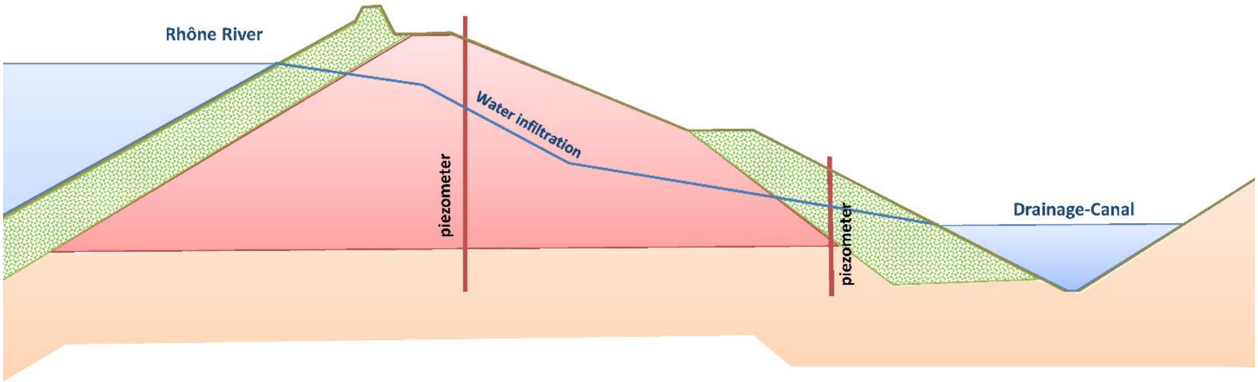

Figure 2: Transversal section of a dike

2.4. Knowledge of the geometry of the structure

In order to supplement the monitoring system with a view to the early anticipation of changes due to aging, CNR wishes to develop acquisitions allowing a continuous geometric definition of the structure. Indeed, this dimension will provide CNR with successive surveys allowing comparisons to be made.

One-off data acquisitions by terrestrial or aerial LIDAR have already been carried out over a few small zones. However, the use of this type of technology is still costly, cumbersome and unsatisfactory in terms of precision (multiple stations, long acquisition time, and precision at best ± 3 to 5 cm).

Given these challenges and in the light of the development of RPAS, CNR approached IGN to study the abilities of these systems to examine linear structures such as dikes.

3. THE PROJECT

3.1. Context

For some years now, civilian RPAS have been developed, in particular in the context of visual inspections of civil engineering structures. Their use for topography is not new either, but few service providers have grasped the concepts of photogrammetry or topography.

Developments in digital cameras, the calculating power of computers, research in photogrammetry and computer vision have resulted in the recent emergence of operational solutions enabling 3D models to be produced automatically from multiple (multi-stereoscopic) photographs. By fitting a consumer-grade good-quality camera on a RPAS or ULM, it is now possible to produce, 100% automatically, visually "perfect" models, or at the very least adequate models as long as they are used as communication supports.

On the other hand, the implementation of these methods is as yet not properly mastered in a context where the 3D model is intended to be used as a measuring tool, in particular in the problem area of monitoring landscape changes. However, there is a strong demand by clients for systems able to monitor in 3D any movements of the ground with a precision of just a few millimetres.

3.2. Objectives

The objective is to have a system allowing the geometry of structures such as dikes to be known in detail and precise to a centimetre from aerial photographs so that comparisons between two successive situations can be produced; in this way, a faster and more economical system is obtained, which also offers a more subtle geometry which is adequate in terms of statutory requirements than the topographical systems currently used. One innovation consists of using consumer-grade digital cameras as measuring tools for deformable structures such as structures made of earth and poorly accessible concrete structures.

Scientific goal:

- the precision of the 3D models is to be analysed, improved and optimised using the current algorithms;
- indicators about the precisions are to be defined and it is to be ensured that they are within the “maximum tolerated deviation” defined by the operator.

Technical goal:

- methodologies are to be developed, and also an operational tool for monitoring and examination operations on civil-engineering structures (dike geometry, concrete structure deformation, detection of scouring etc.).

3.3. CNR’s requirements

In the context of its monitoring, CNR has defined two kinds of requirement: recurring acquisitions and exceptional acquisitions. The main gains sought are:

- finding out the geometry of structures precise to a centimetre so that comparisons between two successive situations can be produced;
- speed of setting-up and processing for the examination of part of a structure in a damaged state (earthquake, problematic access etc.);
- surveys at a lower cost than equivalent systems;

3.3.1. Recurring acquisitions

This relates to the regular examination of localised target zones (in the order of a km) in the context of specific monitoring operations. For this type of acquisition, the expected precision is ± 1 cm so that “centimetric” (± 2 cm) deformations can be detected.

3.3.2. Exceptional acquisitions

They concern crisis situations where CNR wants to have a survey of major linear locations (several dozen km). In this context, CNR wants to have available a tool which is quickly put in place and with which data can be processed quickly (earthquake, problematic access etc.). With this type of acquisition, the expected precision is in the order of ± 3 cm.

Type of acquisition	Frequency	Linear	Requirement	Maximum permissible measurement error (movements to be detected)
Recurrent Reinforced Monitoring	once / year	1,000 metres	Detection of deformations in the context of the monitoring of a clearly defined sensitive zone	± 2.5 cm
Exceptional	Crisis situation	Several km	Comparison with an initial state to produce a survey following an exceptional event (earthquake, flood, navigation incident)	± 5 cm

Table 1: Table summarising CNR’s requirements.

3.4. Reality and benefit of the centimetre precision

In the context of the reinforced examination measurements put in place at CNR on the sections of structures subject to major pathologies (risks of internal erosion for example), CNR hopes to be able to obtain, as early as possible, information about the deformation of the dike surface. This deformation is not calculated by point-by-point comparison as that is not physically realistic; instead, mesh model to mesh model is used, which enables the structure to be understood in its continuity and in its entirety.

3.5. Scientific issues

The photogrammetric process requires 3 main steps:

- Linking the images to each other, via a keypoint detector (Lowe, 2004)
- Determining for each image the camera's position, attitude and distortion parameters. This process is called bundle adjustment (Pierrot-Deseilligny, 2011)
- Creating a 3D model, based on the previous steps, by projecting pixels in ground geometry, a process called dense correlation (Pierrot-Deseilligny, 2006).

The problem with bundle adjustment is that of finding initial values close the actual ones. This is vital as the equations need to be linearised, and then solved by iterations of a weighted least mean square process.

To model a building using photogrammetry, pictures need to be taken all around the subject with a large overlap, so the final images cover the first ones. The algorithm used will understand that the photographs are over 360°, and will compensate for any deviation.
From a photogrammetric point of view, a dike's geometry is problematic. They are very long and narrow objects, with no recovery between the structure's beginning and its end. Tiny errors spread from picture to picture all along the dike, resulting in a curved 3D model. This drift effect has been known for decades from classic photogrammetry, and has been remedied by setting up a number of ground control points (GCP) in the field. The drift can be controlled by adding constraints in the equations.

To improve our technique and make it even faster and cheaper, our work is now focussed on how to limit the number of GCPs to the maximum while maintaining target accuracy.

4. INITIAL RESULT ON THE ROCHEMAURE DIKE

4.1. Terrestrial Lidar survey

The Rochemaure dike was used as a test site to assess the accuracy of terrestrial Lidar surveying (Robin 2013). Two independent surveys were carried out in order to study the measurement repeatability and to establish whether the laser scanner is a suitable instrument for monitoring dikes.

The surveys were carried out using a Riegl LMS620 laser scanner. References were moved to certify the independence of the two models. It took 6 days of work and two engineers to complete the two surveys of the 60 x 600 m dike. Each scan is actually the result of 39 stations, merged using 5 to 12 references, determined with an average RMSE of 10 mm. The point density is from 550 to 600 points/m².

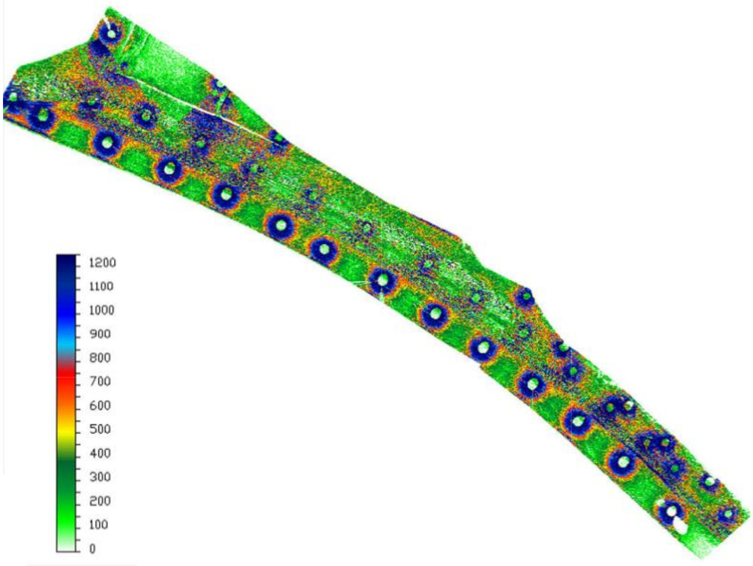

Figure 3: Point density per square metre

The two surveys were compared by different methods.

- Cloud to cloud using CloudCompare, which computes the Haussdorf distance between two cloud points (Girardeau-Montaut, 2006).
- 2.5D grid to 2.5D grid using Surfer with a 5 by 5 cm grid.

The statistical data in

Comparison	2.5D to 2.5D	Cloud to cloud
Mean Absolute Error	27 mm	24 mm
Standard deviation	28 mm	17 mm

Table 2 : show good measurement repeatability.

The main zones (**Figure 4**) presenting big differences are:

- Around the scanning station on the main road (in the cloud-to-cloud comparison, due to low point density),
- Along the subsidiary road on the west (a thin red strip),
- At the eastern extremity, along the river.

In the scrub to the southeast, the errors are easily understandable as the area is mostly covered with trees and vegetation. On the extremity along the river, the grazing angles from the scanner logically reduce its ability to measure the edge correctly.

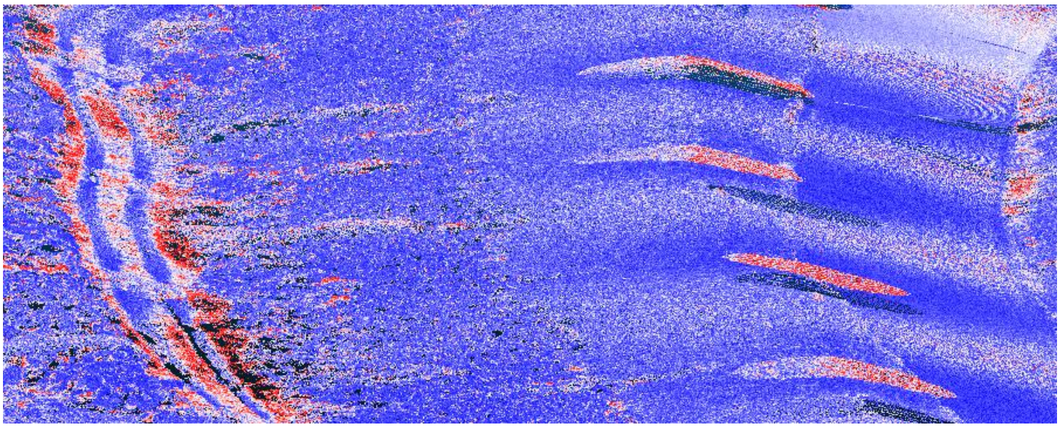

Figure 4: Focus on imprecisions between surveys

4.2. Photogrammetric processing

At the end of June 2013, two months after the Lidar mission, a photogrammetric survey campaign was organised on the Rochemaure dike. We set up two rows of GCPs on a 50-metre grid, and surveyed them both by GPS and precision levelling. We then used IGN's HexaXL UAV to acquire our pictures with an 80% overlap on two parallel strips, at a height of 60 metres to get centimetric pixels.

Although the actual UAV survey was fast (two hours from the first to the last picture), we actually had to postpone the flight due to the particularly windy conditions. That is one of the drawbacks of RPAS. In the event of an emergency survey, we cannot rely on simply hoping that the weather will be good enough to fly. In this case, fixed-wing UAV or even microlight systems can be used with the same technique. Only the flight plan (and the resulting resolution) will have to be adapted.

The acquisition was however successful, and 110 pictures were taken. A visually good 3D model and an orthophotograph were calculated (cf. Figure 5).

Figure 5: Orthographic view and cloud point result

4.3. Comparison with Lidar

We have seen that terrestrial Lidar can acquire high-quality data, and can be used to monitor deformations of 3 cm. However, the equipment is expensive (in excess of € 100 k), and as it is heavy, it cannot as yet be fitted on UAVs, although some developments have been successful (Conte 2013). It is thus not possible to monitor centimetric deformations in this way, and nor can it not be used in an emergency situation on a dike.
We were interested in comparing these terrestrial surveys with the different models we generated with MicMac.

The average results are similar if we compare our work to the first Lidar survey or to the second one. The absolute distances follow a Gaussian distribution globally centred around 4 cm with a standard deviation of 2 cm, regardless of which photogrammetric model we use. This precision is sufficient for the exceptional acquisition case, but should be improved if we want to use photogrammetry from UAVs for regular monitoring.

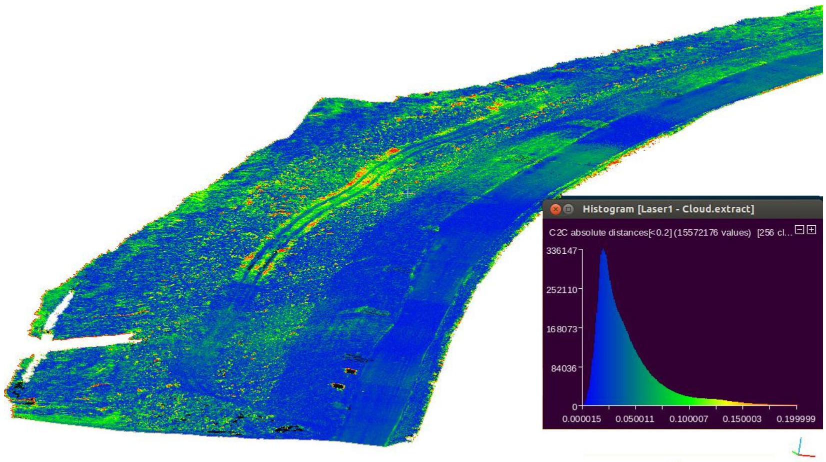

Figure 6: Comparison of LIDAR and photogrammetric surveys

We can see on them the same kind of poor interpolation around the laser scanning stations, which seems logical as the point density is lower there.

The imprecisions around the puddles are still present, but there is greater subtlety than on the first comparison. Actually, the entire zone on the north presents large differences from the Lidar survey. As that area is covered in vegetation, it is not very surprising to find these differences in our comparisons, given the two-month interval between the two surveys.

We did not find any correlation between the calibration residuals, the bundle adjustment results, or the residuals on the GCP when we compared the issued model with the Lidar surveys. These indicators can not be used to define the accuracy of our method, but we can use them to improve our algorithms. Some more work has to be done on the homologous points selection, as well as on calibrating our camera with innovative techniques (for example, by using an interferometer to constraint positions).

5. CONCLUSION AND FUTHER WORK

We have seen in this article how promising the technology appears. RPAS use, combined with increasingly permissive legislation worldwide, is expected to have the same effect on aviation as mobile telephony had on landlines.
The benefit for us however lies in the use of the resulting images. Our innovation is that of working on the development of algorithms so that the images can be automatically converted into sharp geo-referenced 3D models. Taking two days in the field and using consumer-grade equipment, the technique has proven to be faster and cheaper than existing methods, while competing with them in terms of accuracy.
We are very confident that we will be able to reduce the time taken to less than one day by decreasing the number of GCPs needed, making our approach even cheaper. By simulating a typical UAV flight at a scale of 1/20 in a metrological laboratory, we will work on refining the algorithm to improve the accuracy of our technique.
By the end of 2015, we plan to have a fully functional system, allowing us to monitor our structures with centimetric accuracy.

The project presented in this article allows CNR to acquire the resources and methods needed for the monitoring of the future. CNR, as an exemplary concessionaire, has joined forces with a European leader in topographical measurement (IGN) to implement an innovative system for its specific dike examination needs. It will be possible to transfer the solutions found in the context of this thesis (high-precision geo-referenced measurements of structures on large linear developments) to other structures with the same geometry or which are difficult to access. There are numerous applications: pressure pipes, the tops and walls of dams and railways can form the subject of precise geometric surveys.
The public thesis will result in photogrammetric algorithms written in an open-source environment, and open to the entire scientific community. Major advances with regard to the algorithms and results from actual applications will form the subject of a paper at the Dams Congress in 2015.

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