ANALYSIS OF TECHNOLOGICAL SOLUTION FOR AUTOMATIC INSPECTION OF CRITICAL INFRASTRUCTURES

A case study at Águas de Portugal Group

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Abstract

Water supply and sanitation services represent a major contribution to economic, social and environmental development of a country. Typically, the urban water sector has a great number of facilities, such as dams, water treatment plants, reservoirs and wastewater treatment plants, which were built a few decades ago, many of them located in remote areas, difficult to reach and frequently including confined spaces with poor air quality and other hazards for workers. To ensure a safe, reliable and continuous supply of drinking water and sanitation services both infrastructure and their assets must rely on good and planned maintenance, including regular inspections and condition evaluation. Maintenance efforts usually increase throughout the asset's lifecycle, and economic implications of this activity require systematic prioritization. This can only be achieved through asset management, including assessing the current asset service condition. These assessments are supported and enhanced by the information obtained through inspections or monitoring processes.

Traditional asset service condition assessment techniques involve visual inspection, carried out by experienced inspectors, combined with relevant decision-making criteria. Sometimes the anomalies are not quantified accurately, because it is not possible to closely access the infrastructure assets that is intended to inspect or because there aren't used precise instrumentation methods. It is, therefore, necessary to find automated technological solutions that assist human inspectors in carrying out such inspections, with the aim of making inspections faster, safer and more objective, increasing maintenance cost-effectiveness.

This work aims to analyse the challenges related with asset inspection, addressing and proposing automated inspection solutions, with less human intervention. In order to identify the asset inspections that are most relevant to apply these solutions, a methodology for quantifying relevance was developed, based on assets quantity and the severity of inspections.

Keywords: Infrastructure; Asset Management; Maintenance; Inspections; Defects; Severity; Automated solutions.

1. INTRODUCTION

Water supply and sanitation services represent a major contribution to economic, social and environmental development, having had a positive development in recent decades in Portugal. The Águas de Portugal Group operates nationwide through several subsidiary companies, henceforth referred to as AdP Group. The group core activity includes designing, operation and maintenance of infrastructures covering the all extension of the urban water cycle.

These infrastructures include dams, water treatment plants (WTP), reservoirs and wastewater treatment plants (WWTP), and were built a few decades ago. The continuous service supply is ensured by the proper functioning of these infrastructure and their assets, as they should be inspected, and their condition needs to be evaluated. The economic implications of maintenance require a systematic prioritization, this is achieved through asset condition assessment. Additionally, a reliable prognosis of the condition and behaviour of an asset is an important basis for an effective asset management.

In AdP Group the asset service condition assessment is carried out by inspectors. They perform a visual inspection, based on their experience combined with the attribution of relevant criteria. These inspections are qualitative and, sometimes, the defects are not precisely quantified, because the inspector cannot access closely to the asset that need to be inspected or there are eminent hazards.

In this context, the main goals of this work are:

- Development of a methodology that allows to identify AdP Group asset inspections that are more relevant, based on the severity (inspection duration, eminent hazards, access difficulties and need for installation outage) combined with the quantity of these assets in AdP.
- Research of automated technological solutions to perform the relevant asset inspections or assist the inspectors, aiming for a faster, safely and objective inspection, increasing maintenance cost-effectiveness.

2. METHODOLOGY FOLLOWED

2.1. DATA EXTRACTION

AdP Group deals with a huge diversity and quantity of assets, each one associated with an infrastructure. The assets that belong to WWTP, due to the aggressive ambient, tend to deteriorate on a higher rate, and represent a greater concern to the Group, due to is premature failure and frequent maintenance actions required.

It was analysed several reports regarding asset condition assessment from different inspection campaigns. The documents were generated by the support tools, that have been constantly in development on AdP Group. Due to this evolution, it was necessary to adopt different data extraction methods to collect relevant data. Regarding assets, internally, they are distinguished by civil construction and equipment, these two terms were adopted for the development of work. Firstly, it was necessary to identify the different asset typologies. For the equipment, it was collected data from each inspection report: the asset designation, the infrastructure they belong and the defects (anomalies) reported. After this, it was elaborated a list with all the equipment asset typologies. The list proved to be very exhaustive and some typologies were not relevant. In Figure 1 is shown the distribution of equipment asset typologies through infrastructure types. Assuming that, the main goal was to analyse technological solution for inspection, it was required that an asset typology present at least one type of defect. So, there were excluded the typologies of equipment asset that don't present any defects.

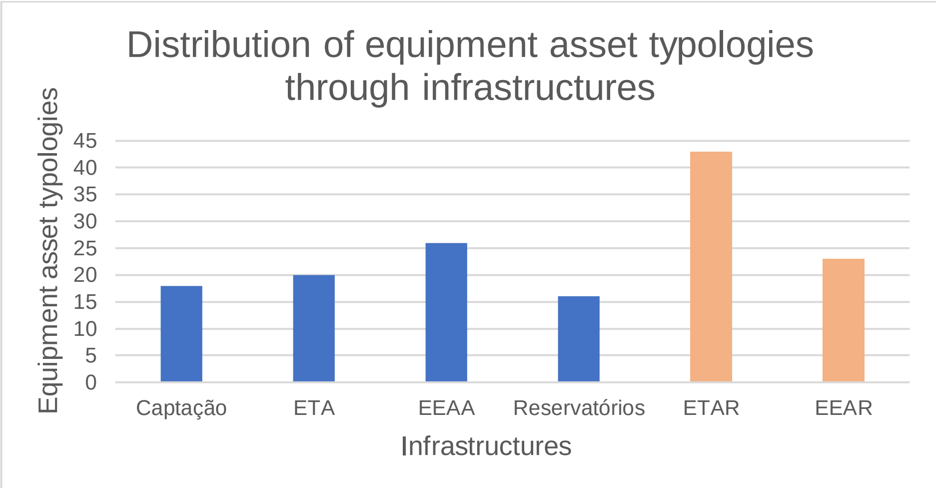

Figure 1 - Distribution of equipment asset typologies through infrastructures.

Regarding the civil construction assets, the extraction data from the reports were not linear as the equipment assets. The terminology or asset designation varies a lot, from report to report, and the information was too detailed, what would lead to an excessive list. So, aiming for a coherent and synthesized list, it was established, with the help of AdP Group, a generic terminology for asset typologies, that was used in all the infrastructure types (except for the dams):

- Exterior – cover.
- Exterior – surfaces (walls, beams, columns).
- Interior access – stairwells, doors, railings.
- Interior – cover.
- Interior – surfaces (walls, beams, columns).
- Enclosure – fences and pavements.
- Other components – illumination and ventilation.

In fact, each infrastructure has their own specifications and characteristics, but being this an analysis for academic purposes, it would be prudent to use this method. Besides these typologies, it was additionally identified:

- WTP:

- Channels
- Clarifiers
- Filters
- Drinking water tanks

- WWTP:
  - Channels
  - Clarifiers
  - Grit removal tanks
  - Aeration tanks
  - Sludge thickeners
  - Digesters
  - Silos
- Pumping stations:
  - Channels

Dams are still included in civil construction asset, but there were defined exclusive asset typologies: upstream and downstream slope, crest, spillways, and water intake towers.

This analysis served to define and identify the asset universe present on AdP Group. This database enables the further development of the work, that is a creation of a methodology for prioritizing assets whose inspections are most relevant.

2.2. DATA ANALYSIS

The process of quantifying the relevance of a certain asset inspection is based on the quantity of a current asset typology on AdP Group and the severity associated with the inspection of that asset. This process is represented in Figure 2

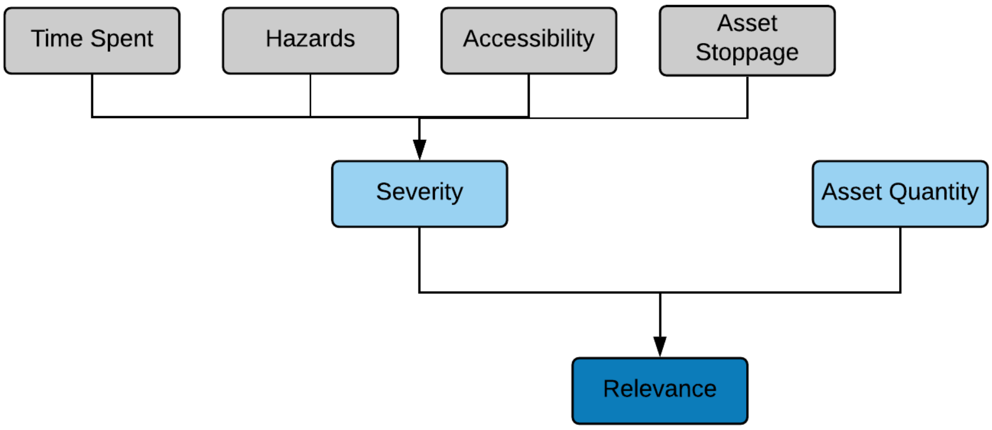

Figure 2 – Schematic representation of relevance quantification.

For the application of this methodology, it was adopted a semi-quantitative approach, based on several qualitative information that were categorized in numerical values. To determine the severity of each asset inspection, it was proposed a matrix with the objective of evaluating the inspections through 4 descriptors: time spent of the inspection, eminent hazards, difficulty on accessing the asset and the need for asset/installation stoppage. It was defined a qualitative scale for each descriptor, from 1 to 4, being 4 the most severe. These descriptors were combined through a weighted sum resulting in a severity value for each asset typology. The ponderation of each descriptor was determined in an iterative process, depending on the output of the severity, the weights were adjusted, aiming for a coherent output with practical experience of inspectors. Additionally, it was extrapolated the asset quantity of each asset typology, to perform a graphic, Severity vs Asset Quantity, and assist the selection of the asset inspections that were analysed in the case study. There were selected the following asset inspections:

- Civil Construction:
    - WWTP: Channels
    - WWTP: Clarifiers
    - WWTP: Grit removal tanks
    - WWTP: Aeration tanks
    - WWTP: Sludge thickeners
    - WWTP: Digesters
    - Reservoirs: Interior cover and surfaces
    - Dams: Spillways
    - Dams: Water intake towers
- Equipment:
    - WWTP: Bar screens
    - WWTP: Scraper
    - WWTP: Penstocks

3. CASE STUDY

3.1. CIVIL CONSTRUCTION

The civil construction assets selected are constructed in reinforced concrete, the structural integrity is compromised when the reinforcement corrodes, it can cause cracks and spalls, that accelerate the deterioration process. In these cases, concrete contacts also with water or wastewater, a protective coating is necessary, and it should prevent chemical attacks from acids and salts presents in wastewater. The most common defects on these civil construction assets are, cracks, spalls, reinforcement exposure, reinforcement corrosion and coating degradation. In the wastewater assets the actual and regular inspections are only made to the exterior and visible part assets, that don't compromise the functioning of the WWTP and don't exposure the inspectors to hazards. In most cases, there is no redundancy of this assets, so emptying a tank is impractical for legal and environmental issues. Through the experience and sensitivity of the inspectors, the exterior condition is extrapolated to the non-visible parts, like the interior of the tank. The only alternative of carry out a complete inspection is to match it with a maintenance activity that involves emptying the tanks. In the reservoirs the same applies, but in some cases, the reservoir has more than 1 cell. For these tanks and reservoirs, inspecting the interior is only possible matching the inspection with windows of opportunity, like maintenance activities or cleaning plans. In the dam assets selected, the human accessibility is difficult and involve hazards, so the inspection is carried out with optical instruments from a safe area.

3.2. EQUIPMENT

The presence of constant humidity and gas contaminants in a WWTP represent a very susceptible environment for corrosion development in equipment and deterioration, forcing frequent maintenance activities or complete substitution of these assets. The sulphur present in wastewater forms a toxic gas, hydrogen sulphide, and combined with humidity it converts into sulfuric acid, that is even more aggressive for the equipment and concrete. The material that constitutes these assets depends strongly on the treatment stage it's going to be applied and the characteristic of the fluid. If the material used is metal and it's a corrosion susceptible type, it needs a protective anti-corrosion coating. The inspections of these assets are usually done during the inspection of civil construction assets that they're inserted. The biggest concern for the inspectors is to look for corrosion, and if it exists, it's necessary to evaluate if it's compromising the structural integrity of the assets. Besides looking for corrosion, in the bar screens is inspected the degradation of the bars and teeth of the automatic cleaning system. This system is checked, tested and examined for any anomalous noises. In the inspection of penstocks, it's tested the sealing, through activation of the penstock and is verified the deterioration of the seals. Such as the need for lubrification of the mechanical components. The inspection of the scraper verifies: the wear of the scraper blades (and their levelling) and support wheels, the condition of the central pivot and the brush collector.

3.3. AUTOMATIC SOLUTIONS

3.3.1. Artificial intelligence techniques applied in image.

Artificial intelligence techniques when applied to image reveal an optimal way to identify and quantify defects, such as cracks, spalls and corrosion, besides that, combining this information with the structural component recognition is crucial [1]. Additionally, adding drones to perform the data (images) acquisition represent a perfect alliance, since drones are robust and can easily reach any place, remotely controlled or autonomously. This solution is very versatile, with only one drone and camera, it's possible to mitigate some issues related with human safety, hazards and accessibility. It can be applied to all the assets that were selected. However, analogously to visual inspection, it can only be inspected visible parts of the components. Like it's shown in Figure 3, it can simultaneously detect the defects and the regions of interest.

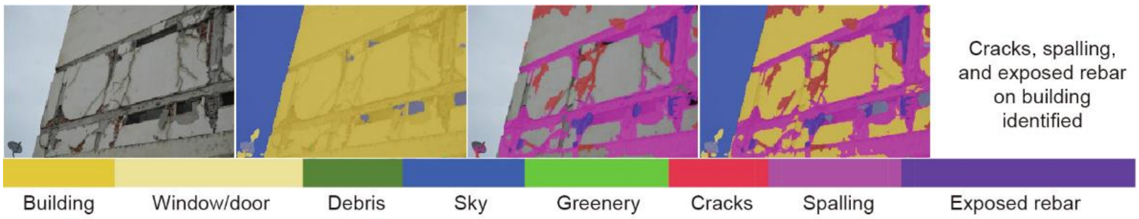

Figure 3 – Results of the proposed method by Hoskere [1].

3.3.2. Methods based in robot systems

Other techniques based on multi sensor systems require a closer proximity to assets, so they are associated with other types of locomotion systems, like crawlers, as shows in Figure 4. When robots are equipped with sensor based on non-destructive techniques the results are more objectives. The robot in Figure 4, ICM Climber is suitable for inspecting surfaces of civil construction assets, it is an automated device that moves on the surface attached to it by using some adhesion mechanism such as vacuum. It deploys both contact and non-contact based non-destructive techniques (NDT) for inspection of reinforced concrete assets. Non-contact NDE method include, visual examination, infrared thermograph, air coupled impact echo and ground penetrating radar (GPR). Contact methods include, impact echo, resistivity, half- cell potential, and shear wave tomography. The ability to equip the crawler with different or multiple NDE techniques allows the automated inspections to be focused on the detection of specific concrete degradation mechanisms [2].

Figure 4 – ICM Climber [2].

The project ‘‘CView’’ [3] addresses one of these inspection problems, underwater inspection. One of the main goals in this project is to find cracks or damaged areas on underwater assets. The platform for developing the guidance algorithms for inspection is the autonomous underwater vehicle (AUV) ‘‘SeaCat’’, shown in Figure 5. This underwater vehicle has a control software system with an user interface for mission planning, a mission control system, a precise navigation system, optimized motor control with an autopilot and sensors for obstacle detection and inspection. For obstacle and inspection target detection, a scanning sonar is used. The sonar images are automatically processed with edge detection and line extraction algorithms to get a simplified environment description, which is used by the guidance methods. A pan–tilt enabled sensor head with camera, laser measurement and MBES (Multibeam Echosounder) is used to inspect the detected objects. Additionally, these sensors provide distance information to the inspection object which can be used by the inspection guidance

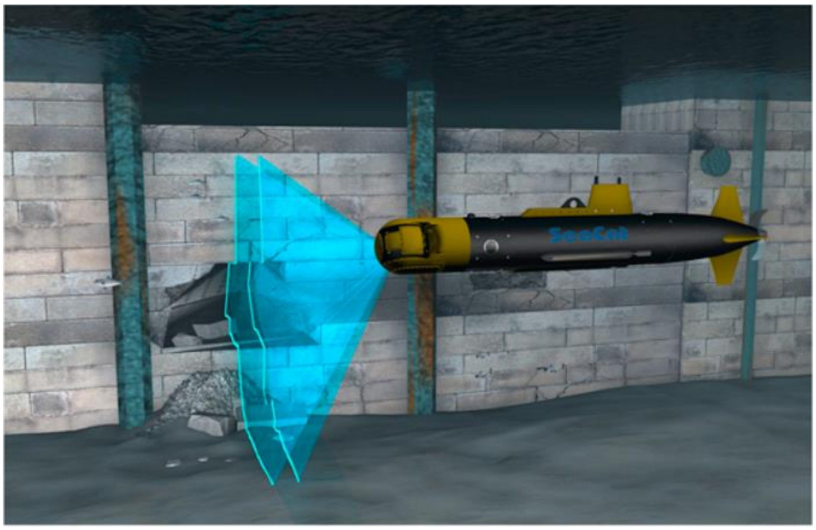

Figure 5 – SeaCat [3].

4. CONCLUSIONS

This dissertation had as main objectives: elaboration of a methodology that allows the identification of asset inspections that are more relevant; and a review of technological solutions for automated inspection of the selected asset inspections.

In a first phase, a methodology was created to understand which inspections are most relevant on AdP Group for a certain typology of assets, combining the severity associated with each asset typology quantity. It was identified that the most relevant inspections are:

- The main tanks and some important equipment of WWTP, due to the aggressive environment where they are inserted, requiring the use of personal protective equipment, and because the inspection of these assets requires a total stop of WWTP.
- The interior of water reservoirs, the accomplishment of an inspection requires emptying the reservoir in cases where there are no redundant cells. The waste of resources makes the inspection impractical, as economic impact is high.
- Spillways and intake towers of dams, due to the accessibility limitations and the hazards that inspectors are exposed, as these assets are located in areas where access assistance is not available.

After establishing which asset inspections were more relevant, it was analyzed automated solutions for asset inspection. The artificial intelligence techniques applied in image when combined with the acquisition of data through a drone, prove to be a very versatile solution, and can be applied in a wide variety of assets, including the assets selected. Because all assets whose components are visible can be photographed and the resulting images, subsequently, analyzed. In addition, the robustness of a drone allows it to move to inaccessible areas or areas that represent hazards to inspectors. The application of artificial intelligence techniques in the interpretation and analysis of images also reveal a huge polyvalence, from the detection of cracks, spalls, corrosion to the recognition of structural components. The detection of anomalies alone does not represent an automated solution, it is necessary to obtain information about the structural component in which these anomalies are inserted. In order that the level of deterioration inspected (based on the type of anomaly and severity) associated with a component represent a useful information, aiding decision-making with greater impact.

Thus, it is also concluded that the automation of asset inspection has two aspects. The autonomous guidance of the locomotion device to perform and cover all the component area, and the autonomous identification of defect allied with structural component recognition.

The solution based on terrestrial locomotion robots or crawlers represent an important field to explore, as attaching a set of sensors that perform non-destructive testing allows a more objective inspection, focusing in quantifying the defects. This solution that be strongly applied in the surfaces of civil construction assets.

The AUVs can allow the inspection of the interior of assets like tanks and reservoirs without the need of emptying them. Additionally, it can inspect submerge structures of dams (intake towers, downstream and upstream submerged slopes) that are actually not inspected or only partially inspected during periods where the reservoir level is lower (usually in summer).

Civil construction assets are typically identic, their characteristic doesn't vary too much, so a single solution for inspecting a typology of assets can easily be applied in another. However, in the equipment side, the variation is tremendous, each has different components, functions, materials, operating methods, etc. In this case, applying a solution that can inspect a set of typologies is difficult, it is necessary to apply solutions that focus only on identifying specific defects, such as corrosion. Corrosion is present in the vast majority of equipment, meanwhile inspecting only the corrosion represents an incomplete inspection. Futhermore, the inspection of equipment requires a lot of human activities, such as opening doors, lifting covers and protections. So, it's impractical to apply an autonomous solution to perform a complete inspection of these assets and that can be applied in other equipment typology.

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