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3D projection of AI-derived concrete cracks on a Hydro Dam outlet tower

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ABSTRACT: In a Structural Health Monitoring (SHM) project, a hydro-dam's outlet tower in Northern Sweden required inspection and assessment. This was due to the lack of digital records regarding existing damage and the client's concerns about its progression. The tower's location in a lake made traditional inspection methods like scaffolding or skylifts extremely difficult. The concrete engineering expert hired for the evaluation was uncomfortable with rope access, making data collection an expensive and cumbersome task. The structure is significantly affected by fluctuating water levels in the lake, leading to suspicions of certain types of damage (e.g., freeze-thaw damage, erosion damage).

For this project, a Phase One P3 camera was used to capture thousands of 100-megapixel images from every angle of the tower. Every inch of the concrete surface was covered by at least five different images.

From these images, a 3D reconstruction was created using Spotscale's proprietary software pipeline[1], which is specifically designed for high-resolution processing. Subsequently, each image was analyzed by Spotscale's machine learning algorithm to detect cracks, spalling, and visible rebar. For every pixel on the 3D model, all images that observed that pixel were analyzed, and this information was used to project the best possible representation of the damage onto the model, creating a 3D texture of the damage.

The results revealed a distinct crack pattern, identified with a 98.7% confidence level when compared to human assessment of the same cracks. This provided the dam owner with a comprehensive understanding of the overall damage and an overview of the most severely affected areas.

KEY WORDS: 3D reconstruction; Machine learning; Crack identification; 3D visualization.

1 INTRODUCTION

Structural Health Monitoring (SHM) plays a crucial role in ensuring the safety and longevity of infrastructure. In this project, an outlet tower connected to a hydro-dam in Northern Sweden required inspection due to the absence of reliable digital records of past damage, combined with recent concerns about deterioration. The structure, situated in a lake and measuring approximately 30 meters in height, posed significant logistical challenges for traditional inspection techniques such as scaffolding, skylifts, or rope access.

Figure 1. An overview of the tower structure

Given these limitations and the client's need for high-resolution documentation, a remote sensing approach was adopted, enabling comprehensive data collection without direct human contact with the structure.

2 DATA CAPTURING

To achieve detailed visual coverage of the entire concrete surface, a PhaseOne P3 camera with an 80 mm lens was mounted on a drone platform. A total of 3,000 ultra-high-resolution images (11664 × 8750 pixels each) were captured in a single day of fieldwork. The drone operated at a consistent distance of approximately 4 meters from the structure, resulting in a ground sampling distance (GSD) of 0.2 mm. This resolution ensured that even fine surface anomalies were detectable.

Every area of the structure was photographed from multiple angles, with at least five images covering each point on the surface, enabling robust 3D reconstruction and redundancy in damage analysis.

High-resolution imaging using the PhaseOne P3 setup involves pre-planned flight paths or starting coordinates for drones or stationary setups for static structures. This ensured complete coverage and minimized data gaps. The image collection for the needed accuracy was performed with a minimum of 80% overlap, with 7-10 meters distance to the object, ensuring that every defect was visible in at least 5 different images from different angles.

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3 DATA PROCESSING

The captured imagery was processed using Spotscale's proprietary photogrammetry pipeline, optimized for handling high-resolution inputs and generating accurate 3D models. The resulting models are both metrically correct and visually intuitive, making them ideal for expert inspection and annotation.

Following model generation, Spotscale's AI-based damage detection system was applied. This system analyzes all available views of each pixel on the surface to detect features such as cracks, spalling, and exposed rebar. The AI consolidates information from overlapping images to create a high-fidelity texture projection of damage across the entire 3D surface, producing a visual damage map with sub-millimeter precision.

4 RESULTS

The final output was a detailed 3D model textured with detected damage patterns. The AI identified a prominent and recurring crack pattern, which was verified with a 98.7% confidence level when benchmarked against expert human assessments. Figure 2 illustrates the resulting damage map, with clearly visible areas of cracking and localized spalling. The damage texture allowed for both global overview and close-up inspection, enabling prioritization of critical zones for further manual investigation or remedial work.

By applying the AI interpretation, concrete experts can predict future decay such as concrete loss from the surface (spallings). The Spotscale software further enables the expert to measure depth on spallings that occurred in a sub-mm accuracy depth representation.

5 CONCLUSION

The combination of ultra-high-resolution imaging, advanced photogrammetry, and machine learning provided a complete and reliable overview of the structural condition of the outlet tower. The results were instrumental in helping concrete specialists understand the underlying causes of the damage, including environmental factors such as freeze-thaw cycles and water erosion.

Beyond the immediate inspection, this methodology offers several benefits: it reduces inspection time and cost, minimizes safety risks, and produces a digital baseline for future comparisons. The success of this project demonstrates the value of remote sensing and AI-powered analysis in modern infrastructure monitoring.

The AI algorithms are also able to detect and classify cracks based on predefined criteria, such as width and orientation. Each single crack can be interpreted as a separate object and represented either in projected raster on the geometry or as a 3D polyline along the center line (medial axis) of the crack (not performed on this specific project). To achieve this kind of geometry, the crack pixels are analyzed from several different viewpoints and compared before projected on the mesh. This analysis significantly enhances the robustness of the Spotscale approach. The ability to transform the pixels to 3D polylines (vectors) enables the possibility to automatically determine medium and max width over the crack length and establish the length in three dimensions.

This innovative approach to non-destructive testing unlocks new possibilities in infrastructure monitoring, making it possible to conduct inspections with greater frequency, precision, and ease. Structures and areas that were previously inaccessible or hazardous to manually inspect—such as the undersides of bridges, confined spaces inside industrial facilities, or elevated constructions—can now be examined in high detail without requiring extensive scaffolding or safety interruptions.

The ability to assess these components without disrupting day-to-day operations or public life significantly broadens the application of this technology. For instance, critical assets like highway bridges, retaining walls, and overpasses can be inspected while traffic continues to flow, eliminating the need for costly detours or shutdowns. Similarly, energy and water utilities can maintain full operational output during inspection processes, reducing the risk of service interruptions and increasing overall efficiency.

With more precise data on structural health, renovation efforts can be optimized both spatially and chronologically. Repairs can be strategically localized and planned based on the most urgent needs, which minimizes waste and maximizes the lifespan of concrete infrastructure. Over time, this data-driven approach contributes to a more sustainable and resilient built environment, where maintenance decisions are grounded in actual structural behavior rather than estimations or reactive measures.

Figure 2. Resulting 3D projected AI interpretation of crack pattern

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[1] www.spotscale.com