Digital Bridge Inspection: Leveraging Drone Photogrammetry and AI for Comprehensive Bridge Management

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Abstract

Effective infrastructure asset management requires comprehensive, accurate condition data to support evidence-based decision-making throughout a structure's lifecycle. Traditional bridge inspection methods, while valuable, face inherent limitations in defect quantification, repeatability, and data accessibility for longitudinal analysis. Point-in-time observations documented in text-based reports can make it challenging to track deterioration rates, compare discrete condition changes across inspection cycles, and prioritize maintenance investments based on objective metrics.

Digital photogrammetry and AI-powered defect mapping are transforming how engineers assess and manage bridge infrastructure. High-resolution 3D models provide permanent digital records of asset condition, enabling precise measurement and quantification of cracks, spalls, and delamination. These models serve as powerful visualization and analysis platforms that support multi-year deterioration tracking, facilitate collaborative engineering reviews, and provide the data foundation for predictive maintenance strategies. When combined with drone-based data collection, these technologies also address accessibility challenges for remote assets and hard-to-reach structural components, expanding the scope of what can be comprehensively inspected.

This presentation explores the integration of drone-based photogrammetry, AI-powered defect detection, and acoustic sensing technologies to compliment traditional bridge inspection practices.

Through two distinct case studies; the Hudson Hope Suspension Bridge in northern BC and the the Deh Cho Bridge in the Northwest Territories, we demonstrate how digital inspection methods deliver comprehensive, repeatable, and safe condition assessments while supporting Canada's infrastructure resilience.

The 206-meter Hudson Hope Suspension Bridge inspection integrated photogrammetric 3D modeling with a breakthrough technology: drone-equipped acoustic sensors for delamination detection in hard to access subdeck areas. The Deh Cho Bridge, a critical year-round link on the Yellowknife Highway replacing seasonal ferry crossings, shows the efficiency of digital methods in remote environments. A comprehensive drone-based inspection captured high-resolution imagery of major structural elements, with AI-powered defect detection identifying defects.

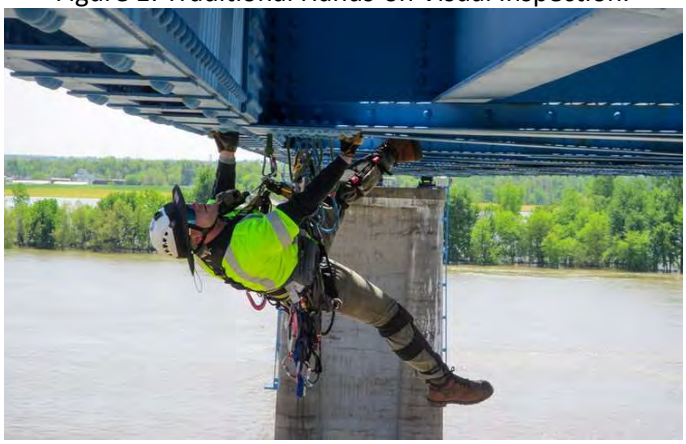
The methodology introduces several advances for Canadian bridge management. Digital models enable precise year-over-year comparison for deterioration tracking and data-driven maintenance planning, while web-based visualization platforms provide permanent high-resolution records accessible to multidisciplinary teams.

Introduction

Traditionally, structural inspections have relied on visual assessments, manual mapping of cracks and spalls, and sounding techniques such as hammer testing/chain drag to detect delamination. These approaches typically required direct physical access to the structures—often involving temporary scaffolding, ladders, elevated platforms, ropes teams, and/or crane baskets. While effective in localized evaluations and providing on-site engineering judgment, these methods can be labor-intensive for large structures, expose personnel to occupational hazards, and may be limited in consistency and coverage if repeated over multiple years. This can be particularly true for large or remote assets, which have additional logistical and access constraints.

At the same time, the civil engineering industry continues to struggle with increasing costs and the prioritization of assets for repairs and rehabilitation.

Figure 1. Traditional Hands-on Visual Inspection.



Photogrammetry, robotics, and artificial intelligence (AI) capabilities have begun to provide solutions to these decades-old civil engineering challenges. The combination of these technologies has provided an

alternative condition assessment method that enhances documentation, enables access to previously inaccessible features, and provides highly accurate quantification data for each defect. When implemented on a time series, these technologies can track each defect over time, facilitating predictive maintenance and optimized resource allocation by tracking deterioration over time.

Hudson Hope Bridge

The Hudson Hope Bridge is a single-span, two-tower suspension bridge crossing the Peace River in northern British Columbia. It is situated between the town of Hudson's Hope and the Peace River hydroelectric development. The structure consists of steel main cables and a reinforced concrete deck.. The bridge is part of the Chetwynd-Hudson Hope Highway, providing a shorter transportation route from central British Columbia to the hydroelectric project and onward toward the Alaska Highway. Completed in 1965, it continues to serve as a key connection in the region's transportation network.

Figure 3. Hudson Hope Bridge



Deh Cho Bridge

The Deh Cho Bridge crosses the Mackenzie River southeast of Fort Providence, NWT, carrying Highway No. 3 and opening to traffic in 2012 after construction began in 2008. It is a long, continuous steel truss bridge with a cable-stayed main span supported by two distinctive A-shaped pylons, providing two traffic lanes and a durable deck system suited to northern conditions. The superstructure consists of twin steel Warren trusses, cross-bracing, and a precast concrete deck topped with asphalt. The bridge is supported by engineered abutments on land and eight ice-resistant piers in the river, which are specially shaped to withstand ice forces and harsh environmental conditions.

Figure 2. Deh Cho Bridge



Methodology

Data Collection Methods

Imagery Dataset

Photogrammetry can be collected using several different methods and the decision on which to use is determined by the desired outcomes. Photogrammetry is a process which uses photographs to extract measurements and generate 3D models. By taking a series of overlapping images of a landscape from various angles, the software identifies matching features across the photos and uses them to reconstruct the object or terrain in three dimensions. Imagery can be captured from phones, handheld cameras, UAVs, aircraft, or any other type of image-capture device.

In this circumstance, to best capture imagery across different parts of the structure, and to provide consistency around image resolution, quality, distance from structure, and overlap of imagery, the decision was made to use a UAV. The equipment used was a DJI M350 with a Zenmuse P1 camera. By equipping the UAV with an advanced camera sensor, large areas could be surveyed efficiently and safely without the need for extensive equipment.

While UAV-assisted inspections offer numerous advantages, they are not without limitations. UAVs are sensitive to weather conditions such as rain and high winds and cannot remove surface debris or vegetation that may obscure the view of defects. For certain structures, handheld camera image capture, in combination with ground control points (GCPs), is an alternative option which can still accomplish the same goal which may avoid some typical UAV restrictions.

Ground Sampling Distance (GSD) in photogrammetry refers to the physical size of one pixel on the ground in a captured image. Essentially, it defines the spatial resolution of aerial imagery, indicating how much real-world distance is represented by each pixel. A smaller GSD means higher resolution, allowing finer details, like cracks or small features, to be detected more accurately, while a larger GSD reduces detail but covers a wider area per image. GSD is determined by factors such as camera sensor size, focal length, and distance from structure.

Acoustic Collection

Niricson's NCX Mini is a compact, UAV-mounted acoustic sensor designed to simulate the traditional concrete hammer test for detecting delamination in concrete bridges. This tool strikes the concrete surface at a rate of 20 taps per second, enabling rapid data collection in hard-to-reach or hazardous areas that are challenging for manual inspections. The NCX Mini employs a high-sensitivity microphone to capture the acoustic response from each strike, which is then analyzed using machine learning algorithms and manual quality control to identify potential delamination zones. Using onboard cameras, the sensor provides georeferenced delamination maps that assist asset owners in monitoring structural integrity over time and can be brought into the AUTOSPEX visualization software.

For the Hudson Hope Bridge, the data collection team collected acoustic data using the NCX Mini drone-mounted sensor in the soffit. The purpose was to identify anomalies on the structure and validate the results of the delamination map generated from the sensor

Figure 4. NCX Mini modeling and development in the Lab at Niricson



Figure 5. Example of a Time Domain Signal from Delaminated Concrete

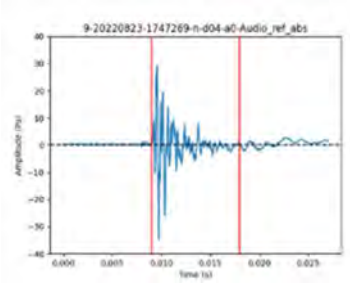
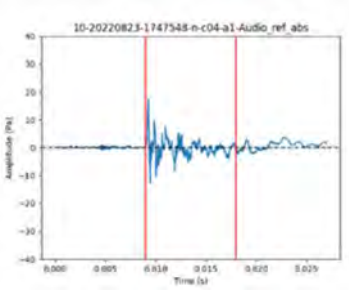


Figure 6. Example of a Time Domain Signal from Sound Concrete



Survey Control

Ground control points were set at various location throughout the site and at accessible portions of the structure. Local survey monuments were used, and new ground control points were set as needed. Ground control points (GCPs) improve the accuracy and reliability of photogrammetry-based condition assessments and 3D mapping. GCPs are fixed, precisely surveyed markers placed on the ground that serve as reference points for aligning aerial imagery with real-world coordinates. By incorporating these points into its data processing workflow, Niricson ensures that the spatial models and measurements derived from imagery are highly accurate, consistent, and georeferenced. This allows for precise defect localization, repeatable condition monitoring over time, and integration of inspection results with engineering design or asset management systems. An example of a ground control point, visualized in a bridge 3D model, is shown below:

Figure 7. Example of Survey Target, Visible in 3D Model



Niricson uses crack gauges as part of its validation process to ensure the accuracy of crack width measurements captured through its advanced imaging technologies. Crack gauges, which provide precise physical measurements of crack displacement, serve as a ground-truth reference against which digital or automated measurements can be compared. By deploying these gauges in the field and cross-referencing the recorded data with readings from their AI tools, Niricson can confirm the reliability of its crack width assessments. This validation step supports compliance with engineering standards and strengthens confidence in the digital inspection results. An example of a crack gauge, visible in a digital 3D Model, is shown below.

Figure 8. Example of Crack Gauge, Visible in 3D Model



Results and Insights

The collected imagery and acoustic sounding data was processed using Niricson's AUTOSPEX™ – an artificial intelligence software for automatically mapping and quantifying, as well as visualizing, anomalies in bridge infrastructure. AUTOSPEX™ uses a deep learning model to detect and quantify defects automatically. The model becomes more powerful as it collects more data over time. The model is also supported with a manual quality control procedure to reduce and eliminate false positives and false negatives that may be identified by the algorithm and further strengthen the algorithm.

The software generates a 3D Model, separates the structure into 2D Structural elements, and generates defect maps. Clients can then access the system to visual the 3D model, 2D Maps, and defect maps. As shown defect maps include the location and quantification of the surface/subsurface defects.
An example of the data is shown below:

Figure 9. 3D Model on AUTOSPEX

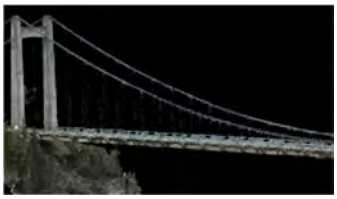


Figure 10. 2D Optical Maps Generated on AUTOSPEX



Figure 11. Defect Maps Generated on AUTOSPEX

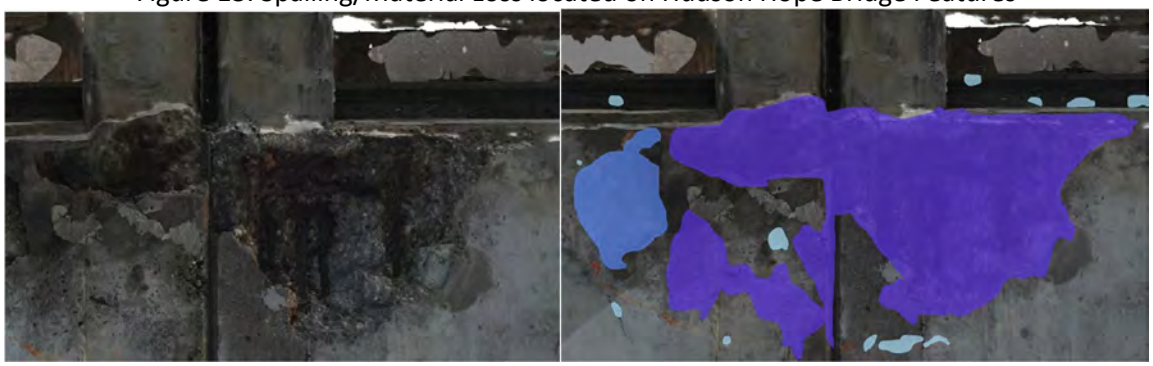


Based on the mapping of the defects with the algorithm, key findings from the condition survey included the following for the Hudson Hope Bridge.

Figure 12. Hudson Hope Crack Maps

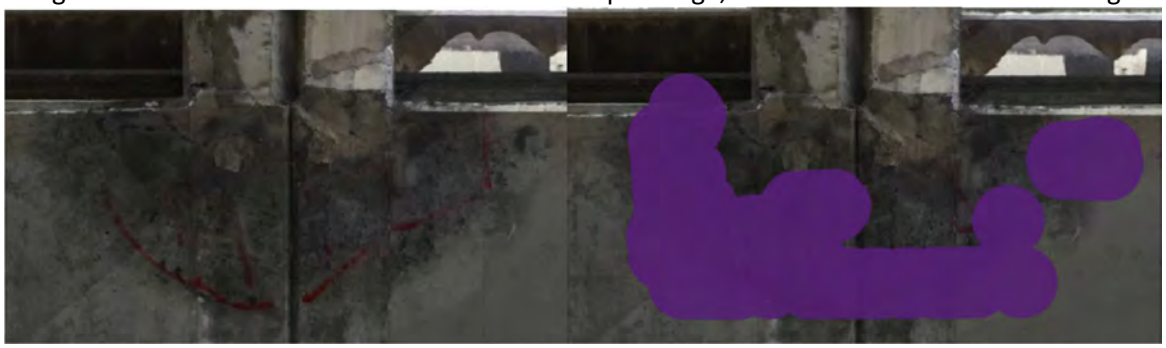


Figure 13. Spalling/Material Loss located on Hudson Hope Bridge Features



Potential concrete delamination (acoustic soundings), identified by the robotic sounding device on the Hudson Hope Bridge.

Figure 14. Potential Delamination on Hudson Hope Bridge, Validated with Previous Markings



Conclusions

The Hudson Hope Bridge and Deh Cho Bridge surveys illustrate how digital condition assessments with AI-assisted defect mapping can enhance infrastructure asset management. Digital technology enables subject matter experts and various stakeholders to remotely access detailed inspection data, eliminating the need for them to physically travel to site. Through high-resolution imaging, 3D models, and AI-driven defect detection, the platform creates a digital replica of the asset that captures both the visual condition and precise measurements.

This digital environment allows engineers and specialists to analyze cracks, spalls, delaminations, and other structural issues from anywhere, collaborating on assessments as if they were on site. By bringing the site to the bridge engineers, it not only reduces travel costs and safety risks but also accelerates decision-making and enables more efficient allocation of expertise across multiple projects. This can be particularly useful for rural sites undergoing construction, major rehabilitations, significant maintenance, and warranty repairs that may have multiple consultants, contractors, and other stakeholders involved.

For the right project, the data generated from this type of survey could be used in the following ways:

- Track Deterioration Rates and Compare Discrete Condition Changes Across Inspection Cycles: When deployed on a structure over time, this technology enables the implementation of preventive and predictive maintenance strategies. By tracking changes in asset condition repairs, engineers can understand how and where their assets are changing, helping them to proactively address issues, reducing the need for costly reactive repairs, and minimizing service disruptions.
- Prioritize Maintenance Investments Based on Objective Metrics: Understanding which assets are deteriorating most rapidly across a portfolio is paramount to allocating rehabilitation and maintenance budgets effectively. By applying this technology across the asset inventory, deterioration rates for assets can be obtained to understand which structures are deteriorating fastest and where asset owners need to spend their limited maintenance rehabilitation dollars to mitigate risks.

As digital condition assessments for bridge infrastructure become more commonplace, these projects represent a step toward digitizing infrastructure portfolios. Scaling these methods across multiple bridges could enable consistent monitoring, improved safety, optimized budget allocation, and extended asset service life. Further research on network-wide implementation of this technology would be needed to understand the cost-benefit of deploying it periodically to track asset deterioration. Additionally, research on stakeholder experience with digital technologies for major rehabilitations would be beneficial to understand additional efficiencies and benefits from multi-stakeholder knowledge-sharing.