Automated Assessment of Defects in Bridge Structures

tech transfer summary

Automation technologies such as unmanned aerial vehicles and artificial intelligence have the potential to improve the accuracy, speed, and cost-effectiveness of bridge inspections and damage assessments.

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RESEARCH PROJECT TITLE
Automated Assessment of Defects in Bridge Structures

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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Objectives

The primary goal of this research was to develop a comprehensive and integrated system combining unmanned aerial vehicle (UAV) technology and advanced artificial intelligence (AI) and machine learning (ML) algorithms to enhance the process of inspection, modeling, and assessment of bridge structures.

Additional objectives were as follows:

- Use automated systems driven by AI and ML to detect and classify structural defects with higher precision while greatly reducing the time required for inspections
- Forecast potential deterioration and support informed decision-making through continuous data analysis and structural health monitoring over time

Background

Effective and timely inspections of bridge infrastructure to detect the consequences of deterioration such as cracking, corrosion, and spalling is crucial to ensuring the safety of the traveling public, extending bridge lifespans, and preventing catastrophic failures.

Traditional inspection methods often involve manual visual assessments and can be time-consuming, labor-intensive, and prone to human error. Recent technological advancements in the fields of UAVs, AI, and ML offer promising solutions to the challenges posed by traditional inspection methods.

Image captured from a UAV

UAVs, commonly known as drones, feature advanced sensors and high-quality cameras that enable high-resolution images of bridge structures to be captured from various angles and distances, making them an invaluable tool for condition assessment purposes.

AI and ML algorithms can process a massive amount of complex data, such as the imagery collected by UAVs, and can detect and quantify damage and potential structural issues more accurately and rapidly than inspector analysis. These technologies also learn and improve over time, becoming more efficient and accurate with each inspection.

Problem Statement

While UAV, AI, and ML technologies have been demonstrated to offer significant improvements over traditional bridge inspection methods, achieving effectiveness requires integration and further development to improve the accuracy and speed of defect detection.

Research Description

An advanced framework was developed and tested for detecting and quantifying structural defects in bridge infrastructure using UAV technology for image capture and ML- and AI-based detection algorithms for analysis.

High-resolution images of a bridge structure in central Iowa were collected using two different UAVs operating at various distances and angles. Different damage types in these images were annotated to create a customized dataset for use in analysis.

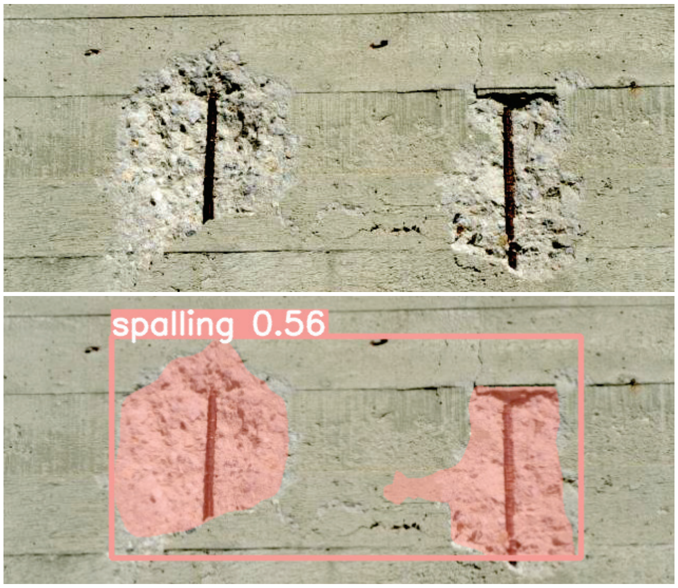
The captured images were then processed through a custom-developed convolutional neural network (CNN) object detection model to locate critical defects such as cracking and spalling. The detection capabilities were improved and extended by modifying the base model's architecture. The model's performance was assessed through multiple case studies, and its ability to detect and quantify defects under different conditions was validated against field data.

Study bridge

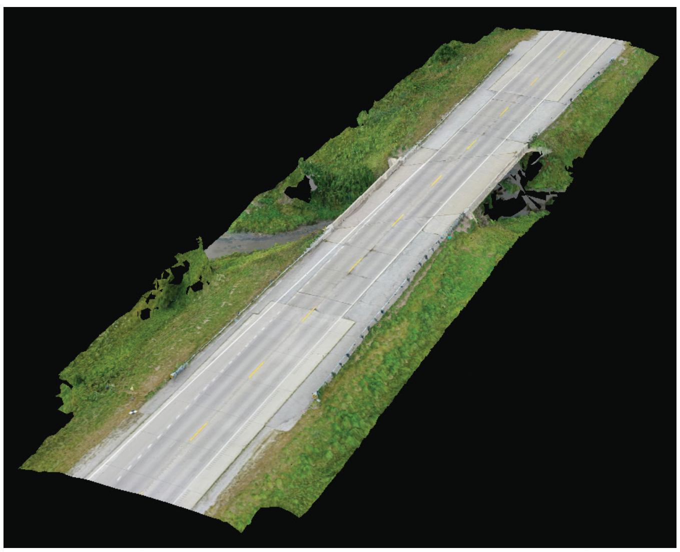
Key Findings

- The developed model demonstrated significant improvements over traditional bridge inspection methods in the detection of structural defects such as cracks and spalling, identifying structural deficiencies within concrete surfaces with high accuracy.
- The model successfully identified cracks (as narrow as 0.022 in.) and distinguished them from natural concrete segmentation lines. Cracks were detected accurately even when the image was captured far from the defect and when the angle of capture was not directly perpendicular to the defect.
- The model detected concrete spalling accurately and precisely. Spalling was detected across varying distances and complex backgrounds, even when the concrete surface had exposed reinforcing steel bars.
- Enhancing the model's predictive capabilities through fine-tuning, which involved adjusting various parameters and training the model with diverse images, yielded notable improvements in damage detection.
- Comparison of the model's predictions with field data showed a low margin of error, confirming the model's capability to be used as a tool for bridge inspections.
- Optimal UAV positioning during image capture was found to be crucial. UAVs operated at closer distances provided more detailed and accurate images, which enhanced the model's ability to detect smaller defects.
- The flight path and control methodology of the UAVs used to acquire images were identified as critical factors influencing the quality of the resultant 3D model. The use of preprogrammed, automated flight paths yielded superior results compared to manual control.

Concrete crack image (left) before and (right) after automated defect detection



Concrete spalling image (top) before and (bottom) after automated defect detection



3D model

Implementation Readiness and Benefits

The comprehensive bridge inspection and damage detection framework developed in this research, which integrates UAV technology with AI and ML, improves the efficiency and accuracy of damage detection, makes inspections safer, and is more cost-effective than traditional inspection methods.

The model developed in this study allows for the identification and quantification of structural defects and potential issues with a precision and speed unattainable by traditional methods. This will not only improve the inspection process but also enable predictive maintenance and support informed decision-making in bridge maintenance and rehabilitation planning.

The model's ability to detect defects with high accuracy across diverse conditions, including varying image resolutions, lighting scenarios, and perspectives, suggests that it can function effectively in the varied conditions encountered in the real world during bridge inspections.