Terrestrial Laser Scanning-Based Bridge Structural Condition Assessment

tech transfer summary

Using computer vision algorithms to process laser scanner point cloud data would allow a bridge's condition to be assessed automatically and remotely, which would ultimately help improve infrastructure management.

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RESEARCH PROJECT TITLE

Terrestrial Laser Scanning-Based Bridge Structural Condition Assessment

SPONSORS

Midwest Transportation Center
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PRINCIPAL INVESTIGATOR

Yelda Turkan, Assistant Professor
Construction Management and Technology Program, Institute for Transportation, Iowa State University
515-294-7539 / yturkan@iastate.edu

CO-PRINCIPAL INVESTIGATOR

Simon Laflamme, Assistant Professor
Civil, Construction, and Environmental Engineering, Iowa State University
515-294-3162 / laflamme@iastate.edu

MORE INFORMATION

www.intrans.iastate.edu/

MTC
Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103

The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

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Problem Statement

While several state departments of transportation (DOTs) have used terrestrial laser scanning (TLS) in the project planning phase, limited research has been conducted on employing laser scanners to detect cracks for bridge condition assessment.

Background

Most bridge condition assessments in the US currently require trained inspectors to conduct complex and time-consuming visual inspections. TLS is a promising alternative method for documenting infrastructure condition. This advanced imaging technology rapidly measures the three-dimensional (3D) coordinates of densely scanned points within a scene to produce 3D point clouds, which are then analyzed using computer vision algorithms to assess structural conditions.

This technology has been shown to effectively identify structural condition indicators, such as cracks, displacements, and deflected shapes, and is able to provide high coverage and accuracy at long ranges. However, large-scale, high-resolution scanning requires a significant amount of time on site, and data file sizes are typically very large and require extensive computational resources. Therefore, advanced algorithms are needed that would enable automated 3D shape detection from low-resolution point clouds during data collection.

Project Objectives

- Measure the performance of TLS for the automatic detection of cracks for bridge structural condition assessment
- Develop adaptive wavelet neural network (WNN) algorithms for detecting cracks from laser scan point clouds based on state-of-the-art condition assessment codes and standards

Laser scanning a concrete cylinder

Research Description and Methodology

To document current bridge inspection practices, several structural engineers and bridge inspectors from the Nebraska Department of Roads (NDOR) and the Iowa DOT were contacted for brief semi-structured interviews.

An adaptive WNN was designed to sequentially learn a compact reconstruction of a full 3D point cloud. The architecture of the WNN was based on a single-layer neural network that is self-organizing, self-adaptive, and sequential.

The self-organizing feature involves the capability to add representations of data points (functions or nodes) at locations where points are sparse. The self-adaptive feature involves adapting the network parameters to learn the compact representation of the structure. The sequential feature refers to the capability of the network to learn a representation in a sequential way, as opposed to a batch process, while scanning is occurring.

The proposed method was successfully tested using two artificial datasets of varying complexity.

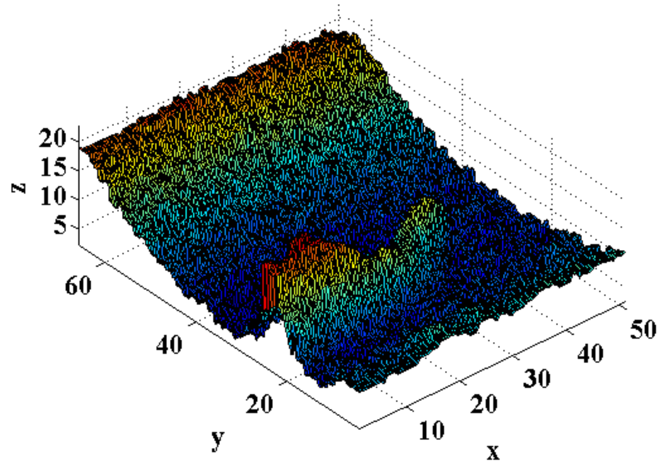
A test bed consisting of concrete cylinders with different dimensions was set up in Iowa State University's Structural Engineering Research Laboratory, and cracked concrete cylinders of various sizes and with different crack widths, orientations, and depths were obtained.

Laser scan point cloud data were collected using a Trimble TX5 laser scanner, and the captured data were processed using MATLAB, a proprietary programming language.

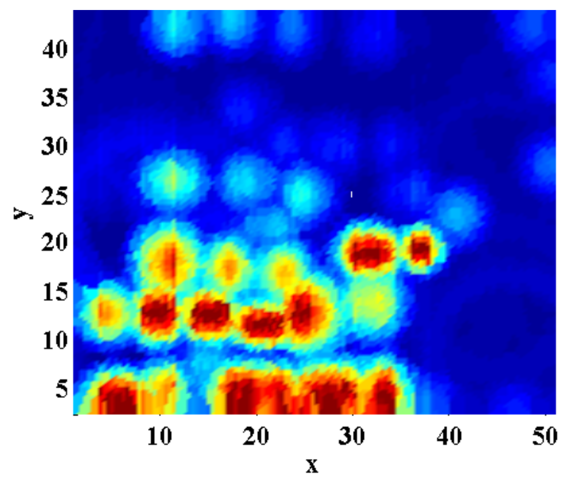
The adaptive WNN algorithm was applied to the data collected from the laboratory cylinders, and the results were analyzed. The algorithm was also validated on a cracked concrete specimen.

The specimen was scanned using the laser scanner on a limited region to focus the study on the algorithm itself. A total of 8,170 points were generated, and the data were fitted using 59 nodes. The root mean square (RMS) error and relative computing time were compared to the number of nodes in the network to determine the accuracy of the representation.

An attempt was made to automatically localize the damage and determine its severity by identifying regions of wavelets (or nodes) of lower bandwidths. This process would indicate a region of higher resolution and thus the location of a more complex feature such as a crack.



Point cloud data plotted in MATLAB

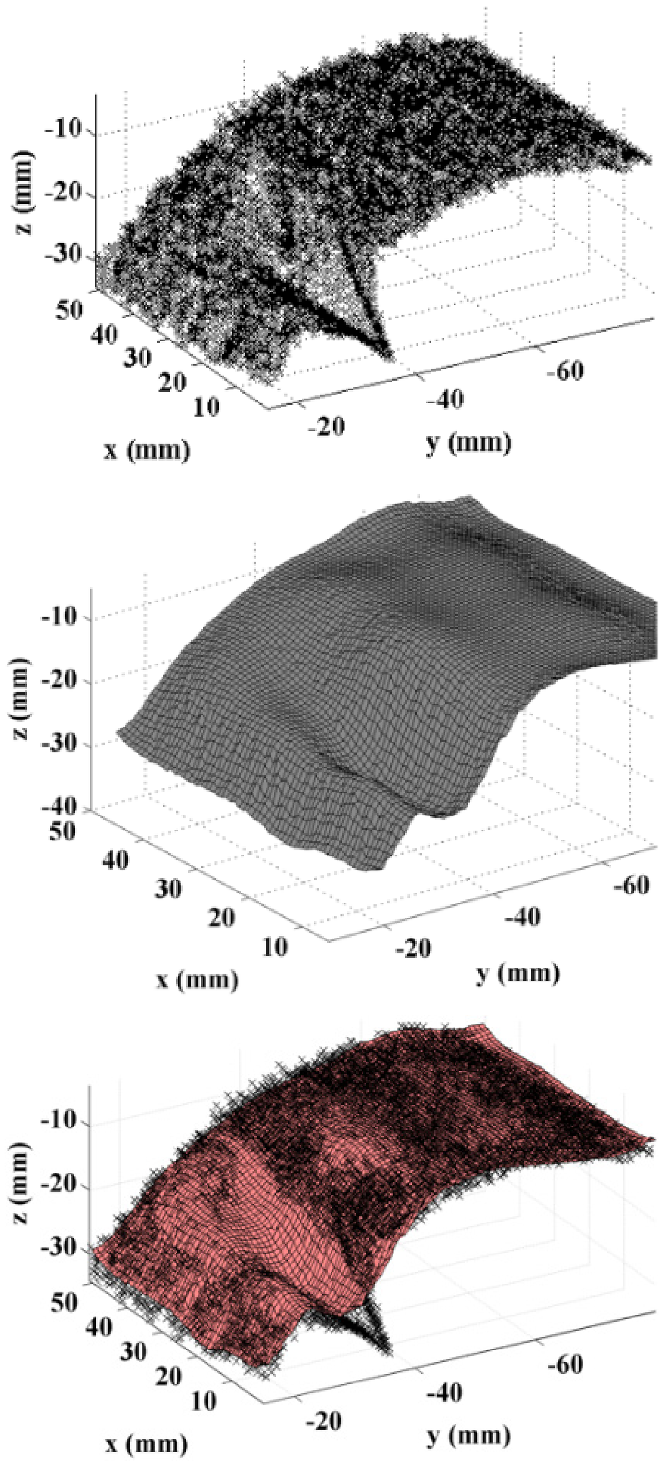


Location of a crack identified with the adaptive WNN algorithm clearly shown between 10 and 15 on the y-axis

Key Findings

- The NDOR and Iowa DOT bridge inspection procedures involve visual inspection and some nondestructive testing protocols, with inspections typically performed every 24 months. NDOR indicated that detecting small hairline cracks is challenging, and some small cracks may close up in certain weather conditions.

- For the experimental data, the compact representation created using the adaptive WNN algorithm provided a good fit of the 3D point cloud and included the crack feature. The algorithm was found to be capable of replacing a set of 8,170 3D coordinates into a set of 59 functions while preserving the key features of the scan data.



Process of fitting the point cloud data to the representation created by the wavelet neural network with point cloud data (top), compact representation (center), and overlap of point cloud and representation (bottom)

- A strategy to sequentially construct a compact representation of a 3D point cloud can be used to transform thousands of 3D point cloud data obtained from TLS into a small set of functions.
- Comparing RMS error and the number of nodes in the network showed that there is a point at which the algorithm provides an optimal representation in term of minimizing RMS error. The accuracy decreased as the number of nodes in the network increased because the network parameters become mistuned. When the network contains more nodes and the initial bandwidth is large, a relatively longer training period would be expected to obtain an acceptable level of accuracy.
- The strategy of identifying regions of wavelets (or nodes) of lower bandwidths was found to approximately localize the damage features and estimate their geometry.

Implementation Benefits and Readiness

Using the proposed method for automated 3D shape detection from low-resolution point clouds would enable automatic and remote assessment of a bridge's condition. This would improve project productivity and safety by reducing the amount of time spent on field data collection, reduce the costs of infrastructure management, enhance maintenance operations, improve project delivery by enabling condition data to be stored electronically, and ultimately improve infrastructure quality.

Applying the developed algorithms to field laser scanners will be straightforward because commercially available laser scanners are generally programmable.

While this research demonstrates the promise of automatic damage detection, developing more complex algorithms could lead to more accurate localization and estimation of damage.