UTC Spotlight

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Colorado State University

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UAVs and Machine Learning Power Next-Level Bridge Inspection System

With a combination of uncrewed aerial vehicles (UAVs), innovative computer image computing and machine learning models, researchers at Colorado State University (CSU), a member of the Center for Transformative Infrastructure Preservation and Sustainability (CTIPS) led by Region 8 North Dakota State University, are developing new ways to inspect bridges. Their system will assure that bridges are safe for travelers and will guide road managers in selecting optimum cost-effective repair and maintenance techniques.

The system will provide a cost-effective alternative to current approaches that involve the placement of sensors and cables, or the use of "snooper" trucks to allow personnel to inspect the underside of bridges. Those approaches may disrupt traffic and put inspection personnel at risk. The Federal Highway Administration (FHWA) mandates State departments of transportation to conduct biannual bridge inspections on more than 600,000 bridges across the country. The typical cost of a routine bridge inspection is between $4,500 and $10,000.

Integrated Approach

The initial system developed with funding from the U.S. Department of Transportation's (USDOT) University Transportation Center (UTC) program integrated UAVs with advanced data processing techniques, including machine learning and computer vision. The system used consumer-grade cameras to capture images of bridges and other structures and then automated the identification, localization, and documentation of structural defects (Figure 1).

The system was tested on two case study bridges to evaluate its effectiveness. Results showed the automated system accurately identified defects across multiple bridge elements, significantly reduced on-site inspection time and eliminated the need for extensive scaffolding or snooper trucks, and developed comprehensive visualizations of defect locations and types that could support data-driven maintenance decisions.

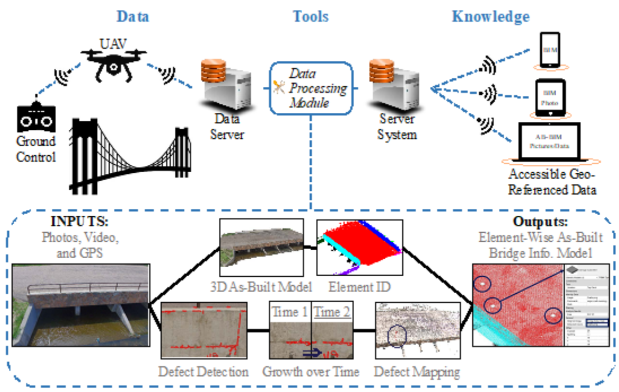

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Figure 1: Streamlined UAV-based bridge inspection system.

Adding 3-D Measurements

Accurate dynamic displacement measurements are crucial for structural health monitoring because they provide insights into the performance of structures under dynamic loads such as wind and traffic. Traditional contact-based displacement sensors, such as accelerometers, often require extensive installation and maintenance, making them challenging to use in hard-to-reach areas.

To address this need, the CSU researchers further developed their system to use two pairs of cameras. One pair of cameras tracks structural displacement in three dimensions. Because a UAV is a less than stable measurement platform, the second set of cameras focus on another stationary object to compensate for UAS motion such as drift and rotation (Figure 2). This use of multiple cameras allows the researchers to obtain a 3-D dynamic measurement of the structure as it is undergoing stresses while compensating for the six degrees of motion (up-down, left-right, forward-backward, yaw, pitch, roll) of the UAV.

Laboratory tests showed measurements from the system were highly accurate to within less than a millimeter when the UAV was less than half a meter away and to within a few millimeters when the UAV was 5 meters away.

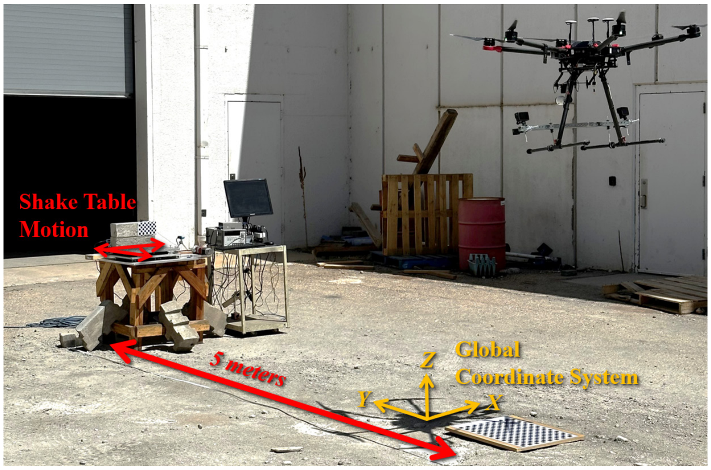

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Figure 2: 3D dynamic displacement measurement using UAV-based dual-stereo vision system.

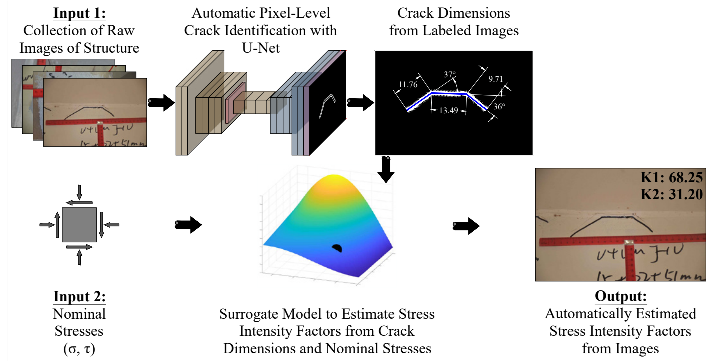

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Figure 3: Workflow of automated assessment of steel structures

New Insights From Image Processing

UAV camera images are processed with machine-learning algorithms to detect and classify defects such as cracks, spalling, and delamination. A 3-D point-cloud model of the bridge is generated using the images, and each structural element is segmented using human-in-the-loop machine learning (Figure 1). This model allows for precise element-wise damage documentation, mapped onto a bridge information model compatible with georeferenced data.

Current bridge inspection is an element-based, detailed inspection where each bridge element, such as the deck, beams, columns, and bearings, is examined and assessed separately. In the CSU system, the computer can tell which element is which and identify defects in each. Those 3-D measurements, coupled with machine learning and development of the structure's "digital twin," allow researchers not only to identify defects, but the cause behind them. This approach incorporates the mechanics that led to the formation defect (Figure 3), which allows bridge managers to identify the most appropriate repair. Depending on the mechanics behind them, similar defects may require completely different repair approaches.

The Next Level

A current project is incorporating a lightweight arm onto UAVs to allow the placement of sensors on structures to enable multimodal sensing, for example ultrasonic, magnetic, and eddy current testing. The project will combine speed, cost, and maneuverability advantages of UAS-based systems with the accuracy of direct-contact sensors to complement the vision-based camera sensors. The new system will allow inspectors to reach and test areas that are often challenging for human inspectors to access, improving both inspection quality and safety.

Unlike most mechanical arms that have a limited range of motion, the manipulator arm is a highly flexible continuum arm similar in appearance and motion to an elephant's trunk (Figure 4). In addition to placing sensors, the arm could be used to remove dust or other lightweight debris that obscure visible inspection or for the placement of dyes or other materials helpful in revealing hidden cracks.

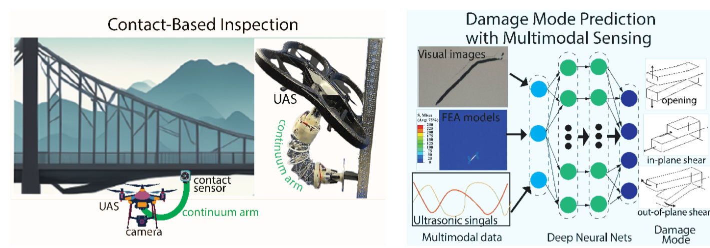

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Figure 4: Left: An integrated UAS system equipped with a continuum arm that can place a contact sensor onto the inspected surface for contact-based inspection. Right: an approach to fuse multimodal sensing data to accurately predict damage modes

This project represents a significant advancement in unmanned arial system (UAS) inspection technology, expanding the potential for transportation infrastructure management. By enabling precise, multimodal damage assessments (Figure 4), the integrated UAS platform promises a new standard for infrastructure inspection, offering safer, smarter, and more efficient ways to preserve critical assets.

About This Project

Initial research for this project was supported under the FAST Act grant to the Mountain Plains Consortium (MPC), renamed CTIPS under BIL, where the research now continues. CTIPS also addresses systemic equity issues in Region 8, especially those stemming from the relatively poor quality of Tribal and rural roads. The current consortium is led by North Dakota State University and is made up of 11 consortium members including two Tribal serving institutions. This project is led by Dr. Yanlin Guo, Associate Professor in the Department of Civil and Environmental Engineering and the Director of Center for Sustainable and Intelligent Transportation Systems at CSU. For more information on this project contact Dr. Guo at Yanlin.Gou@colostate.edu. For information about the full CTIPS UTC program, visit www.ctips.org.