CTIPS Center for Transformative Infrastructure Preservation and Sustainability

USDOT Region 8 University Transportation Center

Camera Based Computer Vision Measurements for Bridge Field Testing

CTIPS-018

Approved 6/17/2024

University

South Dakota State University

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Research Needs

The Alaska Department of Transportation and Public Facilities (DOT&PF) is responsible for condition assessment of approximately 1,000 bridges in the state. Of which, approximately 44% are in good condition, 49% are in fair condition, and 7% are rated poor according to the 2023 National Bridge Inventory (NBI) data (Infobridge, 2024). When a bridge is old or deteriorated, the evaluation of the load carrying capacity of the bridge, usually referred to as "load rating", is necessary to ensure the safety of the traveling public and to prevent excessive bridge damage and collapse. Load rating of bridges can be performed using either analytical or experimental (field testing, **Fig. 1**) methods (AASHTO MBE, 2018). Even though field testing offers actual insights into bridge behavior, it is not a common practice for bridge evaluation. Instead, the analytical load rating is often used. One main reason is the cost related to field operations. For bridge field testing, the cost is higher than an inspection due to the use of sensors, data acquisition system (DAQ), test trucks, and data processing.

(a) Sensor Installations (b) Strain Transducers (c) Field Testing

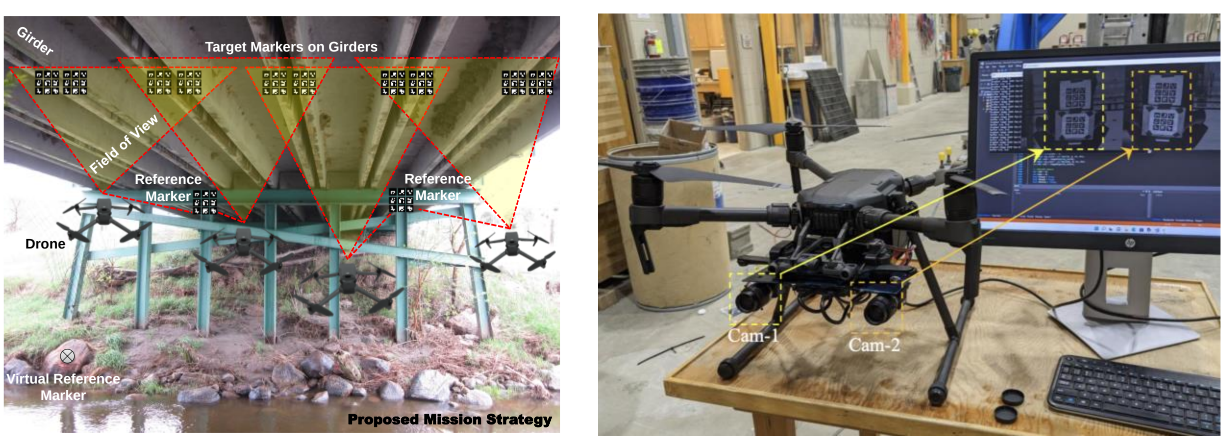
Figure 1. Bridge Field Testing (Rimal et al., 2021)

The use of non-contact monitoring systems is gaining momentum in the US since they need minimal installation time and effort compared with conventional instrumentation (e.g., Linear Variable Differential Transformers (LVDTs), strain gauges, etc.). Computer vision techniques such as digital image correlation (DIC) can be utilized to measure structural responses from distance to extract full-field displacements and strains from images and videos. DIC has a wide range of applications in many disciplines including structural engineering. For a bridge field testing, DIC may offer several advantages including displacement measurements using commercial off-the-shelf cameras, elimination of conventional sensors, DAQ, and heavy inspection equipment, and minimal closure of the bridge for preparation and testing.

A few studies have incorporated DIC in bridge related experiments. For example, Dong and Catbas (2019) and Dong et al. (2019 and 2020) combined the “Scale Invariant Feature Transform” feature points with “Visual Geometry Group” descriptors in a portable system to determine girder distribution factors for a highway bridge. Overall, a reasonable accuracy was reported when DIC was used compared with conventional measurements. Ngeljaratan and Moustafa (2020) used two high-speed cameras to measure displacement response history of a bridge under dynamic testing. The study found that the proposed DIC technique is viable in dynamic tests with a minimum camera recording rate of 30 frames per second. DIC-based research and commercial tools have been developed to be used in bridge applications. For example, Ghyabi et al. (2023) tested two bridges in Delaware using a commercially available DIC package (Video Gauge, 2024) in which the maximum displacement error between the DIC method and string potentiometers was 0.4 mm (0.015 in.). The cost of this commercial tool exceeds $50,000. Other commercial DIC systems exist but they are expensive (some up to $300,000) and have proprietary software. Rajae et al. (2022) has developed a DIC-based displacement measurement system specific for bridge field testing for the Texas DOT, which exhibited less than 1.7 mm (0.067 in.) displacement errors (or 8.7% errors) compared with a conventional sensor when it was used in a bridge field testing. This research tool is now ready for commercial use.

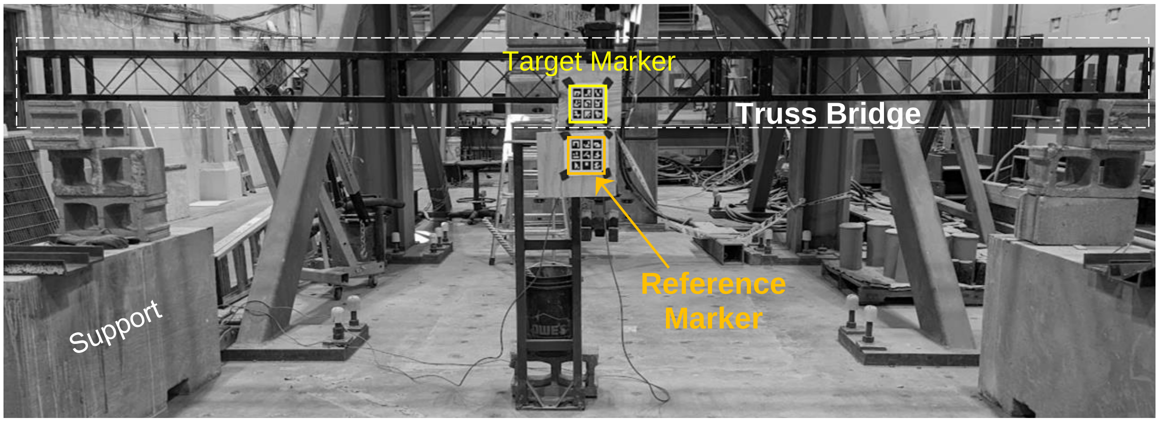
Drones may also be equipped with DIC or other innovative systems to obtain structural responses without any physical contact. Nevertheless, the main challenge in using drone-DIC systems is how to remove false displacements caused by the drone from structural responses. A few studies have developed drone-based structural response measurement techniques (Reagan et al., 2017; Moreu and Taha, 2018; Yoon et al., 2018; Hoskere et al., 2019; Khuc et al., 2020; Chen et al., 2021; Perry and Guo, 2021; Nasimi et al., 2023). Some studies were more successful than the others, but large measurement errors (from 2 mm to 17 mm) were reported. For example, a stereo DIC-drone system was developed by Stuart et al. (2023) to generate full-field strain maps of steel girder railroad bridges. In this method, a speckled pattern was placed on the web of the exterior girder of the bridge and drone data was analyzed using a commercial DIC software. The field testing of a railroad bridge showed that the proposed system had a high level of noise in the strain data and failed to measure the strains caused by the moving train.

Overall, due to the challenges of removing drone movements from structural displacements, past studies have focused on extracting structural modal properties or developed methods that requires manual processing, multi-step corrections, and used costly hardware and proprietary software. Further, none of the past drone-DIC studies were focused on bridge load rating through field testing. Recently, the research team of the proposed work has developed and verified a novel drone-DIC based displacement measurement technique specifically designed for bridge field testing (Lavezzi et al., 2024). We proposed a mission strategy in which a drone (or a fleet of drones) equipped with a set of cameras is deployed to perform bridge field testing using an opensource DIC software. Several camera configurations were studied to determine the best camera candidates for use in the drone-DIC applications. A DIC system was developed and the DIC marker configurations were optimized through a preliminary experimental study. A drone platform was then chosen, aiming to prove the mission feasibility. Finally, the accuracy of the proposed drone-DIC based displacement measurement technique was evaluated by performing more than 70 tests on a truss bridge (**Fig. 2**). Compared with conventional displacement sensors (LVDTs), a ground Raspberry Pi camera tracking two markers in static tests measured displacements with less than 1% error at the peak load, which was equal to a 0.09-mm displacement error. Two synchronized Blackfly cameras mounted on a drone tracking the target and reference markers both at 1.5-m distance measured displacements that had less than 5% errors (0.375 mm displacement error) compared with those of LVDTs in static tests. Furthermore, two synchronized Blackfly cameras mounted on a drone tracking the target and reference markers both at 1.5-m distance measured displacements with an error ranging between 0.44% and 14.2% (or 0.02 mm and 0.84 mm displacement errors) in dynamic tests. Overall, the proposed drone-DIC based displacement measurement strategy and computational tools were found feasible with submillimeter level accuracies. Nevertheless, further investigations are needed to develop field testing frameworks using multiple drones and to evaluate the accuracy of the proposed drone-DIC methodology in actual bridge field tests.

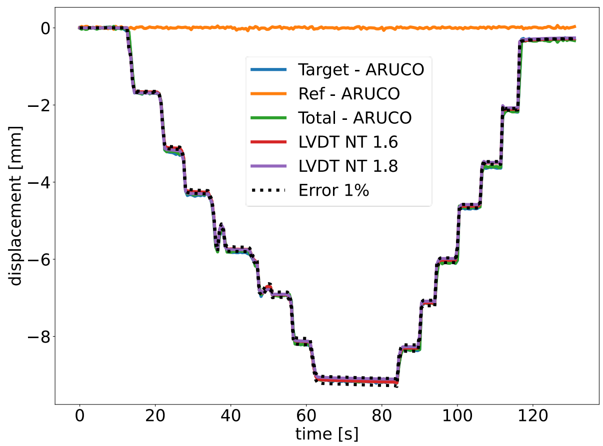


(a) Mission Strategy

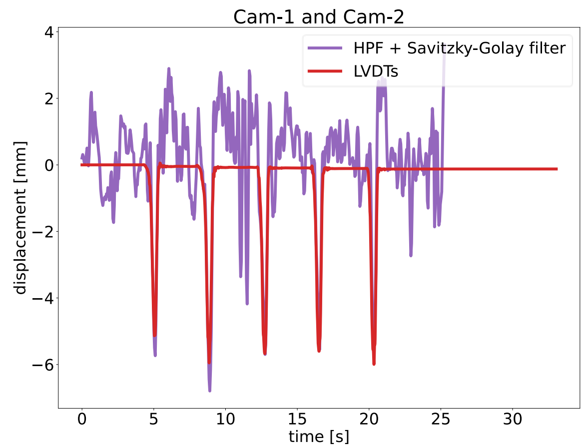
(b) Drone with Two Synchronized Cameras



(c) Truss Bridge Model in Laboratory



(d) Results of a Static Test Using Ground Pi Camera



(e) Results of a Dynamic Test Using Drone-DIC System

Figure 2. Proposed Drone-DIC Bridge Field Testing System

Research Objectives

As discussed in the previous section, DIC is a viable solution for bridge response measurements, but the existing DIC tools are expensive and proprietary. Drone-DIC methods are also feasible but need further development and validation prior to field deployments. The main goals of the present study are to:

1. Develop hardware and software to field test bridges using computer vision including either a ground-DIC system and/or a drone-DIC system
2. Develop frameworks on how to load test bridges using these tools
3. Develop user guides on how to utilize the hardware and software

Research Methods

Instead of using conventional displacement and/or strain sensors and data acquisition equipment, a few cameras, or a fleet of drones each equipped with a camera system will be deployed to measure the bridge responses. To achieve the project goals, the most recent DIC technologies will be reviewed, current commercial and research products suitable for bridge response measurements will be evaluated, low-cost DIC tools and practical frameworks for bridge field testing will be developed, and a few bridges will be load tested using DIC and conventional sensors to validate and further refine the tools.

Relevance to Strategic Goals

The expected outcomes of this project are directly related to the following goals: "Transformation" and "Safety". This project incorporates cutting-edge technologies such as opensource computer vision software packages, low-cost DIC cameras, and drones to load test bridges quickly, safely, and cost effectively. The outcomes of the field testing, which includes the actual behavior of the bridge, allow a more realistic load rating and posting of bridges enhancing their overall safety.

Educational Benefits

This project will provide valuable learning experience to two Graduate Research Assistants (GRAs) at the PhD level, one at Civil and another at Computer departments. The two students will perform the tasks of the project under the supervision of the PIs. The student will have the opportunity to work on this multidisciplinary research project. A regular weekly meeting will be scheduled between the PIs and the students to better train them and to consistently monitor the project progress. Funds have been allocated to involve undergraduate students in field testing of bridges. A priority will be given to underrepresented students especially women and native Americans.

Outputs through Technology Transfer

The main deliverables of the project will be: (1) a final report, (2) a set of verified opensource computer vision codes and the necessary hardware for bridge field testing, (3) field-testing frameworks, and (4) user guides. A project webpage will be designed under the PI's website (https://sites.google.com/view/mostafa-tazarv) in which the sponsors, personnel, and project goals will be presented and the key findings will be frequently updated. The final report (through the PI and CTIPS websites) and the opensource codes (through GitHub) will be publicly available at no cost for use by other researchers, DOTs, and software developers. The research findings will be further disseminated through journal publications and conference presentations. Furthermore, a presentation will be prepared for the CTIPS webinar series, which will be recorded and posted in public domains (e.g., YouTube). The research team will prepare user guides and will organize in-person training sessions for the DOT engineers.

Expected Outcomes and Impacts

The main outcome of this project will be a ready-to-use package including hardware and software for successful bridge field testing. Testing frameworks, user guides, and best practices will be proposed on how to use the tools for bridge load testing. The impact of the work is a substantial reduction of bridge field testing time, effort, and cost by eliminating conventional sensors and DAQ. Since actual conditions and behavior of bridges are captured in these experiments, the load rating thus posting will be more realistic and reliable.

Work Plan

To achieve the project goal, the proposed work is divided into six tasks.

1. Literature Review on Use of DIC in Engineering Applications (2 months)
2. Evaluation of Research and Commercial DIC Technologies (3 months)
3. Development of Computer Vision Displacement Measurement Tools (13 months)
4. Development of Bridge Field Testing Frameworks (1 month)
5. Bridge Field Testing and Tool Validation (2 months)
6. Project Deliverables including Final Report, Software and Hardware Packages, Testing Frameworks, and User Guides (3 months)

Project Cost

Total Project Costs:	$437,999
CTIPS Funds Requested:	$200,000
Matching Funds:	$237,999
Source of Matching Funds:	Alaska Department of Transportation and Public Facilities

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