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RAILROAD BRIDGE INSPECTION USING DRONE-BASED DIGITAL IMAGE CORRELATION

SUMMARY

Continuous railroad operations on aging railway infrastructure requires systematic and effective inspection. Visual inspections are time consuming and can lead to inconsistent results. In a research project conducted between April 2021 and June 2022, the University of South Carolina (UofSC) developed and tested a new uncrewed aircraft system (UAS, or drone) for structural inspections. A stereo digital image correlation system (StereoDIC) on this drone made noncontact measurements of deformation and stress on infrastructure. With support from CSX Transportation (CSX), UofSC tested the system on a railroad bridge in Columbia, SC (Figure 1). Project results show that this type of system may be useful for inspecting railroad bridges and other structures.

BACKGROUND

Using UAS for infrastructure inspection is an emerging application area for this technology. Visual inspection and qualitative assessment of structures are currently typical uses of UAS. However, including non-destructive evaluation (NDE) techniques that accurately measure a structure's dynamic response may expand the utility of UAS inspections. One such system is StereoDIC, a vision-based technology used to measure precise full field 2D and 3D coordinates [1]. Calculations from these measurements include displacements, strains, strain rates, and geometry profiles. StereoDIC can identify and measure microscopic defects as well as measure the structure's response under various loading conditions.

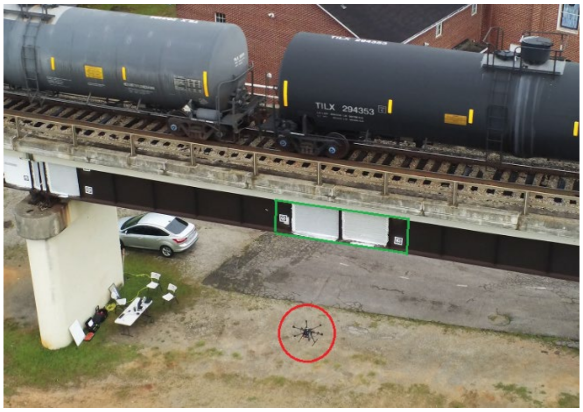

Figure 1. UAS performing DIC measurements on a CSX railroad bridge at Park St., Columbia, SC (the drone is highlighted in the red circle and the speckled area in the green rectangle)

In prior work, UofSC researchers developed and tested the first DIC-enabled UAS platform in a laboratory [2, 3]. However, this prototype system could not be deployed in the field due to payload limitations. In this latest project, UofSC developed a higher performance drone suitable for field deployment.

OBJECTIVES

The project objective was to field test how effective a StereoDIC-equipped drone was for railway infrastructure inspection. The drone needed to satisfy the functional, safety, and inspection challenges presented by the remote location of bridges and difficult to access monitoring points.

METHODS

The research team tackled three major efforts. UofSC first explored various methods for applying a speckle pattern on the bridge. Second, the team developed an autonomous drone platform to collect DIC data from the speckled area of interest. Finally, UofSC processed the data collected to evaluate the effectiveness of the system.

Working with CSX, UofSC selected the CSX-owned bridge on Park St. in Columbia, SC, as the research test site. The bridge spans a large section of open land which allowed for easy drone deployment. No traffic control or other special safety measures were necessary to fly in this area.

StereoDIC measurements need a high contrast speckle pattern. UofSC experimented with various application methods and tested each method by analyzing the StereoDIC data gathered by the drone.

UofSC initially flew the drone manually, but varying weather conditions and the degraded global navigation satellite system (GNSS) signal significantly affected the quality of the measurements. The team developed an autonomous flight controller to overcome these issues. After creating a viable speckle pattern and refining the flight control system, UofSC and CSX collected data about the bridge response with and without train loads.

RESULTS

The application of a speckle pattern for StereoDIC measurements proved challenging. First, UofSC tested speckling white dots directly on the untreated surface of the bridge's steel panels. This method minimized the application time, but the resulting pattern did not have the required contrast levels. The next attempt involved applying a speckle pattern using stickers. This method produced a high contrast pattern, but bubbles formed between the sticker and the steel surface that could affect the accuracy of the measurements. Also, the stickers began peeling after a few months, making this a short-term solution.

UofSC obtained the best contrast and durability through first painting the panel background white and then painting black dots over the white area. The team initially used rollers for painting the dots, but the ink would dry too fast due to weather conditions. Researchers solved the problem with a handheld inkjet printer that could apply a high contrast pattern faster than the roller could. Figure 2 shows the final pattern used. Histograms of selected areas show the contrast levels. The contrast is adequate over the entire panel with some areas even having a bimodal distribution that is ideal for StereoDIC.

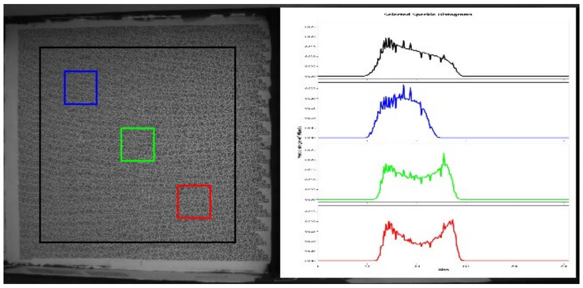

Figure 2. A bridge panel speckled using a handheld printer (left) and the histograms at the four selected regions on the speckle (right)

UofSC developed a new drone platform with a much larger payload capacity and significantly improved DIC camera system. The drone's field system uses a pair of 8.9 megapixel cameras with variable aperture lenses and a computer that allows 30 frames per second image capture. A hardware trigger precisely synchronized the two frames from the cameras.

UofSC also developed a new drone flight system to address the major challenges when flying close to a large structure. These challenges include the degraded position estimation using traditional avionics sensors and weather effects. Fiducial markers attached around the speckled area provided two types of information used to improve the position estimation. They first mark the area of interest and then they provide position and orientation measurements for the drone's navigation and control.

The position information from the avionics and markers are fused to a Kalman Filter, which allows the drone to estimate its position with improved accuracy while also tracking the position of the panel. The filter also includes a nonlinear model of the drone's flight dynamics that estimates the forces produced by the rotors and how these forces affect the drone's position and orientation. By comparing the drone's actual position and orientation with the model outputs, the filter can estimate the magnitude and direction of any external disturbances.

The autonomous flight control system uses a nonlinear model predictive controller (MPC). The MPC combines the nonlinear model of the drone's flight dynamics and the estimated disturbances from the filter to find the optimal commands to control the drone. It can also proactively respond to any weather effects it encounters (e.g., wind gusts). The system keeps the measurement system focused in the area of interest while maintaining the desired offset distance from the bridge. A view of the speckled pattern with the markers is shown in Figure 3. The area of interest is marked with an orange rectangle and information about the drone and panel position are shown.

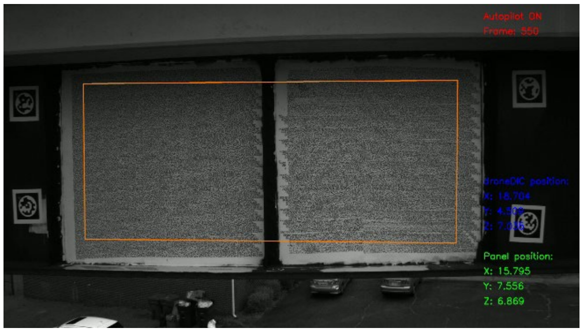

Figure 3. The feed from the DIC cameras annotated with information about the drone and panel position

UofSC successfully deployed the platform multiple times, acquiring images from both a loaded and unloaded bridge. These images were analyzed using VIC-3D software [4]. Data show that the DIC strain measurements contained noise, resulting in reduced accuracy. After lab investigation, the team found that the drone's rotor vibrations cause the DIC cameras to move relative to each other, resulting in high noise levels. Results improved after adding vibration isolation pads to the camera mounts.

Figure 4 shows strain results acquired from the center of the speckled panel while a locomotive is crossing the bridge. The maximum expected strain should not have exceeded 1200 με, yet the system recorded approximately 2000 με. The system is unable to distinguish the difference between loaded and unloaded bridge conditions.

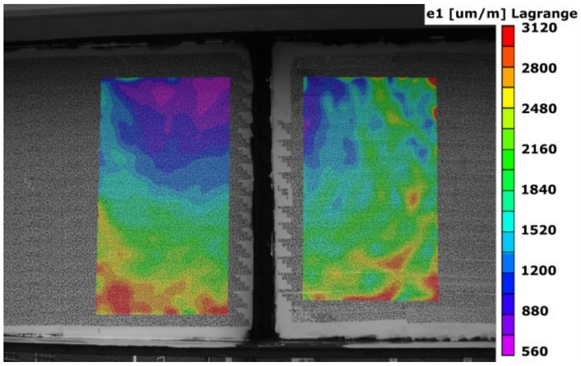

Figure 4. Strain map from the speckled region while the bridge is under load (crossing train)

CONCLUSIONS

While the measurement resolution was not quite accurate enough, this project represents a significant step toward deploying StereoDIC-enabled drones to inspect railroad infrastructure. UofSC succeeded in developing an effective speckle application method to enable StereoDIC measurement of large outdoor structures. The team also developed an autonomous drone platform system to precisely control the drone flight. Finally, the project results highlighted camera vibration due to drone rotor dynamics as a critical factor in the measurement system.

FUTURE ACTION

Future work on this project should focus on designing a StereoDIC camera mount that shields the cameras from any vibrations caused by the drone or the drone's motion. Additional laboratory experiments will validate that improved camera isolation and the resulting measurement precision will allow the system to achieve the accuracy needed for recording the low strain levels found in the railroad bridge structure. If successful, additional field testing will be conducted.

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