Demonstrating the Use of Small Uncrewed Aircraft Systems (Drones) Capabilities and Data for Iowa Transportation and Infrastructure Work:

Pilot Project No. 1 – Use of Small Uncrewed Aircraft Systems for Hairline Crack Detection on Bridge Deck

tech transfer summary

High-resolution sUAS color images collected at low altitudes are useful for detecting fine hairline cracks in bridge decks.

Objective

This pilot study aimed to investigate the feasibility of detecting hairline cracks using red-green-blue (RGB) data collected from low-altitude small uncrewed aircraft systems (sUAS) flights and to provide technical guidelines, recommendations, and best practices for wide-scale adoption.

Background

The use of sUAS, more commonly referred to as drones, has experienced significant growth in many application areas. The Iowa Department of Transportation (DOT) initiated a research project to demonstrate the usefulness of sUAS equipped with a variety of sensors for transportation and infrastructure work through five pilot projects. The first pilot project, described in this summary, was focused on the detection of fine hairline cracks on bridge decks.

The Iowa DOT identified and proposed two bridges for demonstration of this application: (1) the newly constructed Northeast Mixmaster (NEMM) bridge located in Des Moines, Iowa, and (2) a one-year-old grooved-deck bridge located in Humboldt County, Iowa. The NEMM bridge had hairline cracks with widths ranging from 0.0079 to 0.0217 in., and the Humboldt County bridge had hairline cracks with an approximate average width of 0.021 in.

Problem Statement

It is often challenging for humans to physically identify and detect hairline cracks due to their small size and other factors such as contrast and glare resulting from direct sunlight, and the detection and documentation of fine hairline cracks is a major concern for the Iowa DOT.

Recently, sUAS have been widely adopted by state and federal agencies for nondestructive documentation and inspection of fine cracks on road and bridge pavements. Recent work suggests that fine hairline cracks might be detected and documented using RGB data collected through very low-altitude flights.

Research Description

The core research activities were divided into three phases: (1) planning, (2) data collection, and (3) analysis. During the planning phase, the research team visited the bridge sites for a general preliminary assessment and to develop a data collection and safety plan.

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RESEARCH PROJECT TITLE
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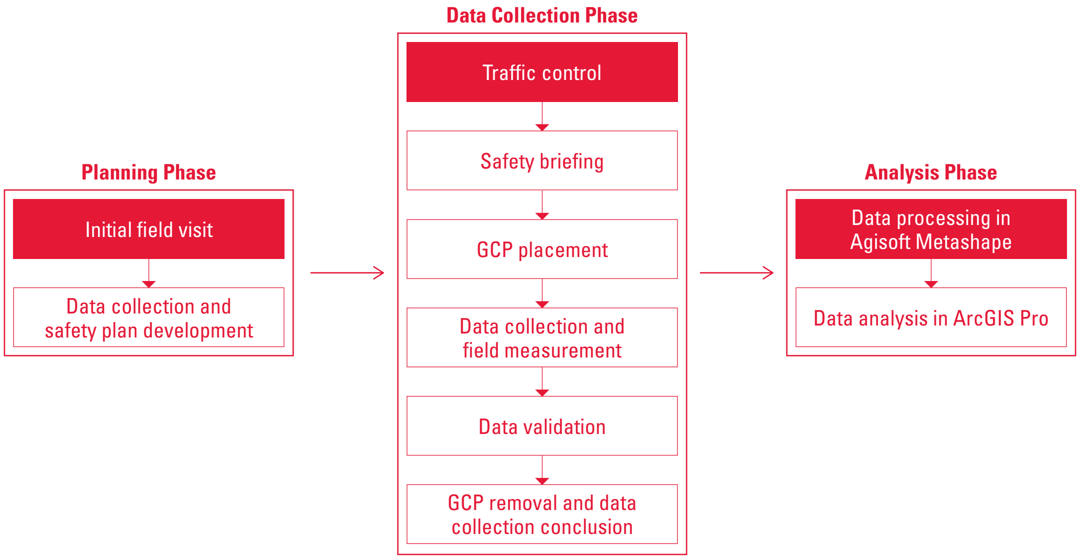


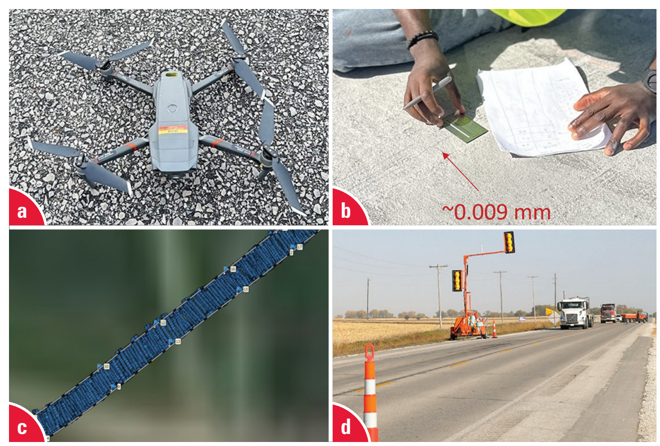
Research activities flowchart, with red boxes executed when required

The research team then visited the bridge sites for data collection. The required traffic control measures were implemented, and safety and hazard briefings were conducted.

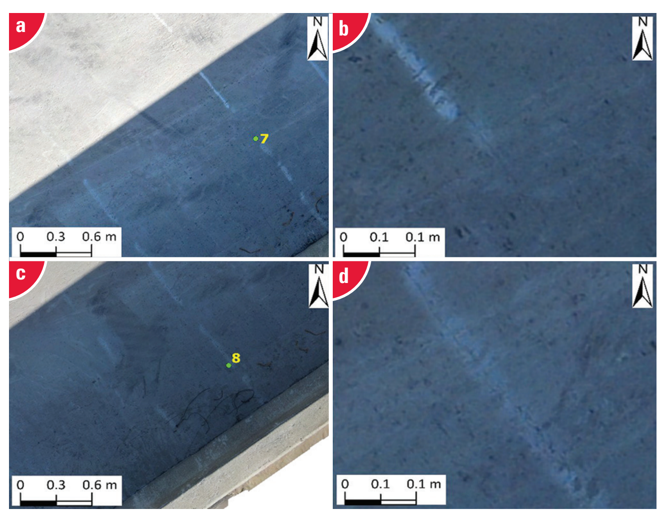
One research team member then strategically placed ground control points (AeroPoints with built-in Global Positioning System [GPS] capabilities) at regularly spaced intervals on both sides of the bridge deck. Concurrently, another research team member identified target distresses, such as hairline cracks, using chalk/colored markers and a crack gauge. Crack widths were measured, and the cracks were circled and labeled accordingly.

The remote pilot-in-command (PIC) and a visual observer (VO) from the research team begin sUAS data collection by flying at the planned altitude and along the designated mission flight path. After each flight, the research team performed a quick visual data validation to ensure that the captured images aligned with the mission flight pattern and resolution needs.

In the analysis phase, the research team processed the collected sUAS image data to generate orthophotos that were then imported into Esri's ArcGIS Pro software for detailed review, analysis, and comparison of crack visibility levels.



(a) DJI Mavic 2 Enterprise Advance (M2EA), (b) crack width measurement, (c) sUAS data processing (d) traffic control



Cropped images from 0.88 mm orthoimages when scaled at 1:5 (corresponding zoomed view of all the left images are displayed on the right)

Key Findings

- Low-altitude flights at 15 ft (4.6 m) could only be flown manually, and therefore data collection took a relatively long time. For example, it took a total of 225 minutes of flight time to cover the NEMM Unit 1 section, while the same coverage would typically have been achieved in 25 minutes if the sUAS had been flown automatically at 50 ft (15.2 m).
- Prolonged manual data collection led to uneven shadow patterns on the bridge deck as shadows shifted over time.
- Since manual flight is hard to control and prone to inconsistencies in speed and overlap, the PIC was cautious to ensure that the sUAS remained on the preplanned route and avoided flying directly above passing vehicles.
- The relatively steep longitudinal slope of the NEMM bridge deck required adjustments to the sUAS's altitude mid-flight to maintain a consistent distance between the bridge deck and the sUAS.
- The flight altitude over the NEMM bridge deck was also adjusted when wind gusts moved the sUAS from the original position. An average wind gust of 13 mph (5.8 m/s) posed significant safety concerns during manual flights, causing the suspension of data collection on the second day of sUAS inspection.
- Passing trucks on the bridge deck required the team to remain vigilant. The VO actively monitored and communicated with both the pilot and truck drivers throughout the operation. The presence of parked heavy-duty equipment under the bridge also limited the drone's ability to collect additional underdeck data.
- Traffic management was crucial for fast and efficient data collection on the busy bridge section. To minimize driver waiting times during manual flights, one lane was kept open to traffic while flying on the closed lane. Due to the close proximity of the two lanes, the remote pilot had to exercise extreme caution when operating near the mid-lane boundary line, and the sUAS operation attracted the attention of drivers and resulted in distracted driving.
- Even with low-altitude flights, remotely detecting cracks on the grooved deck surface from the orthophoto images proved challenging due to the texture and alignment of the grooves.

Recommendations for Implementation

- Achieving sub-millimeter accuracy is crucial for detecting fine cracks using sUAS-collected images, and a flight altitude of 15 ft (4.6 m) is highly recommended if time and resources are available. To reduce time without compromising data quality, the researchers recommend deploying a higher-resolution camera (e.g., LR1 or Nikon D850) at higher altitudes and using resolutions of 60 to 100 MP for follow-up demonstrations.
- Resolutions between 0.026 and 0.035 in./pixel obtained from the 15 ft altitude flight were sufficient to detect hairline cracks with widths ranging from 0.0079 to 0.0217 in. on non-grooved deck surfaces. A similar resolution or higher is recommended for similar tasks.
- To mitigate inconsistencies during manual flight, the flight mode was set to "Tripod," speed was reduced to 1 to 2 mph, and the bridge edges were marked at 6 to 7 ft (1.8 to 2.1 m) intervals, marking crosswise reference lines for proper overlapping flight passes. If available, a similar option should be adopted for precise sUAS data collection.
- Portable and smaller-sized sUAS, such as the DJI Mavic Enterprise, are more suitable and recommended for safer low-altitude manual flights than larger systems such as the DJI Matrice 600 Pro or Tarot X6.
- It is recommended that a portable charging power source be available onsite to facilitate data collection over an extended period.
- It is recommended that a detailed weather analysis be conducted before selecting inspection dates to avoid disruptions, and weather should be monitored during flight periods. In the event of sudden weather changes that create unfavorable or unsafe flying conditions, all flights should be immediately suspended to prioritize safety.

Implementation Readiness and Benefits

Detailed recommendations for implementation are presented in the task report for this study.

High-resolution sUAS data collection and processing require an appropriate and reasonable level of staffing, hardware, and software. A small team from the Iowa DOT using lightweight sUAS can efficiently collect large volumes of bridge and road pavement data for documentation and inspection, contributing to smart transportation infrastructure management by Iowa DOT.