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

Pilot Project No. 2 – Use of Small Uncrewed Aircraft Systems for Gravel Road Monitoring

tech transfer summary

High-resolution color images and DEM data from sUAS are useful for assessing gravel road distress to approximate the overall conditions of gravel roads.

Objective

This pilot study aimed to evaluate the feasibility of using small uncrewed aircraft systems (sUAS) for the identification and rating of gravel road distress. The study also sought to develop a practical workflow that supports strategic data collection, automated and semi-automated distress detection, and broader operational adoption by Iowa county engineers.

Background

The use of sUAS, commonly referred to as drones, has expanded rapidly across transportation engineering applications, particularly in remote sensing and infrastructure monitoring. The Iowa Department of Transportation (DOT) initiated a research project to demonstrate the usefulness of sUAS for infrastructure applications through five pilot projects. The second pilot project, described in this summary, focused on the detection and rating of gravel road distress.

Monitoring Iowa's approximately 70,000 miles of gravel roads represents a particularly significant challenge for the Iowa DOT. Traditional gravel road distress inspections are largely performed through resource-intensive, time-consuming, and potentially unsafe visual field surveys, while the spatial extent of Iowa's gravel road network further complicates timely, consistent assessment.

The U.S. Army Corps of Engineers's (USACE's) *Unsurfaced Road Maintenance Management* manual provides a quantitative framework for evaluating a gravel road's Unsurfaced Road Condition Index (URCI) through direct measurement of the following distresses: potholes, rutting, corrugation, loose aggregate, dust, and insufficient crown. However, manual measurement of these distress types can be challenging and impractical.

sUAS operation on a gravel road in Iowa

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

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The Program for Sustainable Pavement Engineering and Research (PROSPER) is part of the Institute for Transportation (InTrans) at Iowa State University. The overall goal of PROSPER is to advance research, education, and technology transfer in the area of sustainable highway and airport pavement infrastructure systems.

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Problem Statement

Remote sensing technologies such as sUAS have the potential to enhance data collection, safety, and productivity in gravel road inspections. The standardized distress definitions and rating procedures in the USACE manual can support the integration of sUAS-derived data into structured condition-assessment workflows.

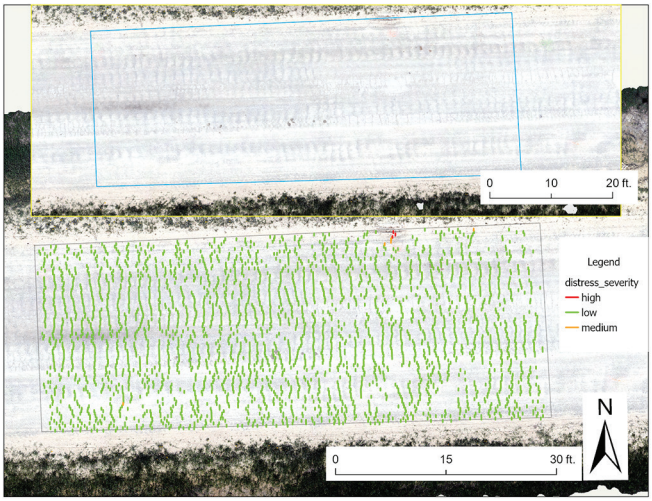
Research Description

This study deployed sUAS and developed proof-of-concept algorithmic tools capable of distress-feature extraction from sUAS products such as orthophotos and digital elevation models (DEM). The core research activities were divided into three phases: (1) data collection, (2) data analysis, and (3) development of a web application platform for distress quantification.

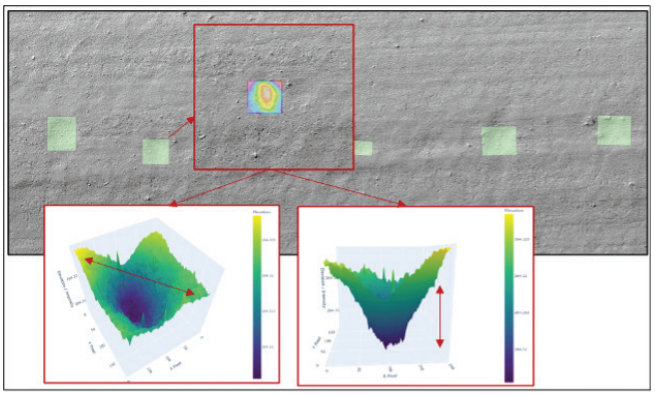
The research team visited four gravel road sites in Iowa: (1) 130th Street, Buchanan County, (2) 150th Street, Buchanan County, (3) Frost Avenue, Buchanan County, and (4) Flemming Ave, Story County. Data collection strategies at these sites were influenced by the type of distress being targeted, whether depth-based distresses such as rutting, corrugation, potholes, and improper cross-section or excessive dust.

To facilitate the integration and rapid analysis of sUAS data based on the defintions and rating procedures in the USACE manual , customized proof-of-concept toolboxes were developed for ArcGIS Pro. The results automatically generated by the toolboxes were assessed through comparisons with manual measurements made at the study sites. Toolboxes were develop for each of the following distresses:

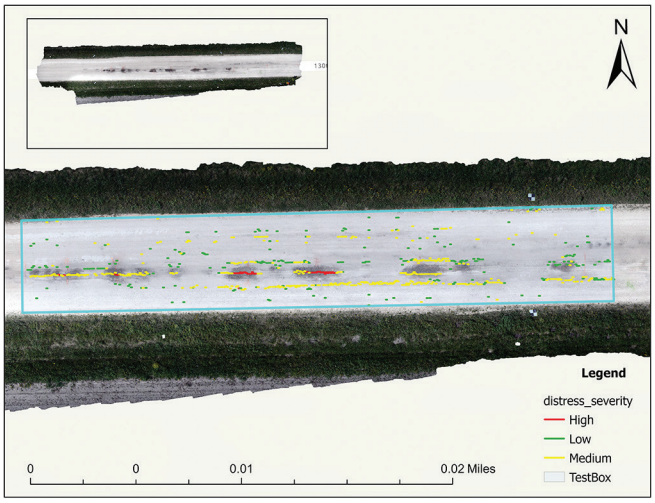
1. **Rutting:** The toolbox measured the length and width of rutting within a sample unit section in square feet to determine its severity level.
2. **Corrugation:** The toolbox measured the severity of corrugation using a procedure similar to that used for rutting.
3. **Potholes:** The toolbox measured the depth and diameter of potholes to determine their severity class.
4. **Improper Cross-Section:** The toolbox measured the slope of the roadway's cross-section at various points and the presence of water ponding and depressions to determine the severity of cross-section distress. A slope/rut matrix was developed for classifying profiles into low, medium, or high crown distress severity.



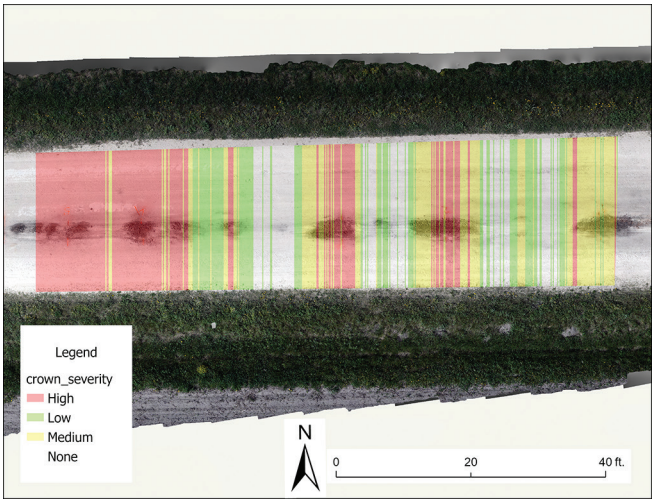
Sample output from the corrugation toolbox showing overlaid corrugated points



Sample output from the pothole toolbox showing detected potholes and 3D plots of diameter and depth



Sample output from the rutting detection toolbox showing rutting locations and severities



Sample output from the cross-section toolbox showing a crown distress heatmap

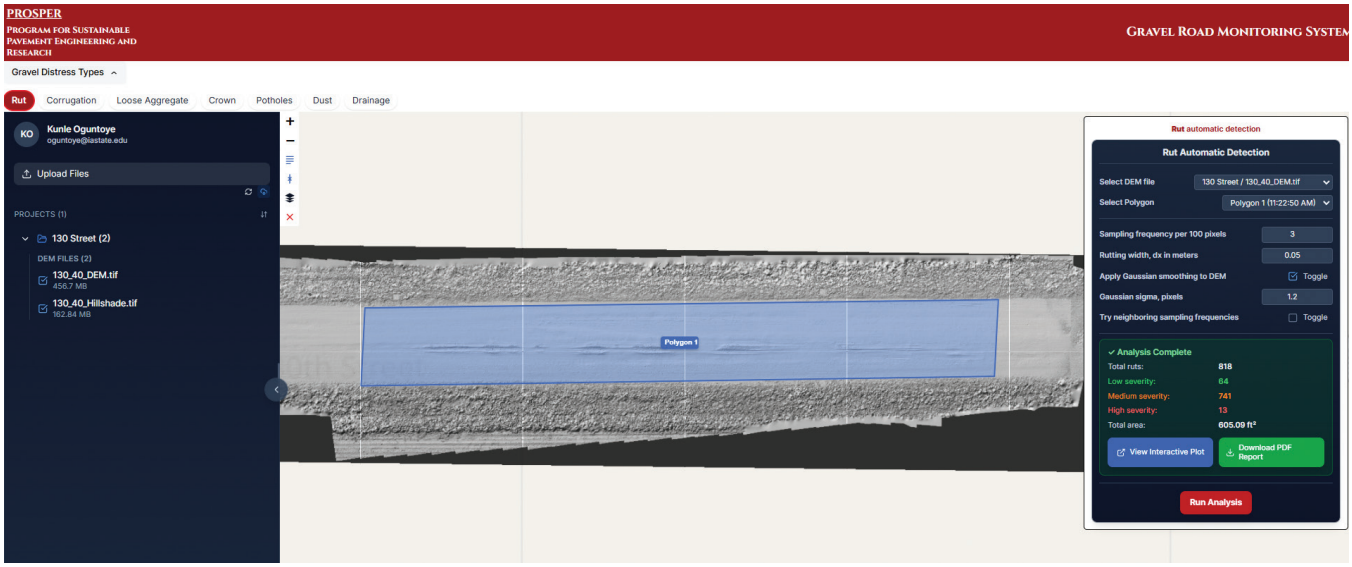
5. **Dust:** sUAS video frames collected while a truck traversed gravel road segments were processed using a trained computer vision model (ResNet152) to classify the dust severity in each image into no-dust, low-dust, and high-dust categories.

To help county engineers monitor the condition of gravel roads using sUAS, a web-based application was developed that enables all analysis to be executed from a single location. The application outputs deduct value plots for use with the USACE guidelines.

Sample training images from the three dust categories

Key Findings

- The time required for sUAS data collection and processing depends on factors such as flight altitude, the characteristics of the gravel road section, and the computational resources available for image processing.
- The proof-of-concept toolboxes for distress quantification show promising results in detecting and quantifying distress severities from processed sUAS data, such as DEMs and orthophotos.
- The rutting tool measured slightly lower rutting values than those obtained through manual measurement but the same severity levels. However, detecting and rating low-severity rutting remains challenging; more data points are needed to further validate the prototype algorithm.
- The corrugation detection tool achieved an R2 value of 0.74 when its results were compared to the ground truth data. A higher correlation is anticipated in a more ideal scenario, free of moving traffic during data collection.
- The trained deep learning model was able to categorize dust severity into No Dust, Low Dust, and High Dust with an F1 score of 0.95 on test dataset predictions.
- The results from the pothole detection toolbox closely matched those of manual measurements in terms of depth and width, with an R2 of 0.98 for depth and an R2 of 0.91 for width.
- Although a toolbox was developed for detecting loose aggregate distress, the toolbox requires additional field measurements to further validate and refine the detection algorithm.
- The profiles generated by the cross-section distress toolbox closely aligned with manually measured profile points.
- A DEM resolution of 1.5 mm or better improves the precision of distress quantification.
- The single-stop web application developed as part of this research enables users to assess rutting distress severity from gravel road datasets.



Screenshot of the web-based application showing a completed rutting analysis

Limitations and Future Development

The major limitation of this study was a lack of gravel road sites that exhibited major distresses due to the frequent grading and other maintenance interventions performed on these roads. This restricted comprehensive validation of the proof-of-concept algorithms developed in this study.

The analyses and workflows developed in this research can be improved through the following enhancements and future research:

- Visit additional gravel road sites and collect more sUAS data to improve the developed pattern recognition algorithms.
- Identify and visit additional gravel road sites with varying levels of loose aggregate distress to validate the algorithm developed for this distress type.
- Develop a framework for drainage condition rating, since the severity of drainage-related distress also contributes to the overall deduct values needed to estimate a gravel road's URCI.
- Refine, train, validate, and containerize the proof-of-concept toolboxes for the Iowa DOT.
- Continue to enhance the comprehensive and robust single-stop web applications where users can upload their sUAS-collected data and perform distress analysis. Visit additional gravel road sites and collect more sUAS data to improve the developed pattern recognition algorithms further.

Implementation Readiness and Benefits

The use of sUAS in gravel road inspections has the potential to enhance the speed, safety, and productivity of data collection and analysis. The proof-of-concept toolboxes for distress monitoring show promising results in detecting and quantifying distress severities from processed sUAS data such as DEMs and orthophotos.

Access to the web application developed in this research is available through the Iowa State University research team.