Field-Testing and Optimizing UAS Transportation Infrastructure Inspection Methods

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University

Colorado State University

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Research Needs

This proposal outlines a plan to synthesize, assess, and prioritize methods used to inspect transportation infrastructure using an existing fleet of fixed and rotary wing UAS aircraft along with state-of-the-art imaging equipment. This proposal explains the methods used, the outcomes expected, and the educational/training plan that will be used to train personnel using these tools.

Transportation infrastructure in the United States faces at least two main challenges: age and usage. Despite heavy investments in maintenance, repair, and upkeep, managing these challenges with limited financial resources will always require triage and a constant supply of updated and accurate inspection data provided by a variety of methods. Despite significant efforts, dramatic improvements in technology, and a variety of inspection guidelines, current inspection methods have sometimes proved inadequate. Figure 1 shows two railway line failures, including one incident where the tracks had been inspected multiple times in the weeks prior to the accident including one completed the same day as the accident. Part of the challenge comes down to manpower and resources.

Figure 1. Two significant derailment failures: Left: 30 BNSF rail cars hauling coal near Pueblo, Colorado, derailed on October 15, 2023, causing extensive damage and one death on I-25 below the bridge (photo courtesy of KVDR); right: 16 rail cars, 15 of which had hazardous material, derailed on June 24, 2023 at Reed Point, Stillwater County, Montana (photo NTSB). In the former case, the tracks had been inspected on the day of the accident.

Professor Allan Zarembski of the University of Delaware has noted that “the track has to be walked, physically walked, or inspected at a very low speed from a slow-moving vehicle once or twice a week depending on the criteria”. Regarding another rail accident, the NTSB has noted that “We also found that walking inspections are important to ensure an understanding of track conditions and that the track inspector’s workload likely prevented him from performing a timely walking inspection of the track in the area of the derailment” (NTSB 2023). Hence there is a huge need to potentially accelerate the inspection process or at a minimum develop inspection tools that that provide workers with more efficient resources.

In the past decade, one class of methods has been introduced that has the potential to greatly assist in the accelerated and possibly more accurate inspection process that include the use of Uncrewed Aircraft Systems (UAS). These systems provide a great deal of flexibility, efficiency, and mobility that can be exploited to potentially revolutionize how, and in what level of detail, transportation infrastructure can be inspected (Whitehead and Hugenholtz 2014). This is especially true for bridges (Chan and co-workers 2015, Ellenberg and co-workers 2016, Dorafshan and co-workers 2017, 2018), where the maneuverability of UAS aircraft have proven to have significant potential. UAS tools have also shown great promise in evaluating both paved (All Sourav and co-workers 2023) and unpaved surfaces (Zhang and Elaksher 2012).

In this proposed study, a selection of UAS aircraft and sensors will be used to help synthesize and optimize a variety of inspection methods for transportation systems with a special focus on current levels of accuracy and an attempt to estimate predictive cost savings over current methodologies. Both quadcopter and fixed wing aircraft will be used that possess state-of-the-art measurement equipment including but not limited to thermal, Lidar, photographic, and multi-spectral imaging capabilities. While bridges and road/rail surfaces are of top priority, various other scenarios will be explored including damage assessment following extreme events, post-collision damage data collection, and degradation of the surrounding landscape of transportation systems. Special emphasis is given to a process in which digital information can be used to generate finite element models of structural systems to allow for additional analysis. We also anticipate at least preliminary investigations on what would be required to adapt existing commercial drones for new sensor technology.

Although a number of studies exist that have explored elements of UAS inspection, there remains a compelling need to assess and differentiate among competing methods to accomplish these tasks. In addition, there is an even more urgent need for a trained workforce to assist in furthering these advances. This project addresses this directly by incorporating a training and educational component into the proposed research tasks. Both of these components are addressed in this proposal.

Research Objectives

There are three primary objectives associated with this proposed research:

1) Determine the level of accuracy that can be obtained by varying imaging techniques when applied to a variety of transportation systems that are subject to manual inspection to measure damage and degradation.
2) Determine the measurement rate at which these assessments be acquired and the ease of translating the acquired data into solid mechanics models of the imaged system.
3) Attempt to quantify the differences between semi-automated UAS inspection compared to manual visual inspection and assessment to predict reductions – if any – in time required to complete these tasks.

In addition to these primary objectives, a significant secondary objective of this work is to specifically educate and train approximately 30 engineering students each year this study is in progress in the use of and familiarity with both UAS systems and the specific inspection tools that will be used in this study. This will be accomplished through the development and completion of an undergraduate class on Engineering With Drones that has significant long-term support within the College of Engineering and will be co-taught by the two investigators of this work.

Research Methods

The methods used in this study can be classified as: 1) data collection using imaging technology already embedded in an existing drone fleet, 2) an assessment of that data with an eye towards determining accuracy and collection rates and a focus on comparing competing methods used to assess damage or degradation using solid mechanics models, and 3) a comparative time and effort assessment of UAS-driven methods compared with more traditional inspection methods.

Here we briefly discuss each inspection tool that can be used in combination of UAS resources with the understanding that several of these methods contain significant overlap. All of these methods are available for use in this study. We also briefly explain the other methods or issues related to this project.

Thermal imaging: Infrared thermography has been widely used for inspection of transportation infrastructure for over 40 years (see ASTM 2013). It provides excellent capabilities for detecting differences in residual heat that can indicate zones of cracking, delamination, or deterioration.

Drone-mounted IT tools allow these inspections to be made for difficult-to-access regions of these structures.

Digital Elevation Models and LiDAR: There are several UAS-mounted tools that can be used to represent elevation data that indicate regions of damage or change when compared with surrounding material. In the applications of this proposal, we use DEM as a general descriptor for collecting elevation data for purposes of determining the presence of cracks, spalling, potholes, or other changes that indicate degradation.

RGB Imaging: RGB images are simply high-resolution camera images in the primary colors red, green, and blue that can be used to document the true physical state of the infrastructure being inspected. It can provide photographic documentation that is frequently used to track changes in the system with time.

Structure from Motion (SfM): SfM is a photogrammetry method that uses digital images to recreate point cloud data that can be used to track damage growth or change. It can be especially useful to compare damage over a period of time by overlaying the resulting point cloud data to track and quantify differences or changes in geometry. An example of Lidar imaging compared with SfM data is shown in Figure 2.

Figure 2. An example of imaging technology, differences in output, and imaging rates for a low-density fibrous composite (a raptor nest 200 feet off the ground). On the left is a still photo from a three-dimensional Lidar scan (which took under a minute to obtain) and the point cloud extension using SfM for the exact same nest but with 26 photos taken using a digital camera, which took about five times as long to obtain.

Finite element models from point clouds: A sub-task of this work is to incorporate the imaging data collected into finite element solid mechanics models. This will not be attempted for every type of damage, but for some structural systems it will allow additional analyses to be attempted. We have shown the general process of this task in Figure 3 for a natural cracked and flawed wooden stump to show the level of detail in this process. For structures that are especially critical, this type of methodology could be of great use to determine residual strength and stiffness of a damaged structure.

Testing locations: The primary locations used to conduct the proposed research include an existing runway (4000 square feet of pavement) adjacent to the CSU Drone Center and a combination of existing and simulated rail lines near that same location. As of this writing we are also in the process of securing access to other potential test sites very close to the CSU Drone Center.

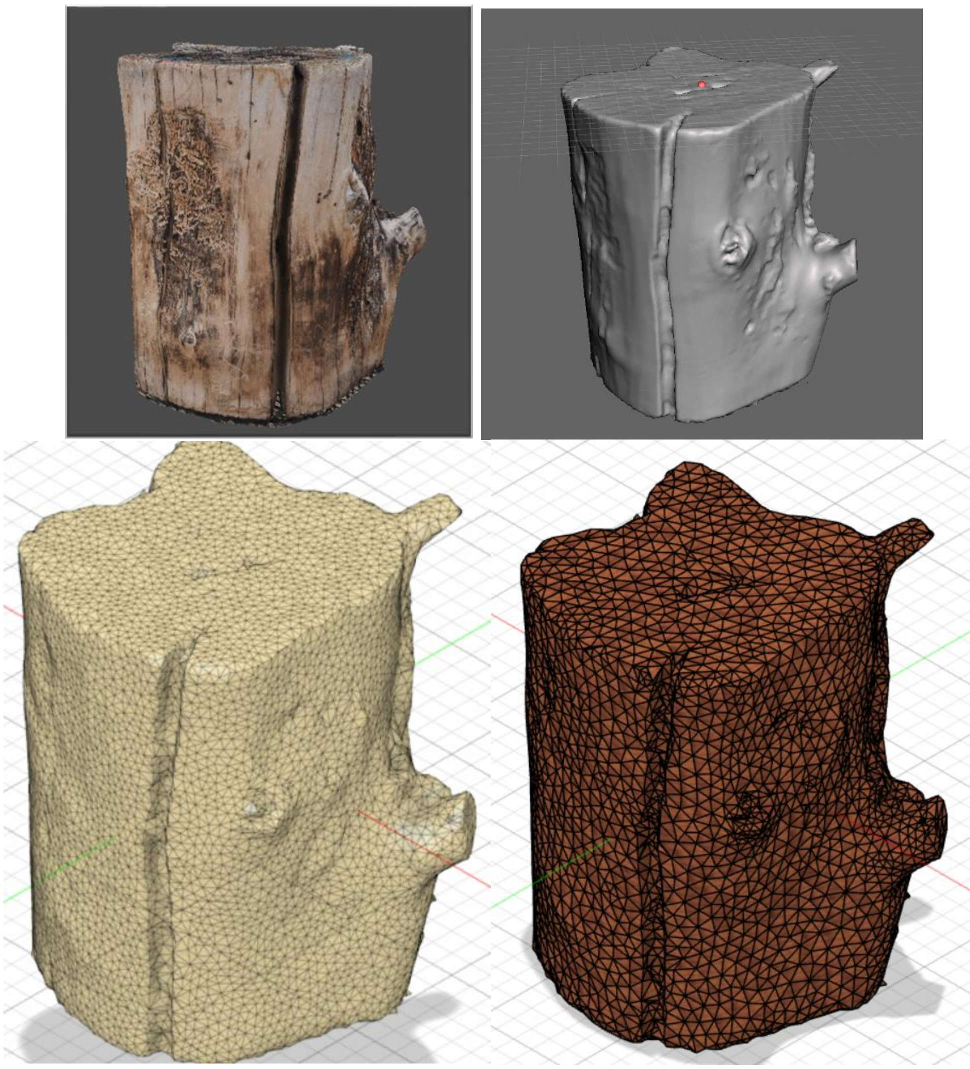

Figure 3. An example of photographic imaging and the transition (clockwise from upper left) of the imaging result of SfM to solid body (MeshMixer) to Fusion 360 STL (coarse) to refined finite element meshes (coarse in rust, fine in tan) for a cracked wooden stump using 50 digital photos. This process allows not only for inspection for but additional mechanics analysis of this cracked or flawed structural system.

Relevance to Strategic Goals

The USDOT strategic goal that is primarily addressed by the proposed project is Safety. A secondary strategic goal is Transformation. We select these two goals because our proposed work with aim to transform the way in which safety inspections and procedures can be completed.

Educational Benefits

A significant part of the proposed study involves development and offering of a class within the Walter Scott, Jr. College of Engineering titled Engineering With Drones. This class will be offered to undergraduates and graduates in the Spring of 2025 and will specifically help train a cohort of about 30 students in drone basics, obtaining their Commercial sUAS Pilot License, and becoming proficient in using inspection tools.

Outputs through Technology Transfer

Our transfer plan involves a combination of refereed journal articles, potential conference presentations, undergraduate research presentations, a bank of online modules containing summary findings of the work, and a group of students educated in the flying of UAS aircraft and experience in making inspection runs using the methods described in this proposal. Our research will be submitted for online distribution via CSU-Source, an online research communication resource with a broad distribution list.

Expected Outcomes and Impacts

The outcomes of this work are expected to be 1) quantified metrics of the levels of accuracy and rate of collection for the methodologies described above, 2) guidelines on incorporated these inspection tools to decrease the time required for a standard inspection, 3) a series of video lectures that explains the use of these tools in transportation inspection, 4) potential journal and conference publications reporting on these tools, and 5) approximately 30 engineering students with the skills to fly UAS systems and perform some of these inspections.

Work Plan

Here we describe the major tasks of the project along with a tentative timeline. We have divided the project into three basic components.

1) *Complete a comparison of methods (Estimated completion date: 4 months from project start)*

   Select two major sources of damage that are shallow and broad (surface deterioration) or narrow and deep (surface cracking), and complete initial assessments of limits of existing technology when compared with each other. These methods will include Digital Elevation Models, thermal imaging, RGB images, SfM assessments, and LiDAR imaging. Our goal here is to assess levels of accuracy when these models are used in direct comparison with the others.

2) *Rates of collection (Estimated completion date: 8 months from project start)*

   Using the results of Task 1, re-run the more promising assessment methods with the goal of reducing the time required for data collection. The goal here would be to determine if, and how accurately, information can be collected at varying speeds. The eventual goal would be to collect all data necessary for inspection in a single overhead pass within a minimal amount of time. At present, there are very few published estimates for these quantified metrics.

3) *Comparison of methods / creation of solids models (Estimated time of completion: 12 months from start date)*

   In this phase of the work, we will attempt to quantify and differentiate among the different methods used for inspection. This will include not only limits on the sizes of defects that can be detected but the rates at which this data can be collected. We also will attempt to directly compare more traditional methods of data collection with a more rapid assessment.

   This phase of work will also involve development of finite element model test cases from the inspection data. Our initial plan is to complete this task for several representative test cases to provide estimates on how damage influences the overall strength and stiffness of the structural system.

   Our results will be compiled in a draft report and will also be used as lecture content from our YouTube channel as part of the Engineering With Drones course to reach as wide of an audience as possible.

Project Cost

Total Project Costs:	$120,000
CTIPS Funds Requested:	$ 60,000
Matching Funds:	$ 60,000
Source of Matching Funds:	Colorado State University

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